Environmental Concerns in Rights-of-Way Management

13th International Symposium

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Environmental Concerns in Rights-of-Way Management

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PREFACE

The infrastructure which allows for the safe, reliable movement of people, goods, and energy throughout our globe is essential for economic development and provides a certain quality of life to humankind. Meeting the needs of our growing population puts significant demands on this infrastructure, as well as our natural resources. We are challenged with constructing, operating, and maintaining these rights-of-ways (ROW) in a safe and efficient manner, while minimizing the environmental impact associated with these activities. When done properly, these ROW can not only serve their intended purpose, but also provide ecological benefits.

On October 9–12, 2022, the 13th International Symposium on Environmental Concerns in Rights-of-Way Management (ROW 13) was held in Charlotte, North Carolina. This event included 336 industry practitioners from around the world representing diverse backgrounds, such as environmental, operations, academia, industry, sustainability, permitting, technology, and the regulatory community. The symposium was comprised of presentations, discussion sessions, and exhibits of the latest technologies and research to achieve the environmental goals of industry practitioners. Additionally, ample time was allocated throughout the symposium for participants to reconnect and network, given the long hiatus since the previous symposium due to the COVID-19 pandemic.

Originated in 1976, this symposium series has two primary objectives which continue to guide the present agenda: (1) provide a forum for discussion of the environmental impacts that result from siting, constructing, using, and maintaining ROW, and (2) draw together and publish practical information on ways of reducing the environmental impacts of developing multiple uses of ROW.

The symposium began with a Sunday field tour, hosted by Duke Energy, in which more than 70 participants were able to visit the Latta Nature Preserve, McGuire Nuclear Station Switchyard and adjacent transmission and distribution lines, and the Cowans Ford Hydroelectric Station. During the tour, participants learned from Duke Energy and Mecklenburg County North Carolina subject matter experts about their vegetation management (VM) program, stakeholder engagement process, commitment to environmental stewardship, energy generation, and delivery. Participants visited ROW that are actively being managed, in partnership with various stakeholders, for rare and threatened plant species, such as the Georgia aster (*Symphyotrichum georgianum*) and Schweinitz's sunflower (*Helianthus schweinitzii*).

The symposium opening remarks and welcome were delivered by Dennis Fallon (Executive Director of the Utility Arborist Association), Travis Rogers (ROW 13 Chair), and Tom Johnson (the local chair), followed by an interactive history lesson on the Catawba Indian Nation—who, according to archeological records, have inhabited the area along the Catawba River for more than 5,000 years. Additionally, the presenters from the Catawba Indian Nation discussed the importance of the plant communities in this area and their spoken history, regarding how they managed the flora and fauna with prescribed fire. The conclusion of their presentation included a lesson in their language and the audience participated in their friendship dance. Harry Sideris (Executive VP of Customer Experience, Solutions, and Services for Duke Energy) provided the keynote address, during which he shared an overview and background on Duke Energy and discussed some of the pending challenges and opportunities facing Duke Energy and the

PREFACE - continued

industry as it looks to serve customers in the future. Following the keynote, the opening plenary panel consisting of Randy Veltri (Director of Transmission Permitting and Environmental Oversight with Duke Energy), Lea Millet (Senior Technical Leader with the Electric Power Research Institute [EPRI]), and David Butler (Riverkeeper and Staff Attorney with Cahaba Riverkeeper) was designed to represent different and unique perspectives related to the siting, construction, use, and maintenance of ROWs. On day two of the symposium, an academia panel featuring Dr. Carolyn Mahan (Penn State University), Ben Ballard (SUNY), Chris Halle (Sonoma State), Gabe Karns (Ohio State University), and Kim Russell (Rutgers University) each highlighted their areas of ROW research, followed by a panel discussion on how to initiate and develop effective partnerships with industry. The plenary on the final day consisted of a fireside chat with Amy Huber (Client Relationship Manager with Jacobs) and Cathy Hope (General Manager, Transmission Siting, Permitting, and Public Engagement from Duke Energy), where they shared their thoughts on the future of ROW development and operations, and discussed where we go from here.

At this year's symposium, both academia and industry sources provided 54 presentations within the following focus areas: Indigenous engagement and stakeholders; ecology; planning, evaluation, and assessment; VM; technology; regulatory and permitting; and reclamation, mitigation, and restoration. Each abstract submission and corresponding paper underwent a comprehensive, independent peer-review process. A special thanks to all of the authors for their extensive work, as well as the peer reviewers who unselfishly committed time to ensure the high quality of papers you'll find in these proceedings. Thank you to the Program and Steering Committees for your leadership, countless hours volunteered, and guidance—and a thank you the Utility Arborist Association (UAA) for making the ROW 13 Symposium a meaningful event.

In today's social climate, the environmental concerns related to ROW establishment and management are rapidly evolving. This symposium is the perfect venue for bringing leaders from industry and ROW research together to share, discuss, and learn how best to meet the growing energy and transportation demands while ensuring we're protecting and enhancing our natural resources for generations to come.

We invite you to explore the symposium proceedings and hope you plan to join us at ROW 14, which will be held in the spring of 2026 in Vancouver, British Columbia, Canada.

ACKNOWLEDGEMENTS

Under normal conditions, planning the Environmental Concerns in Rights-of-Way Management Symposium takes three years of hard work, by a diverse and dedicated group of professionals located throughout North America. The 13th Symposium on Environmental Concerns in Rights-of-Way Management (ROW 13) planning was interrupted by a global pandemic, extending the timeline to four years before the event could take place. The group remained steadfast in resolve to ensure the event would go on as anticipated. Volunteers served on two critical committees. The Steering Committee provided overall leadership in the planning of the symposium and was supported by the Local Planning Committee, which helped ensure attendees would experience the local culture and have the opportunity to observe regional challenges and successes in rights-of-way (ROW) management.

Travis Rogers (Corteva Agriscience) served as the Steering Committee chair, providing overall leadership for the ROW 13 Symposium. Steering Committee members contributed to the planning of the event, participated on specific sub-committees, and moderated sessions at the conference. Our Steering Committee for ROW 13 included Sara Ball, Alexandre Beauchemin, Paula Bentham, Josiane Bonneau, Mike Boyle, Eric Brown, Allen Crabtree, Martin Derby, Jean Doucet, Jim Downie, Dennis Fallon, Matt Goff, Carly Harrower, Carmen Holschuh, Amy Jimmo, Tom Johnson, Normand Lesieur, Carolyn Mahan, James Martin, Will McMillan, Randy Miller, Becky Moores, Mike Murphy, Dean Mutrie, Diona Neeser, Renée Phillips, Sara Race, Michele Richter, Sara Sankowich, Cameron Shankland, Jason Smith, and Doug Stewart. Without their willingness to take time from their valuable schedules, the symposium would not have been possible.

The Local Planning Committee volunteers were led by Tom Johnson (Duke Energy). The committee included Elizabeth Baylis, Scott Fletcher, Jeff Racey, Becky Moores, Tara Ruffin, and Cordy Williamson. This committee was key in developing the tours, recruiting locally relevant speakers, choosing the wonderful venues that made the event great, and creating the opportunity to have the Catawba Nation open the event with a friendship dance and cultural perspective exchange.

Our Plenary Panel Committee was led by Chairs Carmen Holschuh and Allen Crabtree, along with our volunteers Sara Ball, Alexandre Beauchemin, and Josiane Bonneau, who all helped bring us this extraordinary education component. We thank Harry Sideris (Executive Vice President of Customer Experience, Solutions, and Services for Duke Energy) as the keynote speaker, who shared his insights and knowledge. Panelists for the ROW 13 opening panel included David Butler, Lea Millet, and Randy Ventri, and was moderated by Carmen Holschuh. The academia plenary panel, held on the second day, included panelists Chris Halle, Gabriel Karns, and Kim Russel, and was moderated by Carolyn Mahan. The closing plenary panel included Cathy Hope, Amy Huber, and was moderated by Carmen Holschuh.

The Utility Arborist Association (UAA) provided the support necessary for an event of this size and success. Diona Neeser (Operations Manager) served as the event manager, along with the support of Renée Phillips (Membership Manager) alongside of Dennis Fallon (Executive Director) and Matt Goff (UAA Board Champion).

The symposium was dependent on the time and effort of all of these individuals. Equally important was the time and effort put in by more than 100 authors, presenters, and

ACKNOWLEDGEMENTS - continued

panelists, who each contributed to an engaging program that highlighted innovation and best practices in our industry. We wish to recognize the quality of their contributions. We also acknowledge the efforts of their peers who participated in the technical review of the papers submitted—a key role in publishing this proceedings. Finally, we want to recognize our sponsors. These companies, listed on pages viii–ix, gave generously in support of ROW 13.

Author is Dennis Fallon
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THANK YOU TO OUR VOLUNTEERS!

STEERING COMMITTEE

- Sara Ball
- Alexandre Beauchemin
- Paula Bentham
- Josiane Bonneau
- Mike Boyle
- Eric Brown
- Allen Crabtree
- Martin Derby
- Jean Doucet
- Jim Downie
- Dennis Fallon
- Matt Goff
- Carly Harrower
- Carmen Holschuh
- Amy Jimmo
- Tom Johnson
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- Carolyn Mahan
- James Martin
- Will McMillan
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- Sara Sankowich
- Cameron Shankland
- Jason Smith
- Doug Stewart

LOCAL PLANNING COMMITTEE

- Elizabeth Baylis
- Scott Fletcher
- Tom Johnson
- Becky Moores
- Jeff Racey
- Tara Ruffin
- Cordy Williamson

We thank each and every volunteer that stepped up and assisted with this symposium! Without your willingness to take time from your valuable schedules, the symposium would not be possible.

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PART I

Plenary Session

Opening Plenary Session

CHALLENGES AND OPPORTUNITIES OF NEW RIGHTS-OF-WAY PROJECTS

Moderator: Carmen Holschuh, Principal Environmental Planner, Jacobs

Panelists:

- Randy Veltri, Director of Transmission Permitting and Environmental Oversight, Duke Energy
- Lea Millet, Senior Technical Leader, Electric Power Research Institute (EPRI)
- David Butler, Riverkeeper and Legal Counsel, Cahaba Riverkeepers

Note to Reader: The summary below captures the moderator's framing of the panel discussion and core questions asked. Audience questions and exchanges between the panelists enriched the discussion. The full recording of the panel discussion is available at *www.rights-of-way.org/row-13-gallery*.

INTRODUCTION

Challenges and opportunities to develop new rights-of-way (ROW) infrastructure abound and are influenced by a lot of the changes we see in our world today. Principally, our energy needs have never been higher, and there are deep demands to transition our energy reliance from high-emitting fuels to an energy supply with lower greenhouse gas emissions. Recent events in the Ukraine, with Russia's invasion, and the resulting impacts on energy supply in Europe have put an acute focus on the importance of energy security.

These drivers of change are creating conditions that require the development of new ROW, although the way we plan new ROW continues to evolve. And that evolution is a result of many points of pressure. Balanced with environmental stewardship are social justice and equity, and broader societal considerations that inform regulatory policies and public opinion on new projects. Proponents make deep investments on planning new ROW infrastructure, but many encounter even greater challenges securing timely regulatory confidence, schedule certainty, and cost predictability in their development.

Our practice of planning, constructing, and operating new ROW is actively evolving under pressure.

The opening plenary panel discussion focused on three different topics surrounding the challenges and opportunities of new rights-of-way development:

1. The Challenge: why do new energy projects draw so much attention and controversy?
2. What does good look like?
3. How do we make good happen?

TOPIC 1

The Challenge: Why Do New Energy Projects Draw so Much Attention and Controversy?

Our global need for energy is increasing rapidly. By 2050, our global population is projected to reach 9.8 billion people, representing an additional 2 billion people more than there are on our planet today. Energy consumption has increased year-over-year every year for at least the last half century, and the general trend is that developing countries have a more rapid increase in energy consumption than developed countries. The world is *energy thirsty*.

It's also critical that we decarbonize our energy. The U.S. Energy Information Administration has indicated that global energy demand is expected to increase 47% in the next 30 years. Whether for the purpose of domestic use or to feed the export market, it is undeniable that more infrastructure is needed to move energy—both pipelines and electric transmission lines—and this means we need to develop new rights-of-way.

While intuitively, this need for new ROW infrastructure suggests little barrier to their development, the challenges and costs of new ROW are escalating. Pipeline projects, in particular, are lightning rods for controversy that become highly politicized. For example, after billions of dollars spent and years of regulatory reviews, energy companies in both the U.S. and Canada have cancelled several major pipeline developments, such as Trans Canada's Keystone XL, Enbridge's Northern Gateway Project in Western Canada, and the Atlantic Coast Pipeline Project that was proposed by Duke Energy and Dominion Energy. Similarly, electric transmission projects are also not always welcomed with open arms—we only need to look at delays of the New England Clean Energy Connect Transmission Project as an example of project controversy.

The first set of questions posed to the panelists focused on the challenge: why are new energy ROW projects often met with such concern?

Question to Lea Millet: What do you view as some of the root causes that lead to projects becoming an object of public concern or controversy?

Question to Randy Veltri: As a company that has an obligation to its rate payers to fulfill energy demands in your service areas, I'm sure that this controversy is particularly challenging. Can you talk a bit about the challenges that are created by new energy projects when they become controversial? Do you have any insights from your perspective on what fuels the controversy?

Question to David Butler: Your focus is on maintaining a healthy watershed. I imagine when you, or other NGOs, hear about new developments, there are factors that grab your attention. Could you please share some of your insights on what motivates NGOs to mobilize publicly with concerns about new infrastructure development?

TOPIC 2

What Does Good Look Like?

A common theme when examining the challenges could be summarized by stating there is a general lack of trust. And trust is a tricky thing—it's often slow to establish but very quick to diminish. Global communications firm, Edelman, has been running surveys for 22 years of more than 36,000 people across 28 different countries to track societal indicators of trust among business, media, government, and NGOs. In the most recent results (Edelman 2022), released in January of 2022, were some very telling findings, including:

- Business and NGOs are generally trusted, and government and media are viewed as divisive forces in society
- People look to businesses and NGOs to lead and yield results with societal problems
- Top societal fears are climate change, job loss, discrimination, and income inequality
- The data suggests that the societal role of businesses and NGOs is here to stay; that trust is built through demonstrating tangible results; leaders must focus on long-term thinking; solutions over divisiveness; and that every institution must provide trustworthy information

Question to Randy Veltri: When you and your team are asked to take on a new transmission project (whether it's pipe or electric), what are the key areas of focus to build trust with the public, with stakeholders and shareholders, as well as with regulatory agencies that ultimately have to approve the project? What are the desired outcomes? What does good look like?

Question to both David Butler and Lea Millet: You are both part of organizations that fall into the "NGO" category. The Edelman data tells us that NGOs have key roles to play in building or eroding trust. David, with a focus on watershed protection; and Lea, for EPRI, with a focus on thought leadership and research-based programs; could you each please weigh in on the question of "What does good look like?" when it comes to developing new projects, and what you view the role of organizations, such as River Keepers and EPRI, in achieving such a vision?

TOPIC 3

How Do We Make Good Happen?

As we look across North America, a number of different strategies and approaches are being employed that influence the fate of new projects. In some places we have exceedingly complex regulatory process, where regulatory agencies take a very hands-on approach to ensuring project planning considers sustainability, equity, and inclusion as well as environmental protections. This can result in lengthy review processes that are criticized for undermining investor confidence. In other places, the regulatory review processes are less intensive, and in some cases project decisions become elevated to political levels.

In Canada, we are seeing an increased focus on equity ownership in new energy projects, with the rise of organizations like the First Nations Major Projects Coalition. For example, once the Coastal GasLink Pipeline Project is commissioned, upward of one quarter of the ownership of the project will be allocated to First Nations impacted by the project's route, helping to ensure a long-term benefit to those communities for having the project in their territory.

With the rise of focus on sustainability and corporate environment, social, and governance (ESG) tracking, as well as the focus on equity, the Edelman finding that businesses have a key role to play in solving societal challenges appears acutely accurate.

Question to David Butler: Sustainable development of energy rights-of-way—from your perspective—what are the top three things companies should consider?

Question to Lea Millet: On the topic of equity and sustainability, where do you see leading practices evolving from a project planning perspective to increase equity?

Question to Randy Veltri: Building on the vision of what good looks like that we just discussed, as well as David and Lea's insights, can you share how you see the practice of environmental planning/siting and licensing continuing to evolve?

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Closing Plenary Session

WHERE DO WE GO FROM HERE? THE FUTURE OF DEVELOPING AND OPERATING ENERGY RIGHTS-OF-WAY

Speakers:

- Cathy Hope, General Manager of Transmission Siting, Permitting and Public Engagement, Duke Energy
- Amy Huber, Client Relationship Manager and Project Director, Jacobs

Note to Reader: The summary below captures the topics discussed and core questions asked. Audience questions and exchanges between the panelists enriched the discussion. The full recording of the presentation and discussion is available at *www.rights-of-way.org/row-13-gallery*.

INTRODUCTION

The closing plenary focused on the future of developing and operating energy rights-of-way (ROW), including key considerations for building trust with the public, stakeholders, and regulatory agencies. Leveraging her long and successful career in the utility industry, Cathy Hope, General Manager of Transmission Siting, Permitting and Public Engagement at Duke Energy, shared her perspectives of where the industry is going, with a focus on the following topics:

- The history and evolution of planning new ROW development
- Benchmarking of inherent biases by ROW planning practitioners, and the recognition that the expectations associated with planning ROW is in a constant state of flux
- How the practice of building trust with the public has evolved over time, and key considerations for building trust
- The evolution of regulatory process, including changes to the role of the regulator, and the benefits and drawbacks of prescriptive regulatory requirements
- The importance of being in the community
- The importance of sharing information in the industry

INTERACTIVE Q&A SESSION

Following Hope’s presentation, Amy Huber led an interactive discussion that featured audience questions. The following are the key questions asked;

- Regarding benchmarking—love this perspective and your approach—do you have any recommendations for others on what you benchmark and what you evaluate?
- Recognizing the importance of building relationships with communities before projects are planned, can you expand on some examples of how Duke is doing this today?
- Duke developed a stakeholder engagement team approximately six years ago. What additional value and efficiencies have you seen on projects since that time?
- How important is it for stakeholder engagement to continue throughout the full project life (i.e., not just during planning, construction, maintenance events)?
- When siting a new energy project, such as a substation or powerline, how do you use past project successes to help facilitate those new projects?
- Please share your thoughts on the importance of building and developing diverse teams within your organization.
- With a significant amount of investment in Transmission and Distribution assets to meet growing demands, what challenges do you see with the pace of industry growth?

13th International Symposium

Environmental Concerns in Rights-of-Way Management

PART II

Climate Change

Enhanced Biodiversity Initiatives in Utility Rights-of-Way May Promote Climate Resiliency: The Rise of the Fruiting and Vine Plants

Anand B. Persad, Oscar Rocha, Oscar Liburd, and David Bienemann

Biodiversity analyses of utility rights-of-way (ROW) were conducted at sites internationally, including Trinidad and Tobago in the Caribbean, Guam in the Pacific, and several sites in the U.S. All sites were sampled in 2020 to 2022 for snapshot surveys on plant biodiversity in ground and optical surveys following new construction, removal of invasive plant species, weather-related events, and/or major vegetation initiatives towards removal of noncompatible trees and woody plants. Inherent plant characteristics are important in climate-focused greening and vegetation management initiatives and is becoming more and more relevant in response to weather effects, wildlife habitat enhancement, and plant succession. The data indicate that plant and vertebrate (songbirds in this study) dynamics are complex with habitat use by birds exhibiting defined foraging windows. In an ever-changing climate, long-term plant dynamics and succession are important to understand plant dynamics and succession. Plants display broad community structure, and one or more species may become dominant in local situations. Internationally, however, several family groups of fruiting and vining plants are emerging in dominance. These trends may continue to develop and will influence our vegetation management and land stewardship initiatives.

Keywords: Data Analytics, Evaluation, Human Use/Impact.

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INTRODUCTION

Biodiversity in a Changing Climate

Biodiversity analyses of utility rights-of-way (ROW) have been the mainstay as ecological metrics are actively pursued for determination of habitat quality and ecological return on investment (EROI). Through specialized software advances (e.g., Bioaudit™, ACRT), we can now capture and feed data loads from the field to real-time utility vegetation management via personnel facing portals. These data through the same workflow can also be forwarded on for collation of laboratory input of collected data to support field collections. The further use of these analytics can effectively describe ecological dynamics seasonally as sampling occurs during the year, but especially important is the alignment with site conditions and management strategy. The linearity model we work in the utility ROW setting helps to better span our corridors with results of our vegetation management activities, most often in transmission circuits. The use of integrated vegetation management (IVM) strategies helps in judicious use of herbicides and other products as needed as we work to better define our land stewardship ideals in what we now describe as a changing climate. Understandably, the climate is always changing; however in recent years the morph time (MT) or the window of change evident in plant community dynamics has been notably reduced and is often described as "erratic," which attaches a certain connotation of unpreparedness.

Plant dynamics in ROW are well studied (Bramble and Byrnes 1983; Yahner and Hutnik 2005), however the void that most inventories and surveys miss are the state of the individual plant components in the polygons and propensity for survival to the next MT window. Plant species composition projections based on soil type and site conditions and associated management strategies generally can better assist biodiversity initiatives if we can estimate MT windows and predict plant dynamics and migration.

In this work, we report on (1) plant biodiversity in ROW areas and its relationship to IVM site maturity; (2) observations on fruiting and vining plants (2020 to 2022) in three broad regions; and (3) an interesting relationship with songbird visitation and bloom and fruiting in plants from an annual spot mapping field exercise, conducted in 2021. These data—some which include island frontline states (smaller or lesser MTs) along with areas in the mainland U.S.—can help us with the ability to embrace plant community dynamics and manage proactively for incompatible elements. Regional and global-type assessments also can assist us in better understanding the plant dynamics and plant movement that may occur unhindered in the ROW across different climates.

Table 1. Sites in ROW Sampled for Plant Biodiversity Surveys in 2020 to 2022 (Study 1)

Country	City	Latitude, Longitude	Site Code
Trinidad | Tobago			
	Port of Spain	10.670362, -61.519571	TPOS1/ TPOS2
	Arima	10.628750, -61.284508	TM1/TM2
	Tunapuna/ Valencia/ Sangre Grande	10.658794, -61.192517	Tu1/Tu2/TSG1/ TSG2
	Manzanilla	10.492563, -61.045002	Tma1/ Tma2
Guam			
	Tumon	13.502065, 144.791050	G1/G2
	Inarajan	13.294160, 144.751157	GI1/
	Mangilao	13.446243, 144.790848	G3/G4
USA			
	Portage County, Ohio	41.165487, -81.150903	NA 1/ NA2/NA3
	Holmes County (Mt. Hope), Ohio	40.622687, -81.788595	NA4/NA5
	Alachua County, Florida	29.574473, -82.175614	NA6/NA7

Note: site codes may apply to one or more of the three studies described above.

MATERIALS AND METHODS

Study of Site Condition and Plant Biodiversity

Fifteen sites were evaluated in this study, with five sites each grouped according to condition (state of management and/or IVM maturity, if applicable); construction sites ("Con"), where work was done in the previous year and the ROW area is now becoming re-greened; newly converted sites ("NC") where mowing has stopped or has been decreased within the last two to three years; and established sites ("EST") where integrated vegetation management and/or other strategies have been ongoing for at least 6–7 years and compatible plants are existing (Table 1). (These data on biodiversity are presented to illustrate trends in different site conditions and were not further statistically analyzed.)

Plants were sampled in January to May (tropical) and June and July (U.S.) of 2020 to 2022 by recording observations of plants growing in eco-plots set up as 15 square meter randomly marked plots in ROW under wire and/or near roadways (Table 1). In this paper we report on locations deemed “frontline areas” which are the island states of Trinidad and Tobago (Caribbean) and Guam (Pacific), as well as sites in mainland U.S. Plants were field identified, and identification to family was recorded. Plant population compositions were also recorded. These data were used to collate site condition and maturity level with biodiversity index and plant population compositions (number of species collected) and to calculate the Simpson Diversity Index, which was obtained at each site and reported with site maturity level (Con, NC, and EST).

Study on the Change of Fruiting and Vining Plant Composition along ROW

The population percentage of fruiting (12 families) and vining plants (7 families) in ecological plots at ROW sites (Table 1) were assessed in 2020 to 2022. The percentage change of the most dynamic plant families observed was recorded and may provide us with data useful in assessing future plant compositions and provide for proactive management. Data was analyzed using non-parametric statistical tests and Kuskal-Wallis Chi-squared (SAS statistical package v. 9. Cary, NC).

Study on Bloom Windows in Fruiting Plants and Avian Visits and Foraging Activity

Fruiting plants in ROW edge areas (Table 1; Alachua County, Florida) were sampled monthly in 2021 and bloom windows observed by plant families were recorded. Plants in bloom were identified to family and approximate bloom percentage was recorded (percentage of plants in the population that were actively in bloom). For avian activity, spot mapping observations were conducted between 9 a.m. and noon for 20-minute observation windows. The observer was stationed on the edge of the viewing area and utilized a tablet to make flight maps of individual birds upon sight, then followed the flight plan after 20 minutes had elapsed or when the bird was out of the area. Bird visits to fruiting plants were classified according to time spent on the plant (Class 1: 1–5 min., Class 2: 2–5 min., Class 3: 10–15 min., Class 4: 15–20 min., Class 5: >20 min.). Species of songbirds that were regularly observed included Tufted titmouse, Common grackle, Carolina/House wren, House finch, and various sparrow spp. and were most encountered; all visits were pooled and recorded as visits to a particular plant group. (These data on spot mapping were represented graphically to illustrate trends during the year and not statistically analyzed.)

RESULTS AND DISCUSSION

Study of Site Condition and Plant Biodiversity

The data obtained indicate that all of the five established sites (EST) had higher biodiversity scores (> 0.5) at all site locations both in island states and in the U.S. (Table 2) (construction and newly converted sites were variable and mostly ranked mostly at or below 0.5 index). While these data are preliminary and present a snapshot of biodiversity with site condition, it is interesting that established sites in all three regions (both in island situations and the interior sites in mainland U.S.) were similar in having consistently higher levels of biodiversity with site maturity at 6 to 7 years or longer. Vegetation management is a longer-term initiative and these data support that if no major site disturbance occurs, plant

Table 2. Site Biodiversity Simpson Index Scores across ROW Areas with Recent Construction (Con), Newly Converted Sites from Mowing (NC), and Established Sites (EST) with Existing Ground Cover Vegetation for at Least 6 to 7 Years

Site Code	Site Maturity Condition	Simpson Biodiversity Index
T POS1	Con	.6
TM 1	Con	.5
Tu 1	NC	.5
T SG 1	Est	.6
T SG 2	Est	.6
G M 1	NC	.5
G I 1	Con	.4
G3	Est	.7
NA 1	Est	.7
NA 2	Con	.6
NA 3	NC	.3
NA 4	NC	.6
NA 5	Con	.5
NA 6	Est	.6
NA 7	NC	.4

communities can evolve to being areas with enhanced biodiversity by allowing natural plant shifts to occur. In climate resilience programs, however, attention must be paid to those plant components that are more favorable to changing weather conditions and an increase in populations in a relatively short span of time.

Study on the Change of Fruiting and Vining Plant Composition along ROW

Percentage change of vines were all positive for all sites sampled (Figure 1). One family group the convolvulceae occurred in significantly higher abundance compared to percent increase in other vine families. The implications of higher vine plants population on vegetation management are many, as vines are generally harder to manage and can traverse guy wires and electrical poles, potentially impacting on utility assets. Vines over time can also impact compatible and desirable vegetation and can have a crowding-out effect on large tracts of land.

Although not significantly different in percentage change in plant cover in this study, fruiting plants are increasing in abundance. The implications for habitat quality may be favorable but fruiting plants can generate seedstock rapidly and be dispersed readily, resulting in possible loss of biodiversity.

Study on Bloom Windows in Fruiting Plants and Avian Visits and Foraging Activity

Songbirds are a valuable component of our EROI and the knowledge of peak plant usage will help reduce instances of accidental take during management activities and, hence, assist ROW managers in better adhering to regulations, such as the Migratory Bird Treaty Act (MBTA) and other state and local avian laws. Interestingly in this study, although bird visits to various fruiting plants peaked at different

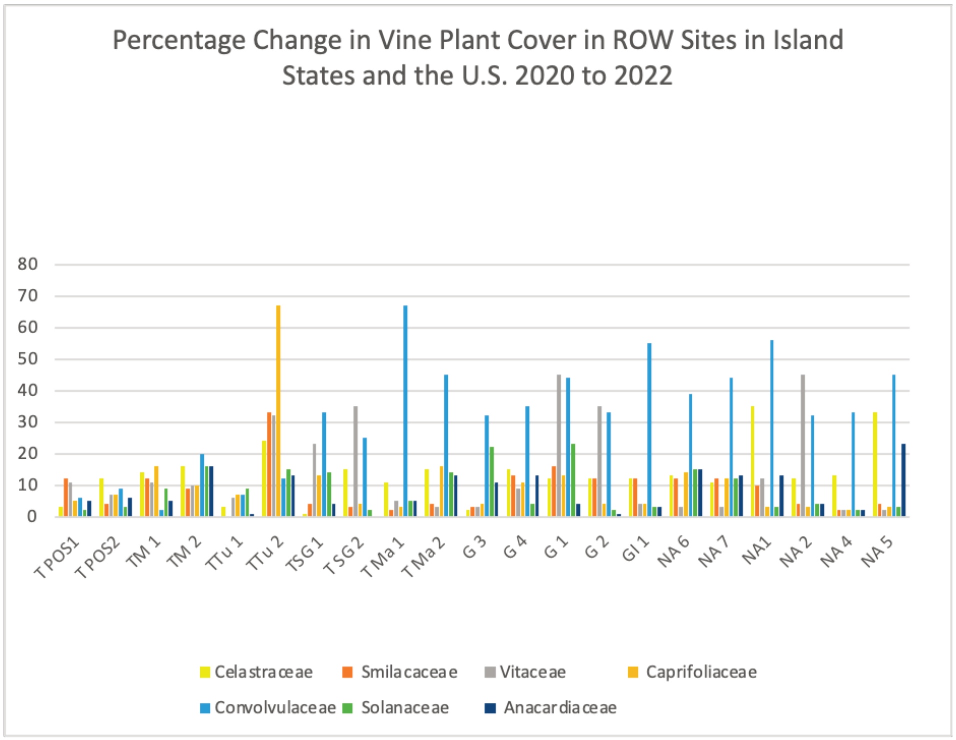


Figure 1. Percentage change in vine (tendrils) populations observed at ROW sites (also see Table 1) (Kruskal-Wallis Chi Sq. 0 .03 DF 6). Family groups of the Convolvulaceae occurred in significantly higher abundance between 2020 and 2022.

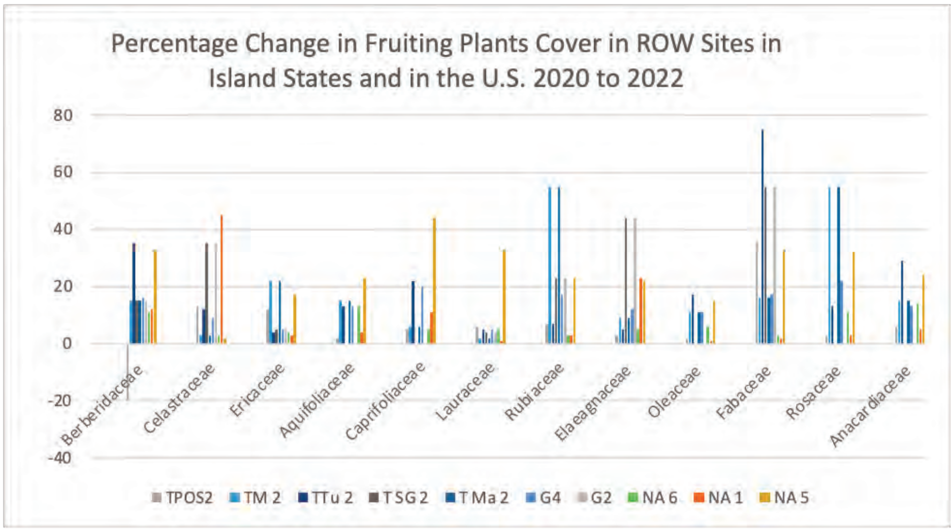


Figure 2. Percentage change in fruiting plant populations observed at ROW sites. No significant differences were observed in percentage change of plant family groups from 2020 to 2022; however, all fruiting plant families occurred in higher abundance
(See Table 1) (Kruskal-Wallis Chi Sq. 0 .74 DF 6).

months, it was not in synchronization with the timing of fruit. During the growing season and when plants may not be in bloom or fruit, some insectivorous birds may take advantage of insects on the new growth (Persad, personal observations), hence understanding the fruit plant ecosystem is the subject of an extended future study.

CONCLUSION

These results, while reporting on preliminary data and part of a broader study into climate resiliency in frontline states, offer a snapshot of plant community and biodiversity in managed areas in or abutting to active ROW areas. Plant dynamic and population changes in climate-resilient programs are important considerations in planning and proactive management, especially in countering more erratic weather conditions. We reported on three studies in different regions, and while we have observed in all sites' stability in established ROW (EST) with minimal disturbance (Study 1), we also observe increases in and skewing towards higher populations of vining and fruiting plants at these and other sites, including in the U.S. (Study 2). As MTs continue to affect vegetation cycles and as we strive for climate resiliency in our ROW programs, the plants that do better under these high swing conditions will become more and more primary occupants of ROW and may eventually become bioindicators for ecosystem health and change. These plant factor considerations all aid in better practices geared towards successful integrated vegetation management implementation (Miller 2001). In addition to plant biodiversity and plant dynamics, we also looked at bloom windows and avian visits (Study 3) to these plants by local songbird species. Songbirds are important components of the ROW environment and their activity in ROW is important to vegetation managers, especially as the MBTA and other wildlife laws may protect avian activity. By better understanding avian

Table 3a. Bloom Windows Observed in 12 Families of Fruiting Plants Monthly in 2021, Alachua County, FL

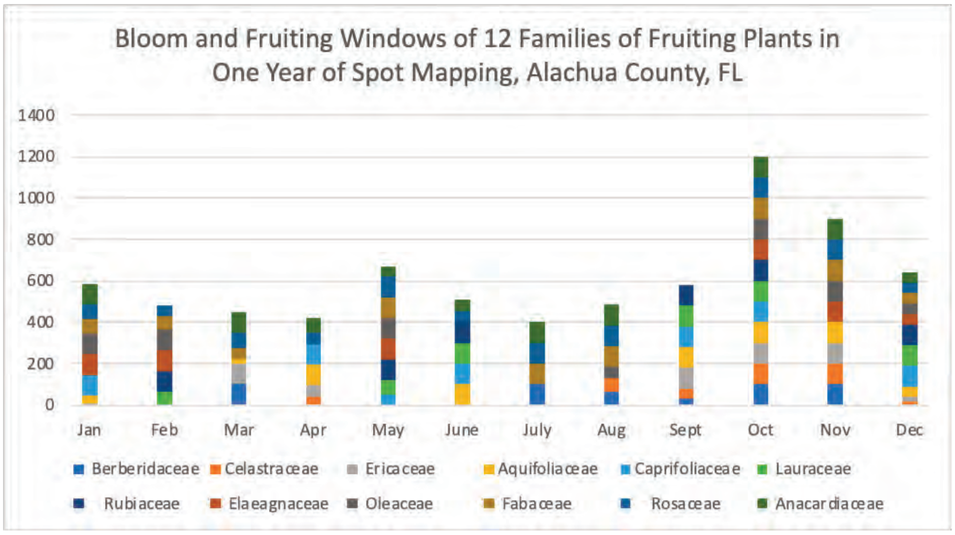
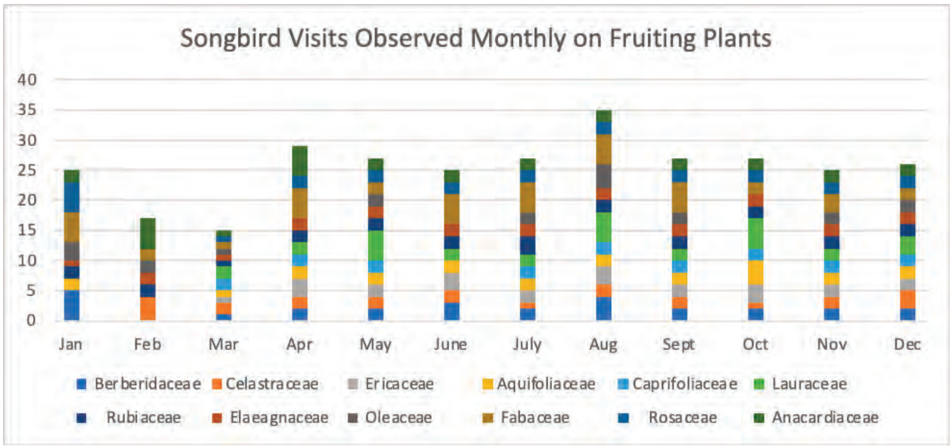


Table 3b. Songbird Observations and Duration of Visits to Fruiting Plant Groups; The songbird peak usage are not in synchrony with peak bloom and fruiting.



usage of habitat, the planning of product applications and other management activities can be better timed to reduce avian conflicts.

Overall, we in the green space management industry—whether urban or utility ROW—can benefit from programs that are informed from real-time ROW data. Proactive planning can only occur if we know what we have and can project within reason a certain degree of preparedness. Only then can we aim to counter shorter MTs and evolving plant populations and cycles. Our deliverable in these instances can be ROW that are better prepared to handle the next wave of change. The proliferation of any one species or group affects biodiversity (e.g., fruiting plants), and the downstream effects are important to begin evaluating ecosystem health and services. In utility corridor edges and urban spaces, trees offer a valuable commodity for our own human and social health, and any proactive measures, such as efficient use of technology and mapping and better tracking of the plant composition of our spaces, will go a long way for preparing us for a future of pivots, short MTs, and hence promoting conservation of our spaces as we realize ecological and economical ROI. By knowing what is happening in ROW, we can adapt our management to proactively prepare for potential edge effects, such as an invasion of vines outwards onto trees and other desirable vegetation as well as utility hardware encroachment.

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PART III

Evaluation and Assessment

A Comparative Analysis of Pipeline Abandonment Options for Terrestrial and Marine Environments

Colin Piggot, Jody Bremner, and Ade Lambo

Keywords: Australia, Canada, Canada Energy Regulator (CER), Commonwealth Offshore Petroleum and Greenhouse Gas Storage Act (OPGGS Act), Evaluation, Environmental Impact, Filing Manual Guide B, Marine, Pipeline, Pipeline Abandonment, Pipeline Removal, Restoration, Terrestrial.

Aging pipeline infrastructure has energy companies around the globe reviewing their abandonment obligations. Pipeline infrastructure that has been removed from service is often abandoned to reduce operational costs and long-term liability. This paper presents a comparative review of abandonment-in-place versus pipeline removal options, using perspectives from marine pipeline abandonment in offshore Australia and terrestrial pipeline abandonment in Canada.

Australia's established regulatory process of comparative assessment under the federal Offshore Petroleum and Greenhouse Gas Storage Act 2006 can provide insights for the relatively new comparative assessment requirements in Canada under the Canada Energy Regulator's recent Filing Manual guidance updates for abandonment (Guide B) and decommissioning (Guide K).

It is important to weigh potential environmental, social, health, and safety impacts and benefits experienced over the short- to medium-term (for example, construction land disturbance) against the far future (for example, contamination resulting from degraded pipe infrastructure) when comparing abandonment in place versus pipeline removal. This paper uses terrestrial and marine pipeline abandonment examples to demonstrate how potential trade-offs of environmental impacts now and in the future can be assessed to support decisions on abandonment options that will deliver the best environmental, social, health, and safety outcomes.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Aging pipeline infrastructure has energy companies around the world considering their abandonment obligations to reduce operational costs and long-term liability. This paper presents a comparative review of abandonment-in-place versus pipeline removal options, using perspectives from marine pipeline abandonment in offshore Australia and buried terrestrial pipeline abandonment in Canada to present recommendations and potential improvements for comparative assessment methods for future abandonment projects.

While the topics discussed may also be applicable to the assessment of pipeline decommissioning (i.e., when a company shuts down operation of a pipeline but maintains and monitors the infrastructure, and service could be reinstated later), this paper focuses on the potential environmental impacts and assessment methods specific to pipeline abandonment (i.e., when a pipeline is permanently removed from service).

BACKGROUND ON PIPELINE ABANDONMENT

This section discusses the Australian and Canadian history of pipeline abandonment.

Australian Pipeline Abandonment

The Australian offshore oil and gas industry has been in "full flow" since the 1960s, with the discovery of significant crude oil reserves within the Gippsland Basin in federal waters (more than 3 nanometres [nm] from baseline) offshore of Victoria. This was soon followed by the discovery of massive gas and condensate reserves in the 1970s within the Carnarvon Basin in the Northwest region of Western Australia (Victorian Department of Jobs, Precincts and Regions 2022). The industry and the hydrocarbon resources are a significant contributor to Australia's national economy and energy security.

While traditional and unconventional onshore oil and gas remains an important contributor to current hydrocarbon production, particularly within Queensland, New South Wales, South Australia, offshore reserves are the primary source of production nationally. There are approximately 136 fixed offshore hydrocarbon facilities (including pipelines) within federal Commonwealth waters, with most reaching the end of their productive lives and requiring abandonment within the next 10 years (Australian Government 2018).

It has been estimated that Australia's offshore oil and gas abandonment liability over the next 50 years will be $21 billion (Wood Mackenzie 2018). To date, large-scale abandonment of offshore pipelines has not been undertaken despite the legislative requirement to do so, with producers, instead, deferring these activities.

A review of Australia's abandonment regime was undertaken by the federal government in 2018 (Australian Government 2018), with the result being an enhancement of the national abandonment framework via a series of amendments to legislation and published abandonment guidelines for industry (Australian Government 2022).

Canadian Pipeline Abandonment

In the late 1940s, large oil and natural gas reserves were developed in Alberta (AB), requiring substantial pipeline development to get crude oil to markets in Eastern Canada and the United States. The discovery of oil reserves in AB began the oil boom in Western Canada, including oil and gas exploration throughout British Columbia (BC).

Canada's pipeline capacity has since expanded greatly with the construction of pipelines linking Canadian oil and natural gas fields with refineries in Canada and the U.S., and export facilities on both the eastern and western coasts of Canada. As of 2020, there were more than 840,000 kilometers (km) of pipelines in Canada (Government of Canada 2020), with more than 440,000 km in AB (AER 2022).

Most pipelines in Canada are buried. As of April 1994, the Alberta Energy and Utilities Board (now the Alberta Utilities Commission) estimated that 17,000 km of pipelines were abandoned in AB alone (CER 1996), with that number expected to have grown substantially over the last nearly 30 years.

Some of these early pipelines have extended past their usable lifespan and remain decommissioned in place. Many Canadian pipeline companies are motivated to remove this aging infrastructure from service by formally abandoning these pipelines to reduce operational costs and long-term liability.

THE AUSTRALIAN AND CANADIAN REGULATORY CONTEXT

This section discusses the Australian and Canadian regulatory contexts for pipeline abandonment.

Australia

Given that most offshore oil and gas assets in Australia are within federal Commonwealth waters, the primary legislation governing abandonment is the Offshore Petroleum and Greenhouse Gas Storage Act 2006 (OPGGS Act), which is governed by the National Offshore Petroleum Safety and Environmental Management Authority as the relevant regulator.

Subsection 572(3) of the OPGGS Act states that a titleholder must remove from their title area all structures, equipment, and property that is not being used for operations. Furthermore, as part of the process of surrendering a title, titleholders are required under the provisions outlined in subsection 270(3) to "provide for the conservation and protection of the natural resources in the surrender area . . ." and ". . . ma[k]e good any damage to the seabed or subsoil in the surrender area caused by any person engaged or concerned in the operations authorised by the title."

In addition to federal and state legislation, Australia maintains international obligations for the prevention of pollution at sea as governed by the United Nations Convention on the Law of the Sea and the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972. The domestic implementation of legislation for these obligations is the Commonwealth Environment Protection (Sea Dumping) Act 1981 (Sea Dumping Act). Furthermore, Australia's abandonment framework considers the requirements of the International Maritime Organization Resolution "A.672(16) - Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and the Exclusive Economic Zone."

The salient point of the abandonment regulatory framework in Australia is that removal of all property (including pipelines) in compliance with provisions of the OPGGS Act is the default requirement (i.e., the base case). While full removal remains the base case abandonment option, alternative options may be considered; however, it must be demonstrated that an alternative option delivers equal or better environmental outcomes compared to full removal and meets the applicable requirements under the OPGGS Act and Sea Dumping Act.

Canada

Regulatory requirements for pipeline abandonment vary across jurisdictions. In Canada, the Canada Energy Regulator (CER) is responsible for regulating interprovincial and international pipeline systems, while individual provincial regulators are responsible for regulation of intraprovincial pipeline systems (CER 2020). Federally regulated pipelines must be granted approval under section 241 of the Canadian Energy Regulator Act to abandon a pipeline. The abandonment must be completed in accordance with the requirements of section 50 of the Onshore Pipeline Regulations.

Application requirements for CER approval to abandon a pipeline are outlined in Guide B (CER 2022b) of the CER Filing Manual (CER 2022a). Due to an increase in abandonment applications that lacked detail and clarity leading to incomplete applications, information requests, and conditions, the CER made final revisions to Guide B in November 2021. One revision changed how proponents must complete their environmental and socioeconomic assessments, with a greater emphasis on comparing the effects of abandonment options (i.e., abandon in place versus removal) in each land cover or ecosystem type encountered. Per Table B-1 of Guide B (CER 2022b), proponents must now complete a detailed effects assessment of various valued components that considers both abandonment options against all land cover encountered.

ABANDONMENT OPTIONS

For both marine and terrestrial pipelines, a range of additional factors (other than regulatory obligations) may influence abandonment considerations, including:

- Environmental
- Safety
- Technical feasibility
- Socioeconomic
- Public interest

In many cases, particularly for large or long pipelines, complete removal may not be practicable or yield the best net environmental outcome. Abandonment options for pipelines generally fall within three broad categories:

1. Leave in place
2. Partial removal
3. Full removal

Leave in Place

A leave-in-place option generally involves a process of flushing, cleaning, and purging the pipeline to remove residual hydrocarbons and contaminated scaling. In a marine context, often the ends of the pipeline are then plugged and buried to limit snagging by fishers. In some cases, where a pipeline or sections are unburied, secondary stabilization (e.g., rock or concrete mattress placement) may be necessary to mitigate the risk of the pipeline moving in the long-term.

In a terrestrial context, if the pipeline is buried, the belowground portion of the pipeline is generally left in place. Aboveground infrastructure is generally removed and the pipeline is exposed, cut, and capped, followed by backfill of surficial material. In areas with higher risk of pipeline collapse (e.g., road and rail crossings), the pipeline may be filled with an inert material, such as concrete to prevent pipeline collapse.

Partial Removal

Partial removal involves leaving most of the pipeline in place and removing only sections that pose an unacceptable risk if left in situ or sections that are relatively simple to remove. In a marine context, removal of the nearshore or intertidal shore crossing sections is often the preferred choice, particularly if unburied. Similarly, sections of terrestrial pipelines typically removed in a partial removal scenario include watercourse crossings or unstable terrain, where there is risk of future pipe exposure or terrain stability impacts that could have safety or environmental concerns that outweigh those associated with removal of the pipe.

Full Removal

Full removal is often the least preferable pipeline abandonment option for owners of the asset, as full removal of the pipeline requires more effort with higher associated costs, and remediation, reclamation, or restoration of the land area or seabed where the pipeline was situated.

Removal in a marine context is generally undertaken by either cutting and lifting sections onto a barge or vessel or by a reverse s-lay process, in which the pipeline is recovered at one end and tensioned before pulling it onto the deck of the vessel, where it is cut into sections and taken onshore for disposal or recycling.

In a terrestrial context, complete removal generally involves a combination of excavating the pipeline (e.g., rights-of-way [ROW] clearing, stripping, excavation, removal, backfill, and reclamation) and pulling segments (that is, pulling cut segments of pipeline from an excavation at one or both ends of the segment).

Table 1. Risks of Abandonment Options

Risk	Relevant Scope	Leave in Place	Partial Removal	Full Removal
Loss of habitat and associated biodiversity	M/T	-	√	√
Seabed or terrain and soil disturbance	M/T	-	√	√
Limitations to or conflict with current or future land or resource use	M/T	√	√	-
Impacts to property value, purchase, or lease agreements	T	√	√	-
Impacts to engineered structures (e.g., future pipe collapse at road crossings)	T	√	√	-
Visual or aesthetic impacts (e.g., unnatural feature on the seafloor)	M	√	√	-
Visual or aesthetic impacts (e.g., from clearing vegetation, soil disturbance)	T	-	√	√
Contamination of soils or water (e.g., from pipeline residue)	M/T	√	√	-
Pipe collapse causing terrain subsidence and change in surface water flow	T	√	√	-
Navigation hazard	M	√	√	-
Navigation hazard (e.g., exposure at watercourse crossings)	T	√	-	-
Atmospheric emissions	M/T	-	√	√
Discharges and spills from vehicles, vessels, and equipment	M/T	-	√	√
Management of waste	M/T	-	√	√
Occupational safety risk	M/T	-	√	√
Effects on communities or individuals	M/T	-	√	√
Reputational risk (e.g., social licence)	M/T	√	√	-

- = not applicable
√ = applicable
M = marine pipeline abandonment
T = terrestrial pipeline abandonment

Abandonment Risks and Benefits

Table 1 identifies a number of potential risks associated with the abandonment options for both terrestrial and marine pipelines. Benefits of abandonment by leaving in place include reduced costs and reduced risks, and impacts associated with removal, such as retaining ecological and habitat values that typically regenerate over existing pipelines during their operational life.

Comparative Analysis of Abandonment Options

It is important to weigh potential environmental, social, health, and safety impacts and benefits experienced over the short to medium term (for example, construction land disturbance) against the far future (for example, contamination resulting from degraded pipe infrastructure) when comparing abandonment in place versus pipeline removal.

Comparative assessment is valuable to understand and evaluate the various pipeline abandonment options. This is generally a transparent collaborative process that can be undertaken with a range of technical experts, stakeholders, communities, and Indigenous groups. Comparative assessments for pipeline abandonment use a set of criteria and relevant factors to be considered, as shown in Table 2.

Comparative assessments of marine pipeline abandonment in Australia involve assessing the risk, benefit, and feasibility associated with each option to transparently demonstrate the preferred abandonment approach. The assessment can be either a qualitative or quantitative process in which the short- and long-term risk and benefits associated with each option are assessed against a number of criteria. In most comparative assessment processes, the abandonment options are subjectively scored against the assessment criteria, with the preferred option generally demonstrating the lowest score.

An example of a qualitative comparative assessment process for the abandonment of an offshore pipeline is presented in Table 3 based on the framework presented in the United Kingdom Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) "Guidance notes - Decommissioning of Offshore Oil and Gas Installations and Pipelines" (OPRED 2018), which is the current offshore industry standard process.

The requirement for comparative assessment of abandonment options is recent in the Canadian context. The CER requires pipeline abandonment applications to assess the short- and long-term environmental and socioeconomic effects of the different abandonment options for each land use segment of the pipeline (CER 2022a). To date, typical comparative assessments provide tables that list the potential effects of the different abandonment

Table 2. Comparative Assessment Criteria and Factors for Pipeline Abandonment Options

Assessment Criteria	Relevant Factors – Offshore Pipeline	Relevant Factors – Terrestrial Pipeline
Safety	Risk to personnel (during abandonment activities)	
	Risk to other users of the sea (after operations)	Risk to other industrial operators
	Health and safety risk to those on land during recovery and waste management of infrastructure	Risk to other land users
Environmental	Marine impacts (seabed disturbance, marine fauna)	Biophysical environment impacts (soils and terrain, aquatic environment, vegetation, wetlands, wildlife, and habitat)
	Contaminant risk	
	Resource consumption	
	Carbon and GHG emissions	
Technical	Risk of abandonment operational activity failure (due to technical issues, such as corrosion, lack of structural integrity of the pipe)	
Societal	Risk to current and future resource use (fisheries impacts)	Risk to current and future resource use (traditional, cultural, recreational, commercial, industrial, agriculture)
	Impacts to individuals and communities (local employment opportunities, Indigenous rights)	
	Social value and reputational risk	
Economic	Enduring impacts to commercial fishing leases	Impacts to property values, land acquisition, or lease agreements
	Cost of abandonment activities	
	Cost of long-term monitoring	
	Liability and associated cost	

GHG = greenhouse gas

Table 3. Comparative Assessment of Offshore Pipeline Abandonment Options

Assessment Criteria	Relevant Factors – Offshore Pipeline	Abandonment Options: Full Removal			Partial Removal			Leave in Place		
Safety	Risk to personnel (during operations)			3			3	1		
	Risk to other users of the sea (after operations)	1				2			2	
	Risk to those on land		2			2		1		
Environmental	Marine impacts (seabed disturbance)			3			3	1		
	Other risks (spills, marine fauna, seabed contamination)			3			3		2	
	Resource consumption			3		2		1		
	Carbon emissions			3		2		1		
Technical	Risk of failure of abandonment operational activities			3			3	1		
Societal	Fisheries impacts (recreational)			3		2		1		
	Social value and reputational risk	1				2				3
	Communities (local employment opportunity)	1				2				3
Economic	Cost			3		2		1		
Sum		3	2	24	0	16	12	8	4	6
Final Score		29			28			18		
Scoring	Low 1	Medium 2	High 3							

options considered. Although rationale for the selection of the preferred abandonment method is required in abandonment project applications, the standard approach to date does not include qualitative or quantitative ratings or scores of the risks and benefits of the abandonment options in the comparative assessment, as is the standard for offshore pipeline abandonment.

In contrast to the standard process applied for marine pipeline abandonment, the Canadian regulatory process requires formal assessment over different timescales. This reflects recent regulatory shifts in Canada toward a stronger focus on sustainability. The modernized Impact Assessment Act defines sustainability as the ability to protect the environment, contribute to the social and economic well-being of the people of Canada, and preserve their health in a manner that benefits present and future generations. The well-being of present and future generations is an important principle of sustainability analysis and is particularly relevant to assessments of abandonment alternatives, as future generations may bear the impacts of infrastructure left in place. In addition to considering extended time frames, the assessment should consider that different communities could have different viewpoints about what well-being means, reflecting the values that are important to them.

The Canadian comparative assessment protocol also requires that the analysis be done for the different ecosystem or land use types along a pipeline route (CER 2022a). Broad land cover or land use categories are often used, such as:

- Agricultural
- Forested
- Grassland
- Industrial
- Rural and urban
- Watercourses
- Wetlands

This process allows the assessment to consider the variability in potential effects in different ecosystems and land uses. Similarly, a comparative assessment within an Australian marine context must consider a range of potential environmental receptors, including:

- Benthic habitats
- Marine fauna
- Sediment
- Water quality

By combining the transparency of applying ratings to abandonment options as done for marine pipeline abandonment in Australia, with the additional formalized requirement for assessing different temporal scales, as is done for Canadian pipeline abandonment, a stronger comparative assessment approach could be realized.

CASE STUDIES

This section presents case studies demonstrating the comparative assessment practices implemented on pipeline abandonment projects in Australia and Canada.

Marine Pipeline Abandonment

Griffin Field, located 68 km off Exmouth, Western Australia, includes:

- 12 subsea wells
- 42 km of flowlines
- Multiple subsea structures (for example, anode skids, mooring, and “Christmas trees”)
- A riser turret mooring
- A 12-inch diameter, 60 km gas export pipeline

BHP Petroleum (Australia) Pty Ltd. (BHP) is the titleholder and operator of the field, with production first starting in 1994 and ceasing in 2009 (BHP 2021). Since production stopped, BHP has undertaken a range of abandonment activities, including:

- Disconnecting and removing the floating production storage and offloading facility
- Pigging and flushing of all subsea infrastructure
- Permanent plugging of the wells
- Removing and using some infrastructure (that is, six mid-depth mooring buoys), in consultation with the state government and other stakeholders, to create an artificial reef structure and fish aggregation device within Exmouth Gulf

BHP is now planning for the final decommissioning and abandonment of the remaining subsea infrastructure. As part of the approvals process, BHP undertook a range of stakeholder activities as well as an independent third-party lead comparative assessment process, held in Exmouth in June 2021 that was open to the public following registration and vetting.

During the comparative assessment process, a range of decommissioning options were proposed, discussed, and assessed for the infrastructure. Options ranged from full removal to leaving in place. BHP, through its technical studies (that is, marine surveys and contamination analysis) and the comparative assessment process, sought to demonstrate that leaving in place some of the subsea infrastructure—in particular, the export pipeline—provided a better environmental outcome than full removal.

As a result of BHP’s technical study work and initial stakeholder engagement, four main issues were apparent and were the predominant challenges that needed to be addressed by BHP:

1. **Naturally Occurring Radioactive Materials (NORMs) –** NORMs commonly accumulate as scale within flowlines and other subsea infrastructure during the normal extraction and processing of hydrocarbons. While these materials are naturally occurring within reservoirs, their accumulation within subsea infrastructure can result in elevated levels of radiation, which could prove harmful to humans or marine fauna exposed to the environment. In the case of Griffin Field, NORMs were known to be present within the production

flowlines, heat exchanger, and choke skids (BHP 2022a). Noting the risks associated with this issue, BHP plans to remove all infrastructure that is shown to contain NORMs exceeding safe levels (BHP 2021).

2. **Mercury –** Similar to NORMs, mercury, which is a common trace element within natural gas, often causes scale on pipelines (as mercury sulphide). The primary risk associated within this issue is the potential for contamination of seabed sediments, as well as the ingestion and bioaccumulation by marine fauna if exposed to the environment on the seabed, following the corrosion and breakdown of the pipeline if left in situ (BHP 2022a). Following a consideration of options, BHP proposed to undertake a process of chemical cleaning and pigging to decontaminate and remove residual mercury within the export pipeline prior to abandonment. Any sections of the pipeline that could not be adequately decontaminated would be removed for onshore disposal, with the remainder remaining in situ (BHP 2021).
3. **Plastics –**Approximately 660 tonnes of plastic material were calculated to remain within Griffin Field. Most of this material occurs as coatings on the flowlines, umbilicals, and well service lines. The remainder occurs as thin polymer coatings on the rigid steel structures, such as the export pipeline and riser turret mooring. Given the recent increased focus on the impacts of plastics in the marine environment, BHP proposed to remove all infrastructure that is predominately plastic from the field prior to abandonment (BHP 2021).
4. **Artificial Reef Habitats –** During the lifetime of the field, the subsea infrastructure has provided effective habitat to a range of marine species (such as, fish, mollusks, crustaceans, and other invertebrates). A recent remotely operated vehicle survey undertaken by BHP noted more than 88 species of fish, some of which are nationally and internationally protected (BHP 2021). Studies indicated that if left in situ, the pipeline would continue to provide effective habitat for marine fauna until such time that the pipeline is buried by natural processes (estimated to take up to 100 years). BHP's assessment contented that leaving the export pipeline in situ provides equal or better environmental outcomes when compared to complete removal (BHP 2022a).

The comparative assessment process demonstrated the gaps in knowledge associated with aspects of the proposed abandonment activities, particularly in relation to long-term intergenerational potential impacts associated with contamination of seabed sediments.

Following the comparative assessment workshop and completion of stakeholder engagement in 2021, BHP submitted separate Environment Plans for the decommissioning of the Griffin Gas Export Pipeline and the remainder of the subsea infrastructure (BHP 2022a, 2022b). In both cases, they sought approval for their preferred option of leaving most of the infrastructure in situ. Both plans are currently under assessment by National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), the Australian Government's offshore energy regulator, with BHP aiming to carry out the decommissioning activities in 2023, following approval. NOPSEMA's decision in relation to this activity is of particular interest to the industry in Australia, as it will set an important precedent about the acceptability of certain decommissioning options.

Terrestrial Buried Pipeline Abandonment

A Calgary-based energy company recently initiated an abandonment program for several underground natural gas pipelines that had been decommissioned more than 10 years ago. The pipelines are located in northern boreal forest regions of AB, BC, Yukon, and Northwest Territories in Western Canada. In 2020, the company began the regulatory process for authorization to abandon the decommissioned pipelines. These abandonment projects were among the first to undergo the comparative assessment process required under the CER's Filing Manual Guide K (CER 2020).

The pipelines are located in Northwestern Canada's boreal zone, where ecosystems are characterized by a mosaic of expansive wetlands interspersed with upland conifer (white spruce [*Picea glauca*], lodgepole pine [*Pinus contorta*], jackpine [*Pinus banksiana*]) and mixed wood forests of conifer and deciduous trees (such as balsam poplar [*Populus balsamifera*], trembling aspen [*Populus tremuloides*], birch species [*Betula* sp.]). Open water wetlands are common and are often created by beaver damming in watercourses. Treed and shrubby wetlands are the dominant landscape feature, where black spruce, tamarack, and a multitude of shrub, forb, and graminoid vegetation species occupy poorly drained peat-based soils. With long, cold winters, along with the nutrient-poor organic soils and high water tables, these ecosystems have short growing seasons, which limits vegetation growth.

There are few roads in these remote boreal regions, and the roads tend to be winter-only access: snow and ice are used to create stable driving surfaces over the wet terrain. Given the challenging access, vegetation management on the operating and decommissioned pipelines was infrequent, which allowed natural vegetation ingress and establishment.

The company proposed partial removal as the preferred abandonment approach. The extent of infrastructure removal was limited to aboveground infrastructure and watercourse crossings where pipe exposure due to scour was an issue. Most of the buried pipelines would be cleaned, capped, and left in place.

Several issues were identified and assessed, including:

- One of the pipelines crosses a watershed boundary, which presented concerns with potential changes in hydrologic flow between watersheds if the abandoned-in-place pipeline degrades in the future and creates a water conduit. This impact would only happen if the pipeline were abandoned in place, and can be mitigated by cutting and capping the pipe at the watershed boundary.
- Risk of pipeline exposure and resultant impacts on the environment and human safety. Previously identified pipeline exposures were replaced or removed as part of the company's operations and maintenance practices to limit long-term risk and liability.
- Habitat for species at risk, including boreal woodland caribou [*Rangifer tarandus caribou*] and wood bison [*Bison bison athabascae*], both federally listed as threatened species. Boreal woodland caribou are susceptible to increased predation risk on and near open linear features that create easier access and hunting efficiency for predators. As a result, removing regenerating vegetation to facilitate removal of a buried pipeline could exacerbate or extend adverse effects on the caribou population. Figure 1 shows an example of regenerating vegetation within a coniferous dominant wooded fen habitat on a pipeline ROW slated for abandonment in Northwestern Alberta. Removal of the abandoned pipeline would require clearing vegetation and stripping surface soils to excavate the pipe, which would set back habitat regeneration within a threatened boreal woodland caribou range by at least a decade. This would trigger the need for intensive habitat restoration and offsets. Avoiding or minimizing clearing of regenerating vegetation and habitat restoration to recover forested ecosystems is important to align with population recovery objectives.
- However, the situation with wood bison (Figure 2) is quite different, as they prefer open habitats. As shown on Figure 3, repeated grazing and wallowing has shaped the vegetation community and is a significant factor in reclamation approaches, as establishing forest vegetation is unlikely to be effective due to the high level of use by bison. Through continued grazing over time, they have prevented natural ingress of woody vegetation and created an open grass-dominant ecosystem. Efforts to restore a forested ecosystem along the abandoned ROW segments frequented by bison would quickly be rendered ineffective unless bison were excluded from the restoration areas. Because exclusion of bison from habitats is difficult and would have potential implications for movement and habitat use of many species in the local area, attempting to reclaim the areas of high bison use to forested vegetation was deemed impractical.
- Exposure and cleanup of contaminants along the ROW and at aboveground facilities. The company was required to document spills and cleanup measures during the operational life of the pipelines. Upon review of documentation and further field assessment, locations with potential contamination issues were identified for remediation, regardless of the abandonment method.
- Areas of high archaeological

Figure 1. Regenerating vegetation on a pipeline ROW slated for abandonment, Northwestern Alberta

Figure 2. Wood bison

Figure 3. Small bison herd grazing on pipeline ROW, Northwest Territories, Canada

potential and the possibility of impacts to intact archaeological sites during abandonment activities. Abandonment in place would avoid potential impacts, but removal of the pipelines has potential need for workspace beyond the already disturbed ROW, which could impact archaeological features.

- Potential for far-future impacts to infrastructure (such as roads that cross the pipelines) resulting from pipeline collapse. Available information based on modelling shows a high degree of variability in abandoned pipeline corrosion rates depending on a range of factors (Det Norske Veritas [USA], Inc. 2015), but indicates that a medium-diameter (24-inch outside diameter), bare steel pipeline situated in stable soil and at typical depth would support a personal truck for approximately 9,000 years before collapsing. Furthermore, if it were to collapse, a ground subsidence of up to only four inches would be expected. As the pipelines have outer protective coatings, it is possible that the time frame for corrosion to cause collapse could be even longer than 9,000 years.

The comparative assessment of residual effects for abandonment in place or removal was completed using a qualitative approach that described the residual effects. Several of the impacts associated with abandonment in place could be effectively mitigated, and the impacts of ecological disturbance and costs of removal were deemed to far exceed the potential adverse effects of abandonment in place. The characterization of effects and significance evaluation was completed only for the preferred abandonment approach, which was partial removal that would leave most of the abandoned pipeline in place and remove only aboveground infrastructure and the segment of pipeline where exposure is a future risk.

CONCLUSIONS

Comparative assessment of different pipeline abandonment options is relatively new in Canada but has been applied to marine pipeline abandonment projects using accepted methods. Tools used to rate risks for various abandonment options have been used in the marine context, so there are useful and proven tools for comparative assessments of pipeline abandonment options in terrestrial environments.

The newer regulatory framework for comparative assessment in Canada outlined in Guide B (CER 2022b) of the Filing Manual (CER 2022a) includes more formalized requirements to address different timescales, including far-future impacts, which aligns with the current trend toward stronger emphasis on sustainable decisions that consider current and future generations.

Elements of both the Australian and Canadian comparative assessment processes can be effectively combined to deliver more transparent evaluations to support decision-making on abandonment methods.

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Application of Drone Technology and Photogrammetry to Paleontological Resources Management

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Keywords: Evaluation, Human Use/Impact, Unmanned Aerial Systems/Drones.

The construction, maintenance, and use of rights-of-way (ROW) can put paleontological resources at risk, particularly in rural areas. The American West is famous for the natural preservation of exceptional fossils. These include dinosaurs, early mammals, and more recent Ice Age creatures, all of which can be found on lands crossed by ROW. These fossils are vulnerable to ground disturbance, so knowing what may be present is critical for planning and protection. Challenges can include long-term protection of known resources as well as the inventory of resources in inaccessible terrain. The use of drone technology and photogrammetry can successfully overcome these challenges, providing safe, accurate documentation of resources and identifying areas of resource potential. We used these methods to document paleontological resources for The Dakota Hogback 16 Project for the Colorado State Trust Land Board. This project involved mapping and close-range photogrammetry of significant dinosaur, bird, crocodile, and turtle trackways and the exploration of potentially fossiliferous inaccessible terrain using drones. This case study shows the practical benefits of using drone technology to identify paleontological resources over large landscapes and challenging terrain to facilitate planning and protection of paleontological resources.

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13th International Symposium

INTRODUCTION

The Dakota Hogback 16 is a state trust property in Jefferson County, Colorado, that is owned by the Colorado State Land Board (CO SLB). The property is known to contain important paleontological localities consisting of crocodile, bird, and dinosaur trackways, and plant impressions in the Lower Cretaceous Dakota Group. Based on fossil locality forms, maps, and reports provided by the CO SLB and History Colorado (SHPO), fossils have been documented on the property since at least 1931. Based on locality records provided by the CO SLB and SHPO, there are three discrete locations preserving significant fossil trackways from dinosaurs, crocodiles, and birds.

The property has supported clay mining since at least the 1870s and knowing and understanding the disposition of these fossils is of great interest to the SLB and History Colorado in order to appropriately manage paleontological resources, while still supporting other uses of the property. In order to assist the SLB and SHPO in their management responsibilities, Paleo Solutions, Inc., now part of Stantec Environmental Consulting Inc., developed a paleontological resources inventory and management recommendations.

Geologic Setting

The Dakota Hogback 16 is underlain by five sedimentary bedrock units: the Morrison Formation, the Dakota Group, the Benton Group, the Niobrara Formation, and the Pierre Shale (Kellogg et al. 2008), of which the Dakota Group was the target of the work described here. These units vary in their paleontological potential, with the Dakota Formation being well known for the preservation of a rich fossil record from the age of the dinosaurs.

The Dakota Group along the Front Range was deposited on the western margin of the Denver Basin, an asymmetrical Laramide-aged structural basin. This basin contains sedimentary bedrock units that are from Pennsylvanian through Pliocene in age and are unconformably overlain by Pleistocene and Holocene surficial deposits. The geology of the strata deposited within the Denver Basin is scientifically important because it records the erosion of the ancestral Rocky Mountains, the development of a vast interior seaway that once covered much of central North America, and the uplift of the Rocky Mountain Front Range during the Laramide Orogeny. Significant paleontologic events recorded within Denver Basin units include the extinction of the non-avian dinosaurs at the end of the Cretaceous Period, the development of tropical rainforest ecosystems and the evolutionary radiation of mammals during the Paleocene, and the changing environments and animals that lived in the region during the Pleistocene ice ages.

The Late Cretaceous Dakota Group, or Dakota Group, was originally named by Meek and Hayden (1862) for the town of Dakota, Nebraska, where the group is well exposed and extensive. The type locality of the Dakota Group is located two miles to the north of Bellevue, in Larimer County, Colorado (Lee 1923). The Dakota Group was deposited during the first major transgression of the Cretaceous Western Interior Seaway in beach, estuarine, and other proximal shoreline depositional environments. The Dakota is well known for its fossil footprints and other trace fossils, and also contains scattered bones and locally well-preserved plant remains. Dinosaur track sites from near the top of the Dakota Group have been reported from numerous localities in Colorado and are considered part of a megatracksite that extends from the front range in Colorado to Oklahoma and Northeastern New Mexico (Lockley 1987; Lockley and Hunt 1992). Waage (1955) cited plesiosaur vertebrae in the Dakota Group in Northern Colorado, and Dakota Group fossils have been the subject of numerous paleontological studies (Snow 1887; Mehl 1931; Waage and Eicher 1960; Young 1960; Rushforth 1971; Chamberlain 1976; Lockley 1987, 1990, 1992; Elliott and Nations 1998).

According to other literature and fossil locality records data on the Dakota Group in this area, the hogback that is located within the property belongs to the Muddy Sandstone Formation, which is equivalent in part to the South Platte Formation (Waage 1955; Lockley and Hunt 1992). However, some literature (Houck et al. 2010) indicates the hogback within the property is part of the South Platte Formation.

The reference locality for the Muddy Sandstone Formation is located near Greybull, Bighorn County, Wyoming, and was originally described from subsurface drilling (Eicher 1960). The Van Bibber Shale member of the Muddy Sandstone contains many of the trackways described throughout the Front Range of Colorado (Lockley and Hunt 1992). The Muddy Sandstone is interpreted to represent valley fill and aggradation of sediments during a transgressive sequence in the overall marine regression during the Early Cretaceous (Dolson et al. 1991). These valley fill sediments were deposited in a system of coastal plain facies including tidal flats, coal-bearing swamps, and overbank deposits associated with river systems (Lockley et al. 1989).

Within the property, the Van Bibber Member has been described as part of the South Platte Formation by some authors (Lockley and Hunt 1992; Houck et al. 2010). The Van Bibber has provided the primary source of clay in the Front Range; including from the Old Clay Pits Quarry that is the subject of this study. This shale unit contains a centimeter-thick bentonite layer (volcanic ash) that a prominent sandstone unit lies on top of and can be traced throughout most of the member (Waage 1955). This bentonite layer is thought to be, in part, the reason for the excellent preservation on many of the trackways reported from the Muddy Sandstone Formation (Lockley and Hunt 1992; Lockley et al. 2009). Fossil trackways documented from the Muddy Sandstone Member are diverse and abundant and include those that have been attributed to multiple taxa of dinosaurs (*Caririchium*), crocodiles (*Mehliella, Hatcherichnus*), turtles (*Chelonipus*), and birds. Most notable is the type locality for *Ignotornis mcconnelli*, which is the first ever documented bird trackway from the Mesozoic Era (Mehl 1931; Lockley et al. 2009). This locality occurs in the Muddy Sandstone Formation, Van Bibber Member, at the contact with the widespread bentonite layer, and is included in the work described here.

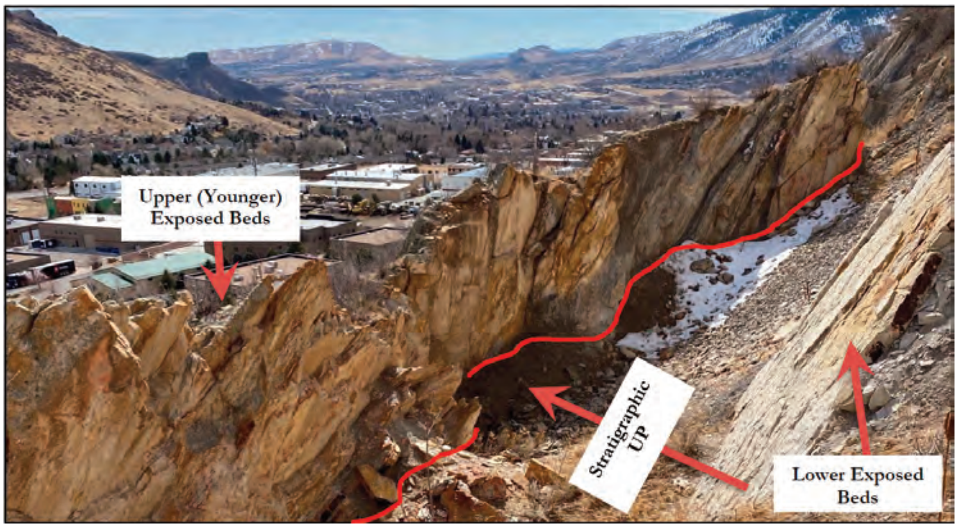

Figure 1. Overview of beds containing the fossiliferous horizon at the very southern end of the section. The red line indicates the bottom of, and the start of, the fossiliferous horizon, facing southeast.

METHODS

While much of the inventory work included traditional methods, such as a review of existing data, geologic mapping, and a pedestrian field survey, the work was enhanced by the utilization of drone technology and photogrammetry to document the trackways, which are not easily collected from the field without damaging the resources. Data collected included locality coordinates using a high-precision GPS receiver, photogrammetry, two dimensional photos, and full lithological descriptions.

RESULTS AND DISCUSSION

A pedestrian survey was completed for the entire 160 acre SLB property with a focus on exposures of the Dakota Group where the main fossil-bearing horizons are known to be. Only the Dakota Group was exposed within the project area. The Dakota Group is composed of interbedded sandstone and clayey silt that has been uplifted and is dipping to the east. A gully exists between lower parts of the exposed Dakota Group and the uppermost exposed beds, which serves as the access to the base of the known fossil-bearing horizon (Figure 1).

All of the previously documented fossil localities were relocated. The fossil horizon that was previously described occurs within a 5- to 10-foot interval, starting at the bottom of the upper (younger) exposed bed where it can be seen on the east side of the gully.

Exposure of the Dakota Group consists of two distinct lithologic horizons, both of which are part of the Muddy Sandstone Formation. The most prominent and lower portion of the exposed Dakota within the project area is a bluish-appearing massive sandstone that can be seen from State Highway 93, and the upper exposed horizon, a yellowish and orangish weathering sandstone with interbeds of silty claystone is mostly removed from the northern portion of the property but exists as a detached cliff band on the east side of the prominent sandstone face.

The upper (younger) horizon is composed of interbedded, well-lithified sandstone, with moderately to poorly lithified mudstone to very fine-grained sandstone composing the upper most layers of this horizon (Figure 3). The well-lithified sandstone beds contain ripples, planar laminations, and cross-laminations; are medium to fine-grained; weather yellowish-gray and orangish-gray; and sometimes contain large mud clasts. The poorly lithified mudstone, silty claystone, and very fine-grained sandstone are medium gray in color. These interbeds of fine-grained rock are part of the Van Bibber Shale Member that was targeted during past mining on the north side of the property where active mining stripped these layers of the Muddy Sandstone Formation. The lower (older) horizon consists of well-lithified, bluish-gray, fine-grained sandstone with ripples and cross-beds.

Fossil Localities

Fourteen fossil localities were documented during the survey. These consisted of three localities preserving common invertebrate burrows, two preserving plant impressions, and nine preserving vertebrate tracks or trackways (including the three previously recorded localities which were relocated). Of these localities, five were recorded using photogrammetry with the assistance of drone technology for photo collection (Table 1). All of these localities are part of fossiliferous horizons, which together provide important information about the flora and fauna of the Cretaceous of North America and contribute to the understanding of the paleoenvironments during this time.

The trackways were left by a variety of animals and record different types of activities. Both turtle and crocodile swim tracks were recorded, as well as bird and ornithopod walking tracks and a single ankylosaur footprint. Of particular note among these fossils are the turtle swim tracks (*Chelonipus* sp.), as they are not well known or well documented in the Dakota Group (Lockley et al. 2006). Additionally, *Chelonipus* sp., observed at F210307-37-01j, is at a much lower stratigraphic level than the four main fossil-bearing horizons (Figure 2). Tying this locality into the overall stratigraphy of the Dakota Group could help to provide interpretations about the evolution of the Dakota Group and the paleoecology and paleogeography during this time.

Another of the trackways, those assigned to *Ignotornis mcconnelli* and attributed to a bird, are the designated holotype of the ichnogenus (Figure 3). This trackway has been heavily collected, with much of the original material now in museums, making the documentation of the remainder of the trackway *in situ* valuable for reconstructing the complete trackway.

Table 1. Five Localities Recorded Using Photogrammetry with the Assistance of Drone Technology for Photo Collection

Locality Number	Fossil Description	Photogrammetry Models
5JF768 (L-52), UCM Locality# 2012052	Type locality for *Ignotornis mcconnelli* - natural cast footprints/complete trackway in-situ on 20-foot wall. Footprints have been collected from this locality: slab with holotypes collected in 1930; additional specimens collected in subsequent years resulting in over 360 individual tracks (original fossils, latex molds, and casts).	https://skfb.ly/6ZDnS
5JF768/5JF3845	Dinosauria natural cast footprints/complete trackway (a) and *Hatcherichnus* sp. - crocodylia natural cast swim tracks (b) on 50-foot overhanging cliff face. Original trackways remain intact, no collection has occurred.	https://skfb.ly/6ZDKs
5JF768 (Bennet's Ranch, MWC-203)	*Ignotornis mconnelii* - natural cast footprint (1) observed during 2021 field visit; this location is where a large slab with *Caririchium* and other *Ignotornis mcconnelli* tracks were collected.	https://skfb.ly/6ZFpq
F210307-37-01f	Cf. *Caririchium* sp. - natural cast ornithopod dinosaur footprint (1)	https://skfb.ly/onIuW
F210307-37-01j	*Chelonipus* sp. - natural casts of turtle swim tracks (4)	https://skfb.ly/6ZFES

Figure 2. Close-up view of newly discovered turtle swim track (*Chelonipus* sp.), F210307-37-01, scale in centimeters.

CONCLUSIONS

The utilization of drone technology to collect a photographic dataset from which to create three-dimensional photogrammetry models of a variety of fossil tracksites enabled the documentation of fossils that are otherwise difficult to collect. This dataset will be useful for the future management of the sites, in order for SLB and SHPO to compare the state of the trackways in the future. This is a case study for how such technology can be applied in similar situations of difficult-to-salvage paleontological resources located in rights-of-way and offers a novel approach to the management challenges such resources represent. Should they be found to be degrading in quality or to suffer from vandalism, more stringent management practices or even collection may prove necessary to prevent their loss. These models also have wide-ranging applications in education and outreach, as they can be used to three-dimensionally print scale or life-size replicas for use in museums, schools, or other educational venues. Such models are highly cost-effective and enable people in a variety of locations to experience paleontology in a hands-on way they may otherwise lack access to.

Figure 3. *Ignotornis mcconnelli* – bird trackway preserving the underprint of at least 30 tracks, several outlined in red, 5JF768 (L-52)/F210307-37-01g. Overview (top) facing east. Insets showing details of the tracks.

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Quantifying Global Powerlines Impacts on Birds and Mammals

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Keywords: Biodiversity, Geospatial, Habitat Loss Impact, Human Use/Impact, Life Cycle Assessment (LCA), Powerlines, Rights-of-Way (ROW), Utility Lines.

There is an expected increase in the global electricity demand. Furthermore, decarbonization and electrification will rapidly expand the current grid network. However, constructing more transmission and distribution lines may impact biodiversity through habitat loss, fragmentation, disturbance, and mortality of birds by collision and electrocution. Life cycle assessment is a common framework to analyze environmental impacts and assist policymakers in reducing potential impacts. However, existing life cycle assessment methods do not yet address the effects of powerlines on biodiversity. We developed a global approach to quantify the habitat loss impact of powerlines on mammals and birds based on the potentially disappeared fraction of species. We calculated how species richness is affected by the current energy distribution system. We identified conflict hotspots, demonstrating the importance of including a spatial component in these assessments. Our model can support sustainable decision-making in future planning of electricity grid networks to reduce the ongoing pressure on biodiversity and ecosystems.

INTRODUCTION

Among the 17 Sustainable Development Goals (SDG), the seventh goal focuses on ensuring everyone the access to clean, affordable, and reliable energy (UN 2021). Two key elements in promoting this SDG are energy production from renewable sources and electrification (IEA 2021). The replacement of fossil fuels with renewable energy and the electrification of heating and transport systems can reduce emissions and play an important role in mitigating climate change (IPCC 2022). Therefore, a successful energy transition is highly dependent on an extensive, modern electricity grid network: transmission lines must cross the long distances between new renewable energy power plants to local powerlines, while distribution lines are required for increasing electricity access and ensuring stable and reliable delivery of energy (IEA 2021).

However, further development of the global electricity grid may sabotage the accomplishments of SDG 15 (Life on Land). Trees and shrubs underneath powerlines are removed to ensure access and to protect infrastructure from the risk of outages. The width of the linear clearing area, also known as the rights-of-way (ROW), can reach up to 100 m. Although powerlines are common along roads and in cities, they are also constructed through diverse landscapes and affect natural habitats (Latham and Boutin 2015). Powerlines cause habitat fragmentation, modification, and loss (Bartzke et al. 2014; Gracey and Verones 2016). In addition, their construction disturbs animals (Biasotto and Kindel 2018) and puts birds worldwide at risk of collision and electrocution (Richardson et al. 2017; Bernardino et al. 2018; Biasotto and Kindel 2018). Nevertheless, expanding powerline networks seems inevitable, as the share of energy production from renewable sources, decarbonization, and electricity demand is expected to increase rapidly (IEA 2021).

An environmental impact assessment framework is necessary to evaluate the numerous biodiversity impacts of electricity distribution to ensure sustainable electrical grid development while minimizing its effect on ecosystems. Life cycle assessment (LCA) is a method that quantifies such potential environmental impacts to support policymakers' decisions. It is a powerful instrument in designing energy policies (Hellweg and Milá i Canals 2014). Life cycle assessment focuses on the different life stages of a product or a service, from the extraction of raw materials, production, and consumption until its disposal (ISO 14044 2006). An LCA analysis quantifies the amounts of consumed resources and released emissions throughout the lifetime of the product or service (Hellweg and Milá i Canals 2014). The so-called characterization factors indicate the impact of one unit of emission or resource use (e.g., per kg of CO_2 emitted or m_2 of land converted). They subsequently help to calculate the environmental consequences of these emissions and resource uses. For example, we can calculate the impact of habitat loss per kilowatt-hour (kWh) produced or consumed for a certain product or service. Life cycle assessment can simultaneously quantify impacts across several categories and identify trade-offs (Hellweg and Milá i Canals 2014) (i.e., between climate change and biodiversity conservation). Life cycle assessment models can also account for spatial regionalization (Verones et al. 2017) and evaluate impacts based on where they occur geographically and which species they damage.

Powerlines were the center of several LCA studies, as highlighted in the review of Gargiulo et al. (2017). They explored their components, different voltage networks, and the construction and operation phases. Climate change, eutrophication aquatic, and resource depletion were the most frequent impact categories. However, potential impacts on ecosystem quality were neglected (Gargiulo et al. 2017) due to a lack of models. While recently developed LCA models quantify the potential biodiversity impacts of electricity production (e.g., hydropower) (Dorber et al. 2019, 2020) and onshore wind power (May et al. 2020, 2021), they exclude impacts from powerlines.

We present in this study a new methodology to quantify the current habitat loss impacts of powerlines on biodiversity. We applied our method on a global country scale to show how the conversion of forested habitats to linear clearings affects the biodiversity of mammals and birds.

METHODS

Derivation of Characterization Factors for Powerlines Related to Habitat Loss

Potentially Disappeared Species

We calculated characterization factors with a countryside species-area relationship (SAR) model, following the approach suggested in Chaudhary et al. (2015) to quantify the impacts of land use changes. Species-area relationship describes the relationship between the area of habitat and the number of species it can support. It assumes that species richness depends on the habitat size (i.e., a larger habitat can sustain more species) (Conor and McCoy 2013). A classic SAR would convert any modified habitat into hostile habitat (i.e., loss of all species), while a countryside SAR assumes that species can survive in modified landscapes

(Chaudhary et al. 2015). Here, the countryside SAR model predicts how many species potentially disappear (potentially disappeared fraction - PDF_j), i.e., become locally extinct, within each ecoregion j due to land use change (Eq. (1)).

$$\mathrm{PDF}_{\mathrm{t,p,j}} = 1 - \left(\frac{A_{new,p,j} + h_{t,j} \times A_{lost,p,j}}{A_{org,j}}\right)^{z_j} \quad (1)$$

$A_{org,j}$ [m^2] accounts for the original area size of each ecoregion j. $A_{new,p,j}$ [m^2] represents the remaining habitat after the construction of the ROW, while $A_{lost,p,j}$ [m^2] is the total area size of the ROW in each ecoregion. We generated PDF values per powerline type p to differentiate between transmission and distribution lines. The constant z describes the slope of the SAR in ecoregion j. We assigned z values (Drakare et al. 2006) for each ecoregion by following de Baan et al. (2013), who assigned ecoregions with habitat types (i.e., island, non-forest, and forest). We classified 23 further ecoregions without habitat category by examining their spatial location and ecoregion description.

The affinity ($h_{t,j}$) indicates how sensitive a taxonomic group t (mammals or birds) is to the conversion of natural habitat to a modified habitat (i.e., how well they can adapt to living in human-modified landscapes). We assume the affinity (h) of a taxonomic group t to their natural habitat equals 1. We calculated the affinity for the conversion of natural habitat to ROW with the following equation (Eq. (2)):

$$\mathrm{h}_{\mathrm{t,j}} = \left(\frac{S_{t,j}}{S_{org,t,j}}\right)^{1/z_j} \quad (2)$$

The affinity ($h_{t,j}$) is generated by the ratio between the species richness in the modified habitat ($S_{t,j}$) and species richness in the natural habitat ($S_{org,t,j}$). If the natural habitat is converted into a more hostile one, their affinity to such modified habitat decreases to zero.

Lower ratios indicate that most species are sensitive to anthropogenic modifications, while higher ratios suggest that many remain in their habitat despite the modification.

We then calculated the regional characterization factors by dividing the PDF values by the area lost within each ecoregion due to the construction of the ROWs (Eq. (3)). The regional characterisation factor represents how many species are lost per m^2.

$$\mathrm{CF}_{\mathrm{regional,t,p,j}} = \frac{PDF_{t,p,j}}{A_{lost,p,j}} \quad (3)$$

Aggregation to Country Values

We performed an aggregation step from ecoregions to countries since electricity production and consumption data were only available at the country level. First, we aggregated the ecoregion level characterization factors to the country level by weighting the area size of the ecoregions within each country ($A_{j,c}$) by the total area of the country (A_c) (Eq. (4)).

$$\mathrm{CF}_{regional,t,p,c} = \sum_j CF_{regional,t,p,j} \times \frac{A_{j,c}}{A_c} \quad (4)$$

The final characterization factors were derived by multiplying the regional country-level characterization factors ($CF_{regional,t,p,c}$) by the total ROW's area size within each country ($A_{lost,p,c}$) and by dividing it by the amount of electricity ($E_{p,c}$) produced (transmission lines) or consumed (distribution lines) in each country (Eq. (5)). The regional characterization factors on the country level represent how many species are per lost per production or consumption of one kWh.

$$\mathrm{CF}_{country,t,p} = \frac{CF_{regional,t,p,c} \times A_{lost,p,c}}{E_{p,c}} \quad (5)$$

Eq. (5) is based on the regional PDF of species due to the associated habitat change per m^2 caused by the construction of powerlines. However, the aggregation of regional species loss may lead to an overestimation: if we lose a species locally, it does not necessarily mean that it becomes extinct globally (de Baan et al. 2015). In that case, the global extinction probabilities (GEP) can be used to assess how likely species will become globally extinct if they locally disappear in ecoregion j. The GEP considers species distributions, threat levels, and richness to assess the probability of species becoming extinct (Kuipers et al. 2019). Therefore, we multiplied the regional characterization factors with the GEP categories per country (Verones et al. 2022) (Eq. (6)).

$$\mathrm{CF}_{country,t,p,global} = \mathrm{CF}_{country,t,p} \times GEP_c \quad (6)$$

Data

Ecoregion j

We obtained a shapefile of terrestrial ecoregions from WWF (World Wildlife Fund Terrestrial Ecoregions of the World). Ecoregions are defined as large areas with similar species and communities based on biogeographic characterizations (Olson et al. 2001). They are commonly used in LCA as a spatial unit to assess land stress (Verones et al. 2017). We excluded "Rock and Ice" and "Lake" categories as they do not have an ecoregion code and are non-forest habitats.

Species Richness

A species range shapefile for terrestrial mammals (version 6.2) was downloaded from the IUCN (2019) (International Union for Conservation of Nature and Natural Resources). Distribution data for birds (Version 2020.1) were acquired from BirdLife International (2020). We counted the number of species that occur within each ecoregion *j*. For the original species richness ($S_{org,t,j}$), we counted species occurrences with present codes 1 (extant) for 5575 mammals and 10,960 birds. Grassland species ($S_{t,j}$) consist of 1,332 mammals and 2,173 birds that are classified as species in grassland habitats (code 1; extant). All species richness assessments were based on native species only (origin code 1).

ROW Data

We used the global grid network data from the World Bank (Arderne et al. 2020). Transmission and distribution lines were extracted separately. We assumed that the construction of ROW, which requires the removal of all tree cover, would convert the original habitat into an open habitat. Forested areas would reduce their habitat size, yet other habitat types may remain unaffected. Therefore, we reclassified a land cover raster for the year 2019 (Version 3.0.1) (Buchhorn et al. 2020) to account for open land cover types that would suffer small or no habitat loss impact (Table 1).

Although the land cover class "Shrubs" may not be highly affected as forests, we assume the construction of powerlines (i.e., distribution lines) could impact shrubland habitats. The raster dataset did not include areas above latitude 78.25°N (Buchhorn et al. 2021). However, these areas mostly do not contain forested habitats. The subset of powerlines within closed or woody habitats was buffered to account for the width of the ROW: 22.5 m for transmission lines and 18 m for distribution lines, based on the World Bank Group Environmental, Health, and Safety (EHS) Guidelines (IFC 2007). We then assigned the ROWs spatially to each ecoregion and calculated their area sizes in m^2. The mapping and geodata calculations were conducted in ArcGISPro 2.9.0 (ESRI [Environmental Systems Research Institute]). The LCA analysis was executed in R 4.2.0 (R Core Team, 2022) with RStudio (version 2022.02.3).

Table 1. Land Use Reclassification of the Land Cover Data from the Copernicus Global Land Service (Source: Buchhorn et al. 2020)

Land Cover Class (Copernicus Global Land Service)	Reclassified Land Cover Class
0: No data	0 No habitat loss impact
30: Herbaceous vegetation	
40: Cropland	
50: Build-up	
60: Bare / sparse vegetation	
70: Snow and ice	
80: Permanent water bodies	
90: Herbaceous wetland	
100: Moss and lichen	
200: Open sea	
20: Shrubs	1 Habitat loss impact
111: Closed forest, evergreen needle leaf	
112: Closed forest, evergreen, broad leaf	
113: Closed forest, deciduous needle leaf	
114: Closed forest, deciduous broad leaf	
115: Closed forest, mixed	
116: Closed forest, unknown	
121: Open forest, evergreen needle leaf	
122: Open forest, evergreen broad leaf	
123: Open forest, deciduous needle leaf	
124: Open forest, deciduous broad leaf	
125: Open forest, mixed	
126: Open forest, unknown	

Electricity Production and Consumption Data

Global production and consumption data of electricity from 2019 were obtained from IEA (2021) to match the land cover raster from the same year. The energy data were in terajoules units. We converted them to kWh units by multiplying the values by 2.78 x 10^{-5} to make it compatible with LCA applications, which use kWh for electricity production and consumption.

RESULTS

We calculated 2,628 characterization factors for ecoregions and 1,084 regional and global on a country scale (Appendix B). The characterization factors indicate the potential fraction of species that disappears per m_2 of constructed ROW of powerlines. Out of the 825 ecoregions, we did not calculate PDFs for 133 ecoregions, as they did not have powerlines infrastructure. Within the remaining ecoregions, 629 were affected by transmission lines and 685 by distribution lines. We calculated regional and global characterization factors for 138 countries, excluding the countries which did not have electricity or powerline data.

Regional Characterization Factors on an Ecoregion Level

The regional characterization factors for mammals ranged across all ecoregions from 1.52 x 10^{-14} to 2.49 x 10^{-10} PDF*y/m_2 for transmission lines and from 1.52 x 10^{-14} to 4.6 x 10^{-10} PDF*y/m^2 for distribution lines. The regional impact of transmission lines for birds varied from 1.58 x 10^{-14} to 2.46 x 10^{-10} PDF*y/m^2 and 1.58 x 10^{-14} to 4.48 x 10^{-10} PDF*y/m^2 for distribution lines. Unsurprisingly, large non-forest ecoregions were hardly affected by powerlines. These include tundra, desert, or steppe ecoregions, but also small remote islands without native species (i.e., mammals) populations or powerline infrastructure. Transmission and distribution lines greatly impacted forested ecoregions (Figure 1), especially along coastal areas with high population densities in Central America and Southeast Asia. Maps for birds can be found in Appendix A.

Regional Characterization Factors on a Country Level

The regional characterization factors were aggregated from ecoregions to a country level. The characterization factors for mammals varied from 3.29 x 10^{-19} to 1.3 x 10^{-13} PDF*y/kWh for transmission lines and 1.94 x 10^{-19} to 4.98 x 10^{-13} PDF*y/kWh for distribution lines. The impact on birds ranged from 3.18 x 10^{-19} to 1.29 x 10^{-13} PDF*y/kWh for transmission lines and 1.86 x 10^{-19} to 4.96 x 10^{-13} PDF*y/kWh for transmission lines. Regional characterization factors varied by seven orders of magnitude for transmission and distribution lines across all countries. Most countries within the Middle East had very small characterization factors values. Transmission lines had a high impact in Central America (e.g., Jamaica and Cuba), Southern Sub-Sahara (e.g., Namibia and Equatorial Guinea), Southern and Southeast Europe (e.g., Montenegro and Albania), and Southeast Asia (e.g., Sri Lanka and Nepal). The impacts of distribution lines had similar patterns yet higher effects, especially in Central America (e.g., Haiti and Jamaica), Northeast South America

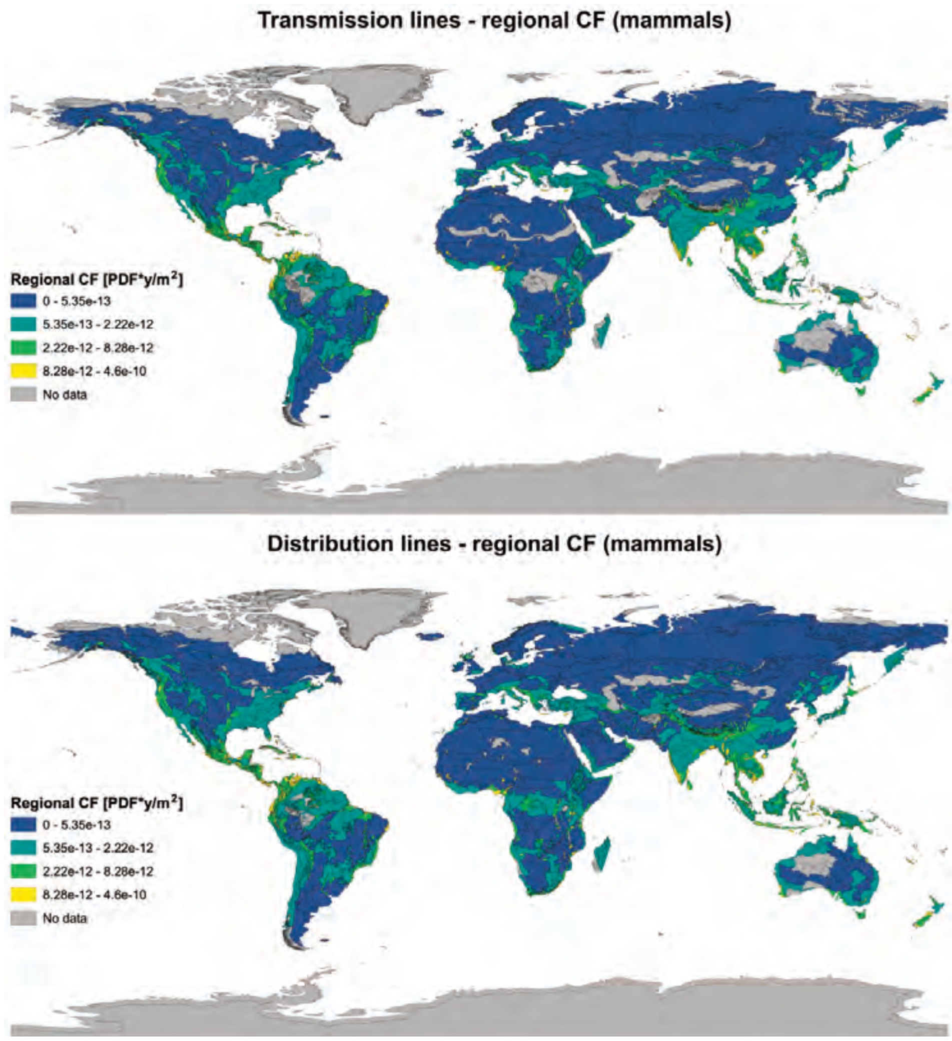

Figure 1. Regional characterization factors of transmission (top) and distribution lines (bottom). Grey areas represent "No data," indicating that no powerlines or mammal species data were available.

(e.g., Guatemala), Southern Sub-Sahara (e.g., Cameroon), and Southeast Asia (e.g., Sri Lanka) (Figure 2). It is important to note that the regional characterization factors derive from the ecoregions and species within each country. Therefore, it is not comparable across countries. Maps for birds can be found in Appendix A.

Global Characterization Factors on a Country Level

While the regional characterization factors represent the potential fraction of species loss per ecoregion, the global characterization factors account for global extinction and hence irreversible extinction. Normally, a global characterization factor represents global species loss within ecoregions. However, we aggregated the regional values to a country level. The global characterization factors of mammals ranged from 2.56×10^{-24} to 4.68×10^{-16} PDF*y/kWh for transmission lines and 6.65×10^{-26} to 2.2×10^{-15} PDF*y/kWh for distribution lines. The variation of the global characterization factors of birds was between 2.47×10^{-24} to 4.7×10^{-16} PDF*y/kWh for transmission lines and 6.42×10^{-26} to 2.19×10^{-15} PDF*y/kWh for distribution lines. The global characterization factors ranged by nine to twelve orders of magnitude for

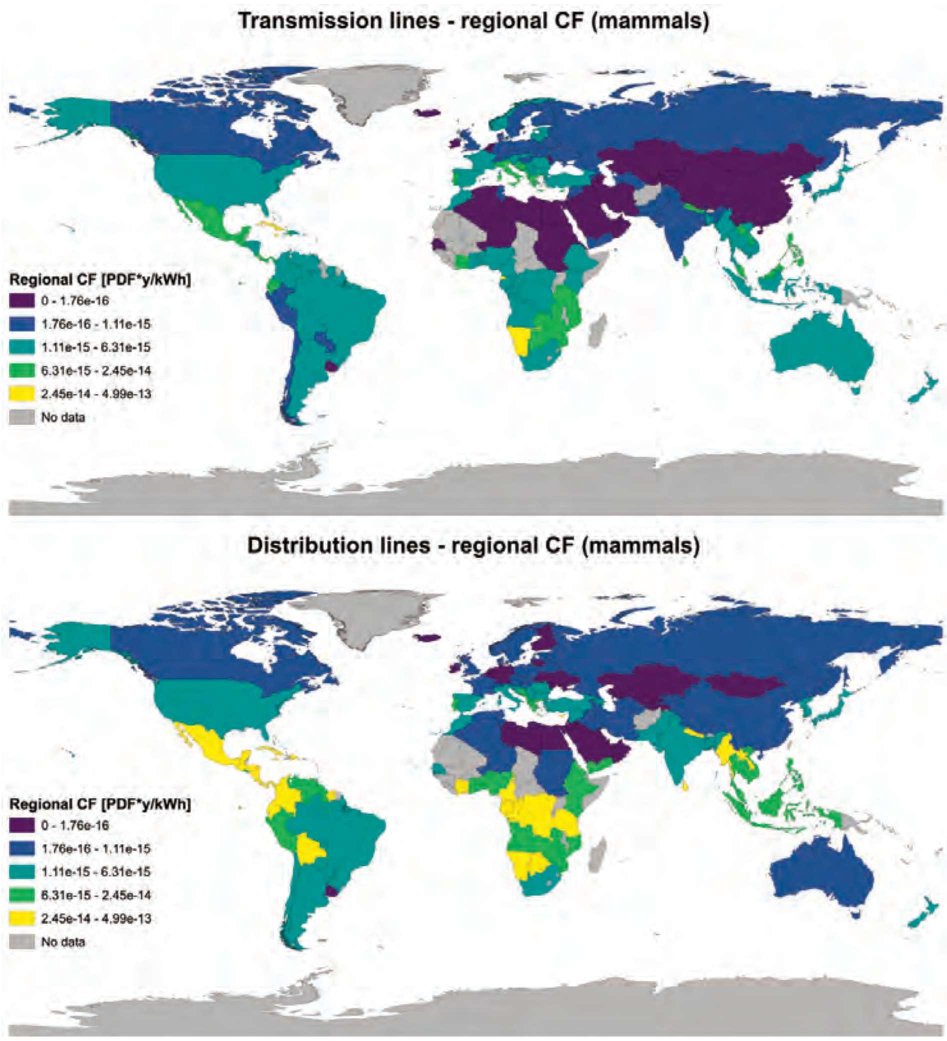

Figure 2. Regional characterization factors of transmission lines (top) and distribution lines (bottom) per country. Grey areas represent "No data," indicating that no electricity or powerlines data were available.

transmission and distribution lines (retrospectively). Transmission and distribution lines greatly impact species richness in Mexico, Jamaica, Indonesia, Sri Lanka, and Ecuador (Figure 3). High global characterization factors from distribution lines also occur in Southern Sub-Saharan countries (e.g., the Democratic Republic of the Congo and Cameroon), Central and South America (e.g., Colombia), and Southeast Asia (e.g., the Philippines). Many of the Middle East countries, as well as northern Europe, had a somewhat small global biodiversity impact from powerlines (e.g., in Qatar, Bahrain, and Iceland). Maps for birds can be found in Appendix A.

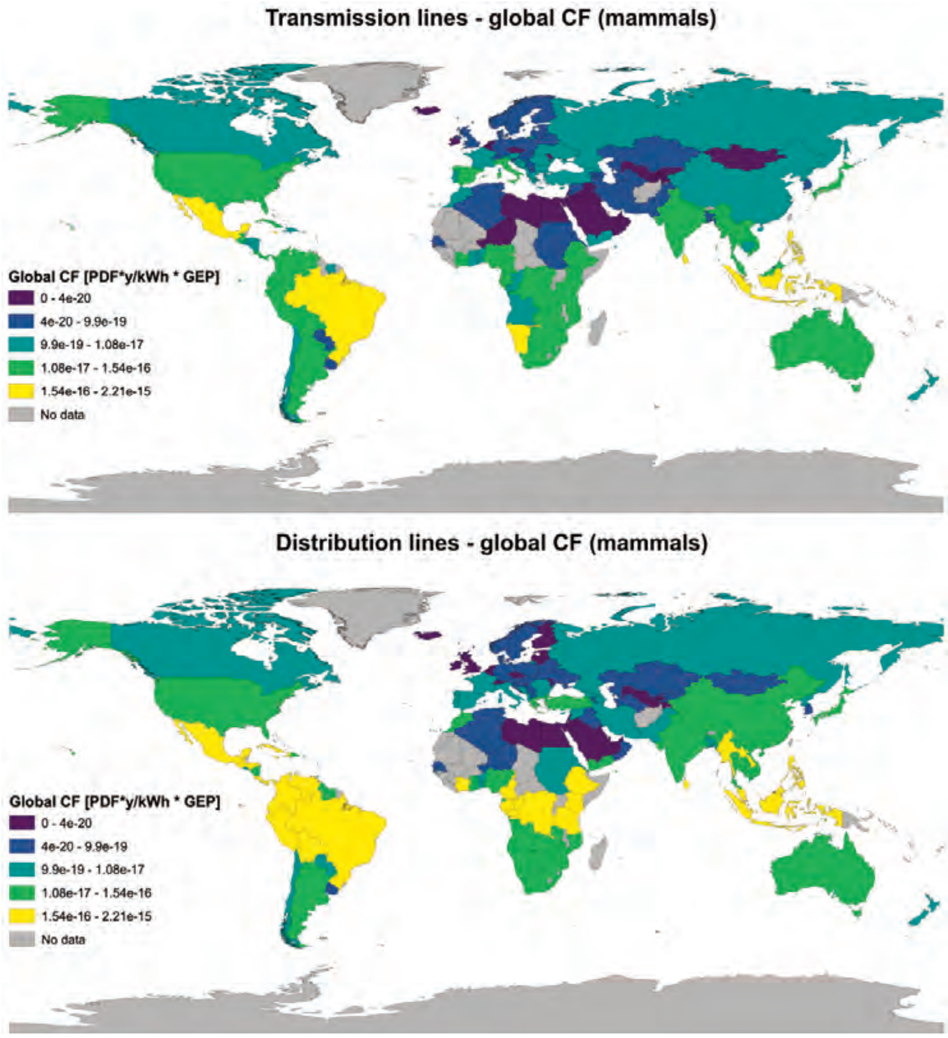

Figure 3. Global CF of transmission (top) and distribution lines (bottom) per country. Grey areas represent "No data," indicating that no electricity or powerlines data were available.

DISCUSSION

In this study, we introduced a new methodology to quantify the habitat loss impact of powerlines on terrestrial mammals and birds. Our model adopted an existing approach that assesses land use change in LCA (Chaudhary et al. 2015), integrating recommended LCA metrics, such as PDF or models that generate characterization factors on a regional and global scales (Verones et al. 2017).

Our results present a high variability between characterization factors across ecoregions and countries. It strengthens the importance of regionalization within LCA, as the impacts of powerlines affect areas differently. The regional characterization factors differ from the global ones (Figures 2 and 3). Global extinction potential was higher in tropical countries: Central and South America, Sub-Sahara, and Southeast Asia. It corresponds with areas rich in mammal and bird species (Howard et al. 2020). It highlights the importance of sustainable planning to construct future powerlines in these countries to avoid global biodiversity loss. While the regional characterization factors cannot be compared because they refer only to the ecoregions and the number of species in each country, by applying the GEP (Kuipers et al. 2019), the global characterization factors become comparable as they present a potential global extinction loss.

The global grid geodata (Arderne et al. 2020) assembled 3,893,160 km of transmission lines and 5,138,180 km of distribution lines. Our results show that distribution lines have, in most cases, higher impacts on species due to habitat loss. Transmission lines had higher impacts in Australia, Japan, the United States, and Italy. However, distribution lines affected more ecoregions and countries, especially in Indonesia, the Democratic Republic of the Congo, Cameroon, and Mexico. That is presumably because of their extensive network, but perhaps also due to their role in linking transmission lines to rural areas. Yet transmission lines receive the most attention from the scientific community. For instance, Biasotto and Kindel (2018) and Richardson et al. (2017) reviewed only the impacts of transmission lines on biodiversity, while Bernardino et al. (2018) showed that most studies related to bird collisions are focused on high-voltage lines, even though birds may also collide with distribution lines.

In addition, although habitat loss is one of the main drivers of global biodiversity loss (IPBES 2019), it is rarely discussed in the scientific literature (Biasotto and Kindel 2018) as most of the focus is dedicated to the collision and electrocution of birds by powerlines (Richardson et al. 2017; Biasotto and Kindel 2018).

The impact of powerlines occurs on the ecoregion level, where habitat is converted into ROW to accommodate powerlines. Our findings are consistent with those of Chaudhary et al. (2015), who quantified regional species loss caused by land use. Although smaller, our regional characterization factors on the ecoregion level vary only in one or two orders of magnitude (Tables 2 and 3). Similarly, birds had slightly higher values compared to mammals.

Table 2. Median Values of Regional Characterization Factors for Ecoregions for Land Use Categories from Chaudhary et al. (2015) for Birds and Mammals (Average Assessment)

	Annual crops	Permanent crops	Pasture	Urban	Extensive forestry	Intensive forestry
Birds	4.35×10^{-10}	4.99×10^{-10}	2.99×10^{-10}	7.89×10^{-10}	6.8×10^{-11}	3.21×10^{-10}
Mammals	1.32×10^{-10}	2.57×10^{-11}	8.5×10^{-11}	1.88×10^{-10}	4.25×10^{-11}	3.11×10^{-11}

Table 3. Median Values of Regional Characterization Factors for Ecoregions for ROWs Construction for Mammals and Birds

	Transmission lines	Distribution lines
Birds	2.54×10^{-12}	2.81×10^{-12}
Mammals	2.42×10^{-12}	2.67×10^{-12}

The foundation of our model lies in the global grid network data. Although the predictive mapping models reach 75% accuracy rates, they have their share of uncertainties. The transmission lines data, for instance, are derived from OpenStreetMap (Arderne et al. 2020), whose data are created by its community and are not necessarily systematically validated. Furthermore, we can expect an overestimation in the prediction of the grid network in cities and an underestimation in rural areas, as it is based on the grid network topology and the presence of roads. Regardless of its limitations, the global grid dataset is, as Arderne et al. (2020) claim, a "valuable starting point" to assess the global impacts of powerlines on biodiversity.

Another source of uncertainty is the width of the ROWs. The EHS Guidelines describe a large variation among widths for transmission lines between 15 m and 100 m. We used the recommended width provided by the EHS Guidelines as a common international standard (IFC 2007). Our results may be somewhat limited and underestimate habitat loss impacts, especially in countries with many transmission lines crossing forested areas.

Furthermore, it is also important to bear in mind our decision to include bushland as an affected habitat for constructing powerlines. While tall trees must be removed from a ROW, bushes might remain to grow underneath the powerlines. That explains, for instance, why our model predicted high impacts for Namibia, a country rich in savanna and woodland ecoregions. Therefore, highly impacted countries without forested landscapes should be interpreted with caution.

Our study focused on two of the most studied taxonomic groups regarding the impacts of powerlines: birds and mammals (Biasotto and Kindel 2018). However, species composition changes within ROWs can also disturb amphibians, insects, plants, and reptiles (Richardson et al. 2017). Existing IUCN datasets provide distribution data of many taxonomical groups (e.g., amphibians, reptiles, and plants). However, there is a lack of data for species within certain taxonomical groups (i.e., plants), while birds and mammals have very high and recent species coverage data (Cazalis et al. 2022).

Despite its limitations, this study shows that habitat loss due to powerlines affects biodiversity. Our characterization factors can be applied to planning a new powerline construction by quantifying the impact of the new planned routes and selecting the least damaging approach. Alternatively, they can be harmonized into existing LCA models that assess the impacts of the energy sector by accounting also for the distribution of the generated electricity.

It is essential to determine the primary impacts that powerlines pose on biodiversity, as it can be a key to developing mitigation strategies (Richardson et al. 2017). However, our study addressed only the habitat loss pathway of powerlines on biodiversity. What is now needed is a further development of more impact pathways. For example, the collision and electrocution of birds are the most studied impacts of powerlines, yet no study evaluated the cumulative impact of the current grid network on bird populations (Bernardino et al. 2018). In addition, an existing method (Kuipers et al. 2021) can be integrated into our model to quantify potential fragmentation impacts. Adding more impact pathways to LCA will enhance the quality of the impact assessment models, providing a more comprehensive evaluation of the effects of electricity systems.

CONCLUSIONS

The framework of LCA is a common, widespread methodology to assess the environmental impacts of products or services across their entire life cycle. Although some impact pathways on biodiversity are integrated into LCA, they fail to cover all known biodiversity loss drivers (Winter et al. 2017). The development of the global grid network is an essential step in ensuring access to sustainable energy (SDG 7). However, expanding transmission and distribution lines will increase the pressure on terrestrial biodiversity, harming terrestrial ecosystems and biodiversity (SDG 15). Life cycle assessment can play a key role in identifying these trade-offs and assist policymakers in mitigating them. Existing LCA models assess the impacts of electricity production on biodiversity, like hydropower (Dorber et al. 2018, 2019, 2020) and wind power (May et al. 2020, 2021), and our model complements these with an additional perspective on electricity distribution, thereby promoting a holistic approach to quantifying the impacts of energy systems worldwide. Harmonizing and integrating these models in environmental planning can contribute to the sustainable development of renewable energy technologies.

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APPENDIX A – FIGURES OF REGIONAL AND GLOBAL CHARACTERIZATION FACTORS FOR BIRDS

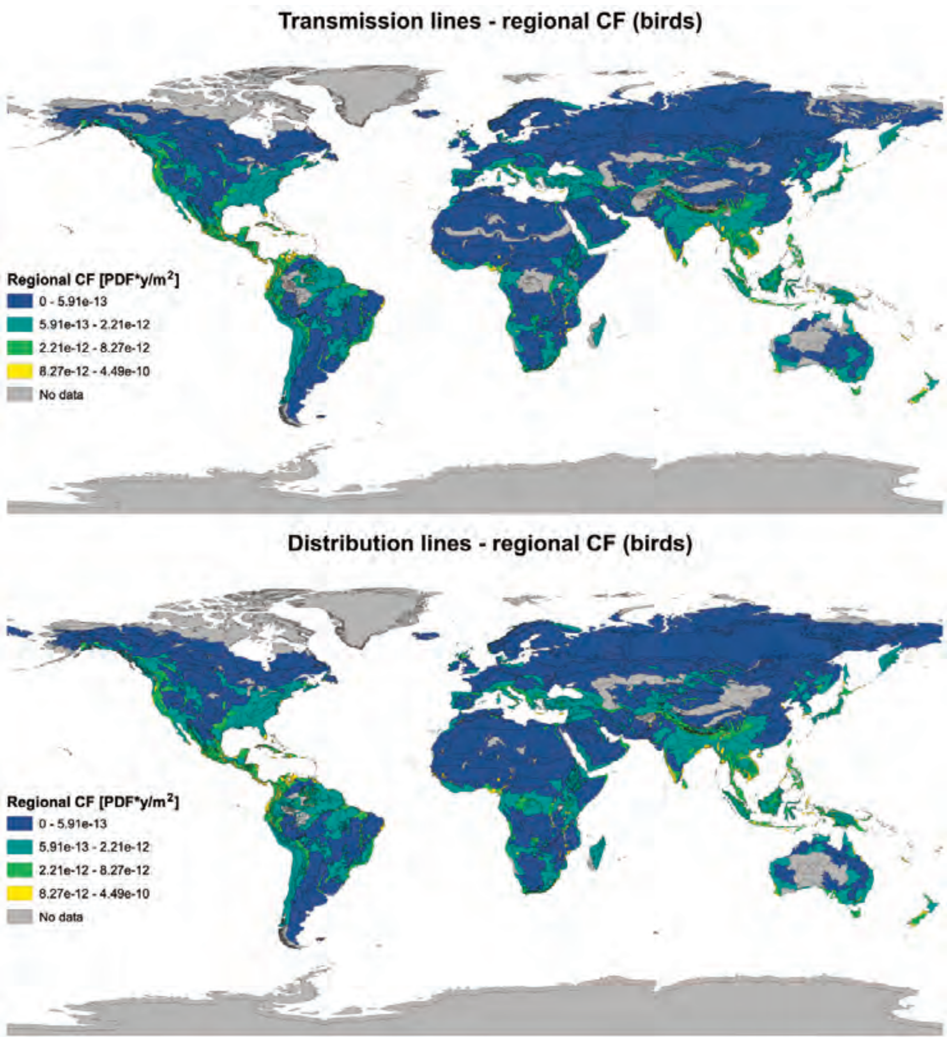

Figure A1. Regional characterization factors of transmission (top) and distribution lines (bottom). Grey areas represent "No data," indicating that no powerlines or bird species data were available.

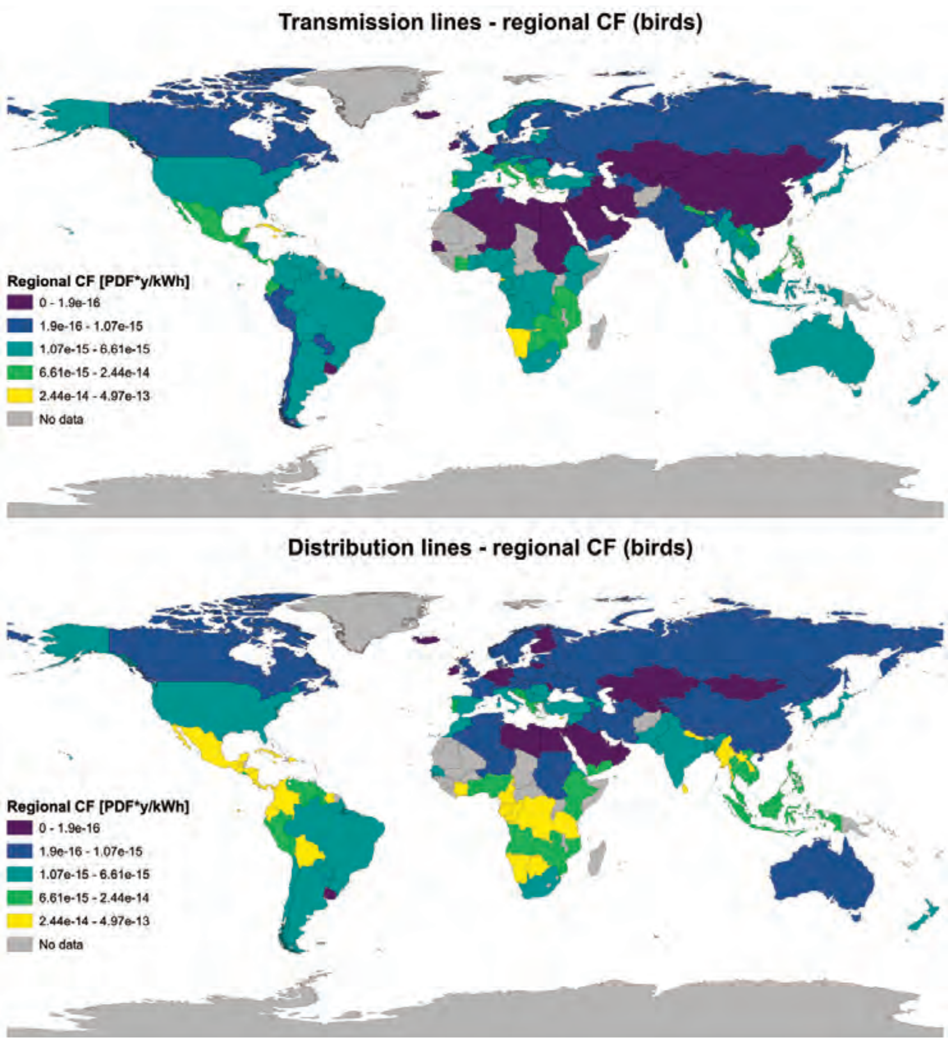

Figure A2. Regional characterization factors of transmission lines (top) and distribution lines (bottom) per country. Grey areas represent "No data," indicating that no electricity or powerlines data were available.

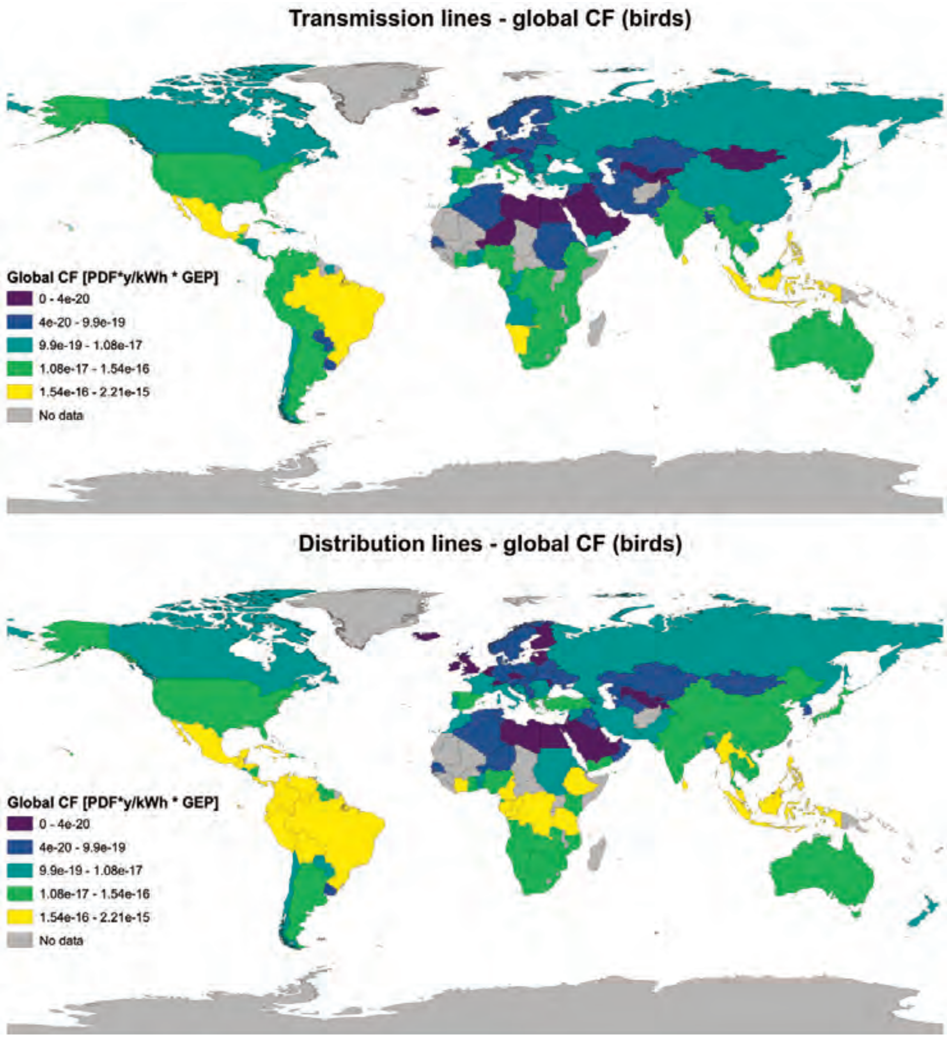

Figure A3. Global characterization factors of transmission (top) and distribution lines (bottom) per country. Grey areas represent "No data," indicating that no electricity or powerlines data were available.

APPENDIX B – REGIONAL AND GLOBAL CHARACTERIZATION FACTORS

Table B1. List of WWF Terrestrial Ecoregions with Regional Characterization Factors (CF) for Habitat Loss Due to Transmission and Distribution Lines

		Mammals			Birds	
Ecoregion code	No. of mammals	Regional CF [PDF*y/m2]		No. of birds	Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
AA0101	23	-	-	118	-	-
AA0102	36	-	3.38543E-11	251	-	3.34894E-11
AA0103	32	-	-	132	-	-
AA0104	25	-	2.99489E-11	194	-	2.96111E-11
AA0105	184	1.49351E-12	1.49381E-12	537	1.49237E-12	1.49267E-12
AA0106	49	-	9.64465E-12	247	-	9.60958E-12
AA0107	99	1.55031E-11	1.55066E-11	428	1.54902E-11	1.54937E-11
AA0108	45	-	-	214	-	-
AA0109	1	-	-	85	-	-
AA0110	26	-	-	185	-	-
AA0111	57	-	7.33056E-12	271	-	7.31323E-12
AA0112	52	-	-	201	-	-
AA0113	9	1.54313E-11	1.54345E-11	135	1.52960E-11	1.52991E-11
AA0114	1	-	-	52	-	-
AA0115	132	1.90748E-12	1.90769E-12	485	1.90568E-12	1.90589E-12
AA0116	88	1.10980E-11	1.10990E-11	425	1.10884E-11	1.10894E-11
AA0117	106	9.30589E-12	9.30543E-12	419	9.07581E-12	9.07537E-12
AA0118	50	1.33419E-11	1.33461E-11	224	1.32611E-11	1.32653E-11
AA0119	48	-	-	255	-	-
AA0120	153	-	3.26859E-12	531	-	3.26520E-12
AA0121	136	2.55431E-12	2.55433E-12	480	2.54924E-12	2.54926E-12
AA0122	147	2.08089E-12	2.08093E-12	494	2.07882E-12	2.07886E-12
AA0123	141	2.22142E-12	2.22204E-12	397	2.21375E-12	2.21436E-12
AA0124	143	3.41170E-12	3.41230E-12	303	3.38584E-12	3.38642E-12
AA0125	42	-	-	175	-	-
AA0126	15	-	-	125	-	-
AA0127	67	-	-	418	-	-
AA0128	95	-	3.33745E-12	483	-	3.33497E-12
AA0201	63	6.42316E-12	6.42545E-12	307	6.34328E-12	6.34551E-12
AA0202	6	5.07646E-11	5.07811E-11	125	5.03105E-11	5.03267E-11
AA0203	21	-	2.33802E-11	208	-	2.29318E-11
AA0204	43	7.53146E-12	7.53469E-12	263	7.41348E-12	7.41661E-12
AA0401	0	-	-	80	-	-
AA0402	93	1.14639E-12	1.14622E-12	465	1.11744E-12	1.11728E-12
AA0403	2	-	-	121	-	-
AA0404	1	9.89031E-12	9.88983E-12	135	9.15671E-12	9.15630E-12
AA0405	2	1.83498E-12	1.83490E-12	142	1.72309E-12	1.72303E-12
AA0406	2	5.56363E-12	5.56370E-12	150	5.27359E-12	5.27365E-12
AA0407	2	-	-	108	-	-
AA0408	1	1.09494E-11	1.09485E-11	137	1.03037E-11	1.03029E-11
AA0409	72	8.10555E-13	8.10526E-13	436	7.78663E-13	7.78636E-13
AA0410	1	1.05976E-11	1.05979E-11	127	1.00547E-11	1.00550E-11
AA0411	32	7.29913E-12	7.29829E-12	215	7.29993E-12	7.29908E-12
AA0412	32	7.65503E-12	7.65487E-12	231	7.65581E-12	7.65564E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
AA0413	32	4.35633E-12	4.35591E-12	224	4.36351E-12	4.36310E-12
AA0414	1	2.56974E-11	2.57014E-11	119	2.44070E-11	2.44106E-11
AA0701	65	1.25585E-12	1.25585E-12	296	1.25476E-12	1.25476E-12
AA0702	111	5.09613E-13	5.09583E-13	471	5.09320E-13	5.09290E-13
AA0703	80	1.71360E-12	1.71362E-12	379	1.70975E-12	1.70977E-12
AA0704	93	-	5.27785E-13	382	-	5.31336E-13
AA0705	108	1.47953E-12	1.47942E-12	394	1.47453E-12	1.47443E-12
AA0706	80	5.46608E-13	5.46611E-13	339	5.51942E-13	5.51945E-13
AA0707	91	3.90244E-13	3.90242E-13	330	3.93567E-13	3.93566E-13
AA0708	62	-	-	341	-	-
AA0709	58	-	8.29092E-13	272	-	8.37813E-13
AA0801	1	2.44623E-12	2.44620E-12	130	2.32405E-12	2.32403E-12
AA0802	48	6.34800E-13	6.34799E-13	279	6.43031E-13	6.43030E-13
AA0803	72	4.67946E-13	4.67942E-13	356	4.67336E-13	4.67331E-13
AA1001	46	1.13299E-11	1.13287E-11	286	1.12442E-11	1.12431E-11
AA1002	149	-	1.64967E-11	410	-	1.64850E-11
AA1003	2	3.37928E-12	3.37926E-12	78	3.29603E-12	3.29601E-12
AA1101	0	-	-	98	-	-
AA1201	34	1.09210E-12	1.09212E-12	252	1.10512E-12	1.10514E-12
AA1202	40	-	-	284	-	-
AA1203	39	2.36748E-12	2.36745E-12	327	2.37689E-12	2.37686E-12
AA1204	25	1.37090E-11	1.37094E-11	251	1.35413E-11	1.35417E-11
AA1205	31	1.00645E-11	1.00639E-11	283	9.94584E-12	9.94526E-12
AA1206	38	5.98243E-12	5.98220E-12	342	5.96852E-12	5.96829E-12
AA1207	62	7.23811E-13	7.23796E-13	333	7.22566E-13	7.22552E-13
AA1208	49	4.90218E-12	4.90215E-12	353	4.84950E-12	4.84947E-12
AA1209	48	9.28876E-13	9.28879E-13	291	9.28925E-13	9.28927E-13
AA1210	38	3.19750E-12	3.19724E-12	281	3.14856E-12	3.14831E-12
AA1301	50	-	1.81113E-12	274	-	1.91162E-12
AA1302	42	-	-	207	-	-
AA1303	30	-	-	149	-	-
AA1304	64	-	-	278	-	-
AA1305	45	3.51147E-13	-	234	3.78846E-13	-
AA1306	31	-	-	221	-	-
AA1307	52	9.26033E-13	9.26033E-13	246	9.94605E-13	9.94606E-13
AA1308	55	2.65172E-13	-	276	2.84710E-13	-
AA1309	56	3.95658E-13	3.95657E-13	343	4.10501E-13	4.10500E-13
AA1310	57	3.35416E-13	3.35417E-13	231	3.61692E-13	3.61693E-13
AA1401	122	9.56404E-12	9.56421E-12	510	9.54680E-12	9.54697E-12
AN1101	0	-	-	33	-	-
AN1102	0	-	-	27	-	-
AN1103	0	-	-	53	-	-
AN1104	0	-	-	50	-	-
AT0101	343	3.25139E-12	3.25197E-12	1013	3.09402E-12	3.09455E-12
AT0102	209	1.81351E-12	1.81377E-12	639	1.72550E-12	1.72574E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2]		No. of birds	Birds Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
AT0103	236	8.84720E-12	8.84883E-12	772	8.38391E-12	8.38537E-12
AT0104	173	-	8.30056E-13	485	-	7.85481E-13
AT0105	10	-	1.19961E-10	94	-	1.18719E-10
AT0106	120	1.64963E-11	1.65016E-11	466	1.56469E-11	1.56516E-11
AT0107	219	6.55282E-12	6.55454E-12	680	6.28221E-12	6.28379E-12
AT0108	319	5.00500E-12	5.00536E-12	1007	4.61272E-12	4.61302E-12
AT0109	260	1.38037E-11	1.38054E-11	826	1.26078E-11	1.26093E-11
AT0110	187	-	3.71908E-12	490	-	3.54104E-12
AT0111	247	1.78878E-12	1.78941E-12	680	1.67180E-12	1.67234E-12
AT0112	249	1.23363E-12	1.23372E-12	832	1.10567E-12	1.10574E-12
AT0113	3	-	-	61	-	-
AT0114	228	1.06816E-11	1.06839E-11	626	9.98593E-12	9.98794E-12
AT0115	117	5.83306E-11	5.83329E-11	441	6.26264E-11	6.26291E-11
AT0116	147	1.12821E-11	1.12825E-11	570	1.15975E-11	1.15980E-11
AT0117	142	2.05985E-12	2.05986E-12	221	2.04670E-12	2.04671E-12
AT0118	164	1.15513E-12	1.15513E-12	228	1.14900E-12	1.14900E-12
AT0119	139	7.58559E-12	7.58604E-12	540	7.55814E-12	7.55859E-12
AT0120	5	-	-	57	-	-
AT0121	153	-	2.99246E-10	487	-	2.93199E-10
AT0122	103	2.37755E-11	2.37833E-11	392	2.28119E-11	2.28191E-11
AT0123	155	5.00753E-12	5.00825E-12	559	4.69999E-12	4.70062E-12
AT0124	311	-	6.39496E-13	886	-	6.04660E-13
AT0125	283	2.26116E-12	2.26131E-12	831	2.15401E-12	2.15415E-12
AT0126	246	7.90913E-13	7.90985E-13	713	7.44349E-13	7.44412E-13
AT0127	9	2.49854E-10	2.50025E-10	98	2.46226E-10	2.46393E-10
AT0128	168	2.02404E-12	2.02413E-12	619	1.89129E-12	1.89137E-12
AT0129	214	-	2.67827E-12	563	-	2.55163E-12
AT0130	224	1.64855E-12	1.64886E-12	638	1.55247E-12	1.55274E-12
AT0201	2	-	-	64	-	-
AT0202	124	-	1.55680E-12	214	-	1.54625E-12
AT0203	155	7.66750E-12	7.66752E-12	545	7.06834E-12	7.06835E-12
AT0701	233	3.03317E-13	3.03337E-13	805	2.96989E-13	2.97009E-13
AT0702	144	1.37047E-12	1.37048E-12	533	1.33381E-12	1.33381E-12
AT0703	0	-	-	27	-	-
AT0704	348	1.72629E-13	1.72636E-13	1048	1.69710E-13	1.69717E-13
AT0705	355	2.24918E-13	2.24929E-13	1132	2.20715E-13	2.20725E-13
AT0706	264	4.14921E-13	4.14934E-13	788	4.03600E-13	4.03612E-13
AT0707	319	3.06653E-13	3.06707E-13	903	3.03542E-13	3.03595E-13
AT0708	178	2.61984E-11	2.61968E-11	600	2.50899E-11	2.50885E-11
AT0709	178	5.16682E-13	5.16682E-13	551	5.04147E-13	5.04147E-13
AT0710	91	-	2.69860E-11	386	-	2.45228E-11
AT0711	316	6.44428E-13	6.44441E-13	1012	6.26696E-13	6.26708E-13
AT0712	353	2.96104E-13	2.96122E-13	1027	2.92871E-13	2.92889E-13
AT0713	229	6.38552E-14	6.38554E-14	818	6.08252E-14	6.08253E-14
AT0714	192	-	1.14919E-11	673	-	1.10797E-11

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
AT0715	264	1.95656E-13	1.95659E-13	902	1.89369E-13	1.89372E-13
AT0716	310	9.19386E-13	9.19400E-13	983	8.98133E-13	8.98146E-13
AT0717	199	7.67213E-13	7.67251E-13	615	7.55852E-13	7.55888E-13
AT0718	217	3.67655E-13	3.67683E-13	803	3.63677E-13	3.63704E-13
AT0719	239	4.63873E-13	4.63882E-13	711	4.52776E-13	4.52785E-13
AT0720	0	-	-	22	-	-
AT0721	351	1.27380E-12	1.27402E-12	1075	1.25373E-12	1.25395E-12
AT0722	251	1.23510E-13	1.23520E-13	750	1.20142E-13	1.20152E-13
AT0723	252	5.06964E-13	5.07026E-13	772	5.01031E-13	5.01091E-13
AT0724	148	5.69988E-12	5.69977E-12	537	5.50455E-12	5.50444E-12
AT0725	278	3.88627E-13	3.88629E-13	772	3.80822E-13	3.80824E-13
AT0726	200	7.15158E-13	7.15167E-13	608	6.87373E-13	6.87381E-13
AT0801	35	6.87788E-12	6.87794E-12	178	6.22471E-12	6.22477E-12
AT0802	0	-	-	39	-	-
AT0803	0	-	-	46	-	-
AT0901	184	-	-	596	-	-
AT0902	82	2.41777E-11	2.41793E-11	351	2.32583E-11	2.32597E-11
AT0903	89	-	-	426	-	-
AT0904	95	-	-	489	-	-
AT0905	134	1.13129E-12	1.13131E-12	538	1.05980E-12	1.05982E-12
AT0906	119	9.46433E-12	9.46442E-12	479	9.34755E-12	9.34764E-12
AT0907	297	1.28860E-12	1.28863E-12	878	1.25431E-12	1.25434E-12
AT0908	128	5.63968E-12	5.63956E-12	504	5.65591E-12	5.65579E-12
AT1001	136	7.75736E-12	7.75782E-12	567	7.61482E-12	7.61527E-12
AT1002	158	2.75520E-12	2.75531E-12	682	2.71301E-12	2.71311E-12
AT1003	108	-	-	382	-	-
AT1004	223	7.47904E-13	7.47924E-13	656	7.38433E-13	7.38452E-13
AT1005	254	6.37777E-11	6.37795E-11	815	6.16049E-11	6.16066E-11
AT1006	162	2.37102E-11	2.37164E-11	534	2.30411E-11	2.30470E-11
AT1007	238	8.19007E-13	8.19036E-13	810	7.88145E-13	7.88172E-13
AT1008	192	7.96000E-12	7.96030E-12	699	7.64215E-12	7.64243E-12
AT1009	161	7.74091E-13	7.74093E-13	527	8.05356E-13	8.05357E-13
AT1010	112	1.52875E-11	1.52876E-11	472	1.47043E-11	1.47044E-11
AT1011	84	-	-	162	-	-
AT1012	150	7.15949E-12	7.15929E-12	557	7.35098E-12	7.35077E-12
AT1013	232	-	7.91382E-11	771	-	7.79472E-11
AT1014	146	1.90486E-11	1.90484E-11	537	1.84927E-11	1.84926E-11
AT1015	208	6.06883E-12	6.06979E-12	675	5.89629E-12	5.89719E-12
AT1201	116	7.68390E-12	7.68369E-12	448	8.02596E-12	8.02573E-12
AT1202	106	4.02772E-12	4.02763E-12	427	4.18225E-12	4.18215E-12
AT1203	121	2.99355E-12	2.99356E-12	435	3.02238E-12	3.02240E-12
AT1301	5	-	-	52	-	-
AT1302	60	2.29533E-12	2.29535E-12	262	2.13834E-12	2.13835E-12
AT1303	63	-	-	348	-	-
AT1304	48	-	-	253	-	-

Ecoregion code	No. of mammals	Mammals		No. of birds	Birds	
		Regional CF [PDF*y/m2]			Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
AT1305	117	1.27267E-12	1.27268E-12	615	1.22019E-12	1.22019E-12
AT1306	36	2.79897E-12	2.79898E-12	251	2.65477E-12	2.65479E-12
AT1307	78	-	-	370	-	-
AT1308	0	-	-	22	-	-
AT1309	143	2.74021E-13	2.74030E-13	464	2.68061E-13	2.68069E-13
AT1310	113	4.11068E-12	4.11076E-12	413	3.94708E-12	3.94716E-12
AT1311	81	-	-	216	-	-
AT1312	57	-	-	197	-	-
AT1313	194	-	2.06820E-12	670	-	1.97362E-12
AT1314	158	4.13151E-13	4.13151E-13	464	4.11288E-13	4.11288E-13
AT1315	86	-	-	309	-	-
AT1316	148	7.89572E-13	7.89569E-13	501	7.54916E-13	7.54913E-13
AT1318	6	-	-	90	-	-
AT1319	71	-	3.14329E-12	372	-	3.02527E-12
AT1320	64	6.91402E-13	6.91430E-13	271	6.29005E-13	6.29028E-13
AT1321	59	2.17766E-12	2.17776E-12	217	1.89247E-12	1.89254E-12
AT1322	124	1.41751E-12	1.41751E-12	401	1.41663E-12	1.41662E-12
AT1401	246	1.10568E-11	1.10581E-11	745	1.04795E-11	1.04807E-11
AT1402	225	1.93025E-11	1.93042E-11	695	1.76094E-11	1.76109E-11
AT1403	212	1.40773E-11	1.40787E-11	705	1.30882E-11	1.30893E-11
AT1404	64	-	-	192	-	-
AT1405	124	2.15498E-10	2.15529E-10	537	2.17478E-10	2.17510E-10
IM0101	15	-	-	159	-	-
IM0102	229	6.04942E-13	6.05128E-13	556	6.03868E-13	6.04053E-13
IM0103	203	2.23723E-12	2.23753E-12	497	2.23341E-12	2.23371E-12
IM0104	185	3.83410E-12	3.83553E-12	476	3.82486E-12	3.82628E-12
IM0105	161	4.60681E-12	4.60728E-12	742	4.66369E-12	4.66418E-12
IM0106	138	7.31092E-12	7.31245E-12	480	7.19226E-12	7.19374E-12
IM0107	158	8.16314E-12	8.16320E-12	482	7.94299E-12	7.94305E-12
IM0108	168	1.57915E-11	1.57930E-11	605	1.56505E-11	1.56520E-11
IM0109	128	-	9.52580E-12	653	-	9.67936E-12
IM0110	0	-	-	49	-	-
IM0111	95	7.49519E-13	7.49567E-13	490	8.13308E-13	8.13364E-13
IM0112	105	1.59785E-11	1.59869E-11	385	1.59054E-11	1.59138E-11
IM0113	114	4.72239E-12	4.72314E-12	406	4.70482E-12	4.70558E-12
IM0114	54	7.14266E-12	7.14364E-12	314	7.08532E-12	7.08629E-12
IM0115	194	6.40155E-12	6.40218E-12	831	6.77140E-12	6.77211E-12
IM0116	65	1.94217E-11	1.94216E-11	396	1.95361E-11	1.95360E-11
IM0117	187	2.12076E-12	2.12085E-12	782	2.09836E-12	2.09844E-12
IM0118	158	4.07228E-13	4.07323E-13	595	4.02462E-13	4.02555E-13
IM0119	206	2.56472E-12	2.56499E-12	729	2.52033E-12	2.52059E-12
IM0120	177	1.04890E-12	1.04896E-12	736	1.05663E-12	1.05669E-12
IM0121	191	4.25718E-12	4.25748E-12	614	4.21307E-12	4.21336E-12
IM0122	72	2.87066E-11	2.87092E-11	342	2.83687E-11	2.83712E-11
IM0123	98	2.51759E-12	2.51778E-12	375	2.49468E-12	2.49486E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
IM0124	105	8.42456E-12	8.42482E-12	485	8.54774E-12	8.54801E-12
IM0125	11	-	4.60044E-10	274	-	4.48868E-10
IM0126	141	6.38575E-12	6.38801E-12	666	6.44720E-12	6.44950E-12
IM0127	50	-	-	188	-	-
IM0128	76	1.39906E-11	1.39926E-11	321	1.39139E-11	1.39159E-11
IM0129	91	2.40890E-12	2.40946E-12	369	2.39886E-12	2.39941E-12
IM0130	51	2.43187E-11	2.43244E-11	281	2.40269E-11	2.40325E-11
IM0131	212	2.06834E-12	2.06885E-12	824	2.05414E-12	2.05464E-12
IM0132	176	4.63449E-12	4.63512E-12	728	4.59643E-12	4.59705E-12
IM0133	15	-	-	122	-	-
IM0134	104	5.86701E-12	5.86681E-12	496	6.04289E-12	6.04268E-12
IM0135	101	9.38905E-12	9.38851E-12	471	9.62603E-12	9.62546E-12
IM0136	201	6.55570E-12	6.55605E-12	605	6.44957E-12	6.44991E-12
IM0137	320	6.67636E-13	6.67760E-13	923	6.56393E-13	6.56513E-13
IM0138	163	1.82618E-11	1.82631E-11	511	1.80261E-11	1.80274E-11
IM0139	177	7.24413E-12	7.24482E-12	630	7.17774E-12	7.17842E-12
IM0140	207	-	5.03037E-12	723	-	4.99599E-12
IM0141	184	1.36165E-11	1.36154E-11	612	1.33941E-11	1.33931E-11
IM0142	62	1.12537E-11	1.12543E-11	394	1.26201E-11	1.26208E-11
IM0143	59	-	1.75279E-11	268	-	1.73512E-11
IM0144	205	1.99161E-11	1.99154E-11	542	1.97937E-11	1.97930E-11
IM0145	160	9.48157E-11	9.48114E-11	466	9.38942E-11	9.38900E-11
IM0146	223	2.73138E-12	2.73187E-12	588	2.71433E-12	2.71482E-12
IM0147	129	2.75985E-11	2.75995E-11	494	2.70598E-11	2.70608E-11
IM0148	0	-	-	143	-	-
IM0149	202	1.29960E-12	1.29964E-12	811	1.27400E-12	1.27404E-12
IM0150	111	1.27994E-11	1.27998E-11	446	1.30386E-11	1.30390E-11
IM0151	110	1.33930E-11	1.33966E-11	443	1.36747E-11	1.36785E-11
IM0152	191	6.88331E-12	6.88323E-12	602	6.81613E-12	6.81604E-12
IM0153	152	7.03741E-12	7.03954E-12	423	7.02353E-12	7.02565E-12
IM0154	81	1.96570E-11	1.96673E-11	330	2.00302E-11	2.00409E-11
IM0155	79	8.01309E-11	8.01910E-11	298	8.14360E-11	8.14981E-11
IM0156	23	-	1.09881E-10	200	-	1.09034E-10
IM0157	151	1.42999E-11	1.43091E-11	466	1.42748E-11	1.42839E-11
IM0158	197	9.95963E-13	9.96639E-13	583	9.94884E-13	9.95558E-13
IM0159	174	3.54086E-12	3.54219E-12	532	3.53701E-12	3.53833E-12
IM0160	142	2.95687E-12	2.95821E-12	454	2.95159E-12	2.95292E-12
IM0161	184	3.38119E-12	3.38240E-12	503	3.37485E-12	3.37605E-12
IM0162	58	1.69060E-11	1.69083E-11	350	1.83854E-11	1.83881E-11
IM0163	239	3.40377E-12	3.40449E-12	723	3.37781E-12	3.37851E-12
IM0164	97	1.24508E-11	1.24521E-11	443	1.21599E-11	1.21611E-11
IM0165	101	1.10883E-11	1.10885E-11	448	1.08436E-11	1.08438E-11
IM0166	112	8.78528E-13	8.78529E-13	670	9.64220E-13	9.64220E-13
IM0167	125	9.70940E-12	9.71291E-12	407	9.66415E-12	9.66764E-12
IM0168	118	6.12846E-12	6.13025E-12	436	6.10769E-12	6.10947E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2]		No. of birds	Birds Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
IM0169	87	1.47558E-11	1.47614E-11	406	1.46065E-11	1.46120E-11
IM0170	29	4.87772E-11	4.87749E-11	193	4.92078E-11	4.92055E-11
IM0171	52	8.16867E-11	8.16334E-11	309	8.41185E-11	8.40620E-11
IM0172	67	6.29561E-12	6.29262E-12	319	6.35421E-12	6.35116E-12
IM0201	91	1.08652E-12	1.08652E-12	424	1.17685E-12	1.17686E-12
IM0202	233	9.91052E-13	9.91096E-13	749	9.73869E-13	9.73912E-13
IM0203	79	1.84342E-12	1.84342E-12	453	2.14984E-12	2.14984E-12
IM0204	56	1.06282E-11	1.06281E-11	332	1.17840E-11	1.17838E-11
IM0205	151	8.40714E-12	8.40718E-12	641	8.28869E-12	8.28873E-12
IM0206	88	8.38006E-13	8.38006E-13	486	9.58695E-13	9.58694E-13
IM0207	96	1.52275E-12	1.52275E-12	479	1.58983E-12	1.58982E-12
IM0208	69	4.12890E-12	4.12916E-12	392	4.80248E-12	4.80282E-12
IM0209	109	3.65501E-12	3.65496E-12	441	3.72852E-12	3.72847E-12
IM0210	208	2.59440E-12	2.59464E-12	619	2.55756E-12	2.55780E-12
IM0211	173	9.17947E-12	9.17950E-12	575	9.08538E-12	9.08541E-12
IM0212	78	5.06600E-12	5.06910E-12	352	5.15531E-12	5.15852E-12
IM0301	227	2.98525E-12	2.98599E-12	886	3.15456E-12	3.15539E-12
IM0302	64	3.34761E-11	3.34841E-11	331	3.30768E-11	3.30846E-11
IM0303	135	-	2.77301E-11	609	-	2.81867E-11
IM0304	157	9.34473E-11	9.34784E-11	487	9.33569E-11	9.33879E-11
IM0401	229	3.02291E-12	3.02354E-12	859	3.13376E-12	3.13443E-12
IM0402	179	-	2.46994E-11	672	-	2.47424E-11
IM0403	167	3.64879E-12	3.64949E-12	703	4.10886E-12	4.10976E-12
IM0501	217	9.04665E-12	9.04743E-12	766	9.46584E-12	9.46669E-12
IM0502	174	5.08896E-12	5.08937E-12	730	5.73416E-12	5.73468E-12
IM0701	160	4.72442E-12	4.72435E-12	745	4.77664E-12	4.77657E-12
IM0901	61	5.26488E-12	5.26488E-12	381	5.98700E-12	5.98700E-12
IM1001	175	5.91350E-11	5.91430E-11	470	5.90228E-11	5.90308E-11
IM1301	109	5.58710E-13	5.58702E-13	512	5.66733E-13	5.66724E-13
IM1302	46	6.28423E-12	6.28416E-12	287	7.33477E-12	7.33467E-12
IM1303	148	3.16872E-13	3.16871E-13	718	3.30924E-13	3.30923E-13
IM1304	71	6.27083E-13	6.27110E-13	381	6.57007E-13	6.57037E-13
IM1401	68	3.75224E-11	3.75253E-11	380	4.15074E-11	4.15109E-11
IM1402	230	1.22785E-11	1.22809E-11	738	1.20968E-11	1.20991E-11
IM1403	78	3.94110E-11	3.94113E-11	471	4.42914E-11	4.42917E-11
IM1404	219	1.48909E-11	1.48945E-11	733	1.47446E-11	1.47481E-11
IM1405	232	6.90069E-12	6.90396E-12	567	6.88652E-12	6.88977E-12
IM1406	58	1.30775E-11	1.30779E-11	361	1.33115E-11	1.33120E-11
NA0201	118	5.04755E-12	5.04790E-12	429	5.15993E-12	5.16030E-12
NA0301	1	-	-	28	-	-
NA0302	208	1.18357E-12	1.18372E-12	524	1.20905E-12	1.20920E-12
NA0303	198	4.07713E-12	4.07814E-12	577	4.22205E-12	4.22314E-12
NA0401	55	2.11233E-12	2.11247E-12	255	2.17746E-12	2.17761E-12
NA0402	74	9.88405E-13	9.88163E-13	263	1.07455E-12	1.07426E-12
NA0403	71	1.21407E-12	1.21389E-12	270	1.30857E-12	1.30836E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2]		No. of birds	Birds Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
NA0404	74	6.08412E-13	6.08322E-13	280	7.06675E-13	7.06553E-13
NA0405	67	3.68886E-12	3.68783E-12	331	4.63454E-12	4.63292E-12
NA0406	55	4.27284E-13	4.27255E-13	279	4.42576E-13	4.42545E-13
NA0407	56	1.36700E-12	1.36691E-12	286	1.42589E-12	1.42579E-12
NA0408	44	3.86036E-12	3.86001E-12	239	4.00375E-12	4.00337E-12
NA0409	57	1.79855E-12	1.79852E-12	308	2.04705E-12	2.04701E-12
NA0410	58	6.65962E-13	6.65932E-13	303	6.86053E-13	6.86021E-13
NA0411	62	1.96646E-12	1.96598E-12	318	2.05212E-12	2.05160E-12
NA0412	61	2.98188E-12	2.98199E-12	262	3.55587E-12	3.55603E-12
NA0413	71	5.95143E-13	5.95106E-13	319	6.48559E-13	6.48515E-13
NA0414	63	7.03337E-13	7.03283E-13	282	7.54478E-13	7.54416E-13
NA0415	64	8.72408E-13	8.72419E-13	293	1.00442E-12	1.00444E-12
NA0416	67	4.81700E-13	4.81678E-13	282	5.47318E-13	5.47289E-13
NA0417	76	1.03193E-11	1.03178E-11	227	1.10213E-11	1.10195E-11
NA0501	58	2.48641E-12	2.48637E-12	234	3.03419E-12	3.03413E-12
NA0502	62	6.69674E-13	6.69651E-13	264	8.83545E-13	8.83506E-13
NA0503	146	1.81412E-12	1.81397E-12	329	2.07199E-12	2.07180E-12
NA0504	41	2.11631E-11	2.11610E-11	297	2.15013E-11	2.14991E-11
NA0505	92	2.20202E-12	2.20199E-12	255	2.56741E-12	2.56738E-12
NA0506	85	7.30743E-13	7.30716E-13	301	9.01731E-13	9.01690E-13
NA0507	87	2.26860E-12	2.26848E-12	266	2.91193E-12	2.91173E-12
NA0508	101	3.11979E-12	3.11946E-12	270	3.68130E-12	3.68085E-12
NA0509	57	1.05090E-12	1.05089E-12	200	1.45748E-12	1.45746E-12
NA0510	87	1.85293E-12	1.85281E-12	279	2.03437E-12	2.03423E-12
NA0511	112	1.27001E-12	1.26999E-12	295	1.50007E-12	1.50004E-12
NA0512	115	2.77560E-12	2.77533E-12	271	3.20969E-12	3.20932E-12
NA0513	41	5.60675E-11	5.60587E-11	277	6.67611E-11	6.67487E-11
NA0514	60	6.56019E-13	6.56015E-13	237	8.50359E-13	8.50352E-13
NA0515	94	3.11533E-11	3.11537E-11	263	3.43543E-11	3.43547E-11
NA0516	92	3.33934E-12	3.33910E-12	276	3.66318E-12	3.66289E-12
NA0517	55	1.48849E-12	1.48843E-12	322	1.66888E-12	1.66880E-12
NA0518	90	4.36481E-13	4.36470E-13	281	5.53568E-13	5.53551E-13
NA0519	80	1.37358E-11	1.37361E-11	305	1.47860E-11	1.47863E-11
NA0520	40	1.10879E-12	1.10881E-12	222	1.52126E-12	1.52130E-12
NA0521	48	2.63102E-12	2.63096E-12	176	3.93679E-12	3.93665E-12
NA0522	81	2.06611E-12	2.06601E-12	251	2.55816E-12	2.55802E-12
NA0523	60	1.38522E-12	1.38506E-12	304	1.67756E-12	1.67733E-12
NA0524	75	5.55267E-12	5.55122E-12	270	6.49936E-12	6.49736E-12
NA0525	6	-	-	128	-	-
NA0526	64	5.78170E-11	5.78154E-11	256	5.98345E-11	5.98327E-11
NA0527	118	3.45189E-12	3.45182E-12	279	3.81958E-12	3.81949E-12
NA0528	109	7.66939E-13	7.66937E-13	293	1.04251E-12	1.04251E-12
NA0529	51	9.34232E-13	9.34115E-13	320	1.05587E-12	1.05572E-12
NA0530	97	4.08651E-12	4.08636E-12	264	4.65591E-12	4.65572E-12
NA0601	29	-	-	170	-	-

Ecoregion code	No. of mammals	Mammals		No. of birds	Birds	
		Regional CF [PDF*y/m2]			Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
NA0602	47	2.57667E-13	2.57657E-13	223	2.84974E-13	2.84962E-13
NA0603	34	1.52628E-12	1.52629E-12	175	2.56910E-12	2.56912E-12
NA0604	38	2.56654E-12	2.56656E-12	150	3.88595E-12	3.88600E-12
NA0605	48	2.48771E-13	2.48761E-13	246	2.74414E-13	2.74401E-13
NA0606	32	1.21236E-13	1.21235E-13	157	1.36153E-13	1.36152E-13
NA0607	44	7.34330E-14	7.34330E-14	198	1.23269E-13	1.23269E-13
NA0608	60	2.21738E-13	2.21734E-13	260	2.76580E-13	2.76574E-13
NA0609	49	1.69705E-13	1.69703E-13	239	1.94870E-13	1.94867E-13
NA0610	52	2.17575E-13	2.17576E-13	203	2.99964E-13	2.99966E-13
NA0611	9	5.37160E-12	5.37138E-12	161	6.63218E-12	6.63185E-12
NA0612	44	8.92032E-14	8.92031E-14	191	1.16884E-13	1.16884E-13
NA0613	55	2.24475E-13	2.24476E-13	212	3.20022E-13	3.20025E-13
NA0614	51	1.09894E-13	1.09894E-13	196	1.59373E-13	1.59374E-13
NA0615	7	4.33588E-11	4.33617E-11	136	5.84604E-11	5.84655E-11
NA0616	43	2.67140E-13	2.67137E-13	200	2.96638E-13	2.96634E-13
NA0617	47	8.52366E-13	8.52351E-13	164	1.16447E-12	1.16445E-12
NA0701	84	1.90443E-12	1.90419E-12	399	2.00022E-12	1.99995E-12
NA0801	89	2.33456E-12	2.33449E-12	274	2.39615E-12	2.39608E-12
NA0802	80	1.73872E-13	1.73870E-13	312	1.89339E-13	1.89336E-13
NA0803	96	4.11976E-13	4.11955E-13	338	4.67563E-13	4.67536E-13
NA0804	101	2.86760E-13	2.86732E-13	341	3.18777E-13	3.18743E-13
NA0805	73	4.11388E-13	4.11384E-13	287	4.53696E-13	4.53692E-13
NA0806	74	2.22117E-12	2.22058E-12	311	2.53274E-12	2.53197E-12
NA0807	58	3.80922E-12	3.80924E-12	258	4.36398E-12	4.36401E-12
NA0808	92	1.02264E-12	1.02262E-12	278	1.18340E-12	1.18338E-12
NA0809	63	1.51935E-12	-	256	1.88517E-12	-
NA0810	88	3.64779E-13	3.64780E-13	312	4.14776E-13	4.14776E-13
NA0811	98	1.26125E-13	1.26125E-13	323	1.52040E-13	1.52041E-13
NA0812	62	1.06950E-12	1.06950E-12	262	1.19070E-12	1.19069E-12
NA0813	94	1.97047E-12	1.97048E-12	253	2.11053E-12	2.11054E-12
NA0814	68	2.74106E-12	2.74007E-12	319	3.03093E-12	3.02972E-12
NA0815	136	2.82308E-13	2.82303E-13	355	3.06766E-13	3.06759E-13
NA1101	44	3.16602E-13	3.16601E-13	215	4.58767E-13	4.58765E-13
NA1102	5	-	-	132	-	-
NA1103	26	-	-	131	-	-
NA1104	27	-	-	147	-	-
NA1105	6	-	-	33	-	-
NA1106	34	-	-	212	-	-
NA1107	32	-	-	189	-	-
NA1108	35	-	-	149	-	-
NA1109	6	-	-	49	-	-
NA1110	8	-	-	54	-	-
NA1111	54	1.71172E-13	1.71172E-13	198	2.52451E-13	2.52452E-13
NA1112	6	-	-	55	-	-
NA1113	4	-	-	53	-	-

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
NA1114	34	-	-	150	-	-
NA1115	19	-	-	86	-	-
NA1116	46	-	1.81543E-13	165	-	2.84819E-13
NA1117	47	5.35059E-13	5.35059E-13	232	7.81642E-13	7.81641E-13
NA1118	19	-	-	80	-	-
NA1201	81	4.03538E-12	4.03499E-12	356	4.08460E-12	4.08420E-12
NA1202	106	2.01053E-12	2.01031E-12	336	2.05749E-12	2.05727E-12
NA1203	96	6.82156E-12	6.82099E-12	340	6.92826E-12	6.92768E-12
NA1301	67	2.10315E-12	2.10325E-12	325	2.11913E-12	2.11924E-12
NA1302	162	3.08125E-12	3.08227E-12	402	3.08439E-12	3.08541E-12
NA1303	179	3.04608E-13	3.04589E-13	429	3.11669E-13	3.11650E-13
NA1304	151	3.92750E-13	3.92734E-13	334	4.12257E-13	4.12240E-13
NA1305	124	3.57405E-13	3.57397E-13	298	3.69304E-13	3.69296E-13
NA1306	56	7.11913E-12	7.11958E-12	271	7.13239E-12	7.13285E-12
NA1307	183	1.40977E-12	1.41036E-12	468	1.41355E-12	1.41415E-12
NA1308	124	1.04137E-12	1.04124E-12	310	1.06101E-12	1.06087E-12
NA1309	125	4.80140E-13	4.80136E-13	283	5.03634E-13	5.03630E-13
NA1310	150	6.72404E-13	6.72325E-13	426	6.80572E-13	6.80491E-13
NA1311	108	1.05198E-11	1.05227E-11	407	1.06434E-11	1.06463E-11
NA1312	121	1.15238E-12	1.15220E-12	440	1.17872E-12	1.17853E-12
NA1313	99	8.02301E-13	8.02301E-13	271	8.65070E-13	8.65070E-13
NT0101	187	1.25964E-12	1.25957E-12	680	1.26450E-12	1.26442E-12
NT0102	220	3.56877E-11	3.56877E-11	825	3.55982E-11	3.55983E-11
NT0103	195	2.86223E-12	2.86237E-12	707	2.86556E-12	2.86570E-12
NT0104	243	1.34052E-12	1.34051E-12	822	1.33941E-12	1.33940E-12
NT0105	290	3.47843E-12	3.47868E-12	1212	3.50319E-12	3.50345E-12
NT0106	128	7.10229E-11	7.10466E-11	364	7.05265E-11	7.05499E-11
NT0107	234	-	1.87266E-12	754	-	1.86941E-12
NT0108	219	1.47035E-11	1.47067E-11	736	1.46493E-11	1.46525E-11
NT0109	242	1.06624E-11	1.06659E-11	968	1.06495E-11	1.06530E-11
NT0110	2	-	-	100	-	-
NT0111	205	3.60296E-12	3.60336E-12	718	3.59577E-12	3.59616E-12
NT0112	205	2.42568E-11	2.42677E-11	689	2.41816E-11	2.41925E-11
NT0113	172	5.45774E-11	5.46266E-11	559	5.44556E-11	5.45046E-11
NT0114	142	-	1.51430E-10	514	-	1.51142E-10
NT0115	257	4.63143E-12	4.63253E-12	1000	4.62781E-12	4.62891E-12
NT0116	0	-	-	41	-	-
NT0117	196	2.32866E-11	2.32938E-11	721	2.31793E-11	2.31864E-11
NT0118	305	5.01360E-12	5.01428E-12	1280	5.00519E-12	5.00586E-12
NT0119	198	3.11793E-11	3.11885E-11	720	3.11099E-11	3.11191E-11
NT0120	30	1.05085E-11	1.05119E-11	261	1.04733E-11	1.04767E-11
NT0121	344	3.34555E-12	3.34645E-12	1421	3.34879E-12	3.34969E-12
NT0122	193	-	1.11107E-10	638	-	1.10976E-10
NT0123	0	-	-	35	-	-
NT0124	263	2.34020E-12	2.34019E-12	910	2.33410E-12	2.33410E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
NT0125	244	7.17222E-13	7.17241E-13	895	7.14532E-13	7.14550E-13
NT0126	199	3.47578E-11	3.47616E-11	703	3.47171E-11	3.47210E-11
NT0127	20	5.04156E-12	5.04341E-12	221	5.02165E-12	5.02349E-12
NT0128	311	2.96326E-12	2.96332E-12	976	2.96227E-12	2.96233E-12
NT0129	232	5.69968E-12	5.70011E-12	898	5.69040E-12	5.69083E-12
NT0130	198	1.15178E-11	1.15200E-11	780	1.14979E-11	1.15001E-11
NT0131	22	2.81896E-11	2.82084E-11	217	2.80786E-11	2.80972E-11
NT0132	259	1.27965E-12	1.27966E-12	812	1.27823E-12	1.27824E-12
NT0133	220	-	-	705	-	-
NT0134	15	-	2.40418E-10	177	-	2.38761E-10
NT0135	322	4.66223E-13	4.66232E-13	1039	4.65677E-13	4.65686E-13
NT0136	295	3.24849E-12	3.24907E-12	1161	3.24102E-12	3.24160E-12
NT0137	223	4.39751E-12	4.39796E-12	755	4.38703E-12	4.38748E-12
NT0138	212	3.89044E-12	3.89071E-12	813	3.87988E-12	3.88015E-12
NT0139	154	2.40892E-12	2.40937E-12	592	2.40158E-12	2.40202E-12
NT0140	230	8.05590E-13	8.05583E-13	826	8.04327E-13	8.04320E-13
NT0141	286	5.13079E-12	5.13098E-12	943	5.12540E-12	5.12559E-12
NT0142	314	1.36739E-12	1.36754E-12	1102	1.36818E-12	1.36833E-12
NT0143	243	-	-	794	-	-
NT0144	117	3.41808E-11	3.41891E-11	418	3.40059E-11	3.40141E-11
NT0145	309	4.22187E-12	4.22295E-12	1197	4.22073E-12	4.22181E-12
NT0146	193	4.04463E-11	4.04728E-11	630	4.06481E-11	4.06749E-11
NT0147	208	-	1.19628E-11	686	-	1.19220E-11
NT0148	131	1.80930E-11	1.80959E-11	458	1.79571E-11	1.79599E-11
NT0149	182	4.42473E-11	4.42539E-11	627	4.40913E-11	4.40979E-11
NT0150	286	5.88728E-13	5.88731E-13	905	5.90807E-13	5.90810E-13
NT0151	136	1.90872E-11	1.90862E-11	469	1.90334E-11	1.90324E-11
NT0152	149	1.47578E-11	1.47582E-11	481	1.47256E-11	1.47260E-11
NT0153	346	1.76812E-12	1.76829E-12	1466	1.77445E-12	1.77462E-12
NT0154	242	2.10079E-12	2.10111E-12	754	2.10016E-12	2.10048E-12
NT0155	13	3.10736E-11	3.10433E-11	195	3.08740E-11	3.08441E-11
NT0156	296	-	1.93160E-12	873	-	1.92991E-12
NT0157	234	1.95431E-12	1.95438E-12	802	1.95304E-12	1.95311E-12
NT0158	242	3.57810E-12	3.57809E-12	752	3.57341E-12	3.57340E-12
NT0159	168	-	6.94273E-11	606	-	6.89459E-11
NT0160	214	2.69067E-12	2.68998E-12	832	2.68681E-12	2.68612E-12
NT0161	112	7.92785E-11	7.93070E-11	463	7.87839E-11	7.88121E-11
NT0162	159	2.85660E-11	2.85788E-11	506	2.83628E-11	2.83754E-11
NT0163	239	-	-	696	-	-
NT0164	31	1.15435E-10	1.15431E-10	265	1.31623E-10	1.31617E-10
NT0165	220	3.65204E-12	3.65237E-12	681	3.75555E-12	3.75590E-12
NT0166	411	4.44135E-13	4.44145E-13	1496	4.44470E-13	4.44480E-13
NT0167	218	2.05534E-11	2.05544E-11	791	2.05133E-11	2.05143E-11
NT0168	216	1.01376E-12	1.01377E-12	785	1.01263E-12	1.01264E-12
NT0169	255	6.73500E-12	-	861	6.71869E-12	-

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Distribution
NT0170	178	1.77721E-12	1.77745E-12	686	1.77175E-12	1.77198E-12
NT0171	80	-	5.28572E-11	376	-	5.27197E-11
NT0172	0	-	-	21	-	-
NT0173	270	7.31117E-13	7.31122E-13	937	7.29724E-13	7.29729E-13
NT0174	287	2.94173E-12	2.94217E-12	1206	2.94719E-12	2.94763E-12
NT0175	228	1.14420E-11	1.14447E-11	804	1.13947E-11	1.13973E-11
NT0176	187	4.19361E-12	4.19456E-12	595	4.23431E-12	4.23528E-12
NT0177	141	5.94669E-11	5.95309E-11	483	6.02704E-11	6.03361E-11
NT0178	191	1.00974E-11	1.01017E-11	751	1.00859E-11	1.00902E-11
NT0179	27	-	1.20288E-10	175	-	1.19766E-10
NT0180	199	1.28137E-12	1.28137E-12	780	1.27809E-12	1.27809E-12
NT0181	120	4.39818E-12	4.39843E-12	463	4.38241E-12	4.38266E-12
NT0182	257	1.48610E-12	1.48609E-12	881	1.48271E-12	1.48270E-12
NT0201	280	4.94644E-12	4.94668E-12	1015	4.94072E-12	4.94096E-12
NT0202	172	2.80951E-12	2.80972E-12	519	2.81647E-12	2.81668E-12
NT0204	153	7.88292E-12	7.88332E-12	398	7.92145E-12	7.92187E-12
NT0205	200	4.92243E-12	4.92431E-12	549	4.92799E-12	4.92988E-12
NT0206	269	4.12088E-12	4.12098E-12	1079	4.18857E-12	4.18867E-12
NT0207	212	4.66469E-11	4.66431E-11	739	4.64801E-11	4.64764E-11
NT0209	242	4.79789E-12	4.79854E-12	903	4.78656E-12	4.78721E-12
NT0210	273	2.17470E-13	2.17479E-13	839	2.18152E-13	2.18161E-13
NT0211	175	2.26464E-11	2.26497E-11	566	2.25819E-11	2.25852E-11
NT0212	243	1.37053E-12	1.37052E-12	858	1.37227E-12	1.37226E-12
NT0213	31	3.39229E-12	3.39275E-12	279	3.37882E-12	3.37928E-12
NT0214	150	1.21630E-11	1.21714E-11	587	1.21601E-11	1.21685E-11
NT0215	20	1.49651E-11	1.49687E-11	223	1.49121E-11	1.49157E-11
NT0216	0	-	-	61	-	-
NT0217	147	1.15782E-11	1.15815E-11	515	1.15728E-11	1.15761E-11
NT0218	21	1.01091E-10	1.01161E-10	207	1.00712E-10	1.00781E-10
NT0219	175	1.96188E-11	1.96242E-11	551	1.95202E-11	1.95256E-11
NT0220	91	-	2.69067E-10	429	-	2.68537E-10
NT0221	232	1.74863E-11	1.74877E-11	758	1.74124E-11	1.74138E-11
NT0222	207	1.10636E-11	1.10640E-11	694	1.10149E-11	1.10153E-11
NT0223	192	-	2.98473E-11	781	-	2.98787E-11
NT0224	163	6.61721E-11	6.61749E-11	684	6.59873E-11	6.59901E-11
NT0225	183	1.51649E-10	1.51652E-10	544	1.50810E-10	1.50813E-10
NT0226	13	1.83786E-10	1.83681E-10	186	1.82741E-10	1.82637E-10
NT0227	43	6.86915E-11	6.86807E-11	243	6.98171E-11	6.98060E-11
NT0228	167	3.61120E-12	3.61169E-12	517	3.63187E-12	3.63236E-12
NT0229	183	1.33643E-11	1.33644E-11	680	1.33034E-11	1.33034E-11
NT0230	198	7.43968E-12	7.44314E-12	691	7.42657E-12	7.43002E-12
NT0232	152	8.25677E-12	8.25930E-12	681	8.23606E-12	8.23858E-12
NT0233	128	4.59833E-11	4.59854E-11	466	4.58597E-11	4.58617E-11
NT0235	90	6.02571E-12	6.02542E-12	381	6.02435E-12	6.02405E-12
NT0301	10	3.12449E-11	3.12534E-11	231	3.10975E-11	3.11059E-11

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
NT0302	119	1.10851E-10	1.10835E-10	484	1.10601E-10	1.10585E-10
NT0303	237	2.89670E-12	2.89812E-12	736	2.88807E-12	2.88948E-12
NT0304	28	3.46931E-11	3.47010E-11	249	3.45707E-11	3.45785E-11
NT0305	20	-	2.00061E-11	204	-	1.98983E-11
NT0306	118	-	1.70588E-11	484	-	1.70073E-11
NT0307	42	-	-	209	-	-
NT0308	195	2.17698E-11	2.17799E-11	656	2.18289E-11	2.18392E-11
NT0309	178	5.10287E-12	5.10587E-12	523	5.08442E-12	5.08739E-12
NT0310	237	3.24652E-12	3.24716E-12	658	3.27298E-12	3.27362E-12
NT0401	0	-	-	40	-	-
NT0402	40	-	-	204	-	-
NT0403	0	-	-	32	-	-
NT0404	79	7.08380E-13	7.08408E-13	263	7.00024E-13	7.00051E-13
NT0702	235	1.58599E-12	1.58601E-12	843	1.58594E-12	1.58596E-12
NT0703	236	7.13237E-12	7.13308E-12	780	7.13175E-12	7.13246E-12
NT0704	388	1.02404E-13	1.02401E-13	1131	1.02410E-13	1.02407E-13
NT0705	0	-	-	27	-	-
NT0707	243	2.01205E-12	2.01208E-12	878	2.01179E-12	2.01183E-12
NT0708	168	5.78148E-13	5.78192E-13	643	5.80759E-13	5.80803E-13
NT0709	298	5.53326E-13	5.53334E-13	1041	5.53283E-13	5.53291E-13
NT0710	132	4.32768E-13	4.32761E-13	611	4.33806E-13	4.33799E-13
NT0801	117	4.63687E-13	4.63688E-13	496	4.75489E-13	4.75490E-13
NT0802	76	3.46951E-13	3.46935E-13	317	3.55373E-13	3.55356E-13
NT0803	88	3.27090E-13	3.27090E-13	413	3.45348E-13	3.45348E-13
NT0805	81	1.69319E-13	1.69318E-13	325	1.71217E-13	1.71217E-13
NT0902	29	3.92405E-11	3.92447E-11	253	3.91014E-11	3.91057E-11
NT0903	18	-	3.69612E-10	200	-	3.67897E-10
NT0904	36	7.97695E-12	7.97676E-12	277	8.47777E-12	8.47754E-12
NT0905	124	7.20767E-11	7.20753E-11	418	7.20646E-11	7.20633E-11
NT0906	172	3.42802E-11	3.42797E-11	498	3.42598E-11	3.42592E-11
NT0907	190	1.11756E-12	1.11758E-12	651	1.11766E-12	1.11768E-12
NT0908	120	4.13346E-12	4.13351E-12	499	4.14106E-12	4.14111E-12
NT0909	106	6.02786E-12	6.02771E-12	471	6.04159E-12	6.04143E-12
NT1001	146	7.07356E-13	7.07375E-13	377	7.09695E-13	7.09715E-13
NT1002	258	8.62250E-13	8.62252E-13	799	8.66820E-13	8.66822E-13
NT1003	266	1.70324E-12	1.70324E-12	1089	1.70476E-12	1.70477E-12
NT1004	205	1.71053E-11	1.71060E-11	836	1.71044E-11	1.71051E-11
NT1005	206	-	7.36849E-11	645	-	7.36557E-11
NT1006	380	7.04499E-12	7.04525E-12	1457	7.04518E-12	7.04544E-12
NT1007	157	-	1.64370E-10	559	-	1.64286E-10
NT1008	99	1.19917E-12	1.19917E-12	251	1.20570E-12	1.20570E-12
NT1010	130	1.35232E-12	1.35237E-12	329	1.36011E-12	1.36017E-12
NT1201	54	1.02151E-12	1.02153E-12	259	1.01142E-12	1.01144E-12
NT1301	166	3.87759E-11	3.87909E-11	534	3.87596E-11	3.87745E-11
NT1303	39	1.51124E-12	1.51124E-12	229	1.66474E-12	1.66473E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Distribution
NT1304	207	2.81237E-13	2.81270E-13	715	2.81263E-13	2.81296E-13
NT1305	36	7.68794E-11	7.69256E-11	257	7.63259E-11	7.63714E-11
NT1306	29	6.92447E-11	6.92768E-11	253	6.89994E-11	6.90312E-11
NT1307	6	-	-	117	-	-
NT1308	197	6.45748E-12	6.45775E-12	687	6.45584E-12	6.45611E-12
NT1309	207	3.00757E-12	3.00743E-12	760	3.00678E-12	3.00664E-12
NT1311	0	-	-	47	-	-
NT1312	150	8.45998E-11	8.46100E-11	531	8.45923E-11	8.46025E-11
NT1313	190	1.27969E-11	1.28007E-11	631	1.27925E-11	1.27963E-11
NT1314	46	4.54619E-11	4.54719E-11	254	4.56431E-11	4.56532E-11
NT1315	140	1.07382E-12	1.07385E-12	466	1.07269E-12	1.07272E-12
NT1316	161	1.91540E-11	1.91575E-11	506	1.91772E-11	1.91807E-11
NT1318	0	-	-	24	-	-
NT1401	362	8.27953E-12	8.28123E-12	1274	8.26547E-12	8.26716E-12
NT1402	60	1.23920E-11	1.23939E-11	425	1.23747E-11	1.23765E-11
NT1403	254	1.15640E-11	1.15648E-11	840	1.15461E-11	1.15469E-11
NT1404	181	3.47604E-11	3.47630E-11	503	3.47171E-11	3.47197E-11
NT1405	240	2.53653E-11	2.53668E-11	839	2.53022E-11	2.53037E-11
NT1406	245	3.08106E-11	3.08086E-11	854	3.07525E-11	3.07505E-11
NT1407	209	4.16600E-11	4.16642E-11	656	4.15164E-11	4.15207E-11
OC0101	4	-	-	103	-	-
OC0102	0	-	-	62	-	-
OC0103	1	-	-	54	-	-
OC0104	0	-	-	69	-	-
OC0105	6	-	-	117	-	-
OC0106	1	-	-	111	-	-
OC0107	0	-	-	67	-	-
OC0108	0	-	-	58	-	-
OC0109	1	-	-	48	-	-
OC0110	1	-	-	95	-	-
OC0111	0	-	-	29	-	-
OC0112	2	-	-	81	-	-
OC0113	1	-	-	57	-	-
OC0114	1	2.44067E-10	2.44150E-10	73	2.43207E-10	2.43290E-10
OC0115	0	-	-	62	-	-
OC0116	1	-	-	47	-	-
OC0117	0	-	-	59	-	-
OC0201	4	-	-	101	-	-
OC0202	1	-	-	108	-	-
OC0203	2	-	-	85	-	-
OC0204	1	-	-	63	-	-
OC0701	1	-	-	66	-	-
OC0702	1	-	-	97	-	-
OC0703	0	-	-	84	-	-
PA0101	165	9.65437E-13	9.65751E-13	518	9.56266E-13	9.56574E-13

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
PA0102	217	1.13849E-12	1.13853E-12	707	1.13532E-12	1.13537E-12
PA0401	64	9.14127E-12	9.14002E-12	208	9.26598E-12	9.26469E-12
PA0402	77	2.89305E-13	2.89292E-13	321	3.01378E-13	3.01364E-13
PA0403	2	-	-	51	-	-
PA0404	97	6.45716E-13	6.45726E-13	320	6.73943E-13	6.73954E-13
PA0405	55	8.03967E-13	8.03968E-13	258	8.40352E-13	8.40352E-13
PA0406	71	1.89550E-12	1.89488E-12	283	1.93781E-12	1.93716E-12
PA0407	102	3.11000E-12	3.11021E-12	337	3.08792E-12	3.08813E-12
PA0408	122	8.67458E-13	8.67482E-13	318	8.90827E-13	8.90852E-13
PA0409	40	3.90226E-13	3.90222E-13	245	4.01001E-13	4.00997E-13
PA0410	70	1.59718E-12	1.59717E-12	304	1.66386E-12	1.66385E-12
PA0411	146	5.06640E-13	5.06654E-13	453	5.43998E-13	5.44014E-13
PA0412	95	1.41077E-13	1.41069E-13	305	1.53405E-13	1.53395E-13
PA0413	53	1.79726E-12	1.79729E-12	292	1.95241E-12	1.95245E-12
PA0414	73	1.69341E-12	1.69359E-12	278	1.88031E-12	1.88053E-12
PA0415	112	5.40928E-13	5.40958E-13	478	5.52199E-13	5.52230E-13
PA0416	76	4.17768E-12	4.17731E-12	275	4.70119E-12	4.70072E-12
PA0417	149	1.39253E-12	1.39281E-12	464	1.40186E-12	1.40216E-12
PA0418	87	2.37025E-12	2.37013E-12	280	2.56640E-12	2.56626E-12
PA0419	111	1.21134E-13	1.21131E-13	328	1.42430E-13	1.42425E-13
PA0420	72	1.78097E-12	1.78102E-12	277	2.01193E-12	2.01199E-12
PA0421	36	1.96749E-12	1.96745E-12	218	2.03190E-12	2.03186E-12
PA0422	98	2.11014E-12	2.11069E-12	321	2.10545E-12	2.10600E-12
PA0423	37	5.14722E-12	5.14552E-12	234	5.23937E-12	5.23761E-12
PA0424	130	4.66903E-13	4.66906E-13	459	4.90409E-13	4.90412E-13
PA0425	3	-	-	61	-	-
PA0426	97	2.59997E-13	2.60002E-13	376	2.89272E-13	2.89279E-13
PA0427	45	7.27394E-12	7.27143E-12	245	7.57686E-12	7.57413E-12
PA0428	62	1.80739E-12	1.80685E-12	280	1.88139E-12	1.88080E-12
PA0429	30	1.78047E-12	1.78047E-12	219	1.90675E-12	1.90675E-12
PA0430	92	6.46338E-13	6.46335E-13	351	6.99459E-13	6.99455E-13
PA0431	92	3.88413E-13	3.88400E-13	275	4.40833E-13	4.40817E-13
PA0432	79	3.02811E-12	3.02800E-12	289	3.37502E-12	3.37488E-12
PA0433	69	5.71746E-12	5.71645E-12	228	5.78685E-12	5.78582E-12
PA0434	156	1.72878E-12	1.72916E-12	431	1.82322E-12	1.82365E-12
PA0435	80	4.69774E-12	4.69783E-12	282	4.88186E-12	4.88196E-12
PA0436	80	9.46812E-14	9.46700E-14	305	1.03646E-13	1.03632E-13
PA0437	151	2.49361E-12	2.49370E-12	427	2.50030E-12	2.50039E-12
PA0438	39	9.34741E-12	9.34622E-12	233	9.76102E-12	9.75972E-12
PA0439	38	1.29916E-11	1.29892E-11	262	1.47349E-11	1.47317E-11
PA0440	49	1.21702E-12	1.21637E-12	288	1.24871E-12	1.24804E-12
PA0441	47	3.87062E-12	3.86844E-12	274	3.91953E-12	3.91729E-12
PA0442	40	-	1.93392E-12	134	-	2.87032E-12
PA0443	72	6.68277E-13	6.68259E-13	313	7.55424E-13	7.55401E-13
PA0444	79	3.66629E-13	3.66618E-13	280	3.88409E-13	3.88397E-13

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
PA0445	92	2.42013E-13	2.41994E-13	287	2.56053E-13	2.56032E-13
PA0446	115	4.79818E-13	4.79828E-13	363	4.73639E-13	4.73648E-13
PA0501	89	8.51965E-13	8.51761E-13	278	9.08907E-13	9.08675E-13
PA0502	128	7.65642E-13	7.65641E-13	341	8.35793E-13	8.35792E-13
PA0503	26	3.03507E-12	3.03505E-12	191	3.18423E-12	3.18421E-12
PA0504	84	9.44067E-13	9.44007E-13	247	1.02476E-12	1.02469E-12
PA0505	79	4.01862E-13	4.01854E-13	292	4.52418E-13	4.52408E-13
PA0506	91	9.79775E-12	9.79789E-12	348	9.96401E-12	9.96415E-12
PA0507	112	2.73772E-12	2.73775E-12	320	2.68539E-12	2.68542E-12
PA0508	63	-	-	186	-	-
PA0509	176	2.42017E-12	2.42029E-12	542	2.51981E-12	2.51994E-12
PA0510	38	2.82886E-12	2.82824E-12	239	2.89555E-12	2.89490E-12
PA0511	60	1.31273E-11	1.31253E-11	239	1.34617E-11	1.34597E-11
PA0512	50	-	-	208	-	-
PA0513	71	8.32018E-12	8.32137E-12	306	7.74059E-12	7.74162E-12
PA0514	140	5.06903E-12	5.06932E-12	597	5.45307E-12	5.45340E-12
PA0515	82	1.62671E-12	1.62688E-12	289	1.54242E-12	1.54257E-12
PA0516	242	3.00309E-12	3.00312E-12	680	3.06324E-12	3.06327E-12
PA0517	123	1.06927E-11	1.06929E-11	331	1.24303E-11	1.24306E-11
PA0518	201	2.94906E-12	2.94968E-12	526	3.02159E-12	3.02225E-12
PA0519	96	2.78002E-13	2.77997E-13	342	2.82468E-13	2.82463E-13
PA0520	33	2.55400E-12	2.55367E-12	228	3.00305E-12	3.00261E-12
PA0521	101	4.38957E-12	4.38959E-12	319	5.25639E-12	5.25641E-12
PA0601	98	1.52817E-14	1.52817E-14	388	1.58056E-14	1.58055E-14
PA0602	2	4.66403E-13	4.66403E-13	84	4.69443E-13	4.69443E-13
PA0603	33	5.49525E-13	5.49525E-13	215	6.85752E-13	6.85753E-13
PA0604	30	4.86327E-12	4.86335E-12	131	6.22628E-12	6.22643E-12
PA0605	46	3.95886E-14	3.95887E-14	231	4.48326E-14	4.48328E-14
PA0606	69	2.65561E-13	2.65560E-13	305	2.94860E-13	2.94859E-13
PA0607	39	1.36968E-12	1.36959E-12	225	1.46855E-12	1.46845E-12
PA0608	76	2.55478E-14	2.55463E-14	307	2.77547E-14	2.77529E-14
PA0609	81	5.13370E-13	5.13362E-13	285	5.49074E-13	5.49065E-13
PA0610	64	3.54370E-13	3.54355E-13	265	4.02150E-13	4.02130E-13
PA0611	76	3.52838E-14	3.52827E-14	304	3.79256E-14	3.79243E-14
PA0801	81	8.04512E-13	8.04512E-13	321	8.59963E-13	8.59963E-13
PA0802	105	9.54609E-13	9.54609E-13	319	1.01495E-12	1.01495E-12
PA0803	52	4.56293E-12	4.56293E-12	283	4.77217E-12	4.77217E-12
PA0804	88	3.76970E-13	3.76968E-13	295	3.92421E-13	3.92418E-13
PA0805	116	7.09034E-13	7.09036E-13	325	6.98771E-13	6.98774E-13
PA0806	83	-	1.22198E-12	292	-	1.41506E-12
PA0807	1	-	-	63	-	-
PA0808	98	6.22783E-13	6.22786E-13	341	6.79831E-13	6.79835E-13
PA0809	102	1.53256E-13	1.53251E-13	327	1.58696E-13	1.58691E-13
PA0810	104	8.68911E-14	8.68910E-14	311	9.25677E-14	9.25677E-14
PA0811	68	8.87120E-13	8.87120E-13	253	1.07865E-12	1.07865E-12

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2]		No. of birds	Birds Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
PA0812	96	1.03057E-12	1.03057E-12	343	9.67052E-13	9.67053E-13
PA0813	128	1.06443E-13	1.06443E-13	388	1.11301E-13	1.11301E-13
PA0814	143	8.23544E-14	8.23539E-14	348	8.74160E-14	8.74154E-14
PA0815	73	2.18302E-12	2.18304E-12	282	2.21966E-12	2.21968E-12
PA0816	102	3.63307E-13	3.63306E-13	325	3.68389E-13	3.68387E-13
PA0817	73	4.05184E-13	4.05147E-13	286	4.02614E-13	4.02577E-13
PA0818	102	7.21617E-13	7.21617E-13	328	8.03642E-13	8.03643E-13
PA0901	72	7.03298E-13	7.03283E-13	276	7.29066E-13	7.29049E-13
PA0902	37	1.01404E-11	1.01409E-11	269	1.11205E-11	1.11211E-11
PA0903	61	-	3.95741E-12	226	-	4.17549E-12
PA0904	61	3.14241E-12	3.14236E-12	284	2.87613E-12	2.87610E-12
PA0905	83	-	2.85756E-12	316	-	2.64533E-12
PA0906	49	4.00318E-12	4.00319E-12	270	3.85223E-12	3.85224E-12
PA0907	71	2.92762E-12	2.92760E-12	282	3.07195E-12	3.07192E-12
PA0908	32	-	2.37280E-11	257	-	2.68505E-11
PA1001	118	8.85917E-13	8.85914E-13	342	9.38699E-13	9.38696E-13
PA1002	109	2.07325E-13	2.07312E-13	294	2.24793E-13	2.24780E-13
PA1003	247	-	1.33131E-12	776	-	1.34131E-12
PA1004	83	-	-	282	-	-
PA1005	82	-	4.47459E-12	314	-	4.56243E-12
PA1006	99	8.93795E-13	8.93796E-13	350	9.46751E-13	9.46751E-13
PA1007	65	-	-	227	-	-
PA1008	83	-	2.03820E-12	270	-	2.03106E-12
PA1009	102	1.11941E-12	1.11941E-12	306	1.08864E-12	1.08864E-12
PA1010	67	-	2.30425E-11	240	-	2.17121E-11
PA1011	69	-	-	182	-	-
PA1012	123	2.65736E-12	2.65742E-12	473	2.86441E-12	2.86448E-12
PA1013	118	5.67978E-13	5.67978E-13	303	5.90456E-13	5.90456E-13
PA1014	91	-	9.22316E-13	305	-	1.00314E-12
PA1015	72	-	-	200	-	-
PA1016	98	8.94901E-13	8.94905E-13	327	9.19895E-13	9.19899E-13
PA1017	243	3.17473E-13	3.17481E-13	578	3.22567E-13	3.22575E-13
PA1018	89	6.07867E-12	6.07870E-12	350	6.04663E-12	6.04667E-12
PA1019	116	3.28090E-13	3.28090E-13	346	3.74179E-13	3.74178E-13
PA1020	93	4.35547E-13	-	287	5.22333E-13	-
PA1021	124	2.11752E-12	2.11754E-12	511	2.21692E-12	2.21694E-12
PA1022	79	-	2.48313E-12	257	-	2.62897E-12
PA1101	4	-	-	49	-	-
PA1102	36	1.09330E-13	1.09330E-13	184	1.23888E-13	1.23888E-13
PA1103	45	-	7.95742E-14	217	-	8.74411E-14
PA1104	30	-	1.15674E-13	157	-	1.34996E-13
PA1105	32	6.09092E-13	6.09093E-13	174	7.75748E-13	7.75749E-13
PA1106	22	5.73696E-13	5.73689E-13	165	6.70478E-13	6.70468E-13
PA1107	29	-	-	119	-	-
PA1108	37	1.27268E-13	1.27268E-13	198	1.33723E-13	1.33723E-13

Ecoregion code	No. of mammals	Mammals Regional CF [PDF*y/m2] Transmission	Mammals Regional CF [PDF*y/m2] Distribution	No. of birds	Birds Regional CF [PDF*y/m2] Transmission	Birds Regional CF [PDF*y/m2] Distribution
PA1109	4	-	-	42	-	-
PA1110	40	1.80045E-13	1.80038E-13	237	1.99796E-13	1.99787E-13
PA1111	37	2.71626E-14	2.71626E-14	170	2.52293E-14	2.52293E-14
PA1112	66	3.87498E-13	3.87497E-13	294	4.31307E-13	4.31305E-13
PA1113	3	-	-	36	-	-
PA1114	36	8.57516E-14	8.57517E-14	152	8.11475E-14	8.11477E-14
PA1201	102	8.96348E-13	8.96423E-13	322	9.04655E-13	9.04732E-13
PA1202	75	1.38220E-12	1.38247E-12	303	1.38135E-12	1.38162E-12
PA1203	8	-	-	115	-	-
PA1204	32	3.40349E-11	3.40307E-11	163	3.39892E-11	3.39850E-11
PA1205	30	1.96342E-11	1.96373E-11	159	1.79660E-11	1.79686E-11
PA1206	25	1.53772E-11	1.53789E-11	204	1.63015E-11	1.63034E-11
PA1207	121	9.21665E-13	9.21749E-13	380	8.91471E-13	8.91550E-13
PA1208	62	3.39241E-12	3.39285E-12	241	3.30772E-12	3.30814E-12
PA1209	74	3.93359E-13	3.93341E-13	290	3.90759E-13	3.90741E-13
PA1210	86	2.62501E-12	2.62449E-12	304	2.70685E-12	2.70630E-12
PA1211	79	1.00847E-12	1.00810E-12	290	1.05087E-12	1.05047E-12
PA1212	76	1.53278E-12	1.53283E-12	315	1.45884E-12	1.45888E-12
PA1213	99	4.94055E-13	4.94056E-13	354	4.64945E-13	4.64946E-13
PA1214	98	3.93103E-13	3.93135E-13	348	3.73860E-13	3.73889E-13
PA1215	90	1.15522E-12	1.15466E-12	309	1.18942E-12	1.18883E-12
PA1216	68	1.89243E-12	1.89256E-12	244	1.91592E-12	1.91605E-12
PA1217	83	2.89682E-12	2.89723E-12	282	2.92444E-12	2.92486E-12
PA1218	60	9.24362E-12	9.24100E-12	204	8.82062E-12	8.81823E-12
PA1219	41	4.23649E-11	4.23537E-11	231	4.35555E-11	4.35436E-11
PA1220	94	1.67168E-12	1.67215E-12	340	1.63278E-12	1.63324E-12
PA1221	58	1.69218E-12	1.69182E-12	289	1.73649E-12	1.73612E-12
PA1222	79	1.62774E-12	1.62711E-12	303	1.64292E-12	1.64227E-12
PA1301	69	-	-	266	-	-
PA1302	126	1.52905E-13	-	313	1.67408E-13	-
PA1303	103	9.19615E-14	9.19615E-14	403	8.51154E-14	8.51154E-14
PA1304	48	-	-	274	-	-
PA1305	91	1.80451E-12	1.80455E-12	313	1.75813E-12	1.75817E-12
PA1306	92	9.04524E-13	9.04524E-13	296	9.25014E-13	9.25014E-13
PA1307	144	5.08966E-13	5.08968E-13	572	5.28991E-13	5.28993E-13
PA1308	107	3.40105E-13	-	328	3.45066E-13	-
PA1309	92	-	-	330	-	-
PA1310	112	1.39509E-13	1.39510E-13	344	1.49467E-13	1.49467E-13
PA1311	86	1.05674E-12	1.05674E-12	303	1.14126E-12	1.14126E-12
PA1312	92	1.90757E-13	1.90756E-13	309	1.94499E-13	1.94498E-13
PA1313	124	2.37195E-13	2.37195E-13	343	2.35513E-13	2.35513E-13
PA1314	86	-	-	200	-	-
PA1315	74	-	-	204	-	-
PA1316	101	5.05176E-13	5.05176E-13	303	5.39547E-13	5.39546E-13
PA1317	126	2.94554E-13	2.94553E-13	335	3.09397E-13	3.09395E-13

Ecoregion code	No. of mammals	Mammals		No. of birds	Birds	
		Regional CF [PDF*y/m2]			Regional CF [PDF*y/m2]	
		Transmission	Distribution		Transmission	Distribution
PA1318	100	-	-	313	-	-
PA1319	77	-	-	279	-	-
PA1320	97	6.63587E-13	6.63587E-13	344	6.24133E-13	6.24133E-13
PA1321	119	9.55491E-14	9.55490E-14	404	8.95015E-14	8.95014E-14
PA1322	93	-	1.27585E-12	317	-	1.37819E-12
PA1323	34	2.15316E-12	2.15316E-12	267	2.07726E-12	2.07726E-12
PA1324	60	-	-	181	-	-
PA1325	74	2.66038E-13	2.66039E-13	347	2.44310E-13	2.44311E-13
PA1326	74	-	4.95160E-13	274	-	5.12265E-13
PA1327	92	3.74966E-14	3.74966E-14	370	3.44471E-14	3.44470E-14
PA1328	95	4.36191E-13	4.36192E-13	382	4.34773E-13	4.34774E-13
PA1329	89	-	1.68708E-13	361	-	1.56099E-13
PA1330	110	1.29973E-13	1.29973E-13	275	1.51609E-13	1.51609E-13
PA1331	18	-	-	76	-	-
PA1332	60	-	-	195	-	-
PA1333	47	-	-	259	-	-

Table B2. List of Countries with Regional and Global Characterization Factors (CF) for Habitat Loss Due to Transmission and Distribution Lines

Country code	Mammals				Birds			
	Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]		Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]	
	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution
AGO	2.01726E-15	1.97428E-14	1.01227E-17	9.90703E-17	1.96733E-15	1.92542E-14	9.87212E-18	9.66180E-17
ALB	1.92917E-14	1.48129E-14	3.18633E-18	2.44658E-18	1.97466E-14	1.51621E-14	3.26146E-18	2.50426E-18
ARE	5.91417E-18	3.97744E-18	7.94068E-22	5.34032E-22	5.59947E-18	3.76580E-18	7.51815E-22	5.05616E-22
ARG	1.29718E-15	1.82554E-15	3.09722E-17	4.35877E-17	1.31634E-15	1.85250E-15	3.14296E-17	4.42314E-17
ARM	5.19721E-16	4.23700E-16	8.17701E-19	6.66627E-19	5.24425E-16	4.27536E-16	8.25102E-19	6.72662E-19
AUS	1.40812E-15	7.08435E-16	5.64062E-17	2.83783E-17	1.41510E-15	7.10239E-16	5.66856E-17	2.84506E-17
AUT	1.36891E-15	8.11828E-16	1.13889E-18	6.75413E-19	1.47084E-15	8.72267E-16	1.22369E-18	7.25696E-19
AZE	1.33070E-16	2.76447E-15	1.07074E-19	2.22441E-18	1.31136E-16	2.72429E-15	1.05518E-19	2.19208E-18
BEL	1.52166E-16	1.26605E-16	3.54115E-21	2.94632E-21	1.59059E-16	1.32341E-16	3.70157E-21	3.07978E-21
BEN	4.86816E-15	8.07694E-15	2.53447E-18	4.20503E-18	4.71342E-15	7.82017E-15	2.45391E-18	4.07135E-18
BGD	1.23421E-15	3.26964E-15	7.27879E-19	1.92828E-18	1.27610E-15	3.38064E-15	7.52586E-19	1.99375E-18
BGR	3.31244E-15	4.58284E-15	1.61602E-18	2.23580E-18	3.44697E-15	4.76896E-15	1.68165E-18	2.32660E-18
BHR	-	7.23725E-19	-	6.65472E-26	-	6.98213E-19	-	6.42014E-26
BIH	9.30761E-15	1.12461E-14	2.01256E-18	2.43171E-18	1.00400E-14	1.21309E-14	2.17092E-18	2.62304E-18
BLR	1.05312E-15	4.14763E-16	1.91280E-19	7.53338E-20	1.14781E-15	4.52052E-16	2.08478E-19	8.21067E-20
BOL	4.63581E-15	2.48827E-14	5.27772E-17	2.83282E-16	4.67090E-15	2.50711E-14	5.31767E-17	2.85426E-16
BRA	3.90245E-15	5.31409E-15	2.58183E-16	3.51577E-16	3.89760E-15	5.30756E-15	2.57863E-16	3.51145E-16
BRN	5.64378E-16	3.55296E-15	1.57431E-19	9.91082E-19	5.63115E-16	3.54501E-15	1.57078E-19	9.88864E-19
BWA	1.45112E-14	2.50159E-14	2.04135E-17	3.51910E-17	1.42941E-14	2.46417E-14	2.01081E-17	3.46645E-17
CAN	5.71830E-16	3.67303E-16	2.99991E-18	1.92693E-18	7.00439E-16	4.53149E-16	3.67461E-18	2.37729E-18
CHE	1.00580E-15	2.56463E-16	1.40459E-19	3.58147E-20	1.07164E-15	2.73247E-16	1.49654E-19	3.81586E-20
CHL	6.59474E-16	1.16902E-15	4.55395E-18	8.07257E-18	6.71947E-16	1.19113E-15	4.64008E-18	8.22524E-18
CHN	9.28713E-17	2.88057E-16	3.64553E-18	1.13073E-17	9.76446E-17	3.05232E-16	3.83290E-18	1.19814E-17
CIV	1.19587E-14	4.02850E-14	7.49660E-17	2.52535E-16	1.12638E-14	3.79434E-14	7.06097E-17	2.37856E-16
CMR	3.63014E-15	8.37755E-14	4.99934E-17	1.15373E-15	3.46034E-15	7.99251E-14	4.76549E-17	1.10071E-15
COD	1.48273E-15	4.65288E-14	3.68556E-17	1.15654E-15	1.44299E-15	4.45707E-14	3.58678E-17	1.10787E-15
COG	1.20756E-15	5.70310E-14	4.41573E-18	2.08546E-16	1.15439E-15	5.44257E-14	4.22128E-18	1.99020E-16
COL	5.55323E-15	2.88942E-14	1.32581E-16	6.89835E-16	5.53984E-15	2.88205E-14	1.32261E-16	6.88076E-16
CRI	2.02442E-14	6.42583E-14	5.14324E-17	1.63254E-16	2.02026E-14	6.41261E-14	5.13266E-17	1.62918E-16
CUB	2.51946E-14	7.72125E-14	8.86685E-17	2.71738E-16	2.51077E-14	7.69461E-14	8.83627E-17	2.70800E-16
CYP	1.57911E-14	3.37221E-14	3.27742E-18	6.99899E-18	1.67403E-14	3.57494E-14	3.47443E-18	7.41975E-18
CZE	2.52477E-16	2.52006E-16	2.34319E-20	2.33881E-20	2.72150E-16	2.71641E-16	2.52577E-20	2.52105E-20
DEU	2.20836E-16	1.73440E-16	7.07188E-20	5.55413E-20	2.32566E-16	1.82653E-16	7.44753E-20	5.84914E-20
DNK	3.18292E-16	2.40566E-16	6.73989E-20	5.09402E-20	3.32573E-16	2.51359E-16	7.04230E-20	5.32259E-20
DOM	4.39359E-15	4.76309E-14	4.09633E-18	4.44083E-17	4.37760E-15	4.74230E-14	4.08142E-18	4.42145E-17
DZA	1.57164E-16	3.97322E-16	3.27619E-19	8.28247E-19	1.47182E-16	3.71565E-16	3.06811E-19	7.74554E-19
ECU	1.10039E-14	5.82602E-14	1.53326E-16	8.11784E-16	1.09996E-14	5.82375E-14	1.53266E-16	8.11467E-16
EGY	1.21370E-17	8.08500E-18	1.73402E-20	1.15511E-20	1.11284E-17	7.42994E-18	1.58992E-20	1.06152E-20
ERI	1.75557E-16	7.00534E-15	8.22300E-20	3.28127E-18	1.65730E-16	6.61318E-15	7.76270E-20	3.09758E-18
ESP	4.55076E-15	3.22140E-15	1.52751E-17	1.08130E-17	4.59185E-15	3.25046E-15	1.54130E-17	1.09105E-17
EST	2.13818E-15	4.19964E-16	5.16611E-20	1.01469E-20	2.34062E-15	4.59722E-16	5.65524E-20	1.11075E-20
ETH	4.02726E-15	1.67087E-14	5.91398E-17	2.45366E-16	3.79139E-15	1.57325E-14	5.56762E-17	2.31030E-16
FIN	4.04601E-16	1.43964E-16	4.01608E-20	1.42899E-20	4.40649E-16	1.56789E-16	4.37389E-20	1.55629E-20
FRA	1.19174E-15	8.00775E-16	6.32889E-18	4.25263E-18	1.22161E-15	8.20843E-16	6.48753E-18	4.35921E-18

Country code	Mammals				Birds			
	Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]		Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]	
	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution
GAB	5.12845E-15	5.27859E-14	1.58081E-17	1.62709E-16	4.87710E-15	5.01985E-14	1.50333E-17	1.54733E-16
GBR	2.75747E-16	2.07823E-16	4.29058E-20	3.23368E-20	2.87549E-16	2.16717E-16	4.47421E-20	3.37207E-20
GEO	5.05177E-15	5.36126E-15	4.71807E-18	5.00711E-18	5.10649E-15	5.41933E-15	4.76918E-18	5.06134E-18
GHA	2.37586E-15	1.62888E-14	8.06844E-18	5.53168E-17	2.24319E-15	1.53789E-14	7.61788E-18	5.22269E-17
GIB	-	-	-	-	-	-	-	-
GNQ	3.18848E-14	6.17165E-14	7.96071E-17	1.54089E-16	3.03623E-14	5.93990E-14	7.58059E-17	1.48302E-16
GRC	8.17264E-15	1.14636E-14	9.12990E-18	1.28064E-17	7.92407E-15	1.11149E-14	8.85222E-18	1.24168E-17
GTM	9.78706E-15	7.66094E-14	4.10834E-17	3.21585E-16	9.76020E-15	7.63991E-14	4.09706E-17	3.20702E-16
GUY	-	2.26929E-14	-	3.40633E-17	-	2.26250E-14	-	3.39614E-17
HND	2.79073E-15	9.16849E-14	6.28614E-18	2.06521E-16	2.78336E-15	9.14371E-14	6.26955E-18	2.05963E-16
HRV	1.30996E-14	6.31028E-15	1.98459E-18	9.56008E-19	1.39928E-14	6.74054E-15	2.11991E-18	1.02119E-18
HTI	6.88889E-15	4.98999E-13	2.16801E-18	1.57040E-16	6.86371E-15	4.96890E-13	2.16008E-18	1.56377E-16
HUN	5.37685E-16	2.42396E-16	2.23813E-19	1.00898E-19	6.10251E-16	2.75108E-16	2.54019E-19	1.14515E-19
IDN	2.30953E-15	2.44733E-14	2.08513E-16	2.20954E-15	2.30107E-15	2.43623E-14	2.07750E-16	2.19953E-15
IND	9.51570E-16	2.05116E-15	2.55139E-17	5.49965E-17	1.01291E-15	2.17878E-15	2.71586E-17	5.84182E-17
IRL	1.73894E-16	1.31020E-16	3.27193E-21	2.46522E-21	1.83197E-16	1.38029E-16	3.44697E-21	2.59711E-21
IRN	7.79116E-17	2.48045E-16	3.95339E-19	1.25863E-18	7.68225E-17	2.44953E-16	3.89813E-19	1.24294E-18
IRQ	5.61346E-18	2.40310E-16	4.54030E-21	1.94368E-19	5.34033E-18	2.28617E-16	4.31938E-21	1.84911E-19
ISL	1.44073E-17	1.12134E-17	2.09272E-22	1.62879E-22	1.45012E-17	1.12865E-17	2.10636E-22	1.63940E-22
ISR	7.91573E-18	4.71852E-17	6.18674E-21	3.68788E-20	7.57336E-18	4.51443E-17	5.91916E-21	3.52837E-20
ITA	6.94075E-15	2.97003E-15	1.08525E-17	4.64390E-18	7.16967E-15	3.06799E-15	1.12104E-17	4.79707E-18
JAM	1.30383E-13	4.50895E-13	2.83291E-16	9.79685E-16	1.29885E-13	4.49170E-13	2.82208E-16	9.75937E-16
JOR	4.36263E-17	4.52914E-17	4.42628E-21	4.59522E-21	4.11367E-17	4.27067E-17	4.17368E-21	4.33298E-21
JPN	3.50748E-15	1.62471E-15	3.15533E-17	1.46159E-17	3.59405E-15	1.66479E-15	3.23321E-17	1.49765E-17
KAZ	1.89464E-17	3.43745E-17	8.76725E-20	1.59064E-19	2.06414E-17	3.77920E-17	9.55157E-20	1.74878E-19
KEN	5.67023E-15	1.46206E-14	6.15564E-17	1.58723E-16	5.37517E-15	1.38806E-14	5.83532E-17	1.50689E-16
KGZ	1.76751E-17	3.07609E-16	1.21820E-20	2.12009E-19	2.01827E-17	3.49802E-16	1.39102E-20	2.41088E-19
KHM	2.49316E-15	2.44607E-14	8.08696E-18	7.93421E-17	2.44595E-15	2.39975E-14	7.93384E-18	7.78397E-17
KOR	1.07936E-15	1.24097E-15	3.42015E-19	3.93226E-19	1.20157E-15	1.38147E-15	3.80741E-19	4.37744E-19
KWT	3.29804E-19	4.31141E-18	2.56449E-24	3.35246E-23	3.18142E-19	4.15894E-18	2.47380E-24	3.23391E-23
LAO	7.49761E-15	5.62200E-14	5.67992E-17	4.25903E-16	7.40162E-15	5.55002E-14	5.60720E-17	4.20450E-16
LBN	1.95999E-16	1.10560E-15	6.16558E-21	3.47790E-20	1.90530E-16	1.07474E-15	5.99354E-21	3.38084E-20
LBY	1.37780E-17	3.04055E-17	1.74894E-20	3.85960E-20	1.28335E-17	2.83114E-17	1.62905E-20	3.59377E-20
LKA	2.30299E-14	1.08442E-13	1.65084E-16	7.77339E-16	2.34359E-14	1.10355E-13	1.67994E-16	7.91051E-16
LTU	2.69123E-15	1.30226E-16	1.11216E-19	5.38162E-21	2.93767E-15	1.42150E-16	1.21400E-19	5.87437E-21
LUX	1.60902E-15	1.47499E-16	4.00954E-21	3.67555E-22	1.70236E-15	1.56055E-16	4.24214E-21	3.88876E-22
LVA	1.71590E-15	7.19478E-16	6.20586E-20	2.60213E-20	1.87836E-15	7.87590E-16	6.79343E-20	2.84847E-20
MAR	1.46392E-15	4.95453E-15	3.32655E-18	1.12585E-17	1.38224E-15	4.67516E-15	3.14094E-18	1.06236E-17
MDA	1.50804E-16	4.53207E-17	1.26768E-20	3.80972E-21	1.67125E-16	5.02253E-17	1.40488E-20	4.22202E-21
MEX	9.62053E-15	3.05265E-14	4.68129E-16	1.48540E-15	9.67546E-15	3.06935E-14	4.70803E-16	1.49353E-15
MKD	4.59587E-15	6.27950E-15	6.48166E-19	8.85612E-19	4.73347E-15	6.46751E-15	6.67571E-19	9.12126E-19
MLT	-	-	-	-	-	-	-	-
MMR	3.69799E-15	4.08823E-14	3.27725E-17	3.62309E-16	3.66737E-15	4.07012E-14	3.25011E-17	3.60703E-16
MNE	2.05942E-14	1.26593E-14	1.78352E-18	1.09633E-18	2.19604E-14	1.34990E-14	1.90184E-18	1.16906E-18
MNG	1.14353E-17	1.01868E-16	3.30622E-20	2.94525E-19	1.20605E-17	1.07123E-16	3.48698E-20	3.09720E-19

Country code	Mammals				Birds			
	Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]		Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]	
	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution
MOZ	1.22424E-14	1.86202E-14	4.38234E-17	6.66537E-17	1.18077E-14	1.79591E-14	4.22675E-17	6.42871E-17
MUS	-	-	-	-	-	-	-	-
MYS	6.37975E-15	1.39294E-14	1.09223E-16	2.38475E-16	6.34462E-15	1.38527E-14	1.08622E-16	2.37162E-16
NAM	1.18673E-13	2.81753E-14	3.44653E-16	8.18276E-17	1.14786E-13	2.72526E-14	3.33366E-16	7.91477E-17
NER	1.09603E-17	3.84175E-16	1.44513E-20	5.06540E-19	1.03924E-17	3.60853E-16	1.37026E-20	4.75789E-19
NGA	5.63478E-15	2.17385E-14	3.74608E-17	1.44521E-16	5.37351E-15	2.07041E-14	3.57238E-17	1.37643E-16
NIC	5.40600E-15	6.18980E-14	9.53276E-18	1.09149E-16	5.39419E-15	6.17493E-14	9.51194E-18	1.08887E-16
NLD	4.40009E-17	5.20875E-17	1.05613E-21	1.25023E-21	4.58375E-17	5.42615E-17	1.10021E-21	1.30241E-21
NOR	1.98273E-15	8.82538E-16	2.95995E-19	1.31751E-19	2.26336E-15	1.00744E-15	3.37889E-19	1.50397E-19
NPL	1.87105E-14	4.36966E-14	4.23090E-17	9.88084E-17	1.97444E-14	4.60722E-14	4.46467E-17	1.04180E-16
NZL	5.11729E-15	3.43673E-15	8.88380E-18	5.96629E-18	4.84737E-15	3.25546E-15	8.41522E-18	5.65160E-18
OMN	2.23614E-17	1.29944E-16	2.35993E-20	1.37138E-19	2.06888E-17	1.20224E-16	2.18340E-20	1.26880E-19
PAK	4.73613E-16	1.40218E-15	8.82992E-19	2.61418E-18	5.08800E-16	1.50460E-15	9.48594E-19	2.80514E-18
PAN	1.49187E-14	5.08429E-14	5.74159E-17	1.95673E-16	1.48867E-14	5.07430E-14	5.72925E-17	1.95288E-16
PER	9.76680E-16	1.13500E-14	2.19205E-17	2.54738E-16	9.77365E-16	1.13584E-14	2.19359E-17	2.54927E-16
PHL	7.71630E-15	2.28245E-14	1.70471E-16	5.04247E-16	7.64737E-15	2.26060E-14	1.68948E-16	4.99419E-16
POL	6.75884E-16	6.00409E-16	1.81432E-19	1.61171E-19	7.22313E-16	6.41651E-16	1.93895E-19	1.72242E-19
PRK	1.87933E-15	4.19066E-15	1.07651E-18	2.40047E-18	2.07176E-15	4.61980E-15	1.18674E-18	2.64630E-18
PRT	7.48369E-15	6.70254E-15	4.50763E-18	4.03712E-18	7.63885E-15	6.84147E-15	4.60109E-18	4.12080E-18
PRY	3.20256E-16	4.70070E-15	6.91596E-19	1.01512E-17	3.21477E-16	4.71861E-15	6.94232E-19	1.01899E-17
QAT	-	1.94091E-19	-	7.69602E-25	-	1.86857E-19	-	7.40917E-25
ROU	1.15302E-15	1.66372E-15	2.42995E-18	3.50624E-18	1.25843E-15	1.81583E-15	2.65211E-18	3.82680E-18
RUS	5.66380E-16	4.22554E-16	6.52378E-18	4.86713E-18	6.16311E-16	4.61197E-16	7.09889E-18	5.31224E-18
SAU	5.07342E-18	2.51451E-17	7.04041E-21	3.48939E-20	4.66804E-18	2.31359E-17	6.47787E-21	3.21058E-20
SDN	5.23839E-17	5.25465E-16	1.38576E-19	1.39006E-18	4.98452E-17	4.98172E-16	1.31860E-19	1.31786E-18
SEN	9.85425E-17	1.35750E-15	6.00507E-20	8.27247E-19	9.41785E-17	1.29738E-15	5.73914E-20	7.90610E-19
SGP	-	1.05011E-17	-	1.13973E-21	-	1.04356E-17	-	1.13261E-21
SLV	7.20979E-15	2.15385E-14	2.61026E-18	7.79787E-18	7.18846E-15	2.14748E-14	2.60254E-18	7.77480E-18
SRB	1.73215E-15	2.86368E-15	3.71370E-19	6.13968E-19	1.84093E-15	3.04351E-15	3.94692E-19	6.52525E-19
SUR	3.59433E-15	3.74616E-14	2.80905E-18	2.92772E-17	3.58206E-15	3.73336E-14	2.79947E-18	2.91771E-17
SVK	1.50255E-15	7.56352E-16	1.98153E-19	9.97459E-20	1.66216E-15	8.36692E-16	2.19202E-19	1.10341E-19
SVN	3.38081E-15	3.25588E-15	1.57049E-19	1.51246E-19	3.65408E-15	3.51904E-15	1.69743E-19	1.63470E-19
SWE	6.29157E-16	3.11104E-16	8.33783E-20	4.12287E-20	6.86751E-16	3.39581E-16	9.10108E-20	4.50026E-20
SYR	2.59027E-16	1.93657E-15	1.78554E-19	1.33493E-18	2.45566E-16	1.83593E-15	1.69275E-19	1.26556E-18
TGO	5.43186E-15	1.23496E-14	2.38607E-18	5.42486E-18	5.18947E-15	1.17983E-14	2.27960E-18	5.18270E-18
THA	2.73477E-15	7.21704E-15	2.13526E-17	5.63493E-17	2.69568E-15	7.11387E-15	2.10474E-17	5.55438E-17
TJK	5.25118E-18	5.31650E-17	2.22558E-21	2.25326E-20	5.69714E-18	5.77613E-17	2.41459E-21	2.44806E-20
TKM	2.28903E-16	1.86980E-16	1.82124E-19	1.48769E-19	2.35364E-16	1.90336E-16	1.87265E-19	1.51439E-19
TTO	-	2.01781E-14	-	4.29177E-18	-	2.01284E-14	-	4.28120E-18
TUN	2.79474E-16	1.02420E-15	1.52793E-19	5.59945E-19	2.62932E-16	9.58498E-16	1.43750E-19	5.24027E-19
TUR	2.04089E-15	4.87982E-15	5.87223E-18	1.40407E-17	2.07123E-15	4.95235E-15	5.95953E-18	1.42494E-17
TZA	7.66163E-15	4.43389E-14	1.19603E-16	6.92161E-16	7.26675E-15	4.21469E-14	1.13439E-16	6.57942E-16
UKR	5.46860E-16	1.75656E-16	1.05438E-18	3.38675E-19	6.03116E-16	1.93725E-16	1.16284E-18	3.73513E-19
URY	1.04653E-16	1.23512E-16	1.43904E-19	1.69836E-19	1.04904E-16	1.23809E-16	1.44249E-19	1.70244E-19
USA	1.49435E-15	1.22153E-15	4.27738E-17	3.49646E-17	1.71510E-15	1.40109E-15	4.90923E-17	4.01043E-17

Country code	Mammals				Birds			
	Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]		Regional CF [PDF*y/kWh]		Global CF [PDF*y/kWh * GEP]	
	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution
UZB	5.91387E-18	1.08369E-17	4.31975E-21	7.91573E-21	6.27948E-18	1.15068E-17	4.58681E-21	8.40509E-21
VEN	5.29675E-15	1.52019E-14	7.08217E-17	2.03261E-16	5.28288E-15	1.51628E-14	7.06362E-17	2.02738E-16
VNM	2.83027E-15	6.95024E-15	3.59920E-17	8.83849E-17	2.78544E-15	6.84014E-15	3.54219E-17	8.69848E-17
YEM	1.05503E-15	9.72360E-15	1.48139E-18	1.36531E-17	9.55352E-16	8.80489E-15	1.34143E-18	1.23631E-17
ZAF	1.69848E-15	2.82045E-15	2.17474E-17	3.61133E-17	1.73363E-15	2.87882E-15	2.21975E-17	3.68607E-17
ZMB	1.22120E-14	1.39121E-14	5.05106E-17	5.75423E-17	1.16465E-14	1.32678E-14	4.81714E-17	5.48774E-17
ZWE	1.10637E-14	1.71399E-14	2.11215E-17	3.27213E-17	1.07849E-14	1.67079E-14	2.05892E-17	3.18966E-17

Underground Transmission Line Siting Through Growing Cities

Pattarin Jarupan and Jonathon Schultis

Keywords: Aboveground Transmission Line, Case Study, Communication, Human Impact, Human Use, Stakeholder Engagement, Transmission Line, Underground Transmission Line, Utility Infrastructure, Utility Lines.

As existing transmission lines need to be upgraded due to age and outdated technology, there are limited opportunities to site them aboveground in growing cities, forcing utilities to consider underground transmission infrastructure. This paper presents a case study about a new underground transmission line routed through a developing urban neighbourhood in Columbus, Ohio, United States. A cohesive understanding of the future and current land uses of the study area guided the efficient data gathering and stakeholder engagement initiatives, which led to the project's success.

When developing a transmission line route through a city increasing in investment and population, concepts like aesthetic impacts and conflicting land uses were of concern to both property owners and regulators. Understanding the resources that were relied upon by the community tailored the stakeholder engagement process at the government and local levels and was vital to developing a routing decision which prioritized public interest.

As underground utility infrastructure improvements are a new focus for developing cities, a project solution must be sensitive to the specific project location to properly analyze constraints. In the Ohio case study, individual meetings with local and state agencies, as well as public information meetings, were vital to gathering constraint data. This paper explores the unique resources of the study area which tailored the stakeholder engagement strategy; and analyzes the balance between aboveground land uses that are vital to the community and the technical constraints of installing an underground asset through a populated area.

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INTRODUCTION

Midwestern cities are developing at a rapid pace economically and demographically and have become a hub for people migrating in search of jobs or educational opportunities. Economic development results in growth and the associated skilled labor and developable land, from downtown headquarters to manufacturing facilities in the suburbs. Companies such as Amazon and Intel have been relocating their headquarters or manufacturing centers to Midwestern cities and are shining the spotlight on them as the place to be for a skilled workforce and available land (Renn 2019). Consequently, there is an increasing need for commercial, residential, and other community-based developments within downtown areas as companies relocate their staff and attract a larger workforce.

Along with this increase in development, the need for improving the existing utility infrastructure becomes a necessity. This rapid demand for additional utility infrastructure to keep up with growing land-use development is a trend across Midwestern cities (Renn 2019). As the need for urban utility infrastructure continues to increase in Midwestern states, regulatory processes concerning the siting and routing of transmission lines are still in flux and evolving, and proponents are required to establish their own processes to obtain public trust to proceed with projects on a rapid time frame.

This document details the importance of understanding the study area and provides an example of how to use that knowledge to guide the siting process. The siting process must be tailored to fit the project's particular landscape and social, cultural, and environmental constraints, while maintaining the use of a standardized and defensible methodology. If done so correctly, this process should yield trust from the public and regulatory authorities.

In early 2020, a new 3-mile-long, 138 kilovolt (kV) transmission line through downtown Columbus, Ohio, was needed to provide additional support to the existing power grid. With the development of a nearby hospital and other community-based infrastructure, the rapid growth and redevelopment surrounding the downtown area required a new high-voltage line to provide grid redundancy. The new transmission line was required to be in service by late 2022 to support the new developments that were in progress within the area and to maintain service to existing customers, without compromising the integrity of the existing infrastructure. The information for this case study is from the referenced documents produced by Jacobs (2020a, b). This case study describes a comprehensive siting methodology for an underground transmission line within a fast-growing city.

METHODS

Transmission line technical specifications and physical characteristics are rarely determined at the same time a project need is defined. When constructing a transmission line through an urban geography, underground solutions cannot be automatically assumed without first vetting the feasibility of overhead solutions. Underground transmission lines are often more costly, so an analysis of the surrounding land use in proximity to the defined connection points must be completed to determine the necessity of an underground line. Therefore, the first step of the Ohio project was to complete an overhead transmission line routing analysis to determine whether an overhead transmission line would provide a compatible land use with existing and future land uses.

A siting study was completed with the goal of identifying potential overhead route options. It was important that the study's goal was not to prove that an underground transmission line was needed, but to objectively analyze whether an overhead transmission line was feasible in the project location. Quantitative factors, such as number of streams crossed, number of properties within the right of-way (ROW), and degrees of slope, along with qualitative factors, such as visual impacts and potential impacts to future land uses, were considered in determining the transmission line's feasibility. With this scope in mind, constraint and opportunity features within the study area were analyzed, and two alternative routes were developed that were feasible, considering the existing land uses.

A comprehensive siting study and report regarding the consideration of an overhead line was completed in the early stages of this project. Upon a qualitative review of the future land-use plans and observing the dense residential developments within the study area, both routes were deemed to be infeasible for this project due to the potential for transmission line equipment being in proximity to houses, with some instances creating a safety hazard with habitable structures within the conductor zone. Stakeholder engagement was not completed at this stage as no viable overhead transmission line routes were identified. With the understanding that an overhead transmission line would not be viable, the siting team shifted focus into conducting a siting study for an underground transmission line.

The first step in identifying underground transmission line route options is to understand the study area. This involves the understanding of current and future aboveground land uses and their impacts on roadways and the associated underground utility infrastructure. Coordination with public stakeholders and governmental and nongovernmental organizations was necessary to understand any changes in land uses, as it may have an impact on potential locations for underground utilities. The aboveground land uses within the study area largely comprised the following.

- **Existing Land Uses:**
    - Dense, single- and multi-family residential housing
    - Schools
    - Community-based services, such as daycares, autobody shops, and small grocery stores
- **Future Land Uses:**
    - Large medical center complex (campus with hospital, with helipad and associated medical offices)
    - Major highway expansion

A large highway crossing was also unavoidable, and active construction was occurring along this highway.

Transportation within this area largely comprised local roads, with parking on both or either side of roads, and bus routes. As the transmission line was proposed to be underground, the construction processes could have limited areas where residents park their vehicles and cause bus reroutes and delays. Large developments, such as hospital complexes, were planned to surround the existing neighborhood; and the project area was observed to be at a low-income level in comparison to the city's medium household income.

With this understanding, it was clear that there were two parts to stakeholder engagement to better understand community needs:

1. Understanding the location of existing underground utilities and other construction projects in the area, through coordination with the city of Columbus
2. Engaging the community to determine a route that minimally impacted their daily lives

Coordinating with the city was necessary to understand the underground utility congestion along existing roadways. Roadways with existing underground utilities were considered a major constraint if there was not available space for the underground transmission line under consideration. As the area was rapidly expanding, finding an underground corridor that was not already encumbered with other underground utilities posed a challenge.

Obtaining city data and having discussions with different city departments aided in the understanding about which underground corridors were able to accept an additional utility asset, which greatly narrowed down the available roadways and provided opportunities for transmission line routing. In more than two months, 10 city departments were contacted to obtain necessary project information.

Coordinating with the city's transit system also revealed which bus routes were the most relied upon by the neighborhood, which helped further narrow down route options. It was also discovered that there were other underground utility infrastructure projects the city was already coordinating. Construction schedules for other underground work in the area were discussed with the city to synchronize with the other projects and reduce construction events that might have resulted in interruptions to the surrounding community.

Additionally, there was a city memorandum dictating that roadways could be excavated in no less than five years from the last time paved. These discoveries made by coordinating with the city saved the project team schedule delays in the future, had this information been discovered during construction.

The surrounding community was largely made up of residences who had lived in this community before rapid development started to occur. These established communities are of lower income and are directly impacted by the gentrification that occurs with the increase in infrastructure investments in the area. Through the route development process, interruptions to transportation services were given significant consideration, as impacts to the roadways may have an impact on the services that community members rely upon. Additionally, most houses within these communities do not have garages, and impacts to street parking would disproportionally impact the community members in this area.

Route development and refinement decisions were made considering impacts to transportation. The project team was sensitive to the community's rapidly changing footprint and set the goal of minimizing disruptions in the daily lives of community members. Development often occurs in low-income areas, and those in the community are hardly given notice about construction occurring or a chance to have their opinions be heard.

In addition to working with the city to make sure landowners were notified about this project, direct public feedback was gathered by the project team. As this project took place at the peak of the COVID-19 pandemic, virtual stakeholder communication methods were used to gather feedback from the public. A letter introducing this project was mailed to every household along with a map showing the routes under consideration and with a prestamped envelope so that the public could easily mail their feedback to the team; the letter was used in addition to virtual communications, as there were likely households with limited internet access.

A project website was hosted that provided project information and an interactive map. This was also another way the public could reach the project team should they have questions or concerns. By communicating with the public and considering the aboveground resources the community relied upon, interruptions to the permitting timeline were consequently mitigated.

Within the state of Ohio, the Public Utilities Commission regulates transmission lines greater than 100 kV through the Ohio Power Siting Board (OPSB). This project required the approval of a Certificate of

Environmental Compatibility and Public Need (application), in which two route options are provided to the OPSB, and the OPSB selects one route option for construction. From the time the application is submitted to board approval is between eight months and a year.

With the fast-paced time frame of this project, the OPSB was notified of the need for application approval during the siting route development and public engagement processes, and the application was anticipated by the OPSB for months before the filing was submitted. Working with the OPSB and keeping the regulators notified about the project's progress throughout the siting process, and having open communication as the project was being developed, allowed for a faster approval time frame, as the OPSB were already familiar with project challenges.

RESULTS

By employing a siting strategy tailored to fit the needs of the project, we were able to anticipate questions from private and public stakeholders because the information that was directly relevant to the project had already been analyzed. A non-biased feasibility analysis for an overhead line resulted in the need for an underground line, even though costs are often higher for underground construction. Early coordination with the city provided an understanding of the existing and future project footprint, the feasibility of siting on certain roadway corridors due to the congestion from other underground utilities, and the necessity of existing aboveground resources to the surrounding community.

When the public is given the chance to provide their input on a project, more information about what is relevant to the community is provided to the project team. As a result, the project team is less likely to make decisions that negatively impact the public, mitigating public opposition. More robust information means there is less likelihood to interrupt engineering and construction timelines by unknown factors.

Rushing the siting process when given a short time frame may result in future interruptions to the project schedule, potentially increasing the overall cost of the project. Even with a project subject to regulatory approval, working with regulators throughout the siting process allowed for a quicker approval process. For a complex project to be successful within a short time frame, using a siting methodology tailored to the needs of the area supports seamless project implementation.

CONCLUSIONS

There is no one-size-fits-all siting method. The strategies employed to provide success for the Ohio project—one with constraints—certainly differs from a project with opportunities—such as a project through a farm field were there are fewer resources to mitigate and the routing opportunities are less constrained. As Midwestern cities grow and the need for fast-paced major utility infrastructure development increases, the siting methodology needs to employ a holistic approach that considers environmental, social, and land use contexts of the landscape, along with constructability, economics, and regulatory processes. In this case, this approach involved communicating with regulatory authorities and the public during the early project planning stages and analyzing qualitative factors as seriously as quantitative factors.

In the Ohio case study, the balance of existing and future land-use characteristics was considered. Even with a condensed project time frame, condensing the stakeholder and public engagement process to expedite other components of the project timeline was avoided. The project team understood that communication completed during project planning prevented future unplanned interruptions during the project's engineering and construction phases.

This project would not have been completed without public opposition if varying transportation methods and their importance to the community were not taken as seriously as quantitative engineering factors. Line routing decisions made in a vacuum by project teams almost always changes later in the project timeline, and this was understood by the project team—even with the pressure of constructing as fast as possible to meet the demands of a rapidly developing environment.

DISCUSSIONS

There is no prescribed formula for the siting process, though the main factors of understanding the physical and political footprint of the existing and future land uses are important in developing any sort of infrastructure in rapidly growing cities. Much like all projects that involve a siting process, project teams must work together and understand that steps cannot be rushed for the sake of meeting customer-defined in-service dates.

Utility infrastructure can exist for decades, and the lasting impact of their construction footprint must be considered. Although utility infrastructure projects are developed with the future in mind, impacts to the current land use are just as relevant to prevent disproportionately impacting existing communities. As Midwestern cities continue to grow, so should the siting methodologies that are employed to appropriately locate utilities harmoniously within existing and future city footprints.

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AUTHOR PROFILES

Pattarin Jarupan

Pattarin Jarupan is a Siting Lead and Project Manager and supports clients by bringing insights into the intricacies of the client-side process, gained from her position as a Siting Specialist for American Electric Power. She brings six years of experience specializing in siting electrical transmission projects. Jarupan has led more than 170 siting projects in the U.S. in Ohio, West Virginia, North Carolina, California, and Oklahoma, and has completed regulatory filings in Ohio and North Carolina. She received her Bachelor of Arts in cultural anthropology and her Master of Public Administration in city and regional planning, both from Ohio State University.

Jonathan Schultis

Jon Schultis is a Senior Land Use Planner and Siting Lead who provides technical expertise and leadership for electric transmission and natural gas projects. He has more than 15 years of professional experience, which includes:

- Siting and route selection studies for gas and electric transmission lines and facilities
- Environmental and regulatory permit management
- Land use and zoning entitlement and permitting
- Public outreach and coordination
- Federal Energy Regulatory Commission 7(c) regulatory involvement, primarily in the Mid-Atlantic U.S.

Schultis has provided expert witness testimony for electric transmission route selection and has successfully represented utility and energy clients at legislative board and commission hearings for zoning and land use entitlements in more than 40 local jurisdictions. He received his Bachelor of Arts in political science and public policy from Case Western Reserve University and his Master of Public Administration in public administration and urban planning from Virginia Commonwealth University.

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Environmental Concerns in Rights-of-Way Management

PART IV

Indigenous Engagement

Habitat Restoration: Why Indigenous Partnerships Matter

Paula Bentham and
Ryan Abel

Keywords: Caribou, Communication, Engagement, Indigenous, Partnership, Planning, Restoration, Stakeholders.

Input from Indigenous communities into linear habitat restoration programs is critical, yet such input is often sought after planning is complete. In contrast, a case study is presented of a partnership approach to restoration planning between Fort McKay First Nation (FMFN), WSP Golder, and Al-Pac for ~1600 km of linear footprint for species at risk. The planning area overlaps with the traditional territories of three Indigenous communities and holds significant cultural importance. Restoration of habitats therefore requires close collaboration to design a plan that reflects the ecological, cultural, and spiritual significance of the area for current and future Indigenous land users.

Early engagement with ongoing communication was extremely important to ensure that input and local knowledge was used in an iterative process to inform the plan. Indigenous knowledge holders provided inputs through a series of workshops, mapping exercises, and field reconnaissance. The project provided an opportunity for incorporation of Indigenous Knowledge into restoration programs and recognizes rights and interests across the area. The partnership approach was critical; having FMFN lead engagement facilitated frequent, repeated, and culturally appropriate engagement with land users, including Elders, knowledge holders, trappers, and leadership. The plan could not have been completed without their involvement.

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INTRODUCTION

Woodland caribou (*Rangifer tarandus caribou*) are a threatened species at risk in Canada, with the boreal population listed on Schedule 1 of Canada's Species at Risk Act. At the national scale, the province of Alberta's woodland caribou populations are among the least viable in Canada (Environment Canada 2011). Alberta has committed to achieving self-sustaining caribou populations through conservation and habitat restoration efforts across the province. This commitment includes restoring legacy seismic lines and inactive oil and gas infrastructure as a primary strategy to recover habitat and to reduce predation rates on caribou (Government of Alberta 2017). Seismic lines represent a significant amount of footprint on the landscape, many not regenerating naturally.

Large-scale and coordinated restoration of legacy seismic lines will be imperative to improving the probability of caribou survival both at provincial (Government of Alberta 2017) and national scales (Environment Canada 2012). These restoration programs are typically in remote regions of Canada and overlap the traditional territories of Indigenous communities, whose relationship to the land is deeply spiritual, and where each community of Indigenous peoples has their own way of interacting with and viewing the natural world. First Nation being the leaders in restoration priority area selection, restoration planning and implementation is therefore of critical importance to the success of restoration actions (Golder 2018). However, input from Indigenous communities into linear habitat restoration programs is often sought but only after planning is complete (e.g., Golder 2017). This approach lacks important knowledge inputs and learnings gathered through oral history or from current land users and knowledge holders, which can include locations of important seasonal habitats for species as well as critical cultural interest areas (Leech et al. 2016).

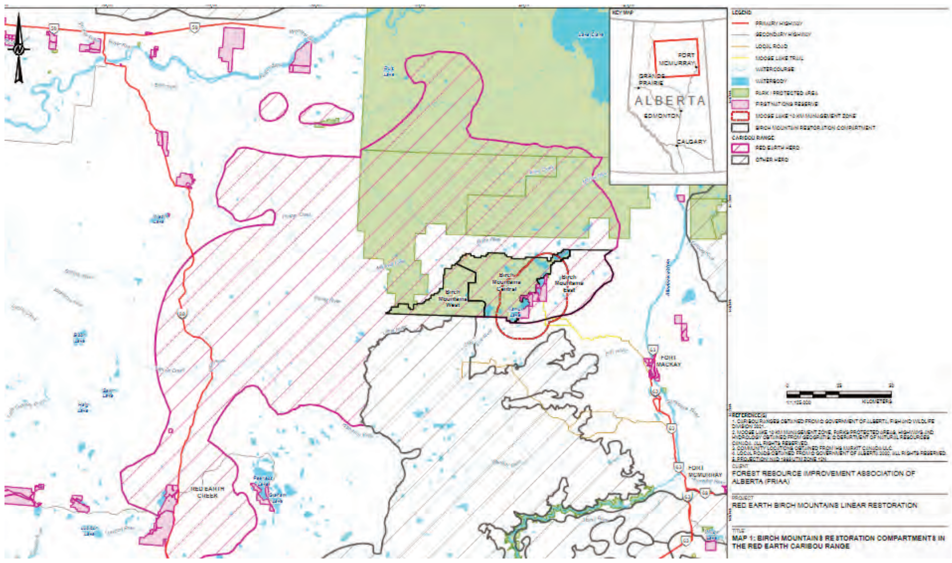

Figure 1. Birch Mountains restoration compartments in the Red Earth Caribou Range

In contrast, a case study is presented of a partnership approach to the development of an Operational Habitat Restoration Plan in the Red Earth Caribou Range in Northeastern Alberta. In 2020, Fort McKay First Nation, Golder a Member of WSP (Golder), and Alberta-Pacific Forest Industries Inc. (Al-Pac) (the project team) partnered to develop a habitat restoration plan covering approximately 1,600 kilometers (km) (994 mi) of legacy seismic lines within and adjacent to the Birch Mountains Wildland Park of Alberta (Figure 1). This planning area overlaps with the traditional territories of the Fort McKay First Nation, McMurray Métis (Local #1935) and Fort McKay Métis Nation; importantly, it also includes the Moose Lake 10-kilometer Management Zone (10 KMZ) extending from Fort McKay First Nation's Moose Lake reserves. Given the significant cultural importance of this area to the Fort McKay First Nation and other Indigenous communities for traditional use, the objective of this restoration planning process was to provide close collaboration with Indigenous community members to design a plan for a species at risk that reflected the ecological, cultural, and spiritual significance of the Birch Mountains and Moose Lake area for current and future land use.

The Importance of the Moose Lake Area

The importance of the Moose Lake Area is described within the Moose Lake Access Management Plan (Government of Alberta 2021) and summarized here. In 1915, Canada set aside reserve lands (I.R. 174A and 174B) for the exclusive use and occupation of the Fort McKay First Nation. These lands are known by members of Fort McKay First Nation and other Indigenous peoples as the "Moose Lake Reserves." The Hamlet of Fort McKay and the Moose Lake Reserves have become surrounded by oil sands leases, open pit mines (existing and approved) and in-situ bitumen projects beginning in the late 1960s (Figure 2). By 2015, the entire hamlet was surrounded with operational projects, and embedded within the existing and approved projects was a series of legacy linear disturbances, including seismic lines, pipelines, and roads. The Moose Lake Reserves, on the other hand, have remained largely intact with the exception of legacy seismic lines. These lands have in fact been in continuous use for countless generations and remain one of the last remaining locations where members of Fort McKay First Nation and other Indigenous peoples feel safe to practice their rights and use the land. In 2004, a resolution of a Treaty Land Entitlement Claim added new lands to the Moose Lake Reserves less than two years after Fort McKay First Nation initiated efforts to preserve and enhance the ecological and cultural integrity of the Moose Lake area to support traditional land uses and the preservation and transmission of its Cree and Dene cultures to future generations. For Fort McKay First Nation, the Moose Lake area is vital for the meaningful exercise of constitutionally recognized and affirmed treaty rights, traditional land uses, and cultural practices. Fort McKay First Nation members also believe strongly that the Moose Lake area is one of the only safe areas remaining where they can practice their rights and transmit Indigenous culture and knowledge to their children and grandchildren.

The Moose Lake area includes a 10 KMZ that overlaps with the Red Earth Caribou Range and captures Moose (Gardiner) and Buffalo (Namur) lakes, Big Island Lake, Sand Lake, other smaller water bodies, a portion of the Birch Mountains Wildland Provincial Park, and tenured (oil and gas/oil sands) and untenured provincial Crown land. This 10 KMZ has been recognized by the province of Alberta as having been established as a place for "management actions to maintain ecological integrity and biodiversity within the 10 KMZ to support the exercise of [Aboriginal and treaty] rights, traditional land uses, and cultural practices while simultaneously enabling well-managed, responsible development of resources" (Government of Alberta 2021).

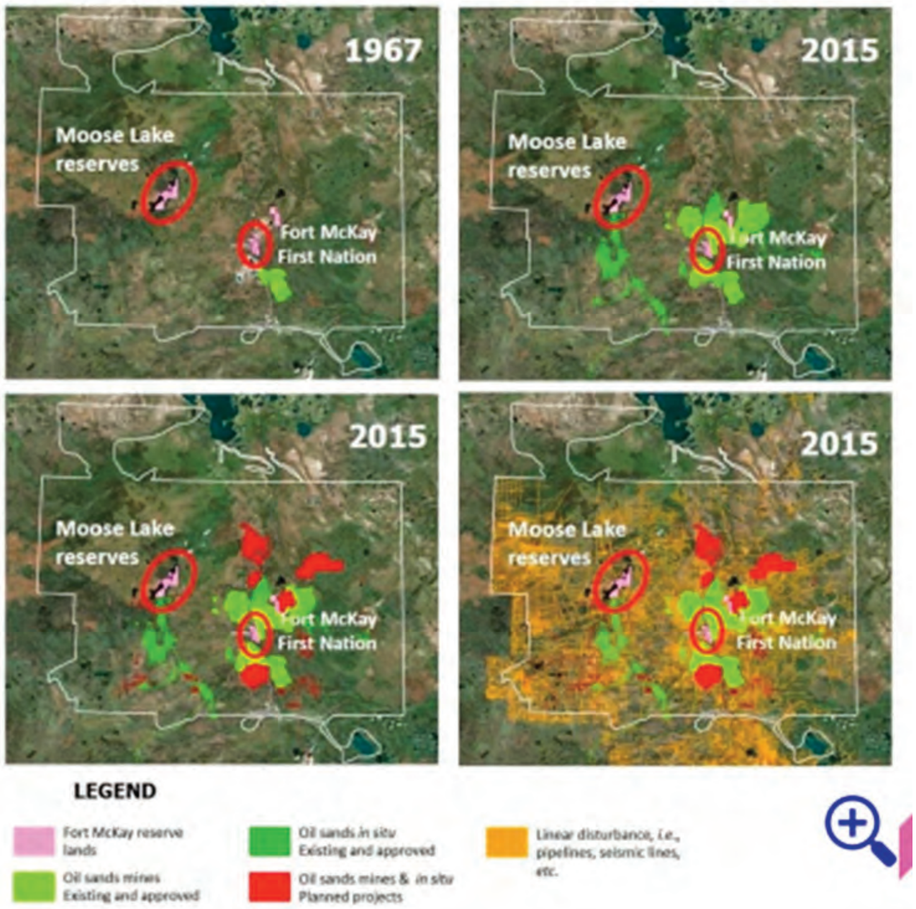

Figure 2. Various states of development in Fort McKay First Nation's Traditional Territory between 1967 and 2015

METHODS

Approach

The northeastern portion of the Red Earth Caribou Range was identified as a priority by the province of Alberta for habitat restoration planning. The restoration area is located approximately 65 km northwest of Fort McKay, Alberta, in the Regional Municipality of Wood Buffalo (Figure 1). The area was split by the province of Alberta into three compartments: Birch Mountains West, Central, and East for restoration planning. Birch Mountains West and Central were located within Birch Mountains Wildland Provincial Park (the Park) with a small portion of the Park in Birch Mountains East. The Park is managed under Alberta's Provincial Parks Act and has environmental objectives to conserve ecological systems, biological diversity, and minimize land disturbance. The Park is intended to be managed collaboratively with interested Indigenous communities. Interested communities in the area include the Fort McKay First Nation, McMurray Métis (MNA Local 1935), and Fort McKay Métis Nation.

In 2020, the project team began a partnership approach to the development of restoration plans and received grant funding through a joint proposal provided to the Forest Resource Improvement Association of Alberta (FRIAA) under the Caribou Habitat Recovery Program (CHRP). Grant deliverables were to prepare up to three operational restoration plans for the Birch Mountains West, Central, and East areas in accordance with the Government of Alberta's (2018) Draft Provincial Restoration and Establishment Framework. Given the importance of the area, restoration work in the region was recognized by the project team as requiring close collaboration with Indigenous communities to both design and implement habitat restoration plans that reflect the ecological, cultural, and spiritual significance of the Moose Lake Reserves for current and future traditional use.

Inclusion of Indigenous Peoples and Knowledge

Fort McKay First Nation representatives provided direction and oversight on the Indigenous engagement approach and on how to report on Indigenous people's inputs and knowledge into the plan. It was recognized early that it was imperative to apply the principles and best practices that were identified from developing the Moose Lakes Plan, and that local Indigenous Knowledge from Fort McKay First Nation land users and knowledge holders would be critical to inform the operational plan, recognizing Fort McKay First Nation's rights and interests across the planning area. This included recognition that the restoration of legacy seismic lines would support the achievement of the ecological integrity outcome and biodiversity of the Moose Lake area and support the exercise of Section 35 rights, traditional land uses, and cultural practices. The restoration areas overlapping the 10 KMZ were considered a priority for restoration, and that the restoration locations and prescriptions needed to consider first and foremost the importance of incorporating Indigenous Knowledge into the restoration plan. Prior to engagement activities starting, an agreement was established between Fort McKay First Nation and Golder, which outlined the use, ownership, and protection of Indigenous Knowledge. Fort McKay First Nation representatives attended all biweekly meetings with the project team to provide ongoing inputs into the desktop review of spatial data, field reconnaissance, and refinement on approach to the plan as the work progressed.

Engagement activities were coordinated through representatives of Fort McKay First Nation and McMurray Métis (Local #1935), who provided direction regarding the community members to engage with what would have traditional and land-use knowledge of the planning areas and access routes used by the community, and who were potentially directly impacted by the restoration activities. Fort McKay First Nation and McMurray Métis (Local #1935) representatives assisted with delivering hard-copy maps of the planning areas and potential treatment lines, gathering marked-up maps, and organizing online meetings and workshops. Fort McKay Metis Nation completed their own process and provided feedback to FRIAA directly.

An iterative process and ongoing communication approach with Fort McKay First Nation land users, including trappers and community members and adjacent Indigenous communities, was used in the development of the restoration plans. Inputs were provided through meetings, workshops, social media and field assessment. Inputs were provided by trapline holders, land users, and knowledge holders, which were verified through subsequent workshops. The final restoration plan was reviewed and refined following the verification process and senior leadership review.

Desktop Analysis and Linear Inventory

Using a variety of available datasets—including the Alberta Biodiversity Monitoring Institute (ABMI) human footprint (2021); Greenlink Forestry, Inc. linear inventory and vegetation attribute data (2015); watercourses and waterbodies (AltaLIS); wet areas mapping (Alberta Agriculture and Forestry [AAF]); Alberta Vegetation Inventory (AAF); Derived Ecosite Phase (AAF); and fire history (Alberta Environment and Parks)—a linear inventory for the entire restoration planning area was prepared. The datasets were combined to create linear segments along each line with similar moisture/nutrient/stand type attribute data. Each linear segment in the restoration planning area was classified at desktop as either advanced regeneration, leave for natural regeneration, treatment candidate, or as a project exclusion.

The linear inventory provided an overview of the existing vegetation status along each seismic line by each linear segment and captured surrounding ecosite/forest stand types, wet areas mapping, width of line, and existing vegetation structure and height. Treatments for candidate linear segments were prescribed such that where vegetation recovery is poor, treatments are recommended to increase vegetation trajectory and/or to minimize human and predator movements. Where advanced regeneration is present (defined as greater than 70% coverage of species capable of reaching 5.0 m height; with at least 50% coverage on both sides of the line [Government of Alberta, 2018]), treatments were recommended as appropriate to ensure regeneration is feasibly protected. Site treatments such as mounding, screening, tree felling, coarse woody debris distribution, and seedling planting (or combination thereof) have demonstrated success at reducing predator presence along seismic lines in the Canadian boreal forest (Dickie et al. 2021), and thus, were considered as potential treatments where natural revegetation was not occurring, or where access control was needed to protect the natural regeneration process.

The determination process used to classify linear segments as advanced regeneration, leave for natural regeneration, or as a treatment candidate involved reviewing and interpreting the Greenlink data (GFI 2015). Lines were inventoried by line type (e.g., pipeline, seismic lines, and trail/cutlines) and attributed with their corresponding line width and classified linear segment length. During desktop review of each linear segment, vegetation height increments were averaged across the width of the line, in nine height categories, and percent cover of vegetation was summed into four height categories of 0 to 0.6 m, >0.6 to 1.0 m, >1.0 to 3.0 m, and >3.0 m. The Greenlink data provided percent LiDAR returns to determine vegetation height, and these percentages were used as a proxy for percent vegetation cover within each height category. Linear feature segments were created in a Geographical Information System (GIS) based on landscape position and adjacent ecosites as these relate to restoration options, namely, upland (e.g., forested upland, upland-dry, and upland-transitional) or lowland (e.g., treed wetland).

An analysis of the interpreted Greenlink data for percent cover of woody vegetation combined with woody vegetation height measurements was used to classify the linear features as either low, moderate, or high candidacy for restoration treatment. The percent cover thresholds to be considered varied between upland and lowland sites based on available restoration monitoring results from previous programs within Alberta (Bentham and Coupal 2015; Filicetti et al. 2019; Spangenberg et al. 2019). The decision to recommend a restoration treatment, or to leave a segment to naturally revegetate based on current vegetation height and cover, considered both research on attributes of linear disturbances that display natural vegetation recovery (van Rensen 2014; van Rensen et el. 2015), as well as research results on predator movements in relation to linear disturbance vegetation heights and type of disturbance (Finnegan et al. 2014; Dickie 2015) and the Provincial draft Restoration Framework (Government of Alberta 2018). Height of woody vegetation (cut-off of 0.6 m) was used in combination with percent cover to classify a linear feature as leave for natural regeneration or a treatment candidate. Only linear disturbances that did not meet project exclusion criteria were assessed for restoration treatment candidacy, and those that met project exclusion criteria were removed from treatment candidacy. Project exclusions captured any linear disturbance under an existing land-use agreement, such as roads and pipelines or traditional access trails identified during the Indigenous engagement. Although project exclusion lines were not restoration candidates, they were assessed for equipment and contractor accessibility for incorporation into the operational plan during the field reconnaissance.

Only lowlands that were characterized by woody vegetation were considered for habitat restoration treatment; graminoid or herbaceous wetlands were not considered for treatment. Organic wetlands (peatlands) with woody vegetation are common across Northeastern Alberta and include wooded fens and bogs. Wooded fens and bogs generally have a much lower percent vegetation cover of woody species than a forested upland site due to relatively poor growing conditions, which limit tree or shrub establishment. The Alberta Wetland Inventory (AWI) (Halsey et al. 2004) was used as a guide to develop thresholds for determining regeneration status of linear disturbances in wetland areas. Undisturbed wooded fens and bogs were classified as “wooded” when woody vegetation was equal to or greater than 6% cover.

Stakeholder Engagement

Using available administrative data inputs within a GIS, a list of trappers, industry stakeholders, and government stakeholders was created. Trapper and industry stakeholder notification of the project was provided by mail or electronically via email with a request for inputs into the restoration planning. Trappers were invited to participate in either workshops, meetings, or phone calls to provide inputs; many on marked-up maps. Virtual meetings with oil and gas/oil sands and forestry stakeholders were completed to gather feedback on reclamation in progress and future potential activity (including reclamation) in the planning area.

Field Verification

An aerial field verification program of all advanced regeneration lines, leave for natural regeneration lines, and candidate treatment lines was conducted within the restoration planning area between July 21 and 31, 2021. The field verification collected data by linear segment on site limiting factors, on presence/absence of human access or game trails, prescribed a restoration treatment where required, identified implementation obstacles such as watercourse crossings, and collected details for restoration implementation access routes. Fort McKay First Nation’s Park Rangers supported the field verification program to verify advanced regeneration segments and treatment candidates and provided invaluable knowledge of access into, and within, the planning area.

A park ranger was available at the end of each day to provide additional inputs into the restoration planning maps, including important cultural locations and the access used to travel to these locations by community members such as cabins, berry picking areas, and graves. These access routes were marked as “project exclusion” in the plan to ensure cultural activities are maintained following restoration implementation. The park rangers also provided additional inputs into the operational plan, including feedback on access condition, logistical considerations for implementing restoration within the area such as timing of restoration, and identifying lines that are actively used by community members.

Ground-based verification plots at representative sites were visited to collect data on site limiting factors, as well as to confirm vegetation height and cover at natural regeneration sites to inform and confirm treatment prescription calls from the aerial survey.

Height and cover of vegetation, soil condition (compaction, organic layer, topsoil, moisture regime [xeric, mesic, or dryer sites, subhygric or wetter, hygric]), slope, plot photos, number/height/leader length/condition of acceptable trees, overall stocking, coarse woody debris cover, and presence of palatable shrubs were recorded along with presence or absence of human or wildlife access trails.

Restoration Plan Preparation

A restoration plan was prepared by linear segment, which incorporated field verification data and prescription recommendations and incorporated accessibility of treatment areas into prescription modification. Seedling counts by species, site preparation, watercourse crossings, and dispositions that may be used or crossed during the plan were summarized. Inputs from Indigenous engagement were incorporated, as well as inputs from trappers and stakeholders.

RESULTS

Biweekly meetings were held with Fort McKay First Nation Sustainability Department representatives during the entire planning process to discuss and tweak the engagement approach to capture community feedback into the plan. Counselors were contacted by a Fort McKay First Nation representative to let them know about the project and to discuss community engagement. A meeting was held with Fort McKay First Nation leadership representatives to provide an update on the engagement and planning process, and direction from leadership to review the final plan prior to submission was provided. The Fort McKay Sustainability Department facilitated an internal review of the draft restoration plan as well as provided briefings to Fort McKay First Nation leadership prior to submission of the final plan to FRIAA and Alberta Environment and Parks.

Community members were identified by Fort McKay First Nation representatives based on trappers (Registered Fur Management Areas [RFMAs]), cabin owners, land users or knowledge holders, and leadership with overlapping use, or in the vicinity of the project area who travel through and are familiar with the project area. These community members were invited to participate in virtual workshops. Workshops were organized by Fort McKay First Nation representatives by RFMA unit and/or by family. Prior to workshops, hard-copy maps of the planning areas and linear features were distributed by Fort McKay First Nation representatives. Some participants were able to participate in virtual mapping exercises in person at the Fort McKay First Nation Sustainability Department's office to access support.

The purpose of the workshops was to provide an overview of the project and objectives of caribou habitat restoration and to solicit input on seismic lines used to access the restoration planning compartment areas and areas of traditional or cultural activities where access would need to be maintained. Also discussed was the current vegetation condition of seismic lines, which lines were candidates for habitat restoration, and inputs on restoration treatments to support habitat recovery for caribou, but which consider other cultural perspectives on the land. Other considerations and knowledge inputs were sought regarding sensitive caribou habitat or ecological features or traditional and cultural use sites to inform restoration planning as well as what considerations should be applied during the implementation of restoration activities by a contractor in a respectful and safe manner.

At each of the workshops, a virtual mapping exercise was undertaken to identify lines that are used by community members and to understand the current vegetation state on seismic lines. Golder's GIS specialist attended each of the workshops to present the digital maps and to pull up any additional GIS data layers as needed or requested. During the workshops, Golder answered questions about the project and Indigenous community members shared their knowledge of the area and provided valuable input and feedback on the cutlines/seismic lines with potential for restoration, on treatment options, and on protection of natural recovery already occurring on seismic lines. Notes were taken by Golder during the workshops which were distributed to all participants afterwards for their review and comment. Feedback and knowledge shared during the virtual workshops were incorporated into draft spatial files of linear segments to treat, or to be excluded from treatment given current natural regeneration (partial restoration) and left open for access.

Verification workshops were held with the same participants to confirm inputs were captured correctly within this operational plan. Additional feedback was obtained from other community members and the draft spatial files were modified to capture verification workshop inputs.

During workshops, it was recommended to reach out to the broader community through social media. A Facebook social media post was developed and shared by Fort McKay First Nation representatives to reach out to other community members with cabins or using the area for trapping, hunting, or plant/berry gathering. The social media post briefly described the project and requested input and guidance on which seismic lines or cutlines should be restored and which are used by land users to access areas that overlap with or are potentially beyond the Red Earth Caribou Range. Community members were asked to contact the Fort McKay First Nation Sustainability Department to view copies of the project maps and provide input.

Fort McKay Métis Nation completed their own process and review of project spatial files and provided feedback to FRIAA directly through the submission of a Traditional Land Use study report. Figures and spatial data from the report provided transportation values and potential habitat restoration areas in the Red Earth Caribou Range and were incorporated into the restoration plan. Fort McKay Métis Nation recommended that prior to restoration implementation, consultation with the community should occur prior to restoration occurring in the areas overlapping with, or near sites, identified as transportation values.

Through the iterative process and ongoing communication approach with Indigenous communities, inputs provided by elders, leadership representatives, trapline holders, land users, and knowledge keepers were incorporated into the final restoration plan (Table 1). Consistent messages during all engagement sessions were that most of the trails are naturally regenerating with important traditional plants, berries, and medicines. It was indicated that many seismic lines have 20 to 30 years of regrowth where travel and access is already limited. Fire has provided a source of natural recovery in the area as well, in some cases. Restoration techniques should avoid disturbing regenerating areas and "avoid doing more harm than good." Key trails along seismic lines are used to access the Moose Lake Reserves, cabins, traplines, and traditional use areas, including grave sites and berry picking areas. These lines were classified as project exclusions and not considered for restoration within the plan.

What We Heard, We Saw

The field survey of potential treatment candidates, confirmation of advanced regeneration, and access considerations, including access routes and watercourse crossings, was completed between July 21 and 31, 2021. Ground-based plots supported the aerial data collection and verification. Where landing was not possible for ground plots due to advanced regeneration, aerial plots were completed from the helicopter.

Fort McKay First Nation's Park Rangers supported the aerial visual reconnaissance flight to field verify advanced regeneration segments, treatment candidacy, and subsequent prescriptions mapped from the desktop analysis and community workshops, and provided invaluable knowledge of access into and within the planning area. A park ranger was available at the end of each day to provide additional inputs into the restoration planning maps, including important cultural locations and the access used to travel to these locations by community members, such as cabins, berry picking areas, and graves. These access routes were classified as project exclusion to support ongoing cultural activities following restoration implementation. Observers in the field did document that even though these access routes are used for access, the trails were very narrow and have significant natural regeneration and were documented as partially restored. The park rangers also provided critical logistical considerations that were incorporated into the operational restoration plan, including feedback on access condition, timing of restoration, staging areas for equipment and workers, and identifying lines that are actively used by community members.

Table 1. Engagement Feedback Incorporated into Final Restoration Plan

CULTURAL	**LOGISTICAL / TREATMENT INPUTS**
• Key trails, cutlines/seismic lines used to access traplines and other traditional use areas were identified for exclusion. • It was critical to Fort McKay First Nation to include access in the 10 KMZ, including access and land use south of Namur Lake. • Some areas regenerating with traditional plants, berries, and medicines are important to the community. The community does not want to see additional disturbance by heavy equipment, roll-backs, or other less intrusive techniques in these areas, and recommended to "leave it the way it is" and "let mother nature takes its course" with revegetation. • Concerns were expressed about closing off cutlines that have been open for a long time (e.g., 40 years), and that there were no trees to roll back. • Avoid, or mitigate impacts from treatments to, archaeological sites or high-potential sites (no treatments around the lakes, treatments avoid known sites). • There is the potential for gravesites to be located near Moose Lake because of the historical settlement in area. This will need to be verified through the community. Access needs to be provided to these sites. **ECOLOGICAL** • Caribou locations, high-use areas, were provided. • Risk of restoration disturbance to areas that are already regenerating, which is "doing more harm than good". In general, many of the cutlines in the areas have 20–30 years of regrowth where travel and access are already limited, and to "reopen" areas for restoration and to apply treatment is perceived as "defeating the purpose." • Is there a positive impact to create intact habitat? Compare to MLAMP calculations. *(*Note: Following development of the restoration plan, the MLAMP calculations were repeated in considering lines to be restored as per this plan. The resultant change would be a 2.7% increase in interior intact habitat from 86.5% to 89.2%).* • Fire provides natural recovery; for example, around Birch Lake (between Island Lake and Namur Lake) the jackpine is approximately 4-feet high, following recent wildfires. • Concerns were expressed about the use of heavy equipment and disturbance to vegetation and wildlife, and impacts on fish-bearing streams/creeks. • Some community members indicated they were using waterways to access their traplines because cutlines were already grown in and they did not want to disturb them. • The island on the north end of Namur Lake is protected as a bird sanctuary—should not fly over this area. • A fire in 2003 burned the area south of Moose Lake and there has been limited growth in the area. • Beyond access routes, it's important to focus restoring more caribou habitat. Caribou, or caribou tracks, have been observed in the planning area (*locations provided*). • It is critical to include consideration of impacts on fish-bearing streams/creeks as part of studies and in the operational plan. • Recommend developing a reclamation monitoring program with the Fort McKay First Nation and other Indigenous peoples to ensure reclamation efforts are on a recovery trajectory, as per the MLAMP. **REGULATORY / LAND USE / DISTURBANCE** • Prior to implementation, Fort McKay First Nation and Fort McKay Métis Nation need to be contacted by the contractor with enough time to provide additional feedback. • Trappers/RFMA holders or their designates have expressed that they would like to participate and support in the field, in particular to support modified treatment options. The contractor should contact RFMA holders well ahead of implementation to plan for this support. • % Gain-in-Undisturbed habitat if planned restoration is implemented should be calculated. • Outside future harvest management plan areas. • Focus restoration in areas with limited future development potential.	• Existing Natural Vegetation Recovery ("Leave for Natural") should not be impacted by heavy equipment/restoration activities. • Less intrusive tree felling was recommended; for example, hand fellers using snow machines to make cutlines less usable by recreational users and dense mounding at access point/intersections to prevent ATV access. • The importance and option of including restoration at intersections where several trails/lines meet, but not to bring in equipment through natural regeneration areas just for small sections. • Concerns were expressed about implementing "roll-back" since there were no trees to roll back, and roll-backs can cause damage to skidoo skis. In addition, companies do not communicate when roll-back happens, and they have roll-back on existing lines that trappers use which creates a barrier to access; for example, one proponent implemented roll-back for their gas plant, which made a specific trail impassable for skidoos for accessing cabin/trapping areas. • Tree planting is a preferred treatment option because it is less intrusive. • It was recommended to use trees that are native to the area, such as spruce. • The importance of identifying existing vegetation in the area (e.g., trees, grass, and berries) to be included in reclamation. It was noted that if reclamation isn't restored to its original state, it won't be effective, and reclamation needs to ensure invasive vegetation (e.g., aspen) is not planted or introduced. • Modified treatments of cutlines would be suitable where approximately 0.5 miles is treated with slash/roll-back as a means to deter other recreational users, as long as trappers/land users can still "skirt around" or drive over the slash and are informed ahead of time of which cutlines would have this treatment applied. • Open to "narrowing" some cutlines to limit access for recreational users. However, recommend that the trapper is working with the contractor at site-specific locations if access is narrowed. The trapper can then inform the contractor on the locations/approach. • The importance of signage with simple language and symbols (e.g., restoration/limited access/no exit or a hand/hazard symbol) to communicate with people at intersections that a line is closed for access and there's a safety risk (e.g., mounds, roll-back). • The importance of communicating to land users and trappers in advance of work starting in the area, so they are aware that people are working in the area, especially for trappers out on their traplines during the winter. If the trapper sees tracks, they will backtrack to ensure people are safe if they do not know there are people working in the area. Social media posts are a good way to communicate what is happening in the area. • Presents a good opportunity for the community to be involved and build relationships during the implementation phase (e.g., seed collection, planting, monitoring; Indigenous-owned businesses). • Winter access would have to be used as the area is too wet to access in the summer with heavy equipment.

Overall, what we heard from Indigenous community engagement is what we saw during the field reconnaissance. The majority of Birch Mountains West (77%) was in a state of advanced regeneration, was remote and protected from human access, and effectively limits human and predator movement in its current natural condition (Images 1 and 2). Traditional access trails and Alberta Park's trails made up 22% of the lines in Birch Mountains West. However, these lines are comprised of narrow snow machine or hiking width trails that would be accessible in the winter, only as per feedback received during engagement sessions from people who travel to the north portion of the compartment in the winter. No restoration treatment areas were identified for Birch Mountains West.

Images 1 and 2. Representative photos of advanced regeneration along entire length of legacy seismic lines in Birch Mountains West. No habitat restoration treatments were recommended within the compartment.

Images 3 and 4. Representative photos of leave for natural regeneration (left) and advanced regeneration (right) and along legacy seismic lines in Birch Mountains Central.

Image 5. Ground plot within Birch Mountains East representative of a leave for natural regeneration prescription. Mean height of natural regenerating black spruce seedlings of 0.6 meters within a lowland treed bog.

Image 6. Ground plot within Birch Mountains East representative of a treatment plot prescribed for site preparation, use of coarse woody debris followed by planting over the line.

Of the legacy seismic lines in the Birch Mountains Central planning compartment, 50% (187 km) were verified as advanced regeneration or prescribed as leave for natural revegetation, given the current vegetation status. Similar to Birch Mountains West, advanced regeneration was observed within treed lowlands; transitional and upland ecosites; and on seismic lines on a north-south, east-west, northwest to southeast, and northeast to southwest orientation (Images 3 and 4).

Forest fires have occurred within the compartment and early successional vegetation is establishing on the seismic lines consistent with the adjacent burned stands. It is possible that historical forest fires in the compartment led to the advanced regeneration to match adjacent stands on seismic lines in the compartment. Trails for accessing cabins, traplines, and for a provincial fire tower as well as active dispositions comprised 43% of the lines. A total of 7% (29 km) of legacy seismic linear segments were identified as restoration treatment candidates. Of the treatment candidate segments, the majority (24 km) were prescribed as a hand fell treatment with remote helicopter access to address a game trail within partially recovering natural revegetation. The remaining individual linear segments throughout the compartment included 4.6 km where a site preparation and planting prescription was recommended to address poor natural revegetation due to moisture or nutrient site limiting factors. However, these treatment candidate sites were deemed inaccessible for heavy equipment as the prescribed treatment would damage existing advanced or natural regeneration.

The Birch Mountains East compartment has been almost fully tenured to oil sands proponents. This tenure has resulted in roads and pipelines with disposition status, which were not the focus of this restoration planning project. Project exclusions were also comprised of trails identified during the workshops and reports provided through the Indigenous engagement. In total, 43% (357 km) of Birch Mountains East linear footprint was classified as a project exclusion. Consistent with the Indigenous engagement feedback, advanced regeneration and leave for natural revegetation classification was associated with 37% (313 km) of lines in Birch Mountains East. Restoration treatments were prescribed on the remaining 20% of linear footprint (170 km).

In general, linear segments were considered leave for natural if vegetation was 60 cm in height with 30% conifer ground cover for uplands, and 10% cover for lowlands. Treatments were prescribed to match each linear segment's site limiting factors to reach the goals and objectives for caribou habitat restoration outlined within the Restoration and Establishment Framework (Government of Alberta 2018). Feedback from Indigenous engagement sessions to minimize impact to natural regrowth was incorporated into the decision to treat, or not to treat, a linear segment. For example, if a linear segment which could be treated would require access that could impact natural regrowth on the line, then the linear segment was prescribed for leave for natural to minimize disturbance to the landscape. Alternatively, to avoid damage to existing natural regeneration, where linear segments were deemed treatment candidates and where adjacent trees were sufficiently sized, the treatment prescription was altered to a hand-felling prescription, accessible by helicopter.

One operational plan resulted after the planning exercise and is specific to the Birch Mountains East and Central compartments; with 191 km of treatments out of the original 1,600 km of linear footprint assessed during the project. In addition to engagement feedback, the plan captures overflight findings, including confirmation of treatment prescriptions, prescription modification based on accessibility, and within-compartment access plans. Site preparation (mounding, screefing), seedling and seed counts, watercourse crossing methods, and active disposition holders are summarized. A total of 99 km of legacy seismic lines were recommended for site preparation and planting treatment, with an additional 91 km of legacy seismic lines prescribed with a hand-felling treatment due to the remoteness of the sites. The plan outlines site-specific limiting factors and associated treatment prescriptions, access requirements, permitting and authorization, as well as stakeholder engagement considerations for a contractor to complete prior to the implementation of restoration treatments.

A number of logistical considerations for restoration implementation are presented in the plan and stem from the Indigenous engagement approach. These included a recommendation for the restoration program to occur in the winter for accessibility, use of an existing cabin as a remote camp, and to implement less intrusive restoration techniques to avoid damaging existing natural vegetation recovery. A number of safety concerns for both restoration workers and land users were also captured and incorporated into the plan. These included adding signage using hand symbols indicating a hazard at intersections where restoration has occurred and to incorporate communication to the Indigenous communities in advance of the work in such a remote area.

Prior to finalization, a draft restoration plan was shared with Fort McKay First Nation Leadership by the Sustainability Department ahead of submission of the operational plan to FRIAA.

DISCUSSION

The restoration area is located approximately 65 km northwest of Fort McKay, Alberta, in the Regional Municipality of Wood Buffalo (Figure 1). The area spreads across the eastern portion of the Red Earth Caribou range. The area was split by the province of Alberta into three compartments: Birch Mountains West, Central, and East. Birch Mountains West and Central were located within Birch Mountains Wildland Provincial Park. The park is managed under Alberta's Provincial Parks Act and has environmental objectives to conserve ecological systems, biological diversity and minimize land disturbance, and is intended to be managed collaboratively with interested Indigenous communities. Interested communities in the area include the Fort McKay First Nation, McMurray Métis (MNA Local 1935), and Fort McKay Métis Nation.

Given the importance of the Moose Lake area for Fort McKay First Nation, restoration work in the region requires close collaboration with Indigenous communities to not only design and plan restoration programs but also to implement habitat restoration plans that reflect the ecological, cultural, and spiritual significance of the Moose Lake area for current and future use. As the restoration planning area overlapped with the Moose Lake 10 KMZ, a landscape-wide approach was applied to facilitate the application of principles and best practices identified within the Moose Lake Access Management Plan. The principles and best practices of the MLAMP that were used to guide the operational plan are summarized below (Government of Alberta 2021):

- Restoration of legacy seismic lines will support the achievement of the ecological integrity outcome and biodiversity of the Moose Lake area to support the exercise of Section 35 rights, traditional land uses, and cultural practices. The restoration areas overlapping the 10 KMZ are considered a priority for restoration, and the restoration planning within the 10 KMZ to consider first and foremost the importance of incorporating Indigenous Knowledge into the restoration plan.

- Fort McKay First Nation members see this area as their last meaningful place to practice treaty rights and traditional uses. As such, a partnership was formed with Fort McKay First Nation with representatives who provided direction and oversight in how best to incorporate Indigenous Knowledge and land user knowledge holders' inputs into the entire planning process. Disturbances used for traditional uses or to access areas to practice cultural activities were identified and noted as being partially restored through natural processes by participants. Recommendations which were provided through workshops and meetings regarding the legacy seismic lines and implementation of restoration were captured within the plan.
- Support traditional land-use capability in reclamation plans as a required outcome by restoring to preexisting vegetation condition.
- Conduct reclamation using enhanced treatments to reach preexisting vegetation condition.
- Ensure vegetation species composition and density reflect traditional cultural and wildlife values and objectives.
- Make efforts to ensure that the Fort McKay First Nation and other Indigenous peoples participate in the development of the final reclamation plan.
- Provide opportunities for Indigenous communities to participate in future monitoring events. Although engagement was completed during the preparation of the restoration plan, prior to implementation, the implementation contractor will need to capture, in the program implementation schedule, time to complete additional engagement with Fort McKay First Nation, Fort McKay Métis Nation, and McMurray Métis for working within the Moose Lakes area, as well as additional Indigenous consultation and trapper engagement.

CONCLUSIONS

Golder, in partnership with Fort McKay First Nation and Al-Pac, developed a restoration plan following the guidance provided in the Government of Alberta's (2018) Draft Provincial Restoration and Establishment Framework and template for operational plans. Three compartments of the Red Earth Caribou Range (Birch Mountains West, Central, and East) were identified for priority by Alberta Environment and Parks for restoration candidacy. Following Indigenous land knowledge-keeper workshops and upon field-truthing, it was determined the Birch Mountains West compartment had significant advanced regeneration, and an operational restoration plan was not required. The Birch Mountains Central compartment also had significant advanced regeneration and natural revegetation with some scattered treatment potential, while the Birch Mountains East required some treatment. One operational plan was prepared which outlines recommended linear restoration activities within the planning area which overlaps with both the Red Earth Caribou Range and the 10 KMZ of Fort McKay First Nation's Moose Lake Reserves.

Early engagement with ongoing communication was of utmost importance to ensure input and local knowledge was used in an iterative process to inform the plan. The approach taken in the development of the restoration plan was to incorporate local Indigenous Knowledge of land users and recognize Indigenous rights and interests across the planning compartments. Fort McKay First Nation, McMurray Métis, and Fort McKay Métis Nation and other land knowledge holders provided inputs into the plan through a series of workshops, mapping exercises, field reconnaissance, and direct reports. Not surprising, the vegetation condition on lines described during Indigenous engagement was consistent with field observations. Key learnings and outcomes for restoration implementation delivery were only captured through engagement and participation with Indigenous community members. These are restoration plan details which would have been missed without following the approach taken. The partnership approach was therefore critical; having Fort McKay First Nation lead engagement facilitated frequent, repeated, and culturally appropriate engagement with land users, including elders, knowledge holders, land users, and leadership, was critical to the success of this project. The plan could not have been completed without their shared knowledge of the area and their support during field work.

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Incorporating Indigenous Partnerships in Vegetation Management: *Wabitsabi Nanna*—To Care for Each Other

MK Youngblood

Keywords: Cultural Burning, Communication, Incident Command System, Human Use/Impact, Indigenous Partnerships, Traditional Ecological Knowledge (TEK), Utility Lines, Vegetation Management.

It is critical to integrate Indigenous Partnerships with our vegetation management programs and into the Incident Command System for current modes of execution within the utility fieldwork, specifically in California, where recent wildfires of severe scale and consequence have impacted Indigenous, private, state, and federal lands. This paper presents the results of a mixed-method strategy of qualitative and quantitative analysis conducted using case studies, personal interviews, and data review to develop a balanced plan for future generations. While Western society tends to validate the outcomes of Western education systems, including degrees achieved often by passive study in particular fields, the lack of Indigenous knowledge of the land—knowledge gained through thousands of years of the land's tending by Indigenous peoples—has pushed current forms of habitation of the planet, often informed exclusively by Western science or politics, toward apocalypse. This work, however, demonstrates findings that strongly suggest the vegetation management field become inclusive of Indigenous Partnerships, placing these in the Unified Command position of the National Incident Management System rather than the traditional stockholding position that has arisen because of colonization.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

This paper acknowledges that the terms *Indian*, *American Indian*, and *Native American* are commonly used interchangeably; however, one should refrain from using these terms, as they can be very misleading and sometimes offensive. The term *Indigenous*, or the cultural name of the people who occupy or had occupied the land, ought to be used in every case internationally. If possible, one should use the traditional name of the people in their own language, with phonetic spelling if needed. For example, the People of the River, Catawba peoples, are those on whose land the rights-of-way symposium has been held.

Before our current cataclysmic disasters can be addressed, we must step back in time to witness the beauty and balance that was once our world—pre-colonization, pre-1492. In the region now called California, thriving communities were already in abundance and Indigenous people worked with nature to make that happen, until the government made it illegal to do so in the early 1900s. The worldview that humankind, or the human animal, is superior to the animal kingdom is a fallacy; we are all part of the greater circle of life. This is evident in the changing of the seasons and the cyclical patterns of nature that we understand in the nitrogen, water, and carbon cycles. This intuitive and essential knowledge has been lost through the Western view of our world. One can see how society has paid a price—sometimes a terrible one, as with the loss of humans and other forms of life in the recent wildfires in California. Tribal elders speak of times when their people, the Toi-a-bin-a-tu-wum (Children of the Mountain) Haslett Basin Holkama Mono, lived in balance with the world around them, spiritually and ecologically, seeing the tribe as part of the greater circle of life, and not at the top of the pyramid. They harvested acorns to process, fished in the rivers, and hunted the lands around us. They also traded with other tribes near and far to obtain items needed for ceremonies, sustenance, or art. Tribal elder Ron Alec spoke to a large group at recent cultural monitor training held on his traditional lands. The Holkama Mono–Bear Clan is the last of these clans in the basin. Alec speaks about the loss of life from disease, famine, and war. All other [groups/tribes] have either been killed or decimated to the point that they no longer have cultural contact with their ancestors and traditional ways and do not know who they are (Alec 2022). This lost knowledge has been revealed and amplified by recent history that exposes weaknesses in our wildfire management policies. The knowledge of 109 federally recognized tribes and approximately 60 non-federally recognized tribes in California alone has been lost (Bureau of Indian Affairs 2022). The way the Indigenous communities integrated fire on the land seems to be the most important at this time of the year, such as in the late summer months, for better plant cultivation. But California fire season, as is much of the Pacific Northwest and Southwest, is now year-round.

TRADITIONAL ECOLOGICAL KNOWLEDGE

In 1850, the federal government passed the Act for the Government and Protection of Indians, which provided for the bondage of Indians and outlawed Native Americans from intentionally putting fire on the land to protect the land and create a more useful landscape for facilitating hunting and gathering purposes. This intentional use of fire was seen as a need, not a nuisance. Fire helps create and maintain an open forest structure that allows grasses to increase, which draws in herbivores, such as mule deer or Rocky Mountain elk. These herbivores create the conditions for oak seedlings to sprout, ensuring the sustainability of California's oak populations *(https://oaks.cnr.berkeley.edu/california-oaks-and-deer/ 1992).* This use of fire also keeps invasive species at bay by destroying non-native plants or natural debris that may inadvertently house invasive species. This fire enriches the soil with nitrogen for new growth. Mistrust of traditional ways has roots in cultural conflict with colonial powers (Peck 2005). This mistake has continued for centuries into the new millennium. Immeasurable knowledge has been lost. Cures for cancer or other modern diseases, for example, may have been destroyed in the burning of the Maya Codex in July of 1562 by Bishop Diego de Landa.

Cultural Burning

The Indigenous practice of cultural burning is the intentional lighting of smaller, controlled fires to offer a desired cultural service, such as encouraging the health of flora and animals that produce food, clothing, shelter material, or ceremonial artifacts. Frank Kanawha Lake, a wildland firefighter of Karuk ancestry and research ecologist with the USDA Forest Service, claims that this "cultural burning" reflects the concept of fire as medicine. When you prescribe it, you're trying to use an effective dosage that keeps all ecosystem functions operating at high levels of production and supporting the ecology in and, critically, for your culture (Roos 2021).

The honorable Ron Goode of the North Fork Mono people, an elder widely respected for his lifetime of fire knowledge and a land steward, explained, "We're burning to restore the land, restore the resources, restore water." Fire is a spirit. It is alive and it must be communicated with. Goode said, "If you are afraid of fire, you won't understand fire." This is an example of traditional ecological knowledge (TEK). Indigenous communities have thus learned to use fire to their advantage throughout the millennia (Goode 2016). For decades, Goode has stressed integration of human relationships with the land and with fire, particularly with the Indigenous relationship with the federal government. These relationships are often ignored to the detriment of society, especially those who live in the wildland-urban interface (WUI) in tier 2 and tier 3 fire risk areas, which are the highest level of fire risk and have the greatest potential for disaster. Goode works tirelessly as a cultural practitioner and stresses the importance of allowing tribes to continue their cultural burning practices to help restore ("the balance"—again, be specific) that has been lost. Immeasurable damage has been done in the past one hundred years by not allowing cultural burning or fire otherwise to be brought to the land, brought in a "good way" (Goode 2011).

This disconnection between Indigenous land management practices and federal or state policy began in the period of colonization with an outright refusal to accept traditional ecological knowledge. For the last 530 years, and under public policy in the last 130 years, this abyss of understanding has led, in part, to the current dire situation in the Western United States.

Fortunately, in some areas Indigenous tribes are continuing their traditions and using prescribed burns to manage their lands, including the Karuk of Northern California. As the largest Tribe in California, they explain that they use ancestral cultural prescribed burning to simultaneously protect and stimulate the land for cultural needs (Karuk 2015): "We want to manage the forest traditionally [and] in traditional management, fire is the primary tool" that is used in concert with the U.S. Forest Service to manage public and tribal trust lands and care for all resources simultaneously (Reed 2016). In 2022, the Karuk Tribe was trying to recover from the devastating Slater Fire of 2019, and also battled the McKinney and Six Rivers Fires in Northern California in June 2022.

Incident Command System

ICS is made up of the following six courses: IS 100, IS 200, IS 300, IS 400, IS 700, and IS 800, which can be taught by the Federal Emergency Management Agency, Texas A&M Extension (TEEX), the National Fire Academy, the Emergency Management Institute, or Homeland Security. These courses teach command, control, and coordination of response and provide modes of coordination for the efforts of individual agencies as they work toward the common goal of stabilizing and mitigating an incident and protecting life, property, and the environment (FEMA 2022).

The Karuk and Hoopa Tribes have been using "good fire" actively, practicing cultural burning on their landscapes since 2013. Each tribe has a complement of fire engines and crews within their respective departments. The Yurok's resources include a fire department and an office of emergency services (OES) staffed accordingly:

- Chief of Fire and OES
- Division Chief of Fire
- Battalion Chief of Fire and Fuels
- Assistant Chief of OES
- Four Fire Captains
- Administrative Officer
- Administrative Assistant
- Office Technician
- Eighteen Firefighters including WUI crew members Response and WUI Equipment:
    - o Three Type 3 Engines
    - o Two Type 4 Engines
    - o One Type 2 Water Tender
    - o Three Track Skid Steer Units (USDA 2019)

These systems are fully integrated into the Incident Command System (ICS) and National Incident Management System (NIMS), which enables interoperability in case of an emergency requiring mutual aid, as required by Homeland Security Presidential Directive 5. This directive "provides a consistent nationwide template to enable Federal, State, Tribal, and local governments, nongovernmental organizations (NGOs), and the private sector to work together to prevent, protect against, respond to, recover from, and mitigate the effects of incidents, regardless of cause, size, location, or complexity" (FEMA 2008). Currently, most utility companies require some ICS training to become a contractor for them due to the need to integrate into ICS on large-scale incidents caused by lightning strikes or utility equipment.

STUDIES

The data shown in Figures 1 and 2 does not include the most recent wildfires in California last year, including the largest fire that topped out at over 1 million acres (August Complex with 1,032,648 acres burned). CAL FIRE has released a list of the top 20 fires in California history, with the top eight occurring since December 2017. Twelve of the overall 20 occurred in the same time frame, resulting in 144 deaths out of a total of 203, or 71% of these deaths, in the last five years alone, as seen in the corresponding charts (Figures 1 and 2) (*www.fire.ca.gov/our-impact/statistics*).

In 2019, the Holkama Mono received a grant from the California Fire Foundation to conduct fuel reduction on their ancestral lands in Fresno County. A Tribal team from Big Sandy Rancheria performed the work, removing dead and dying fuels along the ingress and egress to their ceremonial areas. This allowed for the natural drying of poison oak, which was rampant in the area, and allowed for safer usage of the land for all who attend. Wood management was utilized to mitigate any possibility of fuel storage by using the logs and brush in ceremonial fire pits for sweat lodges and in the traditional Bear Dance. While this may not fall under the definition of cultural burning as it relates to large, controlled fires, it does touch on the fact that the tribe uses fire to mitigate any fuels that may accumulate and avoid a catastrophe (Youngblood 2019).

CONCLUSIONS

Tribes using cultural burning techniques understand both modes of approaching the land, the Western historic approach, and their own, and they can integrate into a Unified Command structure for the mutual benefit of society. Through their knowledge of traditional cultural practices and integration into ICS, cumulative knowledge expands and serves all our needs. This integration should be carried further into the private sector to coordinate with utility companies as well as vegetation management companies on a local level. When utilizing tribes in the planning and operations phases of vegetation management, a whole community buy-in occurs, and fewer stressors resulting from miscommunication or even lack of communication are evident. However, this communication must be at the ICS level and within the Unified Command structure, not at the former stakeholder level. In elevating status of Indigenous systems, long delays can be mitigated

Top 20 Largest California Wildfires

FIRE NAME (CAUSE)	DATE	COUNTY	ACRES	STRUCTURES	DEATHS
1 **AUGUST COMPLEX** *(Lightning)*	August 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, & Colusa	**1,032,648**	935	1
2 **DIXIE** *(Powerlines)*	July 2021	Butte, Plumas, Lassen, Shasta & Tehama	**963,309**	1,329	1
3 **MENDOCINO COMPLEX** *(Human Related)*	July 2018	Colusa, Lake, Mendocino & Glenn	**459,123**	280	1
4 **SCU LIGHTNING COMPLEX** *(Lightning)*	August 2020	Stanislaus, Santa Clara, Alameda, Contra Costa, & San Joaquin	**396,624**	222	0
5 **CREEK** *(Undetermined)*	September 2020	Fresno & Madera	**379,895**	853	0
6 **LNU LIGHTNING COMPLEX** *(Lightning/Arson)*	August 2020	Napa, Solano, Sonoma, Yolo, Lake, & Colusa	**363,220**	1,491	6
7 **NORTH COMPLEX** *(Lightning)*	August 2020	Butte, Plumas & Yuba	**318,935**	2,352	15
8 **THOMAS** *(Powerlines)*	December 2017	Ventura & Santa Barbara	**281,893**	1,063	2
9 **CEDAR** *(Human Related)*	October 2003	San Diego	**273,246**	2,820	15
10 **RUSH** *(Lightning)*	August 2012	Lassen	**271,911 CA / 43,666 NV**	0	0
11 **RIM** *(Human Related)*	August 2013	Tuolumne	**257,314**	112	0
12 **ZACA** *(Human Related)*	July 2007	Santa Barbara	**240,207**	1	0
13 **CARR** *(Human Related)*	July 2018	Shasta County & Trinity	**229,651**	1,614	8
14 **MONUMENT** *(Lightning)*	July 2021	Trinity	**223,124**	50	0
15 **CALDOR** *(Human Related)*	August 2021	Alpine, Amador, & El Dorado	**221,835**	1,003	1
16 **MATILIJA** *(Undetermined)*	September 1932	Ventura	**220,000**	0	0
17 **RIVER COMPLEX** *(Lightning)*	July 2021	Siskiyou & Trinity	**199,343**	122	0
18 **WITCH** *(Powerlines)*	October 2007	San Diego	**197,990**	1,650	2
19 **KLAMATH THEATER COMPLEX** *(Lightning)*	June 2008	Siskiyou	**192,038**	0	2
20 **MARBLE CONE** *(Lightning)*	July 1977	Monterey	**177,866**	0	0

There is no doubt that there were fires with significant acreage burned in years prior to 1932, but those records are less reliable, and this list is meant to give an overview of the large fires in more recent times.
This list does not include fire jurisdiction. These are the Top 20 regardless of whether they were state, federal, or local responsibility.
*Numbers not final.

1/13/2022

Figure 1. Top 20 Largest California Wildfires

The National Interagency Coordination Center at NIFC compiles annual wildland fire statistics for federal and state agencies. This information is provided through Situation Reports, which have been in use for several decades. Prior to 1983, the federal wildland fire agencies did not track official wildfire data using current reporting processes. As a result, there is no official data prior to 1983 posted on this site.

Source: National Interagency Coordination Center

Year	Fires	Acres
2021	58,985	7,125,643
2020	58,950	10,122,336
2019	50,477	4,664,364
2018	58,083	8,767,492
2017	71,499	10,026,086
2016	67,743	5,509,995
2015	68,151	10,125,149
2014	63,312	3,595,613
2013	47,579	4,319,546
2012	67,774	9,326,238
2011	74,126	8,711,367
2010	71,971	3,422,724
2009	78,792	5,921,786
2008	78,979	5,292,468
2007	85,705	9,328,045
2006	96,385	9,873,745
2005	66,753	8,689,389
2004	65,461	*8,097,880
2003	63,629	3,960,842

Year	Fires	Acres
2002	73,457	7,184,712
2001	84,079	3,570,911
2000	92,250	7,393,493
1999	92,487	5,626,093
1998	81,043	1,329,704
1997	66,196	2,856,959
1996	96,363	6,065,998
1995	82,234	1,840,546
1994	79,107	4,073,579
1993	58,810	1,797,574
1992	87,394	2,069,929
1991	75,754	2,953,578
1990	66,481	4,621,621
1989	48,949	1,827,310
1988	72,750	5,009,290
1987	71,300	2,447,296
1986	85,907	2,719,162
1985	82,591	2,896,147
1984	20,493	1,148,409
1983	18,229	1,323,666

Figure 2. Fires and acres burned, broken down by descending year

upfront instead of after the fact with cooperative agreements and MOUs. This is evident within California where no ratified treaties exist, and Public Law 83-280 has blurred lines that determine land ownership, stewardship, and civil and criminal jurisdictions.

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MK Youngblood has decades of public service/first responder experience with core proficiency in Indian Law, Indian Culture, and disaster cleanup. He is also an instructor certified by the Department of Energy (NNSA CTOS), Emergency Management Institute (EMI), and the Center for Domestic Preparedness (CDP). Currently, he is the Safety Manager for ACRT Pacific, LLC, Chief Officer of Emergency Management for the California Tribal Emergency Response & Relief Agency (CAL TERRA), Tribal Secretary for Haslett Basin Holkama Mono in California, and Board Chair for the California Tribal Unilateral Apprenticeship Committee. Most recently, Youngblood contributes to the USDA Wildland Fire Mitigation and Management Commission - Tribal Workgroup, the Homeland Security Advisory Committee - Tribal Annex Workgroup, and the Coalition of California State Tribes. In addition, he has developed approved apprenticeships in environmental science for use in the state of California and submitted them to the U.S. Department of Labor for federal approval.

13th International Symposium

Environmental Concerns in Rights-of-Way Management

PART V

Planning

Managing Environmental Health and Safety Makes $ense

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Keywords: Analytical Hierarchy Process, Benefits, Communication, Consistency Scores, Culture, Elements, Environmental Health and Safety, Evaluation, Human Use/Impact, Perception Survey, Resources, Return on Investment, Safety Management System, System.

Organizations have little capacity for quantifying and undertaking change management required for maturing (improving) their own environmental health and safety (EH&S) culture. The reality is that funding for any program, including funding for EH&S programs, continues to be hard to find. The authors of this case study used the article produced by Jaervis and Collins, "Measuring Safety's Return On Investment," as a guide to achieve two objectives: (1) to develop a reusable tool by which EH&S professionals and operation managers can learn to use system thinking to mature their EH&S culture, and (2) to utilize a safety management system's (SMS) functional elements to help prioritize elemental spending so as to produce the highest possible return on investment (ROI) and mature, or continuously improve, an organization's culture of EH&S. Because "culture always trumps strategy" (Merchant 2015), there is great value in pursuing cultural change when it comes to system thinking. This case study helps safety professionals and operations managers alike visualize their EH&S culture by seeing improved quantitative and qualitative results directly tied to their companies' safe work EH&S practices.

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INTRODUCTION

The case study subject is a utility vegetation management (UVM) organization with approximately 1,500 employees, specializing in consulting services. This same team put themselves through an environmental health and safety (EH&S) cultural gap analysis that produced limited and inconsistent results from an EH&S performance perspective in 2020. That process took several months to complete and evaluate, including the collected opinions of more than 50% of their employees. The subject of this paper is a study of the same organization using a new method that included a perception survey and a modified Analytical Hierarchy Process (AHP), as a cultural progression check and aid in selecting and allocating resources for the benefit of EH&S cultural improvements. The authors of this study modernized the original AHP data collection process (developed by Jaervis and Collins), giving the analysts the ability to survey many participants in multiple locations without time delay. Additionally, this case study added a consistency score for each survey participant to help ensure that each participant was engaged and understood the survey's purpose. The survey's purpose is to generate a quantified return on investment (ROI) benefit for each element within the organization's EH&S system. The outcomes from the survey, through the AHP process, produced a quantitative result, leveraged by desirability and based on qualitative opinions.

"Culture is a complex phenomenon to study. With perception surveys (questionnaires), it is possible to study safety culture from one viewpoint" (Nordlöf et al. 2015). "One way to achieve this is to improve the understanding of safety culture and risk-taking in this context" (Nordlöf et al. 2015). Quite often, organizations have little capacity for trying to quantify their understanding of their culture. It is certainly much easier to say an EH&S culture is "good" when metrics (OSHA metrics such as TRIR [Total Recordable Incident Rate]), DART (Days Away Restricted or Transferred), or EMR (Experience Modification Rating used by workers' compensation insurers to determine insurance premiums) demonstrate only a few events, and "bad" when more events, or their lagging indicators, occur or are less than desirable. It has also been said that "the more compliant workers are with safety rules, the better the safety culture is thought to be" (Nordlöf et al. 2015).

Not unlike a human body or a car, a worker drives to work (they too are systems with many parts that are interdependent of one another) where the interaction of system elements is what defines safety, not our OSHA rates (Howe 2022). System knowledge is crucial to understanding how system elements are interdependent on one another. Without an understanding of interdependence, silos will emerge and a culture will not achieve its potential.

The complexity and interdependencies of culture are simplified and illustrated using the AHP. There are generally two ways the AHP is beneficial to helping EH&S professionals and operations managers better understand their culture: (1) system capacity and (2) incident prevention or frequency reduction.

The first AHP benefit is in helping to describe the capacity of the system. One of the intended benefits of this process is that managers develop a clear and well-defined understanding of what their EH&S management system (EHSMS) is made of. Managers that do not possess EH&S system knowledge will find it difficult, if not impossible, to manage an EH&S culture. Whereas a manager with an enhanced general understanding of EH&S system elements will develop a greater understanding of how to improve that system over time. The purpose of the exercise is to help managers look at those elements systematically, to visualize how they interact or are interdependent on one another within the system, and to maximize the return on EH&S investments.

Secondly, the AHP's influence on decision-making, monetarily and culturally, should result in fewer negative EHSMS incidents. Improving an EH&S system requires thinking about how the elements of that system interact with one another and, maybe more importantly, how those elements influence one another (Howe 2022). In the authors' opinion, every organization holds biases. This AHP process will help balance out those biases by bringing awareness to all the elements of the system and by demonstrating the value-added relationship between system thinking, element management, organizational needs, and monetary constraints that all systems/programs must be accountable for.

Thirdly, the AHP exercise will also help guide an organization's cultural improvement action planning process. These purposes and outcomes hold true for environmental, health, and safety elements in any broad EH&S program and system.

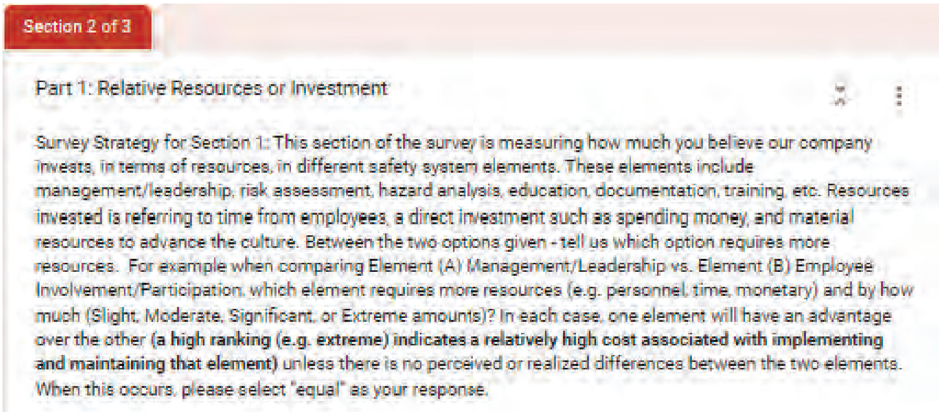
METHODS

The (modified) AHP is the method used to determine which EH&S elements the case study participants think provides the best benefit-to-cost ratio for their organization (Jervis and Collins 2001). "The purpose of the AHP is to assist people in organizing their thoughts and judgements to make more effective decisions" (Saaty and Vargas 2012). To accomplish this task, the AHP requires a preference survey to be completed by accountable thought leaders. Subjective but knowledgeable opinions are then converted into objective results, essentially ranking the elements within their EH&S system. "The AHP provides the objective mathematics to process the inescapably subjective and personal preferences of the individual or group in making decisions" (Saaty and Vargas 2012).

This 4-step process is repeatable and expandible based on the size of the organization; however, it is likely to not achieve the same result each time (Jervis and Collins 2001). "Fundamentally, the AHP works by developing priorities for alternatives and the criteria used to judge alternatives'' (Saaty and Vargas 2012). "First, priorities are derived for the criteria in terms of their importance to achieve their goal, then priorities are derived for the performance of the alternatives on each criterion. These priorities are derived based on pairwise assessments using judgements, or ratios of scale, if one exists" (Saaty and Vargas 2012). Finally, weighting and summation is used to obtain overall priorities for the alternatives as to how they contribute to the goal" (Saaty and Vargas 2012). The modified AHP version used by Jervis and Collins "normalizes the pairwise comparison values within each of the matrices and then averages the values in each row to get the corresponding weights and ratings" (Saaty and Vargas 2012).

As with every human being, there is a lot of diversity to be found within every organization's EH&S system, because the variables and maturity levels of each organization being evaluated can be naturally/organically different. The authors of this document followed the original efforts of Jervis and Collins to see if their results could be replicated and automated to provide immediate organizational feedback for the purposes of helping organizations make real-time decisions. Today's computational and survey tools were not accessible when Jervis and Collins' effort was originally published. The original process steps were adhered to and improved to achieve the following results in this new test case.

Figure 1. Representation of the EH&S system being analyzed as part of this case study


Section 2 of 3

Part 1: Relative Resources or Investment

Survey Strategy for Section 1: This section of the survey is measuring how much you believe our company invests, in terms of resources, in different safety system elements. These elements include management/leadership, risk assessment, hazard analysis, education, documentation, training, etc. Resources invested is referring to time from employees, a direct investment such as spending money, and material resources to advance the culture. Between the two options given - tell us which option requires more resources. For example when comparing Element (A) Management/Leadership vs. Element (B) Employee Involvement/Participation, which element requires more resources (e.g. personnel, time, monetary) and by how much (Slight, Moderate, Significant, or Extreme amounts)? In each case, one element will have an advantage over the other **(a high ranking (e.g. extreme) indicates a relatively high cost associated with implementing and maintaining that element)** unless there is no perceived or realized differences between the two elements. When this occurs, please select "equal" as your response.

Figure 2. Perception survey resource comparison instructions

RESULTS

Step 1: SMS Introduction and Training

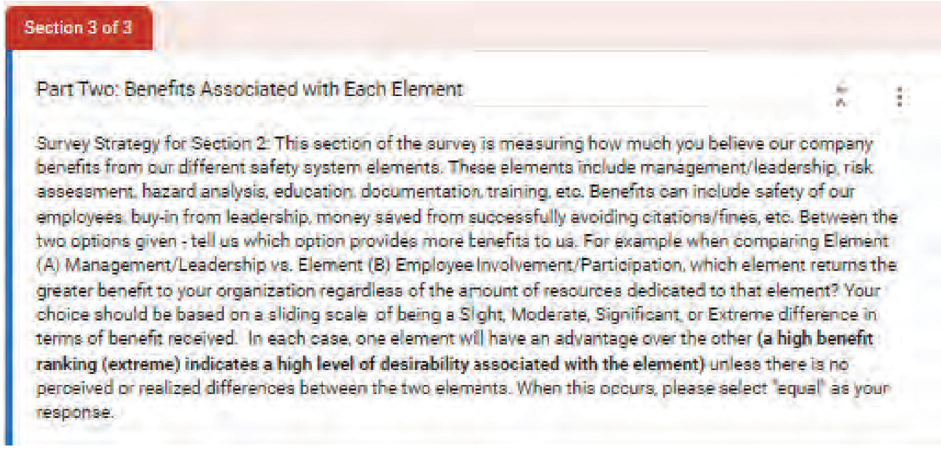
Jervis and Collins made it clear in their original work that prior to developing a perception survey, a clear understanding of the organization's elemental structure and how they are defined would be needed in order to obtain consistency between safety and accountable operations managers, whether it existed on paper or not (Jervis and Collins 2001). Therefore, before the AHP can begin, the organization's environmental safety management system elements must be clearly defined, reviewed, and verified by the survey administrator with those who are managing and are accountable for the EH&S system. The target audience for this case study's perception survey and following analysis was the operations side of a UVM operation business described above. A model of their perceived EH&S system is represented in Figure 1.

Step 2: Administer Perception Survey

The objective of any perception survey, as part of the AHP, is to take some of the subjectivity out of qualitative opinions and solve problems quantitatively to lead to a data-driven discussion on the value of investing in program elements (Jervis and Collins 2001). Simply stated, the primary distinction of a perception survey is that it is intended to discover opinions rather than factual data (Worth 2022). Additionally, the purpose of the exercise is to help an organization look at those elements systematically so they can visualize how they interact or are interdependent of one another within that system in order to maximize their return on their safety investment over time. The SMS perception survey, and its corresponding analytics, is designed to have the impact on safety “team” collaboration, which should in turn drive a robust discussion on how best to achieve cost/benefit results.

Survey responses were presented to the case study participants on a sliding scale, and each participant was only allowed one answer per each element comparison. No two system elements were compared more than once in each part of the survey. Additionally, the case study respondents assigned a weight of measure and importance on how their organization believes it should invest in each different EH&S system element. The weight was determined by using “descriptive terms rather than numbers. These terms—equal, slight, moderate, significant, and extreme—are the same terms used in AHP literature (Jervis and Collins 2001).

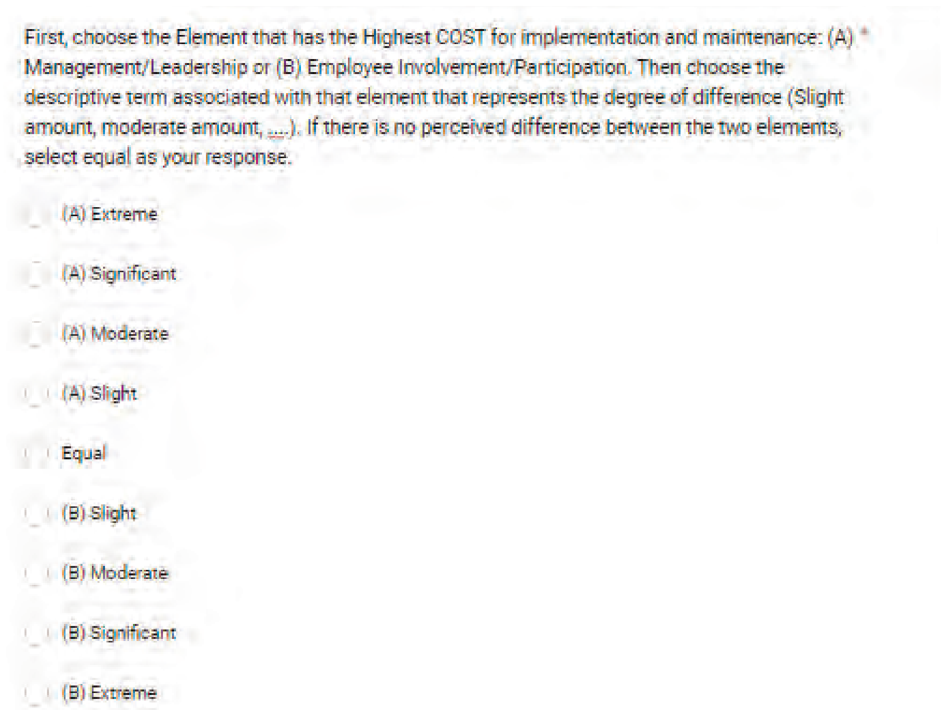
The survey was divided up into two sections: one that focuses on resource or cost comparisons and the other that focuses on benefit comparisons. As element rankings are developed by each participant, the participants must maintain a focus that a high ranking of cost does not equate to a high ranking of benefits. For example, “In the cost hierarchy, a high ranking indicates a relatively high cost associated with implementing and maintaining that element. Conversely, a high benefit ranking indicates a high level of desirability associated with the element” (Jervis and Collins 2001).


Section 3 of 3

Part Two: Benefits Associated with Each Element

Survey Strategy for Section 2: This section of the survey is measuring how much you believe our company benefits from our different safety system elements. These elements include management/leadership, risk assessment, hazard analysis, education, documentation, training, etc. Benefits can include safety of our employees, buy-in from leadership, money saved from successfully avoiding citations/fines, etc. Between the two options given - tell us which option provides more benefits to us. For example when comparing Element (A) Management/Leadership vs. Element (B) Employee Involvement/Participation, which element returns the greater benefit to your organization regardless of the amount of resources dedicated to that element? Your choice should be based on a sliding scale of being a Slight, Moderate, Significant, or Extreme difference in terms of benefit received. In each case, one element will have an advantage over the other **(a high benefit ranking (extreme) indicates a high level of desirability associated with the element)** unless there is no perceived or realized differences between the two elements. When this occurs, please select "equal" as your response.

Figure 3. Perception survey benefit comparison instructions


First, choose the Element that has the Highest COST for implementation and maintenance: (A) Management/Leadership or (B) Employee Involvement/Participation. Then choose the descriptive term associated with that element that represents the degree of difference (Slight amount, moderate amount, ...). If there is no perceived difference between the two elements, select equal as your response. *

(A) Extreme
(A) Significant
(A) Moderate
(A) Slight
Equal
(B) Slight
(B) Moderate
(B) Significant
(B) Extreme

Figure 4. AHP perception survey sliding scale that determines the weighted significance of one element over another

The first section of element comparison questions within the AHP perception survey focuses on resources (cost) invested into each element. Examples of “cost" could be a reference to time invested, money, and/or materials (Figure 2). Whereas, during the second part of the survey, the focus changes from resources utilized to achieve results to the desirability of each element in the system, without regard to the amount of resources utilized. In both sections, the respondent is given two options of the two elements being compared. A single response is required: which option requires more resources/benefits? For example, when comparing Element (A) Management/Leadership vs. Element (B) Employee Involvement/Participation, which element requires more resources (e.g., personnel, time, monetary) and by how much (slight, moderate, significant, extreme amounts)? In each case, one element will have an advantage over the other (from an investment/benefit perspective), unless there is no perceived or realized difference between the two elements. When this occurs, the respondents were asked to select "equal" as their response, as seen in Figure 4. Once the participants completed the survey, the descriptive terms referenced above were converted to numerically or weighted values (otherwise known as Likert Scale). An example of the sliding scale of descriptive terms can also be found in Figure 4.

Every organization holds subjective-based biases around system elements (Steinhauser 2020). It is human nature to be affected by those biases. For example, when an event occurs, it is only natural for a manager to insist that the root cause for the event was "inadequate training." The individual didn't follow the process because they were not trained correctly; that train of thought is a bias. This exercise will help balance out those biases by bringing awareness to all the elements of the system, their interrelationships, and by demonstrating the value of those elements based on organizational needs and monetary constraints that all systems/programs must be accountable for.

Step 3: Survey Analytics

The AHP was chosen because it offers the following insight over other benefit/cost methods: "(1) ability to quantify intangible, noneconomic factors into the decision-making process, and (2) teams can make informed tradeoffs among multiple selection criteria, including multiple performance objectives and output activities" (Jervis and Collins 2001).

After survey completion, the answers were fed into a matrix, based on the descriptive terms' predetermined weights described above (e.g., equal, slight, extreme) as numeric values. For the purposes of this case study, each descriptive term was assigned a numerical value. For example, "equal" was assigned the value of 1, "slight" the value of 3 or -3, "moderate" the value of 5 or -5, and so on. This action allows the survey facilitator to take qualitative data and convert it into quantitative data (Jervis and Collins 2001). "The AHP relies on a matrix format to recognize and manipulate the comparisons of elements" (Jervis and Collins 2001). "To help achieve consistency in the comparison matrix, the reciprocal value is used for reverse comparisons. For example, if the comparison of Element A to Element B yields a value of 5, the reciprocal value (i.e., .20 or 1/5) is automatically used for the comparison of Element B to A in the matrix" (Jervis and Collins 2001) (Table 1).

The analysis requires two separate matrices that are produced as a result of this survey: one for resources and the other for benefits. The scores are normalized in each column to a value of one (Table 2). Furthermore, each element generates a row sum. The priority vector (PV) can then be calculated simply by creating an average for each row on the matrix. Mathematically speaking, since each element is normalized, the sum of all elements' priority vector is also one. The purpose for the priority vector is simply to establish a weighted value of an element compared to another element.

The benefit/cost result is generated by combining both the resource and benefit matrix priority vectors as a ratio. As seen in the case study results in Tables 3 and 4, relative values are calculated for each element. For example, the risk assessment element is

Table 1. Resource Survey Responses Transferred to Matrix

Resources	Management Leadership	Employee Involvement/ Participation	Hazard Mitigation	Risk Assessment	Audits/Observations	Investigations /Causal Analysis	Analytics/Performance Analysis	Education and Training
Management Leadership	1	5	7	7	7	7	7	5
Employee Involvement/Participation	0.2	1	0.2	0.2	0.33	0.33	0.2	0.2
Hazard Mitigation	0.143	5	1	5	7	7	1	5
Risk Assessment	0.143	5	0.2	1	7	7	0.2	0.143
Audits/Observations	0.143	3	0.143	0.143	1	1	0.143	0.33
Investigations/Causal Analysis	0.143	3	0.143	0.143	1	1	0.2	0.2
Analytics/Performance Analysis	0.143	5	1	5	7	5	1	1
Education and Training	0.2	5	0.2	7	3	5	1	1
Column Total	2.115	32	9.886	25.486	33.33	33.33	10.743	12.873

Table 2. Resource Matrix Normalized and Priorities Calculated

Resources	Management Leadership	Employee Involvement/ Participation	Hazard Mitigation	Risk Assessment	Audits/Observations	Investigations /Causal Analysis	Analytics/Performance Analysis	Education and Training	Row Sum	Priority Vector	λmax
Management Leadership	0.473	0.156	0.708	0.275	0.210	0.210	0.652	0.388	3.072	0.384	0.812
Employee Involvement/Participation	0.095	0.031	0.020	0.008	0.010	0.010	0.019	0.016	0.208	0.026	0.831
Hazard Mitigation	0.068	0.156	0.101	0.196	0.210	0.210	0.093	0.388	1.423	0.178	1.758
Risk Assessment	0.068	0.156	0.020	0.039	0.210	0.210	0.019	0.011	0.733	0.092	2.335
Audits/Observations	0.068	0.094	0.014	0.006	0.030	0.030	0.013	0.026	0.280	0.035	1.168
Investigations/Causal Analysis	0.068	0.094	0.014	0.006	0.030	0.030	0.019	0.016	0.276	0.034	1.148
Analytics/Performance Analysis	0.068	0.156	0.101	0.196	0.210	0.150	0.093	0.078	1.052	0.132	1.413
Education and Training	0.095	0.156	0.020	0.275	0.090	0.150	0.093	0.078	0.956	0.120	1.539
Column Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		1.000	11.005

Table 3. Case Study Survey Group - Resources

Resource Rankings			
Element	**Resources Score**	**Relative Value**	**Rank**
Education and Training	0.22	2.73	1
Management Leadership	0.19	2.38	2
Employee Involvement/Participation	0.11	1.39	3
Hazard Mitigation	0.10	1.26	4
Investigations/Causal Analysis	0.10	1.21	5
Analytics/Performance Analysis	0.09	1.14	6
Audits/Observations	0.09	1.11	7
Risk Assessment	0.08	1.00	8

Table 4. Case Study Survey Group - Benefits

Benefits Rankings			
Element	**Benefits Score**	**Relative Value**	**Rank**
Employee Involvement/Participation	0.21	3.43	1
Management Leadership	0.20	3.33	2
Education and Training	0.15	2.48	3
Hazard Mitigation	0.12	2.04	4
Risk Assessment	0.09	1.47	5
Investigations/Causal Analysis	0.09	1.43	6
Analytics/Performance Analysis	0.08	1.31	7
Audits/Observations	0.06	1.00	8

considered to have the lowest relative value from a resource perspective in the case study analysis being performed. Therefore, it is assigned the value of one. For the purposes of this exercise, relative value is a financial term that is commonly used to compare one asset to another. The relative value of comparable assets, or elements in this case study, is a reasonable predictor for future returns and performance, relative to another asset (Tamplin 2022). Every other element can now be compared to the lowest relative value and calculate the remaining values for all the other elements. For example, this AHP perception survey produced a result that the case study participants believe that education and training requires 2.73 times more resources than risk assessment. Once the calculations are complete for all eight elements, a ranking can be achieved for all elements from a cost of implementing and maintaining perspective (Resource Matrix), as well as desirability level (Benefit Matrix) for each element. Strictly from a benefits perspective, the employee involvement/participation is perceived by the participants to be 3.43 times more desirable than audits and observations (Table 4).

With that said, the resulting benefit-to-cost ratio generates a combined result that may seem surprising to the participants at first glance. Intuitively speaking, one might think that the two highest group rankings would produce the highest benefit-to-cost ratio results. To develop a benefit-to-cost ratio, the benefit PV is divided by the resource PV with the same element. The elements rank from highest to lowest, as seen in Table 5.

While employee involvement/participation did maintain its number one ranking from a beneficial perspective, management/leadership dropped significantly to fourth. That is primarily due to the fact that participants judged the cost of maintaining and implementing leadership almost as high as the cost of education and training, within this case study's organization. Employee involvement/participation was ranked the highest by participants in this case study in terms of benefit to cost. That result illustrates to the case study participants that the single-greatest opportunity for them to mature their EH&S culture (highest benefits and lowest cost) is within that element. Similar statements—however, to lesser degrees—could also be made about the remaining EH&S elements.

Table 5. Case Study Survey Group Benefit/Cost Ratio (Preference Ratio)

Benefit to Cost Ranking of Elements						
Element	**Resources Score**	**Rank**	**Benefits Score**	**Rank**	**Benefit/Cost Ratio**	**Rank**
Employee Involvement/Participation	0.11	3	0.21	1	2.48	1
Hazard Mitigation	0.10	4	0.12	4	1.62	2
Risk Assessment	0.08	8	0.09	5	1.47	3
Management Leadership	0.19	2	0.20	2	1.40	4
Investigations/Causal Analysis	0.10	5	0.09	6	1.19	5
Analytics/Performance Analysis	0.09	6	0.08	7	1.15	6
Education and Training	0.22	1	0.15	3	0.91	7
Audits/Observations	0.09	7	0.06	8	0.90	8

Step 4: Consistency Analytics

An additional step was added to the Jervis and Collins model that this case study followed to help the authors better understand and validate the results. A consistency score was established for each of the participants (Table 6). The intent for the score was to give the authors confidence that their participants in the case study understood the content well enough to complete the survey. That is important because if the score results were not acceptable, the perception survey facilitator could potentially go back and improve how the elements are defined or just eliminate scores that may be clearly guesses. The scores were calculated in the following way (Wedley 1993):

Table 6. Consistency Score for Survey Group

Name	Consistency Average
Leader 1	0.217
Leader 2	0.409
Leader 3	0.514
Leader 4	0.163
Leader 5	0.251
Leader 6	0.125
Leader 7	0.166
GROUP MEAN	0.264
GROUP MEDIAN	0.226

- Scores close to 0 = The respondent has a good grasp of the survey and its content
- Scores close to 1 = The respondent does not have a good grasp of the survey/content or may be guessing
- A score of 0.10 or less is traditionally accepted as satisfactory
- With a matrix of eight dimensions, a Consistency Ratio (CR) of 0.141 or less is satisfactory and a CR of 0.282 may be considered tolerable

Consistency Ratios are able to be derived due to the transitive property of the survey. Since each element is compared to all other elements, this means that if we have elements A, B, and C and a respondent ranks A > B and B = C, we would expect A to be greater than C.

Calculating the consistency ratio is fairly straightforward. Starting with the Consistency Index (CI), the first step is to find the Principal Eigenvalue (λmax) which is done by multiplying the priority vector from Table 2 by the appropriate column sum in Table 1. Once all rows/elements are calculated, the λmax value is the sum of those elements. Next, plug in the number of matrix elements for n: 8.

$$CI = \frac{\lambda max - n}{n - 1}$$

where:

$CI = Consistency\ Index$

$\lambda max = \sum_{i=1}^{n}$ (Priotiy Vector$_i$ * Matrix Element Column Sum$_i$)

$n = Number\ of\ matrix\ elements$

What we end up with is:

$$CI = \frac{11.005 - 8}{8 - 1}$$
$$CI = 0.43$$

The next step is to divide our CI by the Random Index (RI). The RI is a randomly generated matrix following the 1–9 and reciprocal scale, intended to find the average CI for any number of elements in a matrix where the CR is .10 or less. When there are eight elements, the RI generally falls around 1.4. We ran 1,000 simulations of matrices with eight dimensions and arrived at an RI value of 1.405.

$$CR = \frac{CI}{RI}$$

$$CR = \frac{0.43}{1.405}$$

$$CR = 0.305$$

The value of 0.305 is the CR of one respondent from the resources section of the survey. This would indicate fairly inconsistent responses. Table 6 combines the CR for each respondent for the two sections of the survey and reports the average.

The group median score for CR of 0.22 and mean of 0.26 is tolerable. There were two higher scores, but five out of seven participants averaged a score below 0.25 between the two sections. Overall, the respondents scored lower (better) on the benefits section than the resources section—by an average of 0.06 points in CR, which is a relatively large amount. This could indicate a preference bias on the part of the case study participants to favor the beneficial aspects of the element comparisons, even when they are being asked to focus on the resource/cost side of the survey.

DISCUSSION

Employee involvement/participation was the predetermined favorite priority by many of the case study participants prior to going through this review exercise with them. From an EH&S cultural perspective, this element, as a focal opportunity for improvement, presents many challenges to an industry that consistently faces employee retention issues. When the case study participants were presented with their ROI results, they found the feedback interesting. However, they were confused on what their next steps should naturally be. There is no "easy button" to push to give any organization the answers they are looking for. The best response to any type of gap analysis on next steps is "It depends." No two organizations are created equal. Therefore, the next actionable step for any organization's cultural maturity plan will depend on the variables it confronts daily. Some examples on how to improve worker participation could, but are certainly not limited to (American Society of Safety Professionals 2019), encourage participation in:

- Incident and near-miss investigations
- Health and safety committees
- Development and implementation of training programs and procedures, and in the safety training of other workers
- Selection of personal protective equipment (PPE)
- Reporting unsafe conditions, policies, procedures, tools or equipment, and practices
- Development and execution of stop work authority programs
- Safety committee operations, duties, and responsibilities
- Training in incident investigation procedures

From a graphical perspective, the results of the case study seem reasonable. The AHP should intuitively produce an elemental preference result for an organizational case study with a low-to-moderate cost paired with a highly desirable relative value (Figure 5 [gold bar]). Almost as interesting as the highest-ranking element comparison found in this case study is the number two, ranking relative value comparison. Hazard mitigation really was not on the participants' radar as a possible improvement opportunity for the organization. However, the case study team was challenged during the discussion portion of the study to really give that element some additional thought. Hazard mitigation can mean a lot of different things to many different organizations. The following questions were asked to gain further clarity here from the participants that may end up leading to a cultural shift to help mature the organization further (Jervis and Collins 2001):

- Does the organization have access to certified safety and health professionals?
- Does the organization have training on the process of hazard identification, vulnerability analysis, developing a strategy for hazard mitigation, and executing hazard mitigation activities on projects?
- Does the organization have a written environmental, safety, and health program that is both size and industry appropriate?

- Does the environmental, safety, and health policy clearly assign environmental, safety, and health responsibilities?

The perception survey results showed some concern with the level of resource utilization. At the same time, the case study participants also recognized the benefits associated from investing in leadership. An accurate accounting of resources utilized would be an additional valuable piece of information for this team to reevaluate their perception responses regarding resource utilization before making adjustments. A real discussion, including additional data, with the participants around this element would also help bring clarity around resources and benefits associated with elemental utilization in this case. At a minimum, it should be relatively easy moving forward to track investments within the management/leadership element. By managing cost systematically, the resource side of the equation will become a lot less subjective and much more objective, to help measure implementation and maintenance of the element's cost to the organization moving forward. Regardless of where this element falls from a rank perspective, it is widely accepted as being crucial to managing and maturing any organization's EH&S culture.

Last of all, the case study team felt very strongly that the exercise should be repeated with mid-level managers (regionally) so the results of their perception survey could be compared to the results of their leaders—the request of an additional gap analysis between mid-level leaders and their managers, in order to consider possible disconnects between management levels within the organization, regionally, or as a whole. Information gained from that exercise would, in theory, produce a better action plan based on the alignment, or lack thereof, between the two management teams. The biggest hurdle to environmental health and safety within any organization could easily be associated with ego or "the belief that we already know the answers to the questions that organizations are forced to ask" (Conklin 2012). When this occurs, there is no perceived need to change from a leadership perspective. "This is why organizations keep doing the same corrections over and over without different outcomes" (Conklin 2012). "Change does not just happen. Change is hard. Change must be managed" (Conklin 2012).

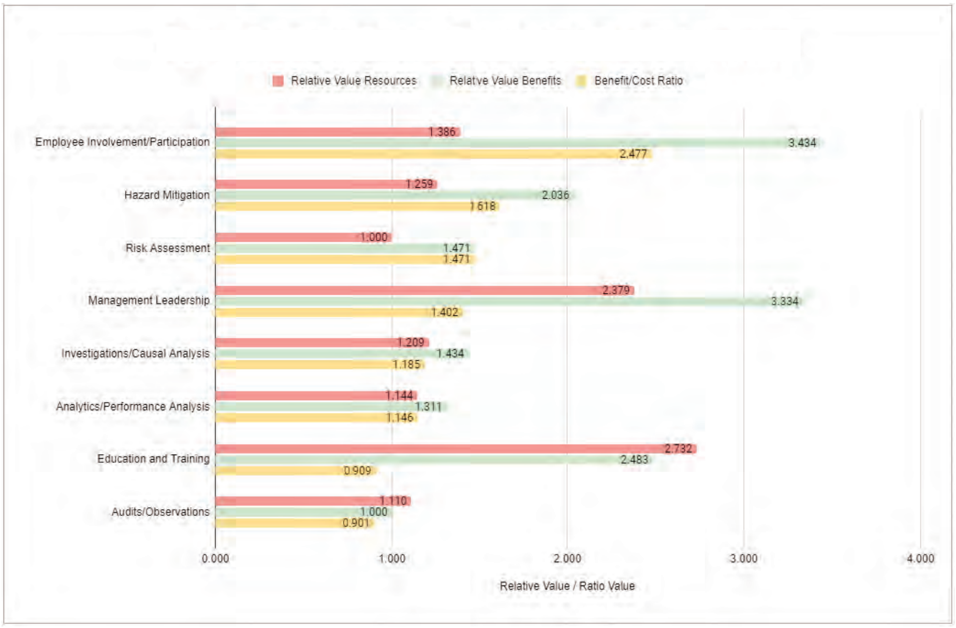


Figure 5. Benefit/Cost Ratio and Relative Value of Benefits & Resources

CONCLUSIONS

This AHP tool and case study participants have produced value—not based on subjective biases or opinions, but based on a collaborative team's perspective that mitigates individual bias. The original authors performed their analysis on one participant; whereas the authors of this study proved successfully that the analysis could manage many participants, with confidence. Enhancements to the original AHP included developing an automated analytical process that allowed for almost real-time analysis from the perception survey and a consistency score that would give the analyst the ability to have confidence in their survey results.

The case study team's first objective was to develop a reusable tool that would help EH&S professionals and operation managers learn to use management systems and system thinking to mature their EH&S culture. To make a difference within that organization, it seems logical/natural for those accountable for the system to develop an understanding of their organization's culture. This occurs within the tool we developed, by allowing those accountable for EHSMS results to compare system elements individually (one element with another) while collectively producing an ROI result for each operational element, that will help prioritize spending and allow for a measurable advancement of the maturity process around EH&S culture development into the future.

The second case study team objective was to utilize EHSMS functional elements to help predict the highest possible ROI. The ROI result accounts for resource and benefit utilization, producing a deliverable cost/benefit analysis that will help prioritize spending and advance the cultural maturity process. Without a comprehension of system thinking related to defined elements, results can only be attributed to luck, or lack thereof. System thinking allows for organizations to focus on opportunities for improvement in a deliberate way, within their capacity to effectively mature their culture in the most efficient manner possible. Whatever an organization's results look like today, they will be almost perfectly aligned with their culture.

As a result of this effort, the case study team will be able to approach their environmental health and safety *culture* from a different perspective because of their new knowledge and understanding of:

- "System" thinking (e.g., improving performance within elements by understanding what influences change and how some elements interact with one another)
- Benefit-cost relationship of SMS elemental spending (e.g., encourages decision makers to plan cultural maturity actions around high-ROI results)
- Recognizing and acting on potential system gaps, as opposed to causal analysis (e.g., people are not the problem, they are the solution; failures occur when systems fail; and recognizing how corporate values are rooted within their elements)
- Recognizing elemental exposure and building into a system with the capacity to fail safely (e.g., "Continuous Improvement" focus)

Conceptually, system management is critical to the success of cultural improvement. "A very effective way to create change in your organization is through conversation" (Conklin 2012). System thinking, and the AHP, can play a powerful role in maturing any program and stakeholder culture with interdependent elements, through the analytics and the discussion around those quantitative results.

In conclusion, there are many variables that make each case study unique. The AHP is an effective way to evaluate these unique variables called elements and help manage the costs and benefits associated within an EH&S program. This refreshed systematic approach of allocating scarce resources can only improve with time and conversation. And if that conversation created the opportunity for the participants in this case study to leave their review with more questions about how to improve, define, and manage environmental health and safety programs within their organization (Conklin 2012), then this would signal that new thoughts have been generated as it relates to EH&S culture management and improvement opportunities that should be actionable.

ACKNOWLEDGEMENTS

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13th International Symposium

Environmental Concerns in Rights-of-Way Management

PART VI

Reclamation / Mitigation / Restoration

Georgia Transmission Corporation's Programmatic Agreement for Routine and Repetitive Impacts to Cultural Resources: How Program Alternatives Can Streamline Regulatory Review for Rights-of-Way Management and Benefit the Environment

Katheryn Ferrall Graff

Keywords: Energy, Mitigation.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

Georgia Transmission Corporation (GTC) is a not-for-profit company that was established in the 1990s to manage the transmission infrastructure of Georgia's electric membership cooperatives (EMCs). GTC's environmental staff quickly realized that the regulatory consultation process regarding routine and repetitive impacts to cultural resources for the construction of new transmission lines and substations was resulting in costly schedule delays on projects that included federal funding or permitting. Therefore, a programmatic agreement was implemented in 2001 between GTC, the Rural Utilities Service, the Georgia State Historic Preservation Officer (SHPO), and the Advisory Council on Historic Preservation that allowed GTC to address these kinds of repeated and minor impacts to cultural resources through ongoing, statewide mitigation. The main component of this mitigation is through funding research, the result of which has primarily been the establishment of the FindIt Program. This paper will discuss the implementation of GTC's programmatic agreement, one of only a handful of its kind in the nation, as well as the 20-year history of the FindIt program. Established in cooperation with the University of Georgia (UGA) College of Environment and Design, the Georgia SHPO, the Georgia Department of Transportation, and other local planning organizations, FindIt is a student-led program that not only allows GTC to fulfill its mitigation requirements, but provides students of historic preservation, landscape architecture, and architecture with real-world experience identifying, documenting, and evaluating historic structures. According to the 2022 Annual Report, to date, the FindIt program has conducted historic resource surveys in 64 counties in Georgia, documented approximately 21,900 resources, and provided 90 graduate assistantships and 169 paid internships for UGA students. The results of these field surveys are shared on a public database to assist others in the preservation and documentation of historic resources in Georgia.

LEARNING OBJECTIVES

- Discuss the regulatory compliance challenges that utilities face on federally funded or permitted projects which can result in repetitive, minor impacts to cultural resources through the construction and maintenance of transmission lines and substations.
- Describe the programmatic agreement that GTC utilizes to streamline the regulatory review process.
- Identify meaningful ways to mitigate adverse impacts to historic resources that benefit the preservation community as well as the utility companies.

Figure 1. Abandoned house located adjacent to a transmission line. Photo by author.

INTRODUCTION

Georgia Transmission Corporation (Georgia Transmission) is an electric transmission cooperative established under the laws of the State of Georgia in 1997. The not-for-profit cooperative, headquartered in Tucker, Georgia, is engaged in the business of building, maintaining, and owning electric power transmission facilities (transmission lines, substations, and switching stations) to serve 38 of the 41 Georgia electric membership corporations (EMCs).

The EMCs, also known as Member Systems, are local, consumer-owned electric distribution cooperatives that provide retail electric service on a not-for-profit basis. The membership of the distribution cooperatives consists of residential, commercial, and industrial consumers, generally within specific geographic areas. This membership represents approximately 4.4 million people in a service area covering 40,000 square miles, or nearly 73 percent of the land area of Georgia.

Georgia Transmission provides transmission capacity to the Member Systems through participation in Georgia's Integrated Transmission System (ITS), which consists of facilities owned by Georgia Transmission, the Georgia Power Company (GPC), the Municipal Electric Authority of Georgia (MEAG), and the City of Dalton Utilities. Georgia Transmission owns and maintains approximately 3,560 miles of transmission lines and 763 transmission and/or distribution substations of various voltages.

Georgia Transmission frequently seeks federally backed loans from the U.S. Department of Agriculture, Rural Development, Rural Utilities Service (RUS) for construction of new transmission lines and substations, as well as for modifications to existing facilities, resulting in a federal action. Federal action could involve financial assistance and/or approvals necessary for Georgia Transmission to construct the proposed projects.

Because most of Georgia Transmission's projects trigger a federal action, they also require compliance with the regulations set forth in the National Environmental Policy Act (NEPA) of 1969 and Section 106 of the Historic Preservation Act (NHPA) of 1966, as amended, among other laws. This, in turn, requires consultation with the Georgia State Historic Preservation Officers (SHPO) regarding impacts to cultural resources. In the late 1980s through early 1990s, under the previous name of Oglethorpe Power Corporation, there was virtually no consistency in review times for compliance documents submitted to the SHPO for review. With review times varying from 60–120 days and mitigation costs skyrocketing, discussions were held to identify ways to mitigate impacts to cultural resources in a programmatic fashion. The result was the "Programmatic Agreement Among the Rural Utilities Service, the Georgia State Historic Preservation Officer, and the Advisory Council on Historic Preservation Concerning the Construction and Modification of Transmission Facilities by Georgia Transmission Corporation."

REGULATORY HISTORY

Tom King defined a cultural resource as:

"…any resource (i.e., thing that is useful for something) that is of a cultural character—generally tied up with some community's identity. Examples are social institutions, historic places and cultural sites, artifacts, documents, and traditional ways of life. Others define the term much more narrowly, often to only mean archeological sites or historic properties. Semi-synonyms include heritage and patrimony" (King 2008).

It is important to note that the terms "cultural" and "historic" resources are often used interchangeably, but the term "historic resource" can have many meanings. To architectural historians and archaeologists, a historic resource generally means any cultural resource that is 50 years old or older. However, in environmental review and compliance, a historic resource is generally defined as a cultural resource that has been determined *eligible* for inclusion on the National Register of Historic Places.

The U.S. Government appeared to have first begun managing cultural resources when Congress appropriated funds in 1800 to establish the Library of Congress, but most early historic preservation efforts in this country were privately funded and focused on places associated with the founding fathers in a concerted effort to establish a national identity. Quite frequently, this effort was undertaken by women, as seen with the founding of the Mount Vernon Ladies Association in 1853, to save George Washington's home (Mount Vernon Ladies Association 2022). After the Civil War, the Smithsonian Institution and the U.S. Department of the Interior began conducting ethnographic research, while the War Department began to acquire and preserve battlefields; however, preservation of buildings remained a private endeavor.

The Antiquities Act of 1906 authorized the president to designate natural and historic resources in the U.S. as national monuments. Created as a reaction to the removal of antiquities (archaeological resources) from federal land, this is generally considered to be the first preservation law in the U.S. In 1916, the National Parks Service (NPS) was created and became the first U.S. agency with conservation of natural and cultural resources as part of its mission. At this time, the management of battlefields was moved from the War Department to the NPS (National Park Service 2000).

In the 1930s, while the country was in the throes of the Great Depression, several public programs that focused on the preservation of cultural resources were established to employ out-of-work Americans. In 1935, the Historic Sites Act authorized a continuing program of recording, documenting, acquiring, and managing places important in the interpretation and commemoration of the nation's history. These sites came to be known as "National Historic Landmarks." It also established the Historic American Buildings Survey (HABS)—this program later included the Historic American Engineering Record (HAER) and the Historic American Landscape Survey (HALS)—which recorded local and regional histories, created the oral history "Born in Slavery: Slave Narratives from the Federal Writers' Project, 1936–1938," and conducted archaeological material and data salvage in advance of large-scale public works projects, such as those constructed by the Tennessee Valley Authority (National Park Service 2016). These programs provided employment opportunities for out-of-work architects who created scale drawings of historic buildings and structures, photographers who documented the condition of cultural resources, and historians and writers who produced local, regional, and oral histories.

During this time, local governments also began looking beyond individual historic buildings or archaeological sites and began considering the idea of historic neighborhoods. Some of the first recognized historic districts were created during the Great Depression in New Orleans, Louisiana, and Charleston, South Carolina.

Following World War II, the U.S. experienced growth on an unprecedented scale. The U.S. Army Corps of Engineers (USACE) began building reservoirs and dams, the interstate highway system was launched in 1950, and urban sprawl saw people leaving cities for new developments in the suburbs in record numbers. Unfortunately, much of this development occurred under the pretense of urban renewal and slum clearance, and eventually people started to recognize that a large part of our cultural heritage was also being lost.

In 1949, Congress authorized the creation of the National Trust for Historic Preservation to accept donations of historic properties and to preserve those properties for the public benefit (National Park Service 2022). Today, the National Trust not only owns and preserves historic resources, but it also advocates for historic preservation and provides a wide array of educational and technical services for historic preservation.

In 1964, the National Trust for Historic Preservation and the group now known as the American Planning Association issued the "Planning for Preservation Report," which criticized federal efforts in preserving historic resources and urged Congress to take specific steps to protect historic resources. In direct response to this report, President Lyndon B. Johnson convened a committee on historic preservation in 1965, and the resulting report, "With Heritage So Rich," was presented to Congress. This report recommended the creation of a national historic preservation program and sketched out its broad outlines (National Park Service 2022).

By 1966, 12,000 places had been documented by the U.S. as part of the HABS survey discussed earlier—half of which had been demolished or damaged beyond repair. That same year, Congress passed the National Historic Preservation Act (NHPA), the Department of Transportation Act, and the Demonstration Cities and Metropolitan Development Act, all of which contained provisions that significantly aided in the protection and preservation of historic resources (National Park Service 2022).

The National Historic Preservation Act of 1966

The NHPA accomplished several things. First, it authorized the NPS to establish a National Register of Historic Places (NRHP or National Register), a list of buildings, sites, districts, and structures, and objects of local, state, national historical, cultural, archaeological, and architectural significance. It created the Advisory Council on Historic

Preservation (ACHP), which consists of 23 members from the public and private sectors who advise the president and Congress on historic preservation. The ACHP also develops policies and guidelines for handling conflicts between federal agencies regarding cultural resources and participates in the Section 106 review process. The NHPA also authorized grants to states to assist them in historic preservation matters, as well as established what became known as State Historic Preservation Officers. Finally, the NHPA included Section 106 (36 CFR Part 800), a requirement that federal agencies must consider the effects of their actions on places included in the NRHP and provide the ACHP a reasonable opportunity to comment.

When the NHPA was passed, it only required consideration of impacts to properties listed on the National Register; however, since the NHPA also established the National Register, it was several years before many properties were *listed* on the National Register. To correct this oversight, President Nixon issued Executive Order 11593 in 1972, which directed federal agencies to treat properties determined to be eligible for inclusion in the National Register, the same as those properties that are listed on the National Register (ACHP 2022).

Because many of Georgia Transmission's projects are determined to be a federal action because of RUS loans or USACE permits, these projects are subject to Section 106 compliance.

The National Environmental Policy Act of 1969

The 1960s were a time of great social and cultural change in the U.S. There was a source of pride in cultural identity, as well as anger and frustration by minority groups who were not equally represented in this country, including the rights of Indigenous people and their tribal heritage. It was also around this time that Rachael Carson's book *Silent Spring* was published. It gained great popularity and brought awareness to the need for government action to protect the environment. This culminated with the passing of the National Environmental Policy Act (NEPA) in 1969.

For the first time, NEPA formed a national policy to "preserve important, cultural, and natural aspects of our national heritage" (Council for Environmental Quality 2022). The law also created the Council for Environmental Quality (CEQ) and required agencies to consider the effects of their actions on the quality of the human environment. NEPA required federal agencies to develop environmental staff and a way to enact environmental impact assessment (EIA) procedures.

As an applicant for federal loans and/or permits, Georgia Transmission follows the policies and procedures for implementing NEPA, as set forth by RUS and the USACE.

Additional Regulatory Changes

Below is a brief overview of additional regulatory changes regarding the protection of cultural resources:

- 1974: The Antiquities Act of 1906 was found to be unconstitutionally vague because it did not include an age an object had to be in order to be considered an antiquity.
- 1976: Tax Reform Act was passed to encourage the preservation of commercial historic structures.
- 1978: American Indian Religious Freedom Act (amended in 1994) allowed Native peoples the right to access sacred sites, and defined some requirements for consultation with Native tribes.
- 1979: Antiquities Act was replaced by the Archeological Resources Protection Act (ARPA)
    - o Clarifies requirements for managing the disturbance of archaeological sites, features, and objects on federal and Indian tribal lands
    - o Requires the need for an ARPA permit from the federal agency before any archaeological survey work can be conducted on federal land (to prevent looting)
- 1987: Abandoned Shipwreck Act
- 1990: Native American Graves Protection and Repatriation Act (NAGPRA)
- 1996: Executive Order 12007–Indian Sacred Sites
- The NHPA also had major amendments, primarily additions to expand the effect of the law or to clarify its implementation, in 1980 and 1992.

Section 106 Compliance

As stated previously, many of Georgia Transmission's projects are required to comply with the provisions of the NHPA and NEPA. Section 106 defines a federal undertaking broadly and includes the use of federal funds, such as federally backed loans, federal permitting, such as a USACE permit, and projects that touch federally owned property. If a project is determined to be a federal undertaking, then impacts to cultural resources must be considered in the project planning process. Because NHPA is a procedural law, the ACHP has developed a four-step review process for Section 106 compliance: initiating the Section 106 process, identifying historic properties, assessing effects, and resolving adverse effects through avoidance, minimization, or mitigation.

For Georgia Transmission projects, this process generally begins early in the transmission line routing and substation siting process when consultants are hired to conduct historic resource surveys of a large study area (archaeological surveys are conducted when an area of potential effect is determined). These surveys are conducted by professionals that must meet the Secretary of the Interior's Professional Qualification Standards. The consultants identify previously documented properties and National Register listed properties, as well as any properties not previously identified that are 50 years of age or older. Properties less than 50 years of age may be documented if they are determined to possess exceptional significance. The consultants provide a recommendation of National Register eligibility and Georgia Transmission uses this information when routing and siting projects, in an effort to avoid or minimize impacts to these resources.

As stated previously, historic resources are defined as districts, sites, buildings, structures, and objects that are determined eligible for or listed on the NRHP. According to the National Park Service, to be eligible for the NRHP, a resource must be considered significant according to one or more of the following criteria:

- Criteria A: Resources associated with events that have made a significant contribution to the broad patterns of our history
- Criteria B: Resources associated with the lives of significant persons in our past
- Criteria C: Resources that embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction
- Criteria D: That have yielded, or may be likely to yield, information important in history or pre-history

In addition to significance in the above categories, the resource must also possess the sufficient integrity in the areas of location, design, setting, materials, workmanship, feeling, and association to reflect its area of significance to be considered eligible for inclusion in the NRHP (NPS Cultural Resources 1990).

After a project scope has been refined, the next phase of cultural resource surveys can begin, including archaeological resource surveys. Consultants determine the area of potential effect (APE) and determine if the project will have an adverse effect on any historic resources (i.e., NRHP eligible resources). Adverse effects result from projects that significantly impact features that contribute to the eligibility of the resource, generally to the extent that render it no longer eligible for the NRHP. Adverse impacts can include visual impacts; damage, destruction, or removal; and change in use or setting.

If a project will result in an adverse effect to a historic resource, the next step in the Section 106 process is to discuss avoidance, minimization, and mitigation measures with consulting parties. Consulting parties can include the State Historic Preservation Officer, Tribal Historic Preservation Offices (THPO), the ACHP, local governments, historic preservation organizations, the public, individuals with a vested interest in the property, and the NPS, in addition to the lead federal agency on the project.

Common mitigation practices for utility projects include intensive survey and documentation of the resource, planting of vegetative screens, cultural resource inventories, and interpretive displays or museum exhibits. Typically, once all parties agree on mitigation procedures, a Memorandum of Agreement (MOA) is signed.

REGULATORY COMPLIANCE CHALLENGES

Section 106 compliance projects completed by Georgia Transmission are subject to review and comment by the Georgia SHPO. When Georgia Transmission was formed in the late 1990s, review times by the SHPO were unpredictable, often lasting anywhere from 60 to 120 days. Projects completed by Georgia Transmission led to repeated and minor impacts to cultural resources through the construction and maintenance of transmission lines and substations, and projects resulted in a high proportion of adverse effects that required the execution of a MOA. The terms of an MOA must be negotiated and agreed upon by all consulting parties, and often included costly and time-consuming mitigation efforts. Project management was extremely challenging with such long and unpredictable timeframes, so Georgia Transmission and RUS began to look for a program alternative.

PROGRAMMATIC AGREEMENT

The Section 106 regulations (36 CFR Part 800) “offer program alternatives through which agencies can tailor the Section 106 review process for a group of undertakings or an entire program that may affect historic properties” (ACHP 2022). A programmatic agreement (PA) is a formal, legally binding agreement between the ACHP and other state and/or federal agencies that spells out the program alternatives to streamline review for routine projects with predictable and repetitive effects to historic resources. According to the ACHP, not only does a PA expedite the review process, but it can also allow agencies to focus their concerns on larger or more complicated projects and/or more significant historic properties. Today, many agencies, including ACHP and RUS, have templates for the development of programmatic agreements. But in the late 1990s and early 2000s, when Georgia Transmission and RUS began to develop their PA, no such templates existed.

Representatives from RUS traveled from Washington, D.C., to Atlanta to meet with representatives from the Georgia Transmission’s environmental compliance staff and the Georgia SHPO (the ACHP became involved toward the end of the process). Through much negotiation and lengthy discussions, all parties agreed on a program alternative. Among the many stipulations included in the PA, one of the most impactful is an agreement for a review of projects on

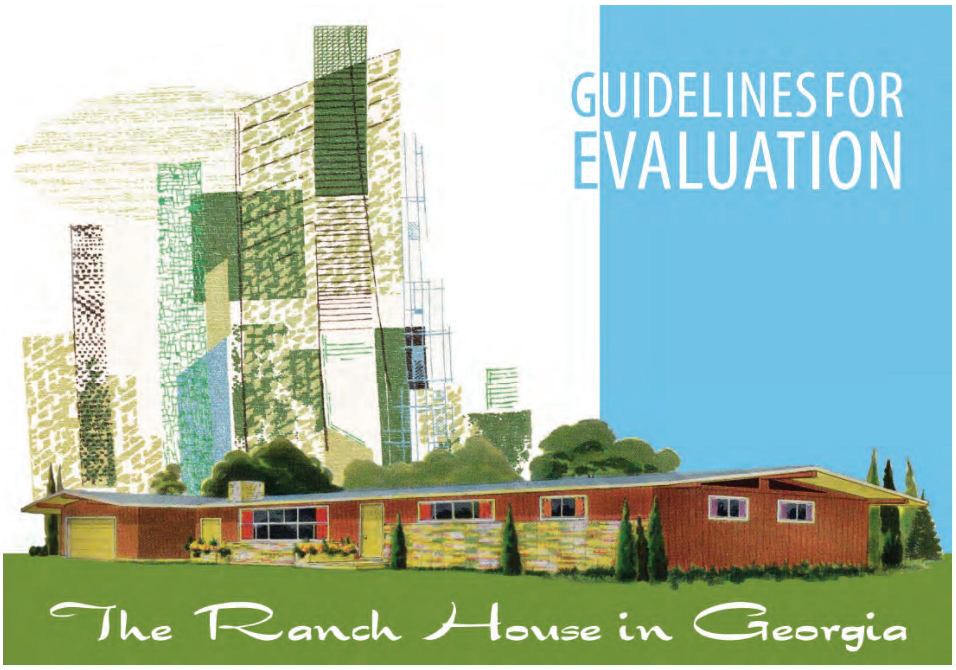

Figure 2. *The Ranch House in Georgia: Guidelines for Evaluation* book cover (New South).

an annual basis rather than a project-by-project basis, with some exceptions. This largely eliminated the need for SHPO to conduct individual reviews of Georgia Transmission projects and no longer required an MOA for every project that resulted in an adverse effect. However, if a transmission facility will have an adverse effect on a National Historic Landmark, a National Register listed property, a traditional cultural property, or an NRHP eligible historic district, Georgia Transmission must initiate consultation with SHPO.

The parties also agreed upon a list of project activities that were considered exempt from Section 106 review, as they had no potential to cause effects to cultural resources. The resulting document is the "Programmatic Agreement Among the Rural Utilities Service, the Georgia State Historic Preservation Officer, and the Advisory Council on Historic Preservation Concerning the Construction and Modification of Transmission Facilities by Georgia Transmission Corporation." The document was signed in 2001 and has been so successful that all parties have agreed multiple times to extend the PA through 2024, at which time it will be replaced by a similar, yet updated, programmatic alternative.

MEANINGFUL MITIGATION

Prior to the implementation of the PA, mitigation undertaken for Georgia Transmission projects typically consisted of photographic documentation and written research that was not readily available to the public; however, in consultation with RUS and SHPO, Georgia Transmission has been able to develop successful strategies for more meaningful mitigation efforts. One way Georgia Transmission accomplished this was through funding the development of *The Ranch House in Georgia: Guidelines for Evaluation*, a book developed in consultation with the SHPO, Georgia Department of Transportation (GDOT), and Section 106 consultants, that established a framework for the documentation and evaluation of a previously understudied resource type. Published in 2010, this is still the primary source for this house type in Georgia. Since that time, Georgia Transmission has sponsored additional research projects on a variety of resource types.

Another form of mitigation was sponsorship of Abby the ArchaeoBus. Although recently retired, this former bookmobile was converted into a mobile archaeology lab and classroom that traveled to countless schools and public events across the state, educating the public on the field of archaeology. Georgia Transmission has also developed a process to preserve archaeological sites in place and established a site monitoring program to continually monitor archaeology sites that are identified on Georgia Transmission property or easements during the Section 106 process.

Perhaps the most significant form of mitigation undertaken by Georgia Transmission is sponsorship of the FindIt program. As a direct result of the PA, Georgia Transmission partnered with the University of Georgia and the SHPO to establish a statewide cultural resource survey program conducted by students in the university's College of Environment and Design programs. The program began in 2001 and has just completed its 21st year of survey work on behalf of the Georgia Transmission Corporation. To date, the program has surveyed 64 counties, documented 21,900 resources, provided 90 graduate assistantships, and 169 paid internships. The program allows students entering the preservation field an opportunity to obtain hands-on survey experience. The survey needs are recommended by a steering committee composed of Georgia Transmission, SHPO, and GDOT—a partnership that has fostered positive relationships between the

Figure 3. Abby the ArchaeoBus. Photo from Georgia Transmission archives.

agencies. Data from the surveys is stored in a publicly available website that contains searchable information about Georgia's archaeological, historic, and natural resources.

CONCLUSION

Although adverse effects to historic resources have not been eliminated, the programmatic agreement between the RUS, SHPO, and ACHP for Georgia Transmission projects has resulted in predictable timeframes for project delivery and much more meaningful forms of mitigation than anything completed prior to the implementation of the programmatic agreement. It has fostered excellent interagency relationships, allowed Georgia Transmission to provide a benefit to the state through the documentation and continued monitoring of historic resources, and has contributed to the development of students into experienced professionals in the field of historic preservation.

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13th International Symposium

Environmental Concerns in Rights-of-Way Management

PART VII

Regulatory

20 Years On: What Have We Learned About UVM from the 2003 North American Blackout and the 2003 European Blackout?

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Keywords: Blackout, Outages, Power Outage, Utilities, Utility Vegetation Management (UVM), Vegetation Management.

In 2003, a massive blackout causing billions of dollars in catastrophic losses occurred in North America, resulting in significant power loss in both the United States and Canada. That same year, a massive blackout causing billions of euros in catastrophic losses occurred in Europe, resulting in significant power loss impacting numerous European countries. The cause was the same in both instances: conflicts between trees and utility lines within the rights-of-way (ROW). Both blackouts were fully investigated by highly qualified government-appointed experts who reached similar conclusions. The policies adopted thereafter in North America and Europe differed significantly, however have produced dramatically different results. A review of the different approaches, studied over a 20-year period, reveal the successes and failures of legal and regulatory regimes aimed at ensuring the safe and reliable transmission and distribution of electric power.

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INTRODUCTION

In the early morning hours of September 28, 2003, as revelers of "Notte Bianca," the White Night, strolled through Rome, lit up late into the night for the city's first ever all-night arts festival, they experienced quite the opposite: the largest blackout in European history (Aljazeera 2003). Italy's "Eternal City" seemed to have reached its limits as Rome succumbed to total darkness. Around 3 a.m., a powerline sagged and connected with a tree, and nearly all of Italy—along with regions in Austria, France, Slovenia, and Switzerland—lost power. Strangely, less than two months earlier, New Yorkers found themselves having to walk across bridges once again (after crossing by during the 9/11 attacks). On August 14, 2003, huge swaths of the United States and Canada lost all access to electricity in the largest blackout in North American history. Just after 4 p.m., modern life in the American Northeast ground to halt (Final Report on the Aug. 14, 2003, Blackout in the U.S. and Canada). All of this happened because of the meeting of a powerline and a tree in Ohio only two hours earlier (Minkel 2008). It affected eight U.S. states and one Canadian province. It covered more than 9,000 square miles and disrupted over 61,000 megawatts of power (Minkel 2008).

The scale of these two blackouts matched the incredible scale of their consequences. Nearly 55 million people across eight states in the U.S. (nearly one-seventh the U.S. population) and the Canadian province of Ontario (one-third of Canada's population) (Walton 2016), and 56 million people in Europe (Bottcher 2016) were impacted by the power loss. In Milan, Rome, and New York, passengers found themselves trapped in stuffy, overheated subway cars and tunnels, as escalators and lifts stopped moving (Australian Broadcast News 2003). Although some of Rome's White Night attendees first believed the sudden darkness was part of the festival entertainment, it soon became clear that power was lost throughout the city and most of Italy (Australian Broadcast News 2003). People found themselves sleeping through the night in Roman train stations and city streets.

The financial losses were huge. In the United States, it was estimated that between four and ten billion dollars was lost (Liscouski et al. 2004), with $250 million lost in perishable goods alone. In Canada, the same investigators calculated that it had lost almost an entire percentage point of its GDP and $2.3 billion Canadian dollars in manufacturing shipments (Liscouski et al. 2004). In Europe, small businesses and farms were the most affected. An association of small traders, representing some 200,000 cafes, pastry shops, and ice cream parlors, estimated that they had lost goods worth 23 million euros and lost 27 million euros worth of earnings (Le Monde 2003). The blackout closed twelve major airports (Galvan 2006). Moreover, it must not be forgotten that lives were also lost. Eleven people in North America died from the impacts of the outage (Walton 2016). In Puglia in Southeastern Italy, two elderly women died falling down dark stairwells and a third woman passed away when the flame of the candle she burned to see in the darkness set her clothes ablaze (Australian Broadcast News 2003). Luckily, diesel generators in Italy kept hospitals working and diesel locomotives were able to tow stranded trains packed with tens of thousands of passengers (Le Monde 2003). The European press reported that more than a million people volunteered in the relief operations that day.

Initially, officials in the U.S. were not entirely sure what had caused the blackout. They wondered if it resulted from an unseen security threat (the specter of 9/11 still in the air), or if a computer virus had infected the electricity grid. A nuclear plant outage in neighboring Pennsylvania was even considered for somehow tripping something up in the power grid. However, soon the government, with the help of utilities and regional organizations, uncovered the root causes of the system failure (Walton 2016). While they declared that communication between utilities and transmission operators—along with other technical and operational issues—had to be addressed, a primary cause of the continent's largest blackout was found to be a powerline hitting a tree (Liscouski et al. 2013). As the U.S.-Canada Power System Outage Task Force explained in its investigative findings in April 2004, computer failures "leading to the loss of situational awareness in [FirstEnergy Ohio]'s control room and the loss of key [FirstEnergy] transmission lines due to contacts with trees were the most important causes [of the blackout]" (Liscouski et al. 2013).

Meanwhile, in Europe, the Union for the Coordination of Transmission of Electricity (UCTE) discovered that, similarly, a root cause of Italy's blackout was a tree flashover. Significantly, the tree and powerline that took down the European power grid was not located in Italy, nor even within the bounds of the European Union. Instead, the tree-powerline collision occurred in Switzerland, Italy's neighbor and, uniquely, an EU nonmember state. The blackout was found to be caused by cascading high-voltage line outages, triggered initially by three separate 345 kV transmission conductors sagging into trees located within their respective rights-of-way (ROW) corridors.

Since those seminal events, a veritable groundswell of renewed awareness by the electric utility industry, regulatory agencies, and transmission owners has erupted regarding the critical importance of all facets of ROW vegetation management (both on the ROW proper and off the ROW; that is, areas immediately adjacent to the outside edge of the legally cleared ROW). Furthermore, during the ensuing international blackout investigations, tree contact was identified as an initiating or contributing factor to seven other major recent electrical outages of the bulk transmission system, resulting in large-scale interruptions of electrical service.

When it became apparent that these crippling electrical outages were all preventable events, particularly if proper transmission line ROW vegetation management had been performed in a timely manner, a clamor arose for the creation of new mandatory standards that would be both measurable and enforceable. After a thorough review and evaluation of the blackout causes and all their attendant ramifications, the investigative committees advised the industry to create and begin the adoption of new, technically sound standards for conducting vegetation management on the ROW occupied by these critical bulk transmission facilities to ensure electric service reliability. At the same time, the governmental bodies were urged to create new legislation to address these very electric reliability issues and to fashion this new regulatory—and ideally, enforceable—scheme. These actions, the committees explained, would improve communication, monitoring, and ensure compliance.

The two reports issued by the two different investigation committees—put together by the U.S.-Canada Power System Outage Task Force and the Union for Coordination of Transmission of Electricity (UCTE) in Europe—reflect the divergent approaches taken to resolve the underlying issues of their prospective power grids.

"Amateurs talk strategy; professionals talk logistics," as famed General Omar Bradley once said. This adage was proven true when in 2006, Europe faced another massive blackout, this time affecting nearly 10 million people in across Germany, France, and Spain, just to name a few of the countries impacted. Whereas the efficient and thorough, legally binding and penalty-driven *logistical* implementation of the North American task force's recommendations in the U.S. and Canada resulted in no further massive blackouts after 2003, Europe found itself in darkness yet again in 2006. The clarity and firmness of the recommendations and policy proposals (backed by a plan for legally binding regulation) provided in the American-Canadian report lie in contrast with the softer, more qualified consent-based recommendations found in the European investigative report. For example, the North American report clearly states that the third major cause of the 2003 blackout was that "[FirstEnergy] failed to manage adequately tree growth in its transmission rights-of-way. This failure was the common cause of the outage of three [FirstEnergy] 345 kV transmission lines and affected several 138 kV lines" (Liscouski et al. 2013). The European report, on the other hand, states, "Root Cause 4: Possible insufficient right-of-way maintenance practices" (UCTE 2004). It goes on to explain:

> "Concerning right-of-way maintenance, best management practices are defined and regulated on a country-by-country basis… Therefore, the Committee did not perform a technical audit of these practices. In the meantime, the Swiss Authorities conducted an investigation on the line maintenance practices *before* the incident. Their findings are that the line inspections and line maintenance measures of the two affected transmission system operators…were both in full compliance with the Swiss regulation in this area" (UCTE 2004).

Here, the report indicates that although a tree-powerline collision was a "root cause" of the massive blackout, UCTE explains that this cause and possible remedies will not be further pursued because the Swiss Authorities, who are not part of the European Union, decided "before" the incident—the massive blackout spurred by a powerline overheating and sagging into a tree—that their utility vegetation maintenance processes were "in full compliance."

In contrast to such a passive response to the Italy blackout, the American report informed its readers that the electric utility industry vegetation management standards were inadequate and needed to be considerably enhanced. "Given that the line to ground faults that precipitated the blackout have been determined to be a result of inadequate vegetation management practices, we believe and strongly recommend that the industry 'average' or standard needs to be substantially improved" (Liscouski et al. 2004). The report makes a point to emphasize that "tree and powerline conflicts have occurred in the past, and they are certain to occur in the future unless there are significant changes in the industry's vegetation management practices and their oversight." The committee then proceeded to recommend specific practices, enumerated under the tenets of integrated vegetation management (IVM) and other best management practices (BMPs) that would reduce the likelihood of future tree and powerline conflicts, and provided a series of detailed recommendations for the oversight and enforcement of selected utility vegetation management (UVM) activities.

With respect to the North American Electric Reliability Corporation (NERC) initiative to collect data on vegetation-caused outages and ROW vegetation management programs, the blackout report stated that "more aggressive action is warranted. NERC [North American Electric Reliability Corporation] should work with FERC [Federal Energy Regulatory Commission], appropriate authorities in Canada, state regulatory agencies, the Institute of Electrical and Electronic Engineers (IEEE), utility arborists, and other experts from the U.S. and Canada to develop clear, unambiguous standards pertaining to maintenance of safe clearances of transmission lines from obstructions in the lines' ROW areas, and to develop a mechanism to verify compliance with the standards and impose penalties for noncompliance." The report went on to state that NERC should "require each bulk electric transmission operator to publish annually a proposed ROW management plan on its public website, and a report on its ROW management activities for the previous year. The management plan should include the planned frequency of actions, such as ROW trimming, herbicide treatment, and inspections, and the report should give the dates when the ROW in a given district were last inspected and corrective actions taken." The requirements and remedies were clear.

Analysis of Differences in Response and Recommended and Adopted Initiatives in North America Versus Europe

In the responses, time, and methodology it took to implement and enforce reliability standards, the differences between the American republican system of governance and operation within its electricity markets was able to react more efficiently and assertively than the European system involving a burgeoning electricity market newly unified and liberalized and still figuring out the power relations between its union's nation-states. After the U.S. Congressional hearings and the U.S.-Canada Task Force investigative report was released in 2004, the U.S. Congress passed the Energy Policy Act of 2005, a game changer in terms of regulation and oversight of the North American power grid. The act expressly provided for—distinctly from the European response—legally binding enforcement mechanisms that included sanctions and penalties granted to the FERC, a governmental agency that oversees interstate transmission of electricity, natural gas, and oil. The Energy Policy Act of 2005 gave FERC the responsibility to ensure the reliability of the high-voltage interstate transmission system. Significantly, FERC, although initially funded by Congress through annual and supplemental appropriations, was to become a self-funding agency, authorized by Congress to raise revenue and reimburse the government via annual charges (and if required, fines) to the natural gas, oil, and electric industries it regulates. This allowed the regulatory work to remain and continue well into the future, which is essential to the maintenance of reliable electricity across such a vast geographic region.

"[The Federal Energy Regulatory Commission] has so far approved 96 new reliability standards. These cover the three T's—trees, training, and tools—identified by the blackout task force but are not limited to them," said Joseph McClelland, director of FERC's Office of Electric Reliability. Standard PER-003, for example, requires that operating personnel have at least the minimum training needed to recognize and deal with critical events in the grid; standard FAC-003 makes it mandatory to keep trees clear of transmission lines; standard TOP-002-1 requires that that grid operating systems be able to survive a powerline fault or any other single failure, no matter how severe (DiSavino 2013).

The act also required FERC's Commission to select an electric reliability organization (ERO), an entirely independent agency which would have the authority to approve and carry out its responsibilities under statutory provisions, and independently enforce Reliability Standards, subject to FERC oversight. Responsible for developing and enforcing mandatory reliability standards, the ERO was essential to the regulatory scheme created by the Energy Policy Act. The Federal Energy Regulatory Commission then named NERC as North America's new ERO. First established in 1968 to develop and enforce reliability standards, monitor the bulk power system, and educate and train industry personnel, NERC was founded as a self-regulatory organization that relied on the collective expertise of industry participants. Selected by FERC as the ERO on July 20, 2006, NERC graduated from an organization relying on voluntary compliance to one possessing the legal authority to enforce reliability standards on all owners, operators, and users of the U.S. and Canadian bulk power system. The certification of the ERO and the NERC Reliability Standards—including those pertaining to transmission ROW vegetation management—would have the full force of law, and no longer be administered through the peer pressured compliance arrangement as NERC standards have been in the past. In other words, the creation of the ERO by FERC completely altered the NERC voluntary concurrence arrangement with its members, transforming it into a top-down regulatory model that contained both mandatory and fully enforceable reliability standards. Furthermore, the identification of regional entities that would be able to enforce reliability standards within their geographic jurisdiction under the authority of the RRO (Regional Reliability Organizations or RROs) streamlined the process and made it easier to implement in all the diverse regions of the North American power grid.

However, the delegation of these RROs by NERC became effective only after FERC approved the delegation agreement. Interestingly, the ERO or RRO could impose penalties on a user, owner, or operator for violating a Reliability Standard, subject, of course, to review by and appeal to FERC. Since vegetation management was a major cause of the 2003 blackout, NERC quickly established mandatory standards for ROW vegetation management. Compliance audits and penalties associated with compliance failures or for outage events caused by ROW vegetation have created new incentives for consistent implementation of highly effective ROW vegetation management practices. Past practices that on occasion resulted in interruptions caused by ROW trees are no longer tolerable. Penalties for violating FERC standards can go up to over one million dollars per day for each violation (Reuters 2017). The numbers compound quickly, with FERC collecting over a billion dollars in civil penalties since it was granted its enforcement mechanisms in 2005.

These newly created NERC standards were intended to improve the reliability of the electric transmission systems by actually eliminating all transmission outages caused by vegetation located on (within) transmission ROW (i.e., both growing into the conductors as well as falling and minimizing outages from vegetation located adjacent to [or off] the ROW from falling into the conductors). It accomplished this new goal by requiring the maintenance of safe clearances between transmission lines and vegetation on and along transmission ROW (but sets no specific distances), and established a system for reporting vegetation-related sustained outages of the transmission systems (nominally +200 kV) to the respective RRO and NERC. This standard would assist in reducing vegetation-related transmission outages by requiring each transmission owner to have a documented vegetation management "program" in place, including documentation of its annual "plan" implementation. Each vegetation management program was to be designed for the geographical area and specific design configurations of the transmission owner's system. This standard would also provide for uniform reporting of vegetation-related outages to the regions and to NERC. This was so that planning authorities and reliability authorities could measure the impact of vegetation-related outages on the reliability of the interconnected electric transmission systems. A two-tiered set of clearances between the overhead conductors and encroaching vegetation is required; one at the time of vegetation management and the other to be maintained at all times (the former is greater than the latter). On October 20, 2006, FERC approved FAC-003-1, the first vegetation management standard that had to be followed by all transmission owners. As an outgrowth of the 2003 blackout, NERC also now has a reliability readiness audit program. The North American Electric Reliability Corporation now regularly conducts "readiness audits" of registered balancing authorities, reliability authorities, and transmission operators. Again, one can see very clearly that the professionals are at work—it's all logistics and straightforward implementation of very specific recommendations and enforceable standards.

A further innovation of the Energy Policy Act was to expand UVM into federal land. Electric utilities have long had difficulty in performing vegetation management on transmission lines on federal land. Such land can be under the control of the Forest Service, Bureau of Land Management, Fish and Wildlife Service, and the National Park Service. Utility vegetation managers encountered varying policies for UVM depending upon the region, agency, and the land manager. Utilities in the Southwest and West, where large tracts of land are managed by federal agencies, are especially affected. Since the West and Southwest generally are more prone to wildfire, which can damage electric facilities, the utilities there had a stake greater than just reliability and cost of maintenance. The August 2003 blackout was seen by utilities as an opportunity to convince the various federal agencies of the need for proper, timely, and streamlined IVM. Discussion with the various federal agencies was slow until the passage of the 2005 Energy Policy Act. This act contains the Shadegg Amendment that helps "expedite any federal agency approvals that are necessary to allow the owners or operators of such facilities to comply with any reliability standard, approved by the Commission under section 215 of the Federal Power Act, that pertains to vegetation management, electric service restoration, or resolution of situations that imminently endanger the reliability or safety of the facilities." On May 25, 2006, a memorandum of understanding (MOU) was signed among the Edison Electric Institute, the U.S. Department of Agriculture (Forest Service), the U.S. Department of the Interior (Bureau of Land Management, Fish and Wildlife Service, National Park Service), and the U.S. Environmental Protection Agency. The MOU establishes a framework for developing cooperative vegetation management practices between utilities and federal land management agencies, thus enhancing reliability.

THE EUROPEAN RESPONSE

A similar process for developing a regulatory scheme and framework for oversight occurred in Europe, not after the 2003 Italy blackout, but rather the 2006 Germany blackout. The European political system likely played a role in this power outage happening. At the time, many EU policy makers pushed for a more centralized form of government. This would give the government as a whole a greater role in regulating Europe's power grids. When the 2006 blackout in Germany cloaked Europe in darkness yet again, these policy makers said this event revealed the fragility of Europe's current power grid system and called on a formal centralized government. On the flip side however, because the power disturbances were quickly contained and dealt with, the power sector spokesperson cited this event as a confirmation of the reliability of the current transnational power grids and praised the decentralized governance model in place at the time.

Since the 2003 blackout, the security system had gone unchanged. The security system did not account for an increase of liberalization of electric supply which caused an increase in cross-border trades, which are not properly accounted for when reviewing the security of the system. Also, due to the decentralized form of government at the time, the transmission system operators (TSOs) would each control their own area, and exchange little information with other TSOs. This inevitably resulted in a slow response time to contingencies. To repair these fallacies so something like this would not occur in the future, a new mode of coordinated operation for real-time security would be needed. But in order to do so, those implementing this would need to overcome a series of psychological, organizational, and legal challenges. The alternative would be to risk yet another major blackout or run the current system very conservatively, which would cause an astronomical cost to the consumers (Bialek 2007).

As the BBC reported in 2006, "EU countries are committed to introducing open markets for gas and electricity—where every consumer has a choice of suppliers…But energy supply is not managed by the EU. Individual countries still keep a close eye on their own energy security, and interests can conflict. France has invested widely in energy projects abroad, but has still not fully opened up its own sector to investment from abroad. Disputes over mergers between big European energy outfits—like E.ON and Spain's Endesa—have disrupted attempts to co-ordinate European energy policy." On the continent there is interconnection, allowing large flows across borders. But it is not one grid, we're not there yet," said Laura Schmidt of Britain's Association of Electricity Producers (BBC 2016).

The report by Swiss authority SFOE identified some of the same factors as causes of the Italian blackout of September 2003: lines clashing with trees, and an increased use of interconnections and long-distance transmission, which increased the complexity, vulnerability, and instability of electrical systems even at night during a period of minimal demand. The report identified a simple conflict: "The underlying causes of the incident that occurred on September 28, 2003, are the unresolved conflict between the trading interests of the involved countries and operators and the technical and legal requirements for safe and reliable operation of the networks" (Thomas and Hall 2003). Firstly, it noted a lack of regional cooperation, and secondly, it observed that the Italian blackout "results from already well-known and still unsolved structural issues transmission system operators (TSOs) are facing in Europe," although UCTE had "repeatedly warned over the especially tense situation in Italy with [its] structural dependency on bulk electricity imports." Finally, like the EU called for after the 2006 Germany blackout, the Swiss called for European-wide regulation employing enforceable security and reliability standards.

The challenge of a newly liberalized electricity market system was that "few companies want[ed] to spend money on assets where the return [was] low or uncertain, especially if the market [was] unwilling to compensate [private companies] for reliability." The earlier regulated system in the U.S. provided a more reliable investment climate, according to credit rating agency Standard and Poor (S&P): "Cost-of-service, rate-of-return environments generally supported credit quality, while the newer competitive environments have heightened credit risk."

The factors identified by the official inquiry into the U.S. blackout included inadequate tree-cutting; inadequate operator training; failure to ensure operation within secure limits; failure to tell neighboring systems about emergencies; failure to see what was happening in other regions; and failure and lack of backup of computer systems. These same factors had already been observed in European systems.

- "However, European TSOs have been experiencing regulatory frameworks that are still mainly driven by cost-reduction incentives (e.g., X-factor/profit-sharing mechanisms) rather than by providing incentives for the efficient and effective fulfilment of the increasing number of (legally mandated) tasks required while carrying out necessary investments" (Henze et al. 2021).
- Until now, National Regulatory Authorities (NRAs) have primarily aimed to reduce TSO costs and keep tariffs stable while providing a certain degree of incentive in their individual regulatory frameworks. Consequently, and due to the efficient management of costs by TSOs, grid tariffs have remained affordable, even though TSOs have carried out huge investment programs. The significant increase of investment efforts projected for the next few decades to achieve climate neutrality by 2050 does, however, highlight the possible shortcomings of existing regulatory frameworks to adequately remunerate TSO activities. Such shortcomings are further exacerbated by artificially low and still-decreasing risk-free rates on financial markets, which have the potential to endanger TSOs (Henze et al. 2021).
- We consider that the Energy Infrastructure Package can have a meaningful impact in the short, medium, and long term. In addition, enhanced cooperation between the commission, the newly formed Association for the Cooperation of Energy Regulators (ACER), and National Regulators can provide much-needed increases in the level of consistency of regulatory regimes and a focus on a consistent set of objectives. This response has focused on creating the conditions which Europe's TSOs consider would deliver the investment which meeting Europe's energy policy goals requires, and has considered actions which we consider can and should be taken to create these conditions. In our view, key issues are:
    - o The goal of European policy makers must be to create stable, transparent, and predictable regulatory regimes and policy frameworks which attract investors to deliver investments in infrastructure. The returns offered via these frameworks must be sufficient to compensate investors for taking the levels of risk associated with TSO businesses, must recognize the scale of Europe's funding challenge, and must recognizes the significant competition for those funds.
    - o Facilitating investment of European interest requires a series of additional issues to be

addressed. The increased planning, market, and technology risks must be reflected in (achievable) returns, and steps should be taken to overcome rigidities and inflexibilities in existing regimes, which prevent viable projects from proceeding.

- o A mindset change among regulators is required. A focus on cost reduction may have served customers well historically but the challenges of the 21st century are different. Promoting delivery, research and development, and innovation must be the goals of policy makers, and national regimes must align with European goals and objectives (ENTSO-E 2011).

The UCTE (Union for the Coordination of the Transmission of Electricity) and TSO (Transmission System Operator) acted swiftly, and were able to restore electricity shortly, however the event highlighted glaring problems. The UCTE and TSO were victims of enormous backlash from the media and the citizens, and there were threats that both corporations might undergo serious managerial overhauls. This forced both companies to go back to the drawing board and determine what possible improvements could be made to prevent such a problem in the future. For starters, the UCTE strengthened its defense system by using blackout simulations with the help of numerical analysis and sophisticated technology. Using these simulations, they were able to bring to life realistic scenarios that could impact these regions in the future, and how the TSO could possibly combat the problems.

This initiated the tweaking of the N-1 criterion in Policy 3 of the UCTE Operation Handbook. Essentially, the interconnected power systems were decentralized, wherein different border lines were responsible for the powerlines running through them, rather than one general body governing the entire system. This process was later known as Resynchronization, and it was able to increase stability within the UCTE if any problems were to arise. Furthermore, *joint-training* workshops were established that would assure that regional dispatchers would have the knowledge and skills to operate the power systems, and would have the ability to implement the solutions given by the TSO under any circumstances.

Europe needs to have a European FERC (Terzic 2018):

- Branko Terzic, an internationally recognized regulator, management consultant, and expert witness in the energy, public utility, and infrastructure industries
    - o Chairmanship of an international committee of experts on cleaner electricity under the UN Economic Commission for Europe and former FERC Commissioner

CONCLUSION

As John Goodfellow, past president of the Utility Arborist Association, pointed out, "It doesn't take but one tree" (Goodfellow 2022). While these huge blackouts may be low-probability events, their potentially enormous consequences—ones already well-documented from the 2003 blackouts—cannot be ignored. One of the realizations since 2003 is that "you can't just look at your system. You've got to look at how your system affects your neighbors and vice versa," said Arshad Mansoor, vice president of power delivery and utilization with the Electric Power Research Institute of Palo Alto, California (Minkel 2008). Clear standards and enforcement mechanisms to ensure a reliable power grid that unites nations across huge distances—continents—came out of the enormous losses of the 2003 blackouts. Since then, the stability created from independent and reliable regulatory agencies has allowed for the development of innovative and creative approaches to utility vegetation management. With the ever-increasing challenges that climate change brings to the management of both the North American and European power grids, the organizations and mechanisms that arose from the aftermath of the 2003 blackouts will only grow in importance as we decide how to adapt and transform our power grids to these unforeseen conditions.

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The views expressed in this paper are those of Ms. Kumar and Mr. Kahn alone, and do not necessarily reflect the official views of Tulane University or of the Utility Vegetation Management Initiative.

Routing a Pipeline through Downtown Toronto: A Case Study of the Enbridge NPS20 Pipeline

Kevin Seel, Moise Coulombe-Pontbriand, Francis-Olivier Joncas, and Melany Afara

Keywords: Alternative Route Analysis, Data Analytics, Evaluation, Environmental Sustainability and Governance, Pipeline, Public Engagement, Urban Pipeline Routing.

The natural gas distribution infrastructure in many of North America's cities is reaching end-of-service life and requires replacement or upgrade to continue serving growing demand. This problem is of greatest concern in large urban areas, like downtown Toronto where Enbridge Gas Distribution Ltd. (Enbridge) proposed to replace approximately 4.5 km of existing high-pressure natural gas pipeline located along Lake Shore Boulevard, from Cherry Street to Remembrance Drive (the Project). Built in 1954, the existing pipeline provides critical natural gas service to residents and commerce and has the highest customer density within the Enbridge Gas franchise area, and is the largest economic center in Canada. The Project was needed due to integrity and reliability concerns with the existing pipeline.

To address the challenge of determining most suitable routes for the replacement pipeline, Enbridge hired Golder (a member of WSP [Golder WSP]). Golder WSP applied a routing process and suite of decision-support tools called GoldSET© that incorporate sustainability criteria to drive pipeline routing decision-making. The resulting Enbridge routing approach integrated multidisciplinary knowledge, including environmental, social, regulatory and permitting, and engineering. Several "what if" alternative scenarios were also developed to represent different possible pipeline routing perspectives that explored how different combinations of environmental, social, and technical considerations influenced potential routes. The routing approach can demonstrate to other operators how routing can be successfully conducted through highly complex and potentially contentious urban environments where there are very rarely any good routes, only a set of "least-worst" options.

Enbridge received a Leave to Construct from the Ontario Energy Board in only 120 days and is currently constructing the pipeline. The authors attribute the rapid approval to addressing the difficult environmental, social, and governance (ESG) considerations early in the process, in a transparent and defensible way.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Enbridge is replacing a 4.3 km segment of Nominal Pipeline Size 20-inch (NPS20), high-pressure steel natural gas main on Lake Shore Boulevard from Cherry Street to Remembrance Drive, and a 230 m section on Parliament Street from Mill Street to Lake Shore Boulevard ("CTB" [the Project]) (Figure 1).

Installed in 1954, the pipeline to be replaced is reaching the end of useful service life and supplies the urban core of downtown Toronto, Canada's largest city. The CTB pipeline is located in a densely populated area of Toronto where failure could place public safety at risk. In addition, the pipeline supplies natural gas to several large-volume customers (including hospitals) who would have their natural gas supply impacted in the instance of failure. To further complicate matters, the existing NPS20 must continue to operate during the installation of the CTB replacement pipeline and therefore cannot be installed in the existing rights-of-way (ROW).

The determination of the most feasible route(s) for the CTB pipeline represented a significant technical routing challenge, given the dense and highly complex downtown urban nature of the location and the need to avoid existing above-ground as well as below-ground development.

Consequently, a strong opposition to the Project was anticipated by Enbridge given the location. The preferred route needed to clearly demonstrate how it minimized possible negative impacts to the public and infrastructure during construction and operation versus less-preferred alternatives. Although the Project consisted of a "size for size" replacement of the existing pipeline, and therefore technically did not require a Leave to Construct (LTC) under section 90(1) of the Ontario Energy Board Act, 1998 (OEB Act), it was decided by Enbridge that it would be in the best interests of the Project to do a full public consultation and in-depth route selection to gain project approvals to construct.

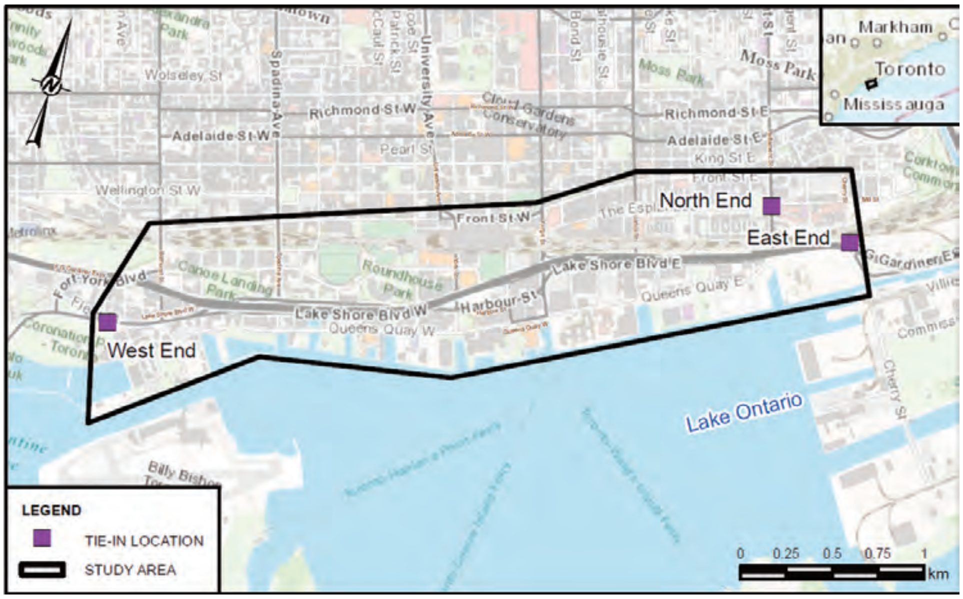

Figure 1. Project study area

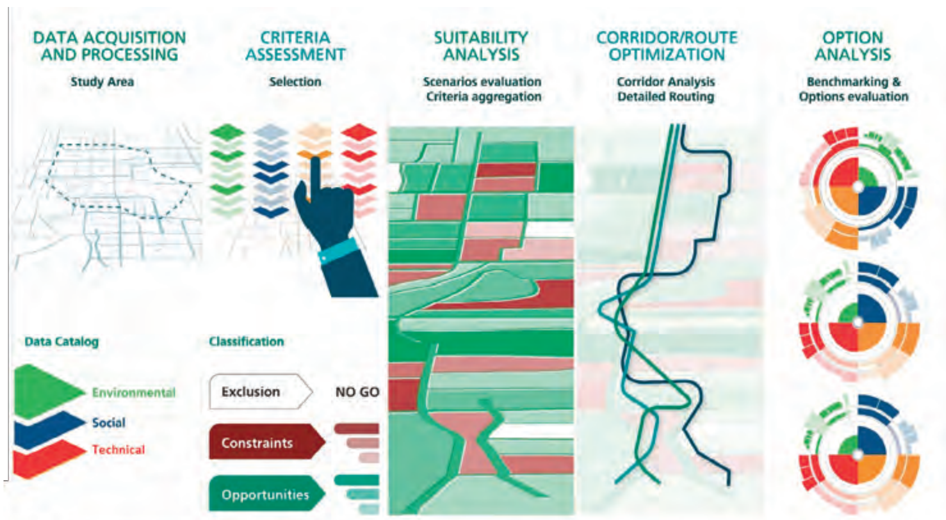

Figure 2. Pipeline routing process

Consequently, Golder WSP was retained by Enbridge to perform a desktop corridor routing study (the Study) to determine potentially feasible corridor options for the proposed CTB pipeline, using a methodology and suite of Geographical Information System (GIS) based tools known collectively as GoldSET© (the Study). This approach allows pipeline routing decisions to be made more objectively based on multiple criteria as opposed to the typical routing process which is largely driven by experts and team experience. The goal of the Study was to make a recommendation towards a preferred corridor, which clearly considered environmental, social, and governance (ESG) as well as technical decision criteria, and demonstrated to the public and stakeholders why the preferred route was the best overall option.

METHODS

An overview of the pipeline routing assessment methodology used is presented in Figure 2. The approach consisted of mapping and quantitatively classifying spatial routing criteria into high-level themes, including technical and sustainability criteria by subject matter experts (SMEs) and Enbridge decision makers through a structured workshop process.

A total of 39 individual indicator spatial data layers were assigned by SMEs and Enbridge decision makers into one of four categories, including (Table 1):

- Exclusion areas
- Constraint areas
- Opportunity areas
- And/or background (neutral)

Exclusion areas were defined as areas where pipeline routing is prohibited for social, legal, or regulatory reasons, or due to physical barriers. These included building footprints and the waters of Lake Ontario, for example. Potential corridors encountering exclusion areas are forced to divert around the obstacle.

Constraint areas can support routing but are assigned a weighting by SMEs and Enbridge decision makers based on the degree of constraint (i.e., high, medium, or low) or potential difficulty for a pipeline to traverse an area. Constraints are cumulative in that several different constraints can overlap on the same area; however, several low constraints cannot add up to a single moderate constraint, and several moderate constraints do not add up to a high constraint.

Opportunity areas represent potential opportunities for routing. Examples of potential opportunities include road allowances and other linear infrastructure which are considered desirable for pipeline co-location. Subject matter experts assigned one of either three categories, defined as high, medium, or low. Conversely to constraints, opportunities act as attractors to pull corridors towards them, the strength of which is determined by the level attributed them. Opportunities are subtractive on constraints; in that, they can lower the level of constraint (i.e., increase the suitability level) on areas they traverse through. However, opportunities are not additive on one another, and only the

Table 1. Sample List of Indicators - Base Case Scenario

THEME*	INDICATOR NAME	INDICATOR INTENT	WEIGHT FOR ROUTING
ENV	Parks and Greenspaces	Avoid parks and greenspaces	Constraint - Low
	Trees	Minimize proximity to trees	Constraint - Low
SOC	Approved Project Developments	Avoid approved projects to be constructed	Constraint – Low
	Archaeological Potential	Minimize proximity to areas with archaeological potential	Constraint - Low
	Emergency Response Services	Minimize or avoid proximity to emergency response services locations	Constraint - Low
	Heritage Sites	Avoid properties identified in the Ontario Heritage Act and the natural heritage network	Constraint - Low
	Marinas and Yacht Club	Avoid marinas, ferry terminals, and the yacht club	Background - Neutral
	Points of Interest	Avoid areas of congregation	Constraint - Low
	Public Art Monuments	Avoid public art monuments	Constraint - Low
	Residential Land Use TRCA	Minimize proximity to residential land use	Constraint - Moderate
	Residential Zones City of Toronto	Minimize proximity to residential zones	Constraint - Low
	Trails and Walkways	Consider trails and walkways based on scenarios	Opportunity - Low
	Conservation Regulated Areas	Minimize proximity to Toronto Regional Conservation Authority (TRCA) regulated areas	Constraint - Moderate
	Water Wells	Avoid water wells	Constraint - Low
TEC	Bridges	Avoid bridges	Constraint - Low
	Building Footprints	Avoid buildings	Exclusion
	Building Setback	Avoid close proximity to buildings	Constraint - High
	Curbs	Avoid routing along curbs	Constraint - Low
	Fire Hydrants	Minimize proximity to fire hydrants	Constraint - Low
	Free - Standing Cell Towers	Avoid free-standing cell towers	Constraint - Moderate
	Gardiner Expressway Ramps	Avoid Gardiner Expressway ramps	Constraint - Moderate
	Proposed Utilities	Minimize proposed utility duct crossings	Constraint - Moderate
	Railway	Minimize or avoid railway crossings	Constraint - Moderate
	Recently Replaced NPS20	Locate near recently replaced existing NPS20 route	Opportunity - Low
	Road Allowances	Maximize use of road rights-of-way	Opportunity - High
	Road Moratoriums	Avoid road moratoriums expiring from 2021 to 2023	Constraint - Low
	Structures Large	Avoid public washrooms and transit shelters	Constraint - Moderate
	Structures Small	Minimize proximity to small structures	Constraint - Low
	Subway/Underground Transit	Avoid subway and existing and proposed underground transit	Constraint - Moderate
	Tram/Streetcar/LRT	Avoid existing and proposed above ground tram/streetcar/light rail transit (LRT) tracks	Constraint - Moderate
	Utilities - High Constraint	Avoid high-constraint underground utilities	Constraint - High
	Avoid underground utilities	Avoid moderate-constraint underground utilities	Constraint - Moderate
	Utilities - Low Constraint	Avoid low-constraint underground utilities	Constraint - Moderate
	Water Crossing	Avoid Queens Quay water crossing	Constraint - Moderate
	Waterbody	Avoid inner harbour on Lake Ontario	Exclusion

highest level of opportunity attributed to a given area is used in the model.

Indicators which were either non-discerning for pipeline routing, unknown in terms of their direction or effect, or relevant only for measurement comparison between corridors in the final decision-making process were assigned by SMEs and Enbridge decision makers as background. Backgrounded indicators had no influence on corridors (i.e., neutral).

BASE CASE SCENARIO

An initial Base Case scenario was developed whereby SMEs and Enbridge decision makers attempted to balance the trade-offs logically and rationally between technical, environmental, and social considerations. The Base Case suitability surface was produced at a high spatial grid (raster) cell resolution of 1.0 m resolution. This resolution was intended to simulate the width of the pipeline trench plus the added workspace required for surface construction.

A second Base Case suitability surface was produced at an even higher spatial resolution of 50 cm, to test where the pipeline alone might be located independent of surface workspace requirements (i.e., trench or workspace). The very high resolution of the routing models was a unique aspect of the Study. Previously published studies using this technique (Seel and Dragan 2016; Seel and Phillips 2019) used much coarser spatial resolutions (e.g., 5 and 10 m) at regional scales. Due to the much higher resolution of the CTB model and the need for local scale analysis, the GIS routing model was configured in the CTB study to produce very narrow corridors that were more representative of detailed pipeline routes as well as more generalized corridors.

The 50 cm data was further refined during the Study to include the surveyed locations of the vertical support structures for the overhead Gardiner Expressway through downtown Toronto. These structures had a footprint of up to 4.3 m_2. This option provided the opportunity to locate the pipeline underneath the elevated express way to avoid impacting traffic along that pipeline segment.

The Base Case suitability surfaces were analyzed to determine the corridor of highest suitability and shortest length between tie-in locations using a corridor optimization algorithm. Linear and corridor information was derived as follows:

- Centerline: The mathematical centerline of highest suitability representing potential pipeline routes at a resolution of 1 m or 50 cm, depending on the model.
- Narrow Corridor: Represents the highest 1% of suitability that produced corridors typically 2 to 5 m wide.
- Medium Corridor: Represents the highest 5% of suitability that produced corridors approximately 5 to 10 m wide.
- Wide Corridor: Represents the highest 10% of suitability that produced corridors typically 10 to 50 m wide.

ALTERNATIVE SCENARIO DEVELOPMENT

The SMEs and Enbridge decision makers reviewed all Base Case indicator weights and preliminary results, which generated useful insights into how the model and the underlying decisions and rationale performed. For example, it was observed that both the 50 cm and 1 m Base Case results indicated the most suitable pipeline corridor was within the road allowances of Lake Shore Boulevard and underneath the Gardiner Expressway. The results led the SMEs and Enbridge decision makers to discuss additional “what if” alternative scenarios that might produce different results, based on other valid perspectives.

Through consensus, the team defined four different alternative routing:

- Base Case Alternative: This scenario tested the sensitivity of the original Base Case scenario by making the Gardiner Expressway and the Lake Shore Boulevard road allowances a weak constraint instead of an opportunity. This alternative explored how strongly the Gardiner was preferred by the routing model versus the next most preferred alternative.
- Social Scenario: This scenario focused primarily on the perceived potential effects of the Project on the public and was configured by increasing the level of selected socially relevant constraints based on team members’ experience dealing with stakeholders. Trade-offs included diminishing the constraint level of certain technical considerations such as underground utilities and decreasing the attractiveness of co-locating with road allowances.
- Permitting Scenario: This scenario was intended to have an environmental focus, but given the highly urbanized landscape was instead configured to examine the path of least resistance in terms of regulatory permitting by avoiding factors which may increase regulatory/permitting challenges.
- Technical Scenario: This was designed to favor pipeline engineering design, construction, and operation. Trade-offs included lowering the influence and constraint level of selected environmental and social indicators.

The four scenario indicator weights and related background information were captured graphically in a document called an “indicator workbook” to describe several aspects of the routing criteria, including indicator name, the intent of the indicator, the source data, GIS processing steps, a graphical depiction of the data, and the scenario weights (Figure 3).

The indicator workbook was intended to explain the routing decision criteria and different scenarios to nontechnical audiences in support of public and stakeholder engagement. It also aided in describing how the project incorporated sustainability considerations (i.e., incorporated environmental and social considerations into the routing) for internal management purposes, and provided greater project transparency and defensibility in communications with regulators during the OEB approval process.

As with the previous Base Case, each of the alternative scenarios were digitally combined by the GIS routing model program to produce maps of pipeline routing suitability across the Study Area. A separate suitability surface and set of corridors was created for each of the scenarios.

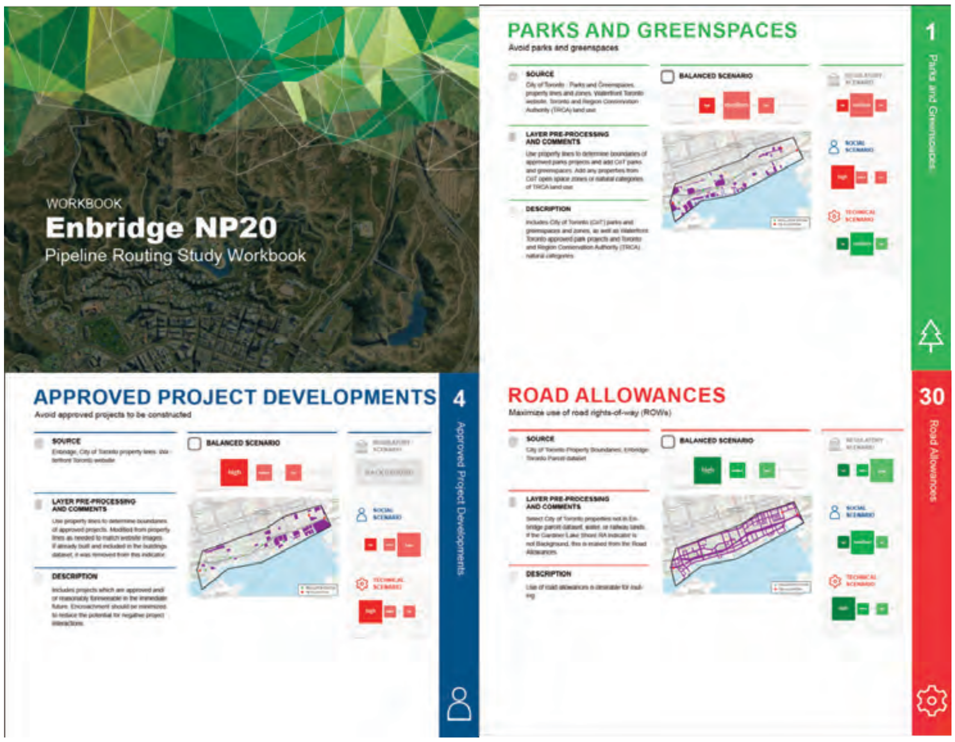

Figure 3. Sample indicator workbook pages

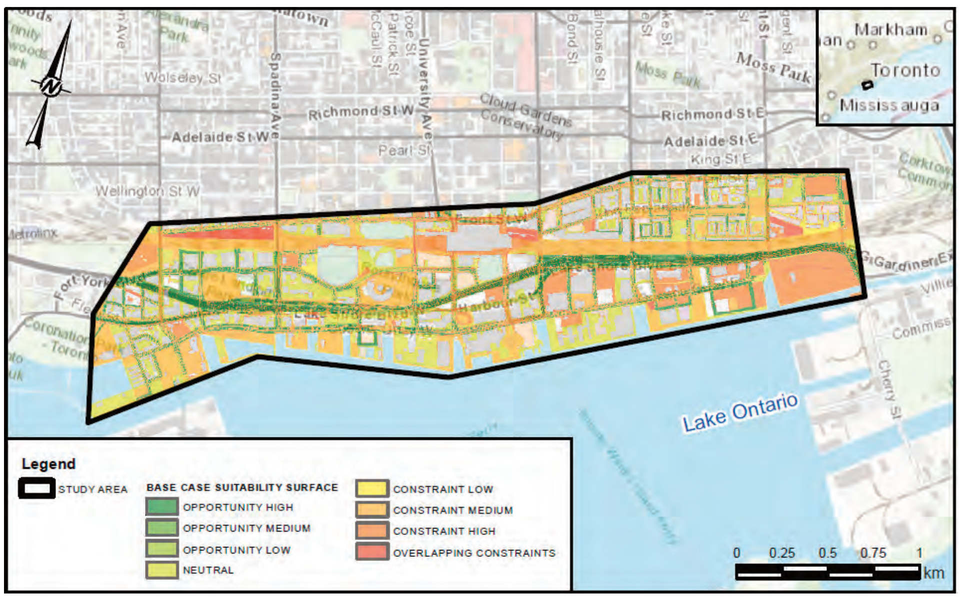

Figure 4. Base Case scenario suitability surface

OPTION COMPARISON AND CORRIDOR SELECTION

The centerlines for each scenario option were buffered by 2 m on either side to create a 4 m wide corridor that simulated a ROW. The simulated ROW was used in a GIS to obtain a set of quantitative metrics that were used to further evaluate and compare corridor options.

The resulting metrics were presented to SMEs and Enbridge decision makers at a final route alternative selection workshop. The objectives of the workshop were to:

- Present and discuss the simulated ROW results for all scenarios
- Present and discuss the comparative metrics for each scenario ROW
- Undertake a short-listing exercise to consolidate results, eliminate routes or route segments which overlapped other results, and to decide which route option candidates were most feasible

RESULTS

A suitability surface represents the combined influence of all indicators and their respective weights depicted in a single “heat map” image. Areas of low suitability (high constraint) are shown in red to orange tones. Areas of moderate suitability are yellow, and areas of high suitability (low constraint) are indicated by green tones. Areas of exclusion are indicated by white areas.

The Base Case suitability surface results are presented in Figure 4. The results show a highly suitable area (dark green) extending from the west to east tie-in locations, corresponding to the Lake Shore Boulevard ROW in the west, extending to the Gardiner Expressway ROW in the east central portion of the image. Smaller and slightly less suitable corridors are associated with disconnected portions of the Queens

Quay and Harbour Street road alignments. The further one moves north or south of this central alignment, the less suitable the landscape is for pipeline routing. This characteristic is generally consistent in all the suitability results.

In comparison, the Base Case Alternative suitability surface results remove the Gardiner Expressway as an opportunity from the original Base Case model to explore other routing options using the same model rationale (Figure 5). The resulting corridors from both scenarios are presented in Figure 6 where the Base Case narrow, medium, and wide corridor preferred the road alignment extending from Lake Shore Boulevard and along the Gardiner Expressway. The Base Case Alternative used the west end of Lake Shore Boulevard but then departed south to access Queens Quay West and traverses east, where it connects to the East End tie-in point along Front Street to Cherry Street. The Base Case Alternative also identified a secondary corridor paralleling a thin margin of unused land on the south margin of Gardiner Expressway.

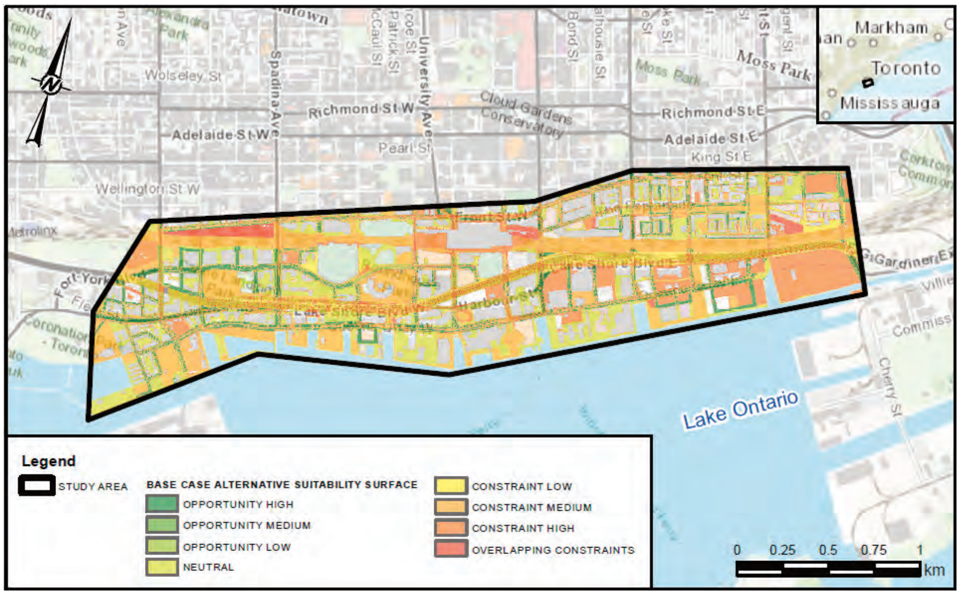

Figure 5. Base Case Alternative suitability surface

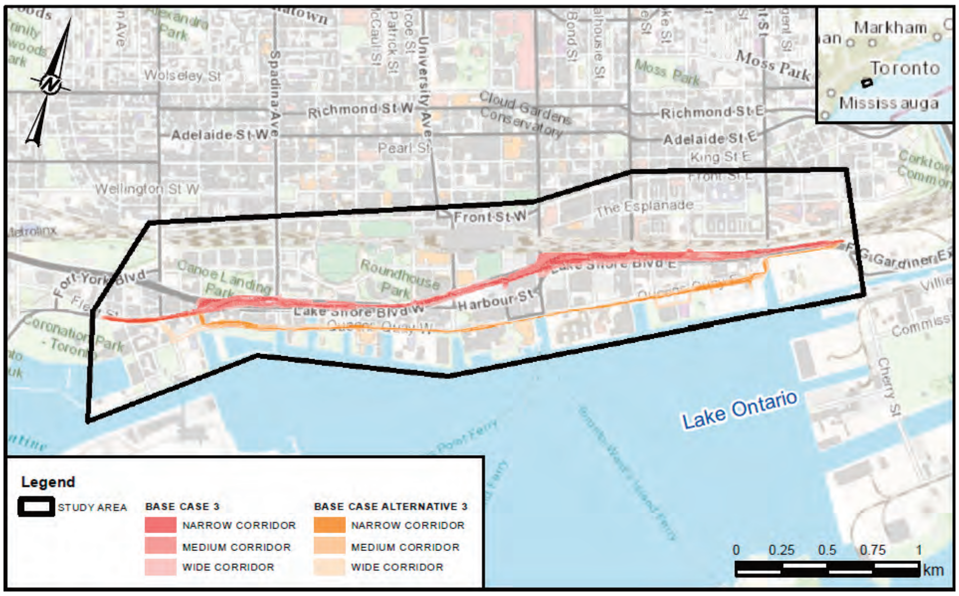

Figure 6. Base Case and Base Case Alternative corridor results

The Social Scenario suitability and corridor results are shown in Figures 7 and 8 respectively. Even with increasing the level of socially relevant constraints and lowering the importance of certain technical considerations, such as proximity to underground utilities, the Social corridors showed a preference for a nearly identical alignment to the Base Case scenario.

The Permitting Scenario proved to be the most restrictive model in the Study, as it explored the potential for avoiding indicators that would cause the regulatory complexity and concern, such as permitting a pipeline route underneath the Gardiner Expressway, which was believed to be a challenging option by Enbridge at the time. As a result, the Gardiner was given a low constraint level in this scenario. The suitability surface and resulting corridors for this scenario are provided

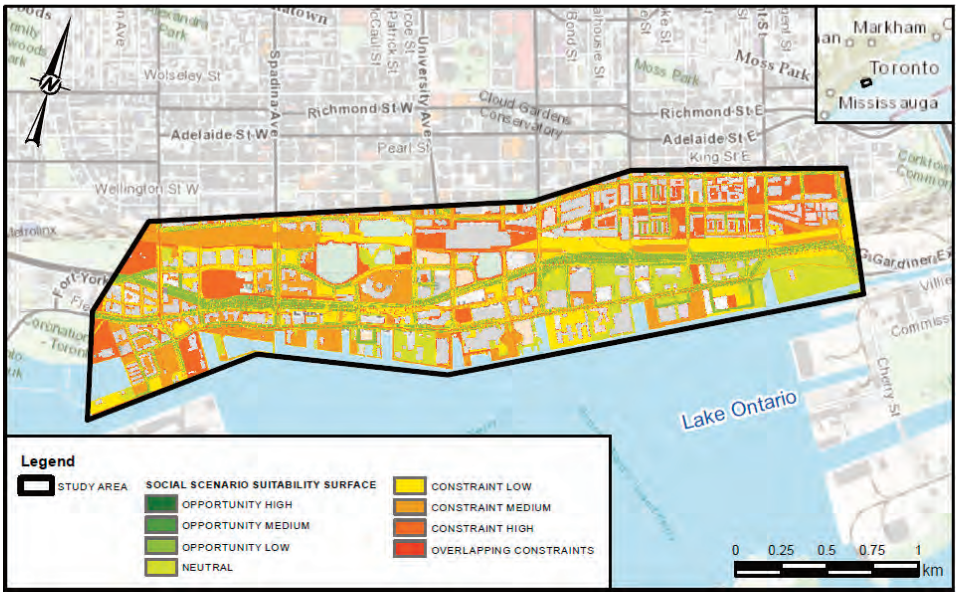

Figure 7. Social Scenario suitability surface

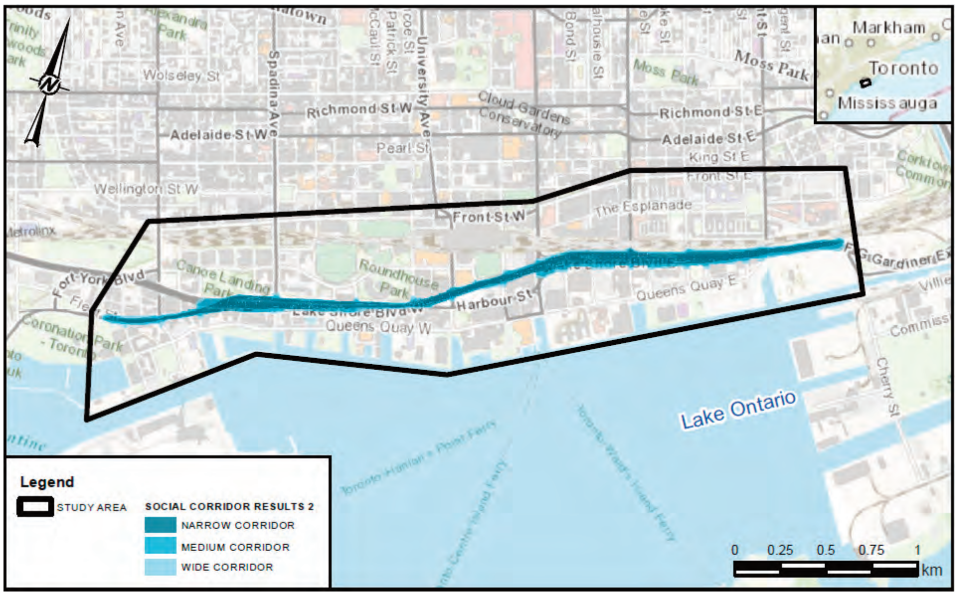

Figure 8. Social Scenario corridor results

in Figure 9 and it shows how little highly suitable areas are available in the model. As a result, it forced the corridors to prefer the less constrained alignment which corresponded predominantly to Queens Quay West, connecting to Lake Shore Boulevard in the west and the Gardiner Expressway in the east.

Conversely to the previous results, the Technical Scenario was the least constrained model in the Study, as it reduced the importance of social and regulatory considerations in the model and focused on engineering and operational considerations, which provided a higher degree of freedom within the Study Area with the exception of crossing other underground utilities, which remained a moderate to high constraint to reduce the number of crossings and optimize crossing locations. As a result, there are considerably more areas which show higher suitability, excluding the rail

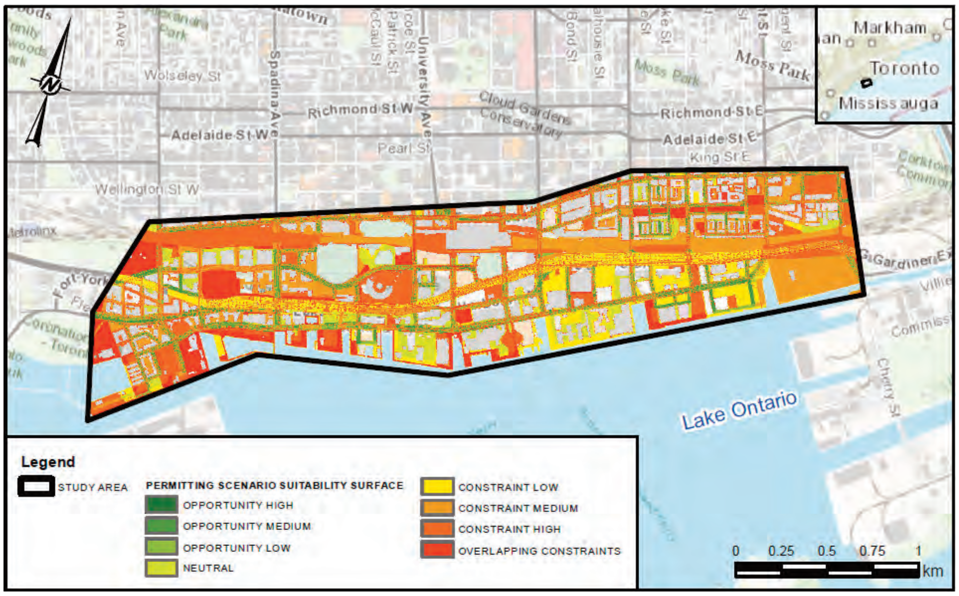

Figure 9. Permitting Scenario suitability surface

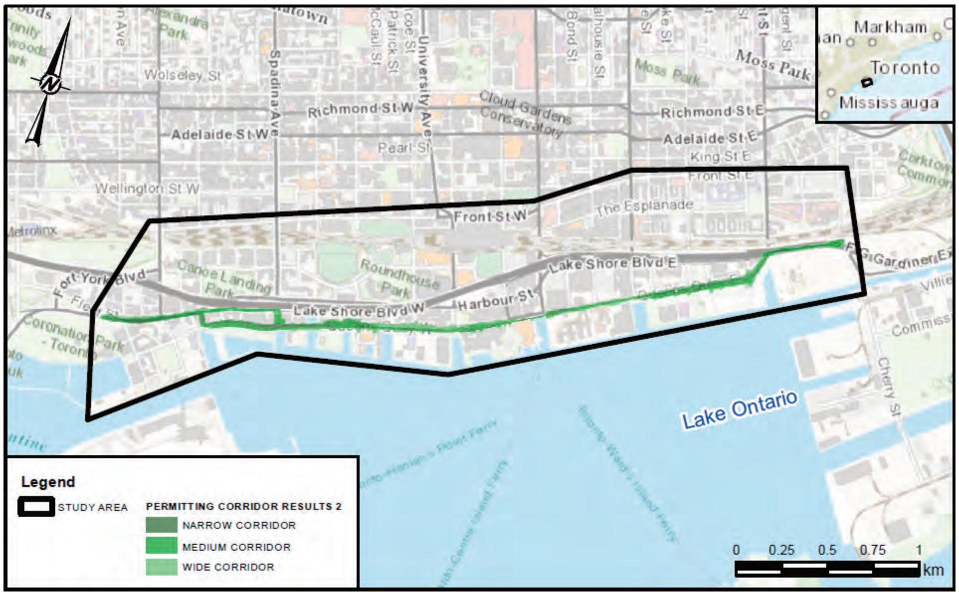

Figure 10. Permitting Scenario corridor results

transportation corridor traversing the study area from east to west (Figure 11).

Even under a lower level of constraint, the Technical corridors preferred a nearly identical corridor to the Base Case, utilizing the Gardiner Expressway and Lake Shore Boulevard. The one exception was an offshoot along Harbour Street which roughly parallels the Gardiner (Figure 12).

DISCUSSION

Analysis of the Study results clearly showed that the alignment connecting the east and west tie-in locations via the road alignments of Lake Shore Boulevard and the Gardiner Expressway was highly suitable from all model perspectives except the Permitting scenario. This result indicated that the Base Case route was robust from a variety of perspectives, including the social and technical considerations.

Consequently, a detailed survey of the Gardiner upright supports was conducted by Enbridge and incorporated into the Base Case model to validate if this corridor was still feasible. From this work, it was concluded that sufficient space existed to locate the NPS20 pipeline and related workspace. That said, constructing around the Gardiner Expressway support columns was the most technically challenging aspect of the Project, but it resulted in the least social and stakeholder impact, and this design choice allowed the project to advance more smoothly.

Two other feasible alternatives to the Gardiner were indicated by the Study, including an alignment located in Harbour Street and another located the Queens Quay road allowance. The only feasible lateral connection to the North End tie-in point was the Parliament Street road alignment, and it is common to all route options.

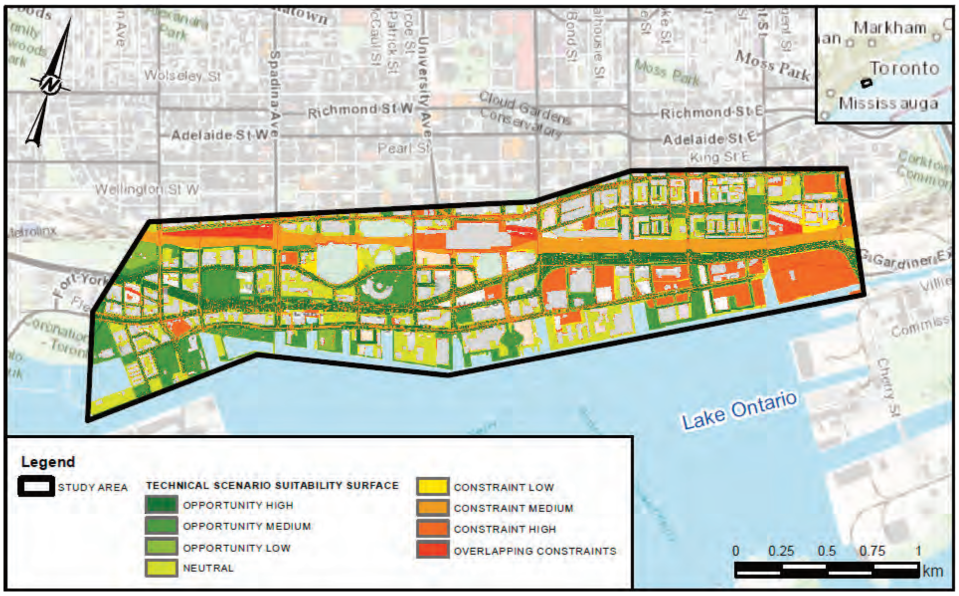

Figure 11. Technical Scenario suitability surface

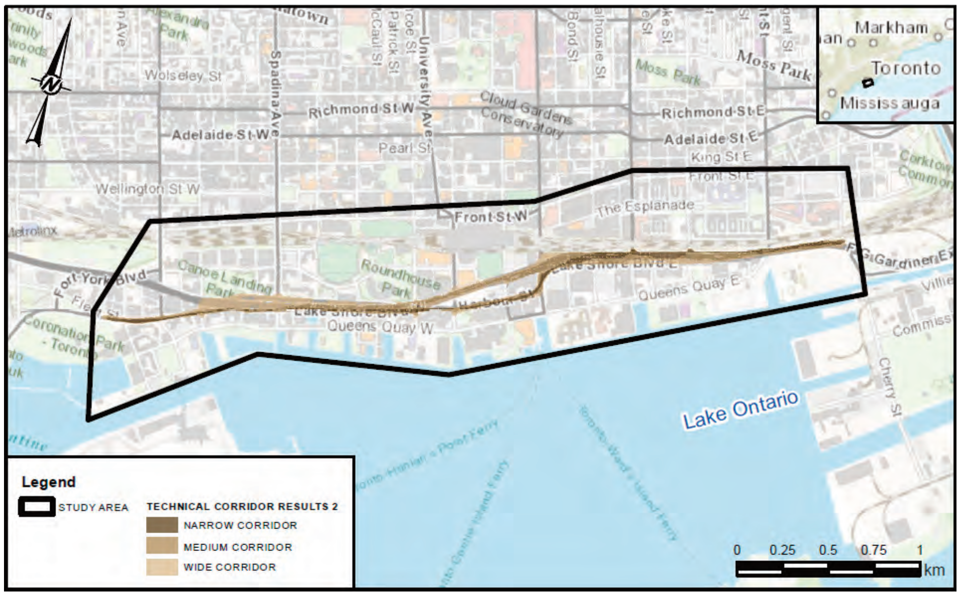

Figure 12. Technical Scenario corridor results

For the purposes of public consultation and subsequent applications for a Leave to Construct under section 90(1) of the OEB Act, the Study results were renamed (Table 2, Figure 13):

Apart from indicators that were assigned to be full exclusion areas (such as building footprints), which were completely avoided, further analysis of the results determined the following indicators to be most influential in terms of resisting corridors due to their location, size, distribution, and extent:

- Utilities – High Constraint, including active pipelines, steam lines, and chambers
- Utilities – Moderate Constraint, including active underground cables and conduits, gas, sewers, storm water, and vaults
- Tram Streetcar Light Rail Transit

  Road Moratoriums–recently paved roads that have a moratorium on activities which would damage or disturb fresh pavement
- Gardiner – Lake Shore Road Allowance
- Approved Project Developments and Setbacks

Corridors avoided or minimized their proximity to the above unless they could not be avoided; in which case they were crossed at the least cumulatively constrained point. Conversely, the most attractive indicator in all scenarios was the Road Allowances Indicator. Only limited use of other opportunities, such as walkways, were made.

Through the course of the environmental assessment process and public and stakeholder consultation, the route combining Lakeshore Boulevard and the Gardiner Expressway (Option B [Base Case Scenario]) was ultimately selected as the preferred route.

Enbridge received regulatory approval (Leave to Construct) from the Ontario Energy Board for the Option B route in only 120 days and is currently in the process of constructing the pipeline (Figure 14). The authors attribute the rapid approval to addressing the difficult ESG considerations early in the process in a transparent and defensible way.

Table 2. Final Route Names

Study Name	Final Route Name
Permitting Scenario	Option A
Base Case Scenario	Option B
Technical Scenario	Option C

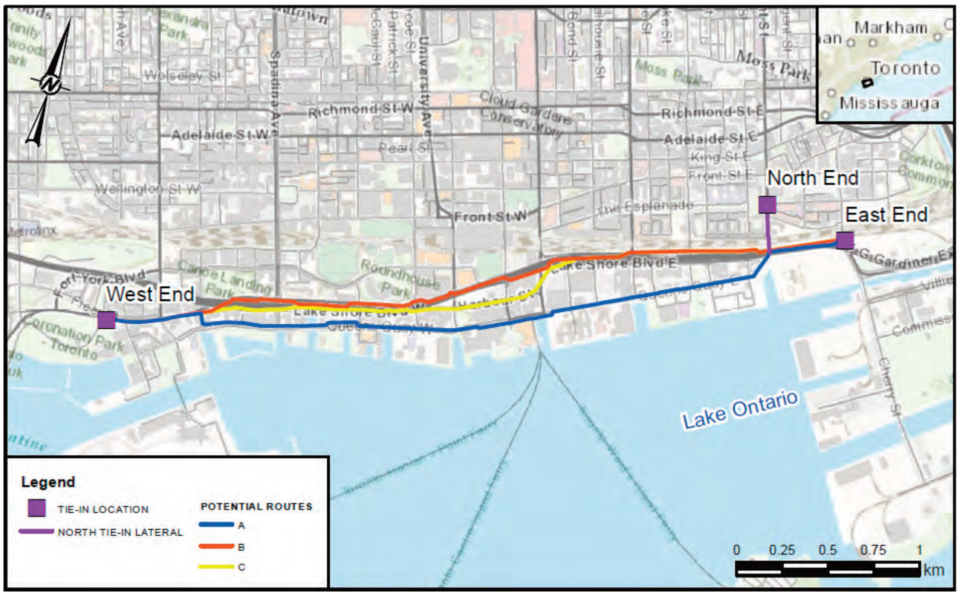

Figure 13. Final route selection

Figure 14. CTB construction under Gardiner Expressway, Toronto, Ontario. (Source: Tom Fowler, NPL Canada Ltd.)

CONCLUSIONS

The Study successfully employed a methodology whereby several feasible pipeline routing scenarios were developed to represent different possible pipeline routing perspectives by systematically exploring how different combinations of ESG and technical considerations influenced potential routes. This work was done at a much higher spatial resolution than previous pipeline corridor assessment studies and shows that in locations where very precise and high-quality data is available, this routing technique and suite of GIS-based tools can be used to inform very detailed preliminary route centerlines as an initial step in pipeline engineering design.

Environmental, social, and governance has become a vital component of pipeline projects, and the importance of understanding the impacts of the project and the asset over its lifetime has risen to the point that no project can successfully be put into service without some measure of acceptability. More and more, carbon policies and the public perception are changing what it means to grow and operate a natural gas utility, and Enbridge is looking at ways to continue delivering the energy people need and want in safe and reliable manner.

The Study demonstrates to other operators how routing can be successfully conducted through highly complex urban environments, where the potential for public and stakeholder opposition is high and there are very rarely any good routes, only a set of "least-worst" options.

ACKNOWLEDGMENTS

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Solving Real Utility Problems with Innovation: Complex Compliance Support Using ArcGIS Online, Python, and FME Server

Donald Handshoe, Jeff Friesen, and Neil Young

Keywords: ArcGIS Online, Digital Innovation, Geospatial, Real-Time Communication, Regulatory Compliance, Stakeholders, Utilities.

The West of Devers Transmission Line Upgrade Project in eastern Riverside County, California, required tearing down and rebuilding 296 circuit kilometers (km) of existing 220-kilovolt (kV) transmission lines, so it was critical to get accurate and up-to-date data from more than 80 km of project extent to more than 100 remotely dispersed field team members. To monitor project compliance, an integrated systems approach was used to integrate data across existing solutions and stakeholder platforms.

The spatial capabilities of Esri's ArcGIS Online platform provided mobile data collection tools, live maps, and dashboards for visualizing project status, giving the project team an at-a-glance view of the compliance state of more than 1,000 individual construction sites. Automated processes were built on top of the live data to scan all project sites and continuously update site status for each location based on environmental, construction, biological, and permitting status inputs from the field or office—all accessible live by project regulators, project proponents, and consulting and construction staff.

Digital transformation of data capture and reporting helped provide a truly integrated, holistic solution that increased quality and responsiveness and, ultimately, saved time (and sanity) for the project team.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

Environmental compliance for large capital projects in California requires intricate data and must follow complex rules. Numerous activities, such as helicopter use and construction site monitoring, require an enormous amount of data to be processed, analyzed, and provided to field teams on-site and to regulators that continuously monitor and inspect the project and individual sites.

Southern California Edison (SCE) constructed and replaced 80 kilometers (km) (296 circuit km) of 220 kV transmission infrastructure in Southern California to help bring electricity to the Los Angeles region and beyond, a project known as the West of Devers (WOD) Project. To address the complex demands for real-time data, a "system of systems" was developed using the Esri ArcGIS Online (AGOL) and Enterprise platforms. These systems gave the construction and environmental compliance teams the flexibility and power to respond to evolving safety, regulatory, and reporting needs.

The AGOL platform allowed flexible solutions to be prototyped for office and field use, then expanded and enhanced as complex mitigation measures were negotiated through constant collaboration between SCE, regulatory agencies, and the many project contractors. Esri's ArcPy and Safe Software's Feature Manipulation Engine (FME) scheduled tasks were integrated tightly with AGOL and Enterprise to integrate SCE's Field Reporting Environmental Database (FRED) with other project environmental data and workflows. This back-end data management and processing provided critical project data to more than 100 field and office users. Collector, Survey123, and "lite" web apps via mobile browser were used constantly by construction, environmental, paleontological, cultural, biological, and regulatory agency staff.

The project team was challenged by the sheer size of the project, coupled with requirements in California for near real-time data for field teams to avoid compliance violations. Staff needed to be able to react quickly to ever-changing events to stay ahead of regulators. With more than 100 team members working on various parts of the project, a system was needed to support the data flow between the various teams, SCE, and state regulators.

Figure 1. West of Devers Project *Note: Grey box shows the project area.* (Map Service Layer Source: Loma Linda University, County of Riverside, San Bernadino County, Bureau of Land Management, Esri, HERE, Garmin, USGS, NGA, EPA, USDA, NPS)

Traditionally, geographic information systems (GISs) have been a bit of a bottleneck in the field work process. Data would come to an analyst, would need to be processed and exported back to a file suitable for a global positioning system (GPS) unit, and then sent out to team members in the field. Team members would then need to use a computer to load the new files into the GPS unit. Using Collector, teams were able to receive live updates to data as they became available and respond appropriately in real time. Regulations required that biological sweeps—the process of surveying for threatened or endangered species—occur on construction sites before any work could commence. If no work occurred for either seven or ten days, depending on the species known to inhabit that area, construction sites would need to be resurveyed before being considered "active" again. With over 1,000 individual construction sites, the logistics of monitoring this work manually was untenable. Additionally, project data routinely changed as construction and engineering adapted to challenges, and these data needed to be disseminated to field teams, contractors, and regulators immediately.

Southern California Edison used helicopters to string conductors on the project. California has stringent regulatory guidelines in relation to bird nests, and it was therefore important to monitor helicopter flights, manage bird nest data, and report on potential flight path violations. Each nest had a buffer distance, which the helicopter could not cross. The distance varied based on the species of bird and the time of year. Additionally, bird nests could become active or inactive, depending on timing and reports from field biologists. These factors made it very difficult to develop a solution that could be automated.

METHODS

Data Management

The AGOL and Enterprise platforms are well-suited to support field work. With commercial off-the-shelf (COTS) solutions, such as web maps, apps, Collector, and Survey123, disconnected field solutions could easily be deployed across the broad range of WOD work sites and teams. Web maps and the Collector app on tablets were used in the field to collect data.

Using the powerful ArcPy library within the Python scripting language, scripts were developed that could analyze the data, look for activity on a construction site, and update the data accordingly. If activity was detected, the seven- or ten-day countdown was reset. If not, the countdown was updated with the remaining days until a site was considered inactive. Each morning, another script summarized this information, noting which sites were inactive, or about to become inactive, and emailed the information to project team members.

Additionally, to visualize the information and provide a one-stop location for monitoring and managing construction site status, we developed a dashboard to relay this data (Figure 2). The dashboard provided metrics for site status, as well as individual site summaries, recent activity, and mapping of all construction sites.

Status could easily be discerned by symbology, which was automatically set using logic based on site staking, regulatory validation, status of bio sweeps, and other criteria. Seven possible statuses were developed for construction sites, and only two of those statuses allowed for entry by construction crews (Figure 3).

Site status was only one component for this project. Multiple teams needed specific information as it pertained to their disciplines. To aid in managing the massive flow of data, a system of web applications was developed to relay specific components of the project to their respective teams (Figure 4).

These applications were assembled in a singular location for ease of navigation using a series of embedded AGOL apps to create a central hub. Documentation could also be linked to describe processes and procedures for using the various applications.

Helicopter Overflights

In developing earlier solutions, a Python script had already been written that could retrieve data from the FRED database, including bird nest information. Using FME, a workbench was created to run each night. This workbench pulled in bird nest data, created buffers based on values in the data, and then packaged everything into a GPS Exchange Format (GPX) file. FME then emailed the GPX file to the contractors to load into their helicopter's GPS. The helicopter pilots

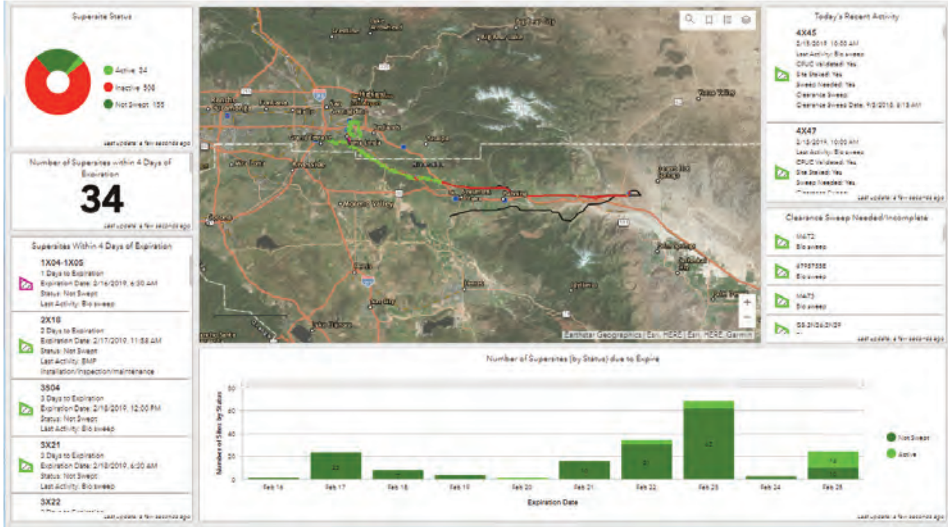

Figure 2. Site status dashboard

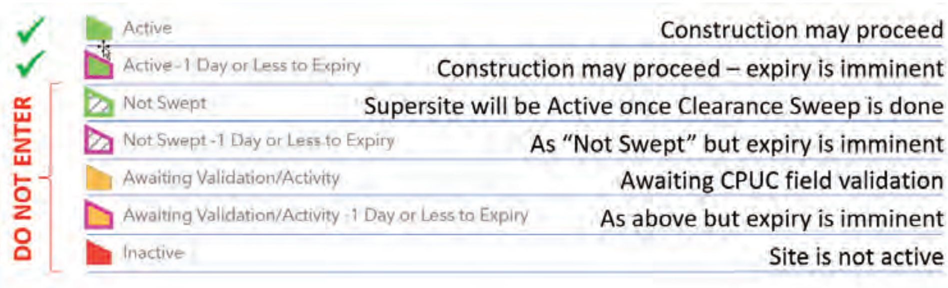

Figure 3. Site status values

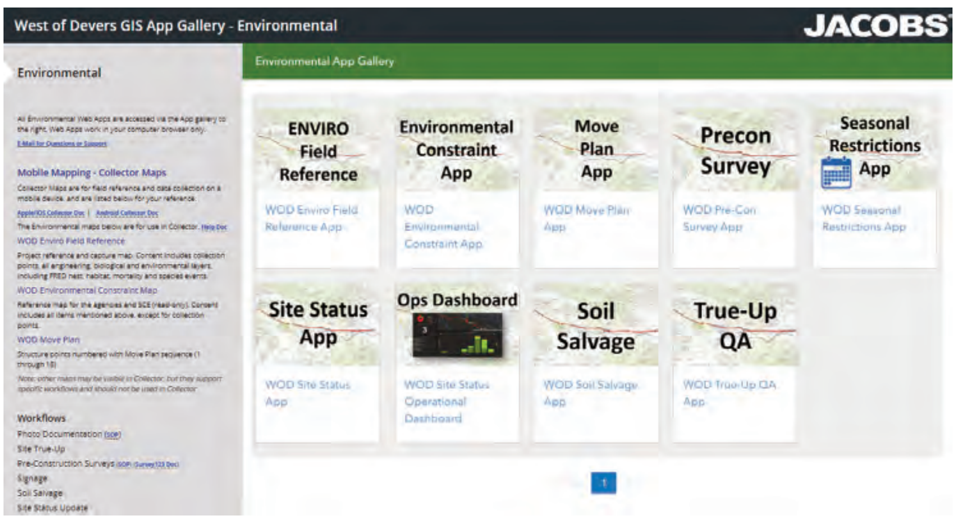

Figure 4. Gallery of web applications

could then use the information to plan their flights and avoid bird nest encroachments (Figure 5).

At the end of each day, the GPX file was downloaded from the GPS and emailed back for processing. Each night, a separate FME workbench ran to look for new GPX files. If a new one was detected, it would be pulled in for processing. The GPS loggers used in the helicopters recorded tracking data as individual points, recorded every three seconds. This results in thousands of data points that were extremely difficult to interpret on their own.

The FME process converted these points into line segments, and then into flight paths. At this point, another Python script would run a four-dimensional (4D) analysis on the data. Bird nest buffers could change within a matter of hours or even minutes. In addition to the normal three-dimensional (3D) analysis (x, y, and z axes), the script needed to consider the time of the flight, thus the fourth dimension.

If the Python script detected an incursion, a report was generated with notifications. At that point, an ArcGIS Pro document could be manually opened to verify the incursion. Using Pro allowed the data to be visualized in 3D. The bird nest buffers were extruded into cylinders, and the flight path data could be visually manipulated to verify the incursion was legitimate. If it was, state regulators were immediately notified. If not, the reason was noted for later review. The most common cause of incursion reports was the delay between official approval of a buffer reduction and the update to the tracking system of that reduced buffer.

To further assure state regulators that SCE was in compliance with regulations, a meeting was conducted every two weeks to review the helicopter data. Reports were generated ahead of time detailing all helicopter flights since the previous review, and an ArcGIS Online web app was developed to review data in real time (Figure 6).

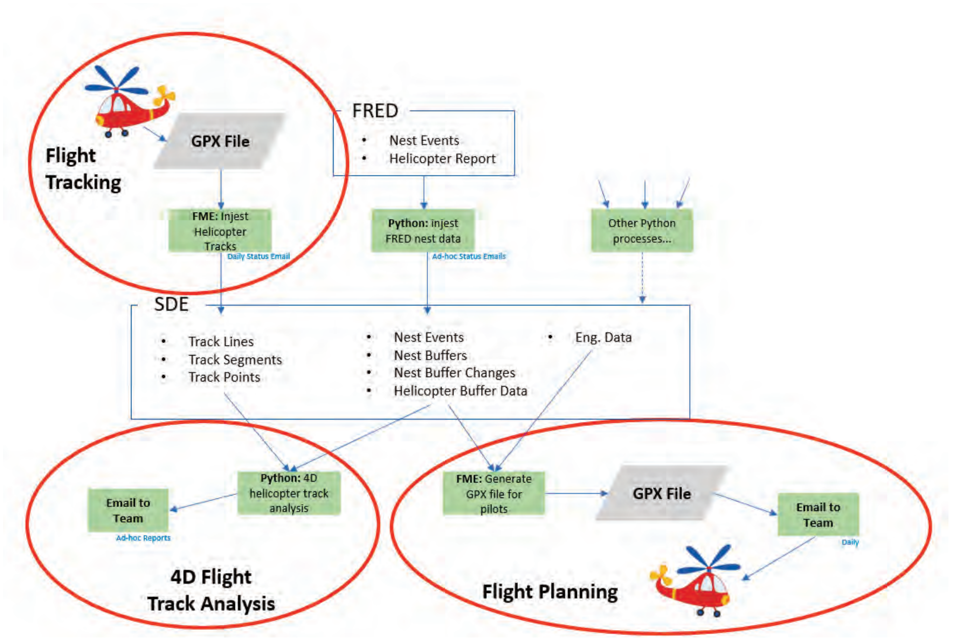

Figure 5. Helicopter data automated processing workflow

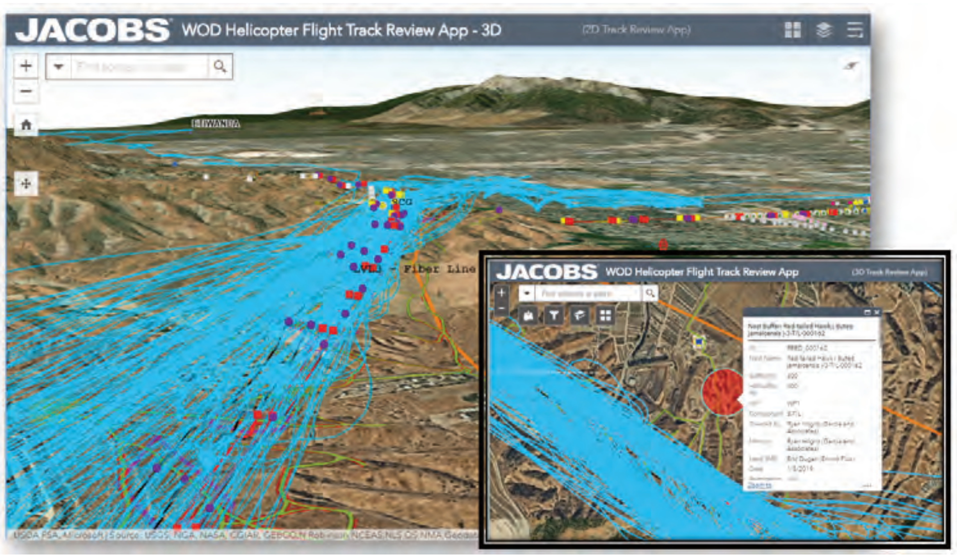

Figure 6. Helicopter review app

RESULTS AND DISCUSSION

By combining multiple platforms, software, and processes, an integrated system of systems was developed, capable of managing a large capital project with massive amounts of data flowing in and out (Figure 7).

This interconnected system allowed us to implement advanced workflows:

- Project construction site status was automatically maintained and widely shared in near real time through an ArcPy algorithm deriving status from site activities, inspection expiry dates and times, and other field-set parameters.
- ArcPy was used with FRED to pull JavaScript Object Notation (JSON) data from needed reports to share active bird nest buffers project-wide.
- Helicopter GPS GPX files were automatically generated and distributed using FME, providing helicopter waypoint and no-fly zone tracks from live project data to the flight team.
- Daily scheduled 4D intersection analysis through ArcPy checks extruded bird nest buffers against flown helicopter tracks to validate minimum flight distances from nests.
- Time-aware data and apps were used in live review of seasonal habitat constraints and helicopter tracks for regulatory agencies.
- Operational dashboards were used to monitor pending site status expiries, road signage status, species mortality events, and other important mitigation metrics.
- Safety issues, such as hornet nests or road washouts, were flagged and tracked by field staff and were immediately available to the full project team.

By developing web applications in AGOL, a data bottleneck was eliminated and allowed near real-time data access to project teams. No longer did teams have to wait for a GIS analyst to process data and export static Adobe Portable Document Format (PDF) maps that could become outdated within a day. This type of access also allowed the project proponent (SCE) and regulators to view data as needed, instead of waiting hours or days for answers to their questions. Teams could also react quickly to critical, time-sensitive events, such as new bird nests or safety hazards, with data being disseminated quickly and efficiently to all involved parties.

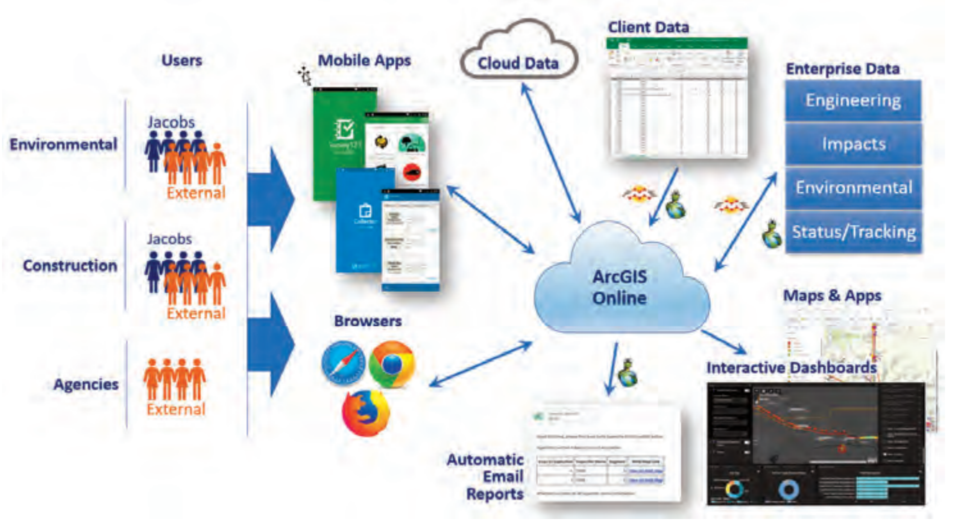

Figure 7. Conceptual system diagram

CONCLUSION

Under normal circumstances, the enormous amount of data processing needed on a project such as this would require a large team of dedicated GIS analysts. By automating the majority of data processing and analysis, the team was reduced to only a few analysts, thereby saving hundreds of labor hours and many thousands of dollars in project costs. There *was* a heavier cost and time commitment on the initial setup than a normal project (development, licence fees, AGOL Project Delivery Organization purchase), but the return on investment was substantial. The approach was successful in satisfying project needs and regulatory requirements.

As regulators, legislators, and even private entities endeavor to address climate change, habitat loss, and other environmental concerns, the need for complex, real-time data processing will continue to grow. To meet this challenge, numerous utilities are investing in technologies to reduce labor costs and automate processes to facilitate better decisions based on better and current data.

By utilizing COTS as a foundation, the way the work was delivered has been transformed while allowing quick alterations to workflows and rapid prototyping of solutions. Additionally, these COTS were combined with custom scripting to develop a "system of systems." This system was agile enough to quickly adapt to changing field protocols; disseminate constantly evolving project data to the entire project team; proactively and automatically test and confirm mitigation requirement compliance; provide near real-time monitoring of work progress and important safety issues; significantly improve the transparency of the project operations for regulators and the owner; and reduce overall cost.

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Donald Handshoe, located in Cincinnati, Ohio, is a Senior Geospatial Solutions and Siting Lead in the Jacobs Federal and Environmental Services Business Unit, where he leads the Siting and Permitting GIS Team. With a strong background in project management, risk assessment, site and route selection, and public engagement, he has spent the last 16 years successfully delivering international and domestic U.S. projects for clients, both big and small. Handshoe is a geospatial leader at Jacobs and uses his skills and expertise to drive digital transformation for electric and gas transmission, as well as offshore wind and other renewable energy projects. He received Bachelor of Arts degrees in classical archaeology and anthropology from the University of Kentucky and a Master of Science in geospatial sciences from Northern Arizona University.

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New infrastructure projects are developing at a rapid pace to meet current and future demands for generation, transmission, and distribution of energy, but many of these projects—particularly those aimed at capturing wind energy—pose a risk of running afoul of laws and regulations that protect birds. Understanding the goals and objectives of these laws and the authorized strategies for permitting incidental take is critical to the successful deployment of new infrastructure. This paper also looks at additional legal tools not normally associated with such projects that could assist in achieving both the goal of reducing bird takings and promoting green infrastructure development, and suggests proposals by which industry, government, and NGOs can cooperate to achieve common objectives.

Understanding Laws and Regulations that Protect Birds and Planning Strategies to Minimize Takings in Infrastructure Development

Timothy Brannan and Lawrence J. Kahn

Keywords: Birds, Construction, Energy, and Mitigation.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION TO THE MIGRATORY BIRD TREATY ACT

Practical and legal applications of the Migratory Bird Treaty Act (MBTA) have sometimes ignored reality; but change is on the horizon. Regulatory and activist agencies are concerned about declining migratory bird populations while, simultaneously, utilities are concerned about facing criminal liability for strict liability crimes they can't prevent. Meanwhile, utility infrastructure is set to increase two to three times in the next three decades, which has the potential to dramatically increase bird takes as well as expose utilities to increased threat of prosecution for such takings. Recent political turmoil with the U.S. Department of the Interior (DOI) has only increased governmental intent to include incidental take in the MBTA. Still, this is only one side of the story. Potentially millions of birds are already dying despite alleged protections afforded to them under the MBTA, and that even if utilities do everything right—every single thing the government tells them to do—those same utilities will still nonetheless "be deemed guilty of a misdemeanor and upon conviction thereof shall be fined not more than $15,000 or be imprisoned not more than six months, or both" (16 U.S.C.A. § 707 [West]). How did we get to this point? We should review the history of the MBTA and related acts that protect birds.

THE MBTA AS A "POLITICAL FOOTBALL"

Enacted in 1918, the MBTA states that "it shall be unlawful at any time, by any means or in any manner, to pursue, hunt, take, capture, kill, attempt to take, capture, or kill…any migratory bird, any part, nest, or egg of any such bird… included in the terms of the conventions…" with Great Britain (now Canada, 1916), Mexico (1936), Japan (1972), and the USSR (1976) (16 U.S.C.A. § 703 [West]). This section has not been substantially modified by Congress since 1936 (Nat. Res. Def. Council, Inc. v. U.S. Dept. of the Interior, 478 F. Supp. 3d 469, 472 [S.D.N.Y. 2020]).

Although the MBTA speaks in terms of absolutes, there is an exception for "incidental take," defined as a wildlife take that is "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity." This was implicitly included in the MBTA until 2017 (Crowell 2020).

Each of the last three DOI Solicitors has authored an opinion regarding the inclusion of incidental take in the MBTA. These opinions do not change whether or not incidental take is legally part of the MBTA; they simply inform U.S. Fish and Wildlife Service (USFWS) officials of how they are (or are not) supposed to enforce the law as concerns this rather vague exception. Under the Obama Administration, Solicitor Opinion M-37041 took a rather extreme view and stated that incidental take was included in, and thus prohibited under, the MBTA (Incidental Take Prohibited Under the Migratory Bird Treaty Act, 2017 DEP SO LEXIS 6, *2). Under the Trump Administration, Solicitor Opinion M-37050 replaced M-37041 and specified that incidental take was *not* included in the MBTA (The Migratory Bird Treaty Act Does Not Prohibit Incidental Take, 2017 WL 9288212, at *25). Most recently, under the Biden Administration, Solicitor Opinion M-37065 permanently withdrew Solicitor Opinion M-37050, implicitly returning incidental take to the MBTA (Permanent Withdrawal of Solicitor Opinion M-37050 "The Migratory Bird Treaty Act Does Not Prohibit Incidental Take," 2021 WL 7286319, at *1).

Warring political ideologies aside, it is fair to state that the world is a different place now than it was when the MBTA was created. A hundred years ago, bird populations were being decimated largely because it was fashionable to wear bird feathers, even whole stuffed birds, on hats and other garments. One of the earliest environmental movements—protection of birds—was borne out of a need to protect them from the fashion industry, not because birds were running into structures or powerlines (Greenspan 2015). Indeed, it should be considered that when the MBTA was signed into law in 1918, scarcely 20% of U.S. households even had electricity (Kaplow 2021).

THE COURTS ARE DIVIDED IN INTERPRETING THE MBTA

Recently (in the lifespan of the MBTA), circuit courts have disagreed over whether or not incidental take is included in the MBTA. These arguments feature prominently in the competing Solicitor's Opinions. Currently, the Second and Tenth Circuits have ruled that the MBTA includes incidental take while the Fifth, Eighth, and Ninth Circuits have excluded incidental take from the MBTA. The other circuits have been silent on the issue, meaning that there are 22 states without circuit court opinions concerning incidental take under the MBTA, which means that the issue is being resolved on a case-by-case basis in the federal courts in those states (to the extent that such cases are being brought at all).

In cases that occur within the Second Circuit (New York, Vermont, and Connecticut), cases will be prosecuted based on the precedent set in *United States v. FMC Corp.* (572 F.2d 902, 908 [2d Cir. 1978]). Here, the court ruled that the defendant was strictly liable for taking birds under the MBTA because the defendant pumped toxic wastewater into a pond and failed to keep birds from landing in the pond. In that case, the court ruled that takings under the MBTA did not require affirmative action or intent to harm birds which results in death or other illegal taking (Id. at 906). Effectively, the court ruled in that matter that the taking of a bird (or a part of a bird or its nest or other territory) was a strict liability crime—it did not matter if the perpetrator wished to cause harm or intended to violate the law. Ordinarily, to be successfully prosecuted for a crime, the perpetrator must be guilty of both a guilty act (*actus rea*) and a guilty mind (*mens rea*); one without the other will not result in a criminal finding. However, the Second Circuit in this matter determined that the underlying treaty, as enacted into federal law, did not require a guilty mind. Violation of the law was all that was required for successful prosecution. Only the *actus rea* was necessary to create liability under the MBTA. The court determined that under the wording of the law, there was no difference between shooting a bird intentionally and failing to take action to prevent a bird take where there is a duty to do otherwise. The court determined that both result in illegal takings, and hence result in criminal liability. Ultimately, the court concluded that the defendant, by bringing toxic waste onto its property, is prima facie responsible for all damages which could reasonably be predicted from this action, regardless of intent (*Id.* at 907).

Incidental take cases brought in the Tenth Circuit (Colorado, Kansas, New Mexico, Oklahoma, Utah, and Wyoming) can also be prosecuted, as set forth in *United States v. Apollo Energies* (611 F.3d 679 [10th Cir. 2010]). Here, the court found that defendant oil drilling operators were liable for incidentally taking birds under the MBTA after birds repeatedly got caught in oil drilling equipment (*Id.* at 682). While the defendants in *Apollo Energies* argued that the active language defining take in the MBTA showed that the act required an intent to take a bird (*mens rea*) to violate the act, the Court did not agree (*Id.* at 685). It was abundantly clear in *Apollo Energies* that the defendants had no intent to cause the deaths of the birds, and the defendants argued that they had merely failed to prevent bird deaths from occurring. The court determined, as did the Second Circuit in *FMC Corp.*, that there is no explicit *mens rea* requirement in the statute, and the plain language of the statute itself showed Congressional intent to impose strict liability for takings under the MBTA (*Id.* at 686). Such strict criminal liability is simply not limited by whether the plaintiff's actions were the proximate cause of the takings and whether the taking might have been reasonably anticipated or foreseen as a natural consequence of the act in question (*Id.* at 690).

But not all courts have followed this line of thinking. Incidental take cases brought within the Fifth Circuit (Texas, Louisiana, and Mississippi) are more likely to be dismissed due to the precedent set by *United States v. CITGO Petroleum Corp.* (801 F.3d 477, 494 [5th Cir. 2015]). In CITGO, the Fifth Circuit ruled that the MBTA's ban on takings only prohibits intentional acts that directly kill migratory birds (i.e., that incidental take is not included in the MBTA) (*Id.* at 494). The Fifth Circuit reached this decision based on a very close analysis of what it means to "take" a migratory bird. The court began by determining that the word "take" had a particular meaning: it meant that animals had been reduced (via killing or capturing them) to human control, and that it was not possible to reduce an animal to human control accidentally (*Id.* at 489). The court supported this definition by comparing the definitions of "take" in the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA) to the one in the MBTA (*Id.* at 490).

While both the ESA and MMPA definitions of "take" possess the terms "harass" and "harm" in their stated definitions, the MBTA does not. The court noted that past cases had used the terms "harm" and "harass" to show that Congress meant for incidental take to be included in the ESA (*Babbitt v. Sweet Home Chapter of Communities for a Great Oregon*, 515 U.S. 687, 705, 115 S. Ct. 2407, 2417, 132 L. Ed. 2d 597 [1995]). Accordingly, the Fifth Circuit reasoned the absence of "harass" and "harm" in the MBTA demonstrated that Congress deliberately meant to leave incidental take out of this particular legislation (CITGO, 801 F.3d 477, 490 [5th Cir. 2015]). Indeed, the fact that MBTA defines take as to "pursue, hunt, shoot, wound, kill, trap, capture, or collect" a migratory bird created that impression that Congress was attempting to make it illegal to hunt migratory birds (which by its nature is an intentional act) and that Congress was not concerned with accidental, unintentional deaths of migratory birds (*Id.* at 491).

The Fifth Circuit disputed the Second Circuit's rationale that incidental take is included under the MBTA because the MBTA imposes strict liability for violations. The Fifth Circuit also took issue with how the Tenth Circuit seemingly sidestepped the issue of defining "take" by reasoning that since the MBTA prohibits killing birds, and the defendant killed birds, the defendant was guilty even though the killing was not intentional. The Fifth Circuit was quite critical, questioning the logic that both a hunter who intentionally shoots and kills a bird that he does not know is a migratory bird, as well as the owner of an electric line that was impacted by a bird (which resulted in the bird's death) when such owner has no intent whatsoever to kill any birds (migratory or otherwise), should both be guilty of the same crime (*Id.* at 493). The Fifth Circuit was critical of the Second and Tenth Circuits for finding criminal liability in the absence of a *mens rea*, holding that there can be no crime without both a *mens rea* and an *actus rea* (*Id.* at 492). In so calling out these differences between its point of view and the holdings of the Second and Tenth Circuits, the Fifth Circuit deliberately set up a split amongst the circuits, which both invited the other circuits to take sides and suggested that the Supreme Court take action to resolve the circuit split.

The Eighth Circuit (North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Missouri, and Arkansas) established that it, like the Fifth Circuit, did not recognize incidental take in *Newton County Wildlife Association v. United States Forest Service.* (However, this precedent comes with a potential caveat which is later relied upon by the Ninth Circuit (113 F.3d 110, [8th Cir. 1997]); see generally, *Seattle Audubon Soc'y v.*

Evans, 952 F.2d 297, (9th Cir. 1991). The Eighth Circuit made quick work of incidental take. In *Newton*, the plaintiffs attempted to enjoin the U.S. Forest Service from making timber sales in a national park on the basis that the lost timberland would result in the taking of migratory birds (including their habitat), and thus was illegal under the MBTA as a "taking" (*Newton Cty. Wildlife Ass'n v. U.S. Forest Serv.*, 113 F.3d 110, 114 [8th Cir. 1997]). The Eighth Circuit rejected this argument, stating that applying strict criminal liability for actions like timber harvesting that only theoretically and indirectly result in the death of migratory birds would be stretching "this 1918 statute far beyond the bounds of reason" (*Id.* at 115). However, the court's actual denial of the requested injunction was actually settled on other grounds. The court determined that the MBTA's explicit language provided that it only applied to "any person, partnership, or corporation" and that government entities, such as the U.S. Forest Service in this case, are not considered "persons, partnerships, or corporations," and hence the statute did not apply.

In the Ninth Circuit (Alaska, Hawaii, Guam, Washington, Oregon, California, Montana, Idaho, Nevada, and Arizona), *Seattle Audubon Society v. Evans* established (with a major caveat) that incidental take is not prohibited under the MBTA (952 F.2d 297, [9th Cir. 1991]). Essentially, the Ninth Circuit agreed with the Fifth and Eighth Circuits in a case that also sought to enjoin the sale of timber from a migratory bird habitat. As in the Eighth Circuit case, the plaintiffs sought to prohibit the timber sale on the basis that it would destroy bird habitat, which they argued was tantamount to a taking (952 F.2d 297, 302 [9th Cir. 1991]). Siding with the Eighth Circuit's reasoning, the Ninth Circuit noted that the MBTA definition of "take" used the hunting-specific language "pursue, hunt, shoot, wound, kill, trap, capture, or collect," which did not mention habitat modification or destruction, and the court refused to extend the meaning of the MBTA to include habitat in this manner. And, similar to the Fifth Circuit's holding, the Ninth Circuit also noted that the ESA included in the definition of "take" the broad terms "harass" and "harm," and likewise concluded that Congress meant the MBTA to be applied in hunting-specific situations and not with respect to incidental takes or takings of habitat.

Despite this holding, however, the Ninth Circuit has also affirmed an Eastern District Court of California decision, *United States v. Corbin Farm Service*, which allowed for the prosecution of incidental take under the MBTA (444 F. Supp. 510, 540 [E.D. Cal.], aff'd, 578 F.2d 259 [9th Cir. 1978]). In *Corbin*, the court found defendants violated the MBTA by improperly applying a pesticide to fields in such a way that it resulted in the deaths of multiple migratory birds (444 F. Supp. 510, 540 [E.D. Cal.], aff'd, 578 F.2d 259 [9th Cir. 1978]). The court reasoned that even though the legislative history surrounding the MBTA supported a focus on hunting, it did not show intent to limit the MBTA so that it would not apply to poisoning (*Id.* at 531). The court supported this position by pointing out that the Bald and Golden Eagle Protection Act (BGEPA), which used the MBTA as a model, included an explicit prohibition on poisoning (*Id.* at 532). The court also emphasized that the MBTA's prohibition described taking and killing "by any means or in any manner," which showed an intent to apply the statute broadly. The Court then went a step further to state that a strict liability finding was justified in this case because, particularly when dealing with pesticides, applicators should know to take special care to prevent injury to the environment and other people—a standard of reasonable care existed which was not met in the circumstances of this case (*Id.* at 536). In the case, the prosecution attempted to convict on the basis of multiple separate counts of violation of the MBTA, but the court declined to accept this invitation. Instead, the court found that the statutory language of the MBTA was ambiguous enough that it could not turn "a single transaction into multiple offenses" (i.e., that the court could not prosecute on the basis of how many birds were taken by a single act but rather on how many acts resulted in the taking of any birds) (*Id.* at 531).

The *Corbin* court distinguished the holding in *Evans*, stating that the habitat destruction that was feared in that case did not actually directly kill any birds and so lacked the proximate cause required to make it a crime (952 F.2d 297, 302 [9th Cir. 1991]), while the misuse of pesticides in *Corbin* actually directly killed the birds in question, and so satisfied the proximate cause requirement (444 F. Supp. 510, 32 [E.D. Cal.], aff'd, 578 F.2d 259 [9th Cir. 1978]).

In so holding, the court made an interesting distinction: third parties cannot enjoin someone from intentionally damaging bird habitat under the MBTA, because it is not clear enough that a crime (the killing of birds) will, in fact, be committed, but an accidental act that in fact kills migratory birds is punishable as a crime, despite that there was no actual intent to kill any birds. It appears then that in the Ninth Circuit, whether a party will be prosecuted for an MBTA violation could well be situational. So, where the Second and Tenth Circuits will prosecute incidental takes and the Fifth and Eighth Circuits will not, the Ninth Circuit has gone its own way, and sometimes will and sometimes won't. For utilities operating infrastructure that crosses federal circuit lines, this "will they or won't they prosecute" question necessarily will yield different results, depending on where the incident occurred.

THE MBTA PERMITTING PROBLEM

In addition to Solicitors' Opinions and court decisions, there arises another problem: there are currently no incidental take permits for the MBTA. While the MBTA allows the Secretary of the Interior to authorize/permit/regulate hunting, taking, capture, killing, etc. of birds protected under the MBTA as long as such decisions are "subject to the provisions and in order to carry out the purposes of" the MBTA, there is no actual incidental take permit under the MBTA (16 U.S.C.A. § 704 [West]). This is not to say that there are no permits available under the MBTA. In fact, the opposite is true. The "Migratory Bird Permitting Handbook" lists 34 permits for activities ranging from imports/exports to taxidermy to educational use to falconry to special purpose activities (USFWS 2022).

The United States Fish and Wildlife Service offers a Special Purpose Utility (SPUT) permit specifically for utilities; however, the permit does not actually allow utilities to incidentally take birds (USFWS 2022). Instead, SPUT permits merely allow utilities to collect and dispose of migratory birds which they have already incidentally taken, or move active bird nests in emergency situations. As part of the permit, utilities must systematically record and report all dead and injured birds found on the utility property to the USFWS Injury and Mortality Reporting System (IMR) and allow DOI agents to enter the permittee's premises "at any reasonable hour to inspect the wildlife, records, and property, and for compliance with the terms of the permit" (USFWS 2018). The stated purpose of the SPUT permit is neither to protect birds nor to protect utilities. Instead, the purpose of the SPUT permit is simply to "enhance a utility's ability to accurately monitor migratory bird mortalities," contribute "to our collective knowledge and understanding of the impacts of the utility on migratory birds," and "promote standardized collection and reporting of mortality data" for cross referencing across specific utilities.

Curiously, utilities are not required to enact avian protection or migratory bird conservation plans in order to qualify for a permit; however, USFWS encourages utilities to do so anyway in exchange for so-called "prosecutorial discretion" (U.S. Dep. of the Interior, USFWS, Director's Order No. 225, Incidental Take of Migratory Birds [2021]). In the "Consideration of the Guidelines in MBTA and BGEPA Enforcement" section of these guidelines, USFWS clarifies that, while following the guidelines will not make takings legal, USFWS officials making the decision on whether or not to refer cases for prosecution "will take such adherence and communication [to the guidelines] fully into account when exercising discretion with respect to such potential referral" (USFWS Land-Based Wind Energy Guidelines, 6).

The Service recognizes that, because incidental take is so widespread, they cannot enforce against all activities which result in incidental take (U.S. Department of the Interior USFWS Director's Order 225, Sec. 5). The Service also seems to recognize that given the vast territories involved, it is simply not possible to constantly patrol the lines to seek out and report upon bird mortalities. Moreover, birds injured by contact with a powerline might land at a point distant (or not reasonably accessible) from the powerline rights-of-way. As a result, the Service chooses to focus its efforts "on specific types of activities that both foreseeably cause incidental take *and* where the proponent fails to implement known beneficial practices to avoid or minimize incidental take (U.S. Department of the Interior USFWS Director's Order 225, Sec. 5). The Service defines beneficial practices as actions "implemented in an effort to avoid and minimize the incidental take of migratory birds." Beneficial practices can also refer to, but are not necessarily limited to, best management practices (BMPs), conservation measures, best practices, and mitigation measures (U.S. Department of the Interior USFWS Director's Order 225, Sec. 5).

Prosecutorial discretion is important in an uncertain legal/regulatory environment; however, it is not the answer. In states where prosecutorial discretion is not recognized, prosecutorial discretion means nothing. Where incidental take is recognized, discretion can be seen as favoritism. The United States Fish and Wildlife Service has been accused of using its discretion to avoid prosecution of renewable energy producers in favor of traditional energy producers (Blackmon 2013).

CHANGE IN THE AIR?

Still, this perception may be changing. The United States Fish and Wildlife Service prosecuted a wind energy company in November 2013 when it brought an action against Duke Energy Renewables, Inc. for taking 14 Golden Eagles and 149 other migratory birds between 2009 and 2013. In the resulting plea agreement, Duke Energy paid a combined $1 million in fines, restitution, and community service. Duke Energy was also placed on probation and required to create a compliance plan aimed at limiting bird deaths as well as applying for an Eagle Take Permit. The compliance plan is estimated to cost $600,000 per year to implement (U.S. DOJ Press Release 2013).

Similarly, in December 2014, PacifiCorp Energy pleaded guilty to violating the MBTA at two of its wind projects in Wyoming. From 2009 to 2013, 38 Golden Eagle and 336 other migratory bird carcasses were found on the premises. As a result of the plea, PacifiCorp was sentenced to pay a combined $2.5 million in fines, restitution, and community service fees, in addition to being placed on probation, being required to create compliance plans aimed at reducing bird take, and applying for Eagle Take Permits for its sites (U.S. Department of Justice 2014).

Most recently, ESI Energy, LLC pleaded guilty to violating the MBTA on three counts, as a result of taking at least 150 Bald and Gold Eagles from 2012 to 2022 across 50 of its wind projects "where ESI had not applied for the necessary permits." The ensuing plea agreement required ESI to pay $1,861,600 in fines and $6,210,991 in restitution. ESI Energy is also being placed on a five-year probation period, during which ESI must follow an Eagle Management Plan (EMP) which will cost upwards of $27 million during the five-year period. ESI Energy must also apply for Eagle Take Permits at each of its facilities where takes have occurred, as well as for four proposed facilities which have yet to be built (U.S. Department of Justice Press 2022).

Interestingly, each of these cases was brought in Wyoming. The United States Fish and Wildlife Service took the position in each case that it had demonstrated prosecutorial discretion by warning each entity multiple times over the course of multiple years that they were illegally taking birds. The agency stated that it was only after these warnings were repeatedly ignored did USFWS prosecute. It is also worthy to note that while each company was prosecuted for violating both the BGEPA and MBTA, each company only pled guilty to MBTA violations but was nonetheless required to apply for Eagle Take Permits as part of the plea agreement. This is likely because the BGEPA does not allow entities which have been convicted of violating the BGEPA from securing BGEPA incidental take permits.

INCREASED PROSECUTION IS LIKELY

In the future, it should be expected that increased prosecution of wind farms and other utility infrastructure for incidental takes under the MBTA is likely to be more of a rule than an exception. President Biden, in Executive Order 14008, set a goal to see the U.S. power sector reach zero emissions by 2035 and the U.S. economy reach zero emissions by 2050. To accomplish these emissions elimination targets, the U.S. will have to undergo a massive and rapid modification to its utility industry. As industries across the board are required to lower emissions that they themselves emit, there will necessarily be a shift away from emissions-producing energy sources and towards an increased reliance on electricity. "[U]nder the high electrification scenarios, 2050 electricity consumption reaches 6,700 TWh, which is 1,900 TWh (40%) greater than in the reference in 2050 and nearly 3,000 TWh (81%) greater than in 2018" (Zhou and Mai 2021).

Most analyses find that to decarbonize U.S. energy and achieve climate goals, it will be necessary to double, or even triple, the size of our electric transmission system before 2050 (Cohen and Reed 2021). Since there are currently "more than 600,000 circuit miles of lines," there will need to be 1.2 to 1.8 million miles of transmission lines in an emissions-free United States.

Looming infrastructural overhauls, as well as contemporary disagreements over legal interpretations of incidental take, provide an inflection point from which protections for birds and utilities must stem, owing to an estimate that the North American bird population has dropped by an estimated 3 billion in the last 50 years (Mock 2019). The United States Fish and Wildlife Service and certain members of Congress see it this way as well. For example, on July 29, 2021, the Migratory Bird Protection Act of 2021 was introduced into Congress. The act primarily sought to codify incidental take in legislation and called on USFWS to develop a streamlined incidental take permitting system and encourage BMPs in the industry (H. R. 4833).

The MBPA calls upon the Secretary of the Interior to issue general permits to industries with "broadly similar levels of incidental take and for which generally applicable best management practices or technologies that can effectively avoid or minimize such impacts" (MBTA21 Sec. 14 [b]). The general permits require that the permittee adopt "practicable and effective" best management practices or technologies as well as paying mitigation and permit fees (MBTA 21 Sec. 14 [b][2-4]). General permits are to be revised whenever incidental take exceeds or significantly differs from the expected incidental take that formed the basis of the permit or when new, practicable BMPs or technology that can significantly reduce incidental take come out in the permittee's industry (MBTA21 Sec 14 [c][1-2]), or, alternatively, every ten years (MBTA21 Sec 14 [c][3]).

The "practicable" solution is critical. "*Practicable* means available and capable of being done after taking into consideration existing technology, logistics, and cost in light of a mitigation measure's beneficial value to eagles and the activity's overall purpose, scope, and scale." For powerlines, the best way to reduce bird takes would be to bury the powerlines; however, the process is extremely expensive and ignores the reality that powerlines need to be updated to handle increased loads in the future. Pacific Gas and Electric, for example, estimates that putting lines underground costs from $1.5 to $2 million a mile (McCarthy 2021). Undergrounding all lines would be an impracticable solution, then. Alternatively, retrofitting existing power poles to minimize migratory bird and eagle mortality is estimated to cost $7,500 a pole. At roughly 43 poles to a mile, this works out to $322,500 per mile (FAWS 86 FR 54642).

A SOLUTION MAY LIE IN INFORMATION GATHERING

Turning back to the language of the MBPA, note that it places priority on issuing general permits to industries where "substantial information exists regarding the extent and nature of incidental take…and practicability of best management practices and technologies in reducing such incidental take" (MBTA21 Sec 14 [e][1]). Specifically, MBTA21 proposes general permits for oil, gas, and wastewater disposal pits; methane and other gas burner pipes; communication towers; electric transmission and distribution lines; and wind power generation facilities within five years of the act's enactment and general permits for solar power generation facilities eight years after the Act is enacted

(MBTA21 Sec 14 [e][2]).

The MBPA dictates that mitigation fees be deposited into the North American Wetlands Conservation Fund, the Neotropical Bird Conservation Fund, or another fund/account established to restore or enhance bird species which are affected by the given activity and identified as a bird of conservation concern (MBTA21 Sec 14 [O]). Further, MBTA21 calls for the Secretary to fund a research program to evaluate and develop BMPs and technology and evaluate the impact of these BMPs and technologies on bird populations (MBTA21 Sec 14 [R]).

While the MBPA21 hasn't passed the House yet, USFWS has announced proposed rule changes to the MBTA that would largely realize the goals of the MBPA21. Of course, the proposed rule changes still rely on Congress to amend incidental take into the MBTA to take full effect.

According to their incidental take permit creation proposal, USFWS wants "a durable solution that effectively conserves migratory bird populations while providing regulatory clarification and certainty to the regulated community" (Proposed Changes, 54669). After codifying incidental take, the Service seeks to create general permits by activity type as well as specific/individual permits. Exceptions would be provided for noncommercial endeavors like homeowners and "certain activities where activity-specific beneficial practices or technologies sufficiently avoid and minimize incidental take."

Like the MBPA, USFWS' incidental take permit proposal is primarily concerned with creating general-permit authorizations for activities which "have been identified as common sources of bird mortality and/or have well-developed, activity-specific beneficial practices" (Permit Change 54669). Beneficial practices encompass BMPs, conservation measures, and mitigation measures (MBTA Permit Change 54668). Of the ten activities USFWS identifies as being sources of bird mortality and having well-developed beneficial practices, six are utility/energy related. The United States Fish and Wildlife Service is specifically considering electric transmission and distribution infrastructure, on and offshore wind projects, solar projects, gas burner pipes, and oil, gas, and wastewater disposal pits (MBTA Permit 54669).

The United States Fish and Wildlife Service proposes that these permits will be activity-specific and come with beneficial practices tailored to that industry in question, as well as reporting requirements which would apply to all permits (MBTA Permit 54669). These reporting requirements could be fulfilled by reporting birds found through ordinary maintenance rather than through more extensive reporting programs (MBTA Permit 54669). General permits would not require Service review before becoming effective, would not be site specific, would not dictate acceptable bird take numbers or species, and would not require extensive monitoring to qualify for the permit (MBTA Permit 54669).

Projects that do not qualify for general permits would have the opportunity to qualify for specific permits but would have to go through USFWS review and comply with custom conditions similar to those required by existing MBTA take permits to do so. Factors which USFWS suggests could factor into who qualifies for a general or specific permit include infrastructure design, beneficial practices, and areas which are known to have high volumes of migratory birds. The United States Fish and Wildlife Service is also considering offering a memorandum of understanding (MOU) to government agencies with existing migratory bird conservation agreements to exempt them from permitting requirements.

A large theme within the MBTA incidental take permit proposal is one of seeking information (MBTA Permit 54670). The Service seeks information on migratory bird death causes; beneficial practices themselves; costs and benefits of retrofitting infrastructure, etc., and also seeks input on whether to focus on compensatory mitigation programs or a conservation fee fund to ensure that incidental take permits are in line with the goals of the MBTA (and also to aid a declining migratory bird population). The two suggested goals of the conservation fee fund would be to research and monitor incidental take by activity type and measure best practice efficacy or to directly address sources of migratory bird population declines like habitat loss and degradation.

As of January 2022, the Service has a collection of pages on their website with activity-specific Incidental Take Beneficial Practices (FWS Collection). The pages cover the previously listed industries/activities as well as the transportation, fisheries by-catch, and gas flares. In general, these pages briefly explain how and why the given activity affects migratory birds before providing links to activity-specific best practices. In addition to industry-specific Incidental Take Beneficial Practices pages, USFWS includes a "Data and Tools" page with links to various resources for facilitating project assessment. Some of these pages and resources are more developed than others. While some resources redirect users to USFWS content, others link to third parties such as the Avian Powerline Interaction Committee (APLIC) and EDM International, Inc.

Another linked third-party resource is the Avian Knowledge Network (AKN). Among other resources, the AKN provides several user-friendly tools which are useful for determining the impacts that existing and proposed projects might have on bird populations. One of these tools is the Rapid Avian Information Locator (RAIL), which compiles bird information from six data sources and allows users to see what bird species have been recorded in the user-selected area as well as a host of information on each bird species. Importantly, the website shows whether the birds are endangered or listed on the MBTA, their phenology (presence and abundance in the area at different times throughout the year), breeding season, and geographic distribution based on breeding season.

The Service also has an Information for Planning and Consultation (IPaC) tool which functions the same way as RAIL while incorporating information from AKN as well as other sources to show Endangered Species, Migratory Birds, Marine Mammals, Coastal Barriers, Facilities, Wetlands, and Critical Habitats in the designated geographic area.

Such tools can be utilized in the Service's proposed incidental take permitting system. While the Service intends general permit conditions to be activity, rather than location, specific, permittees could enter their project sites into a database which cross references with IPaC information (Fed Reg vol 86, No 189 10/4/21/proposed rules 54669). The Service rightly wants to minimize specific permits due to administrative burdens but acknowledges that there will be a need for them. A system which automatically cross-references proposed project sites with at-risk species would be an efficient system to screen for general and specific permit needs and open the door for more comprehensive record keeping down the road.

The Service also intends to create mandatory reporting requirements for general permittees (Fed Reg vol 86, No 189 10/4/21/proposed rules 54669). These reports could be tied into the same database. While the Service does not intend to use dead birds found as a criterion for specific permits, this could change. In a vacuum, bird deaths neither indicate a threat to migratory bird populations nor quantify the efficacy of beneficial practices in preventing bird deaths. Further, bird death reporting needs some system to help narrow bird death estimates. According to USFWS, electrical line collisions kill anywhere from 8,000,000 to 57,300,000 birds each year. This is obviously a wide estimate, and so the more data points that are cross-referenced against each other, the more accurate the Service's picture of migratory bird populations can become. This concept ties in directly with the Service's stated desire to gain more information on migratory bird mortality and population numbers, especially at an activity-specific level, and can be aided by the Service's proposed conservation fee fund. As the Service envisions, this type of monitoring would not require extensive monitoring programs. Instead, the value of the system would lie in having multiple sources of migratory bird data pooled together.

These reporting efforts can be bolstered by technology. One existing solution is to install Bird Strike Indicators (BSIs), such as those produced by EDM International on aerial cables such as powerlines and guy wires. Generally speaking, BSIs detect and record wirelessly transmit bird strike information by monitoring vibrations on lines.

There is also potential to create a network of motion-activated cameras which could autonomously count and identify bird species. A camera network like this could be a key to more fully understanding bird populations and utility interactions with birds. Cameras have the capacity to count and identify several thousand birds in a single photograph far more accurately than human observers (Akcay et al. 2020). Coupling a camera system like this with bird take monitoring and/or BSIs could provide an extremely accurate view of which best practices work and which don't. For example, if 10 bird strikes are recorded and cameras record that a flock of 1,000 birds flew by at the same time, the best practices employed on that stretch of line will be more efficacious than if 10 bird strikes were recorded from a 100 bird flock. Further, this information has the potential to test best practice efficacy on a species-by-species level.

Of course, implementing the camera network will take a great deal of capital and effort. However, the real struggle will be capturing enough data to train the machine learning algorithm to accurately count and identify birds in pictures. The larger a data set for identification is, the larger the pool of information for the machine learning algorithm to draw on must be. Just like it is harder for a human to memorize and identify 1,000 plus bird species, it is harder for a machine learning algorithm to do so. The process could ultimately take many years to accomplish. Still, the technology is undoubtedly established on a smaller scale. Cornell Lab of Ornithology has a "Merlin Bird ID" mobile app which uses artificial intelligence (AI) and information from Cornell Lab of Ornithology's eBird citizen science project to identify birds from user-submitted birdsong clips and photographs (Melendez 2021). There is even a birdfeeder/camera called "Birdfy" which uses motion detection to take photographs of birds before using AI to identify them. The device claims the ability to identify 6,000 plus species (Netvue).

More important than the cameras, though, is the creation and upkeep of a database which collects migratory bird data from as many sources as possible. Doppler Radar can be utilized to keep track of bird migrations (Stuart 2015). There is even the potential to use radar to look at the size and type of birds within migrations. Cornell Lab of Ornithology's "BirdCast" utilizes radar, along with weather reports and machine learning to "produce region-specific forecasts of bird movements a week in advance" and its "EBird" utilizes crowd-sourced data from hundreds of thousands of users to create accurate, "real-time maps of species distribution" which are freely accessible to anyone.

Gaining a more accurate picture of migratory bird population and take numbers within the United States will allow USFWS to calculate realistic, fact-based acceptable take numbers. If a specific bird species shows up hundreds of miles from its typical range and collides with a powerline, the utility should not be held liable for this unpredictable event; however, if hundreds of these birds begin appearing at around the same time a few seasons in a row, the utility should be expected to adapt their management practices accordingly and be held liable if they fail to do so.

This information can be used to dictate what best-practicable/best available technology standards should be. These standards will most likely change in different geographic locations, in different topographies, in different climates, as technology changes, as climate change alters migratory bird life cycles, etc. This practice is in line with established best practices for utilities. The Avian Powerline Interaction Committee recommends collision monitoring studies and field assessments before and after projects are constructed to assess risks to and solutions for bird mortality (Avian Power Line Interaction Committee 2012).

THE BALD AND GOLDEN EAGLE PROTECTION ACT PERMITTING MAY OFFER A CLUE

The recently updated BGEPA permits offers some clues as to how MBTA permitting could work; however, the population dynamics between Bald and Gold Eagles and migratory birds as a whole are too different to provide a step-by-step picture of what MBTA permitting should look like. Instead, BGEPA permitting provides some examples of what could be done in MBTA permitting and some examples of what likely wouldn't work for MBTA permits. These differences really come down to numbers.

Another key aspect of BGEPA permitting is adaptive management: the principle of using collected data to quantify and improve upon management objectives (Fed Reg Vol 81 no 224 Monday, Nov. 21 2016/notices, 83442). This process allows for more accurate representations of bird populations and informs which BMP/APPs best prevent incidental takes (i.e., which standards are best and most practicable). This, in turn, allows USFWS to more accurately reevaluate long-term permits and adhere to best practicable and practicably unavoidable standards better.

The Bald and Golden Eagle Protection Act permitting also relies on quantitative take numbers. The Bald and Golden Eagle Protection Act standards rely on a calculated carrying capacity for the Bald and Golden Eagle population in the United States (73,000). From here, the United States is split into four eagle management units (EMUs) which roughly align with the four main migratory bird flyways of the United States (the Pacific, Central, Mississippi, and Atlantic Flyways). At this point, EMUs are subdivided into local area populations (LAPs). The United States Fish and Wildlife Service then uses baseline population estimates to calculate local population, population growth rate, and carrying capacity numbers before dictating take numbers.

Bald and Golden Eagle Protection Act permits also utilize compensatory mitigation but "compensatory mitigation for this purpose must demonstrate it offsets authorized take by reducing another ongoing form of mortality by an equal or greater amount than the unavoidable mortality, or increasing the eagle population by an equal or greater amount." Compensatory mitigation relies on increasing population numbers to a greater extent than one decreases them. It requires at least semi-accurate population numbers. Migratory birds simply do not have the same level of accuracy as Bald and Golden Eagle counts. Migratory birds need more population and mortality information before efforts like BGEPA compensatory mitigation efforts can be effectively promulgated with accuracy.

GENERAL CONSIDERATIONS

The MBTA initially came into being in order to prevent the extinction of migratory birds from hunting activities, which were motivated by the need of the fashion industry for a robust supply of bird feathers. The world has changed substantially and bird hunting to provide feathers to the fashion industry is now part of a bygone era. That said, however, migratory bird populations are still in great danger. The MBTA has continued utility in protecting bird species.

Unfortunately, a lack of clarity in the original MBTA as to whether it was prohibiting hunting specifically, or any take of a bird and/or its habitat, has led to enormous confusion. Each of the last three administrations has reversed the other with regard to the question of prosecution of incidental bird takes and, complicating things further—without regard to these executive positions—the circuit courts have radically different ideas as to whether incidental takes should or should not be prosecuted and punished as strict liability crimes. This is particularly alarming for the electric utility industry, which most definitely is not intending to take any migratory birds, but is under continuous pressure to expand and enhance its infrastructure so as to meet future electric demand, which necessarily will mean the taking of additional birds and their habitats. It is certainly wrong for the government to demand that utilities undertake this expansion and to then punish the utilities with huge financial penalties with criminal implications as well in conducting the very activity that the government demanded.

The fact of the matter is that no one truly knows how many birds are taken each year as a result of conflicts with utility infrastructure, nor has anyone yet developed a reliable methodology for determining how to capture such data. Based on the recent prosecutions in Wyoming, it seems that utilities are caught: they cannot ignore their bird takes, but they are justifiably concerned about uncovering a potentially uncomfortable situation if they make a full investigation, which in turn could lead to very damaging prosecution.

The government agencies, however, are clearly admitting that they simply don't know enough and would welcome industry assistance. Despite the recent activity in Wyoming, these agencies are also indicating that they are willing to use their discretion to decline prosecution if industry will help provide the scientific evidence needed. Accordingly, utilities should consider leveraging their technological capabilities to explore methodologies for generating data for USFWS and DOI so that the level and impact of bird mortality can be better understood, in exchange for immunity from prosecution, if available. Utilities should likewise consider simultaneously researching methods of discouraging birds from coming into fatal contact with their infrastructure. Doing nothing is no longer a reasonable option, as efforts are being made (fairly or not) to hold utilities to task on this subject.

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The views expressed in this paper are those of Brannan and Kahn alone, and do not necessarily reflect the official views of Tulane University or of the Utility Vegetation Management Initiative.

PART VIII

Stakeholders / Permitting

Aboriginal populations, who have become actors in environmental research, participate in research and scientific discourse by sharing their knowledge. In an effort to assess the use of Aboriginal traditional knowledge in its environmental studies, Hydro-Québec analyzed several projects and environmental follow-up studies. This review shows that the methods of Aboriginal participation and the contribution of Cree, Innu, and Inuit ecological knowledge in the environmental studies conducted by Hydro-Québec have evolved considerably from the beginning of the La Grande complex to the present.

Although the contribution of traditional knowledge to environmental studies poses challenges related to the sociopolitical context of hydroelectric projects; to intercultural communication; and to the process of linking traditional knowledge and scientific data, Hydro-Québec and the Aboriginal communities can derive many benefits from the sharing of this knowledge in the environmental field.

Assessment of the Status of Aboriginal Knowledge in the Environmental Follow-Up Studies Conducted by Hydro-Québec

Stéphanie Eveno

Keywords: Aboriginal, Environmental Studies, Hydro-Québec, Traditional Knowledge.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

The Indigenous populations, who have become actors in environmental research, participate through the sharing of their knowledge, in research and scientific discourse. In an effort to improve its practices in regard to the consideration of Aboriginal traditional knowledge, Hydro-Québec questioned the use of this knowledge in its environmental studies. Several pre-project and environmental monitoring studies carried out during phases I and II of the La Grande complex—or the Eastmain-Sarcelle-Rupert and La Romaine complexes—have been analyzed, among other things. This examination revealed that the methods of Aboriginal participation and the contribution of Cree, Innu, and Inuit ecological knowledge in the context of environmental studies conducted by Hydro-Québec have evolved significantly from the beginning of the La Grande complex to the present day.

The work presented at the 13th International Symposium on Environmental Concerns in Rights-of-Way Management focused on two particular examples (two animal species) of Aboriginal traditional knowledge collection and integration that illustrated the importance of considering this knowledge: the cisco anadrone (*Coregonus artedii*) and woodland caribou (*Rangifer tarandus*). In the wake of the "Two-Eyed Seeing" approach, which invites us to look at and simultaneously adopt the strengths and methods linked to Indigenous knowledge and Western knowledge, these two examples demonstrated the added value of bringing together the Natives and Westerners on an equal footing to collect and analyze certain data. This added value, although it is certainly less and less questioned, is more seldom concretely illustrated. This paper will contribute in this direction.

With the first example, we will illustrate how the collaboration of the two sciences confirmed the existence of a species of fish, which had been unknown to biologists until this study. For the second example, this collaboration led to the implementation of a mitigation measure for woodland caribou. This two-eyed approach will thus have improved environmental assessment and planning.

CASE STUDY

Rupert River Anadrone Cisco

As part of the Eastmain-1-A/Sarcelle/Rupert (Baie-James) project, Hydro Québec had an obligation to monitor cisco. It should be noted that cisco fishing is of particular cultural importance because this resource has been an important source of food for the Cree community of Waskaganish for generations.

From the outset, we were in a situation where the knowledge of the two forms of knowledge were in contradiction. The Cree mentioned a difference between the cisco of the Rupert River and that of the Nottaway River—a difference that the scientists did not know about and that, moreover, initial scientific analyses had concluded these two populations were identical. Thus, following a request from the Crees, Hydro-Québec organized various field activities as part of the environmental monitoring studies carried out for the Eastmain-1-A/Sarcelle/Rupert project.

A three-day knowledge-sharing workshop was organized in Waskaganish, in collaboration with the Crees (Hydro-Québec and Consortium Waska Ressources – Genivar 2009). Note that its success, among other things, could have resulted from prior consultation with the Crees on the choice of methodology used during the workshop. The first two days, the “major users”—the main carriers of knowledge—of the resource on the rivers (e.g., Rupert, Nottaway, Pontax, etc.) were met in a group with a facilitator. The third day consisted of a plenary session, addressed to the entire community of Waskaganish. Some of the topics documented were terminology, uses, and ecology. In addition, elements for determining differences between the Nottaway River cisco and the Rupert River cisco, using morphometric measurements (length, weight, body height, body diameter, number of gill slits, etc.), were discussed during this workshop. These different measurements thus revealed some morphometric differences between the ciscoes of the Nottaway River and those of the Rupert River; the cisco of the Nottaway River is larger in size and weight, for example.

In addition, surveys were conducted by Hydro-Québec on the Nottaway River. The Crees greatly influenced the methodology used for these surveys, influence which proved to be decisive. Indeed, it was at the places (the location of the fishing stations) and time (sampling period) indicated by the Cree that experimental fishing had been carried out. Then, genetic studies carried out by Hydro-Québec on the fish caught made it possible to establish that they were indeed two genetically distinct populations, even if they belong to the same species.

It is important to emphasize that this Indigenous knowledge is in the hands of a few knowledge carriers. The Cree themselves mentioned that not everyone has sufficient knowledge to distinguish a Nottaway cisco from a Rupert cisco. In calling for the contribution of Indigenous knowledge, it is therefore fundamental, just as in Western science, to identify specialists.

Cree traditional knowledge therefore led to this scientific advance: observation of the genetic difference between the anadromous lake cisco of the Rupert River and that of the Nottaway River. It also allowed biologists to locate, at least briefly, the wintering grounds of the anadromous lake cisco. These areas were unknown to Western science until recently.

Woodland Caribou

The second example of collaboration between Indigenous knowledge and Western knowledge relates to the caribou within the framework of the La Romaine project (North Shore of Québec).

The caribou is an animal that is of fundamental importance in Innu culture. It should also be noted that the Nishipiminan agreement signed with Hydro-Québec and approved by referendum by the Innu of Ekuanitshit stands out in regards to the consideration of the community's Indigenous knowledge in the monitoring program for woodland caribou. Thus, as for the cisco, knowledge-sharing workshops were organized: one in Ekuanitshit and one in Nutashkuan. In addition, several environmental follow-ups concerning woodland caribou have been carried out in collaboration with the Innu.

Innu observers from Ekuanitshit and Natashquan participated in aerial caribou inventories, during which their comments were documented. Other Innu observers from Ekuanitshit were also able to participate in the telemetric tracking of woodland caribou, the fitting of telemetric collars, the monitoring of fecundity, post-calving tracking, as well as the monitoring of woodland caribou productivity and the summer survival of fawns.

In addition, the Innu firm Uanan Experts-Conseils, Inc. participated in the winter aerial inventory by helicopter, the telemetry tracking, as well as the evaluation of the summer survival of the 2012 fawns. These activities took place under the aegis of the Romaine Technical and Environmental Committees (CTER), with one of the primary objectives being to ensure meaningful participation of the Innu in the planning and implementation phases of the environmental monitoring applicable to the Romaine complex project.

The advances for Western scientists regarding caribou translate more into the sphere of ecology.

The Innu Aboriginal traditional knowledge has improved the knowledge of biologists about the historical presence of woodland caribou, their characteristics, and their movements according to the seasons. It has improved knowledge of the distribution (and locations) of woodland caribou, their cycle of abundance and rarity, and their diet, which varies according to the seasons. Discussions with the Innu guided certain analyses of the data by Hydro-Québec biologists to respond to Innu concerns, particularly on the impact of wearing telemetric collars on the necks of caribou and their survival, but also the impact of overflights on caribou behavior.

These same discussions pointed to certain possible avenues of research, with respect to the particularity of the antlers of the different ecotypes of caribou, for example. Indeed, current data has not demonstrated this differentiation between woodland caribou and barren-ground caribou that Innu knowledge has raised.

But above all, discussions with users of the territory have enabled Hydro-Québec biologists to fully understand the importance of this animal among the Innu and to understand how much it crosses all spheres. This increased sensitivity has allowed for better reflection on mitigation measures, which has resulted, for example, in the oversizing of certain pylons on a transmission line that will limit the fragmentation of the territory and create a connectivity corridor (Dawe et al. 2022).

We would also like to mention that these scientific advances resulting from the dialogue between Indigenous and non-Indigenous knowledge are also observed for elements of the physical environment, such as ice cover or shoreline erosion.

CONCLUSION

We recognize that the Aboriginal traditional knowledge's contribution to environmental studies poses challenges relating to the sociopolitical context of hydroelectric projects, intercultural communication, and the process of linking data from the Aboriginal traditional knowledge and science. However, several experiments have shown that the dialogue between them offers the opportunity for scientific progress, as well as the possibility of a project that is better integrated into the living environments of the populations concerned and better at responding to their concerns.

So, in this two-eyed approach, Hydro-Québec and the Aboriginal communities have both reaped several benefits from sharing this knowledge in the environmental field.

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AUTHOR PROFILE

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Stéphanie Eveno completed her PhD in anthropology. She has 23 years of experience working as an anthropologist (academic and field work in several Aboriginal communities). Eveno has been an advisor at Hydro-Québec since 2009. She is working on impacts environmental studies, environmental follow-up, the development of new impact assessment methods, and more.

Incompatible Encroachment Identification and Mitigation through Remote Sensing within Transmission Easements

Mark A. Ferrill

Keywords: Compatible, Encroachment, Geographic Information System (GIS), Human Use/Impact, Incompatible, Innovation, Light Detection and Ranging (LiDAR), Mitigation, Proactive, Reactive, Remote Sensing, Rights-of-Way (ROW), Transformation, Transmission, Transmission Asset Protection.

Duke Energy has approximately 31,000 miles of electric transmission powerlines across six states that are protected by an enterprise-wide Transmission Asset Protection (TAP) team. One of the greatest challenges for the team is identifying and mitigating incompatible encroachments within our transmission easements. Transmission Asset Protection is working closely with the company's vegetation management team, which uses an innovative approach to identifying incompatible vegetation threats through remote sensing. Transmission Asset Protection is leveraging this same remote sensing data to identify and address incompatible encroachments. Previously, the team relied on visual inspection through observation flights which typically would identify only the obvious and highest-priority threats to the safety and reliability of the transmission system. With the implementation of the Remote Sensing Program, engineering modeling is used to model maximum operating conditions in conjunction with remote sensing data to identify potential incompatible threats. This data is used to prioritize and categorize the incompatible encroachment threats based on the risk they pose to system reliability, public safety, and employee safety, while helping ensure compatible encroachments are documented. Compatible uses may include trails and paths within the transmission corridor to allow the highest and best use of the land, while protecting the primary use of the corridor for the transmission of electricity.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

The Transmission Asset Protection (TAP) Encroachment Program was initially established in 1998 in the Duke Energy Carolinas utility. Since that time, the program has improved and evolved for use in all six states the company serves (North Carolina, South Carolina, Florida, Indiana, Ohio, and Kentucky). Duke Energy now has a well-established and industry-recognized TAP Encroachment Program that is a disciplined and consistent approach to protect Duke Energy transmission rights-of-way (ROW). The program is focused on transmission system safety, reliability, maintainability, and operability, and is designed to consistently identify and mitigate encroachments in transmission ROWs. The Encroachment Program includes both proactive and reactive components for encroachment identification. The goal of the TAP Encroachment Program is to avoid encroachments from the start. The proactive program is the preferred approach where TAP uses public outreach to property owners to share the work process and review development plans that encroach on the company's transmission ROWs to help ensure compatible encroachments are the only ones placed within the transmission ROW. However, the success of the proactive approach depends on property owners and/or developers coming to Duke Energy TAP to complete the review and working together to ensure no incompatible encroachments are placed within the transmission ROW. This proactive approach avoids thousands of incompatible encroachments every year. Unfortunately, many property owners and/or developers do not contact TAP for review of their plans, do not understand the easement rights granted to Duke Energy within the transmission ROW, or simply choose to place potentially incompatible encroachments in the ROW. Therefore, TAP also has the reactive approach to encroachment identification and mitigation. The TAP encroachment program becomes reactive when a property owner places potentially incompatible encroachments within the ROW. Duke Energy TAP must then work to address the issue and seek a positive outcome.

The foundation for encroachment identification and mitigation is based on reference to: (1) the current Duke Energy Transmission Use Guidelines for Encroachments Involving Transmission Easements, and (2) the applicable publicly recorded Duke Energy transmission easement. These documents, along with regulatory, environmental, and the National Electric Safety Code (NESC) (and/or other similar applicable safety rules and/or regulations), and the facts and circumstances related to a given encroachment, are used by TAP to identify compatible and incompatible encroachments and to mitigate the incompatible transmission ROW encroachments. Considerations include, but are not limited to, compatible ROW uses, protection of granted easement rights, and coordination of the review by all appropriate internal Duke Energy teams.

Through a focus on continuous improvement and operational excellence, the TAP team recognized opportunities to utilize current technology to enhance the reactive approach of the TAP Encroachment Program. The primary goals were to develop a more holistic approach to identify, document, and mitigate encroachments through Remote Sensing Program (RSP) technology and geographic information system (GIS) technology for encroachment data management, along with reducing overall resource requirements for identification, research, and mitigation. The secondary goals were to develop and implement a system to inventory and store all final dispositions of mitigated encroachments, both compatible and incompatible, to enable historical reference and research.

This system will become the source of record for all future encroachments, moving TAP away from past methods of paper documentation and record keeping in disparate systems toward a singular electronic system. Operational excellence and strategic value will be gained by clearly knowing what we are holding. Furthermore, having a holistic baseline of encroachments will enable immediate potential incompatible encroachment identification through change detection methods in future observations, along with reducing, or potentially eliminating, duplicate findings and follow-up inspection efforts.

METHODS

The TAP Encroachment Program reactively identifies encroachments through three primary methods: (1) aerial patrols, (2) ground patrols, and (3) field observations. Aerial patrols are regularly planned utility helicopter patrols using visual inspection via utility observers. Ground patrols are regularly planned visual inspection via regular activities performed by utility workers. Field observations are encroachments recognized and reported during regular utility work activities, such as vegetation management or driving to planned site visits. The challenge with all these approaches, but most specifically aerial patrols, is that it is difficult to identify encroachments unless they are obvious and egregious. In a typical aerial patrol, the helicopter is flying at approximately 35 knots, which makes it challenging to see minor issues or to judge distance on what could be potentially major issues. Accordingly, encroachments may go undetected using our current methods. It is also particularly challenging to detect grade changes unless the ground is freshly disturbed. So, how did TAP determine the next steps toward a data-driven approach for reactive encroachment identification and mitigation?

The answer started in 2017 with Duke Energy's Transmission Vegetation Management (TVM) program that envisioned and implemented the TVM

Remote Sensing Program (RSP). The RSP was identified in 2018 as a best practice by the company's enterprise innovation center, which is dedicated to transforming operations across the company through the implementation of innovative, customer-centric technologies. The TVM RSP was then expanded by the TAP team. The TAP team developed a strategy to expand the TVM RSP to pilot and implement the TAP Encroachment Enhancement Program (EEP), focused on reactive encroachments. Transmission Vegetation Management developed the Remote Sensing Program using Light Detection and Ranging (LiDAR) technology in conjunction with other relevant data. Transmission Asset Protection used the LiDAR data gathered by TVM to enhance encroachment identification, prioritization, and mitigation.

This LiDAR data capture allows identification of encroachments using empirical data rather than human observation. LiDAR removes the potential for human error by using data capture through advanced technology, including a multitude of calculations via algorithms, machine learning, and artificial intelligence using specified data models to identify and document potential encroachments for review.

Beginning in early 2021, TAP piloted the EEP by gathering the survey-grade LiDAR data (accuracy within 2 cm) from the TVM LiDAR data for all Duke Energy bulk electric system (BES) transmission lines (typically voltages 200 kV or higher, as defined by NERC). As of year-end 2021, the additional data for all non-NERC lines (voltages below 200 kV) were also included, covering all the approximately 31,000 miles of transmission lines Duke Energy maintains. The as-flown LiDAR data is then joined by the vendor with the Duke Energy Power Line Systems – Computer Aided Design and Drafting (PLS-CADD), engineering line design data to create wire models that specify vertical maximum operating conditions (conductor sag). It is important to note that at this time, the data models using PLS-CADD overlay to identify vertical maximum operating condition of the transmission line are based on conductor rating.

The LiDAR data are delivered from the vendor as a point cloud. Transmission Asset Protection worked with the vendor to classify the point cloud data into high-level parent groupings called "Feature Classes." Transmission Asset Protection developed five feature classes that align with the Duke Energy Transmission Use Guidelines for Encroachments Involving Transmission Easements and the applicable publicly recorded Duke Energy transmission easements, along with regulatory, environmental, and NESC requirements (and/or other similar applicable safety rules and/or regulations). The five chosen feature classes are: (1) Major aboveground features, (2) Minor aboveground features, (3) Water features, (4) Surface grading, and (5) Hard surfaces. Each of the five feature classes are broken down by child attribute classification into a detailed "Description."

In addition to the feature class and description, Duke Energy TAP, in coordination with Transmission Line Engineering, also supplied the LiDAR vendor with specific distances from the transmission facilities based on the defined feature classes. The distance data criteria returned from the vendor is defined by Duke Energy transmission voltages and the returned dataset from the vendor is matched to the feature class and description. The specific feature class, voltage, and distance combinations are correlated with NESC to further prioritize the data as tiered triggers to address the potential highest-risk encroachments. These triggers direct TAP to the potential encroachments to complete field inspection and additional research to determine if the trigger is a risk or potential clearance issue. Identified triggers are considered Tier I potential highest priority encroachment threats and Tier II potential high-risk encroachment threats.

The data are captured, defined, and identified using LiDAR remote sensing technology. The next important piece of the puzzle is to determine where to store, present, and work with the trigger data. The vendor had a GIS management tool that TAP piloted. The tool worked well, but after evaluation, TAP decided to build an in-house tool. As part of the Encroachment Enhancement Program, TAP engaged a GIS technician, along with support from the internal TVM Strategy and Support team, to implement an Environmental Systems Research Institute (ESRI) based GIS map tool that was named "Enforcer." The Tier I and Tier II feature class data are delivered by the vendor. The description data are parsed and populated by the Encroachment Enhancement Program GIS technician. At this point, the Enforcer map tool now has all Tier I and Tier II data populated and is ready to be worked by prioritization via field inspectors.

Transmission Asset Protection engaged supplemental resources to assist in the field inspections of the Tier I and Tier II data points that were identified across the entire Duke Energy footprint. The Enforcer tool runs on tablets that are deployed with the supplemental resources in the field, which direct them to the encroachment point of interest (POI) to capture inspection data details. Through this process, the inspection not only involves ground truthing in the field, but also includes evaluation of any potential encroachment-related data on file, including easement documents, previous encroachment plan review records, or encroachment agreements. If it is determined through the inspection and investigation that the finding is an allowed compatible encroachment that is not a risk, then the inspection record is completed, and no further action is required. The POI is kept on record in the Enforcer map for future reference to avoid marking the encroachment as a trigger to be inspected again. This step significantly, if not completely, removes duplicate future findings that require inspection since the POI has already been reviewed with no mitigation required and marked as an encroachment allowed to remain.

If the Tier I or Tier II finding is not completed through initial research, then the finding is moved to the Duke Energy work management system as a work order. At this point, the finding is still classified as a potential incompatible encroachment. The work order is assigned to Transmission Line Engineering to complete an internal review of the encroachment with the detail field data supplied by the EEP supplemental resource. This process is the same as a typical encroachment program finding that would also require Transmission Line Engineering review. Transmission Line Engineering determines if the Tier I or Tier II finding is an incompatible encroachment that must be addressed through mitigation. If Transmission Line Engineering designates the finding as a verified incompatible encroachment, then the finding becomes a validated Tier I or Tier II work order, and TAP takes over the work order to determine the appropriate mitigation to resolve any identified risk of the incompatible encroachment.

The mitigation process requires further understanding of the issue and circumstances to determine the appropriate action to resolve the identified risk. In many cases, the appropriate mitigation may require removal of the encroachment because it may simply be incompatible with the transmission easement. Although rare, there may be opportunity to consider an agreement to allow the encroachment to remain and reduce the overall identified risk. It is also a possibility that, in limited cases, Duke Energy may have to perform the mitigation if the circumstances warrant. In most cases though, the incompatible encroachment will require the property owner to take action to mitigate. Transmission Asset Protection and the Encroachment Enhancement Program supplemental resource work with the property owner using a consistent process with established timeline targets to complete the mitigation process. This process includes contacting the property owner via field visit, phone, letter and/or email, if known. The goal is to mitigate the incompatible encroachment issue as quickly as possible based on the tier, but within a 180-day time frame at the latest.

RESULTS AND DISCUSSION

The primary goals of the Encroachment Enhancement Program were to develop a more holistic approach to identify, document, and mitigate encroachments through Remote Sensing Program technology and GIS technology for encroachment data management, along with reducing resource requirements for identification, research, and mitigation. These goals were accomplished by expanding the TVM Remote Sensing Program to meet the needs of the TAP Encroachment Enhancement Program. For Remote Sensing Program technology, the Encroachment Enhancement Program utilized LiDAR and a different set of TAP parameters to identify within the point cloud data from what had already been gathered for the TVM Remote Sensing Program. This approach allowed TAP to maximize utilization of the already flown and processed LiDAR data mapped to the Duke Energy transmission system using maximum operating conditions of the conductor. The TAP EEP further capitalized on the development of ESRI GIS maps to expand the TVM program. The TVM Strategy and Support team led the TAP GIS technician to develop the Enforcer maps for the EEP to document and display the encroachment POIs to be inspected. This major accomplishment created the foundation for the EEP operating today.

Leveraging the work already completed by TVM, TAP was able to reduce resource requirements by utilizing data that were already captured and significantly increase the accuracy and volume of data capture, as compared to the original three reactive approach Encroachment Program methods used by the team (aerial patrols, ground patrols, and field observations). Also, by standing up the EEP, TAP now has a dedicated team of supplemental resources to manage these reactive encroachments. Once the primary goals were met, the Encroachment Enhancement Program advanced to meet the secondary goals of the program, which will set up TAP for long-term strategic operational excellence that will transform the way TAP reactively manages encroachments.

The secondary goals of the EEP were to develop and implement a system to inventory and store all final dispositions of mitigated encroachments. This system will enable documentation and management of each encroachment as a POI, whether compatible or incompatible, and make this data available for future historical reference and research. As noted in the previous paragraphs, two systems were implemented to maintain encroachment data. The first system is the GIS-based Enforcer map and database. This new system of record manages the categorization and prioritization of each identified encroachment, compatible or incompatible. Depending on the mitigation options, incompatible encroachments may still be allowed to stay with an encroachment agreement that will mitigate the identified risks. The Enforcer map and database system is the final inventory POI repository for each encroachment in a geographic visual format.

It is important to note that the full implementation of the Encroachment Enhancement Program is in its first year and is still maturing. Funding was achieved through a business case that is approved for the initial two years of the program. The TVM Strategy and Support team and the TAP team have developed metrics and dashboards to track both the tiered trigger process and the work order process to make these metrics readily available to the team and leadership. Although some parts of the processes are the same as the standard reactive encroachment program, the majority of the Encroachment Enhancement Program is breaking new ground. Transmission Asset Protection is learning how to refine the LiDAR data to reduce or eliminate false positives. Transmission Asset Protection then takes the data from the inspections to provide feedback to the vendor to improve machine learning and artificial intelligence, as well as refining the algorithms used to identify the data.

Phase 1 of the EEP is expected to take 1–3 years to inspect and mitigate the Tier I and Tier II potential incompatible encroachments, based on clearance distances. There are, however, additional encroachments that are not yet mapped. These encroachments are ones that are in the easement and are potentially incompatible but are not potentially the highest-risk encroachments. Note that Tier I and Tier II potential incompatible encroachments are strictly based on distance from the conductor at maximum operation conditions.

Encroachment Enhancement Program Phase I will establish the LiDAR baseline of the entire transmission system. The LiDAR vendor will use the baseline data to provide change detection, which is especially helpful for grade changes that are not easily recognized, unless it is a recent disturbance of the ground. This approach is very methodical to identify and address the inventory of encroachment data. The data-driven approach is critical to achieving operational excellence for TAP. Over time, this baseline and change detection data will establish historical information over and above the TAP Encroachment Enhancement Program POI data, which will be very useful in future identifications, investigations, and mitigation. These empirical data have the potential to provide expert, and potentially irrefutable, evidence of the prior conditions of the ROW as compared to the current conditions. Challenges TAP encountered prior to this capture of empirical data included the inability to "prove" the previous conditions of the ROW as compared to current conditions to achieve property-owner-driven mitigation of the encroachment issue.

An additional benefit to the program is that during Phase I, EEP supplemental resources will share details of the geospatial data points with the Duke Energy Land Services GIS team. Every field visit and update to the GIS data that is appropriate to share with Land Services will help that team reduce the need for additional resources to gather the same information. The review of source documents for easements, encroachment agreements, and other information will also provide validation and feedback to Land Services of the current state of the ROW.

Phase 2 of the EEP is targeted to begin in year four and will review all other encroachments. This phase includes more mapping data that align each corridor base map with the edge of easement boundaries so TAP can use LiDAR to determine if an encroachment is within or outside of the easement. If outside of the easement, typically TAP has no ability to enforce the issue because it is not actually an encroachment, even though it may be a concern. Unlike danger tree rights for TVM that include those threats both within and without the easement, typical easement language does not give TAP any rights to enforce encroachment issues outside of the easement. During Phase 2, Phase I results will be integrated into the overall Encroachment Enhancement Program, and TAP will continue to address the new Tier I and Tier II data. This process will be iterative as new LiDAR data come into the program at defined intervals based on the TVM Remote Sensing Program. These methods discussed are using innovative ideas to truly transform TAP at Duke Energy.

Finally, it is important to note that encroachment mitigation addresses concerns related to safety, reliability, and operational risks, and can be challenging from a public and community relations perspective. This program, utilizing quantitative empirical data, is the beginning of a journey that will transition to an established program once the initial findings are removed or mitigated. The benefit of the empirical data provided through this program is a critical enabler to incompatible encroachment mitigation and ultimate resolution. Although this program seeks positive outcomes focused on safety, maintainability, constructability, and operability of the Duke Energy transmission system, property owners may not initially understand or agree with the need to mitigate incompatible encroachments. Transmission Asset Protection recognizes these challenges and remains focused on Duke Energy customers and what is required to serve them safely and reliably. The ability to mitigate incompatible encroachments is often a matter of education and understanding with property owners who have a publicly recorded easement across their property.

CONCLUSIONS

As noted earlier, the program began in early 2021, using a phased approach to implementation. TAP has matured the Encroachment Program considerably from its inception in 1998. The EEP uses data and technology together to solve problems and give Transmission Asset Protection insight and knowledge used to protect Duke Energy's transmission grid and drive business outcomes. Transmission Asset Protection recognizes it is more important than ever to understand our transmission grid at a level we have never had the technology and data to understand before, and then use that understanding to optimize and leverage data and analytics to deliver value to customers and the company. Through the EEP, TAP embraced the company's innovation culture to identify relevant, meaningful, challenging, and exciting opportunities to serve customers, develop employees and grow the business.

Transmission Asset Protection continually uses the Duke Energy Operational Excellence Framework through continuous improvement focusing on delivering the highest standards in safety, optimized reliability, and efficiency. To achieve Operational Excellence, TAP followed an accountability model that includes an iterative approach to Plan, Do, Check, and Adjust. By taking accountability and striving for operational excellence, TAP is transforming our work through innovation and striving to meet Duke Energy's purpose to "power the lives of our customers and the vitality of our communities."

AUTHOR PROFILE

Mark A. Ferrill

Mark A. Ferrill has served as Duke Energy's enterprise-wide manager for Transmission Asset Protection for the past six years, with the responsibility to protect more than 31,000 miles of electric transmission powerlines across six states. While managing his team during the past three and a half years, Ferrill was also the Manager of Transformation Process and Change Management for the implementation of remote sensing, planning, analytics, and scheduling tools for Transmission Vegetation Management. Ferrill has been with Duke Energy for 34 years and has previously managed enterprise-wide Administrative Services Strategy, Midwest Regional Land Services, and held various individual and leadership roles in Information Technology supporting IT, Customer Billing, Rates, Customer Delivery (Distribution), and Transmission. Ferrill holds a Master of Business Administration and a Bachelor of Science in computer science.

Managing Socio-Economic Effects During Major Project Construction

Sian Weaver

Keywords: Adaptive Management, Construction, Engagement, Government, Human-Use/Impact, Indigenous, Issues, Mitigation, Monitoring, Pipeline, Reporting, Socio-Economic, Stakeholders.

Managing socio-economic issues is critical for business success in Canada's regulatory environment. Socio-economics is constantly changing, which can impact assumptions made during regulatory assessment. Coupled with a heightened social agenda, the industry is seeing an increasing number of socio-economic issues to manage regulatory conditions issued from regulators.

The Coastal GasLink (CGL) pipeline project recognized that socio-economic components are important to supporting sustainable communities and achieving successful business outcomes. Currently under construction, CGL is a 670 km (420 mile) pipeline designed to transport natural gas in Northern British Columbia. CGL's socio-economic Program is focused on regulatory requirements and proactive issues management, undertaken in collaboration with internal disciplines and external groups, including Indigenous communities, provincial agencies, and local governments. The program supports continuous improvement, as potential issues are identified and managed on an ongoing basis. An adaptive management approach is used, given the complexity of the issues that the program addresses and to support flexibility to modify steps or tasks embedded in the program framework.

Using the experience on CGL, this paper will focus on moving beyond impact assessment and into real-world implementation of socio-economic regulatory requirements and issues management during construction through a structured framework.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

The socio-economic effects assessment for the major project you are working on is complete, regulatory approval has been received, and construction is beginning. Construction is expected to have an impact on the socio-economic circumstances of the people and communities in the surrounding areas. As a result, understanding and ongoing management of socio-economic effects are key aspects of the project's responsibility to the people residing near construction activities.

Socio-economic effects (direct effects identified in assessment) and issues (situations that have the attention and concern of external or internal individuals/groups) can be intangible, challenging, and difficult to measure. Using assessment methodology to develop a tangible socio-economic framework supports a structured approach to managing socio-economic effects and issues through a program which is relevant, disciplined, and sustainable through the duration of anticipated socio-economic effects. This becomes increasingly important to the industry, as socio-economic regulatory requirements increase and financial institutions look at a company's sophistication in managing social risk through ESG reporting frameworks. In addition, socio-economic topics deeply matter to people and communities, which can directly impact reputation and relationships short- and long-term.

A program focused on proactively identifying, analyzing, managing, and reporting on socio-economic effects and issues that construction activities have on people and communities facilitates understanding, while mitigating socio-economic components. This approach influences the way socio-economics is defined during construction. It also helps clarify the social component in reporting frameworks in a structured and repeatable manner.

Coastal GasLink

TC Energy is an industry leader in delivering socio-economic activities that address local interests and provide benefits to communities. Building on this experience, Coastal GasLink's socio-economic program is leading and demonstrating the importance of proactively managing socio-economic matters within the Canadian province of British Columbia (B.C.).

Currently under construction, Coastal GasLink is a 48-inch diameter, 670 km (416 mile) pipeline designed to safely transport natural gas from the Groundbirch area west of Dawson Creek, B.C., to the liquified natural gas export facility being constructed by LNG Canada in Kitimat, B.C. Coastal GasLink will have an initial capacity of 2.1 billion cubic feet per day (bcf/d) and represents the first direct path to connect abundant Western Canadian Sedimentary Basin supply to global markets. Once operational, Coastal GasLink will play an important role in the global energy transition.

SOCIO-ECONOMIC PROGRAM

As global socio-economic regulatory and societal expectations continue to increase, the ability to meet this challenge requires disciplined analysis, keen focus, trust with both internal and external audiences, and delivering on measurable results. Canadian jurisdictions are becoming increasingly sophisticated in this space with successful projects shifting toward socio-economic programs that have a framework that is proactive, integrated into project activities, and agile.

Coastal GasLink has a robust and comprehensive socio-economic program that includes activities focused on regulatory requirements and proactive issues management has undertaken in collaboration with various affected external groups and internal disciplines, including community relations, Indigenous relations, environment, land, construction, and regulatory teams. Maintaining flexibility in the socio-economic program is important, given the duration of construction, the 670 km length of Coastal GasLink's corridor, and the diversity of governments, local communities, and Indigenous groups.

Figure 1 shows an overview of the Coastal GasLink socio-economic program during construction.

The overall goal of the Coastal GasLink socio-economic program during construction is to provide a framework to successfully meet socio-economic regulatory requirements and effectively manage socio-economic issues and provide benefits. To achieve this,

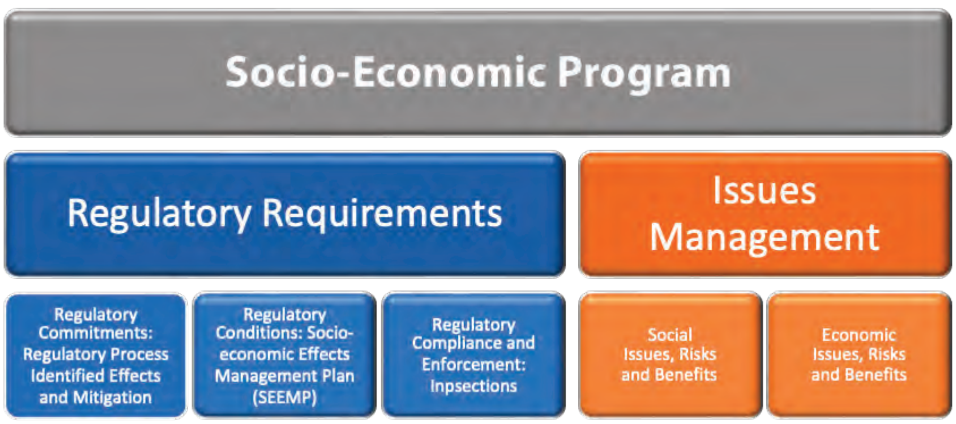

Figure 1. Coastal GasLink socio-economic program overview during construction

the program requires socio-economic technical expertise to:

- Implement socio-economic regulatory conditions, such as management plans.
- Use an adaptive management approach if monitoring indicates that the socio-economic mitigation is not achieving the predicted outcome.
- Collaborate and integrate socio-economic mitigation and engagement activities into relevant construction activities.
- Establish a cooperative dialogue with local communities, Indigenous groups, and government representatives on socio-economic mitigation and issues management.
- Deliver socio-economic opportunities and benefits to the residents and regions affected by the construction of Coastal GasLink, in accordance with the commitments made.
- Facilitate solutions to socio-economic issues.

SOCIO-ECONOMIC REGULATORY REQUIREMENTS

In some jurisdictions, projects are required to comply with socio-economic regulatory requirements, including implementing commitments in management plans, submitting reports, and responding to compliance inspections as identified through the regulatory process. For example, Coastal GasLink has a regulatory requirement to develop and implement a socio-economic effects management plan in collaboration with more than 57 external organizations. An overarching socio-economic program provides a framework intended to facilitate understanding and guide implementation of socio-economic regulatory requirements.

Regulatory Commitments: Regulatory Process Identified Effects and Mitigation

Creating a centralized socio-economic regulatory commitment tracking list that includes all socio-economic commitments made during the regulatory process will support compliance through tracking and communicating requirements. These commitments are actionable tasks that can be assigned to a variety of internal disciplines and tracked centrally to ensure compliance. Coastal GasLink actively maintains a master commitment list to ensure mitigation is being implemented and to identify gaps. See Figure 2 for a socio-economic regulatory commitment tracking list example.

Collaboration and integration of these requirements with other internal disciplines activities and construction tools support alignment and efficiency in meeting construction requirements. Integration of the socio-economic regulatory commitments with other construction-wide commitment tracking tools will further embed socio-economic regulatory requirements with construction activities. This will increase alignment and internal awareness of these requirements. Where applicable, proof of commitment compliance can also be tracked and stored in a central location.

Regulatory Conditions: Socio-Economic Management Plans

As universal approaches to managing socio-economic effects and associated regulatory processes advance, regulators increasingly require proponents to develop and implement socio-economic effects management plans. Robust and well-designed socio-economic management plans ensure there is active monitoring and follow-up on regulatory requirements, to avoid or reduce potential adverse socio-economic effects identified during the regulatory process. Similar to environmental management plans submitted in some jurisdictions during the regulatory application process, socio-economic management plans outline the approach to implementing mitigation, the process for how mitigation effectiveness will be monitored, the adaptive management process, and the reporting approach during construction.

Commitment Reference	Effect	Commitment	Accountable	Due Date	Date Completed	Variance

Figure 2. Socio-economic regulatory commitment tracking list

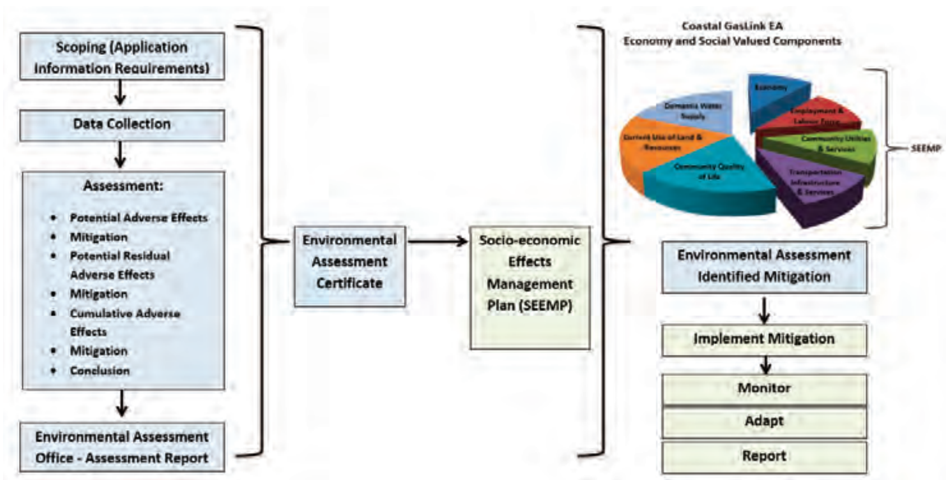

Figure 3. Coastal GasLink socio-economic effects management plan regulatory overview

Coastal GasLink received regulatory approval for its Socio-Economic Effects Management Plan (SEEMP) in 2016. The SEEMP identifies Coastal GasLink's approach to implementing socio-economic mitigation during construction to avoid or reduce potential adverse socio-economic effects on regional and community infrastructure and services. The plan also outlines a process for how Coastal GasLink will monitor and report on the effectiveness of the mitigation and engage with identified groups. Implementation of the SEEMP requires Coastal GasLink to engage externally with identified groups and submit SEEMP monitoring reports twice a year during construction.

Engagement

Engagement is important to the implementation of socio-economic management plans, given the complex human aspects of the potential effects related to construction activities. Socio-economic management plans identify the engagement approach, including the groups to engage with, frequency, and methods. Focused on two-way communication, engagement shares information, monitors mitigation effectiveness, facilitates the gathering and understanding of issues, and strengthens relationships both internally and externally. Consideration of both internal and external audiences is important in implementing socio-economic management plans. Through the SEEMP, Coastal GasLink reaches out to more than 57 organizations a minimum of twice a year to engage on observed socio-economic effects during construction.

Monitoring

Socio-economic monitoring enables industry to track and evaluate expected outcomes and mitigation effectiveness. It also supports collecting and tracking information on mitigation implementation progress, achievements, and compliance with regulatory requirements. Through monitoring activities, the need to trigger an adaptive management process will also be identified.

Monitoring efforts link identified mitigation to time frames, frequency, and data sources, both internal and external. For socio-economic data collection, both qualitative and quantitative methods are used. This would include engagement feedback, observations, and internal data reports. This data helps the industry understand whether mitigation is effective or if adjustments need to be made. Monitoring can identify mitigation that may need to be modified or new mitigation that may need to be developed to address unexpected, adverse effects.

Reporting

Reporting is an important communication tool to inform internal and external audiences, as well as regulators. The content of socio-economic management plan reports will depend on the frequency of mitigation and monitoring strategies outlined in the plan. Typically, reporting is transparent, at regular intervals, and includes updates on construction activities, implemented mitigation status, engagement activities, and adaptive management items. Coastal GasLink submits SEEMP reports to the regulator and externally twice a year, while other construction projects submit annually.

With the vast array of data that is collected for socio-economic reporting and the structured approach that socio-economic management plans provide, natural synergies exist with ESG standards and reporting. Equator Principles Financial Institutions promote assessment and management of social risks and effects during project development and construction to ensure sustainable social performance and outcomes. Effective socio-economic management plans demonstrate sound management practices and provide a framework to manage, monitor, adapt, and report on socio-economic effects and mitigation in a consistent and disciplined manner. As a result, the plan and subsequent reporting would align with ESG reporting standards, turning what has been seen as "intangible" and difficult to measure into something measurable and meaningful to a variety of audiences, including the financial sector.

Regulatory Compliance and Enforcement: Inspections

In British Columbia, regulatory agencies have authority to conduct inspections on compliance with socio-economic regulatory requirements at any time during construction. Typically, there are two types of inspections conducted: administrative (i.e., office-based) and field-based (i.e., on-site). Socio-economic inspections tend to be administrative inspections, which include compliance verification based on a review of documents.

On Coastal GasLink, socio-economic subject matter experts assess the connections between construction activities relevant to inspection requests, facilitate the collection of that data, and develop the response to the regulator in follow-up to those inspections. Socio-economic administrative inspection information usually involves extensive engagement logs, compiled in collaboration with a variety of internal disciplines. Proactively managing socio-economic regulatory commitment tracking lists and collecting proof of how a commitment is met will ensure the inspection process is smooth.

SOCIO-ECONOMIC ISSUES MANAGEMENT

Managing socio-economic issues has become critical for business success in today's environment. The socio-economic landscape is dynamic and constantly changing, which can impact assumptions made at a point in time during the regulatory assessment. Through ongoing engagement with internal and external audiences, socio-

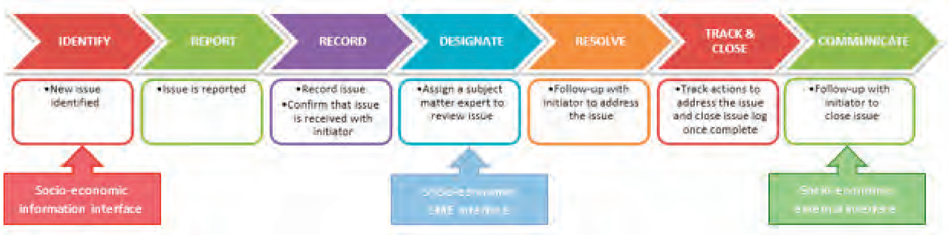

Figure 4. Coastal GasLink's issues management process

economic issues can be strategically identified and addressed appropriately, in a timely manner.

Once a socio-economic issue is identified, a management process should be implemented to ensure transparency and a structured approach to resolving the issue. This process should include tracking the issue from beginning to resolution, collaborating with subject matter experts to address the issue, and appropriate external engagement. Figure 4 illustrates how the Coastal GasLink socio-economic program interfaces with the construction issues management process.

Early issue identification proactively manages the potential for impacts to construction costs, schedule, and objectives. It also supports decision-making in construction execution and influences successful mitigation. It is important that risk is understood, managed, and clearly communicated across the various construction disciplines.

CONTINUOUS IMPROVEMENT

Best-in-class socio-economic programs are designed as a continuous improvement process where potential issues are identified and managed on an ongoing basis. This adaptive management approach is used given the complexity of the issues that the program addresses, where potential issues will be identified on a proactive basis, as much as possible, and resolved with effective avoidance or mitigation. The adaptive management approach also ensures the flexibility to modify steps or tasks embedded in the socio-economic management framework, in case the identified issue requires this kind of change. See Figure 5 for an illustration of Coastal GasLink's adaptive management process.

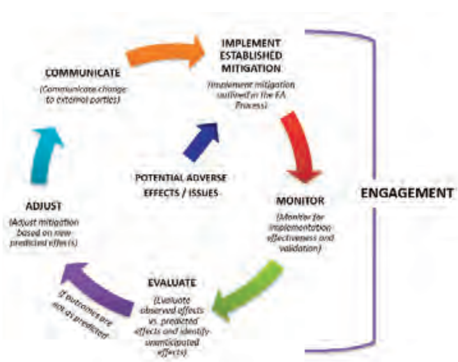

Figure 5. Coastal GasLink's adaptive management process

CONCLUSION

There is a recognition within the industry that striving to address concerns and realizing positive socio-economic effects are key components for ensuring healthy and sustainable communities and successful business outcomes. A well-designed socio-economic program decreases risk during construction and includes consideration of both regulatory requirements and proactive issues management. As demonstrated on Coastal GasLink, this structured approach ensures a comprehensive understanding of socio-economic effects and issues, along with appropriate mitigation and benefit initiatives to address them.

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AUTHOR PROFILE

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As Manager–Socio-Economics for TC Energy's Coastal GasLink Pipeline Project, Sian Weaver has accountability for the socio-economic components, including implementing and managing the socio-economic program. Weaver oversaw the development of Coastal GasLink's Socio-Economic Effects Management Plan (SEEMP), a first for TC Energy. Weaver has held roles across TC Energy, including managing multimillion-dollar corporate community programs for North America; overseeing the socio-economic components of major infrastructure projects; and developing, implementing, and managing new programs, like the Coastal GasLink Construction

Monitoring and Community Liaison Program. Weaver's experience in areas like program management, socio-economic impacts, and building community partnerships contributed positively to how projects are implemented today. Weaver holds a Bachelor of Arts degree in sociology from the University of Calgary in addition to various certificates, including ESG management, corporate community relations, public relations, and public participation.

Minimizing and Monitoring Environmental Impacts from the New York Power Authority/ Vermont Electric Power Company PV-20 Submarine Cable Replacement Project

Tim Follensbee, Lydia Lee, and Jason Gorman

The PV-20 Submarine Cable Replacement Project replaced a vital 115 kV circuit that extended 2.6 kilometers through Lake Champlain between New York and Vermont. The project installed new oil-free submarine cables; removed seven original oil-filled submarine cables that needed replacement due to age, condition, and risk of failure; and upgraded associated facilities. Crossing New York, Vermont, and federally regulated waters, the project required permitting from several agencies, each with different requirements. Given the submarine environment, the team was challenged with designing strategic sequencing, tactical construction methodologies, and monitoring programs to avoid grid disruption and minimize environmental impacts.

Construction methodologies included horizontal directional drilling, jet plowing and diver burial of the cables, and purging of oil prior to the removal of the original cables. Consulting regulatory agencies, the team developed monitoring programs, which included real-time turbidity monitoring, using data buoys, compliance inspections, and underwater cultural resources inspections. The design and monitoring programs allowed the Project to be completed successfully with little disruption to Lake Champlain. Our objective is to present studies, design, compliance, and monitoring plans that resulted in efficient permitting and project execution, with minimal environmental impacts and no opposition from stakeholders or the public, for consideration in similar projects.

Keywords: Construction, Monitoring, Stakeholders, Submarine Cables, Technology, Water Quality, Turbidity.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

The PV-20 Submarine Cable Replacement Project (the Project) replaced the submarine transmission cables that connect the New York Power Authority (NYPA) and Vermont Electric Power Company (VELCO) transmission systems in New York and Vermont (PV-20 circuit) via Lake Champlain (the Lake). The PV-20 circuit provides a vital interconnection between the Vermont and New York transmission grids. The Project resulted in the installation of four new 230 kV electric transmission cables (operating at 115 kV), removal of the original seven oil-filled 115 kV electric transmission cables, and construction of new transition stations and overhead structures.

Project planning commenced in 2013, when NYPA and VELCO determined that the original cables, which were installed in 1958 and in 1970, were approaching the end of their expected useful service life. Main components of the old cable system were obsolete, and a sudden failure would have required extraordinarily expensive custom manufacturing with long lead and lengthy outage times. Additionally, the aging condition of the original cables and increased potential for failure posed a risk of an oil release to the Lake. The Project provided a necessary and prudent solution that involved strategic sequencing design, tactical construction methodologies, supporting studies, and monitoring programs to avoid grid disruption, minimize environmental impacts, and demonstrate compliance with environmental regulations. The Project Team, consisting of NYPA, VELCO, CHA, and VHB, utilized effective stakeholder coordination and collaboration to ensure open and transparent sharing of information with the public and applicable regulatory agencies. This approach assisted in the facilitation of a smooth acquisition of the necessary Project permits and approvals, and successful completion of the Project with no adverse effects to natural or historic resources.

Project Setting

Lake Champlain is a large, natural freshwater lake, located between the Adirondack Mountains of New York and the Green Mountains of Vermont. Lake Champlain is approximately 193 km (120 mi) long and 19 km (12 mi) wide at its widest point (LCBP 2022). The PV-20 circuit is located where the Lake is approximately 2.4 km (1.5 mi) wide, and relatively close to the urban centers of Plattsburgh, New York, and Burlington, Vermont, making it an ideal location for a submarine crossing. Crossing New York and Vermont lands and through Lake Champlain, the Project required several permits and authorizations from New York, Vermont, and federal regulatory agencies.

DESIGN

The Project design was initiated with the completion of land and marine topographic, geophysical, and geotechnical surveys to determine site conditions and constraints. The surveys also confirmed the original cable alignments and depth in coordination with available maintenance and as-built information. This data, in concert with preliminary, known environmental and regulatory conditions and cable design parameters, allowed for development of possible cable alignments and installation methods to prepare the basis of design demonstrating the avoidance and minimization of impacts. The following sections discuss the basis of design that was initially presented to stakeholders and then ultimately permitted and constructed.

New Cable Installation

The new cable alignment considered limiting the line outage durations required for construction and removal; future use of the corridor; construction methods; rights-of-way (ROW) constraints and necessary land acquisition; cable design; and operation and maintenance. Based on the shallow exposed bedrock conditions along both the New York and Vermont shorelines necessitating rock removal (such as blasting) for cable burial, the use of horizontal directional drilling (HDD) was selected to transition the cable from land to water on both sides of the Lake. The use of HDD limited disturbance of

Figure 1. Horizontal directional drilling from land to lake

the littoral zone by terminating at a minimum water depth of 30 feet, and removed the need for changes to the shoreline topography that would have occurred using traditional open trenching. The HDD design included installation of four independent HDPE conduits to facilitate installation of the new cables. The HDD alignments and cable design were evaluated to ensure the cable was able to meet load requirements, based on installation within a conduit in bedrock that limited heat dissipation. The HDD design was complicated by property line constraints, HDD installation equipment capabilities, and geology. On land, the replacement cables were installed using open trench construction methods from the HDD-installed conduits to the new transition stations.

To protect the cable at the exit of the HDPE conduit within the Lake to a depth of 30.5 m (100 ft), a minimum burial depth of four feet was selected, based on the primary uses of the Lake for recreation and with commercial use limited to a ferry service located to the south of the cable alignment. Based on the lake bottom subsurface conditions, the use of a jet plow and diver hand jetting were selected as methods to install the cables in the buried sections. The jet plow was used in New York based on the burial length and cable installation progressing from west to east across the Lake. Due to shorter burial length and space constraints limiting the installation barge's mobility, diver hand burial with a water jet was used in Vermont.

At depths exceeding 30.5 m (100 ft), use of a jet plow was not a viable option, due to increased risk to the cable during installation and cost. Inability to acutely control the tension on the jet plow and cable at these depths can result in overstressing the installation equipment or cable; additionally, special diving techniques are required at this depth. Therefore, the cables were directly laid on the lake bottom at water depths greater than 30.5 m (100 ft). Table 1 summarizes the length and water depths of each installation method that was used in the final design.

Table 1. Summary of Cable Installation Lengths and Water Depths

Installation Method	New York	Vermont	Water Depth
Open Trench (m)	61	54	Land
HDD (m)	407	245	Land to 9.1
Jet Plow (New York)/ Hand Jet (Vermont) (m)	395	203	9.1 to <30.5
Direct Lay (m)	941	573	>30.5
Subtotal (m)	1,803	1,073	
Total (km)	2.88		

The four new cables were installed, with three phases for operation and the fourth as a spare, in a 152 m (500 ft) wide corridor located approximately 9.1 m (30 ft) north of the northernmost original cable, to ensure sufficient clearance during installation. The new cables were installed in two pairs with each cable 15 m (50 ft) apart and a 91 m (300 ft) separation between the pairs. Fifteen-meter (50 ft) separation provides sufficient clearance for installation and 91 m (300 ft) separation between cable pairs facilitates laying a cable back onto the lake bottom without overlaying other cables following cable repairs on a surface work vessel.

The new cables consist of 230 kV rated extruded cross-linked polyethylene (XLPE) dielectric submarine cable, with a diameter of about 14 cm (5.5 in) and weight (in water) of approximately 37 kg/m (26 lb/ft). The conductor is compact, round copper, walled with a semi-conducting water-blocking compound. Additional layers include the conductor shield, insulation, insulation shield, metallic sheath, jacket, and armor. The intended cable operation is 115 kV; the higher rating serves to accommodate potential future upgrades to the circuit. Each cable was installed as a continuous length, with no splices. The cable and armor have a minimum service life of 40 years. The installation included the attachment of an external fiber-optic cable to new cable for communications and a distributed temperature sensing (DTS) system for monitoring cable temperature.

Original Cable Removal

The original cables consisted of four 7.4 cm (2.9 in) diameter cables installed in 1958, and three additional 8.6 cm (3.4 in) diameter cables installed in 1970, for additional capacity and after failure of one of the original cables in 1969. The cables were a passive, oil-filled design with low viscosity oil contained within a duct in the cable, for flow of oil between the gravity-fed oil reservoirs located at transition stations on each side of the Lake. As the temperature of the oil within the cable increased, cooler oil from the reservoirs would flow into the cable.

Within the Lake, the original cables were installed in a single trench on each side of the Lake that extended out about 76.2 m (250 ft) into the water, at a water depth of approximately 6 m (20 ft). Available documentation and surveys performed indicated rip-rap, 60 cm (24 in) thick and underlain by 30 cm (1 ft) of sand, covered the original cables in the trenches.

Complete removal of the cables was necessary to prevent a release of residual oil to the Lake, avoid potential future degradation issues, and avoid the need to remove them at a future date when their condition may have deteriorated more. Complete removal also allowed for future use of the corridor and easements. In addition, the original easement from the New York Office of General Services (NYOGS) required removal at the end of the cables' useful life. To maintain operation of the circuit with limited outages, the removal was planned to be completed after the new cables were installed, tested, and commissioned into service.

To avoid the risk of a release of oil to the Lake, the Project design included purging free phase oil from each cable using a combination of pressurized air and water on one side of the Lake and vacuum pumping on the other, prior to their removal. Open trenching to uncover the land portion of the original cables commenced after the anticipated volume of oil from each cable was recovered. The rip-rap material was temporarily side-cast and then replaced through coordination of a barge-mounted excavator and diver observations. Work within the Lake was performed within a silt curtain to contain suspended sediments and allow them to settle prior to removal of the curtain.

The removal design included a remotely operated vehicle (ROV) survey prior to cable removal to confirm the original cable alignment and make sure they were free of any obstructions or debris. Following confirmation that the original cables were clear, the cable ends were secured to a spool mounted on a work barge and reeled onto the spool to remove the cable directly off the lake bottom, with little to no lateral movement of the cable to minimize disturbance of the bottom sediments.

To avoid a historically significant shipwreck during removal, this procedure was modified to lift the cable laterally to avoid the possibility of disturbing the resource. Once fully recovered, each cable was cut into manageable sections and placed in roll-off containers for recycling. This operation was completed for all seven cables.

Upon construction and commissioning of the new terminal station, the existing station and equipment were decommissioned and removed, and the site was restored.

The thoroughly vetted basis for design parameters described herein enabled focused discussions with stakeholders regarding the more substantial and impactful components of the Project, which are presented in the next section.

STAKEHOLDER OUTREACH

Given the dynamic nature and unique challenges of the Project, the Team took a comprehensive and proactive approach to the permitting and stakeholder outreach aspects of the Project. The Team held frequent meetings and other correspondence with the regulatory agencies to ensure open and transparent sharing of information and expectations. The Team worked with the U.S. Army Corps of Engineers (USACE), the New York Department of Environmental Conservation (NYDEC), NYOGS, the Vermont Department of Environmental Conservation (VTDEC), the Vermont Department of Fish and Wildlife (VTDFW), and other impacted stakeholders. This open communication provided necessary information to evaluate project impacts and ensure compliance with applicable state and federal regulations and permitting requirements. Initial outreach to the agencies started in early 2014 and continued throughout the duration of the Project. The installation and commissioning of the new cables had an aggressive timeline and was completed at the end of 2017. Removal activities were completed in 2018, with final completion of other minor components reached in 2020. Continuous updates and ongoing conversations throughout the Project built a level of trust with the regulatory agencies, which served to facilitate a smooth permitting process and expedite necessary ongoing authorizations.

Throughout the initial outreach efforts, the Project Team determined that the following permits would be required to construct the Project:

- Vermont:
    - o Vermont Section 248 Certificate of Public Good (CPG) Petition through the Vermont Public Utilities Commission
    - o Vermont Lake Encroachment Permit
    - o Vermont Construction Stormwater Permit
    - o Vermont Individual Section 401 Water Quality Certification
    - o Agency of Transportation Permit
- New York:
    - o State Environmental Quality Review Act (SEQRA) Determination
    - o Section 401 Water Quality Certification
    - o Stormwater Pollution Prevention Plan (SWPPP)
    - o NYOGS Permit
- Federal:
    - o USACE Section 404 of the Clean Water Act Permit
    - o USACE Section 10 of the Rivers and Harbors Act Permit

To facilitate the smooth and timely permitting for the Project and to address concerns and suggestions raised by the regulatory agencies throughout the Project's pre-permitting outreach, the Team completed several project-specific studies. The Project Team then utilized the information from these studies to develop project-specific protection plans and permit applications.

STUDIES AND PROTECTION PLANS

Due to the submarine component of the Project, approval by the various state and federal agencies required studies and protection plans above and beyond those typically needed to address standard permit requirements related to utility installations, such as wetland and waterway surveys. To support expert testimony, agency questions and concerns, and stakeholder concerns specific to the uniqueness of the construction and operation of the submarine cables, the Project Team initiated the following studies to identify, avoid, and minimize project impacts through design and planning:

- Natural and Cultural Resource Assessments (land and water)
- Water Quality Modeling
- Total Suspended Solids (TSS) to Turbidity Correlation Study
- Thermal and Magnetic Modeling

These studies led to the development of protection and monitoring plans, used to support construction and confirm that activities were protective of the environment. To provide additional assurances to stakeholders regarding water quality impacts during construction of the Project, the Project Team developed and implemented the following monitoring plans:

- Water Quality Monitoring Plans
- Aquatic Invasive Species Management Plan
- Inadvertent Return Contingency Plan
- Original Cable Removal Plan
- Spill Prevention, Containment, and Contingency Plans

These studies, findings, and resulting design considerations and protection plans are detailed in the following sections.

Natural and Cultural Resources

The Project Team completed wetland and waterway delineations, lake habitat studies, and significant wildlife habitat and rare, threatened, and endangered species (RTE) surveys early in the planning phases to incorporate techniques to avoid or minimize impacts into the design of the Project. Pre-design lake habitat assessments confirmed the absence of unique habitats and rare, threatened, or endangered species within the Project vicinity's littoral zone (EcoLogic, LLC 2015). However, the littoral zone throughout Lake Champlain provides fish spawning habitat, so the Project construction schedule was designed to limit significant lakebed-disturbing activities to timeframes outside of potential fish spawning periods; this work would be completed between June 1 and September 30 for Vermont, and March 30 to October 14 for New York. Thus, installation of the Project would not disrupt significant habitat and/or wildlife.

Pre-design marine and terrestrial archaeological resource assessments were completed in the Project area. No significant terrestrial resources were identified; however, the marine assessment identified a historically significant shipwreck in the vicinity of the Project area, which necessitated specific Project activities and precautions within a defined buffer zone, and the commitment to perform a post-construction ROV survey with documentation to confirm the site had not been impacted. The post-construction ROV survey was completed with video footage, and confirmed the Project had no impacts to the historic site.

Water Quality

Permit authorization from both New York and Vermont regulators required defensible demonstrations and expert testimony that the Project activities would not result in impacts to numerous environmental criteria or result in violations of state water quality standards (WQS). Potential water quality issues largely stemmed from the fact that cable installation via jet plow (and removal, although to a lesser extent) would disturb the lakebed, resulting in the resuspension of sediments into the water column. Jet plow installation relies on high-pressure water jets to fluidize sediment, which allows the cable to be laid at a specified depth below the lakebed. Sediment resuspension leads to localized increases in turbidity and TSS, and a potential short-term release of nutrients (such as phosphorus) and contaminants (such as metals), if present. As part of Project design, the Project Team collected sediment samples from within the Project area for use in analyzing this concern.

Both New York and Vermont have numerical WQS for nutrients and contaminants of concern. In New York, a threshold value of 200 mg/L for TSS was used as the permitted WQS, based on recent approvals for a project using similar installation methods. The Vermont WQS criterion for TSS is based on an assessment of impacts to existing uses. Both New York and Vermont WQS do not have applicable turbidity standards.

To address the qualitative TSS WQS in Vermont, the Project Team evaluated potential TSS impacts on existing uses and identified water supply intakes located to the south of the Project, that withdraw water from Lake Champlain for a community water system and a VTDFW fish hatchery. The fish hatchery requires the withdrawal of a large volume of water with a high level of filtration to provide suitable water quality for the fish, and the VTDFW had concerns that suspended sediment generated by the Project could overwhelm the filtration system, compromising their ability to maintain healthy conditions.

To confirm that the Project, as designed, would not result in these potential adverse effects to water quality during installation, the Project Team completed a detailed analysis and comparison of project-specific sediment properties and installation methodologies to those used in robust modeling studies completed at a similar time, for a comparable project also proposed in Lake Champlain. This analysis demonstrated that assumptions, methodology, results, and conclusions from the comparable project studies were reasonably applicable to the PV-20 Project. Specifically, the Project Team demonstrated that the concentration of the dissolved fractions of detected contaminants, metals, and nutrients in the sediment would be less than the applicable water quality standards for

Vermont and New York, and therefore water quality impacts associated with metals from sediment resuspension would remain in compliance with the applicable criteria of the WQS. The concentrations, dispersal distances, and durations of TSS at the project area were demonstrated to resettle within four hours of cable installation, and would increase no more than 3 mg/L above background levels at a lateral distance of 200 feet from the Project area. Though the methods and results of these studies and comparisons were accepted by the Vermont DEC and the New York DEC, the Project Team developed state-specific monitoring plans to be implemented during construction to provide further assurances to stakeholders.

Vermont Water Quality Monitoring Plan

Although a noticeable increase in TSS concentrations resulting from Project activities was not likely to be detected at the water supply intake, the Project Team provided further assurances to the intake operators through the development of a robust monitoring plan to be implemented during installation activities. Because TSS requires lab analysis with a turnaround time of 1 to 2 days, monitoring for TSS would not provide the real-time information needed to prevent a disruption to the intake (such as by modifying construction methods). Turbidity, on the other hand, can be measured in situ and in real time, but the relationship between TSS and turbidity is highly dependent upon the specific environment (i.e., sediment type and background water clarity). Therefore, the Project Team completed a study to develop a site-specific correlation curve comparing turbidity to TSS, using water and sediment collected from the Project corridor. To do this, a volume of sediment was mixed with lake water in order to achieve water samples with target turbidity values ranging between 1 and 300 NTUs. A sample from the mixed water with a known turbidity value was collected and submitted for laboratory analysis of TSS. Laboratory TSS data were plotted against the benchtop turbidity data to establish the correlation curve. The Project Team was then able to develop turbidity threshold values at specific locations and distances from the Project corridor that, if reached, would trigger response procedures. These values were used in approved turbidity monitoring plans, for both Vermont and New York.

The Vermont monitoring plan was developed with specific consideration of the water supply intake, located approximately 1,200 m (3,900 ft) from the Project area. The plan included monitoring for turbidity during both cable installation and removal, the latter of which was not required for the New York side. Four buoys with turbidity sensors, current meters, and modems that transmitted data in real time to a web-based interface ("data buoys") were installed in the water to the north and south of the Project corridor, to continuously monitor and inform the Project Team of turbidity conditions up-current and down-current of the Project area. The data buoys were placed strategically in order to provide a "warning" system for the water supply intake and to avoid interference with construction and ferry operations. The monitoring system was programmed to send email and text message alerts to Project Team members when certain thresholds were recorded. The Monitoring Plan included contingency measures that would be implemented in the event the trigger thresholds were observed, such as pausing construction and/or modifying installation techniques.

New York Monitoring Plan

To be consistent with similar project approvals, NYDEC requested monitoring during construction to confirm the Project did not violate the WQS. The monitoring plan on the New York side consisted of sampling the water column near the surface, mid-depth, and near-bottom from locations 152 m (500 ft) down-current and 152 m (500 ft) up-current from the jet plow operations for laboratory analysis of TSS, total and dissolved metals (arsenic, copper, and zinc), and hardness. Laboratory samples were collected once every hour, with continuous visual

Figure 2. Buoy monitoring system for cable installation.

observations and in-situ turbidity measurements during installation by jet plowing. The in-situ turbidity measurements informed the Project Team if construction activities were approaching the TSS threshold of 200 mg/L, which, based on the previously completed turbidity/TSS correlation study, was equivalent to 62 NTU, allowing for immediate modification of work to reduce impacts if required.

Both in-situ measurements and laboratory results confirmed that the installation methodology and adjustments did not violate NYWQS.

Thermal and Magnetic Modeling

Stakeholders expressed concerns related to potential impacts that cable operations may have on lake temperature and the local magnetic field that could impact navigation. The Project Team completed project-specific thermal and magnetic modeling to evaluate these impacts. Modeling methodology followed the same general approaches that had been accepted by the regulatory agencies for similar projects to streamline reviews.

Thermal modeling of the PV-20 cables during operation indicated that the new cables would operate at lower temperatures than the original cables, thus having less impact to the water surrounding the cables (Electrical Consulting Engineers, P.C. 2016). This modeling further identified that water temperature increases from cable operation would remain well below 1 degree Celcius at 10 mm (0.4 in) from the cable and would have a zero-degree temperature change on the water at 13 mm (0.5 in) from the cable and beyond. Therefore, the project-specific temperature modeling confirmed that the operation of the Project would not result in undue adverse effects to water quality and would maintain compliance with applicable WQS temperature criteria (specifically, Vermont WQS).

Likewise, the Project Team modeled the magnetic fields associated with the original and replacement cables. The modeling confirmed that the alternating current through the new cables would emit magnetic fields, but that the magnetic fields would not affect compass readings or operation of recreational vessels. The modeling indicated that once the cables were installed, there would be no significant or measurable impacts on recreation and public uses. In addition, the magnetic fields from the new cables were calculated to be less than those from the original cables, due to improvements in cable design.

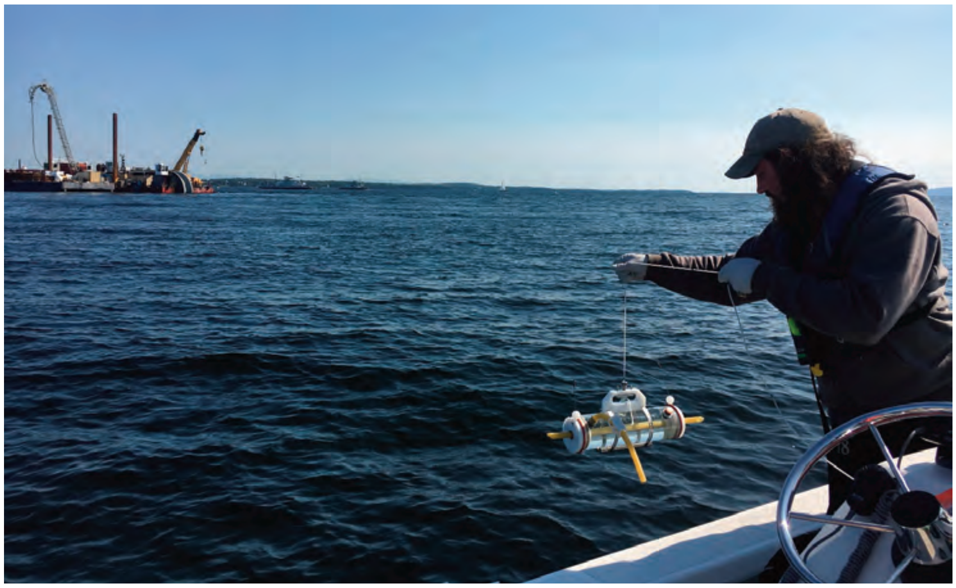

Figure 3. Water quality sampling in New York during cable installation. Installation barge with the cable on the spool is in the background.

Figure 4. Cables on barge at the New York Champlain Hudson Lock System.

Aquatic Invasive Species Management Planning

The nature of the Project required the transport of marine vessels into Lake Champlain via overland transport and through the New York Champlain Hudson Lock System. The transport of marine vessels/equipment from one water body to another poses the risk of introducing new aquatic invasive species (AIS) to the Lake. An AIS Management Plan prepared in consultation with the Project contractors was developed to specify precautionary measures and decontamination procedures for each vessel brought into Lake Champlain. Precautionary measures included the decontamination of vessels transported overland, which was preferred, given the risk of AIS transport through the Champlain Hudson canal system. For vessels that needed to pass through the locks, inspection, draining of storage areas, and decontamination techniques were specified in accordance with state guidance.

PREVENTION AND CONTINGENCY PLANS

The Project Team worked with contractors and stakeholders to develop prevention methods to avoid certain risks and contingency plans that would be implemented if certain aspects of the Project did not go as planned. These considerations are summarized below.

Inadvertent Return Contingency Planning

The potential for an inadvertent discharge of drilling fluids through fractures in bedrock or sediment during the HDD installation effort (commonly referred to as an inadvertent return) presented the potential to impact sediment and water quality. This concern did not require upfront study; however, the Project Team agreed to develop a contingency plan in collaboration with the selected contractor and stakeholders. The Inadvertent Return Contingency Plan detailed best management practices including prevention planning, continuous monitoring, and contingency measures in the event of an inadvertent return during HDD operations.

Although best management practices were implemented during HDD activities, site conditions and subsurface characteristics ultimately led to some inadvertent returns. Impacts associated with these inadvertent returns were mitigated by implementation of the plan and subsequent cleanup efforts performed via suction dredging. Third-party diver inspections performed after the cleanup efforts confirmed that fluid lost during the HDDs was no longer present on the lake bottom. Therefore, impacts, if any, associated with the inadvertent returns were only temporary in nature.

Original Cable Removal Plan

To avoid the risk of a release of oil to the Lake during cable removal activities, the Project design specified purging the cables to remove the oil. The Project Team and contractor developed a robust plan for oil removal, purging, collection, and disposal. The plan included spill response, reporting, mitigation, and containment procedures. The Lake was continuously monitored for the presence of sheens during removal operations. Oil from each cable was sampled several times prior to purging and removal activities and was analyzed for the presence of polychlorinated biphenyls (PCBs). No PCBs were detected, and as such, all cable oil was considered to be non-PCB oil.

The free-phase oil was purged by pulling vacuum on one end of the cable and pressurizing the other end with water. The pressurized water forced the oil in the cable toward the vacuum on the other end where it was extracted. Oil extraction was accomplished over three individual purging events. The cable manufacturer provided information about the pressure capacity of the cable to ensure the integrity of the duct as pressure was applied. Second and third purge events were completed following 36-hour waiting periods after each purge event. The wait period allowed for oil to seep from the soaked insulating paper into the duct for a more thorough extraction of the oil from all components of the cable. The anticipated oil volume was removed from the cables following the third purge event and removal activities commenced.

Due to the age of the cables, some portions of cable were brittle and minor amounts of oil were discharged during cable removal efforts. The Removal Contingency Plan acknowledged this as a possibility and provided the necessary procedures to respond to and report the release immediately after a release was detected.

Spill Prevention and Control Plan

The installation of the submarine cable and removal of the original cables required the transport, handling, use, and on-site storage of hazardous materials and petroleum products, primarily associated with the operation of the equipment and vehicles. To avoid potential impacts from hazardous materials and wastes, the Project Team and contractors prepared a Spill Prevention, Containment, and Countermeasure Plan, which described the spill prevention and contingency methods and procedures to be utilized for on-land Project operations. Adherence to this plan verified that adequate controls were in place, resulting in the successful avoidance of releases to the environment.

CONSTRUCTION COMPLIANCE

The Project Team remained closely involved with the Project through construction to ensure the Project was executed in accordance with engineering designs, plans, and permits. The Project Team engaged in construction oversight, water quality/turbidity monitoring, erosion prevention and sediment control inspections, and spill prevention, control, and countermeasure plans for the final project. Involvement from the same team members from conception to completion of the Project realized efficiencies due to institutional knowledge, allowing the Project to be completed within full compliance of all permit conditions and state and federal regulations.

DISCUSSION

The PV-20 Cable Replacement Project was an important project for the region, given the critical nature of this interconnection between the New York and Vermont transmission grids. Given the age of the original cables and the fact that their condition was deteriorating over time, it was imperative to replace these cables and associated aging terminal equipment prior to a significant failure of the cables or equipment. The Project was a priority since replacement parts are hard to find, not available, or require custom fabricating with long lead times, which would have led to an extended unplanned outage for this interconnection.

The Project's submarine nature and crossing through two state jurisdictions and a federally regulated waterbody made this project unique for the Project Team as well as the regulatory agencies permitting the Project. As such, the Project required a rigorous planning and pre-permitting process with the stakeholders. The results of this process led to the project-specific design, studies, and protection plans, which ultimately resulted in the Project being commissioned on time, within budget, and in full compliance with all applicable permits and regulations.

The key takeaways from this unique and dynamic project are:

1. Undertaking a well-vetted and well-thought-out project design and planning effort, prior to initiating conversations with regulatory agencies and other stakeholders, helped to facilitate project discussions and focus conversations on the more substantial and impactful components of the Project. This approach helped ensure that proposed construction methods and potential impacts were understood and allowed for focused discussions with regulators on the best ways to avoid, minimize, and mitigate these potential impacts.
2. The data collected during project activities confirmed the results from our planning and modeling efforts. Modeling efforts for the Project prior to the permitting phase included evaluating magnetic, thermal, and TSS impacts associated with the jet plow effort. No verification efforts were required to confirm the thermal or magnetic modeling results during operations. The modeled results indicated they would have a de minimis impact on the Lake's ecosystem, and there has been no indication that the modeled values have been exceeded.

   The Project was required to monitor TSS (or turbidity as a proxy for TSS) during construction. All sampling efforts indicated levels consistent with or below the modeling results, even during times when visually turbidity was observed from the surface.
3. Correlation curves between turbidity and TSS can vary greatly based on the type of sediments that may be suspended and the water clarity of the waterbody receiving the sediment. Thus, it was important to perform the site-specific study and develop a specific correlation curve for this project area. Once this effort was complete, we had a correlation curve that was much more precise and could be accurately reviewed against the sediment loading of the water supply intake on the Vermont side of the Lake and against the WQS, and that was also accepted for use during monitoring on the New York side.
4. The use of the water quality monitoring buoys was a valuable tool throughout the installation and removal efforts, as we were able to monitor water quality remotely throughout the duration of the construction and removal activities. This was especially important during night and weekend work efforts, when it would have been difficult and costly to maintain compliance personnel on-site to perform monitoring work. In addition, the Team set up the data collection software to send out notifications to specific personnel if certain turbidity threshold values were reached.
5. The building of open, transparent communication with the regulatory agencies was important, as the dynamic nature of the Project led to several changes throughout the construction effort, which required additional agency authorizations in a timely manner. Making sure that the regulatory agencies had a complete and comprehensive understanding of the Project and the unique challenges it presented was critical to the overall success of the Project. In addition, this continued open communication with the regulatory agencies assisted in building stronger working relationships between the Project owners and the regulatory agencies.

CONCLUSION

The project-specific studies and protection plans developed prior to the construction phase of the Project proved to be valuable assets throughout the duration of the Project for the owners, the contractors, and compliance personnel. These protection plans also gave assurances to regulators that the Project was well designed, with environmental protection considerations at the forefront of the design and monitoring programs. Through the comprehensive approach to stakeholder and regulatory outreach utilized by the Project Team, the Project was successfully permitted, installed, and commissioned on time and within budget.

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The Challenges and Benefits of Virtual Open Houses

Jon Schultis, Donald Handshoe, and Kristen McDonald

Keywords: Analytics, COVID-19, Digital Innovation, Electric Transmission Projects, Stakeholders, Technology, Utilities, Virtual Engagement, Virtual Open House.

The COVID-19 pandemic resulted in a need for new public engagement methods and increased the popularity of virtual open houses. Designed with local accessibility laws and policies in mind, virtual open houses allow communication with stakeholders in an inclusive and interactive environment that can be easily accessed from any computer or mobile device at any time, eliminating the logistic and geographic limitations of in-person public meetings. Demographics traditionally underrepresented at in-person meetings can now engage through web-enabled devices at their convenience.

This paper presents a case study of a virtual platform for transmission line project open houses, incorporating aspects of in-person open houses using an inclusive, easy-to-navigate website. This case study demonstrates how virtual open houses have been vital through the pandemic to inform and provide for comment exchanges among transmission line project proponents, regulatory agencies, and communities, and will continue to be an important engagement tool beyond the pandemic in a hybrid engagement world. We discuss the virtual engagement space development process, including challenges and how consultants, project proponents, and regulators all came together in a visually appealing, easy-to-use virtual space, so that stakeholders could be informed and regulatory requirements satisfied.

The case study also addresses essential design considerations and platform features that maximize meaningful engagement and allow projects to benefit from expanded and more diverse participation.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Siting is the process used by utilities to determine the best location for an electric transmission line or substation. There are many steps involved, but public participation and feedback are some of the most critical components of the siting process.

The siting study for Duke Energy's Pittsboro–Hanks Chapel 230-kilovolt (kV) Transmission Line project in Chatham, North Carolina, United States, included a public open house component. As the project advanced toward this step, the COVID-19 global pandemic brought the world to a grinding halt. Travel ceased, businesses shuttered, and face-to-face interaction became virtually nonexistent.

The suspension of in-person public interaction presented a monumental challenge to the project. Due to the voltage and length of the line, regulatory requirements were triggered from the North Carolina Utilities Commission (NCUC). Most importantly, a public open house was required before the NCUC would grant a certificate of environmental compatibility and public convenience and necessity for the project, a requirement to move forward with the project.

Public engagement using virtual open house platforms had never served as the exclusive public outreach platform for a transmission line project, and the use of this new approach for public engagement would require NCUC approval.

METHODS

A virtual open house is a digital, online platform that allows the public to access project information; explore how it may impact them; and provide feedback from the convenience of their computer, tablet, or mobile phone. Although digital solutions have often supplemented public engagement efforts in the past, exclusive use of virtual technology to engage the public was largely unheard of prior to the COVID-19 pandemic.

The virtual open house needed to adequately inform and engage a very broad audience, provide all of the same information as in-person open houses, encourage users to leave feedback, and allow the community to engage with the project team in a meaningful way. It would also need to be easy to use across devices and diverse demographics. Whether the user was an experienced technology expert or someone who rarely used a digital device, the experience had to be simple and intuitive to allow anyone to navigate with minimal direction—a key requirement to seek approval from the NCUC.

Development of the virtual open house involved three key steps, including storyboarding, developing the visual layout intent of the room, and developing the virtual environment. Each are described further below.

The first step was to conduct a collaborative storyboarding workshop with the project team to:

- Understand what was important to the impacted community
- Understand the audience and stakeholders who would be engaging
- Determine the important features and functionalities required
- Determine the desired outcomes for the virtual open house

What does success look like for the siting engagement process? You want the audience to feel inspired and excited to engage with the space and for them not to feel overwhelmed by the technology or content.

The second step was to determine the branding, style, visual layout, and audience of the virtual room. The team decided that the best approach was to design a space that would emulate the appearance of a typical in-person open house. The visual layout is an important component, as it sets the stage for the story and main messaging the siting team wants to communicate to the audience. Some questions the development team asked included:

- Is the community rural or is it city-centric?
- What is the demographic range of the residents? Is it an older population or is it a community of young families or young professionals—or all three perhaps?

For the community to successfully engage with the virtual spaces, the room's layouts must be meaningful for them: clean, inclusive, and easy to navigate for all community members. One method is to make the virtual meeting space mirror a traditional, in-person meeting space.

At traditional events, attendees enter a room where they see a series of large, informational boards arranged in a semicircular or 'U' shape, typically with team members welcoming them with a sign-in form (Figure 1). Each board presents information on a different aspect of the project, such as the siting process or engineering and environmental considerations. There is also a geographic information systems (GIS) station, where property owners can interactively view project data in relation to their property and leave comments, as well as another station where the public is invited to leave handwritten feedback.

The third step was to recreate these traditional informational boards in a virtual environment. This would appear to be a fairly straightforward task, but the virtual world presented some challenges. These boards often contain large amounts of information, which isn't generally an issue when they're presented on 36-inch by 48-inch boards. In a virtual environment, though, these boards could be viewed on devices as small as a smart phone, so the material presented needed to be concise but comprehensive with all pertinent information. Ultimately, a button was designed that allowed the board to be enlarged to full screen, allowing the information to be more easily read. This same button allowed an Adobe Portable Document Format (PDF) print out of the board to be downloaded as well.

One of the hallmarks of a public open house is the GIS station. Here, community members are able to view their property along with project data, such as transmission line or substation location, environmental data, and local landmarks. They can also record comments for the project team at this station. To facilitate this experience in a virtual environment, an interactive web map was developed leveraging the ArcGIS Online platform called Find My Property. The map contained all of the previously mentioned data in a user-friendly format.

This map was accessed from the main open house website for the Pittsboro–Hanks Chapel project, but in subsequent virtual open houses and projects, an interactive map was moved inside the virtual platform and given its own board for a more streamlined user experience. Using Find My Property, property owners could search for their property by name or address (Figure 2). Once located, a pop-up displayed their public information and provided them with a link to leave comments.

We used Esri's Survey123 to create simple comment forms for property owners to record information for the project team (Figure 3). Once the link was clicked, the form would be prefilled with their information and they needed only to type in their comments.

This was an important component, as typing can be difficult on mobile devices, especially for those who may not regularly engage in this type of activity. Once a comment was submitted, it automatically added their feedback to a Microsoft Excel spreadsheet and generated an email to the project team. The project team had real-time access to answer comments immediately and track and record comments in a database repository, which prevented hard-copy

Figure 1. Virtual open house environment with information boards

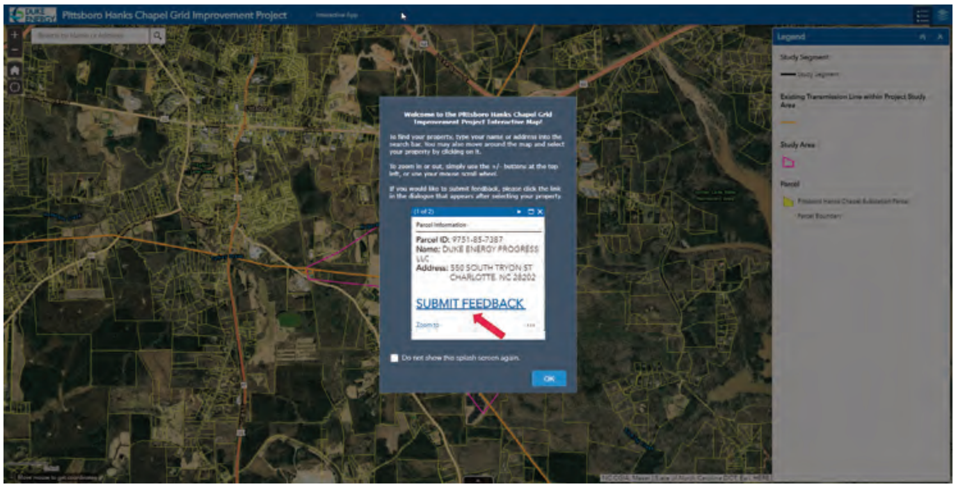
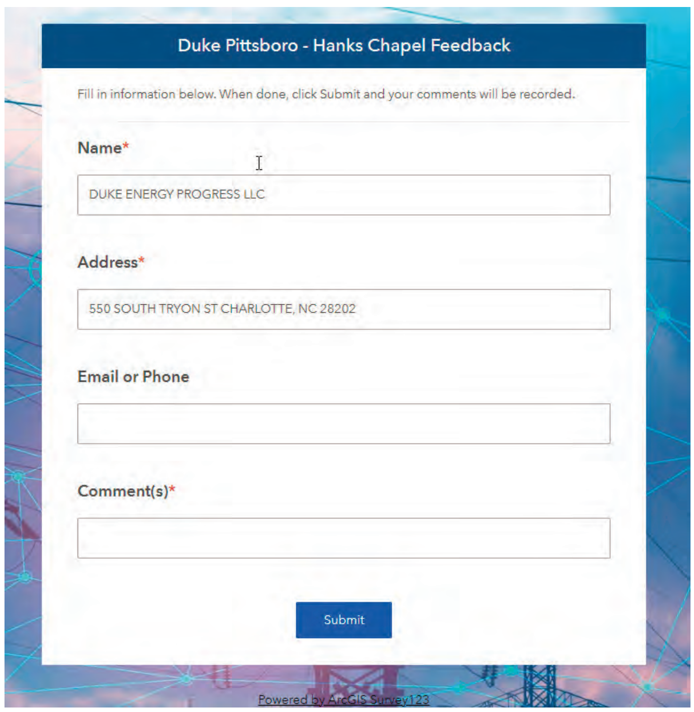


Figure 2. Interactive map for the virtual open house


Duke Pittsboro - Hanks Chapel Feedback

Fill in information below. When done, click Submit and your comments will be recorded.

Name*

DUKE ENERGY PROGRESS LLC

Address*

550 SOUTH TRYON ST CHARLOTTE, NC 28202

Email or Phone

Comment(s)*

Submit

Powered by ArcGIS Survey123

Figure 3. Survey123 comment form

comment forms from being lost.

Two-way communication is vital for a public open house. Not everyone would be inclined to open the interactive map, so other options were included for multiple user touch points and opportunities for submitting feedback comments (Figure 4). The project email address was provided, and a Google Sheet comment form was also created to allow submission of feedback directly from the virtual open house. Live chat sessions were also scheduled to allow the public to speak to the project team directly. Two sessions were scheduled, and the virtual open house provided links to join these sessions.

The final step was the virtual room development build and the integration of Google Analytics into the platform. Using the latest state-of-the art technology, the visual media team created the immersive environment using 360-degree, gaming-engine-based frameworks.

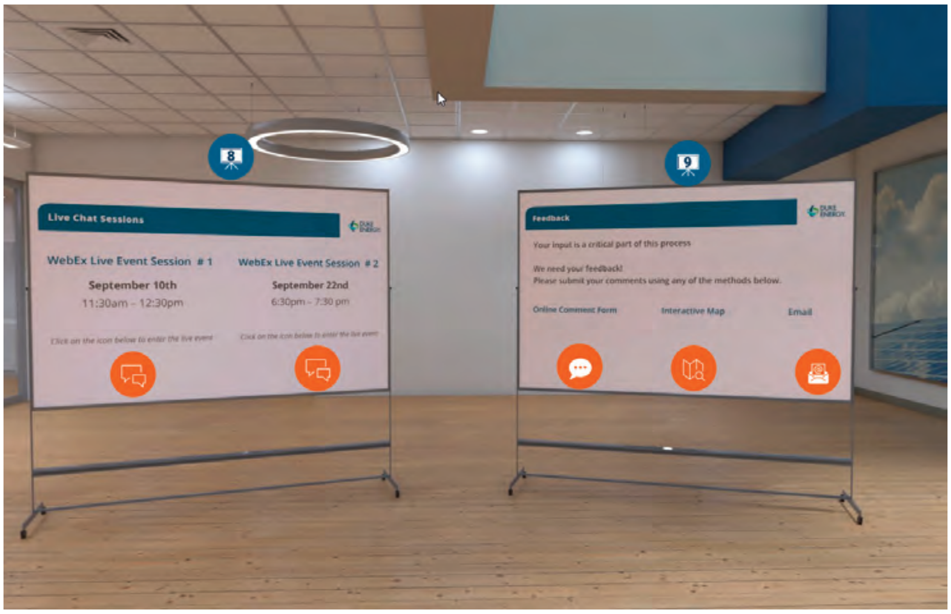


Figure 4. Alternative options for community engagement

RESULTS AND DISCUSSION

The virtual open house platform was developed to meet project goals, including:

- Share project information and solicit feedback similar to traditional in-person meetings
- Promote diverse and inclusive participation
- Engage the public and solicit their feedback
- Track and log visitor feedback
- Provide a rich, synchronous and asynchronous engagement experience

The platform was then presented to the NCUC for their approval. After meeting with officials and presenting our innovative approach, the NCUC agreed that the virtual platform met the requirements for public engagement, and Duke received regulatory endorsement to proceed with the virtual open house system.

Once the platform was live, 460 users visited the virtual open house, and the interactive map recorded more than 650 views. Only a handful of comments was recorded, but this was expected, as the project only impacted a very small number of property owners. Users provided no negative feedback regarding the platform and indicated that it allowed stakeholders to access project information and provide feedback while remaining safely in their own homes.

Early and ongoing communication through this platform contributed to community trust and supported progress on project planning, while increasing the diversity and reach of participants who tended to be underrepresented at traditional in-person open houses due to:

- Disabilities
- Nonstandard work schedules
- Lack of transportation
- Lack of affordable or available childcare
- Incremental weather conditions

Because the system was reusable, the virtual open house platform was easily rolled out on several projects in the following two years. The platform could stay consistent and the slide content at each station could simply be replaced for new successive projects. The features and functionality were incrementally upgraded along the way to improve the user experience and accessibility. Each virtual open house was adapted to fit the specific needs of the individual projects.

Public engagement is a critical step in the siting process. In many jurisdictions, it is a required component to receive regulatory approval for the project. Even when not required, however, it is a step that utilities rely on to maintain positive relationships with the communities they serve. When property owners and local governments are adequately involved in the process, the entire project runs more smoothly, and negotiations are more likely to be successful.

Engagement is also a two-way street. Not only do property owners learn about the project, but the process also allows the property owners to express their opinion on proposed routes and sites and to provide valuable information to the project team. This is often the point when we learn about specific land uses not easily discerned from aerial imagery or windshield surveys, as well as the history of a property that may impact the ability to construct transmission assets. By providing a platform for collaboration even when in-person interaction was not possible, all stakeholders had a voice in the process and were represented as the project progressed.

As we move forward and in-person meetings are once again an option, we must apply the lessons we have learned from the virtual platform. Even now, public engagement is working in a hybrid model, with both in-person meetings and a virtual platform, offering participants a more equitable approach for people who face barriers to in-person events. Not everyone will be comfortable attending face-to-face meetings; and, indeed, not everyone may be capable due to physical, time, or other personal constraints. The addition of this virtual platform to ongoing and future projects provides a flexible approach to support all members of the community and ensures they can be fairly represented, regardless of their ability to attend in-person meetings.

CONCLUSION

Engaging with the public and soliciting feedback as part of the siting process have been challenging during the COVID-19 pandemic. Without the option of in-person interaction, we had to pivot to develop a process that still allowed the public to be a part of project planning process. Digital solutions can create additional barriers if they are complex or otherwise difficult to interact with—so, simple and intuitive design was important.

The virtual open house platform has been a successful engagement tool, recording hundreds of views and the submission of several comments from the community. The platform delivered wide-ranging social, environmental, and economic benefits that supported Duke's siting project engagement priorities.

The platform was later refined and rolled out on subsequent projects, even those with in-person open houses. This integration of a virtual platform along with the more traditional open house allows all members of a community to be included and represented in projects, regardless of their ability to attend in-person meetings.

A virtual open house can share project information with community members, regulatory agencies, and stakeholders in an inclusive and interactive environment that is accessible from any computer or mobile device at any time. Although using in-person meetings or virtual spaces should be determined for each project, virtual platforms will continue to be an integral part of the electric transmission siting process in the future.

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- Land use and zoning entitlement and permitting
- Public outreach and coordination
- Federal Energy Regulatory Commission 7(c) regulatory involvement, primarily in the Mid-Atlantic U.S.

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Environmental Concerns in Rights-of-Way Management

PART IX

Technology

Benefits vs. Burdens: Installing an Advanced Pipeline Leak Detection System in Jasper National Park, Canada

Jason K. Smith and Norm Rinne

Keywords: Energy, Evaluation, Fiber Optics, Impact Assessment, Leak Detection, National Parks, Technology.

Trans Mountain Pipeline ULC (Trans Mountain) applied to Parks Canada to install a fiber-optic-based leak detection system buried alongside an existing 36-inch diameter oil pipeline in Jasper National Park (JNP) in Alberta, Canada. Fiber-optic sensing technology enables continuous, real-time measurements of acoustics, strain, and temperature along the entire length of the pipeline. Using machine learning and artificial intelligence algorithms, this installation will improve Trans Mountain's ability to monitor for pipeline leaks and other integrity risks, including ground movement and unauthorized third-party activity in JNP. Additional benefits of the fiber-optic system include high-bandwidth telecommunications capability to support Trans Mountain's voice and data control systems and the opportunity to improve commercial telecommunications in rural and underserved communities along the pipeline route. This paper explores the application of this new and exciting fiber-optic technology to mitigate the risk of an oil spill and the environmental mitigation strategies employed to minimize the environmental impacts in JNP during installation.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

Trans Mountain Pipeline ULC (Trans Mountain) is installing a fiber-optic-based leak detection system alongside their existing operating 36-inch diameter oil pipeline through Jasper National Park (JNP), a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage site in Alberta, Canada. The total length of the installation in JNP is approximately 80 kilometers (km) and connects with new pipeline and fiber optics being constructed upstream and downstream of the park in Alberta and British Columbia.

In 2018, the Trans Mountain Expansion Project (TMEP) was approved for construction, which will provide increased pipeline access for Canadian crude oil to global energy markets from Canada's West Coast. Trans Mountain Expansion Project involves installing approximately 980 km of new pipeline. Construction is currently underway and expected to be complete in late 2023. The new pipeline will include the fiber-optic-based leak detection system placed directly on the pipe during construction. There is no fiber along the pipe segment in JNP since it was constructed in 2008, well before the fiber-sensing technology existed. As a result, installation of the fiber-optics alongside the existing operating pipeline in the park required a different approach for both permitting and installation when compared to the TMEP installation. The park segment is referred to as the Gaps Connection Project (GCP).

FIBER-OPTIC TECHNOLOGY

The monitoring system uses a single specially manufactured surveillance fiber, installed in one plastic microduct, and a bundle of standard telecommunications fibers, installed in the other microduct. Together, these exist in a single polyethylene conduit. This is shown in Figure 1.

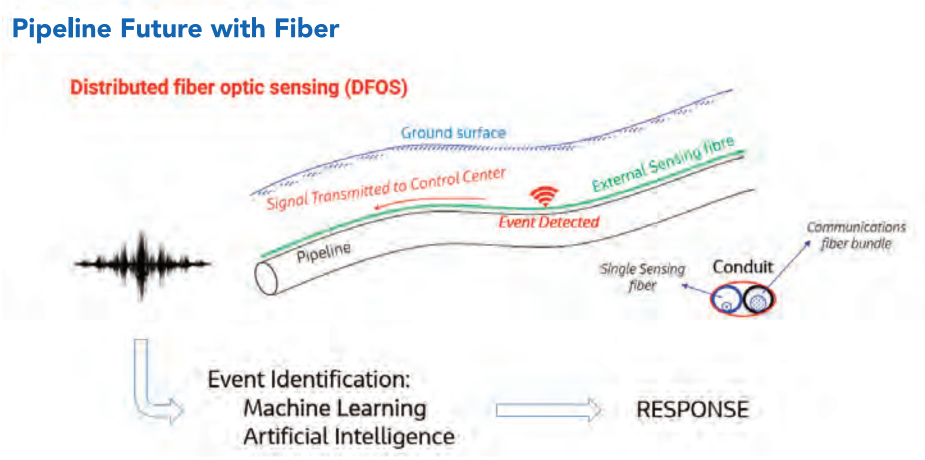

Figure 1. Pipeline future with fiber-optics, including distributed fiber-optic sensing

The single specialty fiber senses "energy events," including changes to acoustics, strain, and temperature. That data is transferred to the conventional telecommunications fibers for high-bandwidth transmission to a control center for analysis and notification of alarms.

The fiber-optic system will monitor the pipeline continuously 24 hours per day, 7 days per week, and is designed to complement existing safety systems.

Leak Detection

Conventional leak detection systems use hydraulic simulations considering flow, pressure, temperature, and density of the fluid taken at monitoring stations to calculate if a leak is occurring along the pipeline between the monitoring stations. Trans Mountain currently employs two separate hydraulic-based leak detection modelling systems. The fiber-optic system takes a completely different approach by constantly sensing for energy anomalies along every inch of the pipeline and reporting the exact location along the pipeline to the control center.

Ground Movement

The Trans Mountain pipeline crosses rugged mountainous and low-lying coastal regions, subject to high earthquake risk. Ground movement, such as landslides, can impart significant stress on the pipeline. Currently, Trans Mountain uses regularly scheduled aerial surveillance flights that could identify larger ground displacement events and also uses specialty internal pigs to travel inside the pipeline that can measure any deformations to the pipe that may require further investigation. The ability of the fiber-optic system to measure strain in the ground next to the pipe will aid the company with its hazard management program to better detect geotechnical issues and prevent leaks from occurring.

Unauthorized Third-Party Activities

Like other utilities, Trans Mountain is part of one-call organizations along the length of the pipeline system. Despite the widespread success of one-call, public education initiatives and extensive rights-of-way (ROW) marking and protection measures, unauthorized third-party activities along the pipeline continue to be a risk to the pipeline. The fiber-optic system will have the surveillance capability to identify potentially damaging third-party activities in real time, allowing immediate dispatch of pipeline protection crews to the site.

PERMITTING AND INDIGENOUS ENGAGEMENT

Constructing and operating linear infrastructure in a National Park and UNESCO site requires careful consideration and more detailed review and approval than work outside of this protected area. Increasingly in Canada, engagement with Indigenous groups is an important part of the permitting process, to understand any issues or concerns that communities may have with the construction and to discuss potential mitigation and accommodation measures that may be of interest.

Trans Mountain undertook a comprehensive consultation program for the entire route of the GCP installation within JNP. This consultation program included 26 Indigenous groups identified by Parks Canada that began six months prior to the commencement of construction. Following a review of Trans Mountain's records of consultation, Parks Canada issued a letter confirming adequacy of consultation, which is a conclusion reached based on Trans Mountain's ability to address concerns raised by the Indigenous groups. These consultation efforts resulted in a collaborative working relationship with Indigenous groups on the project that included direct employment for construction, construction monitoring, and plant harvesting opportunities.

The GCP was applied for and constructed under Trans Mountain's Operations and Maintenance Guidelines, in addition to Parks Canada regulatory requirements. Canada Energy Regulator (CER) is the project regulator, as the fiber installation is linked to the pipeline system and was installed within the same previously cleared ROW. New projects being considered in JNP are referred to and assessed based on their compatibility with the Jasper National Park Management Plan (Parks Canada 2010). The plan establishes land-use zoning for the park in accordance with Parks Canada's policies to minimize human-induced change on lands and culturally sensitive sites. This project was not located on land designated as wilderness under the National Parks of Canada Wilderness Area Declaration Regulations. Section 8(2) of the Canada National Parks Act states that ". . . maintenance or restoration of ecological integrity, through the protection of natural resources and natural processes, must be the first priority of the Minister when considering all aspects of the management of the Park." This project was the subject of a Basic Impact Assessment (BIA) in accordance with Parks Canada Directive on Impact Assessment (2019), to eliminate, reduce, or control potential adverse effects associated with the GCP, given its ability to be installed within the previously cleared areas in the park.

The benefits to the community, including safety, connectivity, and protecting the integrity of the pipeline to avoid potential leaks, were evaluated in light of the short- to medium-term and temporary impacts of other valued components. A determination on the project was completed by Parks Canada, which ultimately led to approval for construction of the project (Parks Canada 2022a, b).

CONSTRUCTION

Gaps Connection Project planning was carried out in 2021, with construction completed in 2023. The 1.5 inch-diameter polyethylene conduit was installed in a shallow trench as close as reasonably feasible to the pipeline, using conventional shallow utility trenching equipment. The fiber-optic cables were pulled into the conduit at hand hole vaults spaced approximately 1.5 km apart along the pipeline.

Installing the fiber close to the pipeline provides the best possible pipeline monitoring capability of the sensing fiber. The target distance of the conduit was between 0.8 m from the edge of the pipeline at a depth of 1 m where terrain and land use allowed. At river, road, and other trenchless crossings, or where the terrain limited safe access to construct close to the pipeline, the conduit deviated further from the pipeline. Installation was completed within the previously disturbed footprint for the original pipeline construction, performed in 2008.

A critical component to accurately install the fiber safely next to the operating pipeline was the use of real-time equipment monitoring technology. RTW uses GPS sensors mounted on the construction equipment to calculate the exact location underground of the conduit being installed. If the equipment approaches too close to the pipeline, audible and visual alarms will alert the equipment operator. Using this RTW technology in this manner provided an additional level of safety while installing the conduit close to the pipeline.

Four different construction methods were used to install the conduit alongside the pipeline. The area of ground disturbance where the conduit was installed varied slightly, depending on the construction methodology.

All construction methods included replacing the soil back into the trench in the sequence it was removed, so native vegetation propagules in the soil were returned as well. Low-impact equipment was used for installation, and where appropriate (during nonfrozen conditions), matting was used on areas along the construction footprint where the ground conditions were soft. In select locations, temporary workspace was used to store equipment, material, and topsoil, but generally did not require ground disturbance. For trenchless installations, the bell holes or entry and exit locations required topsoil and subsoil salvage and replacement.

Vibratory Plow

The vibratory plow proved to be very effective and efficient in all but the most difficult ground conditions. The vibratory plow caused the least disturbance while achieving the highest production rates. Rates of up to 3 km/day were achieved in the best ground conditions. No soil was directly removed or excavated when using the vibratory plow. The conduit was continuously inserted at depth behind the 10-centimeter wide knife plow blade as the tractor moved forward. The project footprint along the conduit path was approximately 2 m wide adjacent to the pipeline (Figures 2 and 3). After the conduit was plowed in, the ground disturbed along the knife path was then pressed back flat to the ground with a track of the supporting equipment. In specific locations, including steep slopes and where ground conditions provided limited traction for the equipment, another piece of construction equipment was used to winch or pull the plow to help safely advance the plow forward.

Figures 2 and 3. Vibratory plow installation

Figures 4 and 5. Chain trencher installation

Chain Trencher

A chain trencher proved to be the best equipment to advance effectively in frozen ground. The chain trencher used the same 2-meter wide tractor unit, except the vibratory attachment replaced the trencher attachment. The chainsaw like blade of the trencher continuously excavated a 15-centimeter wide trench as the tractor advanced. The resulting spoil pile from the chain was distributed along the path behind the tractor generally within the width of the tracks, but some of the spoil may have extended up to 1 meter beyond the track width. The resulting project footprint was approximately 2 to 3 meters wide along the pipeline (Figures 4 and 5). The conduit was placed in the trench by hand, and the spoil pile then pushed back into the trench typically with a small, tracked skid steer or excavator.

Excavator

A small- to mid-size excavator was used where more difficult ground conditions or topography was encountered. An excavator was needed for areas where topsoil or subsoil salvage was required above the excavated trench line. The goal was to use the narrowest bucket width possible that could be accommodated by the size of the excavator used. Bucket widths of 30 to 60 cm were typical for this equipment. The excavators used for this project had track widths that ranged from 1.5 to 3 meters wide (Figure 6). The spoil pile generated extended up to an additional 3 m beyond the width of the excavator. The conduit was placed in the trench by hand, and the spoil pile was then pushed back into the trench, typically with a small, tracked skid steer or excavator. At watercourse, rail, highway, and third-party utility crossings, additional temporary workspace was required with limited surface disturbance.

Figure 6. Excavator working instream to remove large cobbles to allow for fiber-optic installation

Trenchless Crossing Methods

Throughout the planning process, Trans Mountain acknowledged that installation of the sensing fiber at the target distance to the pipeline was not possible at some crossing locations, due to the inaccessibility of the pipeline from ground surface. The pipe was either too deep or the construction effort too invasive to achieve the goals of minimizing disturbance during construction. For these short segments, the fiber-optic sensing cable does not provide the surveillance benefits described in this paper, but essential continuous telecommunications is maintained.

A few different trenchless crossing methods were used. For many of the watercourse crossings and road crossings that were not crossed using conventional open-cut methods, a mini-horizontal directional drill rig was used, resulting in only minor surface disturbance at the drill entry and exit locations (Figure 7). Where the ground conditions were more difficult, a horizontal percussion bore (down-the-hole drilling) was used, requiring entry and exit pits to accommodate the drill. On average, the entry pit containing the drill equipment was 2 m by 10 m at the base, while the exit pit was 3 m by 3 m at the base. The excavation size for both pits was larger than the base dimensions depending on the depth of the installation, the ground conditions, and the need to slope the excavation walls for safety.

At several locations where the pipeline paralleled existing highway bridges at major watercourses, the decision was made to avoid impacts to watercourses, fish, and fish habitat, and simply attach the fiber to the bridge either in existing or new conduit.

Aerial crossings on poles were also installed over two major watercourses, including the Athabasca River, a designated Heritage River and highly visible location from within JNP. The installation over the Athabasca River was approximately 800 m in length before it went underground and rejoined the pipeline.

Another example of minimizing disturbance in the park was the insertion of the conduit inside the annular space of the existing pipeline casing at a railway crossing. This approach was employed to eliminate the need for a separate trenchless crossing at those locations. The work activity required excavation down to the end of the casing on each side of the crossing to install the conduit.

KEY ENVIRONMENTAL FACTORS

Through the regulatory review process and Parks Canada's review of the basic impact assessment, there were select environmental and socioeconomic valued components that needed to be addressed prior to and during construction. These were the key concerns of Parks Canada, outcomes from the basic impact assessment, and feedback from Indigenous groups and the community. These areas of interest included rare plants, Columbian ground squirrels, watercourses, and spills.

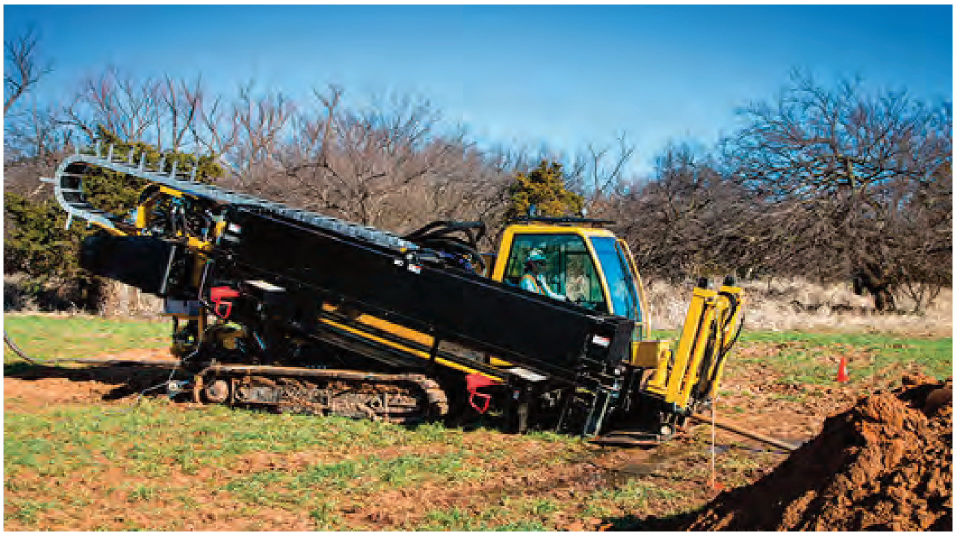

Figure 7. Directional drill rig unit

Vascular and Nonvascular Rare Plants and Plant Communities

Prior to fiber-optic installation, vegetation surveys were completed, as it was known that several areas along the ROW had previously hosted rare plants and plant communities. Forty-eight rare lichen species (as defined by the Alberta Conservation Information Management System [ACIMS] or as recommended by taxonomic experts when not listed by ACIMS [Alberta Parks 2021]) were observed during the vegetation field survey.

Site-specific mitigation measures for rare vegetation followed the mitigation hierarchy of avoid, minimize, and restore on-site. Mitigation measures for rare ecological communities generally fell into categories of avoidance and disturbance reduction; while mitigation measures for rare vascular plant, bryophyte, and lichen occurrences generally fell into categories of avoidance, reducing disturbance, and restore on-site. Qualified resource specialists were on-site to assist construction and provide site-specific mitigation guidance.

Mitigation recommendations for rare vegetation included:

- Making Trans Mountain inspectors aware of the location of plant populations and ecological communities of concern
- Marking and fencing off the area to restrict traffic from impacting the rare vegetation site
- Installing conduit during frozen conditions to minimize disturbance to topsoil and seed bank, and using snow as a buffer layer, if available
- Aligning the conduit to be as close to the pipeline as feasible
- Temporarily covering the rare vegetation site with snow, geotextile pads, or access matting and implementing access restrictions along the covered segments
- Reducing workspace, as practical, and clearly marking the rare vegetation site using temporary fencing or flagging to avoid accidental encroachment during construction

The conclusions of the impact

assessment determined that residual effects on vegetation were localized, reversible in the long-term and of low magnitude (Parks Canada 2022b). It was acknowledged there would be some loss or alteration of rare ecological communities and rare plants.

Columbian Ground Squirrels

Parks Canada and the Canada National Parks Act protects all wildlife species, including the Columbian ground squirrel (*Urocitellus columbianus*). A ground squirrel survey was completed and mitigation implemented to avoid potential project-related effects (such as mortality) where project activities overlap with occupied Columbian ground squirrel colonies or burrows.

Suitable habitat for Columbian ground squirrels is present in select locations along the fiber-optics installation route. Burrows were assessed for their location relative to the route, including signs of recent activity (soil piles, scat, runways through surrounding vegetation). Based on the results of the reconnaissance level survey, burrows located up to 10 m from the area of ground disturbance had one-way exclusion barriers placed at burrow entrances, to prevent ground squirrels from occupying burrows that may be impacted by project activities.

Using one-way door excluder devices at existing burrows has been observed as a method of promoting Columbian ground squirrels to move to another area on their own and is less invasive than trapping of individuals. Exclusion devices are one-way passages fitted at the entrances of a burrow system and designed to prevent squirrels from re-entering their burrows once they have left. Exclusion activities (such as entrance blocking) only took place during one of two time periods during the Columbian ground squirrel's life cycle when they are regularly leaving their burrows, and young or hibernating squirrels are not present.

Residual adverse effects were predicated to be regional, reversible in the short- to long-term, and of low magnitude (Parks Canada 2022b). Wildlife mortality during construction was realized, as was the case with the Columbian ground squirrels; however, extensive mitigation measures and surveys were employed to avoid this potential impact.

Watercourse Crossings, Aquatic Resources, and Visitor Enjoyment

The primary watercourse construction method used was open cut and isolation during seasonally low flows and where possible, during the recommended instream work windows to avoid impacts to fish. A shallow open trench was excavated, the conduit installed, and trench backfilled and reclaimed. An open-cut crossing method was preferred given the short duration to install the conduit beneath the watercourse. For example, installation of the conduit with a vibratory plow across a 5-meter-wide watercourse could take simply 5–10 minutes to complete. In contrast, the use of isolation methods would take much longer to install dams, pumps, and flumes, and often results in additional alteration of riparian area to complete the crossing. Set-up of an isolated crossing for a watercourse that is 5-meters wide could take 1–3 hours to put in place before installation could begin.

There were multiple aerial crossings installed using a combination of existing bridges and poles to string the cable across watercourses. Parks Canada considered the resulting potential reduction in visitor enjoyment. Even with proven mitigation measures to reduce impacts to water quality and quantity and avoid impacts to aquatic resources, the benefits of using an aerial crossing outweighed the challenges of open-cut crossing construction through large watercourses. The residual adverse effects of aerial crossings on viewscapes and noise impacting visitor enjoyment were predicted to be localized, reversible in the short- to medium-term, and of low magnitude (Parks Canada 2022b).

Accidents and Malfunctions

The CER approved and endorsed the installation of a leak detection system to monitor for third-party damage and potential pipeline leaks. There is high concern for spills and releases associated with a crude oil pipeline because of the potential magnitude and overall impact. Unequivocally, the installation of a communication and leak detection system would be nothing but a benefit to the social, cultural, and natural environment in JNP, a UNESCO World Heritage site.

EFFECTS SUMMARY

Potential adverse effects to valued components (human and natural environment) during construction and operation of the fiber-optic installation were reviewed and assessed by Trans Mountain and Parks Canada. Reversible, either short- to long-term, and low-magnitude residual effects included those to:

- Air quality
- Soil and landforms
- Surface water
- Groundwater
- Wetlands
- Fish and fish habitat
- Vegetation
- Wildlife and wildlife habitat

Localized, reversible in the short- to medium-term, and low-magnitude residual adverse effects included those to:

- Traditional land use
- Access and services

- Archaeological resources
- Recreational opportunities
- Viewscapes and noise
- Visitor safety

The health, social, and economic conditions for Indigenous and underserved communities would be improved by enhanced broadband and cell coverage for the regional area. The project enhancements for visitor safety were positive, by improving broadband and cell coverage for visitors and emergency services. Parks Canada concluded there was negligible potential for the project to have adverse effects on the values recognized by the UNESCO World Heritage site designation, due to the enhanced leak detection system that would detect leaks, accidents, and spills, and improve emergency response.

Considering the implementation of the mitigation measures described in the environmental protection plans and the impact assessment, and information contained in the BIA determination, Parks Canada concluded that the project was not likely to result in significant adverse environmental effects.

The GCP's predicted residual adverse effects on value components are not significant. No adverse effects on Indigenous rights are anticipated. Parks Canada predicted there would be no residual adverse effects that are irreversible and of high magnitude, or reversible but not long-term in duration and of high magnitude as a result of the proposed activities, provided that all applicable mitigation measures are followed. Therefore, no significant adverse effects are anticipated for identified value components as a result of the GCP, though Parks Canada has the authority to make the final determination (Parks Canada 2022a, b).

CONCLUSIONS AND RECOMMENDATIONS

This project demonstrates the feasibility of installing and enhancing a communication and leak detection system along an existing and operating transmission pipeline. Using the proper technology and equipment, the installation process can be efficient and cost effective when selecting the appropriate installation methods and limiting the locations where the conduit is not immediately adjacent to the pipeline (e.g., using existing bridges nearby to cross watercourses)—not to mention the incredible benefits of leak detection and surveillance technology.

While aerial crossings at watercourses are an efficient way to install the fiber-optics cable, the purpose of the leak detection system is limited as it leaves a segment of the pipeline unprotected. Proponents and regulators need to balance the benefits of leak detection, the cost, schedule, and environmental impacts when deciding where to route the fiber-optics cable along an existing pipeline system.

Open cut of small watercourses using a vibratory plow-in method was efficient and cost effective to install when the appropriate mitigation measures were employed. Having a qualified aquatics specialist on-site during the crossing, overseeing the fish salvage, and water quality monitoring during the crossing helped direct crews and mitigate impacts to fish, fish habitat, water quality, and quantity. Use of a spyder excavator is also valuable to carefully extract and move instream boulders and logs out of the way of the plow. Temporary removal of these features is needed so the vibratory plow can seamlessly track through the watercourse from bank to bank without stopping instream.

Horizontal direction drill is recommended for rail and highway crossings, if geotechnical and soil conditions allow. In difficult substrate, the directional drill is not always the solution and consideration of set-up, length and complexity of the drill, and location of the pipe are all factors in considering when it should be employed.

Ground disturbance using the vibratory plow in method is minimal and no soil salvage is required. It provides for an efficient way for installation to minimize impacts to burrowing wildlife and limits alteration of the vegetation and plant biome at the surface. After plowing in the fiber optics, a small skid steer can gently and evenly level the surface. Minimal travel back and forth is recommended, as to not to impact the adjacent vegetation or compact the soils.

Development of an Environmental Protection Plan prior to installing the cable is important for the overall success of the installation and for avoiding environmental, social, and cultural impacts. The EPP should be tailored for a fiber-optic installation and not solely rely on traditional pipeline or electrical transmission EPPs.

Energy companies operating pipeline assets have a solution to addressing concerns related to accidents and malfunctions. Installation of a fiber-optic system within an existing ROW is an effective way to optimize the use of emerging technology. In addition, during operations and maintenance activities conducted for pipelines, plastic conduit can be placed in a common trench for future consideration of fiber-optic installation. This forward-looking approach could allow for future installation of a leak detection system, in particular at sensitive environmental, social, or cultural locations along a pipeline. In conclusion, this project has demonstrated:

- Existing pipeline ROW can enable and facilitate the deployment of fiber optics and new technologies
- The monitoring and detection of leaks on liquid pipelines is one of the biggest risks and concerns that can be mitigated with fiber-optics technology
- The regulatory review process and environmental permitting still required for fiber-optics installations required extensive time, resources, and investment, even when the benefits of a project outweigh the burdens on the environment

ACKNOWLEDGMENTS

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Detection of Grassland Songbird Nests Using Drones

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Keywords: Disturbance, Drones, Grassland Birds, Nest Survey, Pipeline, Rights-of-Way, Unmanned Aerial Systems, Wildlife.

The use of drones for varying applications has been expanding greatly in recent years. With the ability to utilize a variety of different instruments (e.g., infrared and high-resolution cameras), drones have the potential to be an effective survey tool for the renewable energy, oil and gas, and transmission industries, among others. Many companies hire staff or consultants to conduct a multitude of wildlife surveys, usually required by regulatory agencies, with data collection being time-consuming and challenging. The data collected is used to develop mitigation measures to minimize or prevent disturbance to wildlife protected under various provincial, state, or federal law. In this presentation, we outlined the 2020 research WEST conducted in partnership with Inter Pipeline, using infrared cameras to detect ground-nesting songbirds on an Inter Pipeline right-of-way (ROW) and adjacent habitat in Alberta, Canada. Preliminary results and data showed that a drone team (consisting of a pilot and wildlife biologist) is statistically as effective and efficient at detecting ground nests as a two-person biologist crew working on foot (traditional method). This technology has the potential to reduce cost, delays, and personnel requirements, while providing accuracy, efficiency, scientific robustness, and a valuable tool in ROW management.

INTRODUCTION

Migratory birds and their nests are protected under federal legislation in Canada and the United States by the Migratory Birds Convention Act (Government of Canada 1994) and the Migratory Bird Treaty Act (MBTA 1918), respectively. In addition to federal regulations, many provinces and states have enacted legislation to further protect birds and prohibit the disturbance or destruction of active nests. Thus, it is often a requirement on a federal, provincial, and state level for companies to have qualified wildlife biologists conduct pre-disturbance nest surveys (hereafter referred to as nest surveys) if they intend to undertake work (e.g., construction, maintenance, or reclamation activities) during the bird breeding season. Conducting nest surveys demonstrates due diligence in mitigating the risk of incidental take (i.e., inadvertent disturbance, harm, or destruction of a nest) through the determination of nest locations prior to the commencement of work.

Finding songbird nests is a challenge in ecological research and applied conservation, as nests are often small and well concealed. Traditionally, nests are located by a biologist observing adult songbirds exhibiting nesting behavior cues (e.g., carrying food or fecal sacs, alarm calling, flushing from a nest). Most nest survey strategies depend on the adult birds attending the nest at the time of the survey and flushing in response to searcher presence (Ralph et al. 1993). The probability of detecting nests also varies between species and depends on the stage of the nest (i.e., laying, incubation, or nestlings) (Smith et al. 2009). As nest detection is contingent on the occurrence of specific events during the survey, some nests are likely to remain undetected (Giovanni et al. 2011). In addition, nest searches are subject to bias, as observers tend to spend more time in areas and habitat they believe are more likely to contain nests (Powell et al. 2005; Peterson et al. 2015). Thus, nest survey methods tend to be species specific, and locating nests of multiple species during one survey is challenging because of the variability in bird behavior around nests.

In recent years, the use of drones has been increasingly explored in the context of avian research and surveys across North America (Ellis-Felege et al. 2021; Martini and Miller 2021; Stander et al. 2021; Bean et al. 2022; Gerringer et al. 2022) in an attempt to improve nest detection and reduce disturbance when compared to traditional survey methods. For example, drones have been used to survey colonial nesting birds where traditional survey methods involved walking throughout the colony and recording nest status (Magness et al. 2019). Additionally, the use of drones for nest surveys has the potential to reduce cost, delays, and personnel requirements, while providing accuracy, efficiency, scientific robustness, and being a valuable tool in rights-of-way (ROW) management. However, there is currently a scarcity of research evaluating the use of drones for multi-species nest detection surveys in the context of a development project.

In 2020, Western EcoSystems Technology, ULC (WEST) and Inter Pipeline, Ltd. (Inter Pipeline) conducted a study exploring the use of drones equipped with an infrared (IR) camera lens in the detection of grassland songbird nests on an active ROW in the Central Parkland and Northern Fescue Natural Subregions of Alberta (Natural Regions Committee 2006). The study objectives were: (1) to determine if a drone could detect both cup and dome nests of grassland songbird species (i.e., nests with different levels of concealment) and (2) to compare the efficacy and efficiency in locating nests between a traditional nest survey method and the use of a drone. Herein, we summarize the detectability of nests for particular species and guilds of grassland songbirds, present preliminary results for measures of efficiency and efficacy between the two survey methods, and describe lessons learned and best practices for drone use as part of future nest surveys.

METHODS

Study Area

Nest surveys were conducted along Inter Pipeline's Viking Connector pipeline (the project area), a 75-kilometer (km) pipeline in East Central Alberta in June and July 2020. The project was placed into service in April 2020 and reclamation efforts began in June 2020. Nest surveys were conducted prior to reclamation activities proceeding within areas of disturbed ROW and areas adjacent to habitat comprising native grassland, tame grassland, wetlands, shrubs, and mixed forest.

Surveys were conducted by a drone team, consisting of one drone pilot and one biologist, and a human team, consisting of two to three biologists. Areas of suitable habitat were targeted by each team, with start and end kilometer post markers and search buffers recorded to track area coverage. Each team attempted to cover areas searched by the other team within two days of the initial search.

Drone Team

A drone equipped with an IR camera is able to detect heat signatures (i.e., hotspots) given off by endotherms (e.g., mammals and birds). In the early morning hours, ground temperatures and landscape features (e.g., vegetation, bare ground, water, rocks) are at their coolest. Thus, the temperature difference between an endotherm and the surrounding landscape is at its greatest during this period, making hotspots easier to detect (Figures 1 and 2). As the landscape heats up during the day, it becomes increasingly difficult to discern a hotspot from the surrounding landscape. During preliminary test flights, optimal drone nest survey time was determined to be between astronomical twilight (approximately 90–30 minutes before sunrise) and 3–4 hours after sunrise. Drone surveys were not conducted during any precipitation events greater than very light rain or in the presence of fog.

The study utilized a DJI M210 drone, equipped with a DJI XT2 camera with a 19-millimeter (mm) lens. A focal length of 19 mm was selected to optimize ground sampling distance (GSD), without sacrificing survey efficiency. Whilst increasing the focal length reduced the drone's viewshed, it also decreased the GSD towards zero, which allowed for more pixels to cover the same ground area, increasing the chance of finding small nests. At an average altitude of 25 meters (m) above ground level (AGL), using a 19 mm lens provided a GSD of 2.2 centimeters. This GSD increased the chances of detecting hotspots the average size of a songbird nest.

The pilot flew the drone 5–10 m ahead of the biologist, at an average flight height of 25 m AGL and at an average rate of 1.5 meters per second (5 km per hour). The drone team flew the drone and walked linear transects, with a width of approximately 15 m. The pilot ensured they could see 10–15 m ahead and approximately seven meters on either side of the biologist. Keeping the biologist on-screen dampened the temperature range of the thermal imagery, better calibrating it to display objects within the desired temperature range of 5–15° Celsius (41–59° Fahrenheit).

The biologist was directed by the pilot via radio to all hotspots that resembled nests, and the classification of the hotspot (i.e., nest or not) was relayed back to the pilot by the biologist. If the hotspot resembled a nest on the imagery but was not a nest (e.g., rock, cow patty, small mammal hole), it was recorded as a false positive. If the biologist observed a bird flushing or other nesting behavior that the drone did not capture, the drone was then used to attempt to find the nest.

Human Team

The human team usually consisted of two biologists, walking transects through the project area. The biologists were spaced approximately 5 m apart, resulting in a transect width of 10 m. Due to construction schedule constraints, the human team was occasionally joined by a third biologist in order to increase survey efficiency. The presence of a third biologist extended the transect width by an additional 5 m, to a total width of 15 m. Nest surveys were conducted between sunrise and approximately 11:00 am, at which time nesting behavior decreased due to the heat of the day. On warmer or cooler days, the survey end time was either shortened or extended, based on bird activity levels and nesting behavior. Human team surveys were not conducted during any precipitation events greater than very light rain.

Data Collection

Both teams recorded the same data for both effort and nest information. Effort data collection included weather, survey duration, ROW start and end kilometer posts (KPs), survey buffer (i.e., distance on either side of the ROW), and Global Positioning System (commonly GPS) tracks. Nest data collection included location, KP marker, nest characteristics, stage of development, species, vegetation metrics, and disturbance data. In addition, the drone team recorded data on the false positives detected by the drone.

Measuring duration of disturbance was an important metric in comparing the two survey methods. The disturbance data collected consisted of the following times: nest suspected, first disturbance, nest found, and end of disturbance, as well as the nesting behavior and disturbance cues that were indicative to the biologist. Start of disturbance was measured as the time that stress or disturbance behavior was first observed (i.e., flushing off the nest, alarm calling, chipping, mobbing the biologist, or broken wing displays), or the time that the nest was found, in the event the nest had no adult present to exhibit stress or disturbance cues. End of disturbance was the time at which the biologist(s) retreated to a species-appropriate buffer distance, typically 30–50 m from the nest.

Statistical Analysis

The metrics of interest for qualitative and quantitative assessment of performance for the drone and human nest searching teams are efficiency and efficacy. For this analysis, efficiency is defined as the number of nests detected per hour. Efficacy consists of several components important to industry's interests as well as the provincial and federal governments' desire to reduce disturbance to wildlife. Efficacy includes duration of nest disturbance and nests located per 100 km squared (km^2). Nest disturbance is defined as the duration of time between start and end of disturbance. Nests per area is calculated as the number of nests detected in a 100 km_2 area.

To qualitatively address other components of the efficacy of the drone nest searching team, we summarized the number of nests detected overall, by species and by nesting type. To quantitatively determine differences in the efficiency metric (nests per hour) and the efficacy metric (nests per km^2), a one-way analysis of variance (ANOVA) was applied. Nests per hour, duration of disturbance, and nests per km^2 served as the response variables, and the predictor variable was team type (i.e., drone or human team). The results from all nest surveys are presented in the overall nest type summaries, however, the inter-team statistical comparisons are only made for nests with accompanying effort data.

RESULTS

Species Composition

In 2020, 125 total nests were found. Of these, it was determined that 119 unique nests were found, accounting for six nests found by both teams. Of the 125 total nests, 71 nests were found by the drone team and 54 nests were found by the human team. However, only 45 nests for the drone team are included in the inter-team effort analyses because the remaining 26 nests were detected outside of standard survey transects, while testing methodology or efficacy in adjacent habitat.

A total of 21 species' nests were detected, consisting of 13 songbird species, one dove species, six waterbird species, and one raptor species (Table 1). Of the 125 total nests found, the most common species were clay-colored sparrow (*Spizella pallida*; n = 23), Savannah sparrow (*Passerculus sandwichensis*; n = 20), and western meadowlark (*Sturnella neglecta*; n = 14).

Of the 125 nests found, the drone team found 10 dome nests (eight western meadowlark nests and two Sprague's pipit [*Anthus spragueii*] nests), and the human team found six dome nests (all western meadowlark; Figure 3). Of the 71 nests found by the drone team, 58% were typical grassland species. Of the 54 nests found by the human team, 85% were typical grassland species.

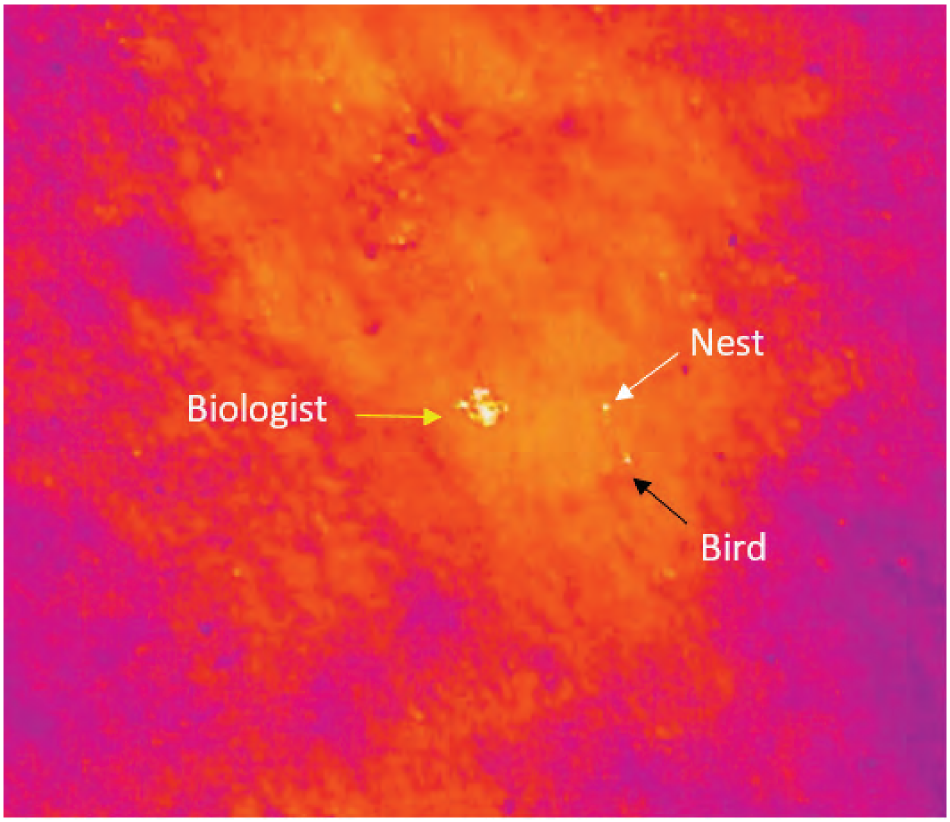

Figure 1. An adult Sprague's pipit flushes from a nest containing eggs, as the biologist approach on foot. The yellow, white, and black arrows indicate the biologist, the nest, and the adult flushing, respectively.

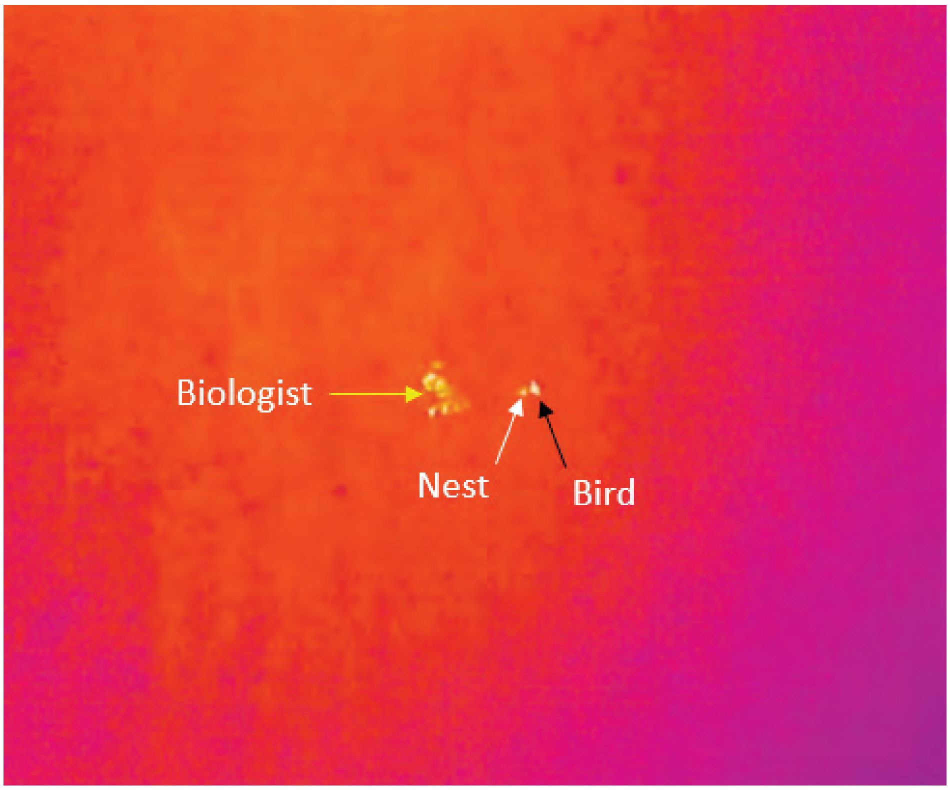

Figure 2. An adult Sprague's pipit flushes from a nest containing eggs, as the biologist approach on foot. The yellow, white, and black arrows indicate the biologist, the nest, and the adult flushing, respectively.

Efficiency and Efficacy

The second objective of the study was to determine individual team efficiency and efficacy, as well as inter-team efficiency and efficacy. The drone team surveyed a total of 2.57 km^2 (634.99 acres) and spent 69 hours surveying, for an average effort rate of 0.049 km$_2$/hour (12.05 acres/hour). The human team surveyed a total of 5.49 km^2 (1,356.35 acres) and spent 153 hours surveying, for an effort rate of 0.037 km^2/hour (8.84 acres/hour).

The drone team located 71 nests in total, with 45 of those occurring on standardized surveys, resulting in an average 0.52 nests/hour per survey and 19.39 nests/km^2 (0.078 nests/acre). The human team located 54 nests in total, resulting in 0.31 nests/hour and 14.56 nests/km^2 (0.059 nests/acre). Thus, the drone team was able to find 1.7 times more nests per hour and 1.3 times more nests per 100 km^2. The ANOVA results demonstrate no significant difference between the drone and human team in either nests per km^2 (Figure 4; $F(1,89) = 0.74$, $p = 0.39$) or nests per hour (Figure 5; $F(1,89) = 3.54$, $p = 0.06$). However, the number of nests per hour analysis approaches significance and future work in 2022 may increase our ability to detect differences.

The drone team recorded an average of 16 false positive heat signatures (i.e., hotspots) per survey, with surveys ranging from 1–36 false positives (Table 2). The majority of the 336 false positives were cow patties (n = 66), rocks (n = 59), and burrows or holes (47; Table 3). Adult (n = 34) and fledgling birds (n = 17) made up 15.2% of all false positive observations.

Table 1. Nest Detections by Species and Team

Common Name*	Latin Name	Type of Nest	Nests (Drone Team)**	Nests (Human Team)	Total Nests
American robin[1]	*Turdus migratorius*	Cup	1	1	2
American wigeon[2]	*Mareca americana*	Cup	0	1	1
Brewer's blackbird[1]	*Euphagus cyanocephalus*	Cup	3	6	9
Clay-colored sparrow[1]	*Spizella pallida*	Cup	7	16	23
Eastern kingbird[1]	*Tyrannus tyrannus*	Cup	1	1	2
House wren[1]	*Troglodytes aedon*	Cavity	3	1	4
Killdeer[2]	*Charadrius vociferus*	Scrape	0	1	1
Least flycatcher[1]	*Empidonax minimus*	Cup	2	0	2
Loggerhead shrike[1]	*Lanius ludovicianus*	Cup	1	2	3
Mallard[2]	*Anas platyrhynchos*	Cup	0	1	1
Marbled godwit[2]	*Limosa fedoa*	Cup	0	1	1
Mourning dove[3]	*Zenaida macroura*	Cup	2	0	2
Northern shoveler[2]	*Spatula clypeata*	Cup	0	1	1
Red-winged blackbird[1]	*Agelaius phoeniceus*	Cup	11	2	13
Savannah sparrow[1]	*Passerculus sandwichensis*	Cup	13	7	20
Sora[2]	*Porzana carolina*	Cup	10	0	10
Sprague's pipit[1]	*Anthus spragueii*	Dome	2	0	2
Swainson's hawk[4]	*Buteo swainsoni*	Stick	1	1	2
Unidentified large bird	N/A	Stick	1	0	1
Unidentified sparrow[1]	N/A	Cup	3	2	5
Vesper sparrow[1]	*Pooecetes gramineus*	Cup	0	3	3
Western meadowlark[1]	*Sturnella neglecta*	Dome	8	6	14
Yellow warbler[1]	*Setophaga petechia*	Cup	2	1	3
Total			**71**	**54**	**125**

* Blue rows indicate typical grassland species. Unidentified sparrow nests were assumed to be typical grassland species.
** Includes nests found while developing methodology
[1] Songbird (passerine) species
[2] Waterbird species
[3] Dove species
[4] Raptor species

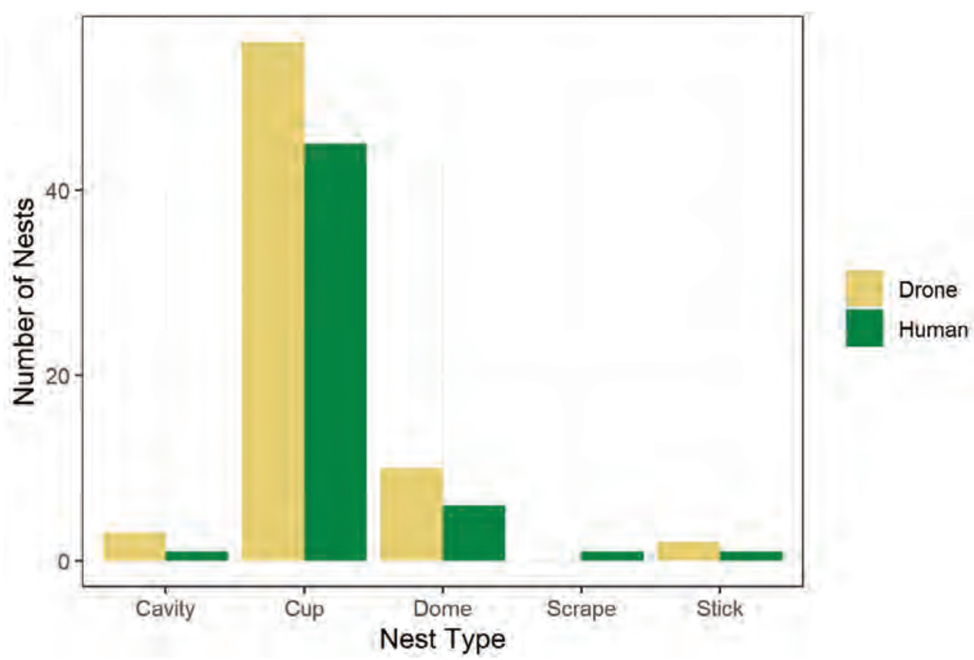

Figure 3. Comparison of nests found by the drone team (n = 71) and human team (n = 54), broken down by nest type.

DISCUSSION

Our study provided three main findings. First, the drone team was able to survey more area faster than the human team. Second, the drone team was able to find more nests per hour. Lastly, certain improvements to the study design are necessary to maximize the effectiveness and statistical inference of future studies.

The primary objective of this study was to determine if the drone could detect both cup and dome nests of multiple grassland songbird species. Previous studies using drones to detect nests of grassland songbirds have focused on single species (Scholten et al. 2019). The drone was successful at detecting nests of grassland songbird species and other species, such as eastern kingbird (*Tyrannus tyrannus*), mourning dove (*Zenaida macroura*), and Swainson's hawk (*Buteo swainsoni*). This technology may have potential for application on ROW with more complex habitats, if appropriately researched to determine if any other habitat or species limitations exist.

Of the songbird species detected, two species construct dome nests: Sprague's pipit and western meadowlark (Davis et al. 2020; Davis and Lanyon 2020). These nests were anticipated to be the most difficult to find by both teams, as dome nests are typically fully obscured with vegetation and often have an enclosed tunnel leading to the nest entrance, which is also fully obscured (Davis et al. 2020; Davis and Lanyon 2020). In comparison, cup nests are a more common nest type amongst grassland songbird species, consisting of a simple cup of woven grasses and other fine materials, located on the ground or within a few meters of the ground, and are typically only partially obscured by vegetation. The drone team did find more dome nests than the human team (n = 10 and n = 6, respectively), but the sample size is too small to draw any further comparisons; however, the

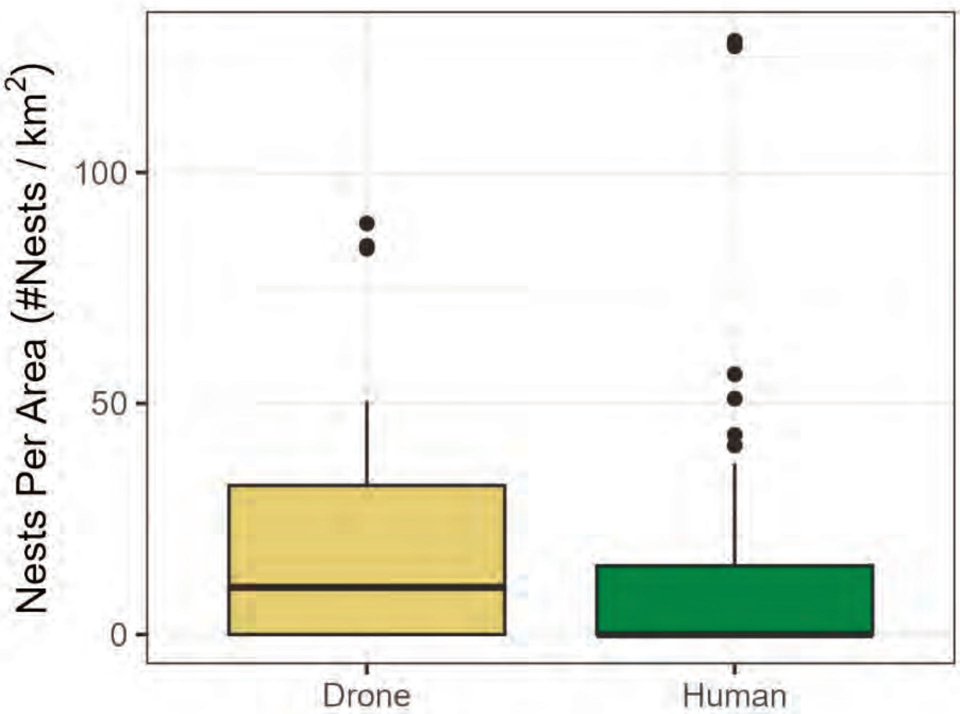

Figure 4. Comparison of nests recorded per kilometer squared by team. The horizontal solid line represents the median.

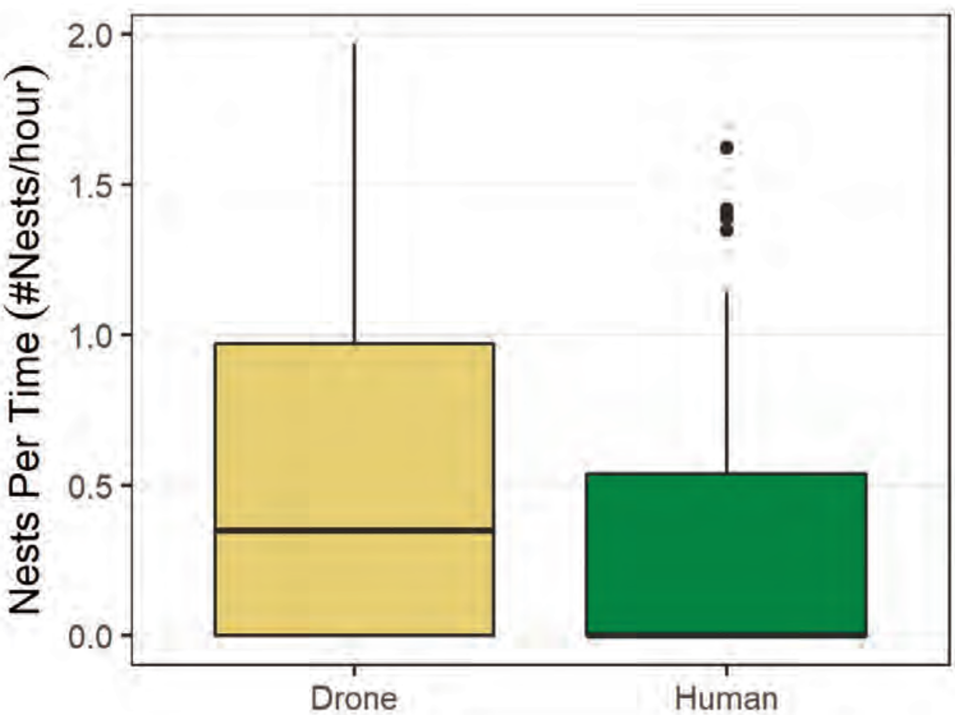

Figure 5. Comparison of nests recorded per hour by team. The horizontal solid line represents the median.

Table 2. False Positive Summary

Total	Minimum per Survey	Minimum per Survey	Average Number Per Survey	Variance Per Survey
335	36	1	16	126.3

ability to locate dome nests was considered an important marker in evaluating the efficacy of drones and the potential applicability of this technology on linear development.

The drone team had higher average nests located per area (efficacy) and higher average nests located per time (efficiency); however, neither metric was significantly different than the human team. Despite detecting 335 false positives and being limited by ambient temperature and inclement weather, the drone team is at least as efficient and effective as the human team. However, a second year of data collection will strengthen our ability to determine if meaningful differences exist between teams.

Certain issues were noted after fieldwork that require adjustment in order to improve future research. The main issue noted was that effort was not standardized between teams, spatially or temporally. This was due, in large part, to project timeline constraints. This resulted in very low overlapping area between teams, which likely resulted in a diminished capacity for both teams to locate the same nest.

If more overlapping areas are surveyed, then the efficacy of using drones as a substitute for human searchers could be evaluated with additional analyses. Specifically, differences in detection probability can be obtained following two-observer abundance estimation protocols (Burt et al. 2014). In the two-observer, abundance estimation nests found by one team serve as the “known” nest observations for the other. Under this framework, it would be possible to compare if the detection probabilities were similar or different between the two teams. The more similar the detection probabilities between the two teams, the higher the confidence can be in the application of drones as adequate replacements for human teams.

The second year of this research, conducted in the summer of 2022 with a different industry partner, prioritized searching the same areas by both teams during the same time frame to calculate differences in detection probability. Detection probability differences between the human and drone team will help solidify efficacy comparisons between the two methods. Regardless of whether the drone team’s results are significantly better, or simply equivalent to human search teams, using drone teams could provide cost savings to industry and reduced disturbance to wildlife without compromising survey efficacy.

Table 3. False Positive Hotspot Summary

Hotspot Type	Count
Cow patties	66
Rock	59
Burrow/hole	47
Mammal	38
Adult bird	34
Bare ground/dirt	33
Vegetation	24
Fledgling	17
Wood	7
Water	6
Ant mound	4
Total	**335**

Methodological Improvements

The 2020 study year provided valuable preliminary data and promising proof-of-concept results for the use of drones in conducting nest surveys. In order for future research to be conducted more effectively, the following improvements on methodology are planned:

- Intra-team methodology should be standardized (e.g., consistent number of biologists)
- Inter-team effort should be standardized temporally by ensuring study areas are being surveyed by both teams within 48–72 hours of each other, to minimize the number of nests needing to be excluded from analysis
- Inter-team effort should be standardized spatially in the form of delineated, predefined transects to be searched
- Data collection and entry can be simplified as appropriate, to increase in-field efficiency and reduce post-field error
- Ensure a minimum number of drone batteries are acquired so there is no delay during a morning’s survey (i.e., 1–2 sets fully charged and 3–4 sets charging all the time)

CONCLUSIONS

The drone team produced equivalent, if not better, results compared to the human team, which shows promise, particularly if methodological issues noted are rectified in future years. This technology shows potential in the application of songbird nest surveys on ROW. Future studies will be focused on comparing inter-team efficacy and efficiency, proof-of-concept for other avian species and guilds of interest, and proof-of-concept in other habitats (e.g., treed environments) typical of linear developments.

Although cost is a key factor for developers when completing nest surveys, a cost analysis could not be completed for this work due to the preliminary nature of this research. The aforementioned methodological improvements need to be adequately addressed before an effective cost analysis can be completed. Future work will be designed to address these concerns.

ACKNOWLEDGMENTS

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Remote sensing can play an enormous role in the mitigation phase for preventing and planning for wildfires. As new remote sensing technology continues to emerge and improve, the value each technology provides depends on the use case and needs. Similar to planting the "right tree in the right place," the *right technology* can capture valuable information for the *right application*. Whether it be to provide a proactive approach for safety, vegetation management (VM), or asset reliability, this paper will describe how staying innovative is the key to maintaining an effective wildfire mitigation program.

Emerging Remote Sensing Technologies: UAV and Mobile LiDAR Applications

Deborah Sheeler, William Ayersman, Rachel Miller, and Jared Hennen

Keywords: LiDAR, Remote Sensing , Rights-of-Way, Technology, UAV, Unmanned Aerial Systems/Drones, Utility Corridors, Vegetation Encroachment, Vegetation Management, Wildfire Management.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

With wildfires increasing in severity and frequency, the importance of wildfire mitigation programs has never been more critical for effective management of vegetation. Making safety a top priority and reducing risks should always be at the forefront of any discussion. Remote sensing has a variety of applications for wildfire and vegetation management (VM). As defined, remote sensing is the acquisition of information about an object without making physical contact with the object (NOAA 2018). Data capture can occur with various sensor devices, such as cameras, radars, and lasers, mounted on multiple platforms based on the ground or on vehicles, aircrafts, unmanned aerial systems (e.g., drones), or satellites. The nature of the collection process dictates the usefulness for specific applications.

While physical mitigation is never 100 percent effective, pre-fire danger can be monitored and predicted using remote sensing to assess fuel moisture, density, fuel types, and topography. Along with traditional methods, using a combination of remote sensing applications and technology yields endless possibilities to assess potential issues and solves problems in and around rights-of-way (ROW). In an industry where mitigating risks are a top priority, remote sensing technology not only provides an important analysis tool for vegetation analysis, but it also can help lead the way to solving challenging problems with asset inspections—such as visual and thermal.

Remote Sensing Approaches

Remote sensing can play an enormous role in the mitigation phase for preventing and planning for wildfires. For many utility companies (gas or electric), vegetation programs follow strict management guidelines that constitute trimming, pruning, or removing potential hazards, whether that be trees or other types of woody and non-woody vegetation (Fellers 2017).

There are several different remotely sensed datasets that can benefit a wildfire mitigation and VM plan. In the electric utility industry, unmanned aerial vehicles (UAVs) have helped companies to survey damage following storms and inspect infrastructure. Recently, however, California utilities are using UAVs as a proactive measure during wildfire season (Fischbach 2018).

LiDAR Data and Analysis

One of the most common remote sensing applications for VM involves the collection and analysis of LiDAR data from a manned aircraft for planning and risk mapping assessments. LiDAR data can be used to understand vegetation encroachment near critical infrastructure that could cause fires or be damaged in a fire (Combs 2017). LiDAR data is collected in a format called point clouds, which are datasets that represent objects or space. These points represent the X, Y, and Z geometric coordinates of a single point on an underlying sampled surface. Point clouds are a means of collating a large number of single spatial measurements into a dataset that can then represent a whole. This enables remote sensing professionals the ability to analyze objects in a 3D environment.

Using this approach, LiDAR data is acquired to detect vegetation heights and assess potential grow-in and fall-in risks to conductors and critical equipment assets. With LiDAR, point cloud data is used to measure tree height, 3D spatial location and canopy width, as well as topography and other parameters. Given a set of clearance criteria, these assessments can identify locations and distances of vegetation encroachment along utility corridors. One downfall to an aerial assessment is that understory trees have the tendency to be underrepresented where crowns cannot be identified accurately—enter mobile terrestrial LiDAR technology.

As an example, Bear Valley Electric Service (BVES), located in Southern California, has adopted UAVs and mobile LiDAR in recent years. With the majority of the BVES distribution system built along accessible transportation corridors, implementation of a mobile mapping LiDAR system provided additional value by efficiently acquiring point clouds or a collection of pixels positioned accurately in 3D space based on the GPS coordinates of the center pixel of each image to generate a digital twin map (Xue et al. 2020). Further analysis allowed BVES to quantify and prioritize clearance work needed along specific circuits to meet reporting standards set for by GO-95 regulations.

Through point cloud tasks, elevations are transformed into raster grids through geoprocessing operations and classification of the point cloud data. Bare earth digital elevation models (DEM) and digital surface models (DSM) were generated to capture vegetation and other object heights. Through height thresholding, the separation of tall and short vegetation is possible, giving the ability to distinguish trees at risk of contacting the conductors from understory vegetation. After vegetation has been processed into appropriate risk classifications, classified data were converted into polygons with analysis geospatial point locations for routing. With terrestrial LiDAR, dense point cloud data can be color-coded by height or fused with RGB color values from associated high-resolution imagery captured simultaneously to generate a powerful 3D visualization mode, as shown in Figure 1.

Imagery Data and Analysis

Another technology application used by BVES to capture remotely sensed data revolves around multispectral imagery and thermal image collection and analysis from UAVs. This method provided the value of a bird's-eye view over traditional ground capture methods. Unmanned aerial vehicles enable utilities to have access to high-resolution imagery and videos to help them proactively identify, detect, and address environmental, structural, and equipment concerns.

The potential value of this method is the faster deployment, data processing turnaround time, and the unique vantage point using high-resolution camera sensors with zoom-in capabilities of capturing close-up, detailed images of equipment over potentially hazardous environments or areas with difficult terrain. Unmanned aerial vehicles were used with multiple payloads or camera sensors, capturing multiple images at once, including visible and thermal images. These types of high-resolution camera sensors with 200 times digital zoom capabilities help utilities pinpoint a variety of potential issues, such as hot spots and equipment defects.

Unmanned aerial vehicles—or any technology, for that matter—cannot replace what experienced professionals bring to the table when it comes to understanding the system and industry knowledge. From visual to thermal cameras, certified UAV pilots work directly with skilled certified thermographers and engineering professionals to process and analyze imagery data.

Figure 1. Example of a digital twin environment, generated by colorized 3D point cloud data captured from a mobile mapping terrestrial LiDAR system. This image depicts current vegetative conditions and their proximity to electric assets.

Figure 2. A UAV collecting photography of a distribution pole and its equipment for a comprehensive inspection. These photos allow analysts to identify any issues proactively to avoid costly failures.

MANAGEMENT IMPLICATIONS

Improving Reliability Metrics

Numerous utility companies openly acknowledge that one of the leading causes of power outages are the result of vegetation-related infractions (Doostan et al. 2018) and system disruptions, ranging from equipment failures to weather and wildlife. When these outages occur, utilities forgo revenues and must bear the costs of fixing the outage quickly. This leads to commercial customers without a means to conduct business and residential customers to have complications at their residence.

Bear Valley Electric Service uses the UAVs to find damaged or missing hardware that would otherwise be difficult to see with the naked eye from the ground. The HD photos that are provided can give BVES useful information on every pole across the whole service territory without using up valuable time of their workforce. For each asset data or structure captured, the engineering department reviews the photos and determines if there needs to be any remediation to the equipment on the pole. The UAV program is an effective tool that BVES uses to find defects throughout the service territory.

Work Planning

Since 2020, BVES has complete both terrestrial LiDAR acquisition of ~215 miles of ROW and a comprehensive visual and thermal asset UAV inspection of their entire distribution system, consisting of more than 6,500 poles. Bear Valley Electric Service relies heavily on the LiDAR results to maintain the enhanced VM around all high-voltage powerlines throughout the whole service territory. Once the LiDAR data is delivered to BVES, their contracted pre-inspectors go out and verify all the possible encroachments that were identified throughout the assessment. After the data points are verified, tree trimming crews are dispatched to correct all issues that were found. With the use of LiDAR, BVES has significantly reduced the number of encroachments on their lines and have proven to increase the reliability of the system. Whether for planning purposes or work requirements, field inspectors can precisely navigate to specific locations to determine equipment needs and relevant safety protocols.

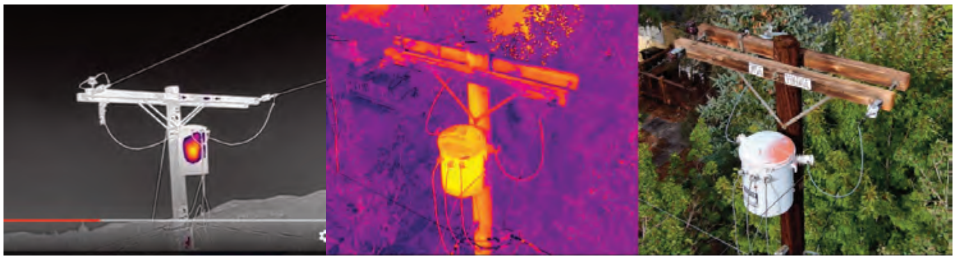

Figure 3. Samples of thermal and visible imagery captured to proactively identify equipment issues. These images provide valuable information back to the utility to mitigate overheating concerns before an equipment failure occurs, possibly resulting in a wildfire.

Other remotely sensed datasets can also benefit similar programs, such as using hyperspectral data that can identify fuel types, fuel moisture and density, and mapping invasive plant species, which can be more combustible than native species. Synthetic Aperture Radar (SAR) and multispectral data can also provide some of these measurements, depending on the sensor. With more information available, more informed decisions can be made and risk maps can be created by combining other data, like topography, wind, weather patterns, location of infrastructure, etc. (O'Connor 2021).

CONCLUSIONS

The methods discussed in this paper are ways that utility companies can proactively plan and manage their vegetation work for wildfire mitigation. These are great examples of how a utility can leverage innovative technologies to complete a comprehensive assessment of their utility assets and maintain and monitor current vegetation conditions along their utility corridors. Utilizing mobile LiDAR over traditional manned aerial LiDAR enabled BVES to capture higher quality, detailed point cloud data that was better suited for their distribution network in preparation for the fire season.

With a focus on improving reliability, products from these assessments have provided BVES with important information for prioritizing line inspections, as well as determining priority circuits for focused VM towards wildfire mitigation efforts. Ultimately, the use of remotely sensed data to prioritize field work can reduce exposure to risks as well as provide an effective approach to capturing a proactive system-wide snapshot of potential vegetation issues.

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Deborah Sheeler joined Davey in 1997 and is currently the Production Manager for Geospatial Services and Software Support with Davey Resource Group, Inc. In this role, Sheeler manages GIS mapping and remote sensing analysis projects at all scales for environmental consulting, utility VM, and asset management services throughout the United States and Canada. She also manages unmanned remote aerial operations, the support of DRG proprietary software, and the continued research and development of innovative and emerging technologies for the green industry. Sheeler holds a master's degree in geography with a concentration in GIS and natural hazards research from Kent State University.

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Jared Hennen is the Wildfire Mitigation and Reliability Engineer for Bear Valley Electric Service. Bear Valley Electric Service is in Big Bear, California, a small mountain town about 80 mile east of Los Angeles. He manages the many inspection programs, including LiDAR, UAV, and ground patrols. Hennen also manages the vegetation management program that incorporates all the inspection data to safely and reliably deliver power to its customers.

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Rachel Miller is currently the Chief Supervisor for Davey Resource Group's small Unmanned Aerial Systems Part 107 and Part 137 Agricultural Operations. She is an FAA Certified Private Pilot, (SEL) as well as a Remote Pilot and holds an ITC Level 1 sUAS Thermographer certification. Miller's primary responsibilities include direct project planning, research and development, and recommending and implementing new sUAS solutions, processes, policies, and standards in support of functions, strategy, and operations. She is also involved in ensuring FAA compliance with all flight regulations and procedures as well as developing and submitting FAA waivers. She has been working within the aviation/drone industry for the last six years and enjoys the opportunities and challenges of building a new service line within DRG to help clients find new solutions to old problems using emerging technology. Miller holds a Bachelor of Arts and Science degree from Kent State University.

Emerging Remote Sensing Tools for Rights-of-Way Management

Kristopher Andersen, Michael Burnett, and Joe Thacker

Keywords: Aerial Imagery, Data Analytics, Drone, Geospatial, Global Positioning System (GPS), Inertial Measurement Unit (IMU), Light Detection and Ranging (LiDAR), Photogrammetry, Remote Sensing Data, ROW Management.

This paper describes emerging tools that collect, process, analyze, and present large datasets applicable to rights-of-way development and management at all asset life cycle stages—from preliminary design, routing, and feasibility studies to asset management, inspection, monitoring programs, and decommissioning. We share case studies to provide insights and lessons learned to advance the practice and maximize the benefits of remote sensing technologies.

Ongoing technological developments in remote sensing allow rapid collection of visible spectrum, thermal, multispectral, hyperspectral, and light detection and ranging data from fixed-wing aircraft for thousands of acres and hundreds of miles of linear corridors in a single day. Fully integrated global positioning systems and inertial measurement units allow direct georeferencing for an accurate and reliable high-resolution mapping solution.

A direct georeferencing workflow and automated data processing provide a high-accuracy solution immediately after landing, quickly producing high-volume orthoimagery. Synthesizing remote sensing data with field-level survey data provides a high degree of accuracy, while dashboard-type interfaces and purpose-built viewers help teams visualize a project's constraints, impacts, and progress. These technological advancements have the additional benefit of making the data collection, processing, analyzing, and presentation process more efficient and economical.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Recent and ongoing technological developments have advanced the science of collecting, processing, analyzing, and presenting remote sensing data. Newly developed sensors and systems allow the rapid collection of visible spectrum, thermal, multispectral, hyperspectral, and light detection and ranging (LiDAR) data from fixed-wing aircraft, yielding data for thousands of acres and hundreds of kilometers of linear corridors in a single day. This paper summarizes experiences of the authors after two decades working in the industry.

Fully integrated global positioning systems (GPSs) and inertial measurement units (IMUs) allow direct georeferencing for an accurate and reliable high-resolution mapping solution. A direct georeferencing workflow and automated data processing provide a high-accuracy solution immediately after landing, with fast turnaround of orthoimagery and efficient high-volume production.

Synthesizing remote sensing data with field-level survey data provides a high degree of accuracy, while dashboard-type interfaces and purpose-built viewers make it easier than ever to visualize a project's constraints, impacts, and progress. These technological advancements have the additional benefit of making the data collection, processing, analyzing, and presentation process more efficient and economical.

Specific applications for these tools include:

- Preliminary design
- Routing and feasibility studies
- Topographic map production and slope and stability analysis
- Vegetation classification
- Change detection
- Asset management and inspections
- Flood modelling
- High Consequence Area and Class location analysis
- Automated and rapid three-dimensional (3D) visualizations

Figure 1. Photogrammetrically compiled features and 3D mesh, 2020. Andersen: The Villages, Florida, U.S.

METHODS

Aerial photography and photogrammetrically derived data have been in the market since we first began flying over a century ago. This section describes some recent remote sensing tools and techniques used to capture right-of-way (ROW) data.

Imagery taken from fixed-wing aircraft and helicopters is used to document existing conditions on the ground at the time of the flight. Aerial imagery is typically used to update base mapping data, such as structures, pavement, vegetation, and hydrography.

Using photography to accurately detect existing conditions or changes in conditions over time is called "photogrammetry." Photogrammetry uses overlapping image frames to create a 3D view of the ground and provide a surface to digitize on (Figure 1). As photogrammetry has advanced, contact prints and film have been replaced by high-resolution digital imagery, and drafting tables have been replaced by software that provides 3D identification and mapping of features, using a conventional personal computer or laptop.

Today, aerial photography is collected using sensors that have embedded high-accuracy GPS and IMUs to tag each frame with an exact location, as well as correct for aircraft tilt and crabbing, ensuring each image is positionally accurate and oriented optimally for feature identification and placement. The airborne GPS can also be used with conventional survey of visible features on the ground to improve positional accuracy to within a few inches, vertically and horizontally.

Aerial photography and accompanying photogrammetry can be used to identify ROW encroachments (both built and natural), map existing assets and infrastructure, and perform change detection to identify slow-moving anomalies within a given corridor.

Aerial photography and photogrammetry derived from fixed-wing aircraft is ideally suited for large areas (greater than 200 acres) or if a target area is unsafe or permission to enter is limited. Cost is highly dependent on geographic location. More remote areas, or areas with cloudy, rainy, snowy weather, are more expensive due to mobilization and allowances for standby time.

LiDAR

LiDAR is a scanner that takes as many as hundreds of measurements per square meter and generates a point cloud. This point cloud is a 3D representation of what the scanner is pointed toward. LiDAR sensors can be mounted to:

- Fixed-wing aircraft
- Helicopters
- Unmanned aircraft
- Moving vehicles
- Tripods
- Backpacks
- Robots

Airborne LiDAR point clouds are used to create terrestrial surface models to help manage and maintain ROWs, including:

- Contours
- Impervious surfaces
- Water features
- Vegetation density
- Building footprints

Airborne LiDAR sensors vary in the density of the point clouds collected, depending on the project requirement and the mode of collection. Fixed-wing aircraft collect between 10 and 50 points per meter, which is suitable for creating contours and delineating hard surfaces (including structures) and water bodies over large areas, from a few hundred hectares to hundreds of square kilometers. Unmanned aircraft and helicopters typically collect a higher density greater than 50 points per meter but, due to limitations in the collection modalities, are not suitable for large areas.

Airborne LiDAR is used within ROW management programs to define surfaces; identify areas of erosion or subsidence; and quickly locate and digitize overhead wires, towers, and structures.

LiDAR derived from fixed-wing aircraft is the best means of collecting detailed topography, vegetation, impervious/pervious surface, and structure footprints for large areas. As with aerial photography, the cost is highly dependent on geographic location and prevailing weather conditions. The additional limitation with LiDAR data is the ground must be dry. Aerial photography can be collected after rain stops, but LiDAR must wait for dry conditions.

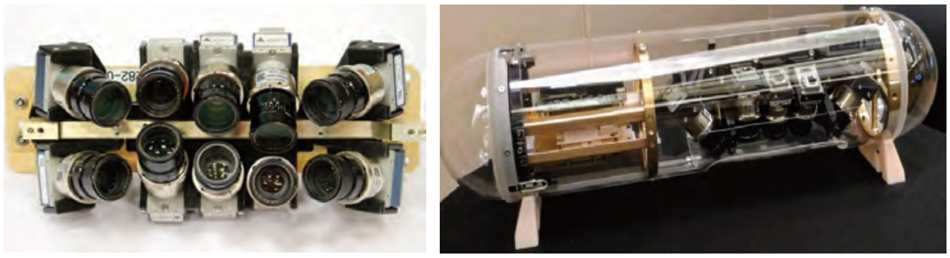

Figure 2. Imaging sensors, 2021. (Used with permission from Aeroptic Lab)

Figure 3. Mounted imaging sensor—view from within aircraft during 2021 field test. (Used with permission from Aeroptic Lab)

Multispectral, Hyperspectral, and Thermal Data

Beyond sensors that collect visible features, multispectral, hyperspectral, and thermal sensors collect and document temperature irregularities that could signify a pipeline leak or indicate a problem with soil condition and vegetation health.

These imaging sensors are getting smaller and lighter and can now collect imagery well beyond the visible spectrum; commonly including near-infrared and short- and long-wave infrared (thermal) (Figure 2). Hyperspectral sensors can acquire and discriminate between hundreds of individual spectral wavelengths.

For ROW management, the type of sensor used is determined by the information being sought:

- Multispectral imagery is ideal for post-construction environmental monitoring and vegetation management.
- Thermal imagery is useful for locating water (e.g., leaking pipelines, wetlands).
- Coupled with field validation, hyperspectral imagery can be used to identify noxious weeds.
- Advantages to thermal imagery are the ability to identify heat signatures and patterns that are not visible to the naked eye.

A limitation is thermal imagery pixel resolution is typically more coarse than conventional 3-band imagery.

Unmanned Aircraft (Drones)

Remotely piloted aircraft systems (also known as unmanned aircraft systems, unmanned aerial vehicles, or drones) are no longer emerging; they're here and offer limitless potential in management and maintenance of ROW corridors. The most exciting aspects of the technology include the following benefits:

- Can perform smaller data collections that were previously cost-prohibitive at scale compared to piloted operations
- Provide aerial access to previously inaccessible areas
- Most significantly, increase worker safety

Drones are easily deployable, safe to operate, and provide rapid turnaround of imagery, LiDAR and thermal data, and recorded or live video of emergencies. Drones fit perfectly in a project schedule between a fixed-wing or helicopter data capture and detailed, time-consuming field unit deployment. Drones can capture smaller areas and corridors in a day, with data in the hands of decision makers in 24–48 hours.

Drones are particularly powerful in performing asset inspections in dangerous or remote locations. They can hover and zoom in and out and have object avoidance capability that make them safe, agile, and easy to operate. However, drones have to operate within airspace limits; therefore they can be difficult to utilize in cities, near airports, or near secure sites. But drone data is relatively inexpensive to collect and process.

Terrestrial Scanning

Terrestrial scanning is a blanket term that includes remotely sensed data from the ground and can be performed from a moving vehicle, a stationary tripod, a backpack, and even an autonomous robot. Terrestrial scanning typically captures more detail on features at ground level that are easily accessible by foot or vehicle. Terrestrial scanning is used when greater accuracy and level of detail is required, or if greater granularity is required in feature identification and attribution.

Terrestrial scanning is also used in tandem with airborne imagery and LiDAR collection to capture data in areas that are obscured from the air, such as beneath a tree canopy or under bridges and overhangs. Terrestrial scan data can easily be tied to airborne data because both sources are georeferenced and have the same file types (image or point cloud). This creates a full static model of infrastructure and facilities, inside and out (Figure 4).

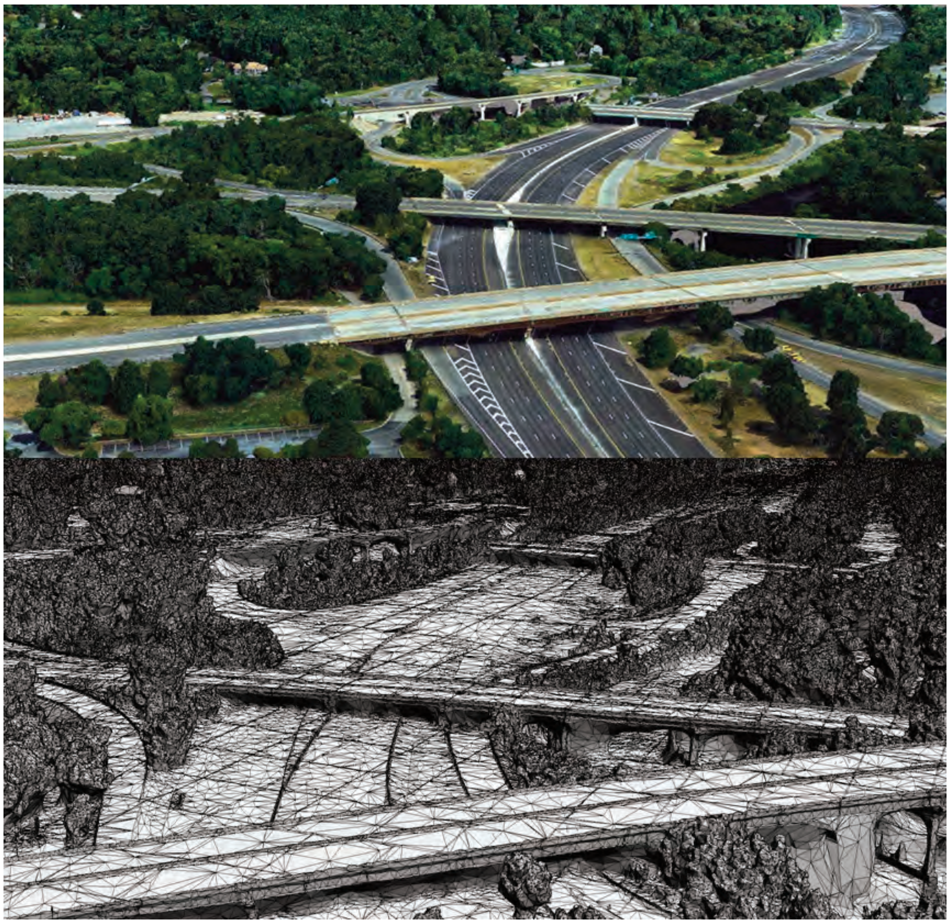

Figure 4. 2020 3D terrain and high-resolution model. Andersen: Newton, Massachusetts, U.S.

Terrestrial scanning can be an effective means of collecting, updating, and maintaining data along ROW corridors accessible by vehicle, and that vehicle does not need to be a car or truck. Terrestrial scanners capable of high-resolution, 360-degree imagery and LiDAR can be mounted to smaller, e.g., offroad vehicles, such as four-wheelers and golf carts.

Terrestrial scanning is a great supplemental means of data capture in areas with significant obstructions from the air. Terrestrial scanning can also be beneficial alone in smaller areas where data is to be used for retrofitting and Building Information Management (BIM).

Satellite Data

Satellites acquire imagery from a low earth orbit. There are free government sources as well as commercial satellite imaging companies. The data ranges from 30-centimeter (cm) resolution to well over 30 meters per pixel, and include options from black and white (panchromatic) to hyperspectral images.

New imaging satellites are continuously being launched, providing multiple daily visits covering most of the Earth's surface.

Satellites don't tend to follow long corridors very well, and tasking of a satellite is not an ideal solution for new imagery, but both government and commercial sources have extensive archives that are relatively inexpensive and can provide outstanding context data layers. The archives can be used to show changes over time within a ROW.

Satellite data can be available to use within minutes or hours of the request, and at much lower cost than a bespoke data collection. A downside is the resolution of the data is much lower than fixed-wing or drone imagery and the data often contains clouds. A user needs to be selective when choosing which satellite to purchase data from and at what date.

Automation and Artificial Intelligence for Remote Sensing Data

Remote sensing data helps ROW project managers rapidly understand existing conditions. To support quick decision-making and get results faster, remote sensing data processing needs to advance as well. One emerging means of processing data rapidly is through autonomous digitization from aerial photography—regardless of collection means.

With the fast growth of the highly specialized and mission-critical remote sensing market segment, technical firms and software providers are investing millions in creating ways to automate analytics from aerial imaging. Seamlessly and accurately delineating current environmental and infrastructure features is essential in providing fast and accurate geospatial data.

There are artificial intelligence (AI) applications on the market that automatically delineate up to 14 different features, with attribution, from mosaicked imagery. This is a leap forward in data mining and has proven to cut production times by as much as 80%—meaning critical ROW data, such as paved surfaces, structures, aboveground utilities, and vegetation, can be automatically delineated in a matter of hours after collection. This elevates the value of the already powerful remote sensing data by reducing response times in emergencies and in fast-tracked design-build programs.

Advanced GPS, IMU, and Focal Length

Traditional photogrammetry involving aerotriangulation of stereo image pairs supplemented with surveyed ground control produces the most accurate orthoimagery. However, advances in GPS and IMU technologies have improved the accuracy of imagery derived from direct georeferencing processing methodologies to better than half-meter horizontal accuracy. New IMUs can maintain positional knowledge of an imaging sensing over long ranges, reducing or eliminating the need for in-flight calibration turns.

Smaller cameras with better optics offer many multi-camera sensor configurations. High-resolution data can be acquired at high elevations, covering wider swaths and multiple look angles with additional spectral bands, increasing the speed and efficiency of data acquisition and making the imagery more useful. These same advancements, along with image processing software and hardware, result in rapid automated processing; orthoimagery can be processed in real time to provide critical information for emergency response situations.

REMOTE SENSING DATA USES

This section describes different remote data sensing techniques and how the resulting data can be used in ROW management.

Terrain Modelling

There are dozens of uses for remote sensing data for managing existing ROWs or defining and targeting new ROWs. High-density LiDAR data (with or without photography) can be used to create a very quick and accurate terrain model and contour map of a corridor, site, or area (Figure 5). On projects we have delivered over the years, we have noticed a reduction of about 90% in field hours when using fixed-wing, helicopter, or unmanned LiDAR to generate an accurate surface and contour map. Accuracy of the elevation data depends on the amount of vegetation cover on the ground and the point density of the LiDAR data.

Preliminary Design

Preliminary design is another end use of remotely sensed data for ROWs. Using a LiDAR-derived surface in combination with surveyed ground control targets and aerial photography, most aboveground features can be digitized within a few inches—which is suitable for conceptual and up to 30% design. This would allow project teams to consolidate field efforts in targeted areas and not waste valuable time and budgets on field surveying areas that are not suitable for constructability.

Most commercial computer-aided design (CAD) software (Autodesk and Bentley Systems) have comprehensive tools and interoperability with large imagery and LiDAR data sets. Features in a CAD environment can be extracted and easily exported to Esri's ArcGIS software and services. Taking the preliminary design mapping a step further, migrating the design data to ArcGIS is a step toward initiating asset management workflows. Utilities, roadway assets, infrastructure, structures, and hydrography can attribute and give asset identifications for work order tracking and development of asset maintenance and replacement plans, based on location.

Encroachment and Inspection

High-resolution natural color imagery is one of the best ways to monitor for encroachment into a ROW. Detailed images capable of locating and identifying structures, vehicles, vehicle tracks, vegetation, and other disturbances can be remotely reviewed, and appropriate response teams can be dispatched to address the situation. The spatially accurate imagery also creates a permanent documented record of ground conditions at the time for future reference and support for potential disputes.

Drainage and Runoff Studies and Flood Modelling

LiDAR coupled with reference orthoimagery is commonly used for flow modelling along a ROW. Liquid pipeline operators are concerned with the potential impact of leaks, and all operators within a ROW share a concern for potential damage from floodwaters.

Detailed LiDAR-derived elevation models and contour maps are ideal for providing insight into areas of concern of both owned infrastructure within the ROW and neighboring properties. The elevation information can be used for preventive planning and can support emergency response activities, should emergency situations arise.

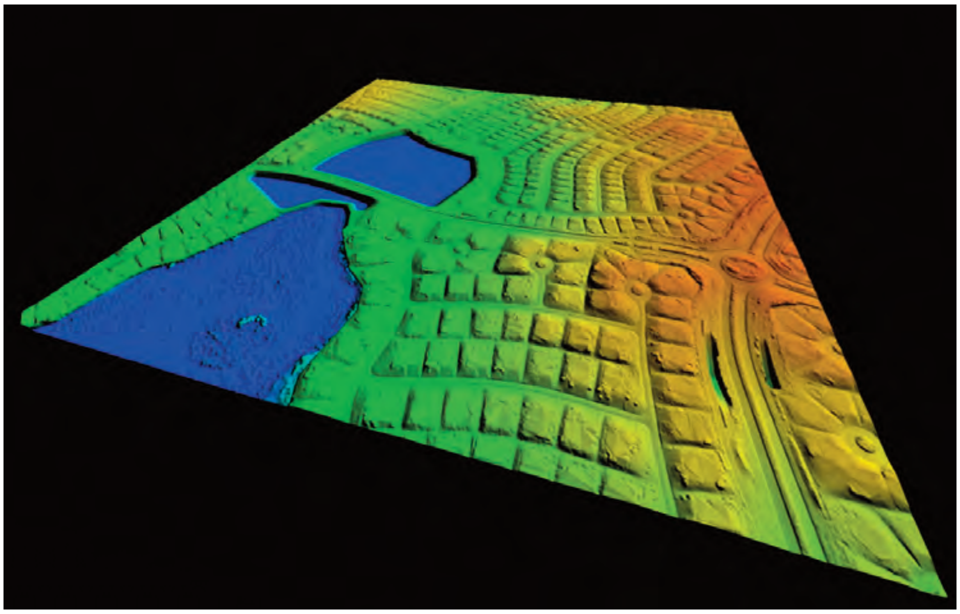

Figure 5. 2020 terrain model and contour map. Andersen: The Villages, Florida, U.S.

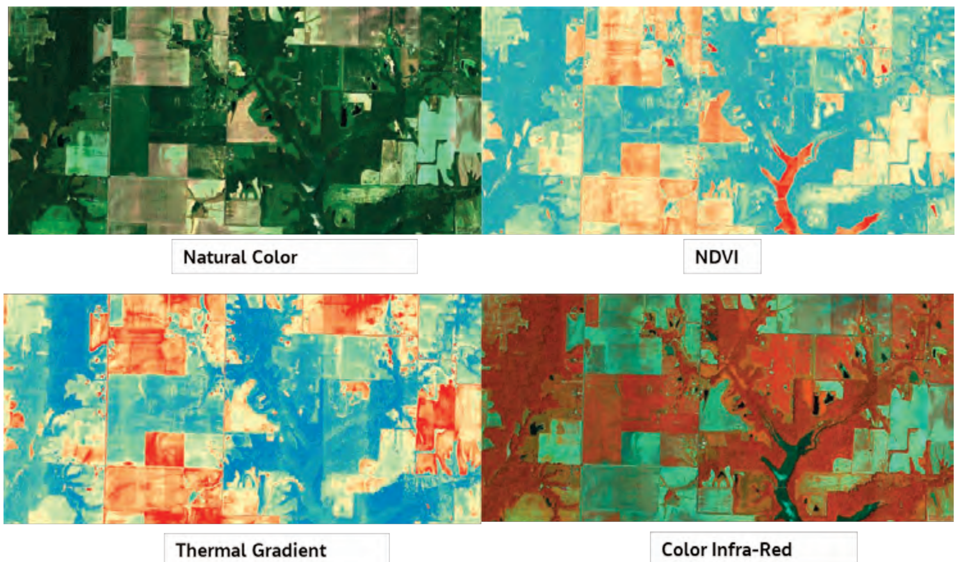

Figure 6. Normalized difference vegetation index during 2020 test flight. (Used with permission from Aeroptic Lab)

Wetland Identification

Long-wave infrared, or thermal imagery, is a device mounted on an aircraft that measures ground temperature. Wet areas tend to be cooler during daytime hours and warmer at night. Thermal imagery can highlight wetlands within a ROW—whether new, expanding, or contracting—to support environmental monitoring.

Vegetation Classification

Vegetation shows as bright red on near-infrared (NIR) imagery. The brighter the red, the healthier the vegetation. Near-infrared imagery and natural color imagery can be used to create a normalized difference vegetation index (NDVI) (Figure 6). Normalized difference vegetation index is a standardized index that quantifies the health of vegetation.

Change Detection

Change detection is one of the most powerful remote sensing applications. Remote sensed data (imagery or LiDAR) can be compared over time to highlight areas of change. Change algorithms can identify and quantify:

- Erosion
- Vegetation expansion or contraction
- Changes in built structures or human activity
- Other visible environmental effects on land within the ROW

Asset Inspections

Remote sensing provides an efficient methodology to monitor and inspect assets along a ROW. Color imagery and LiDAR from both aircraft and mobile systems can be used to identify and inventory transportation, powerline, or pipeline infrastructure at rates of hundreds of kilometers a day. Areas of concern can then be inspected in person or with very high-resolution drone imagery.

Right-of-Way Management

Subsidence along a pipeline ROW is a significant problem that is difficult to monitor along thousands of kilometers. Erosion along river crossings can expose pipelines to the surface. Poor farming practices can remove topsoil, leading to a potential strike by plowing equipment. Subsidence poses a serious threat to pipeline operations.

Regular system-wide LiDAR collections (at least annually) can track centimeter-level changes in elevation along the ROW over time. Accurate ground control is necessary for the first round of acquisition to set baseline elevations. Subsequent acquisitions are co-registered to the first data set, and changes are highlighted with an automated change detection analysis. This information can then be used to take preventive measures before issues arise, helping to protect the integrity of the pipeline network.

DISCUSSION

This section describes three case studies that show how remote sensing can support ROW routing and management.

Pipeline Route Planning

When a new pipeline is planned for construction where the proposed route runs through coastal wetlands, mountains, or Indigenous lands; crosses major waterways; and has very limited road access, field verification of environmental conditions, construction activities, stakeholder consultation, and coordination are requirements to advance the project to a construction-ready state. For a confidential, proposed pipeline with remote route challenges associated with field verifications and construction planning, a high-resolution multispectral imagery (including thermal) flight was accomplished to provide detailed ground condition information, prior to commencement of field work.

Despite difficult weather, the imagery was acquired with a fixed-wing aircraft in about 10 days, and the results provided to the planning team about two weeks after flight. The imagery supported targeted environmental field verifications, greatly reducing the hours (and costs) associated with field work in remote locations. Thermal data helped to locate potential wetlands that may lead to a change in the construction plans or minor route adjustments. Additionally, the imagery, in general, supported discussions with Indigenous leaders to provide detailed visual aids for meaningful engagement

Use of remotely sensed imagery saved time and money on construction preparation and provided higher-quality data for use in the planning process.

Highway Corridor Survey for Colorado Department of Transportation

Transportation corridors are another ROW where remote sensing technologies are being applied to gather large amounts of data about existing conditions, asset locations, and mapping. Remote sensing has become widely adopted in transportation corridor management, due to the speed at which the data are captured and processed, as well as the increased safety benefits of not having to close lanes and put field staff on busy road and rail corridors.

Interstate 270 (I-270) is a busy urban freeway in Colorado that connects Interstate 70 (I-70) near Denver International Airport and Interstate 25 (I-25) and U.S. Route 36 (US 36) that go to Cheyenne and Boulder, respectively. The roadway is narrow, has heavy truck traffic, and in many cases does not have a sufficient emergency lanes.

The Colorado Department of Transportation (CDOT) proposes to widen or replace segments of the entire highway in the coming years and has started surveying the entire 7-mile (11.3 km) corridor. Given the dangerous conditions and high traffic volumes, remote sensing was used to complete the entire survey in less than one year.

Data for the entire corridor were collected using mobile LiDAR mounted to a passenger vehicle travelling at speed. This LiDAR data were tied to detailed control markers set up outside of the roadway but visible in the LiDAR data. Additionally, aerial photogrammetry was used to capture additional features that were farther away from the travelled lanes or obstructed in the LiDAR data. The photogrammetric data were tied to the same control as the LiDAR data, creating a seamless source.

The LiDAR data captured visible features in the ROW that conventional survey would capture, including:

- Hard surfaces
- Bridges
- Guardrails
- Signs
- Gantries
- Utilities
- Overhead wires
- Sound barriers
- Paint stripes
- Other features

These data were accurate to within 0.2 foot (6 cm), both vertically and horizontally.

The photogrammetry outside the roadway collected the same features that were not visible in the LiDAR data and tied directly to the LiDAR-derived features, providing a seamless survey file for the entire corridor without having to send surveyors onto the road.

The remote sensing approach allowed CDOT to proceed with design faster than expected, and due to elimination of weather delays, working overtime and nights, and reduced staffing, saved 30% of the initial estimated budget.

Pipeline Class Location Programs

Per Title 49, Transportation of the Code of Federal Regulations, Section 192.3, Definitions ("Moderate consequence area"); Section 192.5, Class Locations; and Section 192.903, High-Consequence Areas; natural gas pipelines are required by the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration to have a complete inventory of all structures within a specified radius (usually 660 feet) of the pipeline centerline. The quantity and type of structures, as well as other land-use features, determine the pipeline's operating pressure. This is commonly known as class location and high consequence analysis. Continued property development over thousands of kilometers of pipeline poses a significant challenge to maintain data currency. Lack of current data can result in significant fines for the operator.

High-resolution, natural color imagery collected with a fixed-wing aircraft that follows the pipeline offers a cost-effective, safe, and reliable solution to this problem. Hundreds of kilometers of imagery can be collected in a single day per aircraft assigned to a project. Once the data are received at a processing facility, the imagery is processed with direct georeferencing methodologies and posted to the web for delivery. The operating company can then review the imagery from within the office and dispatch field crews to further investigate as needed. In our experience, the entire process can be completed in weeks, rather than months of extensive field verification.

CONCLUSION

Successful ROW management poses challenges on many levels. Remote sensing technologies can assist with addressing many of those challenges in a cost-effective and expedient manner. With an understanding of the types and sources of data available, ROW managers can use the information to:

- Support current management efforts
- Enhance infrastructure inventory and security
- Document environmental compliance
- Support route and construction planning
- Support vegetation management

In many cases, the same data can be used throughout the organization. The long-term, detailed record of ground conditions at the of time data acquisition provides for change detection over time and potentially offers support for legal situations with local landowners. New remote sensing technologies have improved data accuracy and resolution, lowered the data price, and paved the way for remote sensing as a standard practice for ROW management.

ACKNOWLEDGEMENTS

Thanks to our innovative thinkers Adam Parks (Resident Engineer, CDOT) and Brittany Wilson (Assistant Community Development District Manager for The Villages in Florida) for recognizing the benefits of remote sensing data and advocating remote sensing for their important programs.

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Engaging Stakeholders When You Can't Leave the House: A Case Study of the Effectiveness of Virtual Public Meetings and Tools

Alan Belniak and
Sherrie Trefry

Keywords: Communication, Content, Eversource, Functional Discussion Area, Interactive Components, Meeting, Ørsted, Project, Project Team, Stakeholders, Technology, VHB, Virtual Meeting Room, Zoom Webinar.

Ørsted and Eversource's Revolution Wind Project is a next-generation offshore wind farm that will deliver 704 MW of clean energy to Rhode Island and Connecticut.

The Revolution Wind team needed a viable way to inform all stakeholders about the project during the pandemic. Prior to filing with the Rhode Island Energy Facility Siting Board (EFSB), the Revolution Wind team and VHB created a solution to ensure public outreach by developing a virtual meeting room and hosting two virtual stakeholder meetings. The 24-hour accessible virtual meeting room featured an informational video and posters, digital handouts, and a comment card to simulate what attendees would have experienced at an in-person session. The virtual meetings began with a live introductory presentation followed by breakout informational sessions for Q&As between expert panelists and attendees. Attendance exceeded expectations while offering a dynamic opportunity to learn about the project.

The Revolution Wind Farm simulator is another virtual tool developed by Ørsted that has been effective at engaging mariners and allaying navigation concerns. The simulator was designed to provide ship captains with a realistic simulated experience of navigating through a utility scale wind farm. When participants use the simulator, the overwhelming result is confidence that they could navigate through a wind farm, regardless of the conditions.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Ørsted, a global leader in offshore wind development, and Eversource, New England's largest energy provider, formed a joint venture to permit, construct, and operate a 704 MW offshore wind farm on the outer continental shelf to supply clean, renewable energy to Connecticut and Rhode Island. The Revolution Wind Project will generate enough clean energy to power more than 350,000 homes, leading to the reduction of future emissions by one million metric tons of carbon pollution—the equivalent of taking more than 150,000 cars off the road. Project survey work and permitting have been underway since 2016. Construction is anticipated to commence in 2023, within an in-service target in 2025.

Revolution Wind proposes to interconnect the electricity generated by the wind farm's sixty five 11 MW turbines with the New England energy grid at a substation in North Kingstown, Rhode Island. The offshore export cable will make landfall at Quonset Business Park in North Kingstown. From there, two onshore co-located underground 275 kV transmission cables will carry the power up to one mile, with a maximum disturbance rights-of-way (ROW) corridor width of 25 feet to a converter station adjacent to the existing Davisville substation. Direct current (DC) power will be converted to alternating current (AC) power before connecting to the existing substation that will supply power to the grid.

As with any major energy project, there are multiple federal, state, and local approvals required before construction of the facility can begin. Central to the success of any major development project is the engagement and support of local stakeholders. This is required as part of Rhode Island's Energy Facility Siting Board (EFSB) approval process. The EFSB is the licensing and permitting authority for licenses required for siting and construction of major energy facilities in Rhode Island. Revolution Wind requires a license from the EFSB for siting and construction of the offshore cable in state waters and the onshore export cables and converter station in North Kingstown.

In accordance with the EFSB's Rules of Practice and Procedures, the board must hold a public hearing in the affected municipality(ies). The applicant is required to provide 30-day notice in local newspapers in circulation within the affected municipality(ies) and notice to abutting landowners. For the Revolution Wind Project, Eversource wanted to engage local stakeholders leading up to these public hearings to inform the public and interested parties, facilitate an exchange of information, and address questions.

Typical Times, Typical Process

For major energy projects/ROW considerations, Rhode Island has a stringent regulatory review process, and this project was no exception. Rhode Island requires that all affected stakeholders are made aware of such proposed projects. "Stakeholders" is a broad term; stakeholders here refers to affected citizens, regulatory agencies, state agencies, municipal agencies, and more. The amount of coordination and education required for so many stakeholders is vast and, accordingly, the level of effort required to engage them all is commensurate.

Atypical Times, Atypical Process

Pre-December 2019, this stakeholder engagement was mostly managed through live events. In-person public meetings, in a civic or town hall, school gymnasium, or cafeteria were the main way to meet, review information, and solicit feedback. These meetings gave many people in the community ample opportunity to understand the project more fully, ask questions, and get educated, all in a central common space. December 2019 turned the world upside down with the beginning of the multiyear COVID-19 outbreak that would cripple the entire notion of meeting communally for several months. *How will we educate the public? How will we garner feedback? How will stakeholders know we still want to meet? How can we do so safely, professionally, and responsibly, all the while continuing with the charge of bringing safe, renewable electricity generation options online in a timely manner?*

METHODS

Necessities

A good presentation—not just a PowerPoint, but the broader definition of "presentation"—was, and is, key for conveying project details to stakeholders. The public, communal meeting was the cornerstone to such an activity. These meetings provided the public and other stakeholders access to experts and information, such as posters and handouts, that people could read, reread, and consume as they wished.

Email messages are good for asynchronous, text-heavy communications. They lack dynamism, though, and almost cut the feedback loop in half. Videos take it one step further by at least sharing audio and images and other assorted media. Flat, static project websites have evolved to be able to share all kinds of media and let stakeholders consume it at their own pace, but still miss the interactive component and are often not timely—and often not inviting.

Building a Better Mousetrap

These alternative methods for stakeholder engagement could still be employed, but the Revolution Wind project team knew that the public would grow wary, expressing dismay that the team was trying to advance a project without the critical feedback loop. After airing these complications aloud, the project team partnered with Vanasse Hangen Brustlin, Inc. (VHB), a nationally renowned architecture, engineering, and construction (AEC) firm based on the East Coast, to review a proposal they had to address these very concerns. VHB, indeed, had built a better mousetrap. In fact, VHB leveraged its experiences with multiple virtual meeting rooms—and even, specifically, ones for offshore wind clients—to bring best practices forward for subsequent meetings.

VHB evolved the flat, static website to something more personal. Instead of a list of topics and contact information, VHB designed a site to make visitors appear as if they were digitally inside a public meeting exhibition hall. The site was adorned with "posters" representing the topic areas. Visitors could zoom in and out as they wished. Information was displayed in the room through multimedia, including images, text, and videos. Furthermore, interactive components were incorporated as well, such as polls, push-pin maps, and the ability to download documents for later offline viewing.

What made these environments great was the flexibility in their design. Gone are the days of a fixed 45 ft by 90 ft civic meeting room. Instead, digital meeting rooms can be one story or two (or three), with exposed brick walls or bright, sunny windows. The size of the rooms was only dictated by the number of pixels the developers allocated to the room. As rooms were designed and developed leading up to meetings, changes could be made based on the information the project teams wanted to present. Based on public sentiment leading up to the meetings, the designers could even *add an entire station* to the virtual meeting room. Further, if the meeting series spanned multiple days, the designers could flex and insert or delete a station for the subsequent meetings, based on feedback from the prior meeting.

The initial reaction from some was apprehension, with respect to the complexity and added effort of creating new content for the virtual meeting room. But that quickly abated when

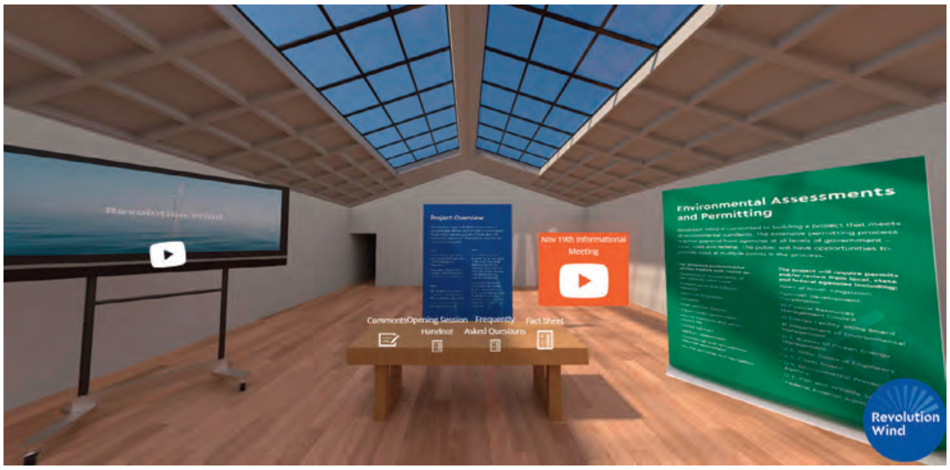
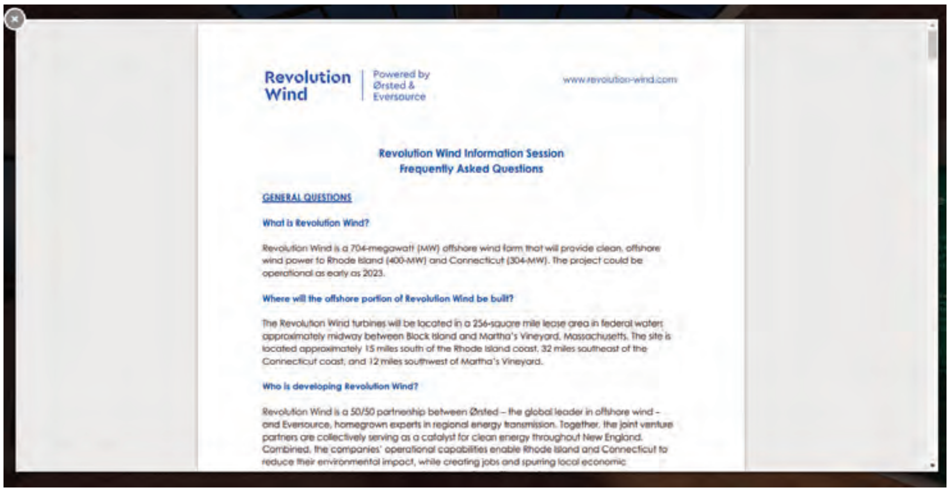


Figure 1. Example of the evolution from a traditional static website to an immersive, in-hall experience



Revolution Wind | Powered by Ørsted & Eversource

www.revolution-wind.com

Revolution Wind Information Session
Frequently Asked Questions

GENERAL QUESTIONS

What is Revolution Wind?

Revolution Wind is a 704-megawatt (MW) offshore wind farm that will provide clean, offshore wind power to Rhode Island (400-MW) and Connecticut (304-MW). The project could be operational as early as 2023.

Where will the offshore portion of Revolution Wind be built?

The Revolution Wind turbines will be located in a 256-square mile lease area in federal waters approximately midway between Block Island and Martha's Vineyard, Massachusetts. The site is located approximately 15 miles south of the Rhode Island coast, 32 miles southeast of the Connecticut coast, and 12 miles southwest of Martha's Vineyard.

Who is developing Revolution Wind?

Revolution Wind is a 50/50 partnership between Ørsted – the global leader in offshore wind – and Eversource, homegrown experts in regional energy transmission. Together, the joint venture partners are collectively serving as a catalyst for clean energy throughout New England. Combined, the companies' operational capabilities enable Rhode Island and Connecticut to reduce their environmental impact, while creating jobs and spurring local economic

Figure 2. Downloads of electronic documents made updating fast and easy, in addition to less paper waste.

VHB reminded the team that much, if not all, of the same content that was going to be used in a live, physical meeting could be easily repurposed for the virtual meeting room. Content and text on posters turned into presentation decks; speaking points turned into text-based slides and takeaway downloads. Furthermore, digital downloads resulted in no printed paper or guessing how many copies of an environmental impact statement (EIS) were required to have as physical, on-site handouts. And if something needed to change last minute, like a figure number reference or a typographical error, the electronic document was edited and revised and re-uploaded—no more costly paper reprints.

Another great thing about this virtual meeting room was that the content was live and accessible 24/7. No longer would a stakeholder have to be present at a specific day and time to consume the content. Much like a website, the content was persistently available. But it was arranged in such a way that made it more inviting and accessible. Plus, with features like interactive maps, feedback forms, and polls, the site itself could gather a first level of feedback, continuously.

The virtual meeting room could also track all kinds of information for future use, via the back-end analytics it collected. Much like Google Analytics tells a site owner where people are clicking and spending time, the virtual meeting site, too, was able to relay where people were spending a lot of time—

and where they were *not*. It tracked the ways and links and methods used to access the site; it tracked what got clicked and what got downloaded, and more. This was a treasure trove of information that could be used to determine what content to focus on in subsequent meetings, what to potentially revamp (or remove), and which methods of advertising worked and didn't work in terms of driving traffic into the site itself.

These virtual meeting sites are not only for the internet- and technology-privileged. Desktop browsing via a high-speed data connection surely helps. But what if a stakeholder doesn't have access to a personal computer? Access from a public library PC works just as well. And if a strong data connection isn't present in a stakeholder's home, the sites work just as well via a mobile device, like a smart phone with a cellular data plan. In fact, one prototype that VHB developed was a "no-frills" version, complete with very little graphics work to make the data payload/download even smaller, to serve even the narrowest of bandwidths. All that's needed is a device (desktop, laptop, tablet, or phone), a data connection, and access to a web browser. No special application to install or local permissions are needed.

Despite representing a big step forward in technology, these virtual meeting sites are refreshingly accessible to stakeholders of all ages and levels of technical savviness. From the person sitting at home on the couch to the person sitting in the car at the grocery store, the sites are accessible for all.

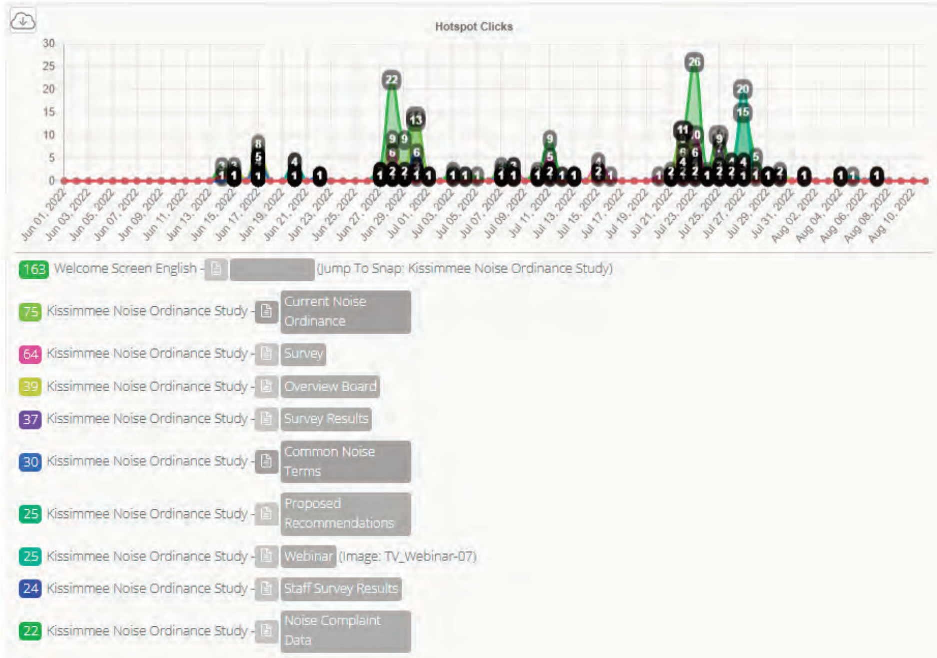


Figure 3. Trackable metrics (example only, shown above) gave site creators insights into what content did—and did not—resonate, and when.

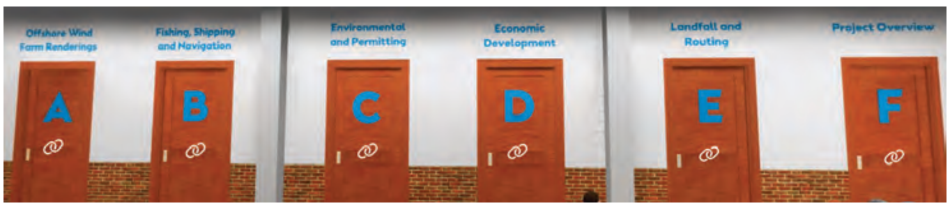


Figure 4. Functional discussion areas (FDAs) provided more intimate discussion on specific topics, where attendees could use their microphones or text/chat their questions, versus just text-based questions in the main session.

Can You Hear Me Now?

While the refreshed approach to the virtual meeting website indeed made the *content* more approachable and inviting, the notion of interactivity still needed to be addressed. And part two of VHB's mousetrap addressed just that. Video meetings have been around for decades, but COVID-19 called them off the bench to play in the big game. Project teams needed a solution where a presentation could be delivered, information conveyed, comments solicited, and live Q&A with the crowd facilitated. Project teams even wished to further make these virtual meetings like real meetings by splitting participants up into smaller groups to have focused topic discussions before returning to the larger main meeting.

Online meetings are great for "democratizing the microphones" and web cameras. But as we all learned at the beginning of the pandemic, open meetings for a large anticipated audience run the risk of a ne'er-do-well entering the meeting and hijacking it, or otherwise running afoul of commonly accepted meeting norms. VHB had prior positive experience using Zoom Webinars, with carefully and clearly explained rules of the road for when the public could share their feedback and ask questions. By using a webinar format, the chance of the meeting being hijacked—audio, image, or video—went to *zero*. In meetings where the topic of discussion could be contentious, it was imperative that the team hope for the best but be prepared for the worst. And that's exactly what they did.

They even took this approach to the functional discussion areas (FDAs, as the team called them). These were parallel webinars run by a VHB technical lead and a subject matter expert (SME) for that topic. All throughout the entire session, stakeholders were given ample and frequent instructions on how to move from topic to topic to topic. A VHB staffer remained in the main room to act as a concierge of sorts, directing anyone who joined late and missed instructions or simply exited a room and needed a bit of assistance in finding another room. Zoom was the platform of choice, after testing several others, due to its ease of use, user interface simplicity, and ability to be understood by people aged seven to seventy.

Lights, Camera, (Inter)Action

Bringing these two ideas of virtual accessibility and interactivity together is what really made the VHB team's virtual meeting approach work well. Inside the virtual meeting room, VHB created a set of digital double doors. Above the doors, text was placed that indicated the date and the time of the next live Zoom Webinar. Since any digital artifact in the virtual meeting room could have its own URL, VHB simply used the URL to the Zoom Webinar underneath the digital double doors. When the time was right, visiting digital stakeholders clicked on the digital double doors and entered the Zoom Webinar. Stakeholders were greeted by a VHB technical professional and meeting facilitator, as well as a key/senior spokesperson from the project team. The administrative items of the Zoom Webinar were explained, and then the project team lead kicked off the meeting. A presentation was delivered. At the conclusion, stakeholders had comments and questions and VHB helped facilitate them live. Other team members were on the webinar as panelists to assist with technical questions, should they come up. And yet even more team members were on standby, via a parallel Microsoft Teams meeting, able to triage questions as they came in to ensure the correct message was delivered. All of this was happening in real time behind the scenes to ensure the stakeholders had as close to an in-person meeting experience as possible.

After the main session, information about which other sessions were available and how to get to them was carefully and clearly displayed on the screen and shared verbally. Information for each session was also displayed in the

Figure 5. A link to the live (or on-demand) meeting, directly from the virtual meeting room (example)

"lobby" of the virtual meeting room, in case stakeholders inadvertently exited Zoom altogether and wished to rejoin the meetings. The virtual meeting room proved to be incredibly successful in getting as many people as possible into the live webinar and subsequent parallel sessions. This saved the team from having to email or otherwise communicate a half-dozen meeting URLs, phone numbers, access codes, and other connection details.

Accessibility

Despite the pandemic bringing in-person meetings to an abrupt standstill, there were some tangible benefits from the remote meeting boom. For one, the project team experienced a different kind of attendance. No longer did stakeholders need to factor in commute time to the meeting place, parking, or getting childcare for an undetermined amount of time. The meetings could be attended from the comfort of their own homes or other more local environments. Further, the ability to hold multiple meetings at different times during the day gave more options to more people, including white collar workers and shift workers alike. The ability to find and offer multiple languages translators also opened the accessibility of the meeting to non-native-English-speaking stakeholders, thus making the meetings more inclusive. This advent in technology also permitted the team to use artificial-intelligence-generated, real-time closed captioning for those who needed it. For those who could not attend the live meetings, they were recorded and offered up for on-demand viewing in the very same virtual meeting rooms the stakeholders visited to get more information on the project itself. And for those not in the position to have a dedicated PC or smartphone device, a dial-in telephone line was provided for each meeting and functional discussion area, complete with the ability for a key press to raise a hand and ask a question. Although not as interactive (e.g., the ability to see presented materials is not available in telephone-only mode), this meeting access option still did provide a way to be more inclusive than a traditional in-person-only meeting.

Ørsted Navigation Simulator Program

In addition to the use of a virtual meeting room to engage stakeholders, Ørsted developed a navigation simulator to engage maritime stakeholders in another virtual experience. Based on extensive outreach to maritime stakeholders and listening to their feedback and concerns, Ørsted innovatively recreated several of its planned U.S. offshore wind farms in full-mission navigation simulators.

In a completely simulated and risk-free environment, participants experience navigating vessels similar to their own in a realistic offshore wind farm that replicates exactly what they will see when the project is built, and in various weather and operating conditions. Participants can practice and experiment at will to fully familiarize themselves with navigating in an offshore wind farm—an opportunity available to mariners nowhere else in the U.S. in either a simulated or real-world environment.

Stakeholders who experience Ørsted's full-mission navigation simulators have improved spatial cognizance of an offshore wind farm environment, increased understanding of how safe navigation can be conducted, and reduced fear of taking their vessels into an actual offshore wind farm.

DISCUSSION

What We've Learned

Overall, the virtual meeting room and navigation simulator were a tremendous success in virtual engagement for the stakeholders, in terms of getting them educated and involved. If or when we do this all over again, there are a few things the project team would change:

- We would communicate the presence of the virtual meeting room in more ways. While we had great attendance, we feel increased participation was possible if we had used additional methods to get the word out. Ideas include a postcard in the mail with a QR code for easy scanning, as well as some paid online advertising that is specifically geotargeted to the affected project area.
- In addition, the team agreed that the room being available sooner would also have been advantageous for engaging stakeholders. It was available for a few days before the meeting, but had the team finalized the content sooner, a few more days would have given people more time to consume the information. Fortunately, the virtual meeting room remained live after the meeting and was linked to the project website to give people time to peruse the information.
- The team also thought that more content in the virtual meeting room would have been nice. As it was, there was much to take in, but again, the goal was to educate and communicate as much as possible. Perhaps getting some early input and reactions from a few stakeholders in a preview/pre-release version to understand the right balance of content is an approach the team could consider.
- For the live events, the team also learned that three days were too many for the approach. The team offered up a weekday midday option, a weekday evening option, and a weekend morning option. The weekend morning option was sparsely attended and very few questions were offered.
- Despite having specific dedicated functional discussion areas, many stakeholders still had general questions about the project overall. One change the team would make for next time is to have a general catch-all room for questions that do not pertain to any of the other specific topics.
- The length of time for the functional discussion areas and the time the SMEs spent in them was also too long. One session was just right, but the others were too long. Meeting technical professionals and SMEs were repeating some of the previously asked questions and answering them again for new attendees, as well as asking each other questions, just to fill some of the silence toward the end.
- The team considered simulcasting the main opening and closing session to YouTube to increase the reach. Though there'd be no way for YouTube watchers to effectively engage with the presenters, this approach would at least expose the presented content to a greater audience.
- Providing the navigational tool to mariner stakeholders resulted in affirmative reactions as users indicated that their experience using the navigation simulator was educational, positive, and an "important tool to disarm fear."

CONCLUSION

Defining Success

The team overall concluded that these virtual engagement efforts were a success. But by what measure?

For virtual stakeholder engagement, regulatory obligations for permitting requirements were met using the virtual format. Only a few technical challenges occurred, and they were able to be mitigated in real time. Increased accessibility of material following the event helped to reach a broader audience.

For the navigational tool, participants reported positive experiences. Here are some quotes:

- *"Invaluable chance to test out multiple scenarios."*
- *"Very positive."*
- *"Very helpful event."*
- *"I think I learned a bunch. It was positive."*
- *"With new/upgraded radar, this will be manageable."*
- *"An important tool to disarm fear."*

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Alan Belniak, PE, is an accomplished technologist, engineer, and marketing professional in VHB's Watertown, Massachusetts, office as Senior Product Manager. He is passionate and driven and provides a wide skill set across online virtual stakeholder and public engagement events. Belniak has extensive experience with conducting virtual meetings and helping clients creatively and innovatively navigate public outreach during the COVID-19 pandemic. He manages an internal integrated team that creates appropriately sized solutions for a wide range of outreach efforts, from hosting small roundtable online meetings to hosting and moderating town board meetings to pairing large discussion areas with persistent online/virtual meeting spaces and digital content. A strategic professional who builds relationships with key stakeholders across an enterprise, Belniak is regarded by others as a champion of emerging digital media technologies and best practices. He holds a Master of Business Administration from Babson College and a Bachelor of Science in civil and environmental engineering.

Sherrie Trefry

Sherrie Trefry, CSS, is an Energy Market Leader who earned her Bachelor of Science and Master of Science at the University of New Hampshire in Environmental Conservation and Natural Resource Management. She served as an Agroforestry Volunteer for the Peace Corps in Pinyin, Cameroon, from 2001–2004 before starting her career as an environmental consultant. Trefry has 18 years of experience in natural resource assessments and environmental permitting in New England. She has served as President of the New Hampshire Association of Natural Resource Scientists and the Soil Scientist Society of Northern New England. Trefry is a current board member of Clean Energy NH.

Living Source of Truth: The Digital Transformation of a Pipeline Project

Ashley Betson, Nicole Gergely, and Jason K. Smith

Keywords: Data Analytics, Environmental Alignment Sheet (EAS), Permitting, Pipeline, Quality Control (QC), Smartphone, Tablet, Technology, Visual Data Portal (VDP), Web Map.

User-friendly mobile devices, such as tablets or smartphones with web map capabilities, allow pipeline construction planning to move from traditional paper environmental alignment sheets (EASs) to digital tools. Environmental alignment sheets are used to convey sensitive environmental, cultural feature locations, and site-specific mitigation approaches; communicate with regulatory authorities, Indigenous groups, and interested stakeholders; and inform construction planning and monitoring.

Digital tools make it easy to accurately collect, manage, and track environmental data, site specific mitigation data, and spatial data. Virtual data platforms—including web maps—mobile applications, and digital forms, can be customized to support environmental management during construction. Data can be immediately directed to databases, web-based dashboards, and custom reports, allowing automatic integration into intuitive maps or charts. These virtual data platforms become the centralized location for quality-controlled spatial information for an entire project.

Automated data storage and dashboard functionality make real-time data collection and review workflows easy and cost-effective, providing immediate feedback to field teams and preventing rework; and reports can be automated, saving time and money while maintaining high quality.

This paper shares lessons learned from a recent pipeline construction project in Western Canada and explores the benefits and limitations of using virtual data platforms.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

More than ever, energy and natural resource companies are seeking ways to develop and maintain a centralized location for project information so data can be easily collected and accessed in a timely and cost-effective manner. While efforts to be paperless and provide a centralized information source where all users can access the same information sounds practical and straightforward, there is still not a consistent industry approach. There are many commercial off-the-shelf programs that can be manipulated to scale according to a project's needs, as well as companies that have customized databases for their needs, only to find themselves resorting back to basic data systems.

It has been the authors' experience that there have been many attempts by major projects to develop a single, centralized repository for project information with controlled access where all the data are housed. Traditionally, project data have been gathered, created, and often separated by different user groups or different departments and altered to meet their purposes; and sometimes data have been modified just for a single user or regulator. Past efforts by companies have resulted in expensive customized databases that do not often meet the needs of all user groups, so they often resort back to paper copies and spreadsheets.

Recently, we developed a visual data portal (VDP) for a large pipeline project. This paper discusses the rationale for transitioning to the VDP, the benefits of the VDP, and how energy companies constructing large linear infrastructure projects may learn from this system and consider applying a similar approach. The VDP is one example from a major project that has proven to be successful for construction management.

WHAT IS A VDP?

The VDP is an Esri ArcGIS integrated online mapping tool that effectively manages project data. It is a cloud-based web mapping product that is accessible anywhere using a mobile device.

For major construction projects, data are provided and used by a number of sources and user groups, such as:

- Survey
- Environmental
- Land
- Engineering
- Construction
- Indigenous relations
- Stakeholder engagement and regulatory
- Third-party consultants

These teams specialize in their area of expertise and help develop and construct a project. Data are uploaded to a web server via various workflows, specific to each scope of work. Data are then visualized in the web interface by end users.

For pipeline construction, these teams include:

- Field survey staff
- Land agents
- Indigenous relations
- Indigenous groups
- Quality reviewers
- Subject matter experts (SMEs)
- Engineering
- Construction
- Regulators

While most of the work on this project is completed remotely in the field and without internet access, maps can be downloaded when there is internet access and then used in the field without losing any relevant project information. Data are collected via offline forms and synchronized to the web service when the internet is available. Subject matter experts, or their designates, complete the necessary quality checks and upload the data to the VDP for visualization every day. This close-to-real-time data availability is critical to support the pace of pipeline construction and ongoing change management. Due to intermittent internet access, this offline function is critical for a remote project.

WHY USE A VDP?

Many of the challenges and lessons learned from pipeline construction projects are repeated because the ideal solution to data centralization and access hasn't been identified. Not having a centralized or user-friendly, accessible location for all spatial project information continues to create challenges for projects, as hundreds of users and multiple contractors need to access the information.

In addition to capturing project data, there are also permits from several governing authorities that need to be located and accessed by project teams. Often, permits have conditions that need to be fulfilled prior to, during, and after construction. It is not only important to be aware of these permit requirements, but also to track the timing and completion of the conditions throughout the project life cycle—and, in particular, during construction when the highest costs for the project are incurred.

Ultimately, not being able to access permits can lead to incomplete construction readiness assessments or noncompliances with regulators. Managing permit conditions and commitments across a project can be challenging. There are also field changes to environmental features immediately prior to or during construction that need to be documented and communicated in real time to avoid introducing a regulatory noncompliance, to allow for construction schedule changes, or to implement mitigation measures.

Traditionally, paper environmental alignment sheets (EASs) were considered the most relevant and accurate source of project information for environmental inspectors and construction managers in the field. These EASs would be submitted to regulators multiple times throughout the regulatory review process with updates to environmental or routing information. Up to 60 days prior to construction, a final set of EASs would be filed with regulators so they could audit the project. There can be a lot of changes to the landscape over 60 days, including seasonality, wildfires, and extreme weather events that can affect construction. Often, the environmental effects on the project footprint would make the EASs inaccurate within a short time frame. Reproduction and distribution of these tabloid-sized paper EASs was also costly. Today, the common practice is to present an EAS as a web-based map for digital access.

Eliminating paper and using a VDP as the ultimate data reference for real-time information allows multiple teams and users to work from the same set of data. With everchanging field conditions and multiple consultants and contractors providing information to field crews, a thorough quality assurance (QA) and quality control (QC) process can be supported by distributing information to various teams using this central ArcGIS platform.

Some of the benefits of having a centralized location for data include:

- Supporting the QA process
- Avoiding or mitigating the likelihood of noncompliance
- Achieving project commitments
- Supporting expedited decision-making
- Minimizing version-control challenges

RESULTS

The VDP was developed as a result of several lessons learned and previous attempts at developing databases on linear infrastructure projects. Ultimately, the VDP on this pipeline project was developed due to its scale, including the sheer volume of incoming and outgoing data from Indigenous groups, regulators, stakeholders, and contractors, as well as updates to permit data and associated changes to manage. As a result of using the VDP instead of traditional paper-based EASs or spreadsheets, the project realized substantive benefits that can be carried forward to other projects.

Furthermore, as lessons learned from projects are shared, there is opportunity to build enhancements into the VDP for future pipeline projects. One important lesson was the lack of a central storage location for project information so that it could be easily accessed and used in the field, in the office, and around the globe. Having a centralized, quality-controlled location for all route information and a comprehensive QA/QC process for data and spatial features has saved countless hours in miscommunication and rework between various teams and users.

A second lesson from previous projects was how an inadequate assessment of construction readiness for permitting can negatively impact a project's schedule and budget. In response, the VDP not only helped to avoid missteps but also provided users with solutions, including:

- Tracking areas with permits where construction could proceed (presented visually as a green "go")
- Tracking areas where permits weren't yet received to determine alternate approaches and strategies (presented visually as a red "no-go")
- Using a relational database so the multidisciplinary teams could plan mitigations together

With several hundred kilometers of pipeline rights-of-way (ROW) undergoing construction, permit readiness was a complex issue that had significant implications for construction start and project cost. The VDP created an ROW "go" or "no-go" determination, which visually displayed areas of the ROW that had permits and could proceed with construction. This allowed teams to determine alternative construction implementation approaches if permits were delayed in one area and could proceed in others where permits had been received.

The foundation of the VDP is a relational database that allows two layers to interact with each other; for example, if certain permits are tied to watercourses, it allows those two layers to "talk," and can show up as red in the VDP if a permit for a watercourse had not been received.

The ability to communicate to field teams working in remote areas that a permit had been received was a substantial benefit to implementing this go or no-go determination because multiple teams, across various geographies, relied on this information and needed to be able to proceed with work as soon as the permit was received, reducing construction standby costs.

Permits are linked in the VDP to associated locations that allowed users to view an Adobe Portable Document Format (PDF) version of the permit with its associated conditions. The commitments in these permits were broken out based on construction phase and location, so it was clear to all users what was required or had been completed.

Using a VDP reduced reliance on paper forms. The transition to digital forms resulted in a number of benefits, including reduced transcription errors, as paper forms rely on manual data entry into large, cumbersome databases.

We also witnessed and measured efficiencies and advantages in the following areas:

- Digital data collection methods
- Digital QA/QC workflows
- Data integration
- Ultimately, automated reporting

Data were collected using digital forms and web applications. Consultants and contractors established digital workflows that facilitated daily uploads of quality-checked data. Digital workflows allow for nightly data quality checks and integration of these quality data into the VDP to facilitate construction the next day, because data (for example, water quality monitoring data at a watercourse crossing) are generally available in four hours or less. Before the VDP, it could take several days to receive quality-checked data. As such, the team is able to support construction, helping determine the appropriate mitigation measures and communicating go or no-go construction areas through the VDP.

Due to the complexity of this project and its extensive length, the idea of having all approvals and permits in hand prior to commencement of construction was not realistic, because the project crossed multiple geographies and jurisdictions. Therefore, this project endured many construction transitions (such as the COVID-19 pandemic) and management of change exercises that have required upfront investment in the VDP and a collaborative, yet iterative, approach to refining the VDP.

The project also realized efficiencies in reporting. Early analytics suggested that up 30% reduced labor in full-time equivalents was needed to collect, quality check, manage, and report on data. Automated reporting has been essential in tight turnaround regulatory reporting and client reporting. Having environmental data accessible in real time and available for multiple users in various geographies allows for quick decision-making, both in the field and office. Particularly with changing schedules and project needs, compounded by changing environmental conditions that may impact construction schedules, being able to access environmental data from the VDP allowed both office and field teams to modify daily schedules and develop alternate workarounds to allow construction to continue. For example, daily field reports could be reviewed and quality checked in a digital dashboard for efficient and timely distribution.

Another benefit of the VDP is the ability to track construction progress. As the data are uploaded, the VDP would show the percent complete for each construction phase (for example, clearing, grading, stringing) and how much work had been completed from one week to the next. This allowed the team to identify parts of the ROW with areas completed and how fast each phase was moving in comparison to other parts of the ROW. This also helped facilitate resource and crew management across the project.

Construction progress and status is a key performance indicator for many user groups and teams and allows for easy comparison to proposed construction schedules. For environmental teams, this allows for an assessment of wildlife and fisheries timing constraints imposed on a project, and determination of whether construction will be able to achieve these timing windows. In cases when construction takes longer than expected, this would allow the company to have discussions with regulators, Indigenous groups, landowners, or other stakeholders in a proactive manner.

An unanticipated benefit of the VDP was its ability to support resource and workload balancing. Not only was the project able to increase resource and worker productivity, because data are centralized, but also allowed teams to balance workloads between time zones to facilitate the demands of pipeline construction. Workload and resource balancing provided an added benefit, especially when resource availability was constrained.

Project management benefits were also recognized through use of the VDP by creating custom reports that helped track progress, hours, and findings, among other metrics. This information could be integrated into the project management tools for efficient cost and progress tracking, which is critical for a project that had extensive change management.

CONCLUSIONS

The development and establishment of a VDP has greatly aided the construction of this pipeline project. Many benefits were identified; and in conclusion, several recommendations can be provided for future projects, including:

- Develop an approach that is clear and easy for team members to understand.
- Prioritize data quality options that are user-friendly to implement, maintain, or improve.
- Use lessons learned from other projects to mitigate risk.
- Acknowledge and embrace change by implementing solutions that are flexible and accommodate continual improvement.
- Encourage success through appropriate chartering, training, and user support.
- Develop a data standardization scope of work and digital forms for pipeline projects that can be used or included in survey, environment, or land Request for Proposal scopes of work.
- Develop a real-time collector tool for environmental inspection to gather necessary inspection data for tracking and effectively managing evidence required for regulatory requirements.
- Develop and implement a thorough data QA/QC process; “good information in” equals “good information out.”
- Incorporate permit-tracking mechanisms.

The VDP has proven to be effective at managing data for a large-scale pipeline project. There were many benefits that were realized throughout construction—some were anticipated and others that were recognized after the fact. The concept of having one centralized source of information for all user groups to manage quality and control of data has been a desire by many pipeline construction projects. While most projects find a way to get things done and meet regulatory requirements and project commitments, the VDP is one of the most comprehensive and user-friendly platforms developed for a project of this scale. Project managers should look to carry forward many of the benefits and lessons learned from this VDP and apply it to pipeline projects of the future.

ACKNOWLEDGMENTS

Coastal GasLink Pipeline Project.

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Smith has provided strategic regulatory advice at early project planning phases; supported Indigenous, stakeholder, and government engagement programs; served as an expert witness in several Canadian Energy Regulator hearings; and oversaw environmental construction implementation. Smith holds his Master of Science from the University of Calgary in Calgary, Alberta, Canada.

Operationalizing Advanced LiDAR Technology for T&D Field Operation Effectiveness

Jennifer Whitacre and Bob Bell

Keywords: Collaborative Vendor Model, Danger Tree, Data Analytics, Electric Reliability, Failure Trees, Forest Fire, Frequency Ratio (FR), Hazard Tree, Integrated Inspection Workforce, LiDAR, Receiver Operator Characteristic (ROC), Remote Sensing, Safety, Strike Trees, Urban Wildland Interface, Utility Gate Keeper Model, Utility Lines, Utility Vegetation Management (UVM), Wildfire.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

This paper will discuss a technology-forward approach for utility vegetation management (UVM) programs that improves efficiencies and reduces risk to communities and the environment. It is the result of a unique partnership between a remote sensing company and full-service UVM company.

Many utility companies work with remote sensing vendors to capture Light Detection and Ranging (LiDAR) and imagery to identify vegetation threats to their electrical equipment. Evaluation of risk is typically limited to measurement of tree proximity to conductor, tree height relative to line, and branches overhanging conductors. Utility companies then work separately with UVM vendors who do the inspections and vegetation work. It is standard operating procedure for the utility company to act as a big-data intermediary, inefficiently funneling information from the source to the end users.

Do the utilities get the full benefit of the LiDAR surveys? Do the utilities understand how to provide this information to the UVM companies? This paper will discuss the benefits of eliminating information bottlenecks through direct data dissemination. These include understanding the value of derivative data analytics to help identify and maintain minimum vegetation to conductor clearances, particularly clearance encroachments caused by tree failure, and thereby reducing risk of vegetation-caused service interruptions and catastrophic wildfires.

INTRODUCTION

Light Detection and Ranging (LiDAR) is an unbiased and proven remote sensing technology that can help utilities identify vegetation threats across their electric and gas transmission and distribution systems. Over the past two decades the industry has seen the technology advance. As the technology advanced, so have the sensors' ability to fly higher and faster while maintaining point density and accuracy on the ground. This has increased the speed in which data can be collected and turned around to the utility.

LiDAR-derived vegetation threats provide a robust tool for field inspectors. This data is a valuable augmentation; however, it is not a replacement for a trained arborist, and it does not communicate with customers or regulators. Light Detection and Ranging does provide value when communicating work plans. Utilizing LiDAR does provide added efficiencies to the UVM workflow. It can provide an Integrated Inspection Workforce, which is a combination of desktop and field patrols. It provides targeted, prescriptive analytics to optimize pruning and tree work. Also, with cloud hosting, LiDAR is available to support field patrols. Currently, LiDAR is not fully adopted in the UVM space.

Currently, many utilities contract and work directly with the remote sensing vendor for LiDAR collection and analytics. They then contract separately with a UVM company for inspection and tree work. This paper defines this operating model as the Utility Gate Keeper Model. By acting as a gatekeeper between the tree company and the remote sensing firm, this often causes delays in the interpretation of the data analytics, plan development, and execution of work.

The end goal is to have all three groups working together to create a communication feedback loop. This provides efficiencies where the inspectors can communicate directly with the LiDAR vendor to help solve problems and expedite the work. This paper is defining this as the Collaborative Vendor Model.

The following is a real-world example of how the Collaborate Vendor Model can work for a utility. Communication helps to enhance and develop additional LiDAR analytics; in this case, to help identify and mitigate fall-in risk in high fire areas. Please see the Appendix at the end of the paper that provides more contextual discussion on recent fire threats in the United States.

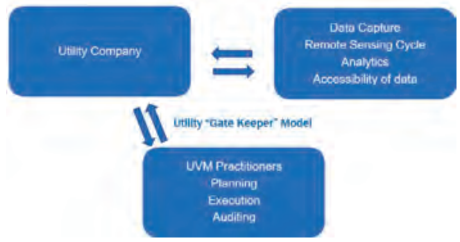


Figure 1. Utility Gate Keeper Model

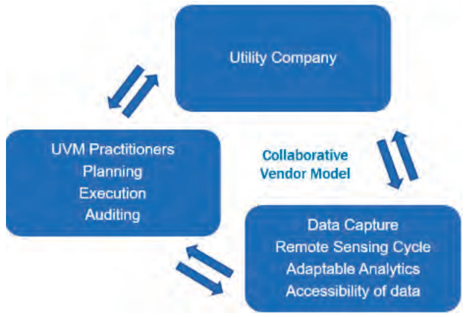


Figure 2. Collaborative Vendor Model

METHODS

Data Acquisition

Remote sensing is used to collect data to support vegetation management (VM) inspections. One type of remote sensing technology that is commonly used is LiDAR. This technology provides an unbiased, high-density point cloud that can be used to provide extremely accurate measurements.

Circuit lists were provided from the utility to generate flight plans for the area of interest to maximize flight efficiency while meeting or exceeding the project accuracy and density. The flight team planned the data collection by optimizing sensor pulse rates, aircraft speed, and flight heights based on the terrain and locations of the circuits to ensure the full corridor width of 91.4 m (300 ft) were collected.

To enable correction and validation of the LiDAR point data, ground control points (GCPs) and quality assurance points (QAPs) were collected using GNSS real time kinematic (RTK), post processed kinematic (PPK), and fast static (FS) survey techniques. Ground control points are used to support the aerial missions and are used during the calibration process to improve the LiDAR accuracy. Quality assurance points are withheld from the calibration process and compared to the final ground surface to provide an independent assessment of the absolute accuracy of the LiDAR data.

Weather data is also collected with the LiDAR data. Weather parameters captured included solar radiation, wind, temperature, and relative humidity. This data is used when modeling the circuits in PLSS-CAD.

Light Detection and Ranging data were collected over a 7-week period starting mid-September 2021 to early November 2021. NV5G uses the latest state-of-the-art aerial LiDAR sensors from Riegl, the VQ-1560ii and VQ-1560 ii-S. The LiDAR system has two 1-MHZ lasers that provide 8-degree overlapping forward and aft look angles to enhance capture of detail on vertical structures, such as poles and towers, and help reduce vegetation shadowing. The two laser sensors collect more than 1.3 million measurements per second on the ground. Other benefits include evenly distributed scanning geometry that captures consistent point distribution and provides high feature definition, including vegetation versus assets on structures.

The systems for this Western utility were set to a pulse rate between 600–

2,000 kHz and were flown at elevations between 300–600 meters above ground level (AGL). The LiDAR system settings and flight parameters were designed to yield high-resolution data of greater than 30 points per square meter (ppsm) over terrestrial surfaces.

To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position, described as *x*, *y*, and *z*, was measured at 2 Hz by an onboard differential GNSS unit. Aircraft attitude, described as pitch, roll, and yaw (heading), was measured at 600 Hz by an onboard inertial measurement unit (IMU).

The LiDAR sensor operators monitored the data collection settings during data acquisition, including pulse rate, power setting, scan rate, gain, field of view, and pulse mode. For each flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing state. Sensor operators were also in constant communication with the ground field crew to ensure proper ground GPS coverage for data quality. All necessary measures were taken to acquire data under good conditions (e.g., minimum cloud decks, no smoke or fog) and in a manner that prevented to possibility of data gaps. Weather conditions were assessed in-flight, as adverse conditions affect data quality and can prove unsafe for flying. All LiDAR systems were calibrated to meet or exceed the Riegl specifications and were tested by NV5 Geospatial for internal consistency every mission using proprietary methods.

Processing and Analysis

The initial processing and analysis of this data were to identify vegetation threats along the transmission rights-of-way (ROW), as flown and maximum operating conditions were used to locate vegetation encroachments, overhang, strike trees, and blow out conditions across the system. For this paper, we are going to focus on the advanced analytics that were provided for strike trees in the High Fire Threat District (HFTD) locations. These analytics provided vegetation risk scores for strike trees that had the highest likelihood to hit the conductors.

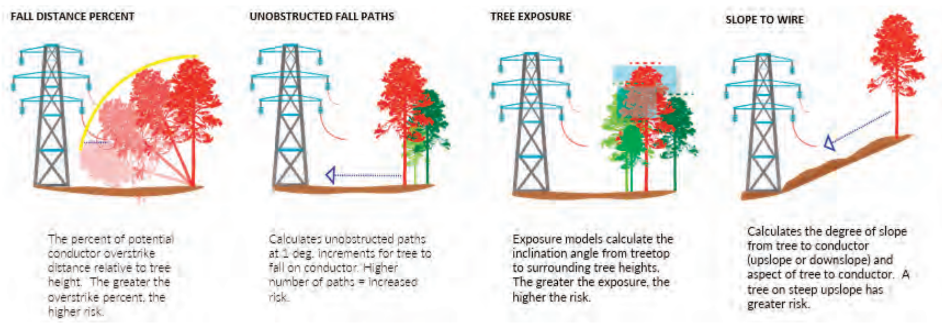


Figure 3. Four Variables for Risk Model

Vegetation risk was analyzed for all treetops within 152.4 m (500 ft) of HFTD zones that could impact a conductor in As Flown conditions. The risk model has gone through many different variations over the past few years. This model was first introduced in 2019. In 2020 the model was back, tested by an independent third party reviewer as well as industry peer reviews that provided recommendations for the 2021 and 2022 (same as 2021) model inputs. The current model looks at four different metrics analyzed in the LiDAR data:

- Fall Distance Percent
- Unobstructed Fall Paths
- Tree Exposure
- Slope to Wire

Fall Distance Percent looks at the percent of potential conductor overstrike distance relative to the tree height. The greater the overstrike percent, the higher the risk. Unobstructed Fall Paths calculates unobstructed paths at 1-degree increments for the potential of the tree to fall on the conductor. The higher the number of paths means an increased risk of the tree striking the wire. Tree Exposure models calculate the inclination angle from treetop to the surrounding tree heights. The greater the exposure, the higher the risk. Finally, Slope to Wire calculates the degree of slope from tree to conductor (upslope or downslope) and aspect of tree to conductor. A tree on a steep upslope to wire has a greater risk of falling on the wire.

The tree risk scores are derived from airborne LiDAR and provide a relative risk ranking that a tree will strike a transmission line if the tree fails. Each tree in the utility transmission ROW has its own unique tree ID. All trees capable of striking the conductor will have an individual tree risk score considering all the metrics above.

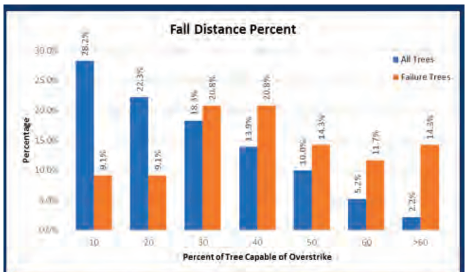
Initial data analysis and conditioning was performed. Original data representing "All Trees," which were the full tree population, and "Failure Trees" population were filtered to include the most applicable data. The original All Tree data included a large population of trees that were not capable of impacting a conductor, those were removed as only the trees that could strike the wire were being used. The original Failure Tree data included occurrences of multiple trees being assigned to a single outage. This was due to the vegetation segmentation process where trees were assigned a unique ID. The trees are sometimes over-segmented in the tree delineation process. When multiple tree segments were assigned to a single outage, only the tallest tree was retained.

Table 1. Original and Filtered Tree Counts

	ORIGINAL DATA	FILTERED DATA
All Trees	n = 840,300	n = 365,006
Failure Trees	n = 126	n = 77
Ghost Trees	n = 128	

The test data were severely imbalanced where the distribution of samples was uneven by a large amount in the training data set. As noted above, the All-Trees population data came out to 365,006 trees and the final Failure Tree data set was 77 trees. Due to the data imbalance, a Frequency Ratio Model was chosen. A Frequency Ratio (FR) is a bivariate statistical method that considers the correlation between dependent factors (historical tree fall ins) and independent factors (fall in causative factors). Frequency Ratio is defined as the ratio of the relative frequency of a feature over the

Table 2. Frequency Ratio



The higher the RF for failure trees in comparison to all trees, the higher the FR score

All Trees			Failure Trees			FR
Bin	*Count*	*Rel Freq*	*Bin*	*Count*	*Rel Freq*	
10	103006	28.2%	10	7	9.1%	0.3
20	81228	22.3%	20	7	9.1%	0.4
30	66718	18.3%	30	16	20.8%	1.1
40	50795	13.9%	40	16	20.8%	1.5
50	36446	10.0%	50	11	14.3%	1.4
60	18953	5.2%	60	9	11.7%	2.3
>60	7860	2.2%	>60	11	14.3%	6.6

Values >1 show increasing correlation and values <1 show a decrease in correlation

population and the relative frequency (RF) of the feature over the failure trees for each causative factor.

The FR results were normalized per causative factor to values between 1–100, where >1 indicates increasing correlation between that feature and tree failure. A weighting was applied to each metric to account for predictive contribution and potential correlation with other metrics.

The final risk score formula = **Overstrike Score*.43 + Unobstructed paths Score*.32 + Slope to Wire Score *.13 + Tree Exposure Score *.12**

When calculating the final risk score, each different metric had the FR applied as well as a normalization. Each of the four different metrics are listed below.

1. **The Fall Distance Percent** measures the percentage of total tree height that is capable of contacting the wire.

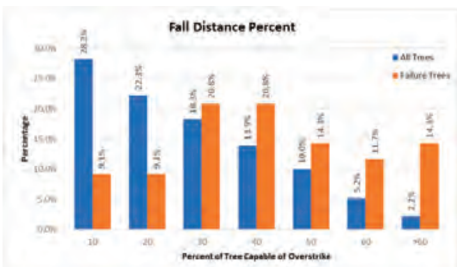
Fall Distance Percent (1–100)

- >0% = 1
- 100% = 100
- Else – percent of three that could potentially strike wire

OVR	FREQ_RATIO	NORMALIZED
10	0.3	1
20	0.4	2
30	1.1	14
40	1.5	19
50	1.4	18
60	2.3	31
100	6.6	100

The weighted contribution for Fall Distance Percent was 42.8%.

Table 3. Fall Distance Percent



2. **Unobstructed Paths** measures the number of potential paths a tree has to the wire, based on a 3D analysis of proximity to wire and assessment of other vegetation that may block potential paths to the wire. Paths are measured in 1-degree increments. The worst case scenario is for a tree to have 179 potential paths to the wire.

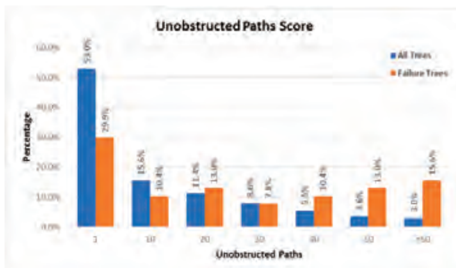
Unobstructed Paths Score (1–100)

- 0 unblocked paths = 1
- 179 unblocked paths = 100
- Else ((potential unblocked paths/179) *99 +1)

UFP	FREQ_RATIO	NORMALIZED
1	0.6	1
10	0.7	3
20	1.1	13
30	1.0	10
40	1.9	29
50	3.6	67
>50	5.2	100

The weighted contribution Unobstructed Paths was 31.6%.

Table 4. Unobstructed Paths Score

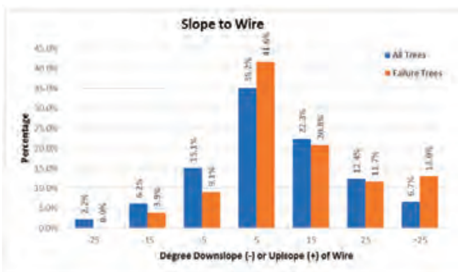


3. **Slope to Wire** effectively measures the degree to which the tree is upslope or downslope of the utility asset. Negative values are downslope and positive values are upslope of the wire. The slope to wire is a continuous variable calculated directly from the LiDAR-generated terrain data.

S2W	FREQ_RATIO	NORMALIZED
-25	0.0	1
-15	0.6	33
-5	0.6	32
5	1.2	61
15	0.9	48
25	0.9	49
>25	1.9	100

The weighted contribution for Slope to Wire was 13.2%.

Table 5. Slope to Wire



4. **Tree Exposure** measurement mimics the canopy class for each tree. The average local canopy height is calculated as the average tree heights in a 16.03 m radial distance (1/5 acre) around each tree. Tree height comparisons to the local canopy height gives an indication of vertical exposure and isolation.

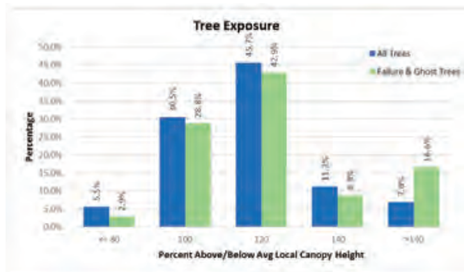
Tree exposure is a continuous variable calculated as:

$$\frac{\text{Tree Height}}{\text{Average Local Canopy Height}}$$

TEX	FREQ_RATIO	NORMALIZED
80	0.5	1
100	0.9	23
120	0.9	23
140	0.8	15
>140	2.4	100

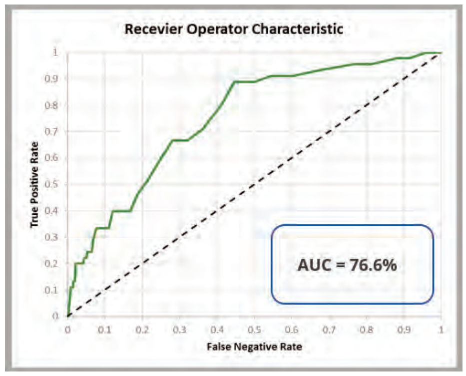
The weighted contribution for Tree Exposure was 12.4%.

Table 6. Tree Exposure



When it came time to validate the model, a Receiver Operator Characteristic (ROC) was used. The ROC tells us that the probability that the risk score of a tree drawn at random from the population of true failures is larger than the Risk Score of another individual drawn at random from the population of non-failures. When looking at the graphic, the Area Under the Curve (AUC) provides an aggregate measure of model performance. The AUC for this model was 76.6%.

Table 7. Receiver Operator Characteristic



When validating the risk score, All Trees and Failure Trees were reviewed. There is not a guarantee that all high scores will cause a failure, or all low scores will not cause a failure. The higher scores are more likely to cause a failure and lower scores are less likely. The overall goal is to increase the AUC score and provide an increased separation between the failures and non-failures.

Table 8. Risk Score Comparison of All Trees and Failure Trees

In the example above, if trees that scored a 20 or higher were prioritized: ~60% of all fall in failures would be mitigated while only visiting ~25% of danger trees.

RESULTS AND DISCUSSION

By 2018, many Western utility companies had adopted industry-accepted vegetation patrol standards and followed both American National Standards Institute (ANSI) standards and International Society of Arboriculture (ISA) best practices for utility pruning of trees and integrated vegetation management (IVM). As a result, it is estimated hundreds of thousands of hazardous trees have been mitigated by Western utilities in the past decade, using traditional evaluation tools and methods. As a further result, typical tree failures into powerlines appear to be green, healthy trees, even to educated observers.

This raises the daunting question of "How does one identify the healthy trees in a population that are more likely than other trees in the same population to fall into a utility company's energized infrastructure?" In other words, "How do we find the needle in the haystack?" In 2019, using a Collaborative Vendor Model, a remote sensing group in partnership with a Western utility client proposed to answer that question by using unique geospatial attributes associated with individual trees throughout a population of trees on the client's service territory. All trees evaluated were selected due to their proximity to high-voltage transmission lines equal to or greater than 60,000 volts (60 kV) and less than 500,000 volts (500 kV). After significant statistical analysis and an expert, third-party review, the remote sensing group and their client agreed on a risk algorithm that passed statistical rigor.

In July of 2021, a field implementation of the tree risk algorithm was performed by a UVM group. Three-dimensional (3D) LiDAR data were loaded into Getac handheld computers as a two-dimensional (2D) rendering. All trees identified as high risk were readily observable to field inspectors based on the geospatial attributes of the subject tree. Once trees with high-risk scores were identified in the field, inspectors performed a detailed tree risk assessment to determine prescription requirement (i.e., branch removal, whole tree removal, no work needed, etc.).

Given that the population of trees evaluated consisted entirely of off-ROW danger trees capable of striking overhead transmission conductors, only two prescriptions were used: remove tree or no work needed. Of the 832 trees evaluated by inspectors between August 16, 2021, and August 5, 2022, approximately 526 (63.2%) were abated (tree cut down) and 306 were determined to be safe and received no additional work prescription. All of the trees that were abated were previously, within the past year, inspected during a routine foot patrol and determined to be safe; however, those inspectors did not have the benefit of knowing the potential risk impact of the geospatial attributes.

CONCLUSIONS

LiDAR tree detections were efficiently integrated into the UVM inspection process. The tree risk algorithm was able to identify a significant number of healthy trees that exhibited empirically measurable risk factors that are not readily observable using traditional, industry-accepted tree risk evaluation criteria. Using the tree risk algorithm, the trees were reevaluated with strike potential considering the new, geospatially derived risk criteria. In doing so, a significant number (63.2%) of trees in the target population were identified that required abatement. Furthermore, the inspectors were able to accurately identify target trees in the field due to the geospatial accuracy (5 cm absolute accuracy) inherent in LiDAR data. These factors made the process effective from a risk evaluation perspective, and both efficient and repeatable from an operations perspective.

By utilizing a Collaborative Vendor Model, a utility can partner with multiple groups that can help promote remote sensing analytics to help better understand their system. Having a direct line of communication between the LiDAR and UVM vendors is key to avoiding unnecessary delays in executing work and reducing potential miscommunication.

It is the conclusion of this paper that the tree risk algorithm developed passes statistical rigor. Participant feedback concluded that the field implementation of this this technology in a Collaborative Vendor Model can be executed efficiently and accurately. However, it is statistically inconclusive whether the Collaborative Vendor Model significantly improved efficiency compared to the Utility Gate Keeper Model, due to the inability to create a statistically acceptable control group. Based on a comparison of similar work performed on electric distribution vegetation inspections, the Collaborative Vendor approach (utilizing a combination of LiDAR and field inspections) fell within the range of productivity expected by the utility. Based on a limited sample size for both models, as tree density (trees inspected per mile) goes up, productivity goes up. For the Collaborative Vendor Model, productivity is disproportionately high, as shown in the Tables 9 and 10.

Utility Gate Keeper Model

Table 9. Showing Results from Utility Gate Keeper Model for Distribution Work

Area	Mileage	Inspected total Trees	Trees/Mi	Units/Hr	Hrs/Unit
Division A	950	707	0.74	0.34	2.94
Division B	1350	341	0.25	0.16	6.1

Collaborative Vendor Model

Table 10. Showing Results from Collaborative Vendor Model Risk Tree Work

Area	Mileage	Inspected total Trees	Trees/Mi	Units/Hr	Hrs/Unit
System	18,172	832	0.05	0.2	4.93

It is also inconclusive at this time if the trees identified as high risk and ultimately mitigated will result in a reduction in tree-related service interruptions or in tree/conductor conflicts that could lead to a wildfire. Tree contact with transmission voltage conductors is a very low occurrence, very high consequence event. It does not lend itself to repeated observations. Continued observation of treated versus untreated populations over the next several years, as well as observations compared to historical results for the same locations, will be needed before statistically valid conclusions may be drawn. Another approach to gathering a higher volume of observations would be to conduct a similar risk evaluation and mitigation on a population of trees in proximity to distribution voltage facilities which typically have much higher tree/conductor conflict occurrence rates.

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APPENDIX

For historical perspective, the 2003 Cedar Fire which is considered the fourth most destructive wildfire in California history, was set by a lost hunter to signal rescuers. The fire burned 110,579 hectares (273,246 acres), 2,820 structures, and killed 15 people. The hunter, who admitted to intentionally setting the fire, was charged with a federal crime. He ultimately was sentenced to forty days of community service, five years' probation, and ordered to pay $9,000 in restitution despite the estimated damages of $1.3 billion.

The October 2007 wildfires that were started by a powerline owned by San Diego Gas and Electric (SDG&E), a Sempra Company, serve as a contrast. SDG&E paid approximately $3 billion in settlements, fines, and uninsured losses. By all accounts, SDG&E responded to this devastating wake-up call, but other Western-situated utility companies still seemed to hold back on taking strong action in terms of fire resiliency and prevention. That changed in 2017.

In October of 2017, a string of wildfires (collectively known as the "wine country fires") were started by utility lines owned by Pacific Gas and Electric Company (PG&E). While still in litigation over the wine country fires, another more devastating fire, called the Camp Fire, was ignited by PG&E electric lines near the town of Paradise, CA. Collectively, these fires resulted in an estimated $30 billion in damages, killed 106 people, and bankrupted one of the largest utility companies in North America. During this same time period, five fires (primarily the Woolsey fire and the Thomas fire), caused by Southern California Edison (SCE) equipment, resulted in nearly $1 billion in fines and losses.

Clearly, by the time the Camp Fire had eradicated the town of Paradise in a firestorm, fire prevention was the new priority. Fire response was no longer sufficient to protect lives and property, nor was it sufficient to ensure the solvency of long-established Western utility companies.

When trees grow in proximity to powerlines there will be occasional interference due to limb or entire tree failure. High winds and other loads combined with internal trunk defects may result in power outages and reduced revenue. While external defects can be easily observed, internal defects or cavities are harder to detect visually and require invasive methods. Sonic tomography is a relatively new technology that utilizes sound waves to detect internal cavities and defects in trees. This article discusses the technology and presents case studies.

Sonic Tomography for the Utility Industry

A.D. Ali, Sarah Ruark, and Chris Fields-Johnson

Keywords: Evaluation, Maintenance, Power Disruptions, Sonic Tomography, Tree Defects.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Trees growing near powerlines occasionally cause interference and reduce supply reliability. When a tree falls and damages a line, it not only causes inconvenience to users, but it may start a fire that can spread and result in loss of lives, destruction of property, and increased liability to the power company. Losses to the U.S. economy from weather-related outages between 2003 and 2012 are estimated at $33 billion (White House 2013). Campbell (2012) estimated annual weather-related power losses at $20 billion to $55 billion. The ability to detect internal tree defects and prevent supply conflicts will result in better service to users and reduced liability to power companies through a proactive approach to risk management.

Sonic tomography (ST) is an advanced technology used to detect internal defects in trees which cannot be seen from the outside, without having to resort to invasive drilling. It produces a two-dimensional image (a tomogram) that can be interpreted to estimate the size of defects within the tree. The technology is used in Level 3 tree risk assessment to supplement other observable conditions. It also provides a more complete understanding of the risk associated with a tree along with better-informed options for mitigating risk.

Several studies have documented the use of ST in detecting wood decay fungi. Giuliana et. al. (2008) documented reduced sound velocity in sycamore when infected with *Kretzschmaria deusta* and *Trametes versicolor*. Ishaq et. al. (2014) showed that ST can detect basal rot in oil palms caused by *Ganoderma boninense* with a 96% accuracy. Karlinasari et. al. (2018) scanned 300 urban and public-space trees and found 80% with varying amounts of internal decay.

METHODS

Measurement Steps

Generating a tomogram image using ST begins with selecting exactly where on a tree to perform a scan. External visual observations, use of a sounding mallet, or previous resistance drilling are typically used to identify suspected defects or cavities. Sensors of the ST equipment must then be set in a two-dimensional plane, so the best place to start scanning will typically be at the suspected weakest point. If it is assumed that this is the section most likely to fail, then any calculated wood strength values from that site should give an idea of the minimum load required to cause tree failure at that site. A cavity or other defect can be scanned in multiple planes by moving the sensors and conducting additional scans as many times as necessary. When sensors are placed in a single plane, typically that plane will be perpendicular to the axis of the part of the tree being scanned, but the plane does not need to be level to the ground or even perpendicular to the tree part if there are reasons to set it up in another way.

Once a plane is selected for scanning, the next step is to set the sensors. Sensors are attached to nails driven into the tree just deep enough to make secure contact with wood beneath the bark. Next, the geometry of the tree around the perimeter of the plane is measured and recorded. If the section is round, then measuring the circumference will suffice. If it is irregular, then a caliper is used to measure the geometry. Computer software then maps the position of each measuring point and calculates the precise distances from each point to all the others. The distances measured are used as part of the calculation to determine how fast sound waves are traveling through the tree.

To generate sound waves, the operator gently strikes a transmitting sensor on one of the measuring points several times with a hammer (either electronic or standard depending on which model is being used). When struck, the transmitting sensor starts a clock in the software which times how long it takes for the sound wave from the transmitting sensor to arrive at receiving sensors placed on all other measuring points. Using these times along with previously measured distances between transmitting and receiving sensors, the speed of sound waves is calculated and recorded by the software. These velocities are then used to produce an image that can be analyzed by the assessor.

Interpretation of Images

Sound wood has a high density and elasticity which allows sound waves to move quickly compared to decayed wood, where sound waves travel more slowly. With cavities, sound waves must travel a longer distance around the cavity rather than directly through the tree. For a single scan, the speed of sound waves generated and received at each point within the plane is mapped and color-coded. Areas of slower travel, interpreted to represent cavities or decay, are assigned certain colors in the image, while areas of faster travel are assigned other colors and interpreted to be higher density.

It's important to remember that the absolute velocity of sound waves moving through a piece of wood depends on other variables such as tree species, wood moisture content, and the temperature of the wood. Therefore, absolute velocities recorded in different trees are not comparable, or even velocities recorded in the same tree on different days. There are some species-specific considerations learned by experience. Palms, for instance, hold large amounts of water in the center of their stems which will cause them to appear to have large central cavities even if they are in fact sound. One other word of caution: ST is not accurate on frozen wood, so it should not be performed during winter in cold regions.

Although so far, we have been thinking about sound waves moving in straight lines between different measuring points in a single two-dimensional plane, the actual movement of sound through wood is more complex. Typically, sound waves move fastest in a longitudinal direction up and down the tree, or lengthwise down a section of wood. This property of sound travel through wood usually does not affect interpretation of images because only the sound traveling in a flat plane across the tree part is measured. The second fastest rate of travel is across the two-dimensional plane, straight through the center of the tree part from one side to the other. However, sound waves also move tangentially around the wood following the growth rings, and this is the slowest rate of travel. This slower tangential movement through wood can cause anomalies in tomograms, such as the cogwheel effect where it appears that there are regular decay pockets around the circumference between each measuring point. Software can correct for this problem and produce an image which more accurately represents the condition of the wood.

Assessing Risk

The goal of interpreting images generated by ST is ultimately to assist in assigning a risk of failure rating to the scanned section of the tree. Once an image is generated, further calculations can be made to estimate the relative strength of remaining sound wood in the scanned plane. Estimated percent loss of wood strength at that point can be compared to the expected gravitational and wind loads on that point to predict the relative likelihood of failure.

Several authors have presented formulas and methods to determine strength loss. Burcham et. al. (2019) developed the Z_{loss} application based on 51 scans of trees from 3 species. The application provides an estimate of percent reduction in section modulus which correlates with strength loss. Kane (2014) developed a mechanistic model of the failure of open grown red oak trees. Ciftci et. al. (2014) modeled varying decay in tree cross sections by considering bending theory to estimate moment capacity loss.

Strength loss calculations are done by using ST image to measure thickness and position of sound wood in comparison to the overall diameter of the cross section of wood. Some degree of experience and judgement will always be required to decide which areas of the image indicate decay or a cavity that would be associated with strength loss. Resistance drilling at key points may be used to verify the boundary between solid and decayed wood, or to verify the size and location of other features that could affect the structural integrity of the tree, such as cracks. Once it is decided which areas will be considered sound wood, measurements of the areas on the image can be taken either manually or by using computer software. Generally, the larger a cavity is in proportion to the overall tree section, and the more offset it is from the center, the greater the loss in wood strength at that location.

Translating percent strength loss into a relative likelihood of failure requires more observation, experience, and judgment. The four categories of likelihood of failure are Improbable, Possible, Probable, and Imminent. Based on the strength loss, the anticipated wind loads on that part of the tree, and the estimated mass of the tree above the defect site, a category is chosen. If large loads are anticipated, then it takes less strength loss to arrive at a higher risk rating. If loads can be reduced through pruning, cabling and bracing, or other methods, then contingent risk ratings can be assigned for the proposed options.

Finally, independent observations must be made of the likelihood of impact and the consequences of failure to arrive at a final risk rating for the tree as-is, and under different options. Although ST can play a key role in helping estimate the size, shape, and position of an area of decay or cavity within a tree, there are still several steps where supplemental information from other observations is required. In this way, ST fits in as a Level 3 tool to supplement the overall tree risk assessment process and to proactively mitigate conflicts with powerlines.

Currently there are three types of equipment on the market: PiCUS3 (Argus Electronics, Germany, *www.argus-electronic.de*), Arborsonic (Fakopp Industries, Hungary, *www.fakopp.com*), and Arbotom (Rinntech, Germany, *www.rinntech.info*). The following case studies show results of ST scans using two types of equipment: PiCUS3 and Arborsonic.

CASE STUDIES

Case #1

Mature Live Oak, Quercus virginiana, on a Substation Construction Site in Florida

The tree has multiple scaffold limbs, some with co-dominant stems. The overall height was 30 m (90 ft), crown spread 38 m (115 ft), and diameter at breast height (DBH) 119 cm (47 in). Three scans were conducted using PiCUS3 as follows: main trunk at 165 cm (65 in) above grade, co-dominant stem 1 (scan 2) at 178 cm (70 in) above union, and co-dominant stem 2 (scan 3) at 211 cm (83 in) above union (Figure 1).

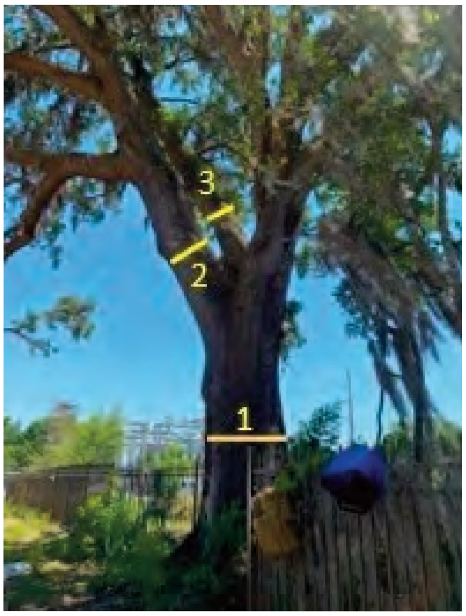

Figure 1. Mature live oak on a substation site in Florida with lines indicating locations of scans

Scan 1

Main Trunk results are shown in Figure 2. The brown color indicates fast sound speeds implying sound wood. A small amount of decay was found in the northwest quadrant of the trunk. Estimated percent strength loss (SL) is 36%, which does not pose an immediate risk.

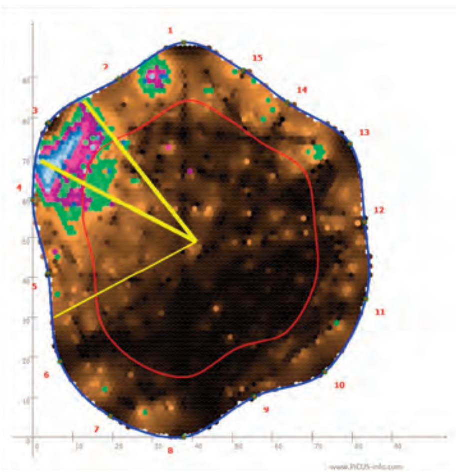

Figure 2. Scan of main trunk with a small amount of decay in the northwest quadrant

Scan 2

Co-dominant stem 1 results are shown in Figure 3. The tomogram indicates that decay is widespread and there is minimal amount of solid wood throughout the cross-section, in particular the outer edges resulting in a 96% estimated strength loss. Due to loads on this stem, risk of failure is high, and consequences would be damage to the surrounding fence enclosure, with possible risk to new substation construction area. Removal of this leader was recommended to mitigate risk.

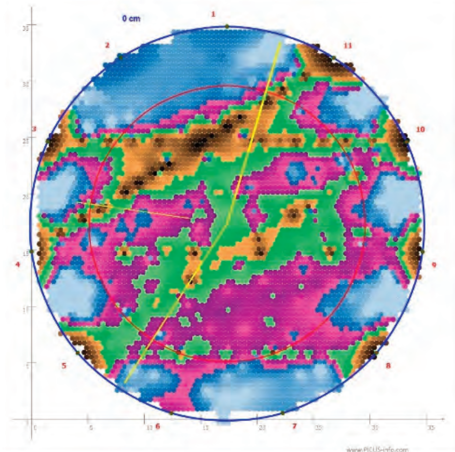

Figure 3. Scan of co-dominant stem 1 showing extensive decay. Estimated SL is 96%.

Scan 3

Co-dominant stem 2 results are shown in Figure 4. The tomogram indicates there are large areas of decay in the cross-section located on the west and east sections of the stem, where prevailing winds normally occur at this location. The estimated strength loss was 92%. There is a high risk of failure, with a moderate risk of consequences due to location of stem. Removal of this stem was recommended.

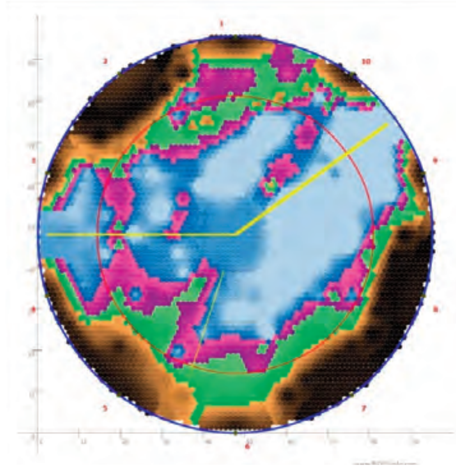

Figure 4. Scan of co-dominant stem 2 showing extensive decay. Estimated SL is 92%.

Case #2

Mature Sabal (Cabbage) Palm, Sabal Palmetto, in South Florida

The tree is growing in proximity to a service drop (Figure 5). Property owner was concerned about interference with the line. The overall height was 7 m (20 ft) and the crown spread 2.7 m (8 ft). A scan was conducted at 137 cm (54 in) above grade using Arborsonic equipment (Figure 6). No external evidence of decay was noted.

Figure 5. Sabal palm growing in vicinity of a service drop

Figure 6. Scan with Arborsonic equipment at 54″ above grade

No decay was detected in that particular scan. As discussed above, palm trunks tend to have softer, moist tissue in the center. The red and blue areas in Figure 7 indicate slower sound speed which is a result of the trunk anatomy.

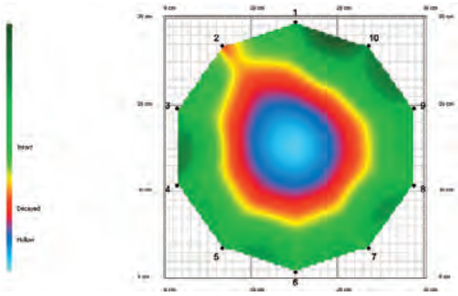

Figure 7. Scan of a Sabal palm showing slower sound speed in center due to softer tissue typically found in palm trunks

Case #3

Northern Red Oak (Quercus rubra) in New York

The tree had visible cavities and is in a heavily trafficked area (Figure 8). DBH is 66 cm (26 in). A scan was conducted at 1.3 m (4 ft) above grade using PiCUS3 equipment.

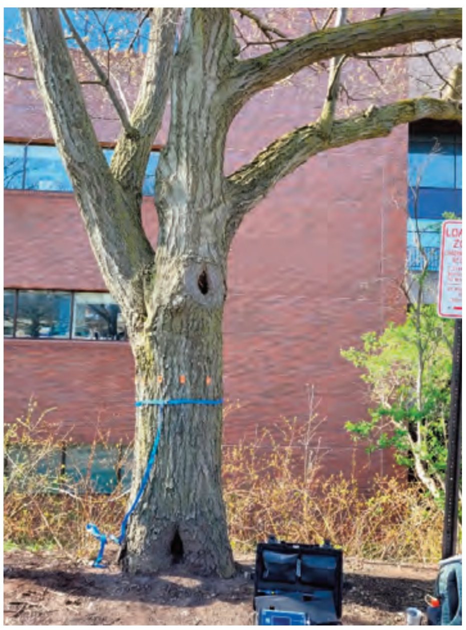

Figure 8. Northern red oak with two visible cavities

The results of the scan are shown in Figure 9. The tomogram indicates there is a large area of decay in the cross-section located on the northwestern half of the stem, which corresponds to the open wound associated with a prior stem removal visible on this side of the tree. Estimated strength loss was 90% at the location of the scan. There is a high risk of failure, and removal of this tree was recommended.

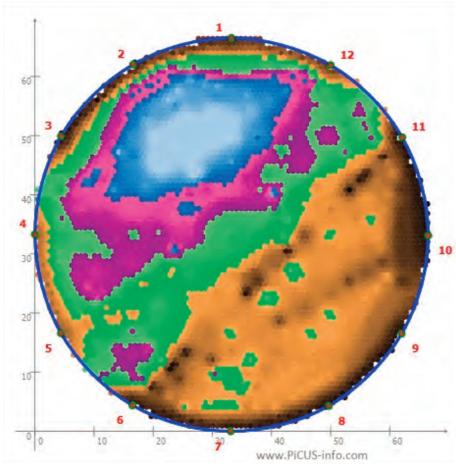

Figure 9. Scan with PiCUS3 equipment at 4 feet above grade

Case #4

Shumard Oak (Quercus shumardii) in Texas

The tree had obvious damage to the structural roots and is in a heavily trafficked area (Figure 10). A scan was conducted above the damaged roots at 1.3 m (4 ft) above grade using PiCUS3 equipment.

Figure 10. Shumard oak with extensive root decay

The results of the scan are shown in Figure 11. The tomogram indicates there is a large area of decay in the southwest portion of the stem, which is just above the most damaged root areas shown in Figure 10. Estimated strength loss was 50%. There is a moderate risk of failure at this scan height, with a severe risk of consequences due to location of stem. Removal of this tree was recommended.

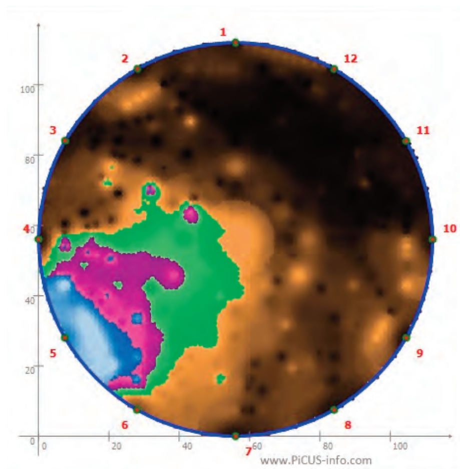

Figure 11. Scan with PiCUS3 equipment at 4 feet above grade

Case #5

White Oak (Q. alba) Located in the Mid-Atlantic region

Visible decay throughout one co-dominant stem and sounded hollow with a mallet. Estimated strength loss was 95% (Figures 12 and 13).

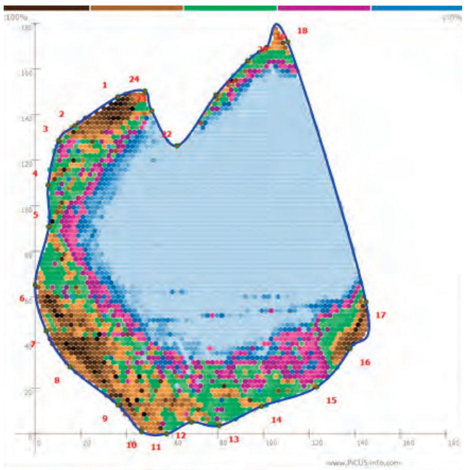

Figure 12 and 13. White oak with visible decay in one co-dominant stem

Case #6

Northern Red Oak, (Q. rubra), Located in the Mid-Atlantic region

Numerous wood decay conks are visible at the base. Estimated strength loss was 96% (Figures 15 and 16).

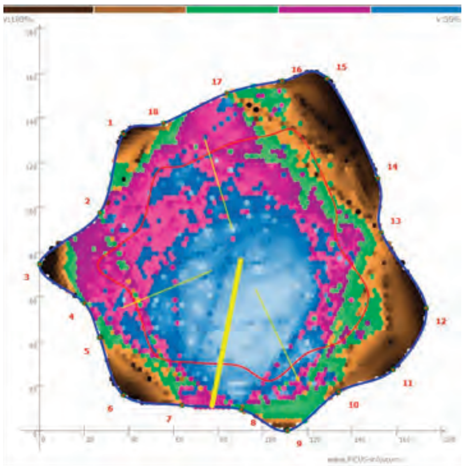

Figure 15 and 16. Northern Red oak with numerous wood decay conks at the base and corresponding tomogram

CONCLUSION

Sonic tomography is an important tool in Tree Risk Assessment. It provides information on structural stability and strength loss when conducting advanced Level 3 assessments. It also provides insight into internal defects which may not be seen with the naked eye. Implementing this technology for ROW Tree Risk Assessment will likely result in preserving trees that do not need removal and removing trees that may cause potential conflicts with powerlines.

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13th International Symposium

Environmental Concerns in Rights-of-Way Management

PART X

Vegetation Management

Annotated Bibliography of Articles, Books, and Research Papers Related to Rights-of-Way Vegetation Management—1950s to Present

Thomas E. Sullivan, Philip M. Charlton, and John W. Goodfellow

Vegetation management has been practiced by rights-of-way (ROW) managers (primarily on electric transmission ROW) since the early twentieth century. Early use of physical control methods, including mechanized and manual cutting of incompatible vegetation, gradually gave way to herbicide-based programs beginning in the early 1950s. Research on the impacts of herbicide use on ROW began in earnest in the 1950s and continues to the present. Impacts to flora, fauna, and human health grew out of general concerns related to pesticides (including herbicides) in the early days of the modern environmental movement. Rachel Carson's *Silent Spring* helped give rise to this movement. Rachel Carson and Frank Egler were among the first to introduce the concept that selective use of herbicides and establishment of a compatible natural plant community can resist invasion by trees. This biological control of incompatible vegetation has been demonstrated through decades of practice and research. Research has informed improved practices over seven plus decades and led to the establishment of integrated vegetation management (IVM) as an industry best management practice. The authors present an annotated bibliography of articles, books, and research that we believe provide the scientific and economic foundation for IVM and can be a resource for current practitioners of ROW vegetation management.

Keywords:
Compatible/Incompatible Species, Economic Sustainability, Environmental Impacts, Herbicide Use, Integrated Vegetation Management (IVM), Invasive Species, Rare/Threatened/Endangered Species, Stewardship, Stewardship Accreditation, Vegetation Management, Wetland Impacts, Wildlife Habitat.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION:

Vegetation management has been practiced by rights-of-way (ROW) managers (primarily on electric transmission ROW) since the early twentieth century. Early use of physical control methods, including mechanized and manual cutting of incompatible vegetation, gradually gave way to herbicide-based programs beginning in the early 1950s. Research on the impacts of herbicide use on ROW began in earnest in the 1950s and continues to the present. Impacts to flora, fauna, and human health grew out of general concerns related to pesticides (including herbicides) in the early days of the modern environmental movement. Rachel Carson's *Silent Spring* helped give rise to this movement. Rachel Carson and Frank Egler were among the first to introduce the concept that selective use of herbicides and establishment of a compatible natural plant community can resist invasion by trees. This biological control of incompatible vegetation has been demonstrated through decades of practice and research. Research has informed improved practices over seven plus decades and led to the establishment of integrated vegetation management (IVM) as an industry best management practice. The authors present an annotated bibliography of articles, books, and research that we believe provide the scientific and economic foundation for IVM and can be a resource for current practitioners of ROW vegetation management.

Our purpose was two-fold: (1) to provide a resource to practitioners and (2) to educate vegetation managers on what IVM is and what it isn't. Various publications, such as the UAA *Newsline*, show that vegetation managers are doing great work in the field and are passionate about their work and environmental stewardship. However, the years of involvement with the Right-of-Way Stewardship program and other consulting show that many vegetation managers talk IVM but cannot articulate a definition of IVM, nor do they understand that it is a system, and cherry-picking certain elements of IVM do not add up to IVM.

The bibliography focuses on the environmental and economic case for IVM. It does not include other bodies of work relevant to herbicide use, such as efficacy, methods of application, mode of action, environmental fate, or public health and safety. The paper also does not include papers on routing of ROW or construction impacts and restoration following construction. Each of these subject areas have extensive literature available.

STANDARDS

- American National Standards Institute, Inc. 2018. A300 (Part 7) Tree, Shrub, and Other Woody Plant Management – Standard Practices (Integrated Vegetation Management). Tree Care Industry Association, Inc., Londonderry, NH.

American National Standards Institute, Inc. (ANSI) standards have rigorous requirements for due process, consensus, and other criteria for approval that must be met by the standards developer. The standard drafting committee was comprised of a broad array of industry, professional society, and government representatives. Use of ANSI standards is voluntary but they are widely viewed and accepted as standards for good practice.

- Miller, R.H. 2021. Best Management Practices - Integrated Vegetation Management Third Edition. International Society of Arboriculture. Atlanta, GA.

The International Society of Arboriculture best management practices (BMP) is a companion document to the American National Standards Institute (ANSI) A300 Part 7 standards for IVM. The publication sets out BMPs for implementing each element of IVM: Communication with Internal and External Stakeholders; Planning and Implementation; Set Objectives, Evaluate the Site, Define Action Thresholds, Evaluate and Select Control Methods, Implement IVM, and Monitor Treatment Effectiveness and Environmental Protection.

- Right-of-Way Stewardship Council: Accreditation Requirements. 2016. Dovetail Partners, Minneapolis, MN.

These requirements and associated accreditation were developed by the Right-of-Way Stewardship Council (ROWSC). Members of the ROWSC include the electric and gas industries, IVM contractors, environmental NGOs, and the public. The accreditation requirements define IVM principles and practices that represent contemporary IVM programs.

BIBLIOGRAPHY

1. Abrahamson, L.P., C.A. Nowak, P.M. Charlton, and P.G. Snyder. 1993. "Cost effectiveness of Herbicide and Non-herbicide Vegetation Management Methods for Electric Utility Rights-of-Way in the Northeast: State-of-the-Art Review." In Proceedings of the 5th International Symposium on Environmental Concerns in Rights-of-Way Management, 1993, Montreal, Quebec, Canada, edited by Doucet, G.J., C. Seguin, and M. Giguere, pp. 27–43.

A multiphase study was conducted to assess available information on herbicide and non-herbicide management methods for electric utility ROW. Goals of the study included: (1) review of existing literature, (2) examination of results on areas where landowner agreements preclude use of herbicides, and (3) evaluation of vegetation management programs that do not use herbicides. The literature review included 188 papers mostly from the 1980s and early 1990s. Direct costs, indirect costs, and effectiveness of vegetation management methods were reviewed and evaluated. Site visits were made to ROWs in New York, Rhode Island, New Jersey, Vermont, and Pennsylvania to evaluate incompatible stem densities on non-herbicide treated sites. Densities of up to 30,000 stems per acre were reported. Direct costs of treatments are reported from four studies. Mechanical treatment costs for the region ranged from $308–$648 per acre. Herbicide treatment costs ranged from $196–$260 per acre. Indirect costs/impacts of mechanical vs. herbicide based programs were also evaluated. Note: the term IVM is never mentioned in this "state-of-the-art" paper—dated in 1993.

2. Ballard, B.D., H.L. Whittier, and C.A. Nowak. 2004. "Northeastern Shrub and Short Tree Identification: A Guide for Right-of-Way Vegetation Management." Research Foundation of the State University of Albany, New York, for and in Conjunction with the SUNY College of Environmental Science and Forestry. Syracuse, New York, USA.

This guide to shrub identification contains a key for identification of the more than 100 shrubs commonly found on electric utility ROW in the northeast U.S. The guide also presents information of ROW vegetation management and border zone/wire zone management. It is included in this bibliography as an example of good practice for education and training of IVM program managers and field workers.

3. Ballard, B.D., C.A. Nowak, L.P. Abrahamson, E.F. Neuhauser, and K.F. Finch. 2002. "Integrated Vegetation Management on Electrical Transmission Rights-of-Way Using Herbicides: Treatment Effects Over Time." In Proceedings of the 7th International Symposium on Environmental Concerns in Rights-of-Way Management, 2000, Calgary, Alberta, Canada, edited by Goodrich-Mahoney, J.W., D.F. Mutrie, and C.A. Guild, pp. 47–55. NY: Elsevier Science, Ltd.

Authors describe an ecological approach to managing vegetation on ROWs, integrated vegetation management, to promote desirable/compatible, stable, low-growing communities that will resist invasion by undesirable, tall-growing tree species. Vegetation management studies consistent with IVM took place on a 25-kilometer section of Niagara Mohawk Power Corporation's Volney-Marcy transmission ROW in Upstate New York. Stem density of desirable and undesirable woody plants were followed over an 11-year period. Two maintenance cycles using herbicides were carried out in this time period. It was hypothesized that stem density of undesirable woody plants would continue to decrease over time and stem density of desirable species would increase or remain the same over time, thus, moving towards a more stable community of woody, desirable species. Undesirable species densities were maintained and desirable densities increased over 11 years using an IVM approach. A stable community of woody, desirable species has not been reached and may need another 10–20 years before it develops on the powerline. Shrub abundance needs to be increased to attain maintenance levels.

4. Bonneau, J., and S. Mucha. 2019. "Climate Change Adaptation Strategies in VM." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 371–380. Utility Arborist Association.

The authors recognize ROWs as containing the most connected landscapes in the U.S. and many other countries around the world. These connected lands are thought to have an important role in the future movement of habitats and species as the climate warms. The authors present research conducted to determine the availability of adaptation strategies for managing vegetation on ROWs in the face of climate change, and present the outcomes of an evaluation of general adaptation strategies for their compatibility with ROW management. The research and evaluation seek to inspire modifications in IVM practices on ROWs to include actions to preserve biodiversity and create resilient ecological communities.

5. Bramble, W.C., W.R. Byrnes, and R.J. Hutnik. 1985. "Effects of a Special Technique for Right-of-Way Maintenance on Deer Habitat." Journal of Arboriculture 11(9): 278–284.

White-tailed deer habitat and use were evaluated on an electric transmission ROW before and after five different herbicide treatments and hand cutting. Evaluations also were made in the adjoining forest. The technique used for all treatments provided for division of the ROW into a central wire zone and two border zones (WZ/BZ). Selective treatment of only tall-growing trees was carried out on the border zones, as contrasted with complete treatment of all trees and tall shrubs in the wire zone. In addition, herbicide in a pellet formulation was applied to the wire zone to produce a herb-grass plant cover. Deer presence increased on all ROW treatment areas from 1982 to 1984. Deer browsed both woody and herbaceous vegetation comparably on the ROW and in the forest.

6. Bramble, W.C., and W.R. Byrnes. 1992. "Small Mammals in Plant Cover Types on an Electric Transmission Right-of-Way." Journal of Arboriculture 18(6): 316–321.

This paper presents results of a study on the abundance and diversity of small mammals in common plant cover types on an electric transmission ROW in Central Pennsylvania. A diverse, small mammal population composed of seven species was captured on the ROW. This diversity was in sharp contrast to the total of two species captured in adjoining undisturbed forest. The authors conclude that ROW act as a large forest opening which not only provided habitat conditions suitable for the forest species of small mammals, but also for numerous other non-forest species.

7. Bramble, W.C., R.H. Yahner, and W.R. Byrnes. 1994. "Nesting of breeding birds on an electric utility line right-of-way." Journal of Arboriculture 20(2): 124–129.

A nesting study was carried out on an electric utility ROW in Central Pennsylvania. Active nests of 13 species were found in the ROW in both hand-cut and herbicide treatment ROW areas. Average nesting success for all species was 68%. Shrubs were the most commonly used nesting cover. Grass and forb cover was also used for nesting. Nesting success in grass and forb cover was 100%.

8. Bramble, W.C., and W.R. Byrnes. 1983. "Thirty Years of Research on Developments of Plant Cover on an Electric Transmission Right-of-Way." Journal of Arboriculture 9(3): 67–74.

The authors present results of thirty years of research on an electric transmission ROW in Central Pennsylvania. Vegetation was maintained with herbicide applications and compared to mechanical treatments. The authors present a general discussion of vegetation regrowth following initial clearing. In this case, oak-hickory forest type was cleared. If untreated, a complex secondary succession will take place following clearing that will tend toward a return to climax forest. There is a small initial reduction in total plant cover following clearing, which will be rapidly made up by the spread of plants common in the forest. Species common in forest gaps and clearings will then increase in the ROW. This plant community is not resistant to reinvasion by trees, mostly from the continuous supply of tree seeds. To produce a low, dense cover that will resist invasion by trees, species that spread vegetatively should be encouraged by appropriate herbicide applications. Reductions in tree species and conversion to low-growing plants was documented over the 30 years of the project to date. Constant use of the ROW by wildlife has been observed over the 30 years of research. Wildlife include white-tailed deer, ruffed grouse, wild turkey, cottontail rabbits, woodchuck, gray squirrel, skunk, opossum, and white-footed mice. Amphibians and reptiles were also observed.

9. Bramble, W.C., R.H. Yahner, and W.R. Byrnes. 1999. "Effect of Herbicide Maintenance of an Electric Transmission Right-of-Way on Butterfly Populations." Journal of Arboriculture 25(6): 302–307.

The authors present results of a study carried out in 1997 of the butterfly populations on the ROW in the Allegheny region of Central Pennsylvania. The objective was to determine if herbicide applications produced an adverse impact on butterfly populations. Results indicate that herbicide applications for vegetation maintenance did not have adverse effects on butterfly species and number of individuals compared to hand-cutting without herbicides. The number of species counted in hand-cut areas was 21. Species counts in herbicide-treated areas ranged from 41 to 63, depending on the treatment type. The presence of flowering plant species was a highly important factor in evaluation of treatments on butterfly populations. Forty flowering species were found in the hand-cut areas. Flowering species in herbicide-treated areas ranged from 55 to 139, depending on the treatment type.

10. Carson, R.L. 1962. Silent Spring. New York, NY: Fawcett World Library, 73–75 pp.

Rachel Carson presents a discussion on selective spraying as a method to eliminate plants tall enough to interfere with electric wires on ROW. The object of selective spraying is to eliminate tall, woody plants by direct treatment and to preserve all other vegetation, such as shrubs, ferns, and wildflowers. There are references to Frank Egler's "Brush Control Recommendations for Rights-of-Way" and introduces the concept of using shrub plant community's natural ability to resist invasion by trees. The context of the discussion is to present sound methods of pesticide application versus the indiscriminate and destructive use of pesticides presented elsewhere in the book.

11. Chick, T.A. 2016. "Resistance Variability of Right-of-Way Ground Cover Species." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 115–125. Utility Arborist Association.

The author explores allelopathy as an element of biological control to resist tree invasion on IVM-managed ROWs. Research by Niering and Goodwin (1974) and Bramble et al. (1990) identified some shrub and herbaceous groundcover species and their ability to provide biological control. These studies suggested that competition for light was the primary driver in slowing plant succession. However, researchers in ecology, forestry, and agriculture also recognized allelopathy as an interference component and have noted additional species that may provide invasion resistance. The paper references lists of plant species with a range of resistance to tree invasion published in other papers.

12. Confer, J.L. 1999. The Diversity and Abundance of Birds Nesting Under Power Lines of New England Electric System Companies' and Eastern Utilities Associates. Study report.

This study conducted by New England Electric System and Eastern Utilities (now National Grid companies) assesses the effect of vegetation in ROWs on bird communities. Shrubland birds are in decline in the Northeast. Rights-of-way provide an increasing important source of shrub habitat for this avian guild. Birds were counted at 258 sites. A total of 77 species were detected. The Eastern Towhee, Prairie Warbler, and Field Sparrow were especially common on ROW in comparison to statewide data, Massachusetts North American Breeding Bird Survey data.

13. Confer, J.L. 2000. Density, Diversity, and Nesting Success of Birds on Managed Shrublands of Northeastern United States: The Importance of Utility Rights-of-Way. Study Report.

Building on the data from Confer (1999), this study looked at nesting success of open cup nesting birds on electric utility ROW in New York, Massachusetts, and Maine. Most of the surveyed ROW were shrublands managed using selective application of herbicides. The study concluded that ROW would support the greatest diversity of shrubland birds if management created some areas dominated by herbs and other areas dominated by shrubs. Nesting success was measured within the ROW, at the forest edge, and within the forest 20 meters from the ROW. Nesting success exceeded 50% (56% for the total sample) in all three areas. This level of nesting success compares favorably to 49% in 35 studies of open cup nests. Study also focused on habitat and nesting success of Golden-winged Warbler. The study noted low level parasitism by Brown-headed Cowbirds in Golden-winged nests, though these nests also successfully fledged Golden-winged Warblers.

14. Confer, J.L. 2002. "Vegetative Structure and Shrubland Birds in Rights-of-Way Management." In Proceedings of the 7th International Symposium on Environmental Concerns in Rights-of-Way Management, 2000, Calgary, Alberta, Canada, edited by Goodrich-Mahoney, J.W., D.F. Mutrie, and C.A. Guild, pp. 373–381. NY: Elsevier Science, Ltd.

The authors present findings from several studies (Confer 1999 and 2000) on point counts of birds in ROW in the Northeastern U.S. Bird density was high with a mean of 14.8 individuals and 12.2 species per point count for birds nesting or foraging in the ROW. Federal surveys show that shrubland birds are declining throughout the Northeastern U.S. Thus, ROW support an abundance of shrubland birds that are declining elsewhere, probably because of the succession of shrublands into forests throughout most of the Northeastern U.S. Vegetation management by selective herbicide sustained more individuals and individual species than cutting. Most shrubland species showed a habitat preference for about 50% shrub cover.

15. Confer, J.L., T. Hauck, M.-E. Silvia, and V. Frary. 2008. "Avian shrubland management and shrubland nesting success." In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich-Mahoney, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 407–412. Washington, D.C.: Electric Power Research Institute.

The authors quantify that electric utilities maintain more acreage of managed shrublands on powerline ROW than is provided by all other sources combined in the Eastern U.S. The study quantified increases in the number of individual birds (21%) and bird species (27%) following thinning shrub density of electric utility ROW in Sterling Forest State Park in New York. Reduction in shrub density was accomplished by mechanical cutting and herbicide treatment of stumps.

16. Donohue, S., M. Tyrrell, and T. Doyle. 2012. "Important Considerations for Utility Right-of-Way Selection, Routing, and Vernal Pool Management." In Proceedings of the 9th International Symposium on Environmental Concerns in Rights-of-Way Management, 2009, Portland, Oregon, USA, edited by Evans, J.M., J.W. Goodrich-Mahoney, D. Mutrie, and J. Reineman, pp. 309–318. Champaign, IL: International Society of Arboriculture.

The authors look at vernal pools on existing and adjacent newly constructed ROW in the Northeast. Twenty-eight vernal pools were documented based on regulatory biological and geomorphologic criteria. Vernal pool wildlife and amphibian egg masses were abundant in pools within and adjacent to ROW. Vernal pool habitat characteristics were maintained in existing ROW corridors. The conclusion was that functioning vernal pools can exist in utility corridors in the Northeast.

17. Duncan, C.P., A. Finamore, A. Slayton, and K. Marcoux. 2012. "Vernal Pool Occurrence and Species Distribution within Transmission Right-of-Ways in Maine." Abstract accepted for the 10th Symposium on Environmental Concerns in Right-of-Way Management, Utility Arborist Association. 2012, Phoenix, Arizona, USA.

This paper examined vernal pool efficacy, including species occurrence and distribution in both ROW and non-ROW conditions, and identified the potential effects of ROWs on vernal pools. Breeding activity in vernal pools within and near over 600 linear miles of transmission lines was identified and evaluated. Data were collected and analyzed for 1,834 vernal pools, all of which contained either wood frog or spotted salamander egg masses, or both. Results indicate that ROW conditions do not prohibit the presence of breeding vernal pool species. Rights-of-way creation and maintenance should not be considered incompatible with vernal pool habitat preservation.

18. Durand, J., B. Windmiller, and F.P. Richards. 2008. "Vernal Pool Identification – Current and Future Permitting Implications." In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 479–492. NY: Elsevier Science, Ltd.

The authors present a discussion on the evolving regulatory framework for vernal pool protection. They point out the habitat value and increasing concern of environmental regulators. The paper does not review ROW construction or maintenance impacts or mitigation. This paper provides an excellent example of how environmental regulations evolve and advises VM managers and project developers to be aware of new issues to address in permitting.

19. Egler, F.E. 1953. Vegetation Management for Roadside and Rights-of-Way, pp. 299–322. In Smithsonian Institution 1953 Annual Report. Smithsonian Institution, Washington, D.C.

This often-cited paper is one of the earliest using and defining the term "vegetation management." Dr. Egler was Chairman of the Committee for Chemical Brush Control Recommendations for Right-of-Ways at the American Museum of Natural History. The paper discusses all types of ROW we refer to today (roadside, railroad, gas pipeline, telephone, and electric utility) and familiar application techniques (basal and foliar). He also discusses impacts to wildlife and aesthetics. Most importantly the paper describes the concepts of "relay floristics" and "initial floristic composition." All referenced plant communities and impacts of use of herbicides are based in the Northeast U.S. Herbicides referenced are 2,4,5 T, 2,4 D and ammonium sulfate. Dr. Egler refers to "research and development areas" established by the New England Power Company in Massachusetts, the Niagara Mohawk Power Corporation in New York, Pennsylvania Power and Light in Pennsylvania, and others. In his summary he stated, "Basal herbicide application results in a shrubland composed of shrubs, forbs, and grass. Such vegetation resists tree seedling invasion."

20. Egler, F.E. 1975. The Plight of the Right-of-Way Domain. Mount Kisco, NY: Futura Media Services.

The subtitle for this book is "Victim of Vandalism." This is a two-volume book on ROW vegetation management. Dr. Egler was a Professor of Botany and Ecology at Connecticut College. The preface to the book was written by William Neiring (Neiring 1958 and 1974). The author details the history of ROW vegetation management (Egler 1953) and proposes a better way forward based on an ecological approach, as opposed to technology-based warfare with unwanted plants/trees. The concept of "floristic succession" is presented as an alternative to traditional plant succession. The author presents requisite elements for a sound vegetation management program: knowledge of the flora, knowledge of vegetation types, long-term planning, conversion of original species, maintenance of low stable vegetation, rights of landowners, conservation organization (NGO) policies, qualifications for a vegetation manager, training for a vegetation manager, position of the vegetation manager in the organization, the environmental impact, cost-benefit analyses, and the vegetation management plan. The book contains quotations from Jonathan Swift and William Shakespeare. The book is dedicated to Rachel Carson and the "Coming Generation," that it may rectify the mistakes of this generation.

21. Electric Power Research Institute. 2000. Technical Report: 1000525. Right-of-Way Treatment Cycles: Update 2000. Palo Alto, CA: EPRI, and ESEERCO.

Authors are C.A. Nowak, B.D. Ballard, and P.M. Charlton. This is a re-publication and update of an ESEERCO report that evaluated cost and effectiveness of mechanical and chemical treatment methods on 18 ROWs across New York State. Seven treatment methods—hand cutting, mowing, cut stump, dormant basal, summer basal, selective ground foliar, and aerial—were evaluated. The study determined long-term costs, cycle length, density and height of capable trees, changes in incompatible vegetation, and the average annual cost among the treatment methods. It discusses the treatment effects on tree density, tree height, shrub cover, and herbaceous cover. Authors show that over a treatment cycle, herbicides had a greater effect in reducing stem density than hand cutting or mowing; tree height response was inconsistent; only cut stump resulted in substantial reduced height; and shrub cover increased after all herbicide treatment types. Herbaceous cover increased in response to mechanical and herbicide treatments. The overall conclusion: research and monitoring showed that selective application of herbicides is the best means to control incompatible tree species, increase desirable (compatible) plant species, maintain site integrity by reducing plant community and soil disturbance, and reduce treatment costs.

22. Electric Power Research Institute. 2002. Technical Update: 1005366. Wildlife and Integrated Vegetation Management on Electric Transmission Line Rights-of-Way. Palo Alto, CA: EPRI.

This report describes the component steps of an IVM system: (Step 1) Understanding pest and ecosystem dynamics; (Step 2) Setting management objectives and tolerance levels; (Step 3) Compiling treatment options; (Step 4) Accounting for economic and ecological effects of treatments; (Step 5) Site-specific implementation of treatments; and (Step 6) Adaptive management and monitoring. The report describes biological control via the persistent presence of desirable grass-forb-shrub communities as the core element of IVM.

23. Electric Power Research Institute 2003. Technical Report: 1005371. Landscape Fragmentation and Electric Transmission Corridor Siting and Management. Palo Alto, CA: EPRI.

Landscape fragmentation, especially forest fragmentation, is often an environmental issue during the siting of transmission ROW. However, little research has been undertaken to quantify possible effects. Landscapes are fragmented by many elements, including urbanization, forestry, agriculture, and the many elements of infrastructure that support the needs of society. It may be possible, through management, to mitigate the fragmenting effects of existing ROW or minimize fragmenting effects of planned ROW. Corridors have been traditionally thought of as connections from one habitat patch to another through a surrounding inhospitable landscape. The literature on corridors remains controversial. Generalizations about corridors and fragmentation are not useful, and specific habitats and species need to be considered when assessing impacts. This report provides a primer on landscape pattern analysis and a guide on using landscape metrics to assess changes in landscape patterns.

24. Electric Power Research Institute. 2004. Technical Report. Transforming Knowledge of Shrub Ecology and Management to Promote Integrated Vegetation Management on Powerline Corridors. Palo Alto, CA: EPRI.

The report draws upon long-term IVM research, primarily in the Northeast and New York State, to develop a framework and training materials for IVM. Training materials were used at a workshop at the SUNY College of Environmental Science and Forestry in September 2003. EPRI and SUNY have made the materials available for IVM training to anyone interested in IVM.

25. Electric Power Research Institute. 2012. Technical Report: 1025379. Cost-effectiveness of Different Herbicide and Non-Herbicide Alternatives for Treating Transmission Rights-of-Way Vegetation: An Illustrative Guide. Palo Alto. CA: EPRI.

The report is authored by C.A. Nowak. The report provides a cost-effectiveness definition, steps, and illustrations to guide application of cost-effectiveness, and provides a model application of cost-effectiveness analysis. It includes Appendix A, long-term cost-effectiveness of mechanical versus chemical treatment of powerline ROWs in New York State. The analysis used data from studies between 1975 and 1995. The Present Value of Cost calculated for mechanical and chemical treatments was $1,329 and $945, respectively. The author caveats about the study due to assumptions necessary to run the analysis, but concludes herbicides are the more cost-effective treatment compared to mowing.

26. Environmental Energy Alliance of New York (EEANY). 1990s. Applications of Integrated Pest Management to Electric Utility Rights-of-Way Vegetation Management in New York State.

The EEANY paper details the evolution of the term "IVM" as an applied form of integrated pest management (IPM) on electric utility ROWs in New York State. From available evidence and personal knowledge, this paper includes the first use of the term IVM. The paper identifies the essential elements of an IPM/IVM strategy: prevention, biological control, monitoring, assessment, and control measures (mechanical and herbicide treatments). Biological control is identified as a core element of IPM/IVM. Biological control on ROW is achieved by promoting establishment of low-growing, relatively stable plant communities. Full text of the EEANY Position Paper is included in: McLoughlin, K.T. (2002) *Integrated Vegetation Management – The Exploration of a Concept to Application.*

27. Environmental Consultants, Inc. (ECI). 1991. Determination of the Effectiveness of Herbicide Buffer Zones in Protecting Water Quality on New York State Powerline Rights-of-Way. Empire State Electric Energy Research Corporation (ESEERCO), Schenectady, New York. Report EP 89–44.

This report and research assessed the effectiveness of herbicide buffer zones to prevent deposition of herbicides into bodies of water and wetlands from herbicide applications in New York State. This research became the technical basis for establishing herbicide application buffer zones in utility vegetation management plans approved by utility and environmental regulators in New York State. More detailed results are presented in Norris and Charlton 1993.

28. Ferrandiz, L.S. 2008. "A Broad-Based, IVM Approach to Right-of-Way Management on Long Island, NY." In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 65–69. NY: Elsevier Science, Ltd.

The author examines social and environmental conditions influencing the application of integrated vegetation management on Long Island, New York. By evaluating soil conditions, property ownership, and population and land use, the Long Island Power Authority

selects and deploys various IVM methods. This broad-based IVM approach strives to balance cost, legal considerations, public acceptance, and environmental impacts.

29. Finch, K.E., and S.D. Shupe. 1997. "Nearly Two Decades of Integrated Vegetation Management on Electric Transmission Rights-of-Way." In Proceedings of the 6th International Symposium on Environmental Concerns in Rights-of-Way Management, 1997, New Orleans, Louisiana, USA, edited by Williams, J.R., J.W. Goodrich-Mahoney, J.R. Wisniewski, and J. Wisnewski, pp. 67–75. NY: Elsevier Science, Ltd.

This paper describes a gradual evolution of herbicide-based vegetation management from broadcast and helicopter-based application to selective use of herbicides within the context of IVM. Selective application within the context of IVM resulted in reduced herbicide usage rates from more than six gallons of concentrate per acre when helicopter spraying, to less than one gallon per acre over two decades. Integrated vegetation management methodology also provided reduced regulatory conflicts, greater public acceptance, enhanced wildlife habitat, improved aesthetics, reduced worker and public exposure to herbicides, and significant cost savings.

30. Frizzell, M. 2012. "Electric Transmission Right-of-Way Reclamation." In Proceedings of the 9th International Symposium on Environmental Concerns in Rights-of-Way Management, 2009, Portland, Oregon, USA, edited by Evans, J.M., J.W. Goodrich-Mahoney, D. Mutrie, and J. Reineman, pp. 465–468. Champaign, IL: International Society of Arboriculture.

This paper presents a study by the Sacramento Municipal Utility District (SMUD) and Pacific Gas and Electric (PG&E) that initiated a cooperative reclamation effort on transmission ROW that had become overgrown since construction in the early 1960s. In the last 10 years at the time of the study, the two utilities had worked together to manage this ROW. In its current state, the ROW required minimal vegetation management annually to maintain compliance and function. After an initial mastication and logging project, three different herbicide applications with various techniques and conditions were administered. The goal was to establish a low-growing, dynamic plant community that thrives well below the conductors and provides competition that suppresses tall and fast-growing species that once populated the ROW. The management techniques utilized have benefited the environment by creating plant species diversity, eliminating exotic invasive species, and providing a valuable fuel break between a fire-prone plant community and three local urban areas.

31. Garant, Y., J. Domingue, and F. Gauthier. 1997. "Effectiveness of Three Vegetation Control Methods in Establishing Compatible Plant Species in Powerline Rights-of-Way in Northeastern Quebec." In Proceedings of the 6th International Symposium on Environmental Concerns in Rights-of-Way Management, 1997, New Orleans, Louisiana, USA, edited by Williams, J.R., J.W. Goodrich-Mahoney, J.R. Wisniewski, and J. Wisnewski, pp. 77–81. NY: Elsevier Science, Ltd.

This study by Hydro-Quebec evaluated the efficiency of three control methods in establishing compatible vegetation, tested in Northeastern Quebec: (1) manual cut, (2) manual cut plus land application of Tordon 101 and TCA, and (3) aerial application of Tordon 101 and Silwet L-77. Sampling plots were randomly distributed in vegetation zones in which the density of incompatible stems were measured. The most efficient method in controlling incompatible woody stems was aerial spraying of Tordon 101. Only 2,900 stems/ha were measured in these spans. Stem density of incompatible species was intermediate (14,184 stems/ha) after a ground application of Tordon 101 and TCA. A high density of 73,000 stems/ha was observed in spans that were treated by mechanical cutting.

32. Goodfellow, J.W. 2012. "Creation of an Industry Best Management Practice for Adoption of a Closed Chain of Custody for Herbicide Use in the Utility Vegetation Management Industry." In Proceedings of the 9th International Symposium on Environmental Concerns in Rights-of-Way Management, 2009, Portland, Oregon, USA, edited by Evans, J.M., J.W. Goodrich-Mahoney, D. Mutrie, and J. Reineman, pp. 369–371. Champaign, IL: International Society of Arboriculture.

The author presents development of a best management practice (BMP) related to the supply chain and use of herbicides in the utility vegetation management industry. The project resulted in creation of an end-to-end strategy for managing herbicide chain of custody from manufacturer to custom blender, distributor, utility owner, and applicator. The BMP is intended to reduce the risk of potential mixing error, public and applicator exposure, and inappropriate disposal of wastes. Once established, the new BMP would be available for incorporation in vegetation management specifications throughout the utility industry. The author later developed and published the ISA Closed Chain of Custody for Herbicide in the UVM Industry.

33. Goodfellow, J.W. 2011. "ROW Steward Accreditation Program-Update." Utility Arborist Newsline 2(6): 28–30.

This article describes the background and opportunity to develop a voluntary, third party ROW vegetation management accreditation program.

The program standards are proposed to be based on ANSI A300, ISA Best Management Practices and EPRI Standards for Assessing Performance of IVM on ROWs. The program was modeled on other successful "green certification" programs developed by the Forest Stewardship Council and the Sustainable Forestry Initiative. The program, as of March 2012, was in the development stage under the sponsorship of the Utility Arborist Association and other industry organizations. The program was looking to identify an international nongovernmental environmental group to act as the accrediting institution.

34. Goodfellow, J.W., C.A. Nowak, and J.E Wagner. 2017 Vegetation Management Business Cost Benefit of Herbicide Use. Centre for Energy Advancement through Technological Innovation (CEATI), Montreal.

The authors present a business case for the practice of IVM on electric and gas ROW. The scope was limited to direct operational/maintenance cost. Two different vegetation management strategies were compared: IVM-based use of herbicides to control incompatible species and repeated mechanical treatment (cutting/mowing) without herbicides. An extensive literature review was conducted to develop models of changes in stocking of incompatible species over time and methods to conduct comparative economic analysis. Twenty-year vegetation maintenance prescriptions specific to three hypothetical case studies based on IVM and mechanical treatments were developed. In each case, the present value of the IVM treatment cost is approximately half of the cost of mechanical treatment. This project convincingly demonstrates that a vegetation management strategy based on the principles of IVM, including the use of herbicides, is less costly than a strategy that makes no use of herbicides but relies simply on repeated mechanical and manual cutting of incompatible trees within the ROW. These findings establish the foundation for a business case for the use of herbicides in the management of ROW vegetation.

35. Goodfellow, J.W. 2019. "Adapting the Principles of Integrated Pest Management to IVM on Electric Utility ROW." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2017, Denver, Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 361–364. Utility Arborist Association.

The author examines the significant revisions made to the ANSI A300 Part 7 standard for IVM which was completed in 2018. The changes were in part an effort to better harmonize the IVM standard with the principles of IPM. This included adaptation of the principles of Economic Injury Level (EIL) and Economic Threshold (ET) that are core to IPM and which correlate to Tolerance Level I (TL) and Action Threshold (AT) in IVM. The revised standard guides best management practice for maintaining utility ROW and other sites where the establishment and maintenance of early successional plant communities is an objective.

36. Goodfellow, J.W. 2019. "Establishing an Empirical Basis for Wire Zone Width on an Electric Transmission ROW." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 395–399. Utility Arborist Association.

Although not suitable in every situation, the wire zone/border zone (WZ/BZ) model has been recognized as an industry best management practice for decades. In practice, the adoption and application of the model have been inconsistent. The author provides practitioners with an understanding of factors that should be considered when adopting the WZ/BZ model, and specifically when defining the appropriate WZ width.

37. Goodfellow, J.W., C. Mahan, and P.M. Charlton. 2018. The Cost Efficiency of IVM: A Comparison of Vegetation Management Strategies for Utility Rights-of-Way. Report funded by the TREE Fund Utility Arborist Research Fund Grant #18-UARF-01.

This report establishes a business case for the practice of IVM on electric and gas transmission ROW. Economic analysis of IVM and non-IVM vegetation management strategies were based on least cost analysis and cost-effectiveness. The report concludes the present value of cost over a 20-year evaluation period are approximately half as much as controlling incompatible plant species without the use of herbicides. The report references three other studies showing 20- to 30-year cost savings from the use of herbicides in the range of 45% to 48%. The cost advantage of the IVM-based strategy was shown to provide additional significant benefits—less site disturbance, water quality, reduced incompatible tree density and height, wildlife habitat, bird species diversity and abundance, amphibian and reptile diversity and abundance, and butterfly species diversity and abundance. These benefits come at no extra costs. Lastly, the IVM strategy demonstrated lower risk (lower maximum height) between treatments.

38. Guerrero-Murphy, G., T. Follensbee, and J. Disorda. 2016. "Best Management Practices (BMPs) for Protection of Threatened and Endangered Species during Integrated Vegetation Management and Operations and Maintenance of Electric Transmission Lines in Vermont." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 345–352. Utility Arborist Association.

Vermont Electric Power Company (VELCO) developed BMPs to protect threatened and endangered species and promote general wildlife habitat and plant biodiversity values along electric transmission line corridors during IVM and line maintenance activities. Vermont Electric Power Company has invested considerably in IVM for many decades, resulting in ROW plant communities that include approximately 50 threatened and endangered plant and animal species. As a result, VELCO needed to protect these species, minimize regulatory compliance risks, address stakeholder concerns, and promote sound ecological and natural capital stewardship. The development of BMPs to Protect Threatened and Endangered Species was completed in October 2013. This effort required stakeholder engagement regarding vegetation management, operations and maintenance activities, and ecological resources; management planning; GIS analysis and management of sensitive species occurrence data; biological surveying to establish baseline data for threatened and endangered species; and evaluation and analysis of existing management techniques and practices. This paper presents an overview of the BMPs for Protection of Threatened and Endangered Species, including the processes for development and implementation, outcomes, and lessons learned.

39. Gwozdz, J., L. Payne, K. Gorski, and J. Kooser. 2016. “Herbicide Use Rates Over Four Treatment Cycles: Proof the IVM Tool is Working.” In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 127–133. Utility Arborist Association.

The New York Power Authority (NYPA) has data from the past four treatment cycles that show a decreasing trend in the herbicide use rates, indicating the establishment of a stable desirable plant community. New York Power Authority began its overall IVM program in 1998 utilizing a four-year treatment cycle and has been collecting these treatment data since. Looking specifically at the treatment methods and amounts of herbicides application rates for each year of the four-year cycle will show a decrease in usage, which will begin to level out at a very minimal rate over several treatment cycles. These data clearly show that the IVM program has proven effective. New York Power Authority has positive data indicating that as the program matures, the herbicide application rates become minimal. A mature IVM program which has developed an established desirable plant community can be maintained with a minimal rate of herbicide use.

40. Haggie, M.R., R.A. Johnstone, and H.A. Allen, Jr. 2008. “Tree, Shrub and Herb Succession and Five Years of Management Following the Establishment of a New Electric Transmission Right-of-Way through a Wooded Wetland.” In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 47–59. NY: Elsevier Science, Ltd.

The authors present results of a 5-year study of vegetation succession following construction of a new electric transmission ROW through a wooded wetland in Delaware. The herbaceous and shrub plant communities were examined following two clearing methods: (1) non-selective clear-cut of all woody plants, trees, and compatible shrubs, and (2) selective removal of targeted tall-growing trees. Integrated vegetation management techniques (selective application of herbicides) were carried out after the clearing. Results showed that IVM interventions stimulated vegetation succession from a mature wooded wetland to a low shrub/herbaceous plant community as successfully in the clear-cut as in the selective-cut areas. The total number of species reflects the loss of trees. Trees were replaced by a two-fold increase in the number of herbaceous species. Shrub species numbers remained relatively stable.

41. Haggie, M.R., H.A. Allen, and R.A. Johnstone. 2019. “Formulation of PSVI to Measure the Benefits of ROW Habitat Change for Pollinators (*Apis* and *Bombus* spp.) Following the Management Transition from Traditional Cutting-Mowing Practices to IVM.” In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinosa, A., and N.G. Pupa, pp. 557–569. Utility Arborist Association.

The authors present a Pollinator Site Value Index (PSVI) applicable to ROWs historically managed using mechanical methods, then transitioned to IVM. The PSVI developed by the authors provides an estimate of a botanical community’s value to pollinators. The vegetation variables assessed include: forbs, vines, and small shrubs; breeding and over-wintering habitat quality; nectar source value; pollen source value; and flowering month range. The PSVI was applied to six case studies in Maryland, Michigan, North Carolina, and Tennessee. The maintenance history, vegetation, and conclusions from each case study are very different. However, the authors concluded the PSVI provides a defensible index to assess plant community value to pollinators at each site and compared mechanical and IVM-based maintenance regimes. In all six case studies, the PSVI showed improved pollinator habitat from IVM-based maintenance.

42. Halle, C., C. Mahan, D. Krause, and E. Brown. 2019. “Future Vegetation Management Observatories: The Value of Industry and Academic Partnerships in Understanding Ecological Impacts of ROW VM

and Engaging Students of all Disciplines in Practical Environmental Issues." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinosa, A., and N.G. Pupa, pp. 401–405. Utility Arborist Association.

This paper summarizes a panel presentation at the ROW 12 Symposium. The panelists reflect on the longest continuous study of the effects of ROW vegetation management on local ecosystems—Pennsylvania State Game Lands (SGL33)—and the value of research and demonstration projects. Until recently, most projects and research had been in the Eastern U.S. Since 2015, an industry-university collaboration has begun to establish similar long-term VM "observatories" in substantially different environments in the Western U.S. In general, the findings from the eastern and western sites seem to support the idea that modifying the habitat can be beneficial (or at least not harmful) for certain wildlife and pollinator species. The panelists commented on the role of the UAA and the Tree Research Education and Endowment (TREE) Fund in sponsoring and promoting future research. The panel also focused discussion on improving student outreach, expanding research opportunities, increasing community awareness, and leveraging industry associations to help recruit trained students into industry careers.

43. Howe, J.L. 2016. "Initial Lessons from ROW Stewardship Accreditation." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 147–154. Utility Arborist Association.

The paper describes the Right-of-Way Stewardship accreditation program administered by the ROW Stewardship Council (ROWSC). The accreditation process presents the opportunity for companies to demonstrate their commitment to ROWSC standards, and third-party recognition ensures an independent, proven process to convey credibility and bring recognition to IVM programs. The purpose of this research presented in this paper was to explore the experience of participants to date in the ROWSC accreditation process in order to better understand their organizational goals and objectives, how those objectives have been realized thus far, and to identify areas of process improvement. The results suggest that early adopters found ROWSC accreditation helps demonstrate the utility's commitment to the environment, helps them gain credibility in the marketplace, supports innovation in utility vegetation management, and results in improvement in their IVM process. Increased participation by utilities and greater recognition of ROWSC over time will likely greatly benefit new and existing accredited utilities.

44. Johnstone, R.A. 1990. "Vegetation Management: Mowing to Spraying." Journal of Arboriculture 16(7): 186–189.

This paper presents a case history of how to change a utility (Delmarva Power) vegetation management program from mowing to selective application of herbicides. Change resulted in reduced maintenance costs and improved wildlife habitat, less negative visual impact from treatments, and better accessibility to the ROW.

45. Johnstone, R.A. 1993. "Vegetation Management with Environmental Stewardship." In Proceedings of the 5th International Symposium on Environmental Concerns in Rights-of-Way Management. 1993, Montreal, Quebec, Canada, edited by Doucet, G.J., C. Seguin, and M. Giguere, pp. 456–459.

The author presents a case history of the application of IVM on electric utility ROWs on the Delmarva Peninsula in the U.S. Historically, vegetation management had been done with brush hog mowing and hand cutting. In the 1980s, Delmarva Power initiated the use of herbicides under the watchful eye of state and federal regulators. The paper endorses a proactive public relations policy and engagement of regulators and stakeholders. Technical aspects of IVM and herbicide application are addressed. Environment stewardship was a core element of Delmarva Power's approach and resulted in partnerships with regulators and environmental NGOs.

46. Johnstone, R.A., M.R. Haggie, and H.A. Allen, Jr. 2002. "Tree, Shrub, and Herb Succession and Five Years of Management Following the Establishment of a New Electric Transmission Right-of-Way through a Mixed Woodland." In Proceedings of the 7th International Symposium on Environmental Concerns in Rights-of-Way Management, 2000, Calgary, Alberta, Canada, edited by Goodrich-Mahoney, J.W., D.F. Mutrie, and C.A. Guild, pp. 73–81. NY: Elsevier Science, Ltd.

The authors present results of a 5-year study of vegetation succession following construction of a new electric transmission ROW through upland mixed forest in Delaware. The herbaceous and shrub plant communities were examined following two clearing methods: (1) non-selective clear-cut of all woody plants, trees, and compatible shrubs, and (2) selective removal of targeted tall-growing trees. Integrated vegetation management techniques (selective application of herbicides) were carried out after the clearing. Results show that IVM interventions stimulated vegetation succession from a mature wooded wetland to a low shrub/herbaceous plant community as successfully in the clear-cut as in the selective-cut areas. Total number of species remained relatively stable but reflect a substitution of trees by herbaceous species, while shrub species numbers remained relatively constant.

47. Johnstone, R.A., and M.R. Haggie. 2008. "Vegetation Management Best Practices for Reliability and Ecosystem Management." In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 27–32. NY: Elsevier Science, Ltd.

The authors report monitored plant community changes and cost of treatment from three cycles of IVM work on Delmarva Power ROWs. Selective herbicide treatment of incompatible trees was observed (no data are presented) to allow more growing space for low-growing plant species, resulting in less disturbance of the plant community from later cyclic maintenance. Cost of second and third cycle treatments was reduced by approximately 50% in comparison to costs of repeated mowing.

48. Johnstone, R.A., and M.R. Haggie. 2012. "Regional Vegetation Management Best Practices Case Studies: An Applied Approach for Utility and Wildlife Managers." In Proceedings of the 9th International Symposium on Environmental Concerns in Rights-of-Way Management, 2009, Portland, Oregon, USA, edited by Evans, J.M., J.W. Goodrich-Mahoney, D. Mutrie, and J. Reineman, pp. 77–86. Champaign, IL: International Society of Arboriculture.

This paper presents four case studies on IVM implementation. The paper references the newly developed and published A300 (Part 7) Tree, Shrub, and Other Woody Plant Management – Standard Practices (Integrated Vegetation Management) (2006). The IVM approach recommended by the standard follows a continuous process: to set objectives, evaluate site, define action thresholds, evaluate and select control methods, implement IVM, monitor treatment and quality assurance, and reset objectives. This paper documents the changes in plant species and wildlife habitat on electric and gas utility ROW in varying types of ecosystems, including the coastal plain pine barrens of New Jersey, a glacial remnant habitat of Michigan, a lake plain habitat of Michigan, and a limestone-dominated lake habitat of Tennessee. Plant species are evaluated as desirable or undesirable for utility safety and reliability, mutual benefits for nature trails, diversity, dominance percentage, number of stems, non-native invasive species, threatened or endangered species, comparison to wildfire, prairie, and benefits to native pollinators and other wildlife.

49. Johnstone, R.A., and M.R. Haggie. 2016. "Integrated Vegetation Management (IVM) Partnerships with Agencies and Utilities to Improve Habitat for Pollinators, Birds, and other Wildlife." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 167–182. Utility Arborist Association.

In 2009, Integrated Vegetation Management Partners, Inc. developed successful partnerships between Baltimore Gas & Electric Company (BGE) and federal/state/local government agencies and conservationists on electric transmission ROW in the suburban community of Columbia, Maryland, and a rural area of the South River Greenway near Davidsonville, Maryland. These partnerships involved the establishment of case studies where plant community changes were followed with photographic and botanical documentation to compare various vegetation management practices, from mowing and hand cutting to broadcast and selective application of herbicides. University, government agency, and volunteer researchers also documented the population changes of birds, butterflies, and bees that were utilizing the ROW habitat for breeding, nesting, and feeding. Results indicate that when ROW vegetation is managed utilizing an IVM approach, selective herbicide treatments will allow early successional plant communities to dominate the ROW and provide habitat for some wildlife species.

50. Jury, K. 2016. "Case Study: Class C Prairie and the Transmission Right-of-Way." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 183–190. Utility Arborist Association.

In collaboration with the scientists at the Chicago Botanic Garden, Commonwealth Edison (ComEd) monitored vegetation at three sites in Northeastern Illinois to determine if it is cost-effective to convert overgrown ROW to Class C prairie. Tall-growing trees and brush were removed at each site consistent with ComEd's Transmission Vegetation Management Plan and IVM BMPs utilizing a brush mower and individual tree removals. Cut stumps were treated with herbicide. While this research is ongoing, floristic quality data indicate a Class C prairie can readily be established on sites adjacent to existing high-to-moderate quality plant communities with moderate added program cost. Initial public reaction had been positive through media commentary and Chicago Botanic Garden publications.

51. Kooser, J., K. Gorski, L. Khitrik, D. Coogan, L. Payne, J. Gwodz, and P. Brier. 2016. "ROW Vegetation Changes Over Four Treatment Cycles, IVM Controls the Growth of Non-Compatible Trees." In Proceeding of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 191–200. Utility Arborist Association.

Since the late 1990s, the New York Power Authority (NYPA) used IVM principles to guide the vegetation management program on 1,400 miles of transmission lines ROW. The authors present the changes observed in plant communities following four cycles of IVM treatments. Data from the initial field surveys (1999–2002) showed medium to high density (1,000 – >3,000 stems per acre). Non-compatible stands occupied 18%, while stands with low densities of non-compatible species (0–1,000 stems per acre) occupied 50% of the total acreage. Data taken after four treatment cycles (2011–2014) indicate that medium-to-high density had been reduced to 6% while the percentage of low density non-compatibles had been increased to 70%. Reductions in the heights of non-compatible species have also been noted. A core principle of IVM is biological control through competition from compatible species. New York Power Authority's data over four treatment cycles clearly demonstrates this benefit of IVM.

52. Krause, D., C.G. Mahan, and R.H. Yahner. 2014. "Game Lands 33 Project: 60 Years of Electrical Right-of-Way (ROW) Research." In Proceedings of the 10th International Symposium on Environmental Concerns in Rights-of-Way Management, 2012, Phoenix, Arizona, USA, edited by Doucet, G.J., pp. 159–162. Utility Arborist Association.

The paper presents the sixty years of research from an initial "five-year" project at Game Lands 33 in Pennsylvania. This is the site of the "Bramble and Byrnes" studies. The original conservationists and sportsmen concerns about the harmful impact that herbicides might have on the flora and fauna on or near the ROW proved unfounded. In fact, the data showed a positive impact. The study found that deer, small mammals, birds, reptiles, and even butterflies—considered a true test of environmental impact—were taking advantage of the cleared ground and were thriving. Furthermore, the plant and animal communities themselves were shown to be unknowing helpers in resisting the invasion of unwanted woody plants, through plant competition and by animal feeding behaviors. The resulting shrubs, grasses, and wildflowers supply food and shelter on the ROW that are not found in the adjacent dense forests.

53. Labarr, M., M. Fowle, J. Disorda, and C. Peterson. 2016. "Collaborating to Enhance Habitat for Priority Bird Species in Vermont's Champlain Valley." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 363–369. Utility Arborist Association.

In 2012 and 2013, Audubon Vermont worked collaboratively with the Vermont Electric Power Company (VELCO) to conduct surveys for seven priority bird species along a transmission line ROW in the southern Champlain Valley. The objective of the study was to determine if priority species were present and if trained volunteers could collect data to assist Audubon in determining if VELCO's IVM treatments created the vegetative structure that supported priority bird species. Data support the conclusion that vegetative structure created by VELCO's current management efforts supported priority bird species. This collaborative effort by VELCO, Audubon Vermont, and Audubon Chapter volunteers demonstrated a successful approach by industry, nongovernmental organizations, and citizen scientists to better understand the presence of priority birds along this ROW. Management recommendations based on the surveys were provided to and incorporated by VELCO.

54. Mahan, C.G., D. Krause, and C. Duncan. 2016. "Plant and Animal Community Response to Long Term Vegetation Management Practices on Rights-of-Way." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 201–204. Utility Arborist Association.

The Pennsylvania State Game Lands 33 and the Green Lane Research and Development Area research projects in Central Pennsylvania began in 1953, in response to public concern about the impact of vegetation management practices on wildlife habitat within electric transmission ROW. Both projects provide invaluable information for understanding the response of plants and animals to vegetation management on ROW. Many of the findings are of particular interest to wildlife managers because species in decline are still found on our ROW study areas. In particular, bird assemblages requiring early successional plant communities are declining throughout the Eastern U.S. and were thriving in the ROW. The objective of this study was to continue this long-term research project and document trends in wildlife and plant species. Results support earlier work that finds many bird species that reproduce in the ROW (e.g., eastern towhee, field sparrow) are on the Audubon society's conservation watchlist. Species of amphibians, often negatively affected by fragmenting landscape features, were found using the unique border zone habitat. The high diversity of native plants potentially support over 200 species of Lepidoptera.

55. Mahan, C.G., B.D. Ross, H. Stout, and D. Roberts. 2019. "The Effect of VM Approaches on Electric Transmission ROWs on Bees Pre- and Post-Treatment." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinosa, A., and N.G. Pupa, pp. 649–652. Utility Arborist Association.

This paper presents research on

ROW habitat and conservation benefits for wild pollinators. The authors surveyed flower-visiting insects in different vegetation management treatments in a long-term research ROW to determine which provide the best promoted pollinator abundance and species richness. Game Lands 33 sites with long-stabilized, early successional habitat were utilized for the study. Data showed a high diversity (96 bee species and 179 non-bee morphospecies) in six ROW sites. Results suggest selective, low-volume herbicide applications may promote high pollinator abundance and species richness. This survey also shows that long-term maintenance of ROW habitat has the potential to support many wild pollinator species.

56. Mahan, C.G., B. Ross, H. Stout, and I. Fisher. 2018–2021. Floral and Faunal Research on Utility Rights-of-Way at State Game Lands 33, State Game Lands 103, and Green Lane Research and Demonstration Areas: Report to Cooperators 2018–2021. Available at https://sites.psu.edu/transmissionlineecology/files/2016/02/2021_FLORAL-AND-FAUNAL_Report.pdf.

This report to cooperators updates research on these well-known "Bramble and Byrnes" research sites, dating back to 1953. This update presents data and research on all aspects of floral and faunal communities on these long-term sites. This paper can also be accessed through the Utility Arborist Association website at *www.gotouaa.org/project/research* (accessed August 2022).

57. Marshall, J.S., L.W. VanDruff, S.D. Shupe, and E. Neuhauser. 2002. "Effects of Powerline Right-of-Way Vegetation Management on Avian Communities." In Proceedings of the 7th International Symposium on Environmental Concerns in Rights-of-Way Management, 2000, Calgary, Alberta, Canada, edited by Goodrich-Mahoney, J.W., D.F. Mutrie, and C.A. Guild, pp. 355–362. NY: Elsevier Science, Ltd.

Shrubland habitats and the birds nesting in them are declining in the Northeast U.S. Rights-of-way can provide productive avian habitat with appropriate vegetation management. The study evaluated the avian productivity of two ROW vegetation management options: mowing and selective application of herbicides. Birds were found to have more territories and nests in areas with more shrub cover, and in this study, the mowed areas. Mowing may create better short-term habitat for birds, and selective herbicide treatments may create a more stable long-term shrub layer. Neither treatment provided more productive habitat. The authors conclude that whichever treatment produces more abundant stable habitat would be more beneficial for birds.

58. McLoughlin, K.T. 1997. "Application of Integrated Pest Management to Electric Utility Rights-of-Way Vegetation Management in New York State." In Proceedings of the 6th International Symposium on Environmental Concerns in Rights-of-Way Management, 1997, New Orleans, Louisiana, USA, edited by Williams, J.R., J.W. Goodrich-Mahoney, J.R. Wisniewski, and J. Wisnewski, pp. 118–126. NY: Elsevier Science, Ltd.

The author presents background on IPM as a process/framework for ROW vegetation management. Integrated pest management is a process that balances the use of cultural, biological, and chemical procedures for reducing pest populations to tolerable levels. Rather than relying solely on chemicals (or eliminating chemicals completely), IPM seeks to produce a combination of pest control options that are compatible with the environment, economically feasible, and socially acceptable. The practice of IPM on electric utility ROWs can better be defined as IVM. This paper is one of the first to use and define the term "IVM," that is now widely accepted in the industry. The paper describes the practice of IVM by New York State utilities.

59. McLoughlin, K.T. 2002. "Integrated Vegetation Management – The Exploration of a Concept to Application." In Proceedings of the 7th International Symposium on Environmental Concerns in Rights-of-Way Management, 2000, Calgary, Alberta, Canada, edited by Goodrich-Mahoney, J.W., D.F. Mutrie, and C.A. Guild, pp. 29–45. NY: Elsevier Science, Ltd.

As a follow-up to the author's 1997 paper on IVM, this paper further explores concepts of IVM and the electric utility industry use of the term. The author laments "the acronym IVM has become synonymous with ROW vegetation management and is now used throughout the industry as an ambiguous descriptive term for virtually all ROW vegetation management activities." The author asserts that an authentic IVM program needs to be based on the principles and practices of the established IPM body of knowledge.

60. McLoughlin, K.T. 2002. "Endangered and Threatened Species and ROW Vegetation Management." In Proceedings of the 7th International Symposium on Environmental Concerns in Rights-of-Way Management, 2000, Calgary, Alberta, Canada, edited by Goodrich-Mahoney, J.W., D.F. Mutrie, and C.A. Guild, pp. 319–326. NY: Elsevier Science, Ltd.

Electric utility vegetation programs have resulted in ROWs becoming refugia for many rare, threatened, and endangered species. While ROW owners and managers welcome their presence as components of the stable, low-growing plant community desired for biological control, the industry is now, in some instances, being "penalized" for having achieved these milestones in biodiversity, in that costly studies, inventories, and surveys are often requested/required when these species are discovered.

61. McLoughlin, K.T. 2014. "Integrated Vegetation Management: From its Roots in IPM to the Present." In Proceedings of the 10th International Symposium on Environmental Concerns in Rights-of-Way Management, 2012, Phoenix, Arizona, USA, edited by Doucet, G.J., pp. 227–270. Utility Arborist Association.

This paper traces the origins of IVM from legislation requiring IPM for all uses of pesticides in New York State (NYS) and an initiative by the NYS Public Service Commission requiring IPM on electric utility ROW. New York State electric utilities had a long history of selective use of herbicides to establish stable low-growing plant communities. The motivation for selective herbicide use and the establishment of low-growing plant communities is traced back to Rachel Carson's *Silent Spring*, and Frank Egler. The author presents how these legal requirements led to development of IVM in the 1980s and 1990s in NYS and the Northeast U.S. The Northeast Blackout of 2003 led to the first nationwide ROW vegetation management standard in 2006: NERC Standard FAC-003-1. In the same time period, ANSI A300 Standards, Part 7 – Integrated Vegetation Management was published in 2006. A set of best management practices based on the ANSI IVM Standard was published by the ISA in 2007. The author compares and contrasts the current popular use of the term "IVM" with the well-defined concepts of IPM, from which IVM first emerged in the 1980s.

62. Money, N.R. 2008. "Development of an Integrated Resource Management Strategy for Transmission Right-of-Way Corridors for Successful Implementation of Integrated Vegetation Management in California." In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 33–36. NY: Elsevier Science, Ltd.

The author describes the historic background for establishment of ROW corridors in California and the evolving interests of landowners and the public in the vegetation management practices employed by the electric utility, Pacific Gas and Electric (PG&E). Pacific Gas and Electric's vegetation management methods evolved from nearly exclusive use of mechanical control to IVM methods, and were to meet the reliability, environmental, social, and economic goals of the utility, landowners, regulators, and the public. The author discusses the integrated resource management decision-making process that was used to develop the IVM program. Integrated resource management is a process framework that identifies all compatible resource uses and objectives long-term vegetation management benefits for the utility, landowners, and the public. Clear identification of resource uses leads to development of vegetation management methods that are then implemented within an IVM program.

63. Murcia, C. 1995. "Edge Effects in Fragmented Forests: Implications for Conservation." Tree 10: 58–62.

The author presents a discussion on the effects of edges in fragmented forests. There is a general notion that edge effects are deleterious for forest fragments, though there is little consensus on what an edge is, how to measure edge effects, or how deleterious they are. The discussion is focused on edge effects in forest fragments and does not review edge effects in unbroken forest.

64. Neiring, W.A. 1958. "Principles of Sound Right-of-Way Management." Economic Botany 12(2): 140–144.

The author notes the vast acreage of landscape traversed by ROW and the opportunity for the application of sound management that would benefit the utility with reduced costs on a long-range basis but also results in high conservation values to the nation.

65. Neiring, W.A., and R. Goodwin. 1974. "Creation of Relatively Stable Shrublands with Herbicides: Arresting Succession on Rights-of-Way and Pastureland." Ecology 55: 784–795.

The authors measured the stability of shrublands to invasion by trees on an electric utility ROW on the Connecticut Arboretum. The study site is on land contiguous to Connecticut College. This ROW had been managed using selective applications of herbicide for at least 15 years. Connecticut College researchers promoted selective use of herbicides to manage ROWs in the late 1950s. The concept of stability can be explained in terms of "initial floristic composition" hypothesis of Egler in the 1950s. The authors conclude that creating relatively stable shrub communities by the selective use of herbicides has practical applications in ROW and wildlife management, naturalistic landscaping, and the maintenance of habitat diversity.

66. Nickerson, N.H., and F.R. Thibodeau. 1984. The Effect of Power Utility Rights-of-Way on Wetlands in Eastern Massachusetts. Study Report submitted to the New England Power Company. MA: Westboro.

This study report summarizes the results of tracking five years of natural revegetation of a newly cleared 345-kilovolt ROW in Massachusetts. The specific goals of the study were to determine how the natural ecological conditions change as a result of ROW construction and maintenance; how long these differences persist; and whether any changes, temporary or permanent, occur in the wetlands which can be considered an important negative or positive impact, in terms of the interests identified in the Massachusetts Wetland Protection Act. The authors concluded that opening forested areas of wetland to construct electric powerlines has a net beneficial effect on many ecological parameters, especially in New England where open space is at a premium because of forest development on abandoned farms. The value of the cleared ROWs as open corridors for connecting otherwise non-contiguous natural areas, for developing shrub rather than tree vegetation, and for developing edge effect feeding/nesting/cover opportunities for many animals, is clearly indicated. In most cases there was no evidence on long-term degradation of wetland values as they compare to the Massachusetts Wetland Protection Act.

67. Nickerson, N.H. 1992. "Impacts of Vegetation Management Techniques on Wetlands in Utility Rights-of-Way in Massachusetts." Journal of Arboriculture 18(2): 102–106.

The paper presents results of studies on vegetation management techniques in wetlands in Massachusetts. The studies compared five ROW treatments (hand cutting, mowing, cut stump treatment with herbicides, basal herbicide application, and foliar herbicide application) to determine their impacts on wetlands on electric utility ROW. The conclusion reached was that there was no significant impact to wetland value or function from any of the vegetation management techniques. Mechanical treatments resulted in higher impacts to cover value for wildlife than those involving herbicides. Residue from petroleum products (bar oil and hydraulic fluid) were recovered on the leaf litter from mechanically treated sites. No herbicides residues were recovered from herbicide-treated sites.

68. Nickerson, N.H., G.H. Moore, and A.D. Cutter. 1994. Study of Environmental Fates of Herbicides in Wetlands on Electric Utility Rights-of-Way in Massachusetts Over the Short Term. Final Report.

This study examined the environmental fate of two herbicide active ingredients, triclopyr and glyphosate, applied to Red Maple trees in wetlands in Massachusetts. The purpose of the study was to quantify the soil residues of the herbicides immediately following application and their environmental fate in the soil up to 12 months after application. Foliar application was found to result in the least residue in the soil. These residues biodegraded to below detectable limits in less than 12 months. Cut stump treatments resulted in the highest soil residues and were present in the soil for up to 18 months. Tests were conducted for movement in the soil. Glyphosate did not move laterally or vertically in the soil. Triclopyr did not move laterally but was found to move vertically in small amounts. Assessment as to the least environmentally damaging and most effective vegetation control measure of the four methods studied points to low-volume foliar application of glyphosate as the method of choice.

69. Norris, L.A., N.H. Nickerson, K. Bentsen, W.C. Bramble, W.R. Byrnes, and K.L. Carvell. 1989. Study of the Impacts of Vegetation Management Techniques on Wetlands for Utility Rights-of-Way in the Commonwealth of Massachusetts. Environmental Consultants, Inc.

The study report describes research performed to evaluate the impacts of vegetation management techniques on electric utility ROWs crossing wooded wetlands in Massachusetts. The project included a review of published literature, interviews with subject matter experts, and field studies on selected ROW wooded wetlands. Models were also used to evaluate the potential risk of groundwater pollution from herbicide use in vegetated wetlands. Five principal vegetation management techniques were evaluated: hand cutting, mowing, foliar herbicide application, basal herbicide application, and cut stump herbicide applications. Results of the study indicated that there are no significant impacts to wetlands from the current vegetation management techniques used on ROW in Massachusetts. Mechanical treatments result in relatively higher impacts than selective herbicide use. Residue from petroleum products (bar oil and hydraulic fluid) were found in the leaf litter on mechanically treated sites. No herbicide residues were found on herbicide-treated sites.

70. Norris, L.A. 1997. "Address Environmental Concerns with Real Data." In Proceedings of the 6th International Symposium on Environmental Concerns in Rights-of-Way Management, 1997, New Orleans, Louisiana, USA, edited by Williams, J.R., J.W. Goodrich-Mahoney, J.R. Wisniewski, and J. Wisnewski, pp. 213–218. NY: Elsevier Science, Ltd.

Dr. Norris asserts that "many environmental concerns about ROW siting, construction, and management can be addressed most effectively with scientific data from field- and laboratory-based research and monitoring programs. Examples of research are used to illustrate this point. Both the public and entities managing ROW will best be served by increased research and monitoring.

71. Norris, L.A., and P. Charlton. 1993. "Determination of the Effectiveness of Herbicide Buffer Zones in Protecting Water Quality." In Proceedings of the 5th International Symposium on Environmental Concerns in Rights-of-Way Management, 1993, Montreal, Quebec, Canada, edited by Doucet, G.J., C. Seguin, and M. Giguere, pp. 147–152.

This study and results published by the Empire State Electric Energy Research Corporation was initially published 1991 (ESSERCO paper is available from ECI). The authors conducted three studies to determine: (A) water quality criteria that will protect aquatic organisms and human health, (B) the effect of buffer zone width and vegetation density on herbicide deposition outside the treated area, and (C) the effectiveness of specific buffer strategies in protecting water quality during operational use of herbicides. The second study determined spray deposition at distances from 0 to 100 feet from the downwind edge of areas treated by either stem-foliar or basal methods. The results showed that in all cases where there was vegetation in the buffer zone, stream water quality criteria would be achieved if buffers of 25 feet or more are used. The third study was a field test of buffer zone effectiveness and was conducted involving high-volume stem foliage and low-volume basal applications of picloram, triclopyr, 2,4-D, or imazapyr. Buffers of 10 to 100 feet were employed. Application of these water quality protection criteria to the results from this project show the buffer zones tested in this study protected surface water quality with a significant margin of safety. While wider buffer zones could be used, results indicate no substantive gain in safety would be achieved. This study has been referenced in many regulatory filings and environmental impact reviews as the basis for buffers to protect surface waters.

72. Nowak, C.A., L.P. Abrahamson, E.F. Neuhauser, C.G. Foreback, H.D. Freed, S.B. Shaheen, and C.H. Stevens. 1992. "Cost-Effective Vegetation Management on a Recently Cleared Electric Transmission Line Right-of-Way." Weed Technology 6: 828–837.

Cost-effectiveness (degree of vegetation control and cost) of several methods of herbicide application are evaluated in this study. Treatments that increase compatible plants and decrease incompatible plants and have relatively low cost are considered to be cost-effective. Three herbicides, 2,4 D, picloram, and triclopyr, were applied in the field using cut stump, basal, and stem-foliar methods. Both selective and non-selective treatments were carried out. Non-selective and stem-foliar application were most effective during first and second conversion cycles, respectively. This paper is the initial published data from a long-term study (Nowak 2012).

73. Nowak, C.A., L.P. Abrahamson, D.J. Raynal, and D.J. Leopold. 1993. "Selective Vegetation Management on Powerline Corridors in New York State: Tree Species Composition Changes from 1975 to 1991." In Proceedings of the 5th International Symposium on Environmental Concerns in Rights-of-Way Management, 1993, Montreal, Quebec, Canada, edited by Doucet, G.J., C. Seguin, and M. Giguere, pp. 153–158.

In this study, tree densities and species composition were compared on powerline corridors in New York State over a 16-year period across a wide range of management schemes, environmental conditions, and plant communities. In 1975, 58 permanent vegetation measurement plots, 0.03 to 0.08 ha in size, were established on 21 corridors across New York. Tree densities and species composition were measured in 1975 and 1991. On ROWs where trees were selectively removed using herbicides, tree populations were observed at constant low density. There was a spatial redistribution of trees in 1991 compared to 1975, with fewer trees in the corridor centerline and more in the border areas along corridor edges in 1991. An increase in tree density was observed on corridors that did not receive herbicide treatments to control trees, hand cutting only. Species composition generally did not change over the study period. Authors concluded that operational, selective removal of trees on powerline ROW with herbicides can lead to the creation of relatively stable, compositionally constant, low-density tree populations.

74. Nowak, C.A., and B.D. Ballard. 2005. "A Framework for Applying Integrated Vegetation Management on Rights-of-Way." Journal of Arboriculture 31(1): 28–37.

The authors suggest that IVM is purportedly being used by many ROW organizations across the U.S. They go on to state, in many instances, IVM has become a name applied to old management approaches. The authors state that IVM is more than repackaged old techniques. Integrated vegetation management is an in-depth system of information gathering, planning, implementing, reviewing, and improving vegetation management treatments. The paper then describes a six-step management system for implementation of IVM.

75. Nowak, C.A. 2014. "What is this Integrated Vegetation Management, this IVM – Now, Today, and into the Future?" In Proceedings of the 10th International Symposium on Environmental Concerns in Rights-of-Way Management, 2012, Phoenix, Arizona, USA, edited by Doucet, G.J., pp. 281–287. Utility Arborist Association.

Integrated vegetation management has been touted over the past few decades as an approach for ROW vegetation management. It is an approach based on IPM systems at its core, but also includes the necessary administrative and institutional support to create a management system. Integrated vegetation management was central to the development of the existing American National Standards Institute (ANSI) A300 Part 7– 2006 Vegetation Management standards and the International Society of Arboriculture best management practices. Integrated vegetation management has continued to evolve over the last decade, with examples of expanded emphasis of work on: (1) broad assessment of environmental impact, (2) building social awareness and responsibility, and (3) elevated focus on safety and reliability of service. This paper presents a history of IVM, its current state and use by ROW industries, and possible future changes. A bibliography of key references is provided.

76. Payne, L., J. Gwodz, J. Kooser, and K. Gorski. 2016. "Integrated

Vegetation Management Works: The Proof is in the Program." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 205–213. Utility Arborist Association.

Implementation of IVM for controlling undesirable, tall-growing woody vegetation, while at the same time promoting the desirable low-growing plant communities on electric transmission ROW, has been proven to be a successful treatment strategy. An overview of the New York Power Authority's (NYPA) program over the past four treatment cycles (1 treatment cycle is 4 years) clearly shows trends that managing for a desirable, low-growing stable plant community is definitely working. New York Power Authority collected extensive vegetation management data over the past four treatment cycles, which clearly show that managing for a desirable stable plant community has proven effective in balancing the utilities operational, environmental, economic, social, reliability, and safety goals on its ROW.

77. Putz, F.E., and C.D. Canham. 1992. "Mechanisms of Arrested Succession in Shrublands: Root and Shoot Competition Between Shrubs and Tree Seedlings." Forest Ecology and Management 49: 267–275.

The authors investigated the relative effects of aboveground and belowground competition from shrubs on the growth of tree seedlings as a mechanism for arresting succession to tree species in old fields in New York State. Tree encroachment (invasion) into shrub-dominated stands can be reduced by both root and shoot competition. The severity of competition varies with site conditions; belowground competition is intense where soil resources are limited, whereas effects of shade are relatively more severe on sites with good soil. As background, the authors reference papers by Egler, Niering, and others at Connecticut College on the management of shrubs as an environmentally sound method for reducing tree encroachment in powerline ROWs.

78. Quant, J.M., C.A. Nowak, and M. Dovcial. 2016. "Human-Based Spread of Invasive Plants from Powerline Corridors in New York State." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 87–96. Utility Arborist Association.

The authors' research goals were to (1) quantify the spread of invasive propagules during typical vegetation management operations, and (2) make recommendations for cleaning protocols for vehicles and workers. Authors met with vegetation management crews over two seasons (2013 and 2014) and sampled material accumulating on workers, ATVs, and mowers to quantify propagule movement. In 2013, an estimated 66,400 propagules were moved from 31 research sites across New York State, and at least 6% of these were clearly identified as IE species. In 2014, an estimated 93,000 propagules were moved from 30 sites, and at least 10% of these were IE species. Data suggest that vehicles have a greater capacity to move propagules than workers. The most frequently transported invasive exotic species were Morrow's honeysuckle (*Lonicera morrowii*) and purple loosestrife (*Lythrum salicaria*). Authors recommend that cleaning protocols should take into account vector type (worker, ATV, or mower), soil drainage, and ecoregion, and should include washing.

79. Richards, N.A. 1973. "Old Field Vegetation as an Inhibitor of Tree Vegetation." In Proceedings of the Colloquim 'Biotic Management Along Transmission Right-of-Way,' 1973, American Institute of Biological Sciences, Amherst, Massachusetts, pp. 78–88. The Cary Arboretum of the New York Botanical Gardens.

The author, a professor of silviculture at SUNY ESF, presents case studies and ecological elements that contribute to sustaining "perennial meadows." These meadows resist and inhibit natural regeneration and tree planting efforts. Ecological factors include: soil moisture and nutrient competition, shading, burying, microclimate extremes, faunal damage, and phytochemical effects. Case studies suggest that old fields dominated by grasses, forbs, and herbaceous species are more resistant to tree invasion than fields dominated by woody shrubs.

80. Rigby, M., M. Gach, and T.E. Sullivan. 2012. "Urban Wildlife Sanctuary Along an Electric Transmission Right-of-Way: A Successful Partnership." Abstract in the 10th Symposium on Environmental Concerns in Right-of-Way Management, 2012, Phoenix, Arizona, USA.

The paper presents a case history of IVM practiced on a ROW within an urban wildlife sanctuary managed by New England Power Company and the Massachusetts Audubon Society. The sanctuary is largely on land belonging to New England Power Company. This historic partnership is a showcase for stakeholder engagement with an environmental organization. Wildlife habitat is the primary ecological value managed for through application of IVM. Published in the *T&D World* Vegetation Management Supplement (2014).

81. Rogers, T.W. 2016. "Impacts of Vegetation Management Practices on Animal, Plant, and Pollinator Habitats." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 227–230. Utility Arborist Association.

The author's objective for this paper was to examine what is known from research and operational experience about the impacts of various vegetation management techniques on animal, plant, and pollinator habitats. Based on years of field research and operational experience, vegetation management techniques employed in ROW management play a significant role in maintaining and improving habitat needed for sustaining threatened and endangered (T&E) animal, plant, and pollinator species. Plant, animal, and pollinator species respond differently to the use of various vegetation management methods. Knowledge from years of practical experience and 60+ years of research will demonstrate that managing ROWs using IVM techniques is the best approach for establishing and maintaining these critical habitats. The paper includes an extensive bibliography of Bramble and Byrnes and Yahner papers from Game Lands 33 and Green Lane studies in Pennsylvania.

82. Russo, L., H. Stout, D. Roberts, B.D. Ross, and C.G. Mahan. 2021. "Powerline Right-of-Way Management and Flower-Visiting Insects: How Vegetation Management Can Promote Pollinator Diversity." Plos One 16(1): e 0245146. http://doi.org/10.1371/journal.pone.0245146 (accessed July 2022).

The authors surveyed flower-visiting insects over two years in different vegetation treatment in long-term stable "Bramble and Byrnes" research sites in Pennsylvania to determine which best promoted pollinator abundance and species richness. Data showed a high diversity of flower-visiting insects (126 bee species and 170 non-bee species) in six ROW plots. Sites requiring and higher level of maintenance work (higher amounts of herbicide applied) had a negative effect on bee species richness, but low levels of herbicide application were compatible with a high abundance and species richness of flower-visiting insects. The authors demonstrate that there is substantial potential for pollinator conservation in ROW, maintained using selective herbicide application within the context of an IVM program.

83. Sheridan, P.M., S.L. Orzell, and E.L. Bridges. 1997. "Powerline Easements as Refugia for State Rare Seepage and Pineland Plant Taxa." In Proceedings of the 6th International Symposium on Environmental Concerns in Rights-of-Way Management, 1997, New Orleans, Louisiana, USA, edited by Williams, J.R., J.W. Goodrich-Mahoney, J.R. Wisniewski, and J. Wisnewski, pp. 451–460. NY: Elsevier Science, Ltd.

The authors present data from field survey on the inner coastal plain and pinelands of Georgia, Maryland, and Virginia. Sixty-five state-listed rare plant species were documented. Endangered and threatened plant species were also found. Powerlines clearly serve as refugia for plants and might serve as a local measure of biodiversity in regions where the surrounding natural vegetation has been highly altered.

84. VanBossuyt, R. 1987. "New England Electric System Companies' Selective Right-of-Way Management Program." In Proceedings of the 4th Symposium on Environmental Concerns in Rights-of-Way Management, 1987, Purdue University, Indiana, USA, edited by Byrnes, W.R., and H.A. Holt, pp. 123–127.

The author presents program development and 20+ years of ROW vegetation management practice on New England Electric System ROW using selective application of herbicides. New England Electric System was the predecessor to National Grid, the holding company of New England Power Company and The Narragansett Electric Company. The author and primary contractor, Vegetation Control Service, Inc., were among the earliest developers of low-volume selective herbicide application methods dating back to 1963.

85. VanSplinter, J.L., C.A. Nowak, and M. Fierke. 2019. "Implications and Guidance from the Literature for ROW Managers Looking to Promote Pollinator Habitat." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 437–448. Utility Arborist Association.

The objective for this study was to determine the current state of knowledge, technology, and practice for managing ROW corridor vegetation with a focus on pollinator habitat. A literature review was conducted to determine the current state of knowledge, technology, and practice. The review includes 36 studies from North America and Europe investigating powerline, roadway, and railway ROW. The authors note that most of the studies were observational with little experimental/conclusive evidence to support one management technique over others. The authors use the available study to develop an eight-step guidance for managing ROW for pollinators. The importance of proceeding with caution, on the ground learning, and adaptive management are emphasized due to the limited evidence available.

86. VanSplinter, J.L., B.D. Ballard, C.A. Nowak, and M.K. Fierke. 2019. "Setting Up a Long-Term Research Study of Pollinators on ROWs: Experience from Literature and the Field." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 631–639. Utility Arborist Association.

The authors discuss the 2014 Presidential Memorandum, "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators," to addresses enhancement and creation of pollinator habitat as a top priority. Electrical ROW and the 9.6 million acres of early successional habitat they provide in the U.S. offer an opportunity to address this need. Determining baseline data, trends, and BMPs require long-term monitoring and research. This paper addresses three key elements of initiating long-term pollinator projects on ROWs: (1) experimental design and site selection, (2) vegetation and insect pollinator monitoring techniques, and (3) obtaining appropriate baseline information. The importance of partnerships between utilities and scientists are emphasized as the "glue" holding research and development of adaptive management for pollinator habitat together.

87. Walden, D.L., S. Morawski, and I.E. Hegemann. 2008. "Mitigation Measures for Rare Species During Necessary Maintenance Activities Within Existing Rights-of-Way." In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 529–539. NY: Elsevier Science, Ltd.

The authors discuss the increasing importance of electric and gas ROW for maintained field and shrubland habitat. Discussion is presented on the diversity and abundance floral and fauna species on ROW and the presence of rare, threatened, and endangered species on ROW. Case studies are presented on practices utilized during maintenance and construction activities on ROW to protect the habitat and species. The case studies all provide evidence that the disturbance associated with the maintenance of utility infrastructure had no impact on the habitat for each of the monitored species.

88. Watkins, C.N., and L.L Young. 2018. "IVM and Environmental Compliance on State, Federal, and Tribal Lands." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 449–458. Utility Arborist Association.

Rights-of-way in the Western U.S. often cross public lands, and many IVM control methods require special authorization by land management agencies. Arizona Public Service (APS) recently navigated this regulatory landscape and obtained approval to conduct an IVM program, including chemical, manual, and mechanical control methods on Arizona state, tribal, Bureau of Land Management (BLM), and U.S. Forest Service (USFS) lands. The authors present this case study as a model for other Western U.S. ROW managers who implement IVM programs on public lands. Successfully obtaining these authorizations took varying investments of time and resources, but the benefits of IVM more than justified the cost of compliance.

89. Wells, T.C., K.D. Dalgarno, and R. Read. 2002. "Reducing Costs Using Integrated Vegetation Management on Electric Utility Transmission Lines in British Columbia." In Proceedings of the 7th International Symposium on Environmental Concerns in Rights-of-Way Management, 2000, Calgary, Alberta, Canada, edited by Goodrich-Mahoney, J.W., D.F. Mutrie, and C.A. Guild, pp. 63–72. NY: Elsevier Science, Ltd.

The authors carried out IVM protocols and treatments on three sites on BC Hydro corridors in British Columbia. Pre-treatment inventories were conducted to define growth rates and stand densities of incompatible species, as well as identifying compatible/competitive ground cover and to determine action thresholds for treatment. A site-based prescriptive approach was taken to select the appropriate combination of manual, mechanical, chemical, and natural control methods to establish short- and long-term site objectives. Results from the study indicate that selective approaches to ROW maintenance allow long-term site objectives to be met at reduced costs. This is achieved by optimizing treatment cycle lengths or reducing maintenance by clearing only what is necessary to establish compatible plant communities. Selective treatments also resulted in protection of riparian zones and wildlife habitats and promoted opportunities for compatible use.

90. Westerhold, M., A. Geggestad, and S. Peters. 2019. "Herbicide Impacts on Pollinators: Current State of Knowledge and Best Management Practices." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 421–432. Utility Arborist Association.

The authors attempt to better understand the potential effects of herbicides and adjuvants on pollination and pollinator habitat through industry outreach and a review of the literature. The review summarizes findings from previous studies and focuses on peer-reviewed research. Direct and indirect effects are summarized for active and inert ingredients common to utility VM. The authors offer numerous BMPs focused on preservation of pollinators and pollinator habitat.

91. Wetteroff, J., and D. Koniecka. 2006. Environmental Consultants, Inc. Transmission Right-of-Way Invasive Non-Woody Plant Species Control. Palo Alto. CA: EPRI.

The authors point out that concerns over invasive plants have been increasing for decades. Executive Order 13112, signed by President Clinton in 1999, was an initial step to "prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause." The paper provides an annotated bibliography of 40 papers. Most of the papers focus on individual problem species and control methods. None of the papers specifically point to ROW as contributing to the spread of invasive plants. The authors surveyed and interviewed a number of electric utilities to provide case studies of how utilities are incorporating control of invasive plants into their VM programs. The paper also presents a list of state and federal laws related to invasive plants.

92. Willyard, C.J., and S.M. Tikalsky. 2008. "Research Gaps Regarding the Ecological Effects of Fragmentation Related to Transmission-Line Rights-of-Way." In Proceedings of the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, 2004, Saratoga Springs, New York, USA, edited by Goodrich-Mahony, J.W., L.P. Abrahamson, J.L. Ballard, and S.M. Tikalsky, pp. 521–527. NY: Elsevier Science, Ltd.

The authors conducted an extensive literature survey on the effect of transmission line ROW on the ecology of the local environment. Research gaps related to fragmentation are grouped into three categories: increased edge, invasive species, and early successional habitat. The authors comment that the ecological effects produced by linear ROW can be grouped into two broad categories: fragmentation of habitat and creation of ROW corridors, both of which can have positive and negative consequences depending on the species in question.

93. Windmiller, B., and A.J.K. Calhoun. 2002. "Conserving Vernal Pool Wildlife in Urbanizing Landscapes." Science and Conservation of Vernal Pools in Northeastern North America, pp. 233–251.

The paper presents background on the ecological value of vernal pools the impacts of urbanization on vernal pools, surrounding wetlands and terrestrial habitat. Impacts to vernal pool wildlife and conservation recommendations are presented.

94. Wininger, K., V. Wojcik, and C. Halle. 2019. "A Comparison of Pollinator Communities in ROWs and Unmanaged Lands: Understanding Habitat Opportunities in California Electric Transmission ROWs." In Proceedings of the 12th International Symposium on Environmental Concerns in Rights-of-Way Management, 2018, Denver, Colorado, USA, edited by Espinoza, A., and N.G. Pupa, pp. 503–512. Utility Arborist Association.

Researchers from Sonoma State University and the Pollinator Partnership conducted a three-year investigation with the objective of assessing and comparing pollinator communities associated with PG&E-managed ROW crossing conservation lands at Fairfield Osborn Preserve in Sonoma County, California, and the adjacent conservation lands, to gauge the value of each landscape to pollinators. Results lend support to the potential of IVM on ROW to increase the value of oak woodlands to pollinators. Pollinator richness was highest in treated ROW, and honeybees in particular showed preference for ROW as opposed to the other habitats studied. Pollinator occurrences increased over the 3-year study period.

95. Wojcik, V., P. Beesley, B. Brenton, E. Brown, and S. Hallmark. 2016. "Innovations in Right-of-Way Management that Support Pollinators, Ecosystem Services, and Safe Energy Transmission." In Proceedings of the 11th International Symposium on Environmental Concerns in Rights-of-Way Management, 2015, Halifax, Nova Scotia, Canada, edited by Doucet, G.J., pp. 249–258. Utility Arborist Association.

Pacific Gas and Electric Company and the Sacramento Municipal Utility District partnered with the Pollinator Partnership and others to research management techniques that support ecosystem services and the specific objective to create pollinator habitat on ROW. The flagship project in this collaboration is the American River Parkway Pollinator Project—the first long-term comparative monitoring field study in the Western Region that examined pollinator communities on actively managed ROW. Results show that ROW managed using IVM techniques designed to control non-native invasive plants and instead favor creation of low-growing, native plant communities resulted in an almost three-fold increase in bee abundance and a two-fold increase in bee species richness. The study provides support for developing BMPs for pollinator habitat management along ROW in Northern California. Additional studies are underway to better understand how these managed landscapes play a role in pollinator and ecosystem services support.

96. Yahner, R.H, W.C. Bramble, and W.R. Byrnes. 2001. "Response of Amphibian and Reptile Populations to Vegetation Maintenance of an Electric Transmission Line Right-of-Way." Journal of Arboriculture 27(4): 215–220.

This two-year study of amphibian and reptile populations was conducted in Pennsylvania. The objectives were to compare diversity and abundance of amphibians and reptiles between the ROW and adjacent forest, among five treatment units on the ROW, and between wire and border zones on treatments on the ROW. Eight species were noted on the ROW. Detailed data is presented for the treatment types and wire vs. border zones. The ROW contained a greater diversity of amphibian and reptile species than the adjacent forest.

97. Yahner, R.H. 2002. "50 Years of Wildlife Research Along a Pennsylvania Right-of-Way." Dow AgroSciences.

The author presents a summary of the 50 years of research on the Game Lands 33 Research and Development Project in Pennsylvania. The R&D project began in 1952 and is the longest continuous study documenting the effects of mechanical and herbicidal maintenance on wildlife and plants along an electric transmission ROW. Researchers on the project have included Dr. Bill Bramble, Dr. Dick Byrnes, Dr. Rich Yahner, Dr. Russ Hutnick, and Mr. Steve Liscinsky. Research has evolved from initially studying the effects of ROW vegetation treatments on game species to development of tree-resistant cover types and impacts on bird populations, amphibians and reptiles, and small mammals. Twenty published research papers are available on the DVD, compiled and published by Dow AgroSciences.

98. Yahner, R.H., B.D. Ross, R.T. Yahner, R.J. Hutnik, and S.A. Liscinsky. 2004. "Long-Term Effects of Rights-of-Way Maintenance via the Wire-Border Zone Method on Bird Nesting Ecology." Journal of Arboriculture 30(5): 288–293.

The long-term nesting ecology of birds was studied during 2002 and 2003 on the State Game Lands 33 R&D area in the Allegheny Mountain region in Pennsylvania. The objectives of the study were to compare nest abundance, success, and placement in hand-cut versus herbicide-treated study sites and in wire zones vs. border zones. Thirty-nine percent of nests of all species combined fledged young in 2002 and 65% in 2003. Nesting success in 2003 was typical of most studies of bird nesting success in a variety of habitats. Fifty-nine percent of the 59 nests were in the wire zones, whereas 41% of nests were in border zones. In conclusion, mowing plus herbicide treatment on a ROW may be the best application of the wire zone-border zone method in terms of resistance to seedling invasion of undesirable trees, cover-type developments in the wire zone, and its value as wildlife habitat. Wire-border zone method is extremely valuable to the long-term conservation of early successional bird species.

99. Yahner, R.H., and R.J. Hutnik. 2004. "Integrated Vegetation Management on an Electric Transmission Rights-of-Way in Pennsylvania." Journal of Arboriculture 30(5): 295–300.

The authors review the history of maintenance of ROW on State Game Lands 33 in Pennsylvania since 1953. Authors note the border zone/wire zone method was implemented on these ROW in 1987. The objective of this study was to present incompatible tree-density data in response to IVM treatments two and three years after treatment in the year 2000. Treatments in historically herbicide-maintained sites included mowing, mowing plus herbicide, stem-foliage, foliage, basal low volume. Stem densities measured in 2002 and 2003 for these sites averaged 104 and 138 stems per acre in wire zones and 329 and 203 stems per acre in border zones. Historically, hand-cut-only sites were also measured. These sites averaged 2,501 and 3,551 stems per acre in border zones and 3,201 and 3,301 stems per acre in border zones. Authors concluded that IVM-based herbicide treatments result in a stable plant community that resists invasion by incompatible tree species. The authors report IVM and the wire-zone/ border-zone method has increased cycle length, thereby reducing labor and chemical costs.

100. Yahner, R.H., and R.J. Hutnik. 2005. "Plant Species Richness on an Electric Transmission Right-of-Way Using Integrated Vegetation Management." Journal of Arboriculture 31(3): 124–130.

In this paper, the authors' objective was to document plant species richness among treatment units and in relation to wire and border zones on the SGL 33 Research and Demonstration Area. Data was collected on the presence of plant species from late May through mid-August in both 2003 and 2004, and observed 125 vascular plant species in the 15 treatment units. The total number of species per unit ranged from a low of 35 species in a mowing unit to a high of 63 species in a basal low-volume spray unit. Of the total number of plant species found on the ROW, 95 (76%) and 110 (88%) occurred in wire and border zones, respectively. In wire zones, the average number of plant species ranged from 31 in mowing units to 41 in foliar spray units. In border zones, the average number of plant species varied from a low of 34 in mowing units to a high of 41 in hand-cut units. The proportion of exotic species did not vary appreciably between wire and border zones (19% and 22% of total, respectively) on the ROW.

101. Yahner, R.H., R.T. Yahner, and R.J. Hutnik. 2007. "Long-Term Trends in Small Mammals on a Right-of-Way in Pennsylvania." U.S. Journal of Arboriculture and Urban Forestry 33(2): 147–152.

The authors update a study of small mammals conducted 15 years earlier (1989 to 1990) on the State Game Lands 33 ROW. Field work involved a two-year live-trapping study in 2004 on small mammal populations on this ROW. The objectives of the study were to determine relative abundance and species richness (number of species) in six major cover types and in the adjacent forest. One hundred twenty-one individuals of 8 species were observed in 2004 and 2005 combined; the most common species was the white-footed mouse (*Peromyscus leucopus*). One of the most important cover types to small mammals on the ROW was forb grass, whereas the forest cover type tended to be less diverse in terms of number of mammal species than in cover types on the ROW. Small mammals are important wildlife species on a ROW by consuming tree seeds, thereby reducing invasion of incompatible tree species.

CONCLUSION

Seventy plus years of research do, in fact, provide a powerful environmental and economic case for managing vegetation on ROW with herbicides within the context of an integrated system. The key word here is "system." Integrated vegetation management provides a system, a process, and a framework for managing to achieve an outcome—not just solving the problem of dense, tall-growing vegetation interfering with ROW objectives. The outcome, of course, is establishing low-growing, compatible vegetation that will prevent incompatible vegetation from dominating the plant community on the ROW. This outcome leads to lower cost inputs—crews, equipment, and volume of herbicide, and less impact on the environment. Rights-of-way managed using IVM provide greater conservation services—cleaner water, a more diverse and stable plant community, and wildlife habitat. All these outcomes demonstrate environmental stewardship by the ROW owner and practitioners. Integrated vegetation management also delivers on ROW objectives—access to assets and reliable delivery of utility services.

One item we were curious about as we reviewed these papers was when the term "IVM" first appeared, and who might have coined the term. The early practitioners cited using selective herbicide applications to develop low-growing plant communities were electric utility companies in New England, New York, and Pennsylvania. The concept of integration of selective application into a system based on IPM principles came out of efforts in New York State. While many attributed Kevin McLoughlin as the primary force (anyone who knows McLoughlin will understand our choice of the word "force"), the earliest use of the term IVM the authors could find was in the IPM position paper for New York State, Appendix A (McLoughlin 2002).

The economic case for IVM has been made by many authors. The most definitive and analytic case using industry-wide data is presented by John Goodfellow and others (Goodfellow and Nowak 2017; Goodfellow et al. 2018).

The authors reviewed more than 150 sources in the process of developing this annotated bibliography. The papers truly do tell an incredible story. Our purpose in writing the annotated bibliography was to provide a resource for practitioners of ROW vegetation management. We hope practitioners find it useful as they develop IVM programs and in educating internal and external stakeholders to demonstrate that IVM is the best approach. Current researchers and practitioners will lead the way in developing the next chapter of this evolving story through research, demonstration of new work practices, publication, and resulting changes to standards. We look forward to their work.

AUTHOR PROFILES

Thomas E. Sullivan
Tom Sullivan has 40+ years of electric utility experience as an employee and consultant to National Grid, and its predecessor companies, and as a Project Management Consultant to other Northeast U.S. utilities. For most of his career, he managed the Transmission Forestry Department at National Grid. As a forester, Sullivan holds a Master of Science degree in biology from Boston University and a Bachelor of Science degree from the College of Environmental Science and Forestry at Syracuse. He is a Certified Arborist and Massachusetts Licensed Forester. Sullivan is active in professional organizations and has served as a Director of the Utility Arborist Association, from which he received the Utility Arborist Award in 2004. He is currently President of the Princeton Land Trust and Tree Warden for his hometown.

Philip M. Charlton, PhD
Dr. Phil Charlton is Principal and Owner of Charlton & Associates, LLC. He has over 30 years of experience in the electric and pipeline utility vegetation management industry and was the 2001 recipient of the UAA Utility Arborist Award. Dr. Charlton holds Master of Science and Doctorate degrees in forest science from West Virginia University. He worked for Environmental Consultants, Inc. (ECI), a utility vegetation management consulting company, for 26 plus years. While at ECI, he participated in the assessment of the distribution line clearance and transmission rights-of-way vegetation management programs of over 150 utilities. Dr. Charlton was also involved in extensive research on tree-caused power outages, a wide range of herbicide use and related environmental issues, and developed cost and effectiveness models for ROW management in New York State. Dr. Charlton retired as President and Chief Operating Officer of ECI in 2006. He served as the Executive Director of the Utility Arborist Association from 2011 to 2021.

John W. Goodfellow
John Goodfellow has 40 years of experience in the utility industry, having held positions of responsibility for

vegetation management, T&D operations, maintenance, engineering, and construction at three electric and gas utilities. He is recognized as a leading authority on utility vegetation management and reliability. Goodfellow currently manages an active portfolio of VM-related research projects focusing on electrical characteristics of tree-conductor contacts, tree biomechanics, and integrated vegetation management practices. Goodfellow was a member of the team that created the Rights-of-Way Steward accreditation program focusing on IVM and serves as Chair of the Technical Advisory Committee of ROWSC. Goodfellow received a Bachelor of Science in environmental resources management from SUNY College of Environmental Science & Forestry and a Bachelor of Science in forestry from Syracuse University.

Approach to Delivering Sustainable Conservation Programs on Pipeline Rights-of-Way and Facilities

David Murk and Mary Youpel

Keywords: Energy, Pipeline, Pollinator.

America's natural gas and oil companies are mindful of the responsibilities associated with affordably and reliably delivering the energy that is fundamental to daily lives here in the U.S. and around the world. American Petroleum Institute (API) members are actively working together to track and improve their sustainability performance while striving for appropriate engagement and transparency with communities and stakeholders. To support its members and their commitment to environmental, social, and corporate governance (ESG) issues, API formed a task force in spring 2021 to support the development of conservation guidelines for oil and natural gas infrastructure management (e.g., rights-of-way [ROW]). The result of that effort are guidelines and best practices for habitat management (HM), integrated vegetation management (IVM), species-specific HM, and coastal restoration projects. The goal is to provide industry and member organizations access to information, tools, and resources to gain knowledge and build capacity for safe and effective conservation programs on ROWs. Built upon adaptive management principles, the API Conservation Program takes an integrated and systematic approach in sustaining ROW land management that is value driven. The result is enhanced safety, community benefits, operational efficiencies, and a healthier ecosystem while maintaining compliance with state and federal regulations and accounting for risk and cost.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

America's natural gas and oil companies are mindful of the responsibilities associated with affordably and reliably delivering energy that is fundamental to public lives. The transmission of this energy should be achieved in a way that recognizes and delivers positive social, environmental, and economic impacts. Midstream companies are actively working together to track and improve their sustainability performance while striving for appropriate engagement and transparency with communities and stakeholders. American Petroleum Institute (API) remains committed to building tools and platforms to help the industry enhance and expand a culture of safety and sustainability throughout all operations.

As part of this initiative to accelerate ongoing conservation efforts, API established a Midstream Conservation Program (MCP) and released new guidelines on February 10, 2022, to help pipeline and energy infrastructure operators advance conservation practices for pipeline rights-of-way (ROW) and other industry infrastructure. These guidelines were the first milestone in a broader effort to develop and implement resources and an industry program for conservation. The program is creating standard approaches for establishing conservation plans for the lands within the footprint of member company operations while driving a deep, long-term, positive impact within and across the industry and the communities in which it operates.

The broader MCP helps industry manage pipeline ROW and other midstream operations in a manner that helps enable effective environmental conservation and community engagement. The goal of the program is to provide industry and member organizations with access to information, tools, and resources to build capacity for safe and effective conservation programs on ROWs. The Midstream Conservation Program's Conservation Guidelines (PDF) provide an initial industry road map for advancing these goals, building on ongoing industry investment.

To help advance the program, industry has established a partnership with Pheasants Forever (PF) and Quail Forever (QF) to implement the MCP. The partnership pairs wildlife habitat management experience from PF and QF with the significant habitat enhancement potential on thousands of miles of U.S. pipeline ROW and facilities. Through leveraging this expertise, industry will help advance environmental stewardship, engage local communities, and establish a basis for further positive impact.

GUIDING PRINCIPLES

The MCP is grounded in many of API's principles and practices that have been adopted by member organizations and industry (Figure 1).

Figure 1. API principles and practices

ROLE OF COMMUNITY ENGAGEMENT

The importance of community engagement in the success of MCP cannot be overstated. Rights-of-way conservation efforts rely heavily on transparent interactions between a variety of stakeholders, including landowners, neighbors, conservation advocates, researchers, and regulators, to understand what would work well in achieving the best possible outcome. Best practices indicate that stakeholders need to be engaged throughout the project life cycle from planning through execution. It is important to engage the right stakeholders at the right level and the right time. This can include identifying stakeholders to stand up a planning team and building a coalition of leaders who will champion the effort. Ultimately, stakeholder buy-in is critical to the success of a conservation effort and to maintaining the company's social license to operate. To further support the pipeline industry in carrying out and strengthening its community engagement, API initiated the development of a new recommended practice, RP 1185, Pipeline Public Engagement. RP 1185 is anticipated to be completed in early 2023 and will address critical topics such as environmental justice, eminent domain, other issues concerning the entire life cycle of a pipeline and support critical engagement within the MCP.

HOW MCP SUPPORTS OPERATORS

Ultimately, a conservation program supports the construction, operation, and maintenance of oil and natural gas infrastructure in a manner that fosters a positive and beneficial experience for communities and the surrounding environment. Specifically, the program helps to:

- Maintain the highest standards of safety
- Increase maintenance and operational efficiencies
- Create a healthier ecosystem (e.g., increasing carbon capture and creating and protecting habitats of threatened or endangered species)
- Improve community relationships
- Support corporate sustainability goals (e.g., ESG reporting)
- Set a foundation for future licenses to operate

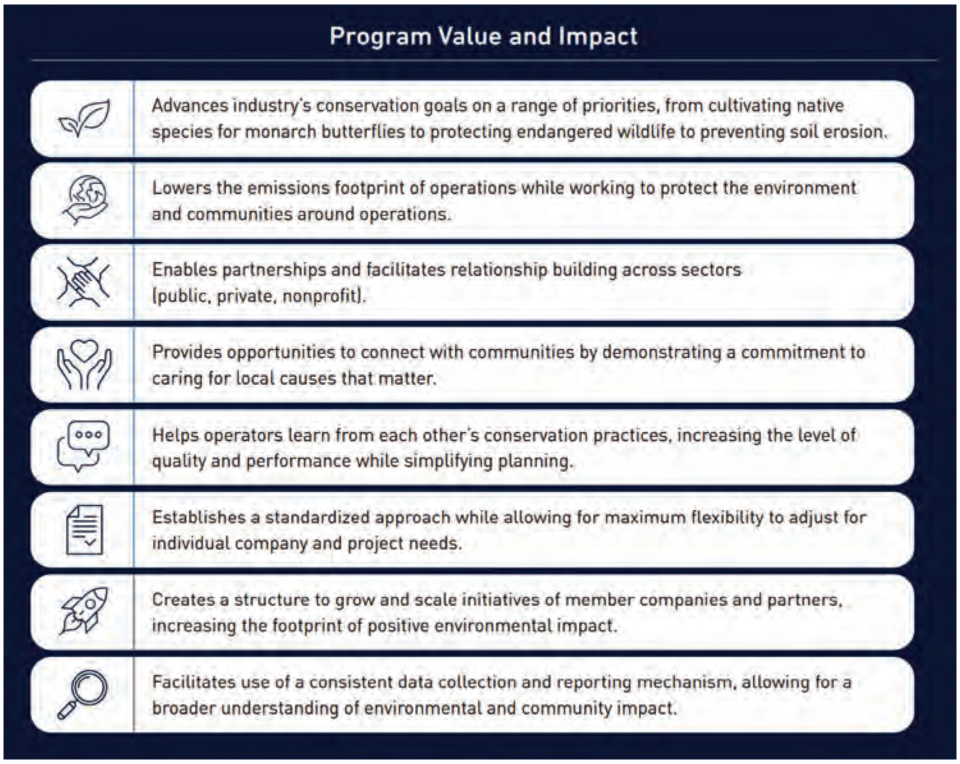

Figure 2. Midstream Conservation Program value and impact—why MCP is important

Figure 3. The Midstream Conservation Program pillars

HOW MCP WORKS

The MCP provides operators with an integrated and systematic value-driven approach to planning, implementing, and sustaining ROW land management. The result is enhanced safety, community benefits, operational efficiencies, and a healthier ecosystem while maintaining state and federal regulatory compliance (Figure 3). Built upon adaptive management principles, conservation projects take a systematic approach to determine the best methods and actions to achieve management objectives while considering benefits, impact, risk, and cost.

OVERVIEW OF THE MCP PROCESS

The ROW Conservation Guidelines are intended to be a starting point for pipeline operators to further mature their management practices to incorporate conservation goals. These guidelines are primarily geared toward oil and natural gas companies evaluating interstate and intrastate pipeline ROWs (pre- and post-construction) to determine whether additional environmental and community value can be derived from the land while maintaining safe and effective transport. It is important that pipeline operators validate with the necessary regulators and landowners before taking any action and to ensure compliance with all appropriate regulatory requirements. Achieving internal alignment is critical for the effort's success.

Pipeline operators should establish a shared perspective and understanding of goals for the conservation effort before they implement new practices. It is recommended that a pipeline operator undertaking conservation efforts establish a planning team that is responsible for engaging the proper individuals throughout the organization at each stage. Proper planning helps prevent unanticipated or unintended outcomes from any changes that result from newly implemented practices. Depending on the goals, ROW conservation programs can vary in their complexity and scope. A simple change to mowing schedules might not require all the same process steps as a full-scale adoption of integrated vegetation management (IVM) practices. There are several planning steps that all conservation efforts are recommended to follow regardless of their complexity. Other steps can and should be layered on top of those foundational elements for more complicated efforts.

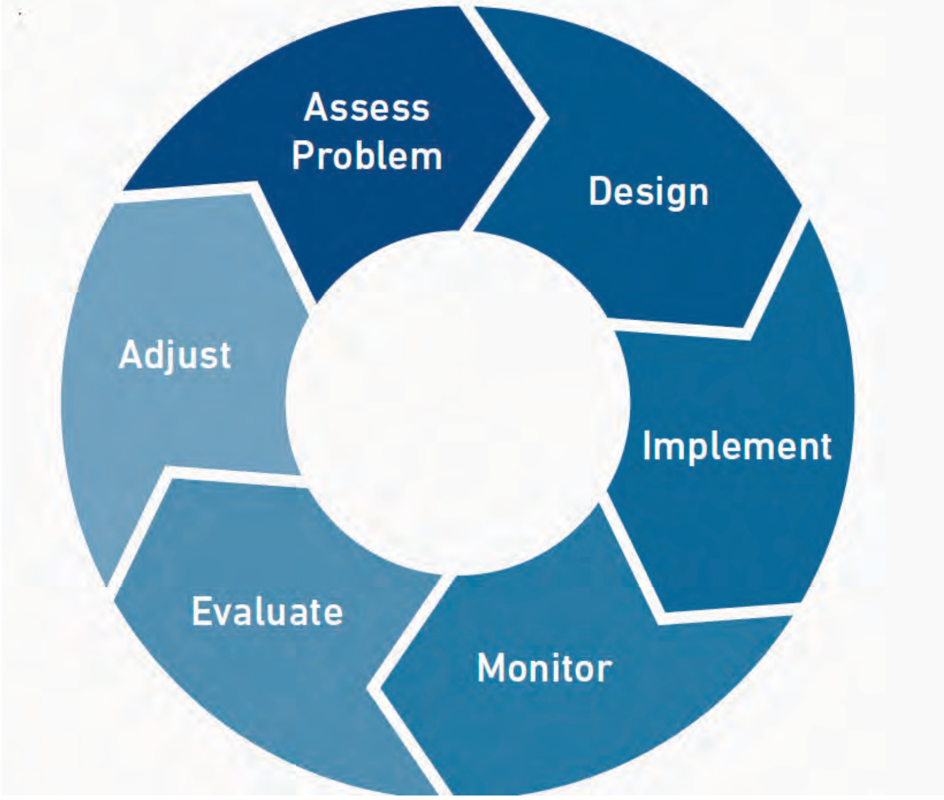

Figure 4. Major steps within the MCP process

MAJOR STEPS WITHIN MCP PROCESS

Identify and Assess Current State of ROW

As planning teams seek to identify potential sites for ROW conservation, they should evaluate the site's opportunities and constraints (Figure 4). Depending on the pipeline operator's level of maturity implementing conservation practices, the planning team may opt to prioritize a site with more opportunities and fewer constraints. As pipeline operators continue to deepen and mature their practices, additional consideration could be given to constrained sites to determine whether some of those constraints can be managed. Pipeline operators should balance the potential benefits of implementing a conservation program with the relative levels of risk. (See Appendix A for a helpful decision-making framework that is adapted from The Nature Conservancy's article, "Risky Conservation: How to Identify and Manage It.")

A pipeline operator does not need to have a perfect sense of all the factors at play, particularly at the early stages of the planning process. Rather, the planning team should be seeking to answer "Is there enough potential to this site to warrant further exploration of a potential conservation program?" Over time, as the decision to embark on a conservation program on a particular site becomes more likely, the planning team should seek to develop a more thorough understanding of the site conditions.

Set Objectives for ROW Site

Setting objectives determines what will be accomplished on the site. For all pipelines, the overarching goal is to provide safe and reliable transmission of oil, natural gas, and their products. However, there is flexibility in how managers meet this goal, and there are opportunities to add additional goals that complement safety efforts. Offering different types of low-growing plant communities or using different treatment methods that conserve elements of the habitat are examples of objectives that can help achieve multiple end goals.

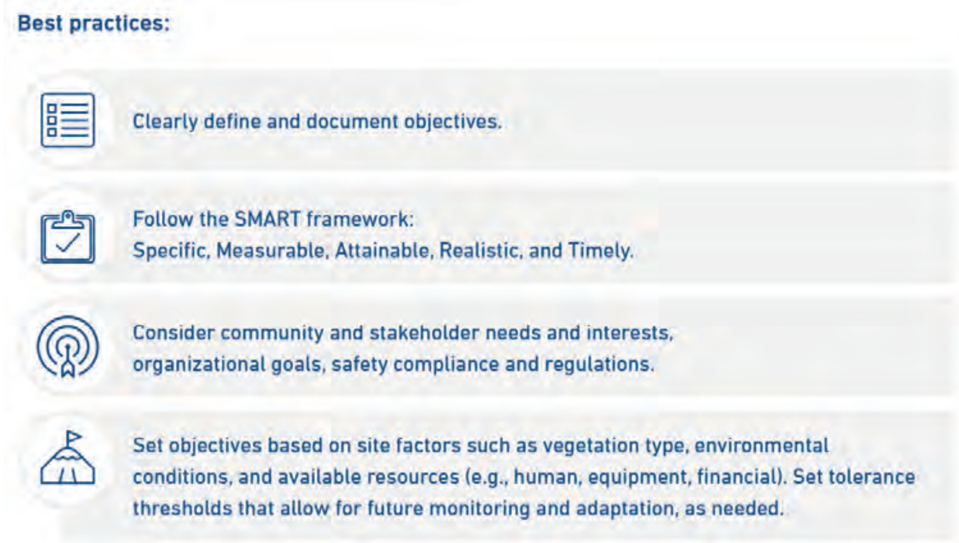

Figure 5. Conservation best practices

Evaluate Potential Conservation Best Practices and Techniques

Based on the site objectives, the planning team should begin to identify specific changes to existing ROW management practices. Broadly speaking, these adjusted practices typically fall in the category of vegetation management, HM, and coastal management. Regardless of the category of the management practice, the ROW planning team should ask themselves the following questions for each management intervention being considered:

- Which of the site objectives will this help achieve? How effectively will it be able to produce that impact? Will it have any additional positive benefits outside of the primary project objectives?
- Will it potentially have negative impacts on any of the other site objectives or any consequences outside the scope of the site objectives? For any potentially negative impacts, do they fall within acceptable levels of risk? If not, might they be mitigated?
- How will our organizational practices need to adjust to help facilitate these changes? Will any policies, contracts, or standards need to be updated to reflect these changes?
- How will it impact costs (up front and long term), if implemented?

Implement Conservation Best Practices and Techniques

The exact process for implementing conservation practices (Figure 5) is likely to vary between pipeline operators. Importantly, the planning team should ensure that practices are in line with existing ROW agreements (e.g., landowner lease or easement) or adjusted in coordination with any landowners, to the extent that changes are necessary. The planning team should also ensure close orchestration with maintenance service providers to make any needed changes to contract language and specifications, guidance with existing service providers, and/or guidance for new service providers are appropriately considered. Prior to implementation, the planning team should also evaluate whether others within their organization have previously made similar changes. If so, the planning team may be able to benefit from the insights gained from that work. Finally, the planning team should validate what, if any, regulatory impacts may exist and should ensure coordination with the proper stakeholders.

CONCLUSION

American Petroleum Institute believes operators can mature their management practices, strengthen their bond with the communities in which they operate, and benefit the environment. American Petroleum Institute expects these guidelines will grow and evolve over time as operators use them and as the impacts become clear.

AUTHOR PROFILES

David Murk

Captain David Murk, U.S. Coast Guard (ret.), is the Director of Pipelines at API and is responsible for the oversight of infrastructure policy and technical issues to support and advocate for the safe and reliable transportation of petroleum liquid, natural gas, and other emerging fuels by pipeline. Prior to joining API in 2016, Murk served 26 years in the public sector, including 24 years with U.S. Coast Guard and two years at U.S. Department of Transportation (USDOT) Pipeline and Hazardous Materials Safety Administration (PHMSA). In his last three years in the Coast Guard, Murk served as the Senior Maritime Advisor to the Secretary of Transportation. At USDOT, Murk served as the Director of Field Operations in the Office of Pipeline Safety, where he helped lead over 140 pipeline inspectors in the oversight of federal safety regulations for natural gas and petroleum liquid pipelines and liquefied natural gas facilities. Murk began his career at the U.S. Coast Guard Academy in New London, Connecticut, earning a Bachelor of Science in applied science and has a master's degree in business administration.

Mary Youpel

Mary Youpel has worked at API since 2019 where she works on Midstream-related topics. In this role, she has helped develop the Energy for Ecosystem program and works with industry members, academic institutions, nongovernmental organizations, and other program partners to advance the industry's conservation efforts. Prior to joining API, Youpel served as Professional Staff on the U.S. House of Representatives Natural Resources Committee where she focused on environmental and oceanic legislation and policy. Earlier in her career, she served as a commissioned officer in the National Oceanic and Atmospheric Administration's Officer Corps, serving at sea. Youpel earned her Bachelor of Science from University of Illinois as well as her Master of Science and Master of Public Administration from Louisiana State University. She is currently working towards her Master of Business Administration from University of Pennsylvania Wharton School of Business.

Assessing Pollinator Habitat Value of Managed Plant Communities Using Pollinator Site Value Indices

Michael R. Haggie, Richard A. Johnstone, and Hubert A. Allen

Keywords: ANSI, *Bombus* and Lepidoptera Pollinators, Electric and Gas Utilities, Energy, Herbicides, Highways, Infrastructure Investment and Education, Integrated Vegetation Management, Invasive Plants, Mowing, Nectar, Oil, Pollen, Prairie, PSVI, Rights-of-Ways, Transportation.

A U.S. federal strategy on pollinators was developed in 2014 due to the decline of honey bees, native bees, birds, bats, and butterflies. Sixty million acres of existing energy and transportation service rights-of-way (ROW) crisscross private, public, and tribal nations lands. The consensus standard ANSI-A300 part 7-IVM recommends that integrated vegetation management (IVM) methods be used to transition the plant community to sustainable, compatible species by facilitating biological controls. Integrated vegetation management can reduce a carbon footprint by managing for native prairie meadow habitat, requiring less maintenance and lower costs; while traditional vegetation mowing hinders climate resiliency efforts and environmental enhancements by increasing greenhouse gas emissions and spreading non-native, invasive plants. This paper documents pollinator habitat improvements through case study research on energy and highway ROW and assesses the nectar and pollen quality for *Bombus* and Lepidoptera insects using pollinator site value indices (PSVI), developed in the Mid-Atlantic area of the United States. These studies assess the success of IVM methods to not only meet the primary objectives of energy and transportation services to the public, but also to restore prime habitat for pollinators and birds. Industry, NGOs, universities, and community colleges are urged to develop the training of skilled workers to apply and assess IVM best practices on ROW, so as we rebuild our nation's infrastructure, we invest in the education and training necessary to restore habitat for insects and birds.

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INTRODUCTION

Integrated Vegetation Management Partners, Inc. (IVM Partners), a 501(c)(3) nonprofit organization, was incorporated in the state of Delaware in August 2003 to develop, educate, and apply best integrated vegetation management (IVM) practices. IVM Partners continued a 20-year collaboration between its Founder and President R.A. Johnstone and Board Member M.R. Haggie, who met when Johnstone was a forester for Delmarva Power and Haggie a botanist for Chesapeake Wildlife Heritage. Together they had documented habitat changes on high-voltage electric transmission rights-of-way (ROW) in Delaware, Maryland, and New Jersey as ROW vegetation transitioned from routine mowing to IVM.

IVM Partners formed partnerships with utilities, agencies, conservationists, and universities to document plant community changes across an additional 22 states, two Tribal Nations, and eight national wildlife refuges; accumulating considerable botanical and photographic data on electric, natural gas and highway ROW, wind farms, solar arrays, golf courses, parks and natural areas, landfills, farms, and rangeland.

With the backing of over 35 years of research data, IVM Partners stresses that the common practice of indiscriminate and untimely mowing decreases biodiversity and raises long-term costs, since it spreads non-native, invasive plants and encourages continued growth of species incompatible with the intended services of ROW and other lands. IVM Partners' significant botanical and photographic data have influenced the American National Standard Institute ANSI-A300 part 7-IVM (ANSI 2018), the ROW Stewardship Accreditation Program, the Federal Strategy on Pollinators, and a Candidate Conservation Agreement with Assurances for the monarch butterfly.

According to the latest ANSI IVM standard, "IVM is used to create, promote, and conserve sustainable plant communities that are compatible with the intended use of the site, and manage incompatible plants that may conflict with the intended use. Chemical methods should be used to transition the plant community to sustainable, compatible species by facilitating biological controls" (ANSI 2018). Properly applied IVM techniques will allow growth of necessary and, in some cases, rare native grasses, wildflowers, and shrubs to proliferate and once again occupy their vital niche. Safe, reliable, and economical utility and transportation services are upheld while converting ROW into biological greenways. Integrated vegetation management reduces erosion, water pollution, and ecosystem degradation while improving habitat for pollinators, birds, and other wildlife.

The Need for a Pollinator Habitat Index

Increased awareness over the last decade of the decline of pollinators—such as colony collapse disorder in honey bees—prompted many conservationists to recommend the planting of pollinator gardens and a wholesale restriction of pesticides. IVM Partners' research showed, however, that native pollinator plants could be restored not by planting but from the dormant native seed bank under an IVM regime that included judicious use of selective herbicide applications to control problem species and facilitate biological controls.

To quantify the benefits of IVM for pollinators, a legitimate measurement of the nectar and pollen values of plants was necessary. Despite substantial web and library searches, a comprehensive list of qualitative nectar and pollen values for bees could not be found. Initially the possibility of incorporating the pollen percent protein data table developed by Roulston and others in 2000 (Roulston et al. 2000) was investigated. Their work on pollen protein average percent is a nutritional value by plant species 'family' but does not include nectar, and many of the plant species analyzed are tropical and not native to North America; thus, for our purposes, their data were incomplete.

In 2014, however, Peter Lindtner, a horticulturalist at the Hagley Museum and a lifelong apiculturist, published the book *Garden Plants for Honey Bees*. His book gives a star (*) rating of 1–5 to measure the nectar and pollen values of horticultural and some native plants of North America for European honey bees (*Apis mellifera* L.). Because of Lindtner's proficiency, expertise, and empirical evaluations of the nectar and pollen values of many botanical genera for honey bees, his star (*) rating represented the beginning of a long sought-after goal of creating a pollinator site value index (PSVI) that evaluated not just plants servicing generalist honey bees, but plants required by specialist native bees as well.

METHODS

IVM Partners and Lindtner started a close collaboration to expand the star (*) *Apis* rating to include all the plants encountered in Mid-Atlantic ROW case study surveys (Table 1). Subsequently, a regional star (*) rating was developed for bumble bees (*Bombus* spp.), with the only changes being the nectar and pollen star (*) values more specific for the genus *Bombus* (Table 2). A *Bombus* PSVI is a better measure of natural habitat restoration than an *Apis* PSVI, as a *Bombus* PSVI reflects the need of dead vegetation and open ground nesting areas (70% of native bees are ground nesting) (Xerces Society for Invertebrate Conservation) instead of colony hive dwelling by honey bees (Figure 1).

Following collaboration with Peter Lindtner, the framework of an initial PSVI was produced that included a biodiversity index (BDI) and adjacent land usage. A BDI measures the total number of plant species in a ROW, both desirable and undesirable. Utility and transportation arborists manage only for plants that are compatible with their primary objectives of safe and reliable transport of services. These plants are mostly low-growing grasses and herbaceous forbs, as well as shrubs and possibly low stature trees in the appropriate ROW zones (explained below). Rights-of-way managers are also restrained by easement restrictions and have no control over shifting adjacent land usage, making that evaluation an unreasonable inclusion in a PSVI. Consequently, our PSVI only measures the compatible plants and subtracts out the incompatible ones, as well as any non-native invasive species, in order to manage a healthy ROW ecosystem.

Figure 1. Ground nesting bee

The final native bee *Bombus* PSVI index consists of the following five parameters:

1. Percent cover of plant species found in field site documentation
2. Nectar * rating of each species' core food value
3. Pollen * rating of each species' core food value
4. Number of regional flowering months per plant species
5. Percent cover of dead vegetation, leaf litter, and bare soil (Maximum 10%) (Johnstone 2021)

The *Bombus* nectar and pollen star (*) ratings (Table 2) are relevant to all states east of the Rocky Mountain front range (excluding Southern Florida), with specific application to the Mid-Atlantic states. It includes the importance of having consistent flowering months to feed migrating pollinators and bare soil or dead plant material for ground and cavity nesting habitat for native bees. The PSVI is designed to be scientifically accurate yet approachable, practical, and easy to use for multiple audiences. The PSVI data helps capture and compare the baseline documented plant community present with existing vegetation management practices, as well as the more diverse native plant community that emerges in the pollinator habitat transition after IVM is implemented. It is an accurate indicator of vegetation being managed for the primary ROW objectives of safe and reliable transport of services to the public, and functionality as a successful pollinator wildlife corridor.

Bombus compilations, which will be referred to as Table 1 (*www.ivmpartners.org/paper-reference-tables-1-6*), list 30 plant orders with 660 species of the Mid-Atlantic region. Where nectar and pollen star (*) values were absent for certain species in a data set, averages were necessarily made by genus, family, or order, whichever least taxonomic unit had the most data, thus creating a truly workable comprehensive list. Further research into nectar and pollen values can fill any gaps and expand to species of other geographic regions.

Where *Bombus* nectar and pollen values are not listed in Table 1 for a plant, either by species or genus, a search for that species at *plants.sc.egov.usda.gov/java* by "Scientific Name," "Common Name," or "Symbol Code" is necessary. At the USDA Plants Database website, under "Classification" at the bottom of the "General" page, the family or order is given according to USDA/NRCS taxonomic criteria, which uses the International Plant Name Index (IPNI) (*www.ipni.org*). Cross-checking the family or order given against existing data (Table 1) will give the average nectar/pollen star (*) value to the lowest taxonomic level achievable. A more concise and easier reference is provided in what we will call Table 2 (*Bombus* Nectar and Pollen Star Ratings Sequenced by Order on the IVM Partners Inc. website). As an example, Eastern blue star (*Amsonia tabernaemontana* Walter), which has no Lindtner nectar/pollen star (*) rating, is in the family *Apocynaceae*, the least taxonomic unit in this case, receives that family (*) rating of 1.0 for nectar and 1.3 for pollen.

When searching the USDA/NRCS website under "Classification" and using Table 1, there are two taxonomic systems referenced: Cronquist and APG III. For example, rough buttonweed (*Diodia teres* Walter) is placed in the Cronquist taxonomic system in the Order Rubiales, but in the APG III system it is placed in the Order Gentianales. The PSVI tables use the Cronquist system, that was developed in 1968, along with the APG system (developed as APG I in 1998), with referenced updates. In the Cronquist system, nectar/pollen values for the family Rubiaceae are 2:1.3, and under the APG III system nectar/pollen values for the Order Gentianales are 1.7:1.2. Thus, rough buttonweed is assigned the values for nectar/pollen of 2:1.3, with priority assignment of N/P values to the lower family level. In the absence of *Bombus* nectar and pollen (*) data, the default is the Lindtner *Apis* (*) ratings (Lindtner 2014).

Though there are situations where statistical differences can be found between the two, the pollen and nectar source values for *Apis* and *Bombus* are similar. Where data for *Bombus* are not available, *Apis* pollen and nectar star (*) values can provide a good measurement.

RESULTS

IVM Partners' case studies are normally performed on 10 x 30 meter managed survey areas that have a mix of plant species representative of the majority of the ROW conditions. Where possible, both upland and wetland sites are chosen and replicated to discern the ecosystem differences. Sampling the same sites in both spring and fall months is preferred, but if only one annual sample is conducted, it is performed during the same annual season.

A skilled botanist is required to discern the plant species since 100% of the case study vegetative cover is documented and the majority of plant species cover less than 1% of the community. We sort our field data tabulated by 20 living plant categories (VT-Vegetation Type) and two non-living categories (DEVE [Dead Vegetation] and BASO [Bare Soil]). From this table we can note and graph the percent ground cover of various plant types (incompatible trees, grasses, herbs), assess whether invasive plants are being controlled by the IVM methods employed, and track the amount of potential nesting sites for native bees.

The core food values of each plant species involve the multiplication of percent vegetative cover by pollen (P) and nectar (N) source star (*) values to create an index with a maximum of 5,000 for nectar and 5,000 for pollen (seasonal cumulative totals). The maximum value of any of our plots never exceeded 40% of the total possible (10,000 N+P) and no site measured zero.

To gauge the success of the IVM program to meet the ROW primary objectives of safety, access, and reliability, plant species that are incompatible with those objectives receive a zero value, as do non-native, invasive plant species that should be selected against. Thus, a case study documentation that has a high accumulative PSVI score will substantiate that the IVM program has selected for a plant community that is compatible with its operational needs, while at the same time producing quality pollinator habitat. This quality pollinator habitat also equates with an ecosystem restoration that provides natural habitat for birds and other wildlife.

We note that fifteen (15) plant taxonomic orders consistently dominate in providing pollinator food, namely: Asterales, which includes the family Asteraceae (asters); Caryophyllales, which includes the family Polygonaceae (smartweeds); Fabales, which includes the family Fabaceae (legumes); Lamiales, which includes the family Lamiaceae (mints); Gentianales, which includes the family Asclepiadaceae (milkweeds); Myrtales, which includes the family Onagraceae (evening primroses); and Sapindales, which includes the family Anarcardiaceae (sumacs). We predict that it may be possible in the future to use satellite imagery or a smartphone camera app to analyze the infrared or ultraviolet signature from a photograph of a site and capture the major plant community to discern the important pollinator species.

Another measure of habitat quality of an IVM program is taken from work on Lepidoptera by researchers at the University of Delaware, Douglas L. Tallamy, and Kimberley J. Shropshire, summarized in the abstract of their 2009 publication "Ranking Lepidopteran Use of Native Versus Introduced Plants."

> *Abstract: In light of the wide-scale replacement of native plants in North America with introduced, invasive species and noninvasive ornamental plants that evolved elsewhere, we compared the value of native and introduced plants in terms of their ability to serve as host plants for Lepidoptera. Insect herbivores such as Lepidoptera larvae are critically important components of terrestrial food webs and any reduction in their biomass or diversity due to the loss of acceptable host plants is predicted to reduce the production of the many insectivores in higher trophic levels. We conducted an exhaustive search of host records in the literature. We used the data we gathered to rank all 1,385 plant genera that*

occur in the Mid-Atlantic states of the United States by their ability to support Lepidoptera richness. Statistical comparisons were made with Welch's test for equality of means. Woody plants supported more species of moths and butterflies than herbaceous plants, native plants supported more species than introduced plants, and native woody plants with ornamental value supported more Lepidoptera species than introduced woody ornamentals. All these differences were highly significant. Our rankings provide a relative measure that will be useful for restoration ecologists, land-scape architects and designers, land managers, and landowners who wish to raise the carrying capacity of particular areas by selecting plants with the greatest capacity for supporting biodiversity.

Similar to our PSVI for *Bombus*, we take the percent cover of each plant species multiplied by the Lepidopteran numerical ranking as a larval host food plant and sum them for that year. Again, plants that are incompatible with the ROW objective, such as tall-growing trees on an electric ROW, receive a zero value to validate the relative success of the IVM program in managing desirable species that meet the operating goals of safe access and reliability while also improving habitat for Lepidoptera pollinators (Table 3, Lepidopteran Larvae Mid-Atlantic Plants Worksheet at *www.ivmpartners.org/paper-reference-tables-1-6*).

IVM Partners' PSVI indices for *Bombus* and Lepidoptera provide a good measure of the success of an IVM program to meet the operational objectives of the ROW or other lands by documenting the botanical community of any section of land; have it monitored over a period of time as to the suitability of the management procedures in place; and rank the benefits obtained for native *Bombus* and/or Lepidopteran pollinator insects.

The potential of ROW to restore habitat critical to the survival of pollinators is immense. Approximately 60-million acres of the United States are

Figure 2. Treatment of invasive Autumn Olive

Figure 3. Treated ROW in milkweed

contained in linear ROW, according to research at Purdue University (Holt 2016). These corridors crisscross every ecosystem in our country, covering more land than is presently protected by the National Park System in the lower 48 states. If these lands are managed with IVM best practices, we are well on our way to protecting 30% of our country by 2030, a goal of the Biden Administration's Conserving and Restoring America the Beautiful (U.S. Department of the Interior 2021).

Our research shows that IVM best practices will improve pollinator habitat while also improving the functionality of the ROW, and will do so through more economical and environmentally acceptable means than conventional practices. We provide the following three documented case study examples where the past practice of mechanical cutting was replaced with IVM techniques that restored native habitat beneficial to pollinators while meeting the operational needs of the ROW corridors:

- Electric Transmission ROW Case Study: Patuxent National Wildlife Refuge, Maryland (Figures 2 and 3)
- Highway ROW Case Study: RT 275, Alabama (Figures 4 and 5)
- Natural Gas Transmission ROW Case Study: J. Percy Priest, Tennessee (Figures 6 and 7)

Our research also substantiates that a ROW should be divided into vegetation management zones, as recommended in the consensus standard ANSI A300 Part 7-IVM. The reliability standard FAC-003 enforced by NERC (North American Electric Reliability Corporation) requires high-voltage electric transmission vegetation to be managed on the ROW to prevent height growth that risks a contact outage that could cause a cascading loss of power. Many utilities obtain this clearance by periodically mowing everything down within the entire ROW. The Wire Zone-Border Zone concept

Figure 4. Highway before treatment

Figure 5. Highway herbicide treated

recognizes that low vegetation types, such as prairie grass and wildflowers, should be managed directly under the electrical conductors (Wire Zone) where clearance is most important, while allowing shrubs and low-stature trees to grow outside the conductor area to the ROW corridor edge (Border Zone) to improve habitat for pollinators, birds, and other wildlife. This type of management requires selective treatment and is not a one-size-fits-all program.

Similarly, the majority of natural gas and oil pipeline ROW are routinely mowed across their entire width to maintain sight distance between pipe markers and to allow periodic leak detection maintenance. But those needs can be accomplished by managing for low-growing grass on a narrow swath directly over the pipes while allowing wildflowers and shrubs to grow in between pipelines and to the ROW edge; a Pipe Zone-Border Zone concept.

Highway ROW recognize three zones. Zone 1 needs to be managed for grass in the area directly adjacent to the road surface to enable sight distance and vehicle escape, but unfortunately most departments of transportation routinely mow not only this critical area, but the entire highway ROW back to the boundary fence, which could be several hundred feet wide. The area next to Zone 1 contains the road drainage area consisting of a swale/ditch designated (Zone 2). Behind the swale/ditch to the road boundary fence is termed the back-slope or Zone 3. Both Zones 2 and 3 do not need to be populated with only grasses but should be managed for wildflowers, shrubs, and low-stature trees that do not threaten vehicle safety but do provide food and nesting habitat for pollinators and birds.

Routine mechanical mowing is the most common vegetation maintenance practice that is destructive to habitat and wildlife and is contrary to the climate resiliency focus of reducing greenhouse gases and use of fossil fuels. Federal land

Figure 6. Pipeline mowed

Figure 7. Pipeline treated: pipe zone-border zone

management agencies, such as the U.S. Forest Service, often require an extensive environmental assessment before a ROW can change from routine maintenance mowing to IVM, siting NEPA (National Environmental Policy Act). This process can hold up the implementation of habitat management using IVM best practices for years. Since knowledge and use of selective herbicide chemistry is necessary to control problem and invasive plant species, IVM Partners can help facilitate this transition by reviewing the unique characteristics of each ecosystem and recommending suitable chemical application techniques. If America is going to upgrade its infrastructure, obstructive regulations and permits need to be fast-tracked as well to enable pollinator and wildlife habitat upgrades.

Case studies are also established to capture the existing plant community where a new ROW is proposed. This baseline documentation is then compared with the plant community that germinates after the existing vegetative cover has been cleared. These studies document that native early successional plants—some of which are classified as rare or endangered species—will germinate from dormancy when the established vegetative cover is removed. Subsequent IVM treatments can remove any germinating incompatible or invasive plants to retain this critical habitat. Tribal Nations recognized this natural plant succession and often used fire, an IVM method, to burn off vegetative cover and regenerate native prairie habitat.

Today, American native prairie and meadow habitats are rare but ROW offer a restoration opportunity if properly constructed and managed. Our studies substantiate the importance of the topsoil layer as the source for the dormant native seed bank and the need for protection and separation of topsoil during ROW construction, rather than wholesale mixing of all soil profiles. Case in point: IVM Partners negotiated a partnership for a natural gas pipeline replacement project crossing a wetland in Canaan Valley NWR in West Virginia that contained a rare plant, Dewey Hayden's sedge (*Carex haydenii* Dewey). The agreed upon plan consisted of the gas company contractor removing the sedges and transplanting them adjacent to the ROW; FWS interns harvesting the sedge seeds and storing them; topsoil being isolated and stored separately from mineral soil profiles; and the pipeline being replaced followed by mineral soil being spread back over to original contours, followed by topsoil being similarly spread. No artificial seeding or mulching was used. The result was the rare plant habitat being restored to its original health. This type of construction practice, and a reassessment of mandated mitigation landscape planting of aggressive introduced grass species to control erosion, could effectively restore native plant communities.

The common construction practice of "deep clearing" (removing tree stumps and roots after felling) should be restricted to the footprint of tower sites and access routes for high-voltage electric transmission or wind turbines, or the road and pipeline routes of highways and natural gas/oil utilities. The majority of the proposed ROW footprint should have the topsoil, which stores the native seed bank population and symbiotic fungi, scraped off and stored separately while the other soil layers are mixed and compacted during construction. This rich topsoil layer should then be spread back across the disturbed soils after construction is complete, and mulched and seeded where necessary with only an annual grain to stabilize soils, while allowing the dormant native seeds lying in the topsoil time to germinate. IVM techniques can then eliminate any incompatible and invasive plant species that may germinate.

These recommended changes in construction practices are extremely important for infrastructure improvements to accommodate wind turbine generation of electric power. Consistent land wind speed for turbine generation occurs in our country's plains states and on mountain ridges, areas presently lacking electric transmission infrastructure. Wind farms do not consist of stand-alone turbines; instead multiple windmills generate power that is downloaded to a substation and then transported as high voltage along a generator lead line to an existing substation tied in to the electrical grid. These new electric transmission line ROW should be established as recommended with IVM as the accepted best practice for new green energy constructions and their transportation access pathways. Facility construction to offset climate change should not be conducted in a fashion that is deleterious to other areas of our environment.

Utility and highway departments already employ biologists for siting and permitting new construction projects yet neglect to use workers trained in IVM techniques nor employ scientists trained to assess the habitat quality of those completed projects. Certification and training in regional plant identification would create a green jobs pathway for vegetation application jobs to become professional careers. Skilled workers with the knowledge and expertise to identify species to retain for pollinator benefit as well as treatment of target species are necessary for the restoration of habitat beneficial to pollinators and wildlife. IVM Partners is uniquely positioned as a liaison to assist universities and community colleges to develop an IVM curriculum for training botany technicians to monitor the successful management of ROW using *Bombus* and Lepidoptera PSVI indices.

CONCLUSIONS

Multiyear case studies (viewable at *www.ivmpartners.org*) using a PSVI metric provide ample evidence for the value of IVM programs for both pollinator and social functions. The Lepidoptera indices have been developed and are ready for use across the country, while *Bombus* PSVI is established for the eastern half of America. We look forward to working with university partners in the Western states and tropical Florida in determining nectar and pollen benefits of their regions' plant species to expand our *Bombus* PSVI.

As our country upgrades and expands its infrastructure to better meet the needs of society and a changing climate, we have an opportunity to simultaneously upgrade and expand vegetation management practices of ROW infrastructure. Integrated vegetation management provides effective and economical practices to improve our country's ecosystems for our pollinators and other wildlife. Plant identification training by community colleges can develop skilled workers and regional botany technicians necessary to apply and assess IVM best practices on ROW. IVM Partners remains available to work with agency, industry, conservation, university, and community college experts for the necessary education and training of workers. As we rebuild our nation's infrastructure, we must invest in the education and training necessary to restore habitat for insects and birds that, in turn, pollinate 90% of our flowering plants.

PERSONNEL CONSULTED

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Table 1. Comprehensive *Bombus* plant list of star ratings by 30 orders. Available at *www.ivmpartners.org*.

Common Name	*Latin Name*	USDA NRC	Family	Order:Cronquist vs AI	Veg type	Nectar BO
Broadleaf arrowhead / duck po	*Sagittaria latifolia* Willd.	SALA2	Alismataceae	Alismatales	HW	
Sweet flag	*Acorus americanus* (Raf.) Raf.	ACAM	Acoraceae	Alismatales/Arales	HF	
Dragon root arum	*Arisaema dracontium* (L.) Schot	ARDR3	Araceae	Alismatales/Arales	MO	0
Jack-in-the-pulpit	*Arisaema triphyllum* (L.) Schott	ARTR	Araceae	Alismatales/Arales	MO	0
Duckweed (water lens)	*Lemna sp.* L.	LEMNA	Lemnaceae	Alismatales/Arales	HW	
Green arrow arum	*Peltandra virginica* (L.) Schott	PEVI	Araceae	Alismatales/Arales	MO	
Skunk cabbage	*Symplocarpus foetidus* (L.) Salis	SYFO	Araceae	Alismatales/Arales	MO	
				Alismatales		0
Purple stem angelica / great an	*Angelica atropurpurea* L.	ANAT	Apiaceae / Umbe	Apiales	HF	
Hercules' club / Devil's walking	*Aralia spinosa* L.	ARSP2	Araliaceae	Apiales	SL	
Gerard's hare's ear	*Bupleurum rotundifolium(gerar*	BURO	Apiaceae / Umbe	Apiales	HF	1
Caraway	*Carum carvi* L.	CACA19	Apiaceae / Umbe	Apiales	HF	
Queen Anne's lace	*Daucus carota* L.	DACA6	Apiaceae / Umbe	Apiales	HF	1
English ivy	*Hedera helix* L.	HEHE	Araliaceae	Apiales	VH	
Spreading hedgeparsley	*Torilis arvensis* (Huds.) Link	TOAR	Apiaceae / Umbe	Apiales	HF	
Golden alexander	*Zizia aurea* (L.) W.D.J. Koch	ZIAU	Apiaceae / Umbe	Apiales	HF	1
				Apiales		3
Swamp holly / possumhaw	*Ilex decidua* Walter	ILDE	Aquifoliaceae	Aquifoliales/Celastrales	TS	
Inkberry / gallberry	*Ilex glabra* (L.) A. Gray	ILGL	Aquifoliaceae	Aquifoliales/Celastrales	SL	
American holly	*Ilex opaca* Aiton	ILOP	Aquifoliaceae	Aquifoliales/Celastrales	TLa	4
Common winterberry	*Ilex verticillata* (L.) A. Gray	ILVE	Aquifoliaceae	Aquifoliales/Celastrales	SL	
				Aquifoliales		4
Canadian wild ginger	*Asarum canadense* L.	ASCA	Aristolochiachea	Aristolochiales	HF	
				Aristolochiales		
Common yarrow	*Achillea millefolium* L.	ACMI2	Asteraceae / Con	Asterales	HF	1
Lesser snakeroot	*Ageratina aromatica* (L.) Spach	AGARA	Asteraceae / Con	Asterales	HF	
Lesser snakeroot	*Ageratina aromatica* (L.) Spach	AGARA	Asteraceae / Con	Asterales	HF	
Snakeroot	*Ageratina sp.* Spach	AGERA2	Asteraceae / Con	Asterales	HF	2
White snakeroot	Ageratina altissima (L.) R.M. Kin	AGAL5	Asteraceae / Con	Asterales	HF	
Common ragweed	*Ambrosia artemisiifolia* L.	AMAR2	Asteraceae / Con	Asterales	HF	0
Great ragweed	*Ambrosia trifida* L.	AMTR	Asteraceae / Con	Asterales	HF	
Nodding beggar-tick	*Bidens cernua* L.	BICE	Asteraceae / Con	Asterales	HF	3
Beggarticks	*Bidens sp.* L.	BIDEN	Asteraceae / Con	Asterales	HF	3

Table 2. *Bombus* Nectar and Pollen Star Ratings Sequenced by Order. Available at *www.ivmpartners.org*.

BOMBUS 680+ Plants SEQUENCED BY PLANT ORDER						
Order	**Description**	***Bombus* N Accumulative value**	***Bombus P* accumulative value**	**n #**	**Nectar**	**Pollen**
Alismatales/Arales	Arums/water plantains/pondweeds/duckweeds	0	2	2	0.00	1.00
Apiales	Wild carrot/wild parley/Hedera	3	3	3	1.00	1.00
Aquifoliales/*Celastrales*	Ilex hollies	4	3	1	4.00	3.00
Asterales	Sunflowers/composites	121	112	59	2.05	1.90
Asterales - Helianthus only	Sunflowers	17	22	6	2.83	3.67
Asterales - Solidago only	Goldenrod	6	8	3	2.00	2.67
Asterales - Symphyotrichum only	Asters	12	12	6	2.00	2.00
Asterales - Verbesina only	Crownbeards	7	5	3	2.33	1.67
Asterales - Vernonia only	Ironweeds	5	4	2	2.50	2.00
Brassicales/Capparales	Mustards/pepperweed/yellow rocket/Brassicas	1	1	1	1.00	1.00
Campanulales/*Asterales*	Bellflowers	1	2	1	1.00	2.00
Caryophyllales/*Polygonales*	Smartweeds/pinks/catchflies/cacti/succulents	19	7	7	2.71	1.00
Caryophyllales - Polygonales alone	Smartweeds	15	6	6	2.50	1.00
Caryophyllales alone	Pinks, catchflies/cacti/succulents	1	1	1	1.00	1.00
Celastrales	Bittersweet/Euonymus	1	1	1	1.00	1.00
Commelinales	Day flowers/Pickerle weeds	8	8	3	2.67	2.67
Cornales	Dogwoods/hydrageas/Nyssas	2	3	3	0.67	1.00
Dipsacales	Honeysuckles/elder/viburnums	9	10	5	1.80	2.00
Ericales	Blueberries	22	16	12	1.83	1.33
Euphorbiales see ME (APG II)	Spurges					
Fabales/Polygalales	Legumes/milkworts	62	50	30	2.07	1.67
Fabales - Desmodium only	Ticktrefoils	3	2	2	1.50	1.00
Fabales - Lespedeza only	Lespedeza	21	17	7	3.00	2.43
Fagales/Myricales	Bayberries/beech/birch	3	6	6	0.50	1.00
Gentianales	Milkweeds/dogbanes	11	9	6	1.83	1.50
Gentianales - Asclepiadaceae only	Milkweeds	7	3	3	2.33	1.00
Gentianales - Apocynaceae only	Milkweeds	2	3	2	1.00	1.50
Geraniales	Geraniums/crane's bills/woodsorrels	5	4	3	1.67	1.33
Hamamelidales	Witch hazels/plane trees	1	2	2	0.50	1.00
Juglandales/*Fabales*	Walnuts	0	1	1	0.00	1.00
Lamiales/Scrophulariales/Boraginales	Mints/figworts/bugloss	32	31	20	1.60	1.55
Lamiales alone	Mints/vervains	15	11	9	1.67	1.22
Lamiales - Lamiaceae - only	Mints	12	8	6	2.00	1.33
Lamiales - Scrophulariaceae - only	Penstemon/mullein, veronica	6	8	5	1.20	1.60
Laurales	Spicebush/sassafras	1	2	1	1.00	2.00
Liliales	Greenbriers/lilies	7	6	5	1.40	1.20
Magnoliales	Magnolia/tulip poplar	5	3	1	5.00	3.00
Malpighiales/Theales/Euphorbiales/Violales	St. Johnswort/violets/willows	23	26	16	1.44	1.63
Malpighiales/Euphorbiales	Spurge/croton	6	3	3	2.00	1.00
Malpighiales/Theales	St. Johnswort	5	5	5	1.00	1.00
Malpighiales/*Violales* only	Violets, passionflower	3	3	3	1.00	1.00
Malvales	Mallows	6	6	3	2.00	2.00
Myrtales	Evening primrose/myrtles/loosestrifes	7	7	3	2.33	2.33
Myrtales - Onagraceae only	Evening primrose	3	3	1	3.00	3.00
Papaverales	Poppies	5	7	4	1.25	1.75
Plantaginales	Plantains	0	1	1	0.00	1.00
Ranunculales	Buttercups	5	9	4	1.25	2.25
Ranunculales - Ranunculaceae		2	4	2	1.00	2.00
Rhamnales	Grapes/buckthorns/VA creeper/olives	15	18	6	2.50	3.00
Rhamnales - Vitaceae only	Grapes	10	14	5	2.00	2.80
Rosales	Roses	65	67	30	2.17	2.23
Rubiales/*Gentianales*	Bedstraw/madder	1	1	1	1.00	1.00
Sapindales	Sumac/maples	30	29	10	3.00	2.90

Table 3. Lepidopteran Larvae Plants Worksheet, Mid-Atlantic Plants. Available at *www.ivmpartners.org*.

Lepidopteran Larvae Family 1360+ (as listed by USDA)	Family as per Robinson et al. 2002	Genus	common name	herb or woody	origin (for analysis)	origin	species counts (Mid-Atlantic numbers unless otherwise indicated)	total Lep spp	exotic Lep spp	Native Lep spp
Caprifoliaceae	Caprifoliaceae	***Abelia***	abelia	w	alien	alien	1 alien	1	0	1
Malvaceae	Malvaceae	***Abelmoschus***	okra	h	alien	alien	1 alien, perhaps another if cultivated	11	0	11
Pinaceae	Pinaceae	***Abies***	fir	w	native	both	3 natives, 1 alien perhaps others if cultivated	117	4	113
Malvaceae	Malvaceae	***Abutilon***	indian mallow, velvet leaf	h	alien	alien	1 alien, perhaps others if cultivated	5	1	4
Fabaceae	Leguminosae(M)	***Acacia***	acacia, wattle	w	native	native unless cultivated	1 natives, perhaps many aliens if cultivated	11	1	10
Euphorbiaceae	Euphorbiaceae	***Acalypha***	copperleaf	h	native	both	5 natives, 1 alien (NY&NJ)	3	0	3
Asteraceae	Asteraceae	***Acanthospermum***	starburr	h	native	both	1 native, 2 aliens	0	0	0
Aceraceae	Aceraceae	***Acer***	maple, boxelder	w	native	both	9 natives, 5 aliens perhaps others if cultivated	297	10	287
Asteraceae	Compositae	***Achillea***	yarrow, sneezeweed	h	native	both	1 native, 4 aliens perhaps others if cultivated	21	1	20
Amaranthaceae	Amaranthaceae	***Achyranthes***	chaff flower	h	alien	alien	1 aliens perhaps 2 others if cultivated	0	0	0
Calyceraceae	Calyceraceae	***Acicarpha***	acicarpha	h	alien	alien	1 alien	0	0	0
Lamiaceae	Lamiaceae	***Acinos***	basil thyme	h	alien	alien	1 alien	0	0	0
Asteraceae	Asteraceae	***Acmella***	spotflower	h	alien	alien	1 alien perhaps another if cultivated (native further south)	0	0	0
Ranunculaceae	Ranunculaceae	***Aconitum***	monkshood	h	native	both	3 natives, 1 alien perhaps others if cultivated	3	0	3
Acoraceae	Acoraceae	***Acorus***	sweetflag	h	native	native unless cultivated	2 natives, perhaps 1 alien if cultivated	0	0	0
Ranunculaceae	Ranunculaceae	***Actaea***	baneberry, bugbane	h	native	native unless cultivated	6 natives, perhaps 1 alien when cultivated	4	0	4
Actinidiaceae		***Actinidia***	kiwi, tara vine	w	alien	alien	Cultivated, 1 alien, perhaps 2 others.	0	0	0
Pteridaceae	Adiantaceae	***Adiantum***	maidenhair fern	h	native	native unless cultivated	3 natives perhaps aliens if cultivated	0	0	0
Fumariaceae	Fumariaceae	***Adlumia***	Allegheny vine	w	native	native	1 native	0	0	0
Ranunculaceae	Ranunculaceae	***Adonis***	muskroot, pheasant's eye	h	alien	alien	2 aliens	0	0	0
Adoxaceae	Adoxaceae	***Adoxa***	adoxa	h	native	native	1 native	0	0	0
Poaceae	Poaceae	***Aegilops***	goatgrass	h	alien	alien	3 aliens perhaps others if cultivated	0	0	0
Apiaceae	Umbelliferae	***Aegopodium***	goutweed	h	alien	alien	1 alien	1	0	1
Fabaceae	Leguminosae(P)	***Aeschynomene***	shyleaf, jointvetch	h	native	native unless cultivated	3 natives, perhaps aliens if cultivated	1	0	1
Hippocastanaceae	Hippocastanaceae	***Aesculus***	horsechestnut, buckeye	w	native	both	6 natives, 2 aliens (1 must be cultivated)	32	0	32
Scrophulariaceae	Scrophulariaceae	***Agalinis***	false foxglove, gerardia	h	native	native	9 natives	4	0	4
Lamiaceae	Labiatae	***Agastache***	hyssop	h	native	native	2 natives	2	0	2
Asteraceae	Compositae	***Ageratina***	snakeroot	h	native	native	2 natives	5	1	4
Asteraceae	Compositae	***Ageratum***	white weed, ageratum	h	alien	alien	1 alien perhaps others if cultivated	7	0	7
Rosaceae	Rosaceae	***Agrimonia***	agrimony, churchsteeples	h	native	both	6 natives, 1 alien	1	0	1
Poaceae	Gramineae	***Agropyron***	wheat grass	h	alien	alien	2 aliens perhaps another if culivated	8	0	8
Caryophyllaceae	Caryophyllaceae	***Agrostemma***	corncockle	h	alien	alien	1 alien	0	0	0
Poaceae	Gramineae	***Agrostis***	bent grass	h	native	both	6 natives, 2 aliens perhaps others if cultivated	5	1	4
Simaroubaceae	Simaroubaceae	***Ailanthus***	ailanthus, tree of heaven	w	alien	alien	1 alien	6	2	4
Poaceae	Poaceae	***Aira***	hairgrass	h	alien	alien	3 aliens	0	0	0
Lamiaceae	Lamiaceae	***Ajuga***	bugle	h	alien	alien	3 aliens	0	0	0
Lardizabalaceae		***Akebia***	chocolate vine	w	alien	alien	1 alien	0	0	0
Fabaceae	Leguminosae(M)	***Albizia***	albizia, silktree	w	alien	alien	1 alien, perhaps others if cultivated	5	2	3
Malvaceae	Malvaceae	***Alcea***	hollyhock	h	alien	alien	2 natives (1 must be cultivated)	22	3	19
Rosaceae	Rubiaceae	***Alchemilla***	lady's mantel	h	alien	alien	1 alien perhap others if cultivated	1	0	1
Liliaceae	Liliaceae	***Aletris***	colicroot	h	native	native	2 natives	0	0	0
Alismataceae	Alismataceae	***Alisma***	water plantain	h	native	native	3 natives	0	0	0
Brassicaceae	Brassicaceae	***Alliaria***	garlic mustard	h	alien	alien	1 alien perhap	[illegible]	0	[illegible]
Liliaceae	Alliaceae	***Allium***	onion	h	native	both	5 natives, 7 aliens perhaps others if cultivated	21	1	20
Poaceae	Poaceae	***Alloteropsis***	summergrass	h	alien	alien	1 alien	0	0	0
Betulaceae	Betulaceae	***Alnus***	alder	w	native	both	4 natives, 1 aliens perhaps others if cultivated	255	7	248
Poaceae	Gramineae	***Alopecurus***	foxtail	h	native	both	2 natives, 4 aliens, others cutlivated	2	1	1

AUTHOR PROFILES

Rick Johnstone

Rick Johnstone serves as President and Founder of the nonprofit corporation IVM Partners and is Owner of VMES, LLC vegetation management consulting. He directs vegetation management research and training under IVM Partners and is an advisor for and liaison between federal, state, and tribal land management agencies, universities, electric and natural gas utilities, and conservationists. Under VMES he provides vegetation management consultation and is an expert witness in litigation. Johnstone served as System Forester for two electric utilities and is Past-President of the UAA and a Registered Professional Forester with a Bachelor of Science degree in forest resources management from West Virginia University. He has more than 45 years of experience and is a technical advisor for restoring native pollinator and wildlife habitat using cost-effective integrated vegetation management strategies.

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Michael Robin Haggie is the Botanist for IVM Partners, a nonprofit corporation which advises agencies and conservationists on the best IVM practices to manage lands and restore habitat essential to the survival of Lepidoptera, native bees, and other pollinators. His botanical surveys cover energy and transportation ROW in more than 15 U.S. states, demonstrating greater access, reliability, cost savings, and improved vegetation management through the implementation of IVM methods. Haggie created a Pollinator Site Value Index to measure pollinator habitat improvements for Lepidoptera and native bees. He and his wife, Marcia, raise Border Leicester sheep for wool and he manages a small apiary on Maryland's Eastern Shore. He has a Bachelor of Science in agronomy and natural resources from Cornell University, New York (1978) as well as Oxford and Cambridge Board Advance Level Certifications in zoology, botany, biology and geology from his native U.K.

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Hubert Allen is an independent researcher. He has an undergraduate degree in applied math and biology with a focus on quantitative ecology from Brown University, and a Master of Science degree in biostatistics from Johns Hopkins University. One of the most important and long-term projects of his as a statistician has been with the co-authors of this paper, evolving evidence-based techniques to improve the management of ROW over a 25-year period.

Beyond the Butterfly: Managing Rights-of-Way for Ecological Productivity

Kieran Hunt

Keywords: Ecology, Habitat, Integrated Vegetation Management (IVM), Pollinator, Restoration.

Most roadside and utility vegetation managers are aware of the importance of managing plants for threatened and endangered species, but any individual species is only a very small piece of the puzzle in a healthy ecosystem. More importantly, healthy, diverse, and functional ecosystems are resilient to disturbance and more likely to support and benefit local flora and fauna. Integrated vegetation management (IVM) is a powerful tool that should be utilized for safety, compliance, and to establish and support communities of native vegetation that are compatible with our land use. In particular, IVM should be employed to achieve goals beyond safety and compliance to benefit local ecosystems and mitigate the habitat loss that is ubiquitous in many developed regions of the world. This paper focuses on innovative practices that use IVM to promote healthy, productive ecosystems, with an eye toward supporting functional food webs and improving bird and other secondary consumer populations.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Broadscale, human-caused disturbance of natural systems is causing global declines in biodiversity and viable habitat. Current best estimates for threats to plant diversity estimate that at least 20% of plant species are threatened with extinction (Brummitt et al. 2015). Insects, broadly understood to be essential to ecosystem function, are also in decline (Wilson 1987; Hallman et al. 2017). One in five of the world's bird species is under threat of extinction, and 1 in 20 is already functionally extinct, which also deteriorates the viability and functionality of ecosystems and their associated food webs (Şekercioğlu et al. 2004).

Pollinators are integral to the function of terrestrial plant communities, and their loss has cascading detrimental effects on the plants and other animals occupying these systems (Hopwood et al. 2015). Managing rights-of-way (ROWs) through IVM can benefit native pollinators and the ecosystems they occupy. The State Game Lands 33 long-term ROW vegetation management (VM) research study in Pennsylvania, USA, has demonstrated that managing ROWs utilizing IVM, including the use of herbicides, supports native animal life, including pollinators (Russo et al. 2021), birds (Ross et al. 2022), rodents (Wolfkill et al. 2021), snakes, and ground beetles (Mahan et al. 2018). Invertebrate-driven pollination networks are integral to functional ecosystem dynamics, and recent ROW managers' special focus on them and their linkage to plant and trophic dynamics is warranted and critical for terrestrial ecosystems (Memmott et al. 2004).

Focus on pollinators and the critical role they play in ecosystem dynamics has benefitted ROW VM through heightened public awareness and buy-in, but vegetation managers should be cautious about focusing on individual species or groups of species. Pollinator declines are a symptom of the larger problem of human-driven habitat loss and fragmentation. Treating the cause means establishing healthy, functional, and resilient ecosystems that can support pollinators and the myriad other plants and animals that utilize the low-growing plant communities compatible with ROWs. Rights-of-way can also serve as effective corridors to link healthy habitats—or detrimental corridors that can spread undesirable vegetation.

Utility and roadside ROW VM has been shifting focus in recent decades from pure compliance-based VM to a focus on IVM, sustainability, and utilizing a variety of control methods to offset costs, while also benefitting the environment (Nowak 2014). Managing ROWs through IVM achieves utilities' primary goal of maintaining safe and reliable transmission of electricity, and roadside managers' primary goal of maintaining necessary sightlines for safe vehicular travel, while achieving additional benefits through focused management of compatible plants (Miller 2021).

CURRENT STATE OF IVM

Vegetation management has changed drastically over the past 100+ years, including the transition from using solely manual and/or mechanical controls to mechanical plus chemical controls; advances in tools, techniques, chemistry, and applications; and utilization of adaptive management (Nowak 2014). The current movement toward sustainability and finding more holistic approaches to land management are leading us toward an ecosystem-based approach.

Integrated vegetation management is a management system that involves planning treatments based upon present conditions, action thresholds, and tolerance levels, performing treatments, assessing the efficacy of those treatments, and adapting subsequent management to new conditions utilizing analysis of past treatment efficacy and vegetation responses (Miller 2021). Practicing IVM on ROWs requires true adaptive management and should improve efficacy and reduce costs over time as multiple cycles of treatment, auditing, and process enhancement and improvement are implemented (Miller 2021). There are many spray programs throughout North America that term themselves "IVM," but fail to practice adaptive management or re-inventory and re-evaluate new treatments.

An integral part of IVM is the utilization of low-growing (compatible with ROWs) plant cover to occupy growing space that would otherwise be overtaken by high-growing (incompatible with ROWs) woody vegetation, such as trees (Miller 2021). The utilization of compatible plant and animal communities to combat incompatible vegetation through competition, allelopathy, herbivory, and other natural processes is termed biological control in the IVM system, and it very effectively reduces the cost of VM compared to purely mechanical controls over multiple treatment cycles (Goodfellow 2019).

Herbicides are currently one of the most effective tools ROW vegetation managers have to control incompatible plants, and their application under the IVM framework leads to a reduction in herbicide use over time (Nowak and Ballard 2005; Westerhold 2018; Miller 2021; Russo et al. 2021). When using adaptive management to promote compatible plant communities, vegetation managers can guide the succession of plant species and communities in an area by utilizing other biological control mechanisms, such as competition and herbivory (Nowak and Ballard 2005). While most IVM programs focus on achieving stable plant communities and reducing management inputs, not all attempt to guide these other mechanisms or focus on improving ecological integrity.

DISCUSSION

A 2019 report on drivers of ecosystem collapse points to the urgent need for transformative change, that reverses ecosystem decline while addressing the socioeconomic drivers of ecosystem deterioration (Díaz et al. 2019). The cost-efficiency of IVM is a strong motivator for ROW managers to convert to this system, and modest additional investment will allow utilities and other ROW managers to be leaders in sustainability and environmentalism by promoting the integrity, productivity, and functionality of ROW ecosystems.

Managing for compatible native plants is a first step. Utilizing ecologists with knowledge of local ecosystems will improve integrity-based ecosystem management. Creating functional food webs in a particular area may require knowledge of interactions between ecosystem components, such as soil, hydrology, plants, and animals. Managing for local keystone plants, or those plants that support large groups of primary consumers, may be helpful for the rapid establishment of productive food webs early on (Narango et al. 2018). In many cases, rare or unexpected native plants may seed in naturally once a compatible ecosystem is re-established (Johnstone and Haggie 2009).

Many plants, including those that are compatible with ROWs, are adapted to habitat types with particular hydrology, soil chemistry and composition, slope, aspect, exposure, and climate (Smith et al. 1997). Key to establishing robust, functional ecosystems is selection of plant types that are naturally adapted to the respective growing site. Plants adapted to a site will be more resilient to disturbance, capable of self-management and proliferation, and able to thrive with fewer management inputs (Smith et al. 1997). Effective strategies for delineating habitat types for smart ecosystem planning are already established. Utilizing remotely sensed and digitized land cover information, much of which may be available for free or low cost, can allow land managers to overlay various criteria, such as soil type, aspect, slope, and hydrology, to determine suitability for a particular ecosystem type (Bernier et al. 2018; Pekar and Race 2018).

Where feasible and appropriate to local ecosystems, ROWs should be managed with different vegetation types in the wire zone (the area directly beneath the wires) and the border zones (the areas bordering, or just outside of, the wire zone). Establishing communities of shrubs and other medium-height woody plants in the border zones to create a soft edge between lower-height wire zone plants and adjacent forested areas is important for birds and other animals in some forested ecosystems (Halle et al. 2019; Ross et al. 2022).

In addition to habitat loss, the invasion of non-native plants has degraded ecosystems. Insect larvae, such as Lepitopterans, are highly valuable food sources for many bird species (Morse 1989), and a 2009 literature review of plant-insect interactions utilizing Lepidopterans as a surrogate for all phytophagous insects estimates that as many as 90% are specialized to feed on only one or a few specific plant species or genera (Tallamy and Shropshire 2009). Functional terrestrial food webs require energy to move from plants to plant consumers, and from there up the food web to other consumers at higher trophic levels. Many insects serve as primary consumers, bridging the gap between plants and other consumers that cannot digest plants and access their energy directly (Tallamy and Shropshire 2009). When these links are severed, such as when invasive exotic plants displace the native plants that local consumers have obligate relationships with, energy transfer is disrupted from plants to higher trophic levels.

While managing for native plants is generally considered to be a best management practice (BMP), there are some established non-native plants, such as autumn olive (*Elaeagnus umbellata*) and wineberry (*Rubus phoenicolasius*) in the Northeastern United States, that can be utilized by native animals as food and habitat sources. Some Indigenous perspectives of non-native plants view these assemblages of exotic organisms as migrants who, now established, should be accepted as members of modern plant communities (Reo and Ogden 2018).

Allowing non-native plants to dominate an ecosystem reduces species interactions between caterpillars and plants (Richard et al. 2018). Allowances can be made for some compatible non-native plants on the ROW where they serve an ecological and practical function, but it is important to note that most non-native plants provide little ecological value, and allowing them is not a BMP. Many escaped ornamental plants were selected for import specifically because of their pest resistance (Dirr 1998), which means few or no native consumers can bring their energy into food webs. Caution should be taken when non-natives are allowed on the ROW, as their lack of predators can give them a competitive advantage over other plants, and an overabundance of non-natives can create an ecological desert for many native animals (Narango et al. 2018). Allowing non-natives to dominate ROWs also facilitates their spread through these corridors to other regions.

CONCLUSIONS

Rights-of-way VM should utilize technology, ecological expertise, and evolving IVM BMPs to establish robust ecosystems that are native to the respective locale, adapted to the specific growing conditions, and able to contribute to ROW management through biological controls. Many utilities and departments of transportation have moved to a geographic information system (GIS) framework to manage their ROWs, and these tools can be utilized to perform spatial analysis for habitat suitability and delineation.

When plant communities that are best adapted to the respective growing conditions are established, they will be most resilient to conversion back to incompatible cover types, bolstering biological controls and reducing management inputs and costs in the long-term. Most importantly, they will serve as ecological reservoirs of functional native habitats that our declining floral and faunal communities desperately need.

Many of the ecosystem benefits to pollinators and other flora and fauna will naturally generate once stable compatible plant communities have been established. Ecosystem integrity can subsequently be supported and enhanced in a variety of ways, including planting, assisted proliferation of plants, introduction of biological controls, and habitat alteration to favor rare, threatened, or endangered species (UAA 2021). Enhancement- and integrity-based interventions will depend on the habitat type and respective needs of local plant and animal communities.

As responsible stewards of this planet, land managers have a moral and ethical responsibility to pursue sustainable ecosystem management, both for the health of ailing floral and faunal communities and for the downstream impacts that their loss would mean for human health and well-being.

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Developing Pollinator Habitat While Mitigating Fire Potential in Southern California ROW

Vince Mikulanis and
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Keywords: Habitat, Integrated Habitat Management (IHM), Integrated Vegetation Management (IVM), Invasive, Native Species, Pollinator, Restoration, Rights-of-Way (ROW), Seeding.

With millions of acres of utility rights-of-way (ROW) throughout North America, utilities continue to evaluate methods for cost-effective and sustainable solutions for vegetation management. The establishment of a low-growing, early successional herbaceous habitat in the wire-zone has long been a recognized best management practice.

In the West, particularly in arid portions of Southern California, an early successional herbaceous habitat often allows for the establishment of flashy, fire-prone, non-native grasses. These grasses have the potential to reduce the population of native species, including pollinator species. Disturbed ground also promotes the establishment of invasive species such as Russian thistle (*Kali tragus*), more commonly known as tumbleweeds. Tumbleweeds in particular can be concerning due to their extreme fire potential, as they tend to accumulate along fence lines common to restrict public access to the utility ROW.

Across North America, there is also growing concern over the decline of pollinator species—stemming from multiple reasons, including loss of habitat. Is it possible to selectively eliminate invasive, fire-prone herbaceous species in the utility ROW while promoting native, pollinator-friendly landscapes? With millions of acres of utility ROW across North America, the potential for this habitat creation is attractive. The benefits can be multifaceted, reducing mowing and maintenance requirements, while promoting environmental stewardship in the form of pollinator habitat creation.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Southern California Edison serves a population of over 15 million people throughout Southern California. Southern California Edison's service territory includes over 12,600 miles of transmission lines, traversing a variety of terrain, from coastal communities, dense urban centers, sparse desert communities, to mixed conifer forests.

In the urban centers of Southern California, SCE's transmission ROW generally consists of flat to moderate terrain. Particularly in the populated valleys, the landscape has been modified through long-standing mowing practices to consist mostly of herbaceous plants, with few to no trees or brush species.

This reliance on mowing as a vegetation management practice may be effective for maintaining minimum clearance distances. However, it has also, over time, given rise to invasive grass and other flora dominating the landscape. These species require multiple mowing applications annually in order to be compliant with local weed abatement codes aimed at reducing fire potential. Additionally, these established species limit the ability to reintroduce desirable native pollinator species that can require a lower frequency of mechanical treatments to maintain compliance with local fire regulations.

In 2021, SCE and the Davey Resource Group began a pilot project on approximately 14 hectares (36 acres) of transmission ROW in San Bernardino County. The goals of the pilot program are to evaluate different methodologies for reclaiming the ROW from invasive species and establishing native, low-growing pollinator plant communities. This paper is meant to provide a summary of the pilot program to date and describe the methodologies, challenges, and current status of the pilot program.

Figure 1. Cedar Ave. location

Figure 2. Cedar Ave. aerial view

METHODS

Southern California Edison identified multiple company-owned parcels in two locations for the pilot project. The locations were collectively referred to as the "Cedar Ave." and "Utility Access Rd."

The Cedar Ave. location is in a highly urbanized area, surrounded by mostly single-family homes and assorted small businesses. Seven distinct parcels are found at that location, delineated by city roadways, private property fences, and a utility easement road running down the middle. There are approximately 9.7 hectares (24 acres) at this location.

The Utility Access Rd. location, while still in an urbanized area, only has concentrated housing on the south side. There is a downward slope toward the east that leads to a new, large-scale commercial business development. To the west and northwest is open space. Two distinct plots were identified at this location, totaling approximately four hectares (10 acres).

A third location was initially identified, however, it was found that the parcels were a mix of SCE and municipally owned; it was determined that the best course of action was to not perform the pilot at this location to avoid confusion. There were indications of fairly heavy use of this location by adjacent residents for recreation purposes, which likely would have resulted in complications during chemical applications.

Figure 3. Utility Access Rd. location

Figure 4. Utility Access Rd. aerial view

Initial Inspections

Davey Resource Group conducted initial inspections of the plots in November 2021. The purpose of these inspections was to identify and catalog herbaceous species present. The species were separated into invasive and California native species, as presented in Table 1.

During the inspections, it was also noted the locations, particularly the Cedar Ave. locations, were being abused by trespassers. A large amount of trash and other debris had accumulated, including household waste, tires, refrigerators, and potentially hazardous chemicals substances, such as gas and oil. The project plan included mitigation of this waste.

Table 1. Species Present

Invasive Weeds/Grasses	Native Weeds/Grasses
Russian thistle (*Kali Tragus*)	Telegraph weed (*Heterotheca grandiflora*)
Bermuda grass (*Cynodon dactylon*)	Golden crownbeard (*Verbesina encelioides*)
Starbur (*Acanthospermum hispidum*)	Field sagewort (*Artemisia campestris*)
Italian wild rye (*Festuca perennis*)	Common sunflower (*Helianthus annuus*)
Perennial rye grass (*Lolium perenne*)	Desert saltgrass (*Distichlis spicata*)
Common mallow (*Malva neglecta*)	Flatspine bur ragweed (*Ambrosia acanthicarpa*)
Arundo (*Arundo donax*)	Reflexed aromath (*Amaranthus retroflexus*)
Tree of heaven (*Ailanthus altissima*)	Goosefoot (*Chenopodium*)
Common storks-bill (*Erodium cicutarium*)	Desert wild grape (*Vitis Girdiana*)
Dandelion (*Taraxacum*)	Black nightshade (*Solanum americanum*)
Field mustard (*Brassica rapa*)	
Cheesewood mallow (*Malva parviflora*)	

Figure 5. Trash and debris at site

Project Plan

Davey Resource Group divided the two locations into nine distinct plots. Plots were designed to evaluate the performance of different combinations of pre-treatment and seeding methods, as presented in Table 2.

Davey Resource Group consulted with two native seed providers, S&S Seeds, Inc. and Stover Seed Company, for appropriate low-growing pollinator species that also may present a lower risk for wildfire when compared to the current population. From those discussions, three seed mixes were identified. Each plot would be subdivided into three sections to evaluate the performance of each seed mix. Pollinator mixes were identified as Terra Bella low-profile wildflower mix and Xerxes Southern California pollinator mix. For the third seed mix, California no-mow native grassland mix was added to the Terra Bella mix. The grass mix was included as a potential competitor to invasive grasses, such as invasive bermuda grass (*Cynodon dactylon*). Included species for each seed mix are presented in Table 3.

A review of climate data from *www.usclimatedata.com* shows that the proper timing of planting to take advantage of the limited rainfall window was from December to February each year.

Table 2. Treatment Plans

Plot	Treatment	Site Prep	Seed Method	Target Seeding
1	None. Potential Herbicide Follow up	None	Broadcast	Target Date: 12-2021
2	None. Potential Herbicide Follow up	None	No-Till Drill	Target Date: 12-2021
3	Herbicide	Till	Broadcast	Target Date: 11-2022
4	None. Potential Herbicide Follow up	None	Hydro Seed	Target Date: 12-2021
5	Herbicide	Till	Hydro Seed	Target Date: 11-2022
6	Herbicide	None	Hydro Seed	Target Date: 11-2022
7	Herbicide	No Till	Broadcast	Target Date: 11-2022
8	Herbicide	No Till	No-Till Drill	Target Date: 11-2022
9	Herbicide	Till	No-Till Drill	Target Date: 11-2022

Table 3. Seed Mixes Used

Low-Growing Native Mix	Xerxes S. Cal Pollinator Mix	CA Native Grassland Mix
Achillea millefolium (Yarrow)	*Achillea millifolium* (White Yarrow)	*Festuca rubra* 'Molate' (Molate Creeping Red Fescue)
Acmispon glaber (Deerweed)	*Clarkia amoena* (Farewell-to-spring)	*Festuca occidentalis* (Western Fescue)
Camissoniopsis cheiranthifolia (Beach Evening Primrose)	*Eriophyllum confertiflorum* (Golden Yarrow)	*Koeleria macrantha* (June Grass)
Clarkia bottae (Punch-bowl Godetia)	*Eschscholzia californica* (California Poppy)	*Deschampsia elongata* (Slender Hairgrass)
Collinsia heterophylla (Chinese Houses)	*Gilia capitata* (Bluehead Gilia)	*Poa secunda* (Sandberg Bluegrass)
Eschscholzia californica (California Poppy)	*Grindelia camporum* (Common Gumplant)	
Festuca microstachys (Small Fescue)	*Helianthus annuus* (Sunflower)	
Lasthenia californica (Dwarf Goldfields)	*Lupinus microcarpus densiflorus* (White Whorl Lupine)	
Layia platyglossa (Tidytips)	*Nemophila menziesii* (Baby Blue Eyes)	
Lupinus bicolor (Bicolor Lupine)	*Phacelia californica* (California Phacelia)	
Lupinus nanus (Sky Lupine)		
Mimulus aurantiacus longiflorus (Sticky Monkeyflower)		
Mimulus aurantiacus puniceus (Mission Red Monkeyflower)		
Muhlenbergia microsperma (Littleseed Muhly)		
Nemophila maculata (Five Spot)		
Sisyrinchium bellum (Blue-Eyed Grass)		

Implementation

To test the requirement of herbicide application, it was initially determined that the three seeding methods would be applied to plots where no herbicide application was conducted. While it was assumed there would be limited success in conversion to the desired habitat types, it is necessary to test this hypothesis.

Davey Resource Group performed broadcast seeding of the three seed mixes to plot 1 in late December 2021, with no herbicide treatment. Due to delays associated with obtaining permits for fire hydrant use for hydroseeding, hydroseeding was delayed throughout January until February 2022. By that time, early season rains that occurred in November 2021 had resulted in significant invasive weed growth to all remaining plots. It was determined that the most appropriate action, given the delays, was to only use plot 1 as a control in terms of no herbicide application and apply herbicide to all remaining plots.

Davey Resource Group contracted a minority vendor to clear the site of refuse and debris in January 2022. Efforts were made to better secure the site; however, trespassers continued to cut locks and use the site as an illegal dump. However, through additional efforts, the sites are relatively clear of unwanted debris.

Herbicide application was conducted in late January 2022. Plots 1–7 had herbicide broadcast applied via an unmanned aerial vehicle (UAV). Plots 7–9 had herbicide applied via utility terrain vehicle (UTV) a week later. The UTV was also utilized in plots 7–9 to apply in areas the UAV could not, such as immediately adjacent to fence lines, within 20 feet of private property, within and around the transmission tower footprints.

As seeding on multiple plots was planned for 2022, the decision was made to only use post-emergent herbicide.

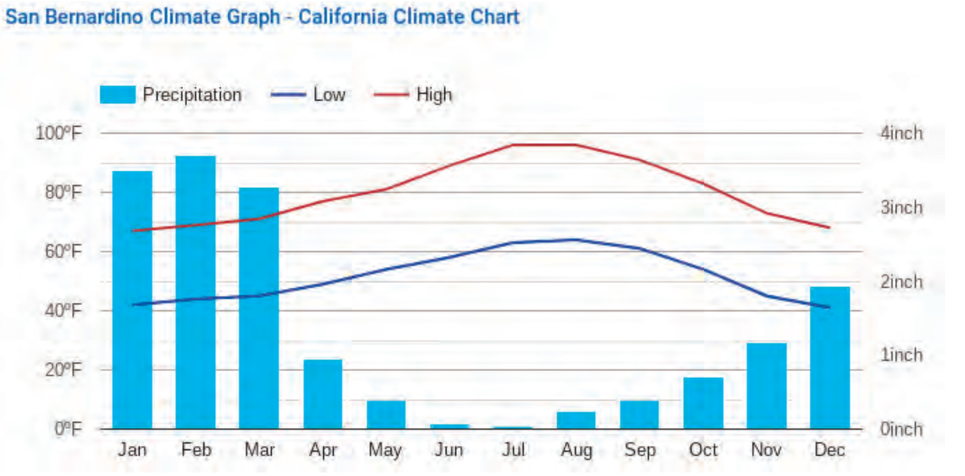

Figure 6. Average climate in San Bernardino. Source: *www.usclimatedata.com*

Figure 7. Aerial spray drone

Figure 8. UTV herbicide application

Pre-emergent herbicides could have rendered the plots unable to be seeded until at least 2024. Davey Resource Group applied a mix of Roundup Pro®, Vastlan™, and Methylated Seed Oil (MSO) with the UTV, and Roundup with Liberate using the drone. Using the UTV, we applied 2% Roundup and Vastlan, 1% MSO, at a rate of 25 gallons mix per acre. Using the drone, we applied Roundup and Liberate, at 4% and .5% respectively, at a rate of 5 oz of concentrated product per acre.

Plot 2 was hydroseeded with the three seed mixes in February 2022. Delays with the contracted drill seeder equipment availability and malfunctions resulted in drill seeding being scheduled in March 2022. As has been well discussed at the national level, rainfall in Southern California fell well below expectations and averages. Historically, January, February, and March should have been the wettest months of the year and provided ample moisture for seed sprouting. However, in 2022, severe drought brought on by a second straight La Niña weather pattern resulted in less than one-inch rainfall in the study area. By mid-February, when it was clear that rainfall would be less than optimal, a decision was made to postpone the scheduled drill seeding until November 2022—with the hope that rainfall patterns would improve for late 2022 and the 2023 rainy season.

Rainfall totals for 2023 are presented in Figure 9. It is important to note that average rainfall amounts for January through March are typically in excess of three inches per month.

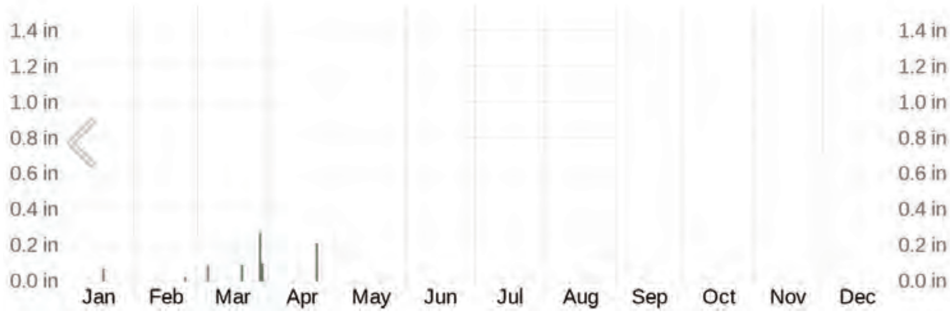

Figure 9. 2022 Daily Precipitation in San Bernardino. Source: *weatherspark.com*

RESULTS

The sites were monitored regularly (minimum once per month) throughout 2022 to observe and document current conditions. The persistence of invasive species and their ability to adapt to low-moisture conditions was readily apparent.

The dry conditions, combined with a sandy soil structure, resulted in extremely poor seed sprouting on both the broadcast and hydroseeded plots (1 and 2). The low rainfall and soil structure were exacerbated by persistent wind conditions throughout both study locations. In some instances, the plots were visited the day after the most significant rainfall events, only to find them completely dry—with little evidence that any rainfall had occurred.

In March of 2022, discing occurred on half of the plots. This is to evaluate the turning of ground to provide more of a bare mineral surface. Many of the native plants being seeded required direct contact with the soil to sprout. Conversely, discing has the potential to unearth dormant seeds below the soil surface, resulting in additional sprouting of invasive species that would not be desirable as future seeding of the native species takes place.

By April 2022, Site 1, which was untreated with herbicide, required mowing as the ground cover exceeded 24 inches in height. This was all with extremely low recorded rainfall and speaks to the aggressive nature of invasive species.

In June 2022, significant weed regrowth was observed on all plots. This is due to the properties and behavior of post-emergent herbicides. Only plants that were currently sprouting with post-emergent herbicides were affected. Late season sprouting was not expected, given the limited rainfall; however, the existing seedbase and root sprouting was significant enough to warrant a complete reapplication of herbicide.

Throughout the summer of 2022, DRG continued to monitor the sites. Herbicide applications to control continued sprouting of Russian thistle, *Brassica*, and *Ailanthus* were conducted at a cadence of approximately every two to three weeks. By the last week of August 2022, populations were coming under control, although some sprouting and treatments were still occurring. The Utility Access Rd. sites performed much better than the Cedar Ave. sites in terms of invasive species control. During the initial observations, there was a smaller percentage of Russian thistle population at Utility Access Rd. when compared to Cedar Ave.

As of early September 2022, current forecasts were calling for a rare, potentially third-straight La Niña weather pattern. This is expected to again affect the sprouting of desirable species. The future plan is to perform hydroseeding and drill seeding, but only on a limited number of plots. Observations and documentation will continue to occur and herbicide treatments on all plots will be conducted as necessary. On plots where seeding occurred in 2022, selective treatments will be applied. On plots where no seeding occurs, broadcast herbicide applications will be applied as necessary.

DISCUSSION

It is clear in Southern California that success of integrated habitat management (IHM) programs is highly dependent on receiving adequate rainfall. The poor performance of seeding operations in 2022 is directly related to the extremely limited rainfall the region received.

Supplemental irrigation was considered and irrigation plans had been developed. Plans were in place to utilize the fire hydrant permit to run temporary irrigation to the sites. Plans included only irrigating portions of the plots to be able to evaluate the effectiveness of irrigation. It is expected that supplemental irrigation, properly applied, will greatly improve success. This is evidenced by observations made in areas where disturbance and reseeding has occurred and irrigation is provided.

Given the serious drought conditions Southern California experienced, it was determined that including irrigation as part of the pilot program was not advisable. From both a public relations standpoint, and common sense, irrigating otherwise fallow land would, at best, be a poor use of water—and potentially, a public relations nightmare.

Future considerations could include locating test plots in areas that are accessible to "purple pipe" or recycled water that is intended for landscape use. Another consideration is to use recycled water trucked in. Irrigation could either be provided by a tank system (for example, "rain for rent") or applied directly from the truck. However, the amount and frequency of application required for successful sprouting and establishment may be cost prohibitive.

Figure 10. Persistent invasive weeds

Despite the challenges presented during the course of 2022, historically low rainfall may be a benefit to the pilot program. The unanticipated vigorous resprouting from established invasive species showed that extensive targeted herbicide treatments are required to successfully eliminate the undesirable vegetation from the site. This could have been complicated if there was successful sprouting of desired species.

Given the continued presence of invasive species, after multiple herbicide applications, no rainfall since March, and continuous hot and dry weather patterns, additional consideration to pre-emergent herbicide mixes is being evaluated. An herbicide mix that includes Esplanade 200SC should provide months of control, once activated by rainfall. This will allow for the existing vegetation and seedbed to deteriorate to the point they are no longer widely established in the corridor. A plan to include two years of herbicide application and monitoring before any seeding of desirable species is conducted will help to promote the establishment of the low-growing, desired pollinator habitat.

CONCLUSION

This initial pilot demonstrated that while control of invasive species in the utility ROW can be accomplished with persistent herbicide applications, establishment of a desirable pollinator plant community is highly dependent on local weather patterns. Site conditions also contribute to this establishment. The identified project area consisted of mostly sandy soil which retains even less rainfall, making establishment more difficult.

Initial goals of pollinator habitat creation should focus first on control and eradication of invasive species. This is a process that can take multiple years and continued monitoring will help ensure success. Attention should be paid to expected rainfall patterns, especially for predicted events—such as El Niño, where more-than-average rainfall can be expected.

Consideration should also be taken to identify sites with access to recycled water. This can be used to provide supplemental irrigation to help ensure the establishment of the desired species palette after the invasive flora has been eradicated.

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AUTHOR PROFILES

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Vince Mikulanis provides operations oversight for the Southwest region of Davey Resource Group, leveraging experience with project management of multiple utility and forestry projects. He is involved with developing teams of experts for our utility and forest management partners, producing utility vegetation management plans, integrating herbicide programs, and incorporating cutting-edge technology into forest management and UVM systems and programs. Mikulanis joined Davey Resource Group in 2003 as a consulting utility forester in San Diego. He has a bachelor's degree in forest conservation from Humboldt State University in Arcata, California. Mikulanis is an ISA Certified Arborist, Utility Specialist™, and Municipal Specialist®. He is Chair of the Western Chapter ISA Utility Committee.

Chuck Dykes

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Mowing is a common practice employed to suppress invasive plants and improve aesthetics of rights-of-way (ROW). However, mowing usually leads to an increase of invasive plants, making management more difficult. Spreading seeds via equipment is often cited as the reason for these increases, but other factors such as mowing height, timing, frequency, and technique used to transverse topography also have a significant impact on the encroachment and longevity of invasive plants. This paper examines how these factors influence weed encroachment and discuss approaches to minimize the negative impacts of mowing on plant communities.

Effect of Mowing Height, Mowing Frequency, and Terrain on Invasive Plant Encroachment

Scott Flynn

Keywords: Chemical Mowing, Invasive Plants, Mowing, Self-Thinning, Vegetation Management.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Managing vegetation in rights-of-way (ROW) is challenging given the expectations by stakeholders involved. Public, government, and self-imposed company standards all converge into vegetation management (VM) systems that seek to address a variety of needs. Government and private entities are concerned with public safety, service interruptions, legal compliance, and public perception. However, the public tends to focus more on aesthetic issues, with little thought given to cost or difficulty associated with ROW management. These factors, in combination with budgetary constraints and increased scrutiny on herbicide use, have resulted in mechanical methods of vegetation control, such as mowing, being the primary method employed by many state DOTs and private companies.

Mowing provides immediate results and is visually gratifying to VM managers and their stakeholders. Depending on budgets, managers may employ mowers several times per year or on a 2-to-3-year cycle when a site is lower priority. State DOTs, especially, tend to conduct mowing operations multiple times per year in preparation for holidays such a Memorial Day, Fourth of July, and Labor Day. During these times, traffic increases and state and local governments want to ensure a safe and aesthetically pleasing journey for travelers.

Mowing results are short-lived, with vegetation beginning to regrow within days. At the beginning of this regrowth period, invasive plants, if present, will likely become visible first due to the competitive characteristics that allow them to invade plant communities. This quick response puts many of our desirable species at a disadvantage, strengthening the foothold of the invasive species within the community and furthering its ability to spread. Many people ask the questions “Where did it come from?” and “How did it become a problem so quickly?” The blame is usually placed on seed dispersal by tractors and mowers used during VM operations, but the reason for the severity of these infestations is much more complex.

NATURAL POPULATION ADJUSTMENTS IN PLANT COMMUNITIES

Population ecologist have spent decades studying the factors involved in plant population changes and botanical shifts. One of the concepts derived by population ecologist is referred to as Yoda’s law, -3/2 self-thinning rule, or simply the self-thinning rule. Li et al. (2000) described the rule as “Relating average plant biomass to density when density-dependent mortality occurs, such that populations decline in density as biomass increases.” In other words, as average plant size increases, plant communities can become overcrowded, and resource limited. In response, population reductions (self-thinning) must occur for the community to continue growth and maintenance. This phenomenon is observable in our day-to-day lives with shorter maintained cool-season grass lawns reaching densities over 10,000 tillers/m^2 (Sheffer et al. 1978), while old growth redwood stands may have just over 100 trees/ha.

Self-thinning is a natural part of plant communities and usually occurs in a gradual, controlled manner when no other sources of disturbance are involved. Gradual changes allow the community to maintain a dense, photosynthetically active canopy that maximizes light interception and prevents encroachment of non-desirable species. This is achieved because healthy green canopies absorb a significant portion of red light (570–700 nm) while reflecting or transmitting much of the far-red light (700–750 nm). It’s this higher proportion of far-red that is transmitted through the canopy to the soil surface that represses seed germination and helps control the population. When a disturbance such as mowing occurs, it can significantly reduce the canopy, allowing a higher proportion of red light to reach the soil surface to trigger seed germination.

EFFECT OF MOWING ON PLANT POPULATIONS

Several studies have examined changes in plant communities within mowed ROW but there is also considerable knowledge that can be gained from studies in turf and forage management to help ROW managers. As previously discussed, plants growing within a community can become crowded, which results in population thinning. However, when growth is managed and kept within a target height/mass range, the population can also be somewhat managed. Well-managed lawns are mowed frequently to maintain short, aesthetically pleasing stands; as a result, they have a relatively dense canopy. Sheffer et al. (1978), while studying five bluegrass varieties and their optimal mowing heights, documented tiller densities of approximately 27,000, 23,500, and 13,000/m^2 for average sward heights of 1.3, 2.5, and 5.1 cm, respectively. Not only do these observations put into perspective the potential number of tillers in a bluegrass turf, but it also shows the relationship between density and the managed height. Similar relationships between average tiller density and average tiller height can be seen in Buffel Grass (Beltrán et al. 2001), Perennial ryegrass (Matthew et al. 1996), and Bermudagrass (Sbrissia et al. 2001).

Rights-of-way are generally not maintained at a uniform height due to the enormous labor and financial burden involved. In most cases, ROW are mowed after stands have matured and self-thinning has occurred. The combination of a low mowing height and a thin stand will result in increased soil exposure and a higher probability for invasive plant encroachment.

INTERACTION BETWEEN TERRAIN AND MOWERS

Rights-of-way terrain varies by geographic location but also by the function of an area or structure found within the overall ROW. For example, roads located on relatively flat terrain still require structures such as on and off ramps, bridges, overpasses, and ditches, which require moving soils to build up or cut away areas to accommodate these structures. The highly variable terrain left behind, while aesthetically pleasing, becomes a series of obstacles that mowers must now navigate. When ROW are cut short to lengthen the period between mowing/maintenance events, the interaction between cutting height and terrain begins to expose the soil to excessive periods of sunlight which, in turn, makes it easier for invasive plants to gain a foothold in the desired plant community. This is especially true on the shoulder of slopes where the ridged, flat cutting mechanism of the mower can scalp the vegetation and possibly disturb the soil on the shoulder of the slope when straddled. After repeated disturbance, these areas can become weakened and extremely eroded, making invasion by non-desirable plant species highly likely.

Equipment movement across steep slopes also can have a negative impact on the soil and the resiliency of desirable ROW plant communities. In many cases, slopes must be traversed across rather than top to bottom due to drainage or the width of the ROW. This movement across slopes means that equipment must contend with gravity and less traction as it performs its task. The result is significant damage of the soil and vegetation from increased friction at the contact point of the tire. This effect is exacerbated as soil moisture and slope increases.

SUPPRESSIVE EFFECT OF PLANT LITTER

Mowers cut but don't remove vegetation. Instead, the direction and action of the blades create windrows across the landscape that eventually degrade and become plant litter on the soil surface. Moderate amounts of plant material pose little issue to the living plant community; however, cutting too much of the standing plant material can create very dense windrows that smother the remaining canopy either killing or hampering the regrowth of desirable plants. As discussed previously, a disadvantage to desirable plants increases the likelihood of plant invasions.

SUCCESSFUL MOWING STRATEGIES

Disturbance in plant communities (i.e., fire, grazing, mowing, etc.) can help create and manage healthy diversity, but in severe cases can disadvantage the desirable vegetation and allow for invasion of non-desirable species (Hobbs and Huenneke 1992). Cutting vegetation too short or damaging soil and vegetation mechanically during ROW maintenance creates severe disturbance that allows for unwanted botanical shifts. When these actions are repeated multiple times over several years, the management favors invasive plants and many times creates monocultures that choke out desirable species.

The most influential mowing strategy for preventing invasive plant encroachment is to increase mowing height of the desirable species in accordance with the population and the species. Doing so leaves behind more leaf area of desirable species, allows for quicker recovery of the plant canopy, leaves behind less plant litter to smother vegetation, and reduces the likelihood of damaging scalp-prone areas in uneven terrain.

SUMMARY

Mowing is a powerful tool for ROW managers, yet it can be one such source of disturbance to allow invasive plants to take a foothold. While it is difficult to control the issues with mowing that create weed invasions, it is important to understand the mechanisms by which they occur. Only in doing so will meaningful solutions be created to help mitigate the underlying issues.

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AUTHOR PROFILE

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Scott Flynn, PhD, works for Corteva Agriscience as the Zonal Biology Leader for Pasture and Land Management in North America. Throughout his career, Flynn has focused on development of new herbicide products to improve broadleaf weed control in forage systems, such as DuraCor, TerraVue, HighNoon, and ProClova herbicides. His research has also studied the economic benefits of weed control on cattle production, the management of fescue toxicosis with chemical seed head suppression, and removal of invasive plant species in wildlife areas and ROW. Flynn currently lives in Lees Summit, Missouri, with his wife, Rebecca, and sons, Emmitt and Elijah.

The Environmental and Economic Impact of IVM

Darrell Russell

Keywords: Biodiversity, Environmental Sustainability, ESG, Evaluation, Integrated Vegetation Management, Landowner Relations, Maintenance, Pollinator, Resource Management, Vegetation Management.

Making slight adjustments to vegetation control strategies can significantly enhance vegetation management programs and provide a variety of economic and environmental benefits for energy companies throughout the United States. Operational experience and decades of environmental research have validated these outcomes and prioritized certain strategies as best management practices across various segments of the energy sector. Adapting these practices can help organizations and their vegetation management partners enhance not only site accessibility and the reliability of energy resources, but also biodiversity, annual resource management, and landowner relations.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Vegetation managers work to establish and maintain successful maintenance programs throughout utility rights-of-way (ROW) across the country. However, a variety of environmental, social, and economic roadblocks can impede their success and productivity. Incompatible vegetation poses a constant threat to system reliability; landowners and land entities question applied strategies; and budget or workforce limitations often force today's practitioners to do more with less.

Despite these persistent challenges, the implementation of integrated vegetation management (IVM) practices can improve system reliability and resiliency while increasing efficiency for utility vegetation managers, which helps their program's dollars stretch further over time. Integrated vegetation management programs also enhance environmental sustainability, which should be one of the industry's core tenets as it supports biodiversity as well as communications with landowners or customers. Slight adjustments can help vegetation managers embrace IVM practices and significantly enhance electrical service reliability, annual resource management, and the development of tree-resistant ground cover that improves long-term program efficacy.

To understand the potential impact of these adjustments, it's important to first examine the primary goals of vegetation management (VM) programs and strategies vegetation managers can use to achieve them successfully. Eliminating potential outages caused by vegetation interfering with overhead powerlines, pipelines, and other equipment is the primary goal of most utility vegetation managers. However, associated objectives include compliance, safety, and site accessibility for infrastructure maintenance and restoration.

The immediate control or removal of trees and brush that jeopardize the integrity of utility infrastructure might help practitioners achieve these objectives in the short term. However, industry research shows that providing support to the development of low-growing, stable plant communities helps utility vegetation management programs reach new levels of productivity, cost efficiency, and environmental stewardship. In addition to protecting utility infrastructure, these results can reduce the risk of soil disturbance and erosion, improve annual resource management, and support the development of biodiverse wildlife habitat.

DISCUSSION/RESULTS

The Lasting Impact of IVM

Most VM programs incorporate mechanical control methods, such as mechanized mowing, hand-cutting, or tree-trimming practices, to prevent incompatible vegetation from interfering with utility infrastructure. While these methods are effective at controlling targeted trees and brush species throughout utility ROW, they also control or remove desirable plant species that could otherwise impede the development of incompatible vegetation in the future.

Since mechanical control methods stimulate regrowth and seed spreading, programs relying on these strategies exclusively often encounter ever-increasing maintenance requirements. Without the means to prevent the cyclical development of undesirable trees and brush species, vegetation managers can expect an increase in incompatible stem counts and average tree heights over time, which elevates long-term maintenance costs and skilled labor staffing needs.

Fortunately, complementary vegetation control strategies, namely selective herbicide applications and grass-friendly brush mixes, can be used as part of an IVM-based strategy to help vegetation managers prolong the control of incompatible vegetation, and simultaneously support the development of native plant communities. In the past, industry practitioners allowed the use of non-selective herbicides as long as they were selectively applied.

Unfortunately, this technique frequently results in collateral damage to adjacent vegetation. In fact, as noncompatible stem densities rise, these selective applications turn into more of a broadcast application, which results in complete control of all vegetation and the removal of all ground cover. Comparatively, the use of grass-friendly herbicide mixes can help maintain grass cover on treated ROW. While decades of environmental research show the positive affects these results can have on the environment, let's first examine the economic impact of an IVM-based approach.

Economic Benefits of IVM with Herbicides

The use of IVM-based strategies featuring selective herbicide applications allows utility vegetation managers to effectively target incompatible vegetation, promote the development of compatible plant communities, and establish tree-resistant ground cover. As a result, IVM programs can effectively impede the growth of problematic trees and other invasive species, which helps prevent future tree invasions and reduces costs associated with long-term maintenance requirements.

The Cost-Efficiency of IVM report (found at *www.gotouaa.org/research-publications*) developed by John W. Goodfellow of BioCompliance Consulting, Inc. references a Least Cost Analysis study, which shows that herbicide applications can effectively complement mechanized mowing practices over a 20-year period to yield significantly lower incompatible stem densities and tree heights within utility ROW. This translates into lower ROW maintenance costs over time as well as improved reliability and access.

Goodfellow has led a variety of VM research projects as chair of the Right-of-Way Stewardship Council's technical advisory committee, and his cost-efficiency analysis examines the durability of cost projections for IVM and mechanized mowing against multiple cycle periods. This analysis also details varying levels of predicted efficiency for utility vegetation management programs that use either of the two strategies.

Goodfellow's report references a base case featuring four-year treatment cycles, which were used to assess stem densities and estimate long-term maintenance costs for IVM and mechanical-only strategies. Two additional test scenarios were also used to assess the impact of potential change in stem densities over time to create upper and lower cost projections. Base case stem densities were increased by 75% for the high-density scenario, while a 75% decrease was applied to the low-density scenario.

As utility vegetation management costs are directly impacted by the height and density of incompatible vegetation, Goodfellow's 20-year present value cost predictions consistently demonstrated that IVM with herbicides can provide significant cost savings over programs that rely solely on mechanical control methods. In fact, IVM programs consistently demonstrated cost savings between 25% and 57% over the exclusive use of mowing practices (Goodfellow 2019).

By effectively reducing average stem heights, IVM programs featuring herbicide applications in Goodfellow's study supported longer treatment cycles at lower maintenance costs for sites maintained once the height of targeted vegetation exceeds a predetermined action threshold. If established and well-maintained ROWs are left unmanaged, which can occur as a result of maintenance budget cuts, heavy densities of extra-tall tree and brush species can develop on the ROW over time. When this occurs, VM programs shift from maintenance to a potential point of reclamation.

Whether vegetation maintenance isn't applied for years after initial ROW establishment, or if the ability to use herbicides within ROW corridors is lost after years of IVM practice, this analysis demonstrates how using mechanized mowing practices to execute deferred maintenance on established ROW can be 16% more expensive than IVM

Cycle	Mechanical	IVM	Cost Savings for IVM	Max. Avg. Height (feet)	
				Mech Mow	IVM
3	$3,116	$1,705	45%	12	8
4	$3,114	$1,352	57%	15	9
5	$2,334	$1,149	51%	18	10.5
6	$1,888	$1,412	25%	21	12

Figure 1. Effect of cycle length on 20-year present value cost for IVM-based and mechanical mowing strategies (Source: Goodfellow 2019)

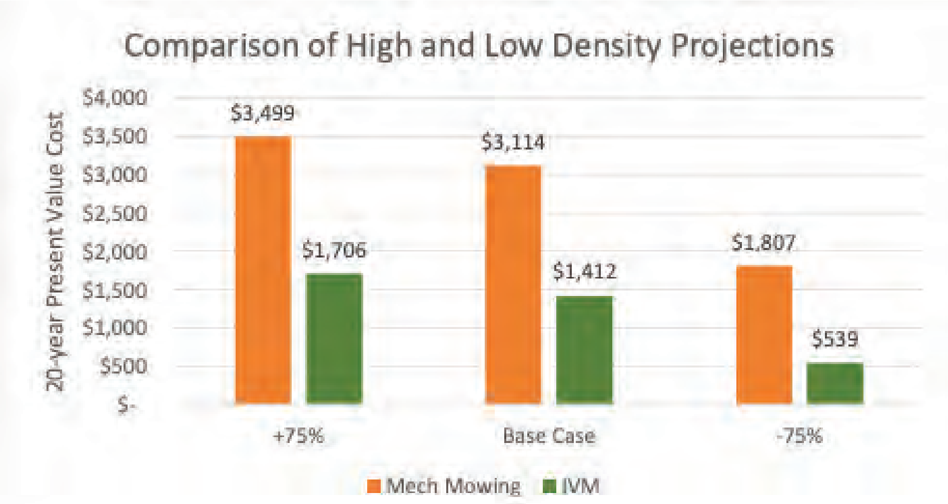

Figure 2. Total owned costs in situations where stem density is extremely high (+75%) or low (-75%) (Source: Goodfellow 2019)

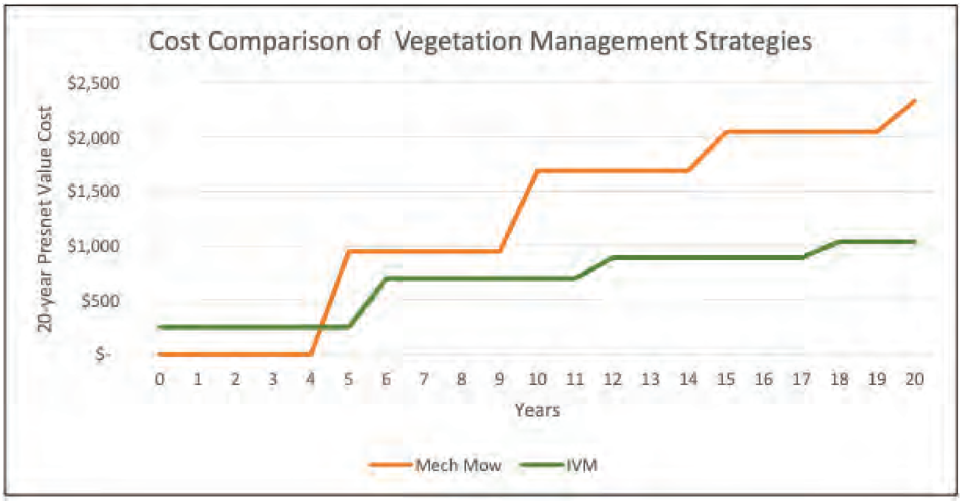

Figure 3. Twenty-year present value costs, comparing maintenance using mechanical mowing-only treatments and IVM treatments (Source: Goodfellow 2019)

strategies. The same analysis suggests that the present value cost of mechanized mowing would increase by nearly one-third in the years following a loss of herbicide use (Goodfellow 2019).

Integrating herbicide treatments as part of an IVM-based approach does require an initial investment that is slightly higher than programs that choose to mow exclusively. However, the difference in projected costs can be eclipsed by the time of the first maintenance cycle following integration, making IVM with herbicides an effective approach to reducing skilled labor requirements and long-term maintenance costs while safeguarding the integrity of utility infrastructure. As fewer labor resources are needed to conduct IVM treatments over time, utility vegetation management programs are empowered to reallocate funding to at-risk sites or projects that would otherwise receive little attention under a mechanical-based approach. When assessing these beneficial results, it's clear that what's good for the environment is good for business.

Environmental Research and Results

It's important to note that one size does not fit all when it comes to using selective herbicides and grass-friendly herbicide mixes as part of an IVM-based approach. However, industry research continues to show that, unlike mechanized mowing and other non-selective control methods, coupling selective herbicide applications with grass-friendly herbicide mixes can help create barriers against woody plants by leaving off-target vegetation unharmed. This supports the development of grasses and small forbs that provide the following benefits:

- Prevent problematic plant species from reestablishing
- Lower incompatible stem counts
- Provide habitat for small mammals who consume woody plant seeds, which further facilitates biological control

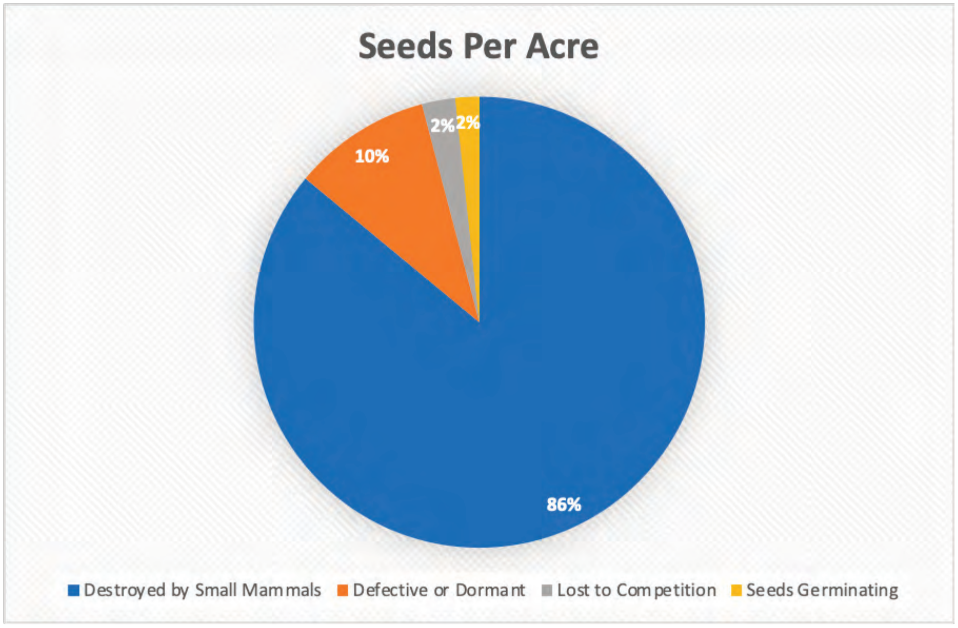

Figure 4. Results from the State Game Lands 33 research project, concerning the fate of every 1,000 seeds per acre containing tree-resistant cover types

Long-standing environmental research studies conducted by The Pennsylvania State University (PSU) and associated research partners has taken a closer look at the environmental impact of VM strategies for several decades. Led by researchers with PSU, the State Game Lands 33 (SGL 33) research project in Central Pennsylvania has measured the impact of VM strategies on plant diversity and wildlife habitats throughout utility ROW for nearly 70 years. As the longest continuous study of its kind, SGL 33 has demonstrated that an IVM program featuring selective herbicide applications is the most effective approach to enhancing biodiversity and habitat development for various wildlife and pollinator species.

Most recently, SGL 33 researchers released the 2021 Floral and Faunal research report, which details results from the latest three-year research cycle conducted by SGL 33 contributors. Five different vegetation control strategies tested on SGL 33 plots in 2016 were assessed over a 3-year period to help researchers identify best practices for the establishment of tree-resistant cover types. These strategies included hand-cutting and mechanical mowing practices, as well as high-volume foliar, low-volume foliar, and low-volume basal herbicide applications.

Each strategy was managed to include plots up to 3 acres in size, as well as a 95-foot wire zone and 30-foot border zone on each side of the transmission line corridor. When results for each plot were measured in July 2019, SGL 33 data revealed several key takeaways (Mahan 2021):

- Compared with hand-cutting and mowing plots, those on which low-volume and high-volume foliar applications were used generally resulted in lower incompatible stem densities in both the wire zone and border zone.
- Plots treated with low-volume basal applications also resulted in lower stem counts.
- Zero incompatible trees were recorded in the wire zone of at least one plot treated with a low-volume basal application.
- A second low-volume basal plot yielded a stem count lower than sites treated with mechanical control methods.

These results show that using herbicide applications as part of an IVM-based program can help utility vegetation managers enhance the management of incompatible vegetation, support the development of herbaceous-dominated plant communities throughout the wire zone, and establish beneficial, low-growing shrubs and trees within the border zone. These outcomes safeguard the integrity of utility infrastructure, minimize soil disturbance or erosion, and enhance habitat biodiversity for a variety of native wildlife species, including breeding birds and endangered or at-risk pollinators.

Maintaining areas where grasses and small forbs can flourish hinders woody brush seed germination and supports the development of biodiverse habitat for small mammals. In turn, those mammals offer biological control by consuming the viable seeds of incompatible plants. Long-term research studies like SGL 33 show that teaming all aspects of an IVM-based approach can significantly lower viable woody brush seed germination (Figure 4). As an added benefit, using selective herbicide applications as part of an IVM-based approach can not only reduce water runoff and erosion caused by slopes or heavy rainfall, but also improve soil health.

Put simply, supporting the development of tree-resistant cover types can provide environmental and economic benefits to utility vegetation managers and the land they manage. In 2021, Corteva Agriscience partnered with an investor-owned utility in the Southeastern United States to conduct a transmission ROW vegetation cover type study. This study tested the performance of low-volume backpack applications containing two different herbicide prescriptions:

- Selective tank-mix containing aminopyralid, triclopyr choline, and surfactant blend
- Non-selective herbicide tank-mix containing glyphosate, imazapyr, aminopyralid and surfactant blend

Vegetation cover was assessed one year after treatment. Results achieved through this analysis revealed the following findings (Figure 5):

- Selective treatment supported the development of a mixture of grass and forb species while controlling incompatible brush species better than untreated plots
- Treatments using nonselective herbicides negatively impacted grass and forb growth compared with untreated areas
- Selective treatment significantly reduced the amount of total vegetation control and enhanced compatible forb growth more effectively than nonselective treatment

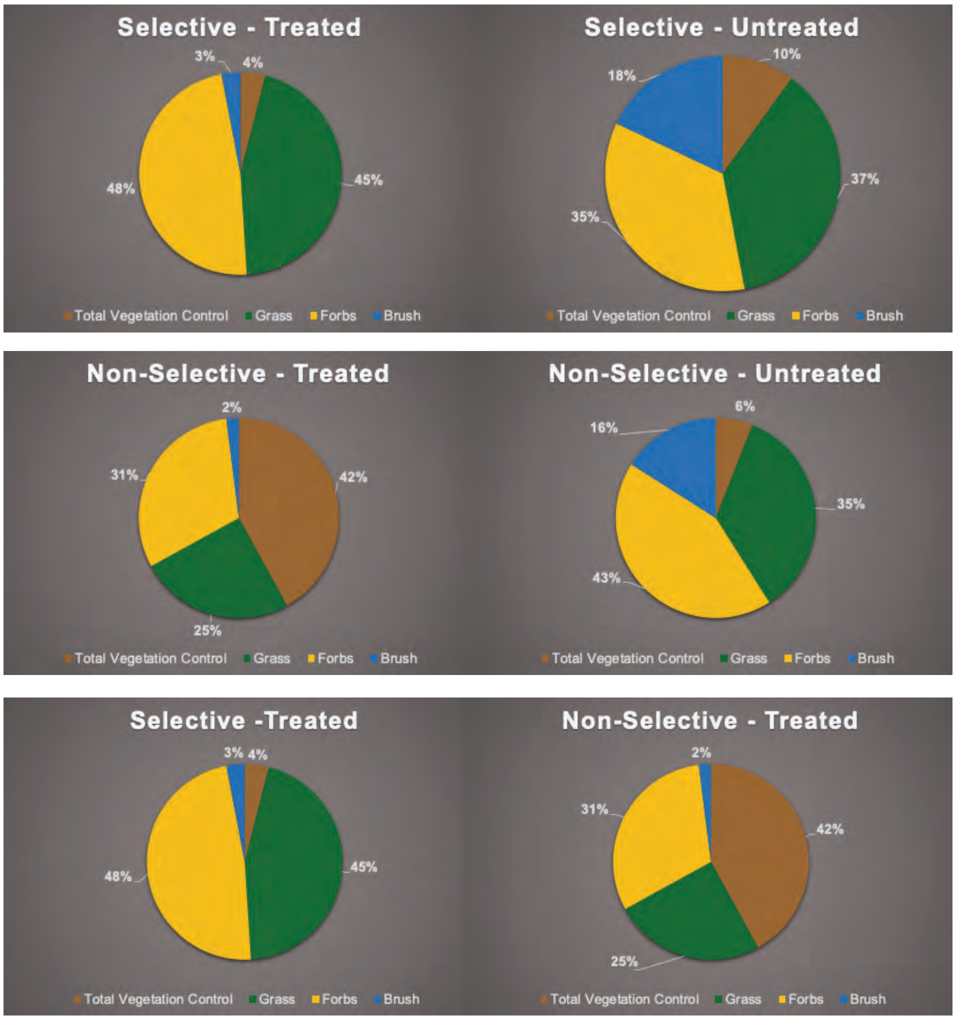

Figure 5. Comparison of results achieved through selective herbicide applications, nonselective herbicide applications, and untreated plots (Source: Russell 2022)

These positive results can be shared with customers and local landowners to help utility companies build and maintain trust between their organization and numerous public entities regarding the use of selective herbicide applications as part of an IVM-based approach.

Improving Landowner Relations

Environmental, Social, and Governance (ESG) reporting can be exceedingly valuable for utility companies, particularly as it relates to public perceptions and landowner relations. The public is known to take a variety of factors into consideration when scrutinizing utility companies. Those factors include a utility's ability to deliver reliable service as well as their handling of infrastructure disputes or environmental concerns. While many businesses commonly leverage ESG reporting to enhance and protect their reputation through the sharing of workforce inclusion and diversity insights or biological and lobbying activities, utility companies may benefit the most from sharing details about their impact on biodiversity management.

By unlocking the environmental benefits of an IVM-based strategy, utility companies can complement mowing practices with selective herbicide applications to enhance the development of biodiverse habitat and healthy ecosystems for the benefit of various wildlife and pollinator species. When proven to yield no net loss or net positive impact on biodiversity, these activities commonly qualify for ESG reporting, which utility companies can report quantitively or qualitatively on the ESG indices of their preference.

For example, habitat loss has been identified as a primary cause of dwindling pollinator populations in recent years. Millions of acres of utility ROW weave throughout the United States, and these areas represent ideal environments in which professionals can effectively support habitat biodiversity for various pollinator species. Reducing opportunities for undesirable plant invasions and enhancing the development of grasses and beneficial forbs can provide season-long support to various insect pollinators. Implementing IVM practices to control vegetation that is incompatible with utility infrastructure and pollinator habitat allows utility companies to enhance the reliability of electrical service, support the development of pollinator habitat, and subsequently complement ESG reporting.

Using herbicides as part of an IVM-based approach may draw intermittent criticism from customers, landowners, or other land entities, but documenting and communicating the environmental benefits of these treatments is an effective way for utility companies to positively address public scrutiny and proactively offset unforeseen industry headwinds.

CONCLUSIONS

Cost efficiency, land stewardship, and public perception are three key pillars that dictate the image and success of VM programs across the country. Whether energy companies and their contract partners are looking to improve one or enhance all three, IVM practices provide reliable solutions that can yield sustainable results. Consequently, associated practices can positively impact annual resource management, environmental sustainability, and customer satisfaction for generations to come.

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Transmission Vegetation Management Transformation: Leveraging Technology for Condition-Based Program Management

Jack Gardner

Keywords: Corridor, Data Analytics, Duke Energy, GIS, LiDAR, Maintenance, Optimization, Predictive, Reactive, Remote Sensing, Rights-of-way (ROW), Transformation, Transmission, Vegetation Management.

Utility maintenance strategies typically fall into one of three different categories: interval or time-based maintenance, condition-based maintenance, and predictive maintenance. Transmission vegetation management (TVM) programs have traditionally relied on interval/time-based maintenance approaches along with specification documents to plan and execute vegetation management work. In 2017, Duke Energy TVM began a business transformation to address the ever-increasing challenges of safety and effectively managing vegetation along its transmission corridors. This journey included a shift toward a more data-driven operational strategy, as well as organizational realignment, adoption of innovative technologies, and development of new processes and procedures.

This transformation provided the opportunity for the company to transition from an interval-based maintenance approach to a condition-based strategy, with predictive elements to drive reliability and program effectiveness. To help ensure that the transition would be sustainable, Duke Energy TVM implemented an enterprise-wide remote sensing program (RSP) and developed the Work Planning, Analysis, and Scheduling System (WorkPASS) to manage and execute the work.

These innovative programs and applications have allowed Duke Energy to migrate away from manual processes and tools, such as spreadsheets, to more advanced processes that leverage technology. The new technology also provides field access to the data through mobile geographic information system (GIS) solutions. These applications allow the TVM team to better manage system integrity and reliability over a multiyear horizon and enhance the company's integrated vegetation management (IVM) strategy, while also balancing the needs of Duke Energy and property owners.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

The Duke Energy transmission vegetation management (TVM) organization is responsible for managing vegetation across six states (North Carolina, South Carolina, Florida, Indiana, Ohio, and Kentucky). The organization includes four geographic operating regions (Carolinas East, Carolinas West, Florida, and Midwest) that are responsible for managing transmission vegetation work execution. In addition to the four regions, the organization also includes a strategy group that is responsible for providing enterprise TVM strategy, technology solutions, and common processes and procedures. The TVM team plans and manages vegetation work on more than 31,000 miles of transmission line, comprising approximately 6% of the total NERC FAC-003 applicable circuit miles in the United States. Duke Energy has a well-established and industry-recognized TVM program that has maintained a disciplined and consistent approach to managing vegetation along Duke Energy Transmission rights-of-way (ROW). Until recently, TVM's approach to managing vegetation along transmission lines has relied on interval-based maintenance with specifications that prescribe what work needs to be performed.

An interval-based maintenance approach has served the industry well for decades, but the regulatory and public environment has evolved rapidly. While resource constraints were typically the primary challenge for TVM programs in the past, the industry has seen utility commissions, regulators, legislators, and property owners become more engaged, resulting in increasing expectations for the program.

As these challenges and expectations continued to evolve, TVM determined that continuing to perform work as it has in the past (i.e., managing the program manually through spreadsheets and performing maintenance using an interval and specification-based approach) was no longer a sustainable approach and that Duke Energy needed to transform the way work is planned and executed. Hence, the TVM team embarked on a transformation to establish a sustainable path for the future. The TVM business transformation initiative included changes to operational strategy, organizational realignment, technology solutions, and program documentation. Core to the success of this journey was the implementation of data-driven technological solutions, along with analytical capabilities, to sustainably manage increasing expectations by performing the right work, at the right place, at the right time.

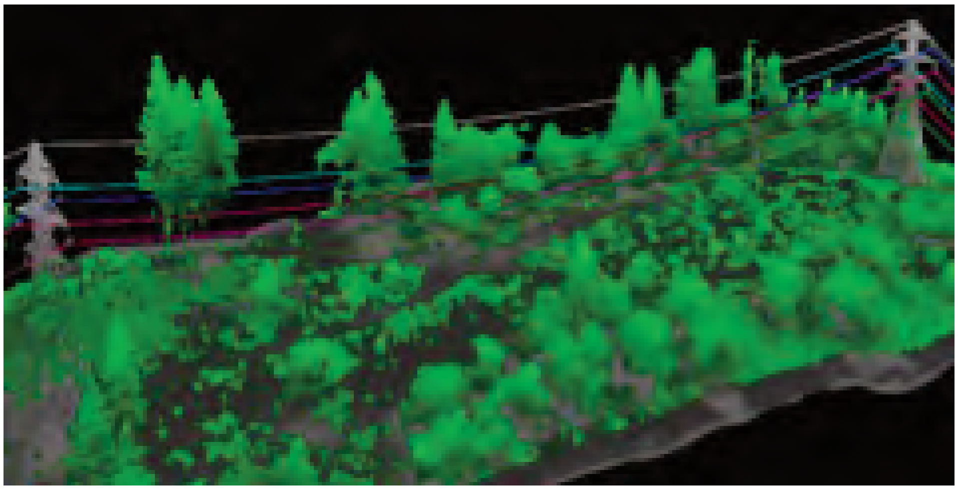

Figure 1. RSP Digital Model

METHODS/ IMPLEMENTATION

TVM Business Transformation

While many actions were associated with TVM's business transformation, two key actions proved critical to the sustainability of the initiative: strategic focus and organizational alignment. The team took a strategic focus using advanced data to identify and address potential vegetation threats and eliminate the previous reliance on a specification-based approach that could over- or under-prescribe the work required to address the true threats.

While the strategic focus provided directional guidance, the organizational alignment changes needed to support the new strategy, including the creation of a central TVM Strategy and Support (TVM SAS) organization. Transmission Vegetation Management SAS, which combined personnel from the TVM regions and the company's Vegetation Governance organization, was created to develop an enterprise approach for TVM programs and implement innovative and cost-effective technology solutions. Prior to the creation of this group, TVM processes, procedures, and operational practices varied across the regions and technological innovation was a low priority.

Technology Initiatives

Two technology-related efforts were initiated to support the transformation: implementation of both an enterprise Remote Sensing Program (RSP) and a Work Planning, Analysis, and Scheduling System (WorkPASS). The RSP initiative was established to create a digital model of lines that can be analyzed to predict potential vegetation threats over the next 6 to 8 years (Figure 1).

Predicted threats from these analytics provide the data necessary to support a condition-based maintenance approach. The WorkPASS initiative was established to develop and provide the necessary tools and applications to effectively manage and execute a condition-based maintenance program focused on reliability and program effectiveness.

Reducing Risk

While some level of inherent technical risk is associated with technology implementations, Duke Energy TVM's experience with previous remote sensing and technology solution initiatives led to three issues being identified as potential risk factors:

1. The sheer volume of data and ability to manage it
2. Solutions not being designed to fully meet use case needs
3. Limited capability to produce concise actionable deliverables for execution

These risk factors were determined to be controllable if they are considered and addressed during the early stages of initiative planning. The following guidelines were used to mitigate these risk factors and to provide general direction for the RSP and WorkPASS initiatives:

- Provide tree canopy polygons
- Analyze threats under all rated electrical operating conditions
- Document reactive work threats
- Predict vegetation threats over a 6–8 year period
- Provide capability to manage and transfer large data sets
- Develop predictive reliability risk analytics
- Provide scenario planning capabilities for annual work planning
- Create optimized annual work plans
- Create application that supports an end-to-end approach for the Corridor (Planned), Floor, and Reactive Management Programs
- Support work unit and "should cost" predictions
- Support multiyear work planning
- Provide actionable deliverables for execution (i.e., predicted work units per stem at the tree canopy polygon level)
- Support field mobile access
- Support assignment of work for execution
- Provide completed work reporting capability
- Meet business case objectives

Establishing the Remote Sensing Program

After the guidelines were identified, the development of the RSP began with an evaluation of remote sensing options, which included satellite imagery, photogrammetric detection and ranging (PhoDAR), and light detection and ranging (LiDAR). The results determined that LiDAR was the best option to meet the accuracy and resolution requirements of the TVM use case and support use of engineering PLSCADD models to identify vegetation threats under all rated electrical operating conditions. In addition, the LiDAR option also supported additional use case needs associated with transmission line engineering and asset protection.

The methodology used to manage the threats was the next key decision point for Duke Energy's RSP initiative. Across the industry, different approaches have been used for each unique program, some of which were tree inventories. Based on the size of Duke Energy's program, as well as limits with remote sensing technology, a tree inventory did not completely align with the company's strategic direction, and a volumetric approach (threat polygons) did not meet work assignment needs. Based on the evaluation, Duke Energy selected tree canopy polygons which were attributed with their highest threat as the basis for managing threats.

Once a remote sensing data source was determined and the method for managing threats was established, requirements related to RSP data capture and processing were defined. The capture requirements included average LiDAR points per square meter, survey absolute locational accuracies, relative accuracies for the LiDAR point cloud, ground control points, LiDAR point cloud feature coding, minimum corridor processing delivery widths, coordinate systems, and many other factors related to imagery. The processing requirements were established to include the creation of tree canopy polygons, tree canopy tops representing the highest point within the canopy polygon, and vegetation threat polygons. The deliverable requirements supported the ability to associate vegetation threats at the tree canopy polygon level.

The final step of the RSP was to establish requirements for vegetation condition and threat analysis. With an expectation for all rated electrical operating conditions of the conductor be considered (which meets FAC-003 requirements), vegetation threat modeling was built around "max sag," "as-flown," and "design blowout" conductor positions. Threats from vegetation, using one or more of the conductor positions, were to be predicted for the next 6–8 year period and categorized as "grow-in," "blowing together," and/or "fall-in" threats (Figure 2).

The RSP deliverables provide the foundational data needed to support a condition-based management approach. By requiring the threats from vegetation to be predicted over a 6–8 year period, the RSP deliverables support multiyear work planning and allows Duke Energy to understand and prioritize work on a condition (which indirectly accounts for time) and threat type basis. Further, this approach is foundational for the company's risk analysis, discussed in a later section.

Work Planning, Analysis, and Scheduling System

Once the RSP was established, the WorkPASS initiative began to develop the tools, applications, and predictive analytics necessary to manage the data, to provide actionable execution information, and to support field mobile access to the data. WorkPASS consists of more than 20 task or workflow applications. Each application/analytic solution falls within one of the following categories: geospatial data management, data enrichment, risk predictions and optimization, and a work execution system.

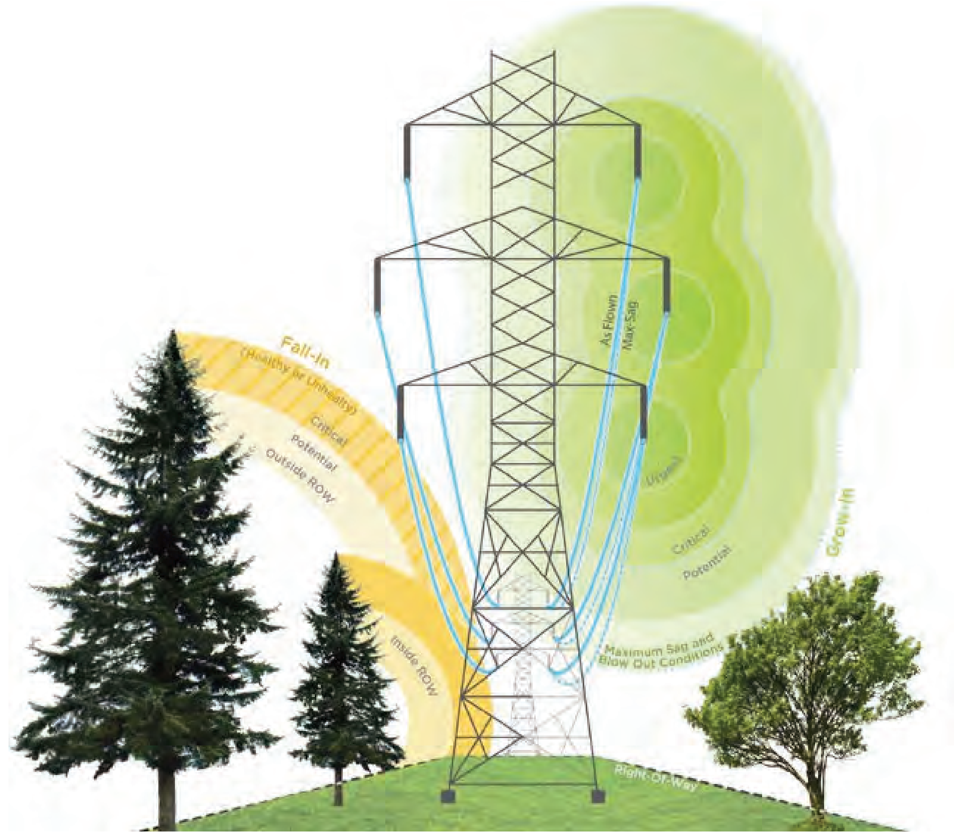

Figure 2. Graphic depicting Duke Energy RSP threat modeling

Geospatial Foundation

Geospatial data management applications in WorkPASS provide a platform to manage and access RSP data and imagery deliverables. Across Duke Energy's four regions, 70–100 million trees have been assessed for threats by the remote sensing program and are managed in the WorkPASS geodatabase. This database provides the foundation for all WorkPASS geospatial data and is integral to all data viewed, edited, and updated through the applications.

Enriching the Data

Data enrichment provides analytics that enhance the RSP data with critical information for optimizing and executing the work. While the RSP data provides general insight into what the predicted work type will be (mowing, herbicide, removal, trim), it is not sufficient to provide actionable information for execution. WorkPASS uses data science to predict work units for each tree canopy. Once those units are identified, the next step is to associate predicted work unit cost, or "should cost," information at a tree canopy level. These enrichment steps are performed each year and involve millions of tree canopy polygons.

Risk Predictions and Optimization

Once the data enrichment process has been finalized, the WorkPASS risk prediction analytics provide reliability risk values for fall-in threats along each transmission line. The analytics use a combination of variables to predict the reliability risk value and apply it at the tree canopy polygon level. These values provide an input for annual work plan creation in the scenario planner tool. Additionally, the values are used by the field personnel during field work planning and marking.

To create an annual work plan, the scenario planning application uses tree canopy reliability risk predictions and the enriched RSP data to evaluate numerous scenarios to develop an optimized annual work plan for corridor management in each region. While the reliability risk predictions and RSP tree canopy polygons can provide potential risk probability from threats for scenario planning, they are also important to understand and account for the impact or consequence if an outage were to occur. To address this important variable, Duke Energy TVM created a line criticality index. The line criticality index is a weighted assessment of the consequences of an outage, which does not consider voltage as a factor. Once annual work plans are finalized, the scenario planning application optimizes the work plan for each region (multiyear planning is also supported) to include all circuits and polygons that are to be addressed in the corridor management work plan.

Work Execution System

The WorkPASS Work Execution System currently provides solutions to plan and execute the Corridor Management and Reactive Management Programs. Floor Management is limited to field planning tools in support of the interval-based program.

Once an annual work plan is published for corridor management in each region, a central hub called ROOTS allows users to assign, monitor, and track work as it progresses through the work steps of planning, ready for work, assigned for work, ready for QA, and complete. In addition, ROOTS provides the ability to create an annual schedule for work plan completion and monitor actual progress against that plan. Once the work is assigned for planning in ROOTS, multiple mobile applications provide field users the ability to locate, field plan, and mark corridor management work. These apps allow the field user to assess and change the predicted work units as site-specific and/or arboricultural conditions require. Upon completion of the field work planning, ROOTS provides the ability to assign the work to a general foreperson. The general foreperson now has visibility of the assigned work in an app called LEAFOUT for execution and reporting of completed work. Completed work returns to ROOTS ready for quality assurance, and once the QA process is performed, the work can be either closed or sent back for rework as necessary.

While the apps supporting the reactive management work function like those for corridor management, the field planning and marking of reactive work findings is completed using the REACT field mobile app, with access to point cloud images (Figure 3). Following reactive work planning, the findings are available in ROOTS for work assignment and then in LEAFOUT for execution.

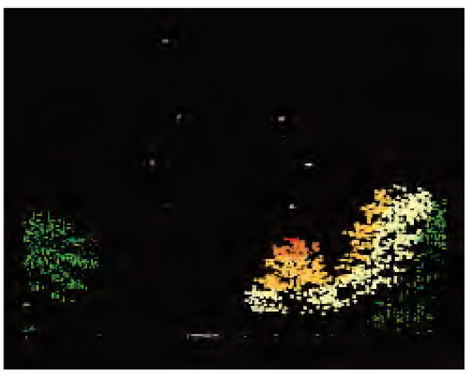

Figure 3. Point cloud image of reactive finding location

Duke Energy's Floor Management program continues to use an interval-based maintenance approach, and it is important to note that the RSP-derived tree canopy polygons do not represent all the work that should be handled under the floor program. Currently, the WorkPASS applications are only focused on supporting the field work planning tasks for floor management.

RESULTS AND BENEFITS

Innovative technological, analytical, and application solutions were implemented through the RSP and WorkPASS initiatives. They have provided a solid foundation to continue to adapt, transform, and expand well into the future and have produced meaningful long-term benefits. With these implementations complete, Duke Energy TVM has gained the ability to manage each of the vegetation management programs with an end-to-end approach from the initial identification of conditions through closing of the work orders. These solutions also provide the capability to create annual work plans, with actionable deliverables. Work execution system applications support execution by the regions by providing mobile access for field work planning of actionable work units at a tree canopy polygon level. The new processes for field execution support the program's integrated vegetation management (IVM) strategy to identify compatible and incompatible vegetation along and within our transmission corridors.

End-to-End Program Management

Duke Energy's TVM business transformation technology initiatives support an end-to-end approach for managing TVM program high-level workflow tasks (Figure 4). The technology solutions have provided significant advantages over the manual processes, such as spreadsheets or nonintegrated task-specific applications previously used to manage TVM programs. An end-to-end approach removes subjectivity in assessing threats, provides common vegetation threat definitions across the enterprise, eliminates decentralized documentation, and reduces human performance risk.

While many reporting tools and solutions still need to be developed, data associated with all identified corridor and reactive work are available to be tracked and monitored across the workflows within an individual program and across programs. The Reactive program is an example of the improved visibility and tracking with a standardized and integrated solution. Prior to mid-2020, reactive finding identification and status tracking was a manual process and was managed by personnel responsible for areas within a region. This decentralized documentation limited access and visibility to the data by region and enterprise leadership. With the implementation of WorkPASS, the status of reactive findings from identification through execution is now tracked daily

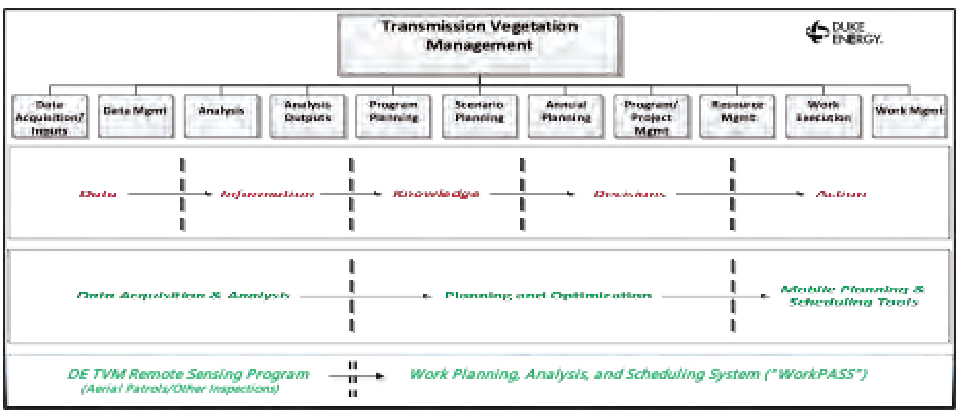

Figure 4. High-level TVM program workflow tasks

in a PowerBI report, with performance to the established expectations being reported on monthly TVM scorecards.

Reliability Risk Probability Modeling

While transmission vegetation-related outages are rare and are typically caused by off-ROW trees, they can have significant impact. To eliminate those significant impacts, all identified fall-in threats from off-ROW trees would need to be removed or mitigated, which is neither practical nor possible. With the limited number of vegetation-related outages on transmission lines, using outage data to target specific circuits with a history of outage was not a viable option.

The WorkPASS initiative provided Duke Energy TVM the opportunity to explore options to proactively address, where possible, off-ROW threats. PREDICTIONS, a WorkPASS solution, employs risk modeling using a variety of data sets combined with RSP data to identify off-ROW tree threats that are most likely to cause a future outage.

Using reliability risk probability modeling data during work planning is a way to explore opportunities to reduce, if possible, the potential for those type of outages. This approach is like a baseball coach stacking the lineup against a pitcher for greatest opportunity of success.

Scenario Planning

With the transition to a condition-based approach for corridor management, simple prioritization methods that were used previously to adjust interval-based work plans would no longer be sufficient. This led to another significant benefit from WorkPASS, and that is the ability to consider different scenarios when creating annual corridor management work plans, and then optimize and publish those annual work plans.

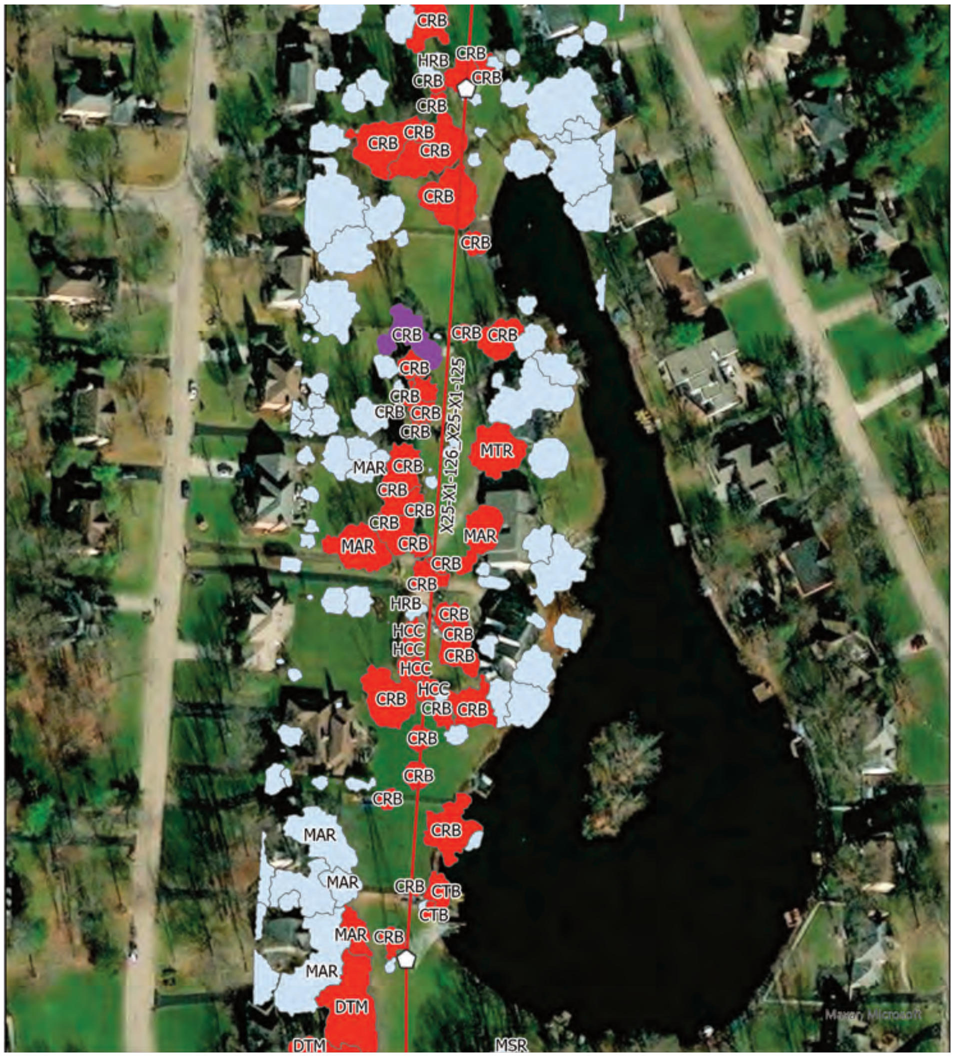

Figure 5. View of threat data used for field work planning

One of the keys to increasing the value provided by scenario planning was separating vegetation threat probability of failure into two components: the integrity index (from on-ROW threats) and the reliability index (from off-ROW threats).

The scenario planning application has provided the flexibility to create an annual work plan that can be adjusted to meet constraints or objectives that include compliance adherence, risk reduction, cost control, specific threat targeting, reliability and integrity performance, critical facilities, etc. This functionality provides optimal annual work plans and valuable insights when mid-plan adjustments are needed.

Work Execution System

Work execution system applications provide numerous benefits for the execution of TVM work:

- Mobile access to data for field personnel
- Reduced need for spreadsheets
- Ability to create an annual schedule for the work plan
- Data access and workflow support for field work planning and marking (Figure 5)
- Assignment of work to a general foreperson
- Web browser access to assigned work and to report completion of work

Program Management Effectiveness

The greatest benefits may be the RSP and WorkPASS centralized database information. The data will provide insights into TVM programs that were not previously possible.

As discussed in a previous section, the access to Reactive Management program data has already led to improvements in the planning and execution of reactive work. The data will continue to provide the information needed to improve each of the three TVM programs: Corridor, Floor, and Reactive Management.

While the data supports improvement of processes, planning, and execution for each of the three programs, the next step is to leverage the information to assess the effectiveness of TVM across all programs. To that end, Duke Energy TVM has already started to leverage the data to develop a TVM program effectiveness report. While still in the early stages of implementation, the TVM program effectiveness report will focus on four areas of the program: asset management (strategy), program conditions, program reliability, and work management (execution).

CONCLUSIONS

Duke Energy continues to enhance and transform the TVM program, and the ability to leverage technology will remain critical to transformation efforts. Transmission vegetation management experience during implementation of the RSP and WorkPASS initiatives has demonstrated that fully leveraging technology requires more focus and planning than adopting an existing solution. To successfully leverage technology and derive the benefits, there are four crucial elements that must be considered: strategic direction, deliberative implementation, flexibility/adaptability, and change management.

First, strategic direction (or more simply put, "What do we want to be when we grow up?") defines the technology and business requirements. While the drivers for each utility's TVM program can and will vary, a key strategy focus area for Duke Energy's TVM was to implement an end-to-end, data-driven solution, addressing threats over a multiyear period to drive reliability and program effectiveness. With this strategic focus as a driver, TVM was able to begin with the end in mind, limiting the time needed to consider the art of the possible.

Next, a deliberative approach to development and implementation is essential. This approach includes assessing options and desirability, determining viability, assessing feasibility, and refining the solution. Following the assessment of options such as accuracy, data resolution, or threat identification to meet work needs, a pilot or prescribed demo effort can be used to confirm viability and feasibility. Once viability and feasibility has been established, a pre-scale implementation provides an opportunity to refine the solution prior to full implementation, reducing the risks associated with user adoption.

Finally, flexibility and adaptability need to be primary considerations when technical options and feasibility are being discussed during the development phase. Since technology changes quickly and base-use case needs will evolve, building flexibility into the solution is vital. From an enterprise utility perspective, ensuring the adaptability of the data and technology solutions for other potential use cases, such as asset protection, transmission line engineering, distribution VM, and corporate GIS systems, is also extremely important when practically supported within the business case. Since other potential use case needs were considered during the development of the RSP and WorkPASS, the TVM data, applications, and systems have been leveraged by other organizations, such as the transmission line engineering and asset protection teams.

Successful implementation of Duke Energy's TVM's RSP and WorkPASS initiatives was made possible by addressing these three critical elements and employing a robust change management effort within the organization as the technology-related initiatives were developed and implemented.

Together, the RSP and the WorkPASS applications provide Duke Energy's TVM with the foundation necessary to meet the challenges associated with ever-increasing expectations.

Transformation through innovation remains critical as TVM strives to achieve operational excellence—and this will continue to support Duke Energy's mission to power the lives of our customers and the vitality of our communities.

AUTHOR PROFILE

Jack Gardner

Timothy J. (Jack) Gardner is Duke Energy's Manager for Transmission Vegetation Strategy and Support. His team is responsible for providing enterprise TVM strategy, business transformation, technology, and support. Gardner also led TVM Business Transformation initiatives and managed the development and implementation of planning, analytics, and scheduling applications for TVM.

Gardner holds a Bachelor of Science in civil engineering from Virginia Tech and has been with Duke Energy for 22 years, after 20 years at AEP. During his career, he has led and managed TVM Strategy and Support; TVM Regions; Transmission Line Construction and Maintenance; ROW Acquisition; Asset Protection; Aerial Patrol Programs; Regulatory Strategic Planning; Asset Management; Transmission GIS; Transmission Line Mechanic Training; Remote Sensing Programs with more than 110,000 circuit miles acquired; numerous enterprise technology and process improvement initiatives; and construction engineering and project management on several hundred miles of 69–765 kV transmission line and fiberoptic projects.

Tree Sapling Growth Rates and Associated Treatment Cycle Lengths on Powerline Corridors

Benjamin D. Ballard, Philip V. Hofmeyer, and
Christopher A. Nowak

Federal regulations (NERC FAC-003.4 R3), state (e.g., NY PSC's 16 NYCRR Part 84) regulations, and industry best practices require utility companies to manage vegetation to ensure safe, reliable transmission of electricity. However, on powerline rights-of-way (ROWs), trees can grow into or too close to the conductors, causing unsafe conditions and disrupting electricity transmission, requiring tall-growing tree species be regularly removed from ROWs. Frequency of treatment cycles to remove trees depends, in part, on fastest tree growth rates. Many factors, including soil conditions and regional climate, are known to affect growth rates of different tree species, necessitating estimates of growth rate by region. This study, conducted in Central and Upstate New York, sampled 30–45 tree saplings of seed and sprout origin for each of eight tree species, across a range of ROW growing conditions. Age-height relationships were analyzed using linear regression, and prediction intervals were estimated for each species and origin type. Upper bounds of 99.9% prediction intervals were used to estimate maximum tree sapling growth rates (fastest growing individual trees), which were then used to evaluate treatment cycles for ROW vegetation management. Maximum height growth rates of common tree species ranged from 1.4–3.8 feet per year for seed origin trees, 3.7 feet per year for red maple sprouts, and 20 feet per year for tree of heaven root suckers. For a 20-foot critical height in this this region, a treatment cycle length of 5–7 years is appropriate to avoid trees growing too close to the conductors. Cycle length should be substantially shorter if 15-foot critical height is required. Methods used in this study could be replicated in other regions to refine ROW vegetation management treatment cycles.

Keywords: Maintenance, Treatment Cycle Length, Tree Growth Rates, Utility Lines.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

On electric utility powerline corridors (rights-of-way/ROWs), trees can grow into or too close to the conductors, causing unsafe conditions and disrupting electricity transmission. Both federal (NERC FAC-003.4 R3) and state (e.g., NY PSC's 16 NYCRR Part 84) regulations, and industry best practices, require utility companies to manage vegetation to ensure safe, reliable transmission of electricity, requiring that tall-growing trees must be regularly removed from a ROW.

Current North American Electric Reliability Corporation (NERC) requirements under NERC FAC-003.4 specify:

R3. Each applicable Transmission Owner and applicable Generator Owner shall have documented maintenance strategies or procedures or processes or specifications it uses to prevent the encroachment of vegetation into the MVCD [Minimum Vegetation Clearance Distance] of its applicable lines that accounts for the following:

3.1 movement of applicable line conductors under their Rating and all Rated Electrical Operating Conditions

3.2 inter-relationships between vegetation growth rates, vegetation control methods, and inspection frequency that utility companies have documented maintenance strategies or procedures or processes or specifications it uses to prevent the encroachment of vegetation into the MVCD of its applicable lines.

In New York, the Public Service Commission's (PSC) rules and regulations, 16 NYCRR Part 84, and the PSC's Order in Case 04-E-0822 have substantive requirements to manage vegetation on the transmission powerline corridors to promote compatible vegetation and require utilities to have a system-wide, long-range plan to that effect (Lew Payne, personal communications, 2021).

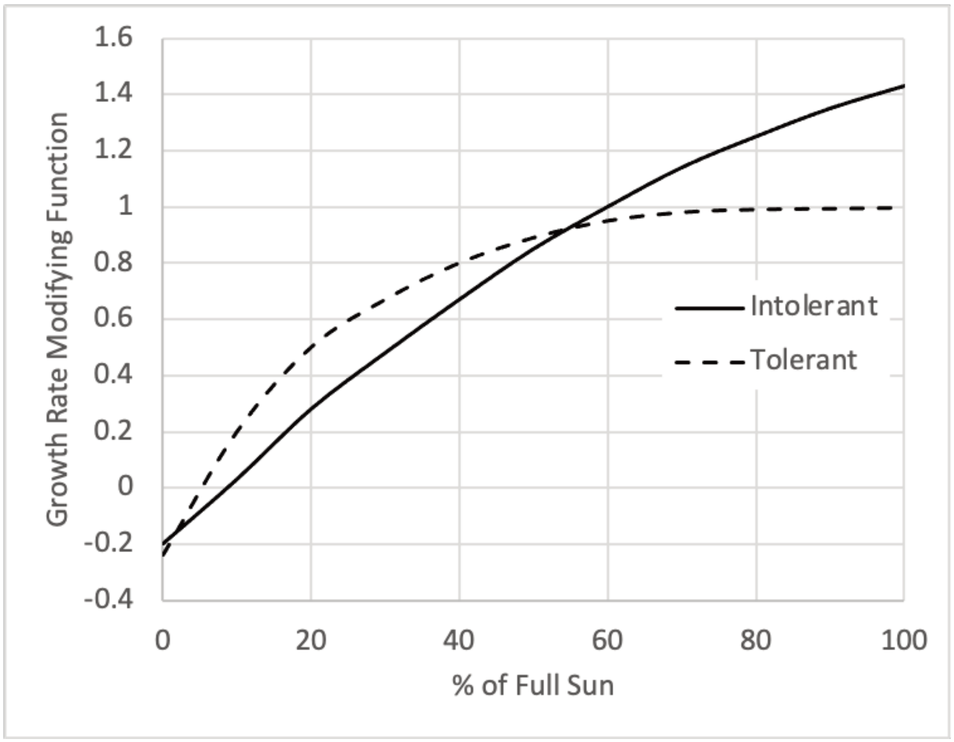

Figure 1. Growth adjustment coefficients in the FORET growth model based on shade tolerance and percent of full sun exposure (adapted from Pacala et al. 1994).

Applying the NERC requirements (NERC FAC-003.4 R3) to typical electric utility powerlines ranging from 115 kV to 765 kV, Goodfellow (2019) determined that the maximum "not-to-exceed" vegetation height ranges from 19.5 to 30.9 feet, respectively. However, in some cases the maximum tree height may be set lower as determined by the electric utility company.

For example, New York Power Authority (NYPA) applies the concept of an inviolate "Wire Security Zone" (WSZ) which exceeds the MVCD. The WSZ is used to determine the appropriate distance allowable between the vegetation and the conductors, which is achieved at the time vegetation management is performed. This WSZ distance is then applied in the field at the design maximum sag and sway of the conductor and follows the catenary of the conductor as viewed in the "as built" plan and profile drawing of the transmission facility. Therefore, the maximum allowable height for NYPA ROWs is typically around 15 feet and varies with the location on a ROW in relation to the conductors (Payne 2021).

To comply with federal and state requirements to ensure reliable transmission of electricity, the frequency of the treatment cycles to remove tall-growing trees depends, in part, on the rate of tree growth. However, a number of factors, including soil conditions and regional climate, are known to affect the growth rates of different tree species.

Height growth rate differences among species have been studied extensively to guide forest regeneration and recruitment into larger-size classes for sustained forest management (Smith and Ashton 1993). However, most of these studies relate to some partial cutting strategy (Beckage and Clark 2003; Moores et al. 2007; Hofmeyer et al. 2010) in existing forest types and/or silvicultural clearcutting practices (Brown 1994; Allison et al. 2003) to foster stand replacement. Few studies examine height growth rates as a detriment to desired conditions as they would be for utility ROWs.

Height growth-rate differences among species varies by shade tolerance. Shade tolerance has been correlated to diameter and height growth of saplings (Pacala 1994; Finzi and Canham 1999), though this relationship is complex and dependent on the availability of light (Figure 1). When light availability is high, shade-intolerant tree species commonly exceed the growth of shade- tolerant species, though this relationship reverses in lower light availability conditions. Because ROW managers treat existing tree and shrub communities, light availability is modified on a recurring treatment cycle. Particularly with extensive canopy reductions, sapling growth is expected to be high, as is observed in gap selection systems (Kaelke et al. 2001).

Along with shade tolerance and light availability, sapling growth upon release tends to vary significantly among new seed origin, new sprout origin, and advance regeneration seedlings existing in the plant community (Brown 1993; Liptzon and Ashton 1999). Commonly, sprout and sucker saplings have greater height growth rates and are more likely to persist for at least five years post-release. Because ROW treatments may result in sprouts, suckers, and new seedlings, and release advance regeneration seedlings and saplings, height growth rates and time to reach the WSZ is critically important to investigate when determining treatment cycles.

In addition to the factors identified above, tree seedling growth rates are expected to vary by region, necessitating that utility companies locally determine growth rates and an appropriate treatment cycle length to meet the federal and state requirements for ROW vegetation management. Therefore, this study was conducted to determine growth rates for common ROW tree species in Central and Upstate New York.

The study objective was to determine the height growth rates of common tree species on NYPA electric transmission line ROWs in Central and Upstate New York so as to answer the following questions: How long does it take for common New York tree species to reach the maximum "not-to-exceed" vegetation height? How many years would it take for the fastest growing individual trees (upper 0.05%) to reach the critical height? What is the appropriate treatment cycle length to avoid trees growing too close to the conductors?

METHODS

The main study area was a 113-kilometer section of NYPA's 345 kV Fitzpatrick-Edic (F-E) powerline corridor from Marcy to Scriba, New York. The study area is located primarily in the Eastern Great Lakes Lowlands (level III ecoregion) (Bryce et al. 2010), including the Mohawk Valley (83f, level IV ecoregion) on the eastern portion, extending into the Ontario Lowland (83c, level IV ecoregion) to the northwest. A small section of the study area passes through the Tug Hill Transition (58af, part of the Northeastern Highlands level III). Additional sampling for tree of heaven (*Ailanthus altissima*) was conducted on NYPA's Rochester-Pannell portion of the NATL powerline in Perinton, New York, which is also in the Ontario Lowlands. Sampling for white pine (*Pinus strobus*) was conducted on NYPA's Massena Sub-Utica powerline in the towns of Booneville (83f, Mohawk Valley) and Lyonsdale, New York (58ab, Northern and Western Adirondack Foothills, part of the Northeastern Highlands level III ecoregion).

Bryce et al. (2010) described the soils and climate of the ecoregions as follows:

- The Mohawk Valley soils are loamy, moist alfisols derived from glacial till.
- The Ontario Lowlands soils are alfisols, generally deep and finely textured, derived from limestone and calcareous shale.
- Lake Ontario tempers the climate of the Ontario Lowland, reducing summer heat and winter cold, but results in higher snowfall.
- Tug Hill Transition soil are derived from siltstone and shale and has the same wet climate as the Tug Hill Plateau, resulting from bands of lake-effect precipitation in winter.
- The Northern and Western Adirondack Foothills transition from shale and limestone of the river valleys to less erodible rock of the Adirondacks, and commonly has extensive glacial till deposits.

Eight tree species were sampled including red maple (*Acer rubrum* L., ACRU), tree of heaven (*Ailanthus altissima* [Mill.] Swingle, AIAL), gray birch (*Betula populifolia* Marshall, BEPO), white ash (*Fraxinus americana* L., FRAM2), white pine (*Pinus strobus* L., PIST), quaking aspen (*Populus tremuloides* Michx., POTR5), pin cherry (*Prunus pensylvanica* L. f., PRPE2), and black cherry (*Prunus serotina* Ehrh., PRSE2). Tree saplings of seed origin were sampled for all species except tree of heaven, which were assumed to be root suckers. Additional tree saplings of sprout origin were collected for red maple and gray birch. A sample of 30–45 tree saplings were selected for each species, stratified along the length of the main study area. Since tree saplings (0.5″ to <5″ diameter at 4.5 feet aboveground) are not common on well-managed ROWs, the largest available saplings were sampled, sometimes in the area between the NYPA's F-E and National Grid's Volney-Marcy powerlines, to achieve a stratified sample along the length of the main study area.

Each tree was felled as close to the ground as possible, and tree height was measured (Figure 2). The cut stump was aged in the field by counting the growth rings (a 10x hand lens was used, as needed) and stem discs were collected. Stem disc sections were brought back to the lab and triple counted to ensure accuracy of measurement. Origin of stump sprout saplings was ensured by sampling from mechanically treated plots and documented by field photos of the stump (Figure 2).

A total of 344 trees were sampled, ranging in age from 1 to 27 years, though most trees (93%) were less than 10 years old (Table 1). The average age for each species and origin type ranged from 2.9–8.3 years. The youngest group was tree of heaven root suckers (1–7 years) and the oldest saplings were a red maple (27 years) and a white ash (26 years) of seed origin. Tree heights ranged from 4.3–28 feet, though the average height of sampled trees ranged from 7.3–13.5 feet (Table 1 includes a more detailed breakdown by species and origin).

Figure 2. Field sampling of tree saplings conducted on ROWs in New York State. A sample of 30–45 tree saplings were selected for each species, stratified along the length of the main study area. Each tree was felled as close to the ground as possible, and tree height was measured. The cut stump was aged in the field by counting the growth rings (a 10x hand lens was used, as needed) and stem discs were collected. Stem disc sections were brought back to the lab and triple counted to ensure accuracy of measurement. Origin of stump sprout saplings was ensured by sampling from mechanically treated plots and documented by field photos of the stump.

DATA ANALYSIS

A visual inspection of age-height scatterplots for each species by origin type was used to identify general trends and potential data entry or other errors associated with the data. Descriptive statistics were calculated to characterize the populations sampled (Table 1). Simple linear regression was used to determine the average annual height growth line for each tree species by origin type (Figure 3). Because the range of tree ages was relatively narrow (93% of all 344 sampled trees were less than 10 years old), average height growth as a function of age was described reasonably well with a linear model for most species.

For each species and origin type, a linear model was used to estimate tree height as a function of age. Since a better fit was achieved when the "best fit line" was not forced through the graph origin for some species, this approach was used for all species. This was considered a better approach because we generally are not interested in predictions close to age zero, and we could get a better fit (and prediction) by allowing for non-zero intercepts terms. Additionally, small seedlings are often browsed or suppressed for multiple years before adding any substantive height or diameter growth, suggesting that a *y*-intercept of zero may not be ecologically warranted (demonstrated that root collar age was always higher than age at 30 cm) (Gutsell and Johnson 2002). The slope term of the linear model was used to describe the average annual growth rate for that species by origin type, though this is not strictly correct, because each species has a different intercept and we would expect that the growth in early years might be very slow if growing in a suppressed/shaded condition (Brown 1994; Kaelke at al. 2001) or height reduced when browsed by animals (Gorchov and Trisel 2003).

Based on the regression analyses best fit lines, a 99.9% prediction interval was then calculated for each species and origin type. A prediction interval was used because the upper limit of a 99.9% prediction interval describes the likelihood that a future single ROW tree of that species and origin in this region of New York will exceed the upper limit 0.05% of the time (5 in 10,000 trees). This also means that a future tree will fall within this prediction interval range 99.9% of the time (and 0.05% of the time below the lower prediction limit). The prediction interval accounts for the uncertainty of estimating the mean and the uncertainty associated with the distribution of trees; therefore, the upper bound of a prediction interval is useful for estimating the upper limits for one of the fastest-growing trees in the future.

The time for each tree species and origin type to reach 20-foot height (an example) was calculated for the average tree and the fastest-growing tree based on the average growth rate (linear regression line) and the upper prediction limit curve, respectively. These results were portrayed graphically (Figure 4) so that other threshold heights could be evaluated (e.g., in situations where 20 feet is not the critical height for safe, reliable transmission of electricity).

RESULTS AND APPLICATIONS

The simple linear regression resulted in a good fit for nearly all the tree species (by origin type) with R^2 values ranging from 0.18 to 0.68 (p-values <0.01; Table 2 and Figure 3). The one exception was gray birch sprouts, which had a poorer fit (R^2 = 0.11, p = 0.07). The linear regression best-fit line describes the average growth for the tree species and origin types over the age range observed on the New York ROWs (Figure 3).

Treatment cycles for vegetation management on ROWs can be refined by predicting the height growth of *fastest*-growing trees on a ROW, so the *average* growth rate is not the primary concern for determining treatment cycle lengths. Therefore, the 99.9% prediction interval, focusing on the upper limit (Figures 3 and 4), provides a method for identifying/quantifying the fastest-growing trees, which could then be used to determine treatment cycle length.

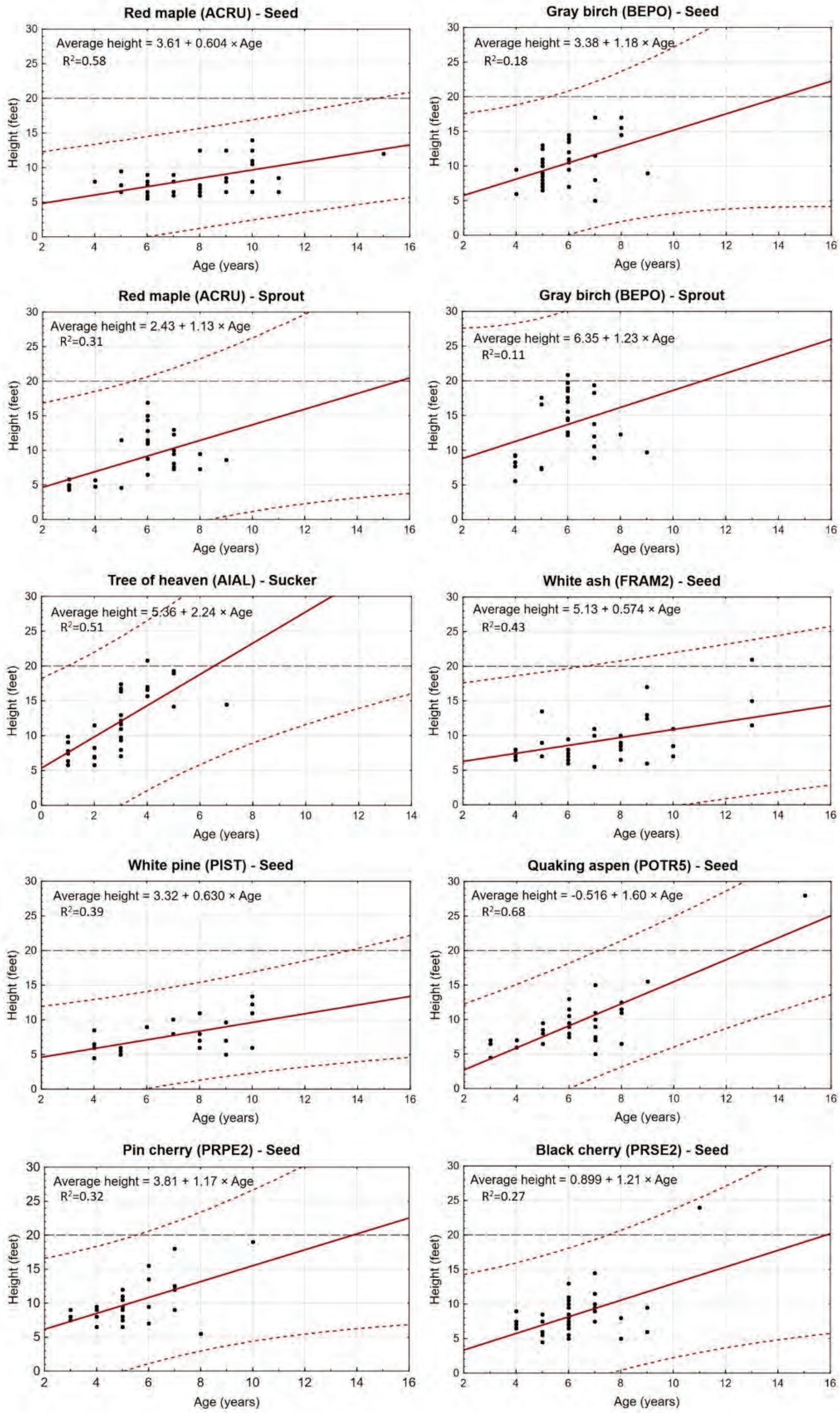

Figure 3. Scatterplot of tree sapling age (years) versus height (feet) by species and origin (seed, stump sprout, root sucker) for trees sampled on powerline ROWs in Central and Upstate New York. The solid line is the average fit using linear regression of tree age and height. The dashed lines are the 99.9% prediction interval. Note: to standardize axis scaling, the oldest trees are not portrayed in the graphs here for white ash and red maple seed origin, but those data were included in the analyses.

Based on the 99.9% prediction limits' age to reach 20-foot height (Table 3), we calculated upper limit growth rates ranging from 1.4–3.8 feet per year for seed origin trees, 3.7 feet per year for red maple sprouts, and 20 feet per year for tree of heaven root suckers.

One of the potential limitations of the study/results is the regional nature of the data and the variability in tree growth as a function of climate and region of the country. However, from a broader context, the results are similar to growth release studies across a much wider range and follow typical seed/sprout as well as shade tolerance patterns (Table 4). We observed average growth rates (as indicated by slope terms in the average fit lines) ranging from 0.6–1.6 feet per year for seed origin trees, 1.1–1.2 for stump sprouts, and 2.2 feet per year for tree of heaven root suckers (Table 2). These results are consistent with the range of average and maximum growth rates for both hardwoods and conifers reported (or inferred) from other studies (Table 4) from both forest gap/release and ROW conditions, across a broad geographic range.

Applications of these results and how they could be used for ROW vegetation management include the following:

- Using 20 feet as an example threshold for tree heights, the 99.9% prediction limits result in treatment cycle lengths ranging from <1 year to nearly 15 years (Table 3 and Figure 4).
    - o Based on the 99.9% prediction limits, treatment cycle lengths on a ROW with a 20-foot permissible tree height would require a treatment cycle length of 5–7 years for six of the seed origin species and red maple sprouts (Table 3).

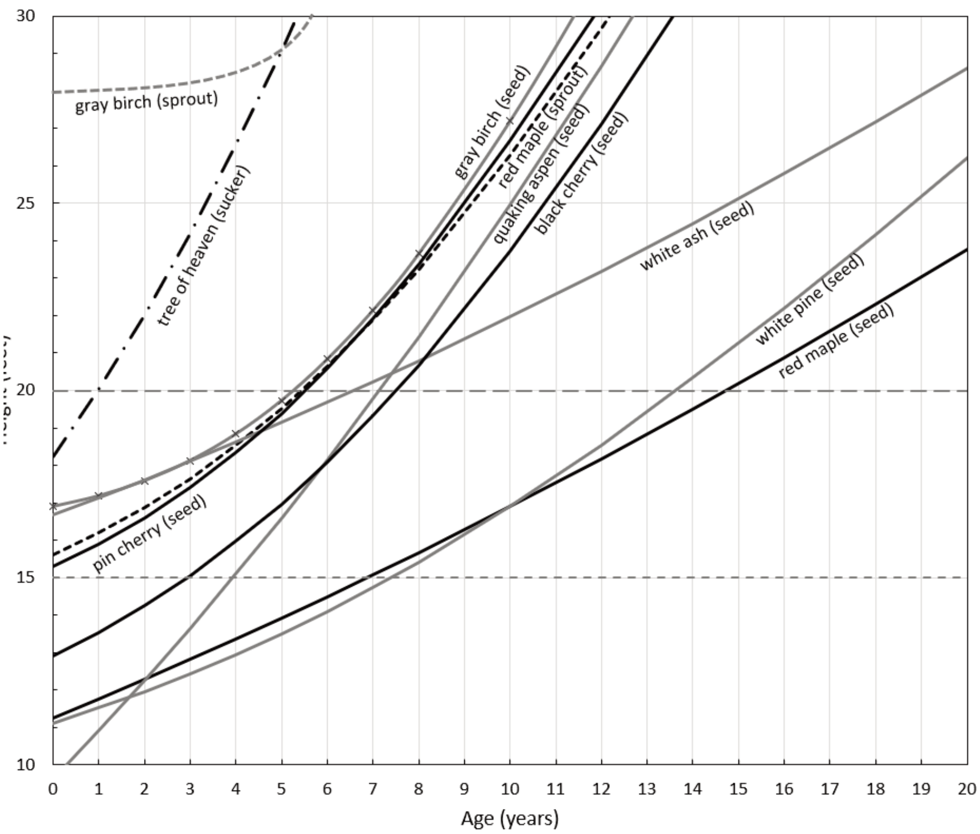

Figure 4. The 99.9% upper prediction limits for tree height growth by species and origin (seed, stump sprout, and root sucker) for tree saplings sampled on powerline ROWs in Central and Upstate New York. Tree species include red maple (ACRU), tree of heaven (AIAL), gray birch (BEPO), white ash (FRAM2), white pine (PIST), quaking aspen (POTR5), pin cherry (PRPE2), and black cherry (PRSE2). The reference line of 20 feet height was used as an example to determine treatment cycle lengths.

Table 1. Descriptive statistics of tree age (years) and height (feet) by species and origin for tree saplings sampled on powerline ROWs in Central and Upstate New York.

Tree age (years)	ACRU	ACRU	AIAL	BEPO	BEPO	FRAM2	PIST	POTR5	PRPE2	PRSE2
Statistic	**Red maple (seed)**	**Red maple (sprout)**	**Tree of heaven (sucker)**	**Gray birch (seed)**	**Gray birch (sprout)**	**White ash (seed)**	**White pine (seed)**	**Quaking aspen (seed)**	**Pin cherry (seed)**	**Black cherry (seed)**
Mean	8.3	5.6	2.9	5.9	5.8	8.3	6.3	6.2	5.3	6.2
SE	(0.62)	(0.32)	(0.264)	(0.18)	(0.23)	(0.74)	(0.42)	(0.38)	(0.27)	(0.21)
Minimum	4	3	1	4	4	4	4	3	3	4
Maximum	27	9	7	9	9	26	10	15	10	11
n	38	30	30	39	30	38	30	33	31	45

Tree height (feet)	ACRU	ACRU	AIAL	BEPO	BEPO	FRAM2	PIST	POTR5	PRPE2	PRSE2
Statistic	**Red maple (seed)**	**Red maple (sprout)**	**Tree of heaven (sucker)**	**Gray birch (seed)**	**Gray birch (sprout)**	**White ash (seed)**	**White pine (seed)**	**Quaking aspen (seed)**	**Pin cherry (seed)**	**Black cherry (seed)**
Mean	8.6	8.7	11.9	10.3	13.5	9.9	7.3	9.5	10.0	8.4
SE	(0.49)	(0.66)	(0.83)	(0.50)	(0.84)	(0.65)	(0.43)	(0.74)	(0.56)	(0.48)
Minimum	5.5	4.3	5.8	5	5.6	5.5	4.5	4.5	5.5	4.5
Maximum	21.5	16.9	20.8	17	20.9	23	13.4	28	19	24
n	38	30	30	39	30	38	30	33	31	45

- White pine and red maple seed origin species were slower growing and would not reach the 20-foot mark until 13–15 years, so they could be managed with the other group (5–7 years) without detriment.
- For some saplings (especially older ones), the tree may have grown very slowly for many years in an understory condition (e.g., shaded out and/or browsed by animals) before reaching a height in full sun; this is likely for shade-tolerant species. Browsing pressure and dense shrub cover may reduce seedling growth into sapling stages, but reductions in either suppression mechanism may result in rapid height growth.
- Two species-origin types resulted in exceptionally short treatment cycle lengths: tree of heaven root suckers and gray birch sprouts (Table 3). In the case of tree of heaven (1–7 years old root suckers), the regression fit was good (R^2 = 0.51), and the observed growth rates were very fast. Tree of heaven may reach 20 feet height in one year for the fastest-growing suckers. Gray birch stump sprouts (4–9 years old), exhibited highly variable growth rates, resulting in a poor fit of the linear regression model. Subsequent prediction limits for gray birch sprouts were therefore very wide (and not useful; e.g., *negative* years to reach 20 feet) and suggest that careful consideration be given for gray

Table 2. Summary of linear regression by species and origin for tree saplings sampled on powerline ROWs in Central and Upstate New York. A linear model (y=ax+b) was used for the average fit, where x=tree age in years and y=tree height in feet.

Species	Origin	R^2	n	p-value	Slope	Intercept
Red maple (ACRU)	seed	0.58	38	<0.01	0.60	3.61
Red maple (ACRU)	sprout	0.31	30	<0.01	1.13	2.43
Tree of heaven (AIAL)	sucker	0.51	30	<0.01	2.24	5.36
Gray birch (BEPO)	seed	0.18	39	<0.01	1.18	3.38
Gray birch (BEPO)	sprout	0.11	30	0.07	1.23	6.35
White ash (FRAM2)	seed	0.43	38	<0.01	0.57	5.13
White pine (PIST)	seed	0.39	30	<0.01	0.63	3.32
Quaking aspen (POTR5)	seed	0.68	33	<0.01	1.60	-0.52
Pin cherry (PRPE2)	seed	0.32	31	<0.01	1.17	3.81
Black cherry (PRSE2)	seed	0.27	45	<0.01	1.21	0.90

Table 3. Estimated age to reach 20 feet tree height by species and origin for tree saplings sampled on powerline ROWs in Central and Upstate New York. The age estimates are based on the fitted linear regression equations for average ages and upper 99.9% prediction limits for 99.9% predicted years. The 99.9% average growth rate was calculated using the predicted years to reach 20 feet height (e.g., for red maple seed origin: 20 feet/14.7 years = 1.4 feet per year).

Species	Origin	Average years to reach 20 ft. height	99.9% predicted years to reach 20 ft.	99.9% average growth rate (feet/year)
Red maple (ACRU)	seed	27.1	14.7	1.4
Red maple (ACRU)	sprout	15.6	5.4	3.7
Tree of heaven (AIAL)	sucker	6.5	1.0	20
Gray birch (BEPO)	seed	14.1	5.3	3.8
Gray birch (BEPO)	sprout	11.1	< 1	-
White ash (FRAM2)	seed	25.9	6.6	3.0
White pine (PIST)	seed	26.5	13.6	1.5
Quaking aspen (POTR5)	seed	12.8	7.2	2.8
Pin cherry (PRPE2)	seed	13.8	5.5	3.6
Black cherry (PRSE2)	seed	15.8	7.5	2.7

birch sprouts in vegetation management plans.

- o Do results make sense in comparison to conventional treatment cycle lengths? New York Power Authority treatment cycle lengths are typically about 4 years (Payne 2021), which seems reasonable based on these study results where most species-origin types could be managed on a 5- to 7-year cycle for 20-foot tree height limit (i.e., 4 years is conservative). However, if a 15-foot limit were specified for all parts of the ROW, the fastest-growing trees (upper 99.9% prediction limit, or top 0.05% of trees) of many species could reach that height in less than one year (Figure 4).

- Practitioners in other regions are encouraged to compare observed field growth rates from their locale (e.g., destructive sampling of at least 30 representative trees) and use the prediction limit method to estimate the fastest growth, since sampling is unlikely to yield the tree population's fastest growers (e.g., the fastest five trees in 10,000, corresponding with a 99.9% prediction limit).
- Even using the 99.9% prediction limit method to set treatment cycle lengths does have a limitation. The 99.9% upper limit implies that 5 in 10,000 trees will exceed the growth rates of the upper prediction limit (Figure 4). On well-managed ROWs it is possible to have <50 tree saplings per acre (Kooser et al. 2016). On such ROWs, 10,000 tree saplings would be spread across ~200 acres, with the potential 5 saplings that exceed the 99.9% limit spread across >10 miles of ROW corridor (assuming ~150-foot wide ROW). This will necessitate routine monitoring (e.g., helicopter inspection flights, LiDAR, field/site inspections) to catch those exceptionally fast-growing trees.
- The treatment cycle for a ROW corridor will likely be determined by the fastest-growing species (and origin type). However, by identifying those species and origin types that are extreme (e.g., tree of heaven root suckers or gray birch sprouts), a more refined approach could be used, whereby the other common species and origin types are used to set the overall treatment cycle length. Then using site-specific inventories to identify known problem species-origin types, critical maintenance areas could be identified/mapped and then managed on a shorter cycle to deal with expected faster growth rates. This would allow for longer treatment cycles for the corridor overall, reducing costs and focusing resources on anticipated problem areas. Similarly, a wire-zone border-zone (WZ/BZ) type of approach could be used, whereby the vegetation under the conductors (WZ) is treated differently than the borders (e.g., all woody vegetation treated in the WZ). For example, Ballard et al. (2007) presented a modified WZ/BZ that identifies "critical wire zones" (e.g., under the conductors at mid-span) where shorter cycles or more intensive treatments could be used, and less critical WZ and BZ areas could use longer cycles or less-intensive treatments, minimizing the expense of treating the full width of the ROW at every entry.

Table 4. Sapling growth rates from forestry and ROW literature.

Source	Year	Species	Height growth (m/yr)	Height growth (ft/yr)	Sapling ecological conditions	Region
Alison et al.	2003	pin cherry	0.25	0.82	strip clearcuts	Massachusetts, USA
		poplars	0.22	0.72	strip clearcuts	
		white ash	0.18	0.59	strip clearcuts	
Brown	1994	stump sprouts	0.2	0.66	clearcut for ROW establishment	Ontario (NE of Toronto), Canada
Good & Good	1972	chestnut	0.2	0.66	low light conditions	New Jersey, USA
		beech & oak	0.17	0.56	low light conditions	
Hett and Baumert	1987	conifers (average)	0.37	1.2	seedlings, after operation ROW mowing treatment	Pacific Northwest, (Washington), USA
		red alder	0.7	2.4	sprouts, after operation ROW mowing treatment	
Hofmeyer et al.	2010	northern white-cedar	0.33	1.1	suppressed saplings after release	Maine, USA
Knapp & Canham	2000	*Ailanthus*	0.2	0.66	growing in natural gaps	New York (Hudson Valley), USA
Moores et al.	2008	balsam fir	0.6	2.0	suppressed saplings in gaps	Maine, USA
		red spruce	0.55	1.8	suppressed saplings in gaps	
Nowak et al.	2002	gray birch	0.7	2.3	seedlings on managed ROW	New York (upstate), USA
Smith & Ashton	1993	pin cherry	0.82	2.7	maximum growth rate in groups of clearcuts	Connecticut & New Hampshire, USA
		paper birch	0.76	2.5	maximum growth rate in groups of clearcuts	
		gray birch	0.67	2.2	maximum growth rate in groups of clearcuts	
Wells et al.	2002	alder, aspen, birch, cottonwood	0.9-1.3	3.0-4.3	hardwood sprouts, after mechanical treatment of ROWs	British Columbia

CONCLUSIONS

- Height growth rates of common tree species on NYPA electric transmission line ROWs in Central and Upstate New York ranged from 1.4–3.8 feet per year for seed origin trees, 3.7 feet per year for red maple sprouts, and 20 feet per year for tree of heaven root suckers. (Note: these are maximum growth rates; average growth rates were generally less than half that of maximum growth rates.)
- A 20-foot critical height could be attained by a ROW tree in <1 year to nearly 15 years, depending on species and origin.
- A treatment cycle length of 5–7 years is appropriate to avoid trees growing too close to the conductors. This cycle length should be substantially shorter if a 15-foot critical height is required.
- Rights-of-way vegetation management plans should account for fastest-growing individual trees for common tree species. Site-specific inventories should be used to identify critical management zones with populations of faster growing species/origin types. This approach would allow for reasonable operational treatment cycle lengths for the system, while ensuring that areas with known problem species are managed more intensively.

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Understanding Herbicide Compatibility with Pollinator Habitat

Sam Ingram

Keywords: Invasive, Pollinator, Utility Lines.

Improving current or establishing new areas with native plants for wildlife and pollinators is a goal for many energy companies, government agencies, and private landowners. Costs to establish these desired landscapes can vary considerably based on several variables. Noxious weeds are a major challenge in establishing and maintaining wildlife areas that are diverse habitats composed of wildflowers, forbs, and small shrubs. We were interested in evaluating herbicide's ability to control noxious weeds while also evaluating potential impact to native, desirable species and, fortunately, our findings were positive. Aminopyralid is a selective, broadleaf herbicide that controls several noxious, invasive weeds. It is registered for use on rights-of-way (ROW), rangelands, natural areas, and wildlife habitat. Multiyear studies across different locations showed several native forbs were moderately tolerant or tolerant to aminopyralid during establishment or reconstruction of native forb areas. Further, selective herbicide applications combined with diverse plant communities provide better resistance to invasion by noxious species. Although perception of herbicides may be viewed as having a negative impact by some, our studies that utilized this tool as a part of the integrated vegetation management (IVM) approach provided safely maintained, functional ROW in addition to promoting diverse habitat.

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INTRODUCTION

Rights-of-way (ROW) utilized by utility companies cover an enormous amount of land area across the U.S. It is estimated that there are 157,000 miles of high-voltage transmission lines (Johnston 2019) and 321,000 miles of gas pipelines across the U.S. A land manager's primary objective for ROW is to ensure safe and reliable transmission and delivery of utilities to consumers (Persad et al. 2019). To meet that objective, land managers must control unwanted and incompatible vegetation. More recently, utility companies have increased focus on secondary objectives for ROW, such as improving wildlife habitat, pollinators, aesthetics, biodiversity, and invasive species management. This is a response to the public's interest in a utility company's environmental impact as well as the environmental goals set by the utility companies. Fortunately, integrated vegetation management (IVM)—which utilizes biological, cultural, mechanical, and chemical control methods—can meet both the primary and secondary objectives for many of the utility companies (Goodfellow 2019).

Chemical control (i.e., herbicides) is an integral tool within IVM that has improved the safety and cost of managing incompatible vegetation (Clark et al. 2012). Herbicides were adopted by several companies during the mid-twentieth century because of their effectiveness in controlling woody vegetation, which helped meet their primary goal of maintaining safe and reliable delivery of utilities. These herbicides were typically applied via broadcast and were a combination of nonselective and selective chemistries and resulted in drastic reduction in all vegetation within the ROW and ROW edge. Although primary objectives are achieved with these types of herbicides and application techniques, achieving secondary objectives is difficult. Fortunately, the industry has shifted to more selective herbicide options and an individual plant treatment application which has resulted in controlling unwanted vegetation without the drastic change in the entire ROW habitat (DiTomaso et al. 2007; Isbister et al. 2016). Within the ROW secondary objectives, there has been a large focus on pollinators, and a data summation on the compatibility of herbicides and pollinators is needed to provide information for the decisions being made for companies' IVM strategies.

METHODS

Peer-reviewed journal articles, conference proceedings, and industry publications from North America examining IVM strategies that included chemical methods, herbicide efficacy on ROW, and IVM strategies' impact on pollinator and or wildlife habitat were collected and examined to provide a better understanding of the compatibility of herbicides and pollinators within a ROW.

RESULTS

This search resulted in several publications related to the efficacy of herbicides on tree or broadleaf species within the ROW. Further, the potential impact to pollinator habitat with differing IVM strategies is well documented in the literature. However, this search only resulted in three studies found that focused on herbicides' potential impact on pollinator occurrence within the ROW, of which two were in Pennsylvania (Bramble et al. 1997; Russo et al. 2021) and the other in California (Wojcik et al. 2016).

In Pennsylvania, Bramble et al. (1997) examined the potential impact of five ROW maintenance treatments on butterfly species. All treatments used the wire zone/border zone method (Bramble et al. 1985). Treatments were applied in 1987 and 1993; herbicides used for treatments 4 and 5 were changed from 1987 to 1993. Treatments included: (1) hand cutting trees and tall shrubs to a 4-inch stubble height; (2) mowing trees and tall shrubs to a 6-inch stubble height; (3) mowing trees and tall shrubs to a 6-inch stubble height and immediately applying a mixture of Tordon® (picloram) and Garlon 3A® (triclopyr) to the cut stubble; (4) applying a mixture of Tordon® (picloram) and Garlon 3A® (triclopyr) in 1987 and a mixture of Garlon 3A® (triclopyr) and Escort® (metsulfuron-methyl) to trees and tall shrubs in 1993; and (5) applying Accord® (glyphosate) in 1987 and either Accord® (glyphosate) or Krenite S® (fosamine) in 1993 to the foliage of trees and tall shrubs. Density of trees per acre greater than 1 foot in height in 1995 averaged 2,300, 1,400, 300, 400, and 100 for treatments 1, 2, 3, 4, and 5, respectively.

Butterfly counts were taken 5 times during the flowering period of May through August. Average collection time was 3.5 hours from 9:00 a.m. to 12:30 p.m. Butterfly species, behavior, and location within ROW was recorded during the collection period. The number of individual butterflies that were observed per treatment for the 5 sampling periods were 109, 143, 117, 145, and 115, respectively. No statistical differences were observed between treatments for butterfly species occurrence.

In California, Wojcik et al. (2016) examined management practices that create or enhance bee habitat while also meeting forest ladder fuel reduction goals, as wildfires are a major concern in this region. Two treatments—mowing and herbicide—in a replicated field trial were applied in 2012, 2013, 2014, and 2015. Herbicides used for treatment 2 were Milestone® (aminopyralid) and Vista® (fluroxypyr). Bee visitation counts were conducted across replications using a square meter quadrat bi-weekly from April 2012 to October 2012 for an average of 5 minutes, and again in April 2013 to October 2013. Of the seven native bee types recorded during the sampling period, bee type occurrence was not different among the two treatments. However, total native bee abundance was statistically significant

($p<0.05$), greater for the herbicide treatment in comparison to the mowing treatment.

For the most recent study in Pennsylvania, Russo et al. (2021) examined the impact of four treatments: (1) hand cutting; (2) low-volume basal herbicide mixture of aminopyralid, imazapyr, triclopyr, and bark oil; (3) low-volume individual plant treatment herbicide mixture of glyphosate and imazapyr; and (4) high-volume broadcast herbicide mixture of aminopyralid, imazapyr, triclopyr, picloram, and glyphosate on insects found on flowers. Surveys were conducted across treatments using a hand net to capture insects visiting flowers during the morning and afternoon for the months of May, June, July, and August in 2016 and 2017, for a total of 192 hours per treatment spent collecting insects. The author noted that treatment 1 was overgrown with brambles and therefore they were unable to collect insects for this treatment. Bee abundance when log transformed was significantly higher for low-volume basal herbicide treatment in comparison to treatment 3 and 4.

CONCLUSIONS AND DISCUSSION

Semi-natural habit such as ROW have been identified as areas that can preserve and improve pollinator populations that are declining across the globe (Potts et al. 2010). Research focused on pollinator habitat for ROW and the impact vegetation management has on the habitat has increased in recent years. However, research focused on herbicides' potential impact is limited to only a few studies examining a small percentage of the herbicides available to land managers. As awareness and interest in the potential impact herbicides applied on ROW can have on pollinators and their habitat, there is a need for more research in different geographical regions of the U.S. These studies would generate data that helps identify best management practices for meeting land managers' primary and secondary objectives.

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Using Unmanned Aerial Systems Technology and Machine Learning to Detect Pollinator Habitat on Utility Rights-of-Way

Ashley B. Bennett and
Wei Wang

Keywords: Drones, Machine Learning, Milkweed, Monarch Butterfly, Pollinator Habitat, Unmanned Aerial Systems (UAS), Unmanned Aerial Vehicle (UAV).

Rights-of-way (ROWs) can make a substantial contribution to pollinator conservation by providing critical foraging and nesting habitat. However, identifying and suppressing undesirable species while protecting important flowering native plant species is a constant challenge. Utilities need monitoring tools that will increase the efficiency and specificity of vegetation management (VM) on ROWs. Identifying native plant species that support pollinators can help utilities prioritize maintenance activities, protecting critical habitat. The overall goal of this project was to evaluate the use of unmanned aerial systems' (UAS) collected imagery and machine learning to detect pollinator habitat. UAS imagery was collected across grasslands in Colorado in 2020 and Illinois in 2021, targeting habitat with milkweed species. Collected imagery was used to develop a classification model for showy milkweed (*Asclepias speciosa*) in Colorado and common milkweed (*Asclepias syriaca*), as well as butterfly milkweed (*Asclepias tuberosa*) in Illinois. The classification model developed for showy milkweed yielded a mean accuracy of 89% while the classification model developed for common milkweed had a mean accuracy of 88% and 94%, respectively. Preliminary results exploring the use of UAS technology to detect important species for pollinator conservation were promising. However, models developed should be refined and tested in multiple geographies with larger plant sample sizes within study sites. The use of remotely sensed data to inform ROW vegetation management plans and promote pollinator conservation will continue to advance and offer new tools for vegetation monitoring and management.

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INTRODUCTION

Pollinators play a vital role in our ecosystem by providing pollination services to agricultural crops, as well as native trees, shrubs, and flowers. Unfortunately, pollinators are in decline globally as well as in North America, threatening the delivery of critical ecosystem services to agricultural and natural areas (Cameron et al. 2010; Potts et al. 2010; Koh et al. 2016; Powney et al. 2019; Sanchez-Bayo and Wyckhuys 2020; Zattara et al. 2021). One pollinator that has experienced sharp declines is the monarch butterfly (Schultz et al. 2017; Thogmartin et al. 2017; Belsky and Joshi 2018; Pelton et al. 2019). The declines in monarch butterfly populations have become so severe that the U.S. Fish and Wildlife Service (USFWS) continues to monitor the butterfly for listing as a threatened and endangered species (Spaeth et al. 2020; Pocius et al. 2022). One factor consistently identified as contributing to reductions in pollinator populations is the loss and degradation of habitat (Koh et al. 2016; Belsky and Joshi 2018; Malcolm 2018; Wilcox et al. 2019; Dicks et al. 2021). The conservation of existing habitat, re-establishment of flower-rich native plant communities, and VM practices that protect pollinators, such as reduced chemical inputs and mowing timed to decrease negative impacts on flowering resources, are habitat management strategies recommended to benefit pollinator populations (Fischer 2015; Thogmartin et al. 2017; Knight et al. 2019).

The utility industry is one group interested in implementing conservation actions that promote the protection and recovery of pollinators on utility lands. Integrated vegetation management (IVM) programs on utility lands are compatible with habitat management practices that protect and augment pollinator populations. The goal of IVM is to suppress the growth and establishment of undesirable vegetation on utility lands while promoting compatible vegetation, which is often low-growing grass and flower species. Utility companies may currently implement IVM on a variety of lands including rights-of-way (ROWs), substations, and solar facilities. ROWs, however, dominate the acreage of land utility companies manage using IVM, and present a unique opportunity to contribute to pollinator conservation. First, ROWs transect the landscape and can provide foraging, nesting, and larval host plants in landscapes lacking these resources, such as areas with high urbanization or intensive agriculture. Second, the management of ROWs with IVM is compatible with the habitat requirements of pollinators. Implementation of IVM practices discourage woody encroachment while encouraging a herbaceous plant community. When targeted chemical and mechanical practices are implemented, flowering resources can be protected and augmented on ROWs, providing a source of nectar and pollen across the landscape. In addition, many utilities are further tailoring their IVM programs to specifically plant native seed mixes that include flowering forbs and grasses that are highly attractive to pollinators and plants that host larval insect stages, such as species of milkweed.

One pollinator utility companies are targeting with conservation actions is the monarch butterfly. Conservation groups, private industries, and government agencies are collectively working to prevent the listing of the monarch butterfly by the USFWS under the Endangered Species Act (ESA) (Thogmartin et al. 2017; Thakur and Hurley 2021). While the monarch butterfly utilizes fir forests in central Mexico as overwintering habitat, the monarch breeding grounds cover large areas of the U.S. and southern regions of Canada (Cariveau et al. 2019). Migrating and breeding monarchs require flowers for nectar and milkweeds to support the development of larval stages. Many companies within the utility industry are actively participating in the monarch Candidate Conservation Agreement with Assurances (CCAA). The monarch CCAA is a voluntary agreement between transportation and energy organizations, University of Illinois at Chicago, and the USFWS. CCAA enrollees receive assurances that additional conservation measures, beyond those they commit to implementing on their adopted acres in their application, will not be required if the butterfly is listed, giving regulatory predictability to those participating (Monarch CCAA/CAA Development Advisory Team 2020). Those participating in the monarch CCAA are required to document foraging resources for the monarch butterfly and, in some regions, the presence of milkweed plants. Utility companies would like to avoid listing the monarch under the ESA because listing could bring regulatory restrictions around vegetation maintenance and other activities on utility lands. In addition, many utilities have environmental stewardship and sustainability reporting goals, which could leverage pollinator conservation activities to meet reporting goals. In general, monarch conservation strategies have two components: (1) increasing habitat that supports floral resources used as sources of nectar for migrating adult butterflies, and (2) adding milkweed plants for breeding populations (Pleasants 2017; Thakur and Hurley 2021). For those parties who have chosen to participate in the Monarch CCAA or who are more broadly wanting to identify and support pollinator habitat for conservation goals, monitoring tools are needed to document the presence of foraging and host plant resources.

Remote sensing technologies present an opportunity to develop new tools in biodiversity monitoring. Utility companies manage thousands of miles of ROW habitat, and performing labor-intensive ground surveys to document pollinator habitat is not feasible for most companies. Remote sensing technologies may offer new tools that facilitate rapid monitoring across large areas, making biodiversity surveys increasingly feasible. Remote sensing technologies are being used to assess plant diversity, document rare and invasive plants, and detect milkweed plants (Mockel et al. 2016; Gholizadeh et al. 2018; Blackburn et al. 2020; Fauvel et al. 2020; Gholizadh et al. 2020; Ozcan et al. 2020; Papp et al. 2021; Rominger et al. 2021). Developing remote monitoring tools that can detect pollinator foraging resources and key host plants, such as milkweed, are needed to further pollinator conservation by identifying habitat to target for protection and management. These same tools could also be utilized by CCAA partners to assist in annual biological monitoring efforts required under the CCAA.

The overall goal of this study was to evaluate the use of UAS or drone technology to detect and accurately identify plant species known to support pollinators. The value of this study to the utility industry is developing a tool that facilitates habitat monitoring across large spatial scales, informing the effectiveness of IVM practices on creating habitat capable of supporting pollinators. One of the plant species targeted in this research was *Asclepias*, or milkweeds. The project objectives reported here include: (1) using a UAS platform to capture milkweed species during flowering, and (2) developing a machine learning algorithm to accurately detect different milkweed species.

METHODS

For this research, milkweed species were sampled with UAV flights across two years in two different regions of North America. In 2020, showy milkweed (*Asclepias speciosa*) was targeted in five restored grassland sites in Boulder County, Colorado (Figure 1). In 2021, common milkweed (*Asclepias syriaca*) and butterfly milkweed (*Asclepias tuberosa*) were sampled across seven restored grassland sites in Shelby and Coles Counties, Illinois (Figure 1). Butterfly milkweed occurred in three of those sites and common milkweed was present in four sites. Flights were performed during peak flowering season, early-to-late June in 2020 and 2021, respectively.

Figure 1. Milkweed species sampled during the 2020 and 2021 field seasons included: (A) Showy Milkweed (*Asclepias speciosa*), (B) Butterfly Milkweed (*Asclepias tuberosa*), and (C), Common Milkweed (*Asclepias syriaca*). Photo A: D. Sabastian; Photos B and C: A. Bennett

UAS Hardware Specifications

For data capture, a Mavic Pro 2 with a Sentera Double 4K Red Edge sensor was used (Figure 2). This UAV, or drone, was chosen due to its size, precision, obstacle avoidance, increased battery life, and compatibility with the Sentera sensor. Overall, the Sentera Double 4K Sensor is fully configurable, capable of capturing five precise spectral bands: blue, green, red, red edge, and near-infrared (NIR). This sensor collects visual band imagery and allows calculation of vegetation indices based on the addition of NIR or red edge, including normalized difference vegetation index (NDVI) or normalized difference vegetation red edge (NDRE) data. For this research, a combination of the individual bands, NDVI, and NDRE were used for classifying imagery in the models.

UAS Software Specifications

FieldAgent Mobile was the software used to plan and execute UAS flights. This software allows users to set flight parameters, such as altitude, flight speed, and imagery overlap. FieldAgent Mobile also facilitates the drone's autonomous take off, flight along a predetermined route, and automatic return to the designated landing zone upon completion of the flight plan. The altitude is an important parameter during flight planning, as it factors into the Ground Sampling Distance (GSD). In this research, the altitude for flights was 70 m to ensure tree, utility line, and other obstruction clearances. The flight altitude resulted in a GSD for all flights of 1.5 cm, which means that one pixel in the image represents 1.5 cm x 1.5 cm (2.25 square cm). The flight speed used for data collection was 15 m/s. This

Figure 2. Mavic Pro 2 with Double 4k Red Edge Sensor. Photo: D. Sabastian

speed was selected because flying at higher speeds tends to blur images but flying at a slower speed will not allow capture of larger areas in a timely manner. With an average flight area of roughly 10 acres per site, 15 m/s allowed an acceptable average for all sites and other parameter settings. This flight speed also ensured no more than two batteries would be required to complete data collection for all planned flights.

Image overlap is also an important parameter in UAS data capture, especially in the post processing of collected imagery. Two types of overlap are required: frontal and lateral image overlap. Frontal overlap is the percentage successive images capture the same information along a flight line. In this study, the frontal overlap of images was 10%, meaning each image had a 10% overlap with the image immediately before and after its capture. The side lap (also referred to as lateral overlap) is the same information captured between images from adjacent flight lines. Lateral overlap of adjacent flight lines ensures no gaps in coverage across the study site. The side or lateral overlap used for all flights in this research was 25%. A summary of all flight parameters is shown in Table 1. Once UAS flights were completed, Pix4Dmapper was the software used to process collected imagery. Pix4Dmapper was used to stitch individual images into an orthomosaic map. The photogrammetry algorithms Pix4Dmapper uses then transforms the aerial images into digital maps for classification modeling.

Table 1. Flight Parameters Used Across All Study Sites

Parameter	Value
Altitude	70m
Flight Speed	15 m/s
GSD	1.5cm
Frontal Overlap	10%
Lateral Overlap	25%

Field Data Collection

A mobile application was developed and used to collect field data. The mobile application collected two types of field data: (1) ground control points and (2) GPS coordinates for targeted pollinator plant species. The first step in collecting ground control points was to physically place four pads on the ground. One ground control pad was placed near the north, south, east, and west corners of each study site, which outlined the boundaries of each flight area. Next, the GPS location (or point) of each ground control pad was recorded, which documented the precise locations of all four ground control points. The four ground control pads are visible in captured UAS images. Because the ground control points have highly accurate coordinates, they are used in correlation with drone mapping software to accurately position the drone- collected images and resulting maps in relation to their position on the earth. Finally, the mobile app was also used to identify and record the GPS locations of pollinator plant species within the flight areas. The target pollinator plant species reported here included showy milkweed, common milkweed, and butterfly milkweed. The collected GPS points that represented the different plant species were used to develop unique cover class categories, used in the final models.

Modeling Software and Methods

Once the UAS imagery and field data were collected, Pix4D software was used to mosaic, or combine, all images for a study area into a single image. Ground control points were used from the field collection to ensure proper spatial and geographic alignment of the orthomosaic image in relation to its position on the earth. This step created orthomosaic images representing each study area. Field capture GPS locations representing pollinator plant species of interest were then used to create a "signature file." A signature file uses the spatial locations of known points or polygons. In this case, it was the location of target pollinator plant species. This signature file captures the collective spectral information for all classes that were captured in the field. Additional classes were included for inclusion in the signature, in which the modeler was 100% certain of an identifiable object in the orthomosaics, such as water, forest, impervious (e.g., roads and buildings), rocks, and shrubs. This methodology was chosen due to the landscape of the selected study sites. Study sites were selected where different target pollinator plant species dominated the areas identified for UAS flights. Using broad cover classes, such as impervious, forest, and water, in combination with the classes developed for each flower species, generated signature files used in the classification process.

Once the signature file was created, a segmentation analysis was performed. Segmentation is an object-based classification. The process of segmentation takes neighboring pixels together that are similar in color and have certain shape characteristics. Combining pixels of similar color and shape is useful when classifying different land cover classes because it tends to better represent objects in the landscape than the original pixels (Preetha et al. 2012; Tian et al. 2013). According to Schiewe (1999), segmentation is the process of merging pixels that represent landscape homogeneity and heterogeneity by combining pixels with similar traits (e.g., color and texture), as well as pixels with characteristics distinct from neighboring pixels. In this study, segmentation was used to identify homogeneity and heterogeneity of pixels, which assisted in the classification process. By grouping pixels with common traits, segmentation is similar to land cover mapping or classification (Wang et al. 2020). Once the segmentation layers for each study site were created, a random trees classifier was used to generate the classification layer. The classification layer is a geospatial file that represents a classification of every pixel within a study site. The use of a random trees classifier has shown significant improvement in classification accuracy when generating multiple trees and allowing the algorithm to choose the most popular classes (Breiman 2001; Fan 2013).

Random trees classifier is the combination of multiple tree predictions. Each tree prediction is based on the values of an independently sampled random vector, and all trees within the forest will have the same distribution (Breiman 2001). An example would be for the classifier to randomly select locations from ground truth data to determine which class a given pixel best fits. This process is repeated and randomized by subsets of training data to grow each tree within the forest. The process continues until model agreement is determined, which the final classification layer is based.

Table 2. Accuracy Assessments for the Three Milkweed Species Surveyed

	Overall Model Kappa Coefficient	Accuracy Showy Milkweed	Accuracy Butterfly Milkweed	Accuracy Common Milkweed
Field 1 - 2020	0.85	0.90		
Field 2 - 2020	0.75	0.89		
Field 3 - 2020	0.72	0.85		
Field 4 - 2020	0.75	0.82		
Field 5 - 2020	0.84	0.99		
Field 1- 2021	0.81		0.93	0.77
Field 2 - 2021	0.91			0.91
Field 4 - 2021	0.87		0.94	
Field 6 - 2021	0.88		0.95	0.94
Field 7 - 2021	0.89			0.89
Flower Average		0.89	0.94	0.88

ACCURACY ASSESSMENT

Once all classification layers were created, an accuracy assessment was conducted to determine how well the classification model predicted each pollinator plant species. The accuracy assessment used in this research was a confusion matrix. A confusion matrix is calculated based on the classification of randomly selected points from the final classification layer. The confusion matrix calculates accurate assignment of pixels to classes. For this research, 500 randomly selected points were created for each class. For example 500 randomly selected points were created on known showy milkweed locations—that is, ground truth points. The randomly selected points will be assigned two values "ground truth" and "classified." The "ground truth" assignment is based on reference data (i.e., the GPS located pollinator plants). Each point is first assigned the class value of the ground truth data in which the point resides (i.e., showy milkweed, impervious, non-target flowers, etc.). The "classified" assignment represents how each point was classified during the generation of the random forest classifier model. Therefore, the same points are then updated to reflect the classification value of that point by the classification model.

The confusion matrix calculates a user's accuracy and producer's accuracy for each class as well as an overall kappa value, which represents the overall model accuracy. The user's accuracy is based on the classification of the ground truth data points while the producer's accuracy is based on the classification results from the model. Accuracy rates range from 0 to 1. In the confusion matrix, accuracy values are reported as proportions, but are often interpreted as percentages where 0.90 represents 90 percent accuracy and 1 would represent 100 percent accuracy. The kappa value gives an overall assessment of the accuracy for all the cover classes modeled. The kappa value measures the agreement between the points classified by the random forest model and the locations of ground truth points. The overall kappa value is used to interpret model performance (Landis and Koch 1977). Kappa values range from 0–1, with 0 being no agreement and 1 being perfect agreement. When interpreting the kappa value, the goal for model output is a kappa value greater than 0.61. Models having a kappa value of 0.61 or greater are considered models with substantial agreement between the ground truth data and the results generated from the model.

RESULTS

In 2020, showy milkweed was sampled in a total of five study sites in Boulder County, Colorado. In 2021, common milkweed was surveyed across four fields and butterfly milkweed in three fields across Coles and Shelby Counties in Illinois. The classification model for showy milkweed produced accuracy values (i.e., kappa coefficients) ranging from 0.82 to 0.99 or 82%–99% for individual study sites, and a mean accuracy of 0.89 or 89% across all fields (Table 2). The overall model, which represents all the classes included in the model and is the average of all individual kappa values, has accuracy values lower than those calculated for the individual showy milkweed class. For example, Field 1 has an overall model accuracy of 0.85 or 85% compared to the showy milkweed class, which has an accuracy of 0.90 or 90% (Table 2). The classification model for butterfly milkweed produced accuracy values ranging from 0.93 to 0.95 or 93%–95% for individual study sites and a mean accuracy of 0.94 or 94% across all fields (Table 2). The accuracy scores for common milkweed were lower compared to butterfly milkweed, with accuracy values ranging from 0.77 to 0.94 or 77–94% (Table 2). The mean accuracy for common milkweed averaged across all study sites was 0.88 or 88% (Table 2). The overall accuracy for models that included all classes including butterfly milkweed and common milkweed ranged from 0.81 to 0.89 or 81–89% (Table 2).

DISCUSSION

Overall, the results of this research are promising and suggest UAS-developed models can identify pollinator plant species. In this study, detection of milkweed species was a focus since the monarch butterfly is under consideration by the USFWS for listing under the ESA. For utilities wanting to participate in the Monarch CCAA or for those looking to advance their pollinator conservation efforts, developing new tools that document the presence of foraging resources and host plants is needed. Here, UAS collected imagery, coupled with the development of classification models for three species of milkweed in two different growing regions (i.e., the Great Plains and the Midwest), suggest remote detection and identification of at least some species of milkweed is possible. Showy milkweed and common milkweed yielded similar classification results with average accuracies at 89% and 88%, respectively. Butterfly milkweed produced slightly higher model results with an average classification accuracy of 94%.

Remote sensing technologies show promise for pollinator plant and habitat assessments. Other studies have employed UAS technology to map milkweed species. In Hungary, common milkweed is considered an invasive species, and high-resolution hyperspectral images collected using a drone were used to detect and document invaded natural areas with an accuracy of 92–99%, depending on the classification algorithm applied (Papp et al. 2021). While the results presented in Papp et al. (2021) used hyperspectral imagery compared to the multispectral imagery used in this study, both types of imagery were successful in identifying common milkweed. The higher accuracy achieved by Papp et al. (2021) may have resulted from their use of hyperspectral data, which contain significantly more spectral bands of data (138) compared to the 5 bands collected with the Sentera Double 4K Red Edge multispectral sensor. Desert shrubs have also been successfully identified and classified with an overall accuracy of 93% using a UAV coupled with a multispectral sensor (Al-Ali et al. 2020). Finally, remote sensing technologies have successfully assessed plant diversity (Gholizadeh et al. 2019; Fauvel et al. 2020) as well as ecological characteristics of grassland habitat (Blackburn et al. 2020), suggesting continued advances in this research can protect pollinator habitat through improved remote monitoring tools.

While sensors and collection platforms will influence detection and accuracy, flower characteristics will also affect classification models. Flower size, shape, and color may all influence detection and accurate classification (Carl et al. 2017; Rominger et al. 2021; Gallmann et al. 2022). In the case of the milkweed species evaluated, butterfly milkweed has a bright orange flower. While the shape of the flower head is a cluster similar to the other two milkweeds evaluated, this species of milkweed is one of the few orange flowers present in prairie plant communities. As a result, the color of this flower makes it unique and likely increases its detection and successful classification. In contrast, one advantage common and showy milkweed species may have that increases their detection and classification is the fact they often grow in colonies. Both showy and common milkweed spread by seed, but they also spread by rhizomes, which means they often occur in large patches. Flowers growing in large patches, as opposed to singly, may increase their detection with remote sensing technologies because patches of flowers may be more easily detected at lower resolutions. In contrast, flowers with small heads and of a color similar to other species blooming at the same time may increase the difficulty of detection and model classification. As an example, two flower species, prairie coneflower and blanket flower, were captured in imagery in 2020. Classification models were unable to successfully detect each species separately, but when both flower species were combined into one class, models significantly improved and resulted in a mean classification accuracy of 89%.

Based on the preliminary results of this study, several future areas of research are recommended. First, more research is needed to determine if the models developed for the milkweed species can be improved by sampling multiple geographies and increasing plant sample size within study sites. Second, preliminary milkweed models produced encouraging results, suggesting other milkweed species might generate similar classification accuracies.

The monarch butterfly has a large geographic range, and its larval stage feeds on many different species of milkweed (Pocius et al. 2017; Baker and Potter 2018; Pegram and Melkonoff 2020; Brym et al. 2021). Developing models for different species of milkweeds in regions across the U.S. could facilitate the identification and protection of critical monarch habitat. While milkweed-specific models would assist in the identification and monitoring of monarch habitat, models of other key pollinator plant species could also document essential foraging resources for pollinators. A third research need would build on the results here by developing models that target key native plant species that provide critical foraging resources for native pollinators. A fourth area of research is exploring tools that assess overall pollinator habitat quality. Vegetation managers could use remote sensing technologies and the models they produce to inform VM plans by tailoring practices to protect existing pollinator habitat or target areas with potential conservation value. Lastly, additional research is needed to continue evaluating the potential for satellite imagery to provide a solution to the logistical and economic challenges present with UAV-based data collection and processing.

CONCLUSIONS

Identifying and conserving pollinator habitat is increasingly important as many species continue to experience population declines. The monarch butterfly is one species on a growing list of pollinators that are experiencing population declines. The utility industry and land managers need effective tools that can inform VM plans that facilitate targeted management for at-risk species. The results presented in this report suggest UAS imagery and the models created may be an effective way for land managers to identify plant species that support declining pollinators, like the monarch butterfly. The results presented here document the potential to identify regionally important pollinator plant species, suggesting land with conservation value for pollinators can be remotely detected and monitored.

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Dr. Wei Wang, PhD

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Vegetation Management Science of Performance: Using Vegetation Inventory Metrics to Enhance Vegetation Program Performance

Jeff Filip and Stacie Grassano

Keywords: Data Analytics, Maintenance, Technology.

Florida Power & Light (FPL), one of North America's largest Electricity Transmission and Distribution Utilities, has used LiDAR technology for gathering vegetation data in and around rights-of-way (ROW) for more than ten years. While the data is highly accurate by way of geospatial proximity and measurements, it is not always reflective of detailed "utility program specific" meta data (e.g., which trees need to be cut, by how much, and the associated costs). For this reason, LiDAR data is typically used by utilities as a "compliance to measurements tool," and then field resources are used to scope and determine the required work.

The technology company Intelfuse has focused on the next generation of automation and analytics of LiDAR vegetation data to produce specific utility program meta data. The Intelfuse technology, called datafuse3D, creates individual 3D vegetation canopies, full digital twins of vegetation within a given corridor, to provide cost, risk, and work requirements and to facilitate comparisons of annual vegetation populations and effectiveness of routine and reactive maintenance plans.

FPL and Intelfuse worked on a 2-stage Proof of Concept (PoC) to ascertain if automated algorithms, tuned to FPL requirements, could be used to derive items such as trim and removal costs, diameter at breast height (dbh), estimated and actual growth rates, mitigation work types, outage and wildfire risk ratings, vegetation clearances to conductor and structure, and regulation zones as defined by voltage and conductor type.

As part of the PoC, the Vegetation Digital Twins were used to automatically assign work prescriptions for the execution of work. The methodology and results of the PoC will be discussed, plus the future potential of using remote sensing processing automation to automatically generate work prescriptions for vegetation management (VM).

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Just like sports science has been used to improve individual athlete and sporting team performance, vegetation inventory metrics can be used to enhance vegetation program outcomes. While the use of metrics to enhance performance may seem obvious, the challenge in the utility vegetation management (UVM) sector has always been the availability of specific performance information that is meaningful for regulators, asset owners, and work delivery practitioners.

As utility vegetation program data have become more available, so has the quest for data science and the proof of business case, which is typically highly leveraged by improved organizational UVM program outcomes.

Across the globe, regulators have developed vegetation management codes, legislation, and requirements, essentially stipulating Compliance Clearance Zones to help guide asset custodians of vegetation to line clearances and other risk mitigation requirements. Examples of these include NERC FAC-003.4 in North America, the South Australia Electricity (Principals of Vegetation Clearance) Regulations, and the Electricity (Hazards from Trees) Regulations in New Zealand, to name but a few.

Science of Performance Objective

With the help of a group of industry players and researchers from Australia's University of Melbourne, Intelfuse set about the task of developing a suite of science-based industry metrics to assess vegetation program performance, validate various UVM Compliance Clearance Zones, and draw conclusions for the data-driven UVM business case assumptions.

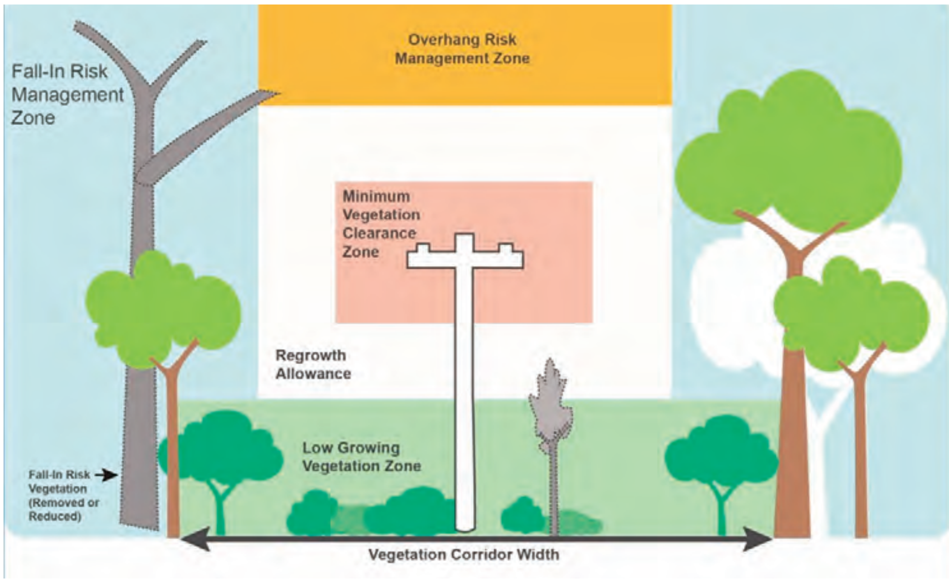


Figure 1. Essential Energy Vegetation Management Plan – Illustration of Minimum Vegetation Clearance Zone (Compliance Clearance Zone)

The objective of the Science of Performance exercise was to determine the performance levers required to effect change on poorly or moderately performing UVM programs. Performance of UVM programs was assessed as to their optimal spend for risk abated and other reliability and safety outcomes.

METHODS

Data Methodology Challenges

The first challenge was to nominate data sources that gave the accuracy and consistency required, and the second was to develop the data processing and management system that allowed appropriate assessment of results. Regarding data source, the growing availably of satellite, on-ground industry-collected, and LiDAR data all posed their various pros and cons. It was decided to use LiDAR data, due to the high level of accuracy and growing availability of utility and freely obtainable data sets.

In the area of data processing and management, no commercially available platforms could address the processing, required vegetation granularity, and utility-specific Compliance Clearance Zone specifics. Complex information, such as voltages, conductor types, span lengths, and operating conditions, was added to the requirements of collecting individual tree information. Other key items in the information arena included fall in and hazard potential; location of tree under, over, or beside line; ground slope; plus a myriad of other key risk-based metrics. To solve the issue, Intelfuse worked with the University of Melbourne, Australia, to develop a processing system that used machine learning to identify individual trees, but also model the required specific utility and line information.

Utility Industry Collaboration

The availability of suitable LiDAR data has become more and more mainstream over the past decade. While many transmission and distribution (T&D) utilities are collecting LiDAR data, there has also been growth in the availability of free data that can be used. Utilities that have data are interested in learning more from their data, and Intelfuse has used information gained from unencumbered "free issue" data to assist in developing representative samples of various UVM data metrics in North America, Australia, New Zealand, and the European Union. Representative samples are portions of network data that embody the density of trees per hectare and the mix of T&D distribution lines that exist across the network.

Surprisingly, even though UVM works have been ongoing on T&D for some 70+ years, very few granular metrics have been collated or retained by utilities or are available in the research arena (e.g., historical stem or tree counts, tree densities, tree sizes, growth rates, and species types). The significance of the nonavailability is noted in benchmarking studies, such as the Australian Energy Regulator's annual benchmarking report, electricity distribution network providers (November 2021): "We note that route line length contains lengths of lines that are not vegetated. Vegetation maintenance spans is a better indicator of the length of vegetated spans. However, we have used overhead route line length instead of vegetation maintenance span length due to DNSPs' estimation assumptions affecting maintenance span length data." With the limitations of not having detailed vegetation density information noted, Vegetation OPEX per km of overhead circuit length (AUD $2,020) for the period 2016 to 2020 is shown in Figure 4.

Similar to the situation of visual inspection and the lack of granular data available from historic collections, with the advent of satellite and LiDAR data, the majority of utility data is

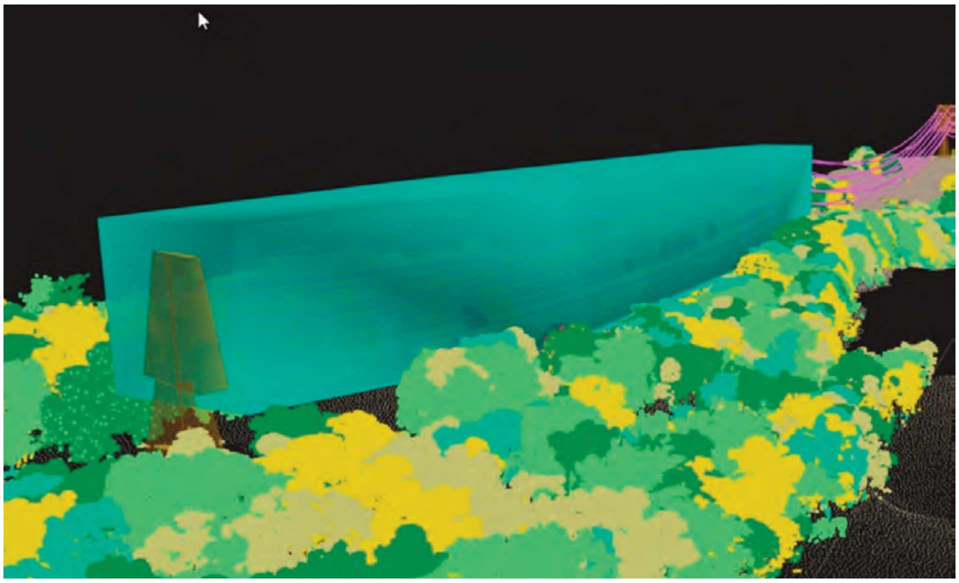


Figure 2. Machine learning processing system identifying individual tree canopies, T&D line models, and vegetation compliance clearance zones

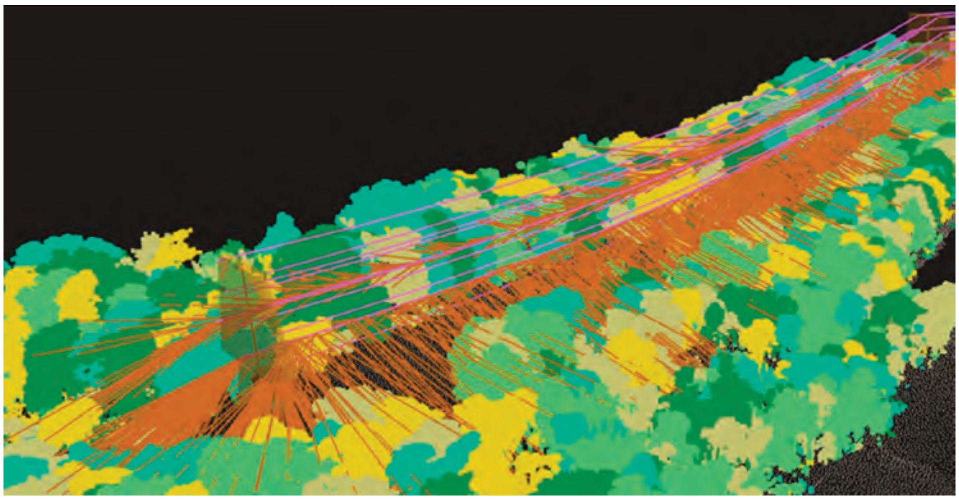


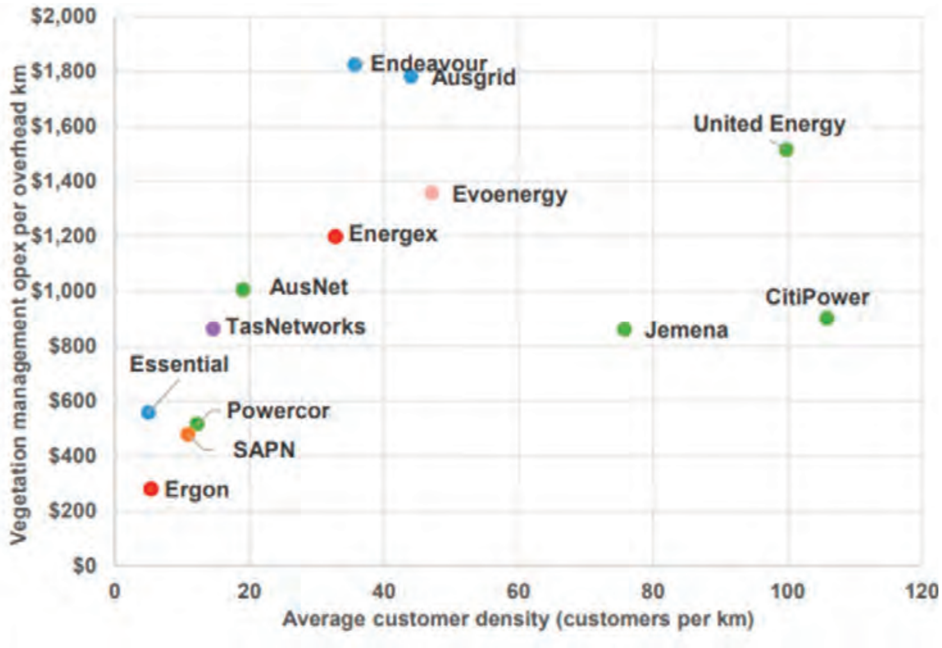
Figure 3. Machine learning processing system with automated closest point measurements from conductor to tree

visualization of point clouds and imagery, rather than granular information that can be used to benchmark and compare performance. For this reason, the benefit of developing individual tree and asset models with the University of Melbourne has been an important foundation in the collation of specific UVM metrics that can be used across the global arena.

RESULTS

The first observation that becomes apparent in multiple data sets from multiple global locations is the sheer variability of the data. Vegetation sizes, volumes, densities, and growth rates all had some common traits and then a number of outliers that clearly made the exercise interesting. One of the most striking differences is the tallest tree in the data sample comparisons. Not surprisingly, the prize for the tallest tree went to a 105.4 m (345.8 ft) *Sequoia sempervirens*, or California redwood. Other interesting items included 90 m (295 ft) transmission towers and conductor spans over 1 km (1,609 ft or 0.62 mi), to name just a few. Different network configurations for T&D in the different countries were also of great interest, with Australia and New Zealand typically having much longer distribution spans than North American networks, as well as North America having a greater volume of smaller pole-mounted transformers and Australia having larger transformers with long low-voltage subsidiaries in the urban areas.

Vegetation densities were spread consistently with what you'd expect from the variations in different climate zones. For example, greater-rainfall tropical climates generally had more dense vegetation. While this was the case, we did end up focusing on the density in the immediate ROW, plus a typical overstrike distance, normally a 100 m (328 ft) swath. Results for tree densities were captured in trees per km for the given swath. This made it easier to compare different networks in different countries rather than attempting to capture trees per hectare.



Source: AER analysis; Category Analysis RINs; Economic Benchmarking RINs.

Figure 4. Vegetation OPEX per km of overhead circuit length (AUD $2,020) for the period 2016 to 2020

The other interesting observation was the amount of financial spend various utilities applied to their UVM programs. Many of the expenditures were highlighted in company and regulatory reports, but for most, a comparison was made using industry benchmarked costs for various UVM activity. These items are commercially sensitive and did have some departure from those listed in the company and regulatory reports (e.g., tree rates, span rates, and lump sum comparisons). When vegetation density was transposed with customer density in the comparison to vegetation program OPEX per km of overhead line circuit, the performance comparison between utilities was much more obvious. This information is not provided due to the commercial sensitivity of the results.

Performance Metrics

With the Science of Performance objective being metrics that could identify the level of UVM performance, the overarching categories of assessment were divided into the three categories. Once overall performance of a UVM program was assessed, a more detailed analysis was undertaken to identify what specific opportunities existed to change the level of performance.

The three performance categories are:

1. **Compliance Effectiveness –** how effectively was the utility maintaining vegetation in the Compliance Clearance Zone?
2. **Compliance Financial Efficiency –** how efficiently was the utility using the financial resources assigned to maintain the Compliance Clearance Zone?
3. **Compliance Audit –** what was the actual performance of the execution of field work compared to that required by the Compliance Clearance Zone?

For the first metric, Compliance Effectiveness, a comparison of the trees within the innermost 80 percent of the Compliance Clearance Zone was compared to the total amount of trees within the Compliance Clearance Zone and subtracting the amount from 1 to arrive at a Compliance Effectiveness percentage—100 percent being totally effective and below less so. This measure allows immediate assessment of Compliance Effectiveness and can also readily be compared to other utilities.

The second metric, Compliance Financial Efficiency, requires either an understanding of the existing financial expenditure of the utility to maintain the Compliance Clearance Zone—or if unavailable, a benchmarked work rate for the given sample. In development of the benchmarked work rate, known market rates were used in conjunction with the growth rates, as determined by a statistical growth model.

The third metric, Compliance Audit, uses a "post work" comparison with the processed LiDAR data of outstanding items within the Compliance Clearance Zone. To illustrate the results, Figure 5 shows assessed vegetation inside the clearance zone compared to the distance in meters of the individual tree between the conductor attachment points. The sample uses trees and compliance zones from several utilities and assessment of more than one million trees. From the analysis, it can be shown that work completed is less likely to be compliant the greater distance the tree is located toward the middle of the span or in comparison to the structure. This is of concern as it shows that the higher the potential risk a tree poses (due to span length and position in the span), the higher the likelihood it is that the violation will not be accurately assessed by visual assessment.

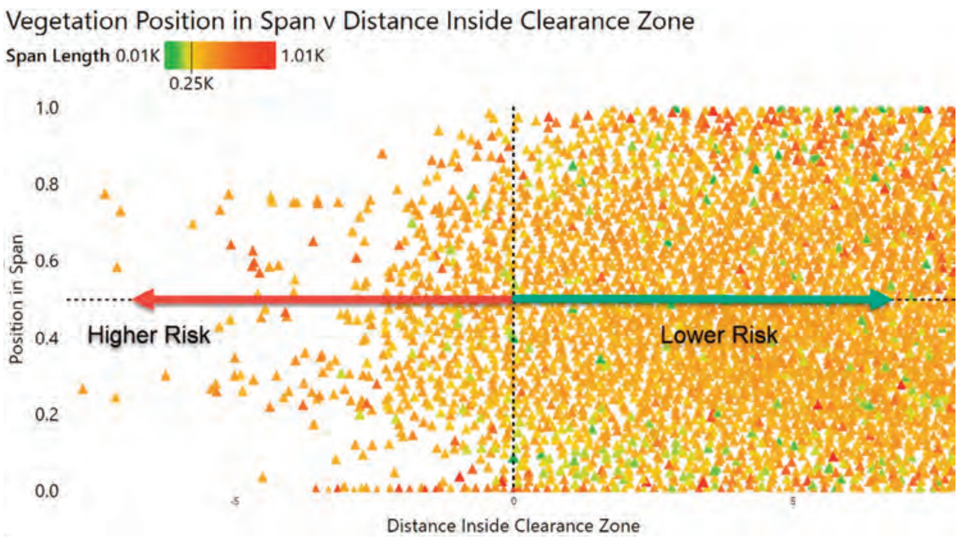


Figure 5. Vegetation position in span (each tree) compared to distance inside Clearance Zone in meters (color indicates span length—green shortest, orange median, red longest)

CONCLUSIONS

Findings, Implementation, and Performance Coaching

The findings of the Science of Performance exercise did reveal that most UVM programs do fall short of the goal of keeping clear the Compliance Clearance Zone, with most results falling between 60 percent and 80 percent effective. It was also found that Compliance Financial Efficiency also came out between UVM program funds being somewhere between 30 percent and 50 percent of funds either being not required or at least could have been better spent.

While the results are disappointing at an industry level, it does add some information to explain why UVM programs are still causing challenges for asset custodians in the area of vegetation being the poorest performing asset category for network outages and fire ignitions. UVM programs also have the infamous position of being one of the highest OPEX spend areas for T&D utilities.

It was clear in the study that regulators and utilities were aware of the challenges of poor performance, but were less connected to what needed to be done to rectify the performance issues.

Like sports science has emerged in the sports arena, we believe that as regulators and UVM Program Owners, become aware of the opportunities to be gained from understanding detailed UVM performance. There will be an emergence of utility sector science-based analytics capability that will enable a transformation in UVM performance for the ultimate positive benefit of stakeholders, shareholders, and end users of electricity T&D assets.

AUTHOR PROFILES

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Why Don't You Use Goats?

Richard A. Johnstone, Michael R. Haggie, and W. Bryan Hall

Keywords: Goats, Herbicides, Invasive, Mowing, Pollinators, Utility Lines.

A vegetation management partnership was developed between Choptank Electric Cooperative and Washington College for maintenance of an electric distribution rights-of-way (ROW) crossing Chino Farms near Chestertown, Maryland. The farm's research professor emeritus suggested that goat grazing should be used instead of pesticides for vegetation control. A decision was made to establish vegetation management case studies on the electric ROW to directly compare selective herbicide treatments with goat grazing, as well as side-by-side studies in an adjacent field comparing selective herbicide treatments with goat grazing and conventional brush hog mowing.

The quality of habitat for birds and pollinators was assessed using a Pollinator Site Value Index (PSVI) that measured the established plant community benefit for native bees (*Bombus sp.* Latreille) and compared it to the plant community derived after the vegetation controls were implemented. Photo and cost documentation were also conducted throughout the trial.

This paper provides a direct comparison of varying vegetation management methods, the pros and cons of each method, and unbiased documentation of the resulting plant communities, and their respective impact on the electric reliability and access objectives of electric ROW vegetation management, the habitat quality for pollinators and birds, and the costs incurred.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

IVM Partners, Inc., a 501(c)(3) nonprofit corporation, assisted Choptank Electric Cooperative in developing an integrated vegetation management (IVM) partnership with Chino Farms near Chestertown, Maryland, beginning with discussions about planned tree trimming and mowing in 2018. Chino Farms is part of the Washington College River and Field Campus, classified as an important bird area by the National Audubon Society, and home of the Chester River Field Research Station (CRFRS) (*chesapeakebaymagazine.com/back-to-nature*).

Choptank Electric Cooperative is a nonprofit electric utility formed in 1938 that serves over 52,000 rural Maryland customers over more than 10,000 distribution line kilometers. One of these lines crosses Chino Farms where Choptank Electric was historically restricted to only performing manual and mechanical vegetation cutting to provide reliable services. In an effort to improve habitat for pollinators along its electric line rights-of-way (ROW), Choptank Electric's forester, Bryan Hall, asked if the latest tree trimming and mowing operations could be followed with selective herbicide treatments of interfering trees and invasive plants.

A field meeting was held at Chino Farms in spring 2019 to review a proposal for establishing baseline vegetation management (VM) botanical surveys for comparative case studies following the ROW cutting operations. The studies would be established along the Choptank ROW that was cut in 2018 and within a fallow field that was last mowed in 2016 (after having a controlled burn in 2014). The field meeting was arranged with Dan Small, the Natural Lands Project (NLP) coordinator for Washington College's Center for Environment and Society, Choptank Forester Bryan Hall, IVM Partners President Rick Johnstone, and botanist Robin Haggie.

IVM Partners had conducted IVM case studies using the same criteria throughout the United States on electric, natural gas, and highway ROW to document habitat changes using various techniques. The results of these studies have been used to educate the utility industry, government agencies, tribal nations, academia, and the public on the best IVM practices as outlined in ANSI A300-Part 7 Integrated Vegetation Management.

METHODS

The Choptank-Chino partnership case studies were designed to compare the vegetation conditions maintained through routine mechanical brush hog mowing, with that derived from selective backpack herbicide treatments. Dr. Doug Gill, Professor Emeritus University of Maryland—who initiated the original Chino Farms research—requested additional research with the questions: "Why do you have to use poisons? Why don't you use goats?" So, we decided to include documentation of habitat changes derived from goat browsing.

The Choptank-Chino case studies documented habitat changes on areas representative of the habitat types encountered on the 12-meter-wide ROW by keying all plants along a 2 x 33 m transect. Two case study sites were chosen following the 2018 mowing and hand cutting to document results of selective herbicide treatments: one riparian study crossed by a drainage ditch and one upland study. For purposes of the comparative studies, only the upland ROW herbicide study was evaluated along with the adjacent upland ROW goat browsing study, which borders the access road.

Baseline documentation was also established along the fallow field edge on side-by-side 0.1 hectare plots (12 x 92 m) to mimic the width of a distribution ROW and conduct direct comparisons of goat browsing, selective backpack herbicide treatment, and brush hog mowing.

IVM Partners coordinated with River Valley Forestry, LLC to selectively backpack herbicide treat the Choptank ROW and field herbicide plots with a combination of the herbicides Milestone (aminopyralid) at 0.94 liters/hectare, Viewpoint (aminocyclopyrachlor, metsulfuron, and imazapyr) at 0.73 kilograms/hectare, and the surfactant MSO (methylated seed oil) at 1.87 liters/hectare in July 2019. The chemical and labor cost for treating the fallow field 0.1 hectare case study was $44 or an extrapolated cost of $435 per hectare.

Chino Farms coordinated the brush hog mowing of the entire fallow field with their tractor in March 2019, so we estimated the cost of the mowing case study using the average cost of Choptank ROW mowing, which ranged from $355–$740 per hectare depending on the equipment used, or a median estimate of $549 per hectare, for comparison.

Sustainable Resource Management, Inc. was hired to fence off the goat browsing case study areas (ROW and field) and bring in the goat herd for a $1,000 delivery charge plus a $100 per diem rate for browsing. The goats browsed their ROW study for three days in July, their field study for another three days in July, and six days in August. Splitting the delivery rate evenly between the ROW and field studies—at $500 each—the ROW cost $800 while the 0.1 hectare field study cost $1,400, or an extrapolated cost of $13,838 per hectare (Figure 1).

Baseline botanical documentation was conducted at all case study sites in June 2019 to capture the first year's growth of the field mowed case study and prior to VM interventions by herbicides or goats on the field and ROW studies. The difference between the ROW herbicide and goat case studies and their field case studies was that the field had three growing seasons of vegetative growth since it had been last mowed in winter 2016, while the ROW had one growing season since it had been mowed in fall 2018.

Historically, growth resulting from three growing seasons after mowing produces a dense growth of trees and invasive shrubs as high as 4 meters, making it difficult to selectively herbicide treat without collateral damage to non-target herbaceous plants. The woody trees and shrubs are also less palatable to browsing animals, lessening the effectiveness of goat browsing. In contrast, the one year of vegetative growth in the ROW is ideal for both selective herbicide treatments and goats, since the low-growing, young growth is more accurately targeted with the herbicide spray and is more palatable to browsing animals.

The VM objectives of the ROW and the fallow field were different but compatible:

- Choptank Electric manages ROW vegetation for reliable electric service with safe and ready access for line maintenance workers. They want to discourage tall-growing trees and interfering, dense shrubs and encourage grasses and herbaceous plants. Choptank also wants its ROW to be pollinator greenways by allowing native wildflowers and small shrubs to provide nectar and pollen for bees, butterflies, and birds.
- Chino Farms manages the fallow field primarily for bobwhite quail and other songbirds. Therefore, tall-growing trees and non-native invasive plants are discouraged while grasses, wildflowers, and small shrubs are encouraged. Small, woody shrubs provide structural support to protect quail during high-snow events, like Chino Farms experienced in 2010.

Figure 1. Goats browsing ROW study

Figure 2. ROW herbicide case study

RESULTS

The ROW herbicide case study was in a wooded upland area (Figure 2) and the adjacent ROW goat browsing study was due east, with one side bordering the farm road to enable easy access for shepherding. Thirty-five baseline plant species were documented in the herbicide study in June 2019 that reduced to 24 species in the fall of 2020. The goat browsing study started with 26 species and reduced to 17. Of these species, the target trees and shrubs that were incompatible with access and reliability goals of an electric ROW dropped substantially with the herbicide application, while the goats had little effect (Table 1). This was mainly due to black walnut (*Juglans nigra* L.) trees, which the goats had not controlled. Black walnut produces a natural herbicide juglone, a naphthaquinone, which is probably unpalatable or even toxic to goats. (Figure 3).

As for low-growing forbs and grass, the herbicide treatment released these while the goats, again, appeared to have little effect (Table 2). On closer analysis, however, the goats concentrated their feeding on native goldenrod (*Solidago spp.* L.), an important pollinator plant, while ignoring non-native mugwort (*Artemisia vulgaris* L.)—a main source of hay fever and asthma symptoms (Table

Table 1. Percent Ground Cover Target Vegetation

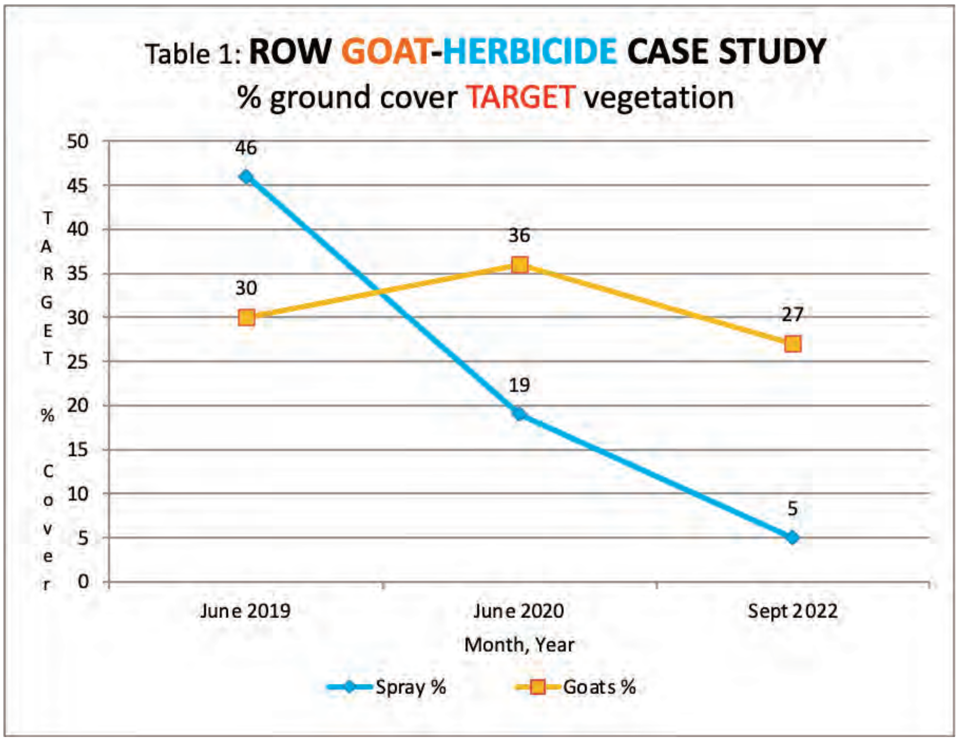


Figure 3. Goats avoided black walnut and Callery pear

3). The results were that herbicide treatment increased pollinator habitat for native bumblebees (*Bombus* sp.), while goat browsing preferences decreased bee pollinator habitat (Figure 4 and Table 4).

Each of the field case studies ran 12 meters wide along 92 meters of a wood edge of a fallow field to duplicate a 0.1 hectare of a typical electric distribution ROW maintained by mowing with three years' growth. The preferred IVM method for tall, dense woody growth was brush hog mowing to remove the established plants, allowing for germination of dormant seeds. After one growing season, the next IVM step would be a selective herbicide treatment to remove the incompatible woody plants and allow the forbs and grass to proliferate. These low-growing plants and the wildlife that inhabit them would then provide biological controls to help manage a plant community compatible with electric reliability. By relying solely on mowing, this plant community transition was short-lived and, at times, highly disruptive, allowing the incompatible woody plants to reassert their dominance.

Table 2. Percent Ground Cover Compatible Vegetation

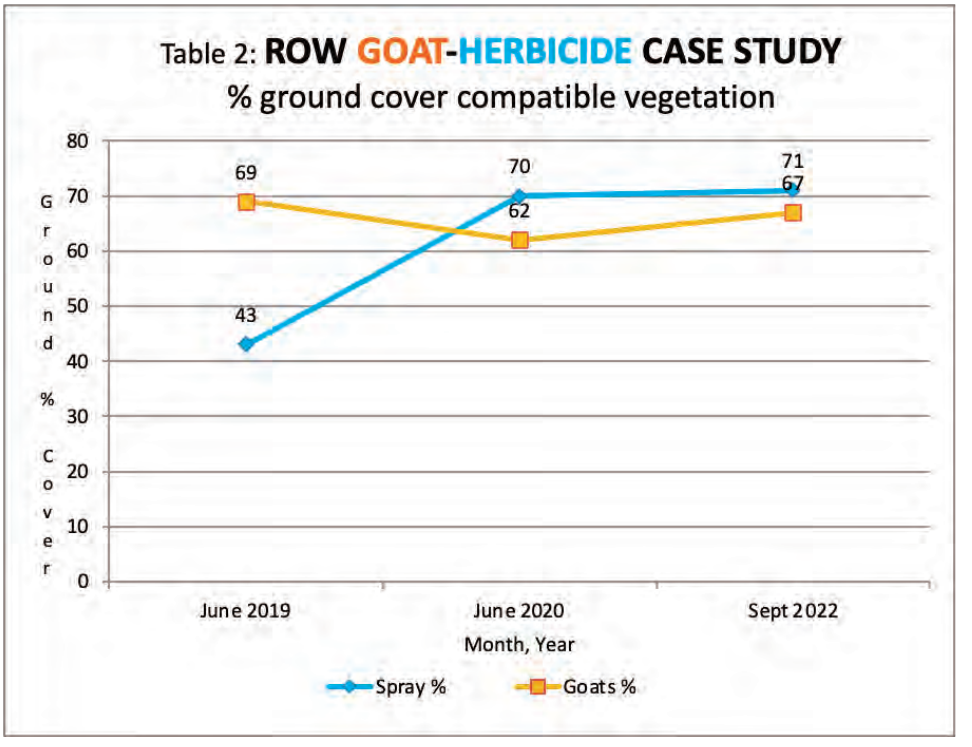
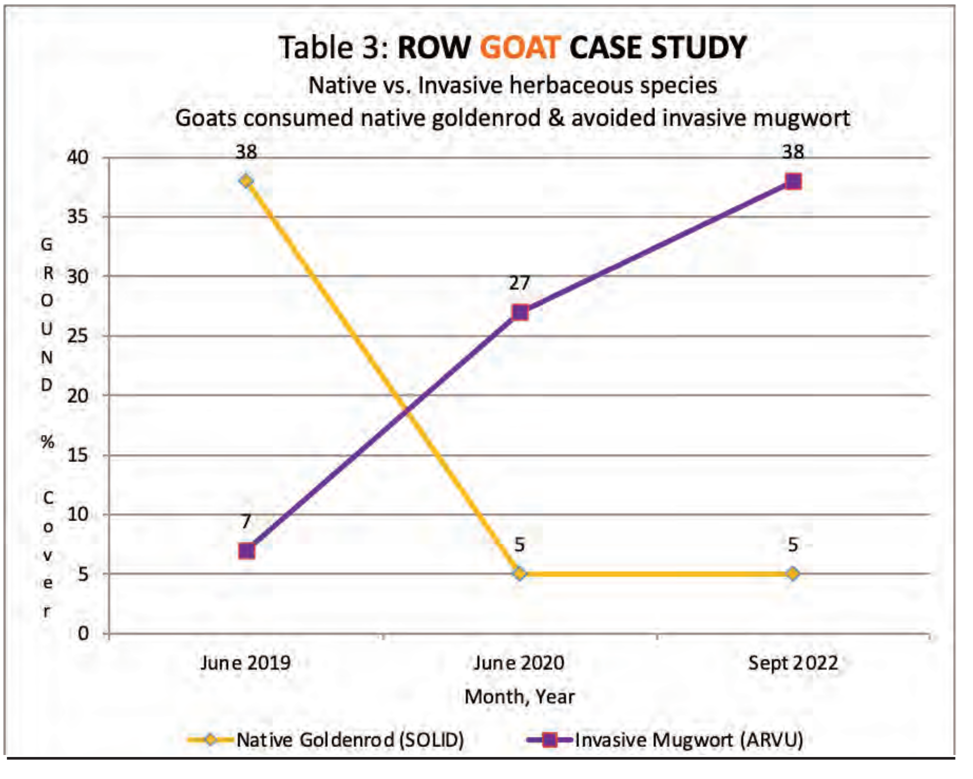


Table 3. Native vs. Invasive Herbaceous Species Goats Consumed



The field mowing study clearly demonstrates this boom-and-bust cutting effect, with the number of plant species doubling the first growing season following the March 2019 cutting (Figure 5), only to see incompatible woody plants dominate again after the second season (Figure 6 and Table 5).

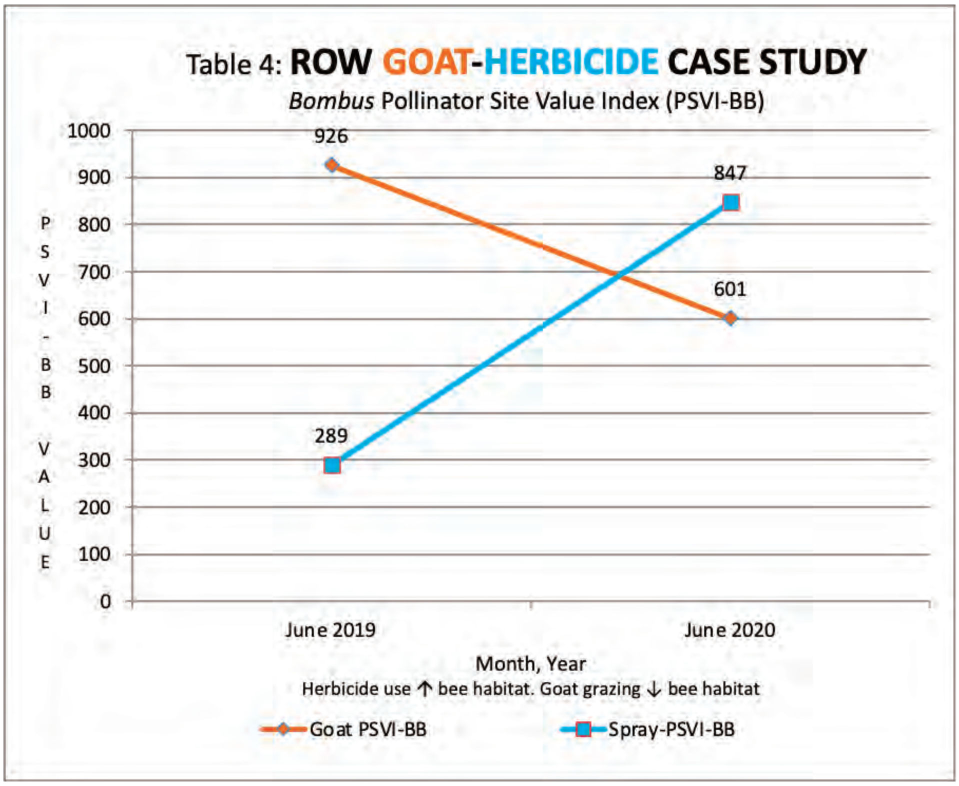
The percent cover of herbaceous plants went from 36% in 2019 to 73% by the fall of 2020. But this was not necessarily beneficial due to the species composition change. Non-native mugwort, already relatively high in the 2019 understory at 25% ground cover, exploded to 61% ground cover by the fall of 2020. The competition was detrimental to quail habitat, as it kept grasses in check at only 2% cover. Beneficial cover of blackberry (*Rubus* sp. L.) decreased from 9% to 4%. The average cost of $548 per hectare was competitive, but the rapid regrowth of woody plants diminished biological controls and the need to repeat the same level of cutting at regular intervals made it impossible to reduce future costs.

The field herbicide spray study showed that it is possible to control three-year-old woody plants with a selective backpack herbicide treatment. But spraying tall, dense target plants incurred collateral damage of desirable pollinator plants and a corresponding increase in grasses (Table 6).

Target tree and invasive shrub control was good, but herbaceous plants decreased from 72% ground cover to 17% by the fall of 2020, while grasses increased from 4% to 55%—primarily giant foxtail (*Setaria faberi* Herrm). Giant foxtail was not a detriment because it

Figure 4. Incompatible trees and invasive mugwort after goat browsing

Table 4. *Bombus* Pollinator Site Value Index



produces seeds that are an important food source for many birds, including bobwhite quail, and another benefit for quail was increased woody support cover of blackberry, that increased from 2% to 15%. The $440/hectare cost was low and a subsequent herbicide treatment in 2021 provided continuous improvement while being more selective and yielding a corresponding decrease in chemicals, application time, and costs (Figure 7).

The field goat browsing study showed that browsing goats are ineffective at controlling 3-year-old woody species (Table 7), especially those that may be unpalatable due to plant chemical production, such as juglones in black walnut and glycosides that can yield cyanide in the invasive Callery pear tree (*Pyrus calleryana* Decne). Their feeding preferences also reduced the site's pollinator benefits and native herbs that corresponded to an increase in invasive plants, woody trees, and shrubs (Figure 8).

Figure 5. Mow field study one year after cutting

Figure 6. Mow field study two years after cutting

The fixed price of a $1,000 delivery charge plus a $100 per day rate equaled an average $14,000 per hectare, a cost-prohibitive method.

CONCLUSIONS

The VM objectives of both Choptank Electric and Chino Farms were to control tall-growing woody trees, shrubs, and invasive plants as well as proliferation of grasses and herbaceous plants that provide nectar and pollen for bees, butterflies, and birds, and habitat for bobwhite quail.

Previously, brush hog mowing was the primary method of vegetation control, but our case study showed that its benefits for ROW VM and wildlife only last for one growing season and must be continuously repeated. To effectively manage for electric reliability and access, plus quail and pollinator habitat, control measures need to be performed after each growing season, elevating its relative cost.

Selective herbicide treatment is a better alternative for both compatible plant community development and costs. But for improved pollinator habitat, the tall, dense vegetation should first be cut and then herbicide treated after one growing season. A subsequent herbicide treatment should be

Table 5. Field Mow Case Study—March 2019

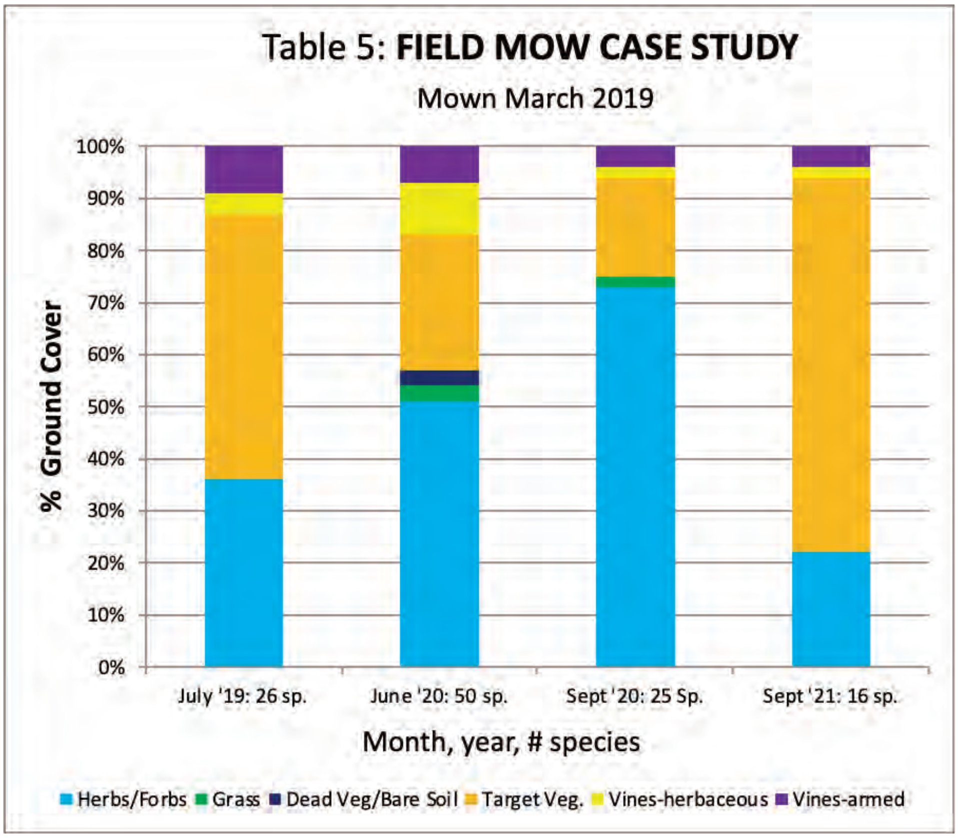
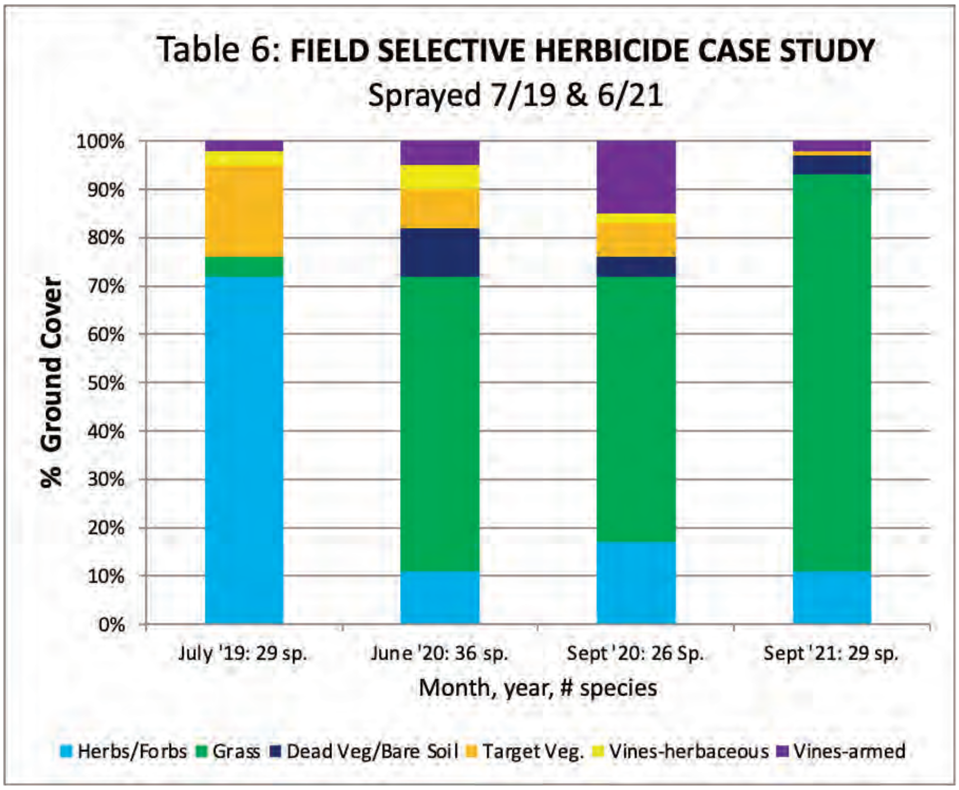


Table 6. Field Selective Herbicide Case Study—July 2019–September 2021



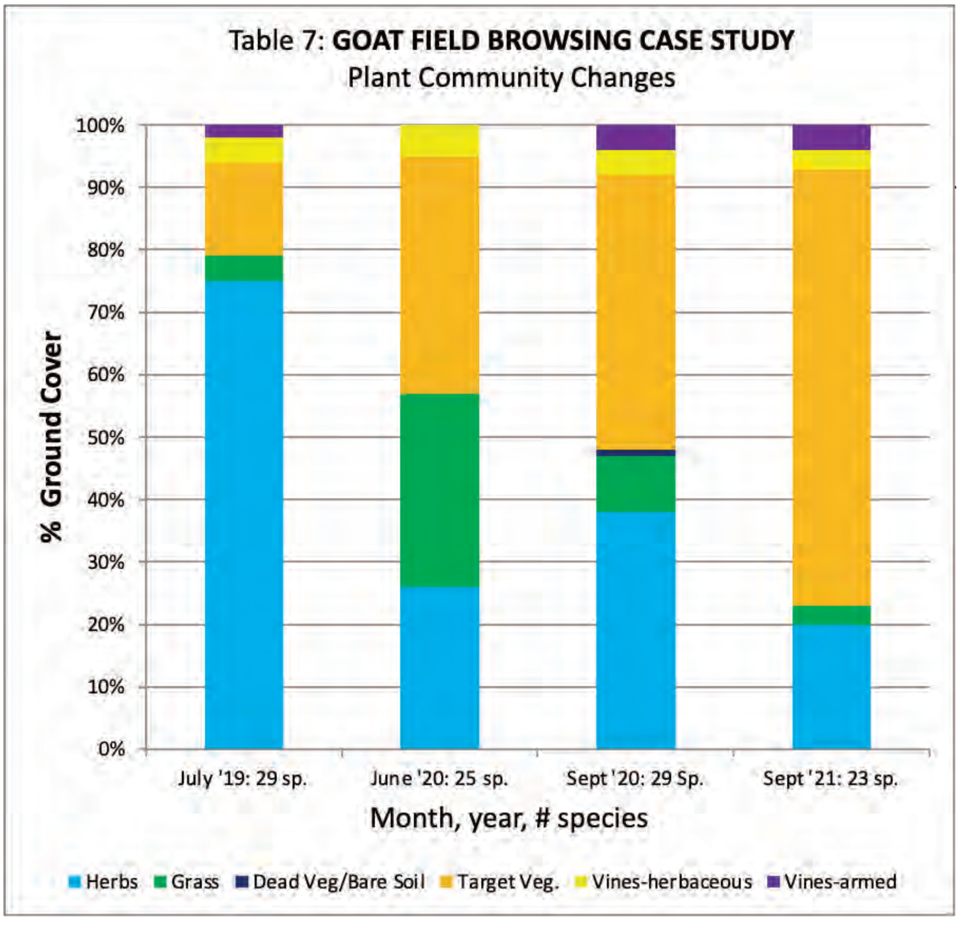
performed within two growing seasons to achieve adequate plant community conversion to obtain IVM biological controls and continuous improvement.

Goat browsing is advertised as an effective invasive weed control alternative and environmentally preferred over the use of herbicides, but our case studies do not defend these claims. To the contrary, invasive woody and herbaceous plants increased their dominance in both the three-year-old field study and in the more palatable one-year-old ROW study—and input costs were prohibitive. Since the target woody trees and shrubs are not initially controlled by goat browsing, there is no way to obtain a plant community transition without em-ploying an alternative management strategy.

Our case studies provided a snapshot of plant community changes and their relative impact on pollinator and bird habitat, ROW reliability and access, invasive weed control, and costs of three very different VM methods. The results should be considered with the reality that there are millions of acres of utility and highway ROW in the United States where seasonally rapid-growing vegetation must be managed to provide safe and reliable services to the public, as well as providing habitat for pollinators and birds.

Figure 7. 2021 follow-up herbicide treatment field study

Table 7. Goat Field Browsing Case Study—Plant Community Changes



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Haggie, M.R., H.A. Allen, and R.A. Johnstone. 2018. "Formulation of a Pollinator Site Value Index (PSVI) to measure the benefits of utility rights-of-way (ROWs) habitat change for the pollinator genera *Apis* and *Bombus* spp. following the management transition from traditional cutting-mowing practices to Integrated Vegetation Management (IVM)." In Environmental Concerns in Rights-of-Way Management: 12th International Symposium, pp. 557–569. Denver: CO.

Figure 8. 2021 goat browsing field study

AUTHOR PROFILES

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Rick Johnstone serves as President and Founder of the nonprofit corporation IVM Partners and is Owner of VMES, LLC vegetation management consulting. He directs vegetation management research and training under IVM Partners and is an advisor for and liaison between federal, state, and tribal land management agencies, universities, electric and natural gas utilities, and conservationists. Under VMES he provides vegetation management consultation and is an expert witness in litigation. Johnstone served as System Forester for two electric utilities and is Past-President of the UAA and a Registered Professional Forester with a Bachelor of Science degree in forest resources management from West Virginia University. He has more than 45 years of experience and is a technical advisor for restoring native pollinator and wildlife habitat using cost-effective integrated vegetation management strategies.

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Michael Robin Haggie is the Botanist for IVM Partners, a nonprofit corporation which advises agencies and conservationists on the best IVM practices to manage lands and restore habitat essential to the survival of Lepidoptera, native bees, and other pollinators. His botanical surveys cover energy and transportation ROW in more than 15 U.S. states, demonstrating greater access, reliability, cost savings, and improved vegetation management through the implementation of IVM methods. Haggie created a Pollinator Site Value Index to measure pollinator habitat improvements for Lepidoptera and native bees. He and his wife, Marcia, raise Border Leicester sheep for wool and he manages a small apiary on Maryland's Eastern Shore. He has a Bachelor of Science in agronomy and natural resources from Cornell University, New York (1978) as well as Oxford and Cambridge Board Advance Level Certifications in zoology, botany, biology, and geology from his native U.K.

Bryan Hall

Bryan Hall is a classically trained Forester and Land Use Planner who uses his passion for the outdoors to build lasting relationships with Cooperative members to grow our natural resources. With over 25 years of service in both public and private sectors, Hall has experience in urban forest management, forest management, arboriculture, land use planning and utility forestry. Hall has managed such projects within these fields for the Delaware Forest Service, Delaware Office of State Planning and Coordination, and Choptank Electric Cooperative. Hall holds an Master of Science from Wesley College and a Bachelor of Science from West Virginia University and is a Maryland Licensed Forester and Tree Expert, an ISA Certified Arborist, and an AICP Certified Planner.

13th International Symposium

Environmental Concerns in Rights-of-Way Management

PART XI

Wildfire

Ignition Prevention on Overhead Powerlines: Assessing and Mitigating Risk from Wildlife

Duncan Eccleston, Nathan Groh, Richard Harness, Paul Petersen, Ryan Brockbank, and Tim Rogers

Keywords: Data Analytics, Geospatial, Utility Lines.

The growing wildfire threats from climate change, declining forest health, aging electric infrastructure, and expansion of the wildland-urban interface have made ignition prevention and system protection priorities for utilities serving susceptible areas. Equipment failure and treefall are familiar causes of utility-related ignitions, but public data indicate that wildlife interactions also pose a significant risk, comprising 11–23% of all ignitions for two California systems. Examples include direct ignition from electrocuted wildlife and expulsion fuse operation triggered by wildlife. An analysis suggested that Black Hills Energy (BHE) experiences fewer wildlife outages than most utilities in the United States, but the total number of electrocutions, the vast majority of which were non-native/non-protected species, still represented fire ignition risk. Black Hills Energy and EDM International used internal records and public geographic information system layers to develop a spatial model of pole-specific wildlife electrocution risk. Modeled wildlife electrocution risk was geospatially superimposed on Hazardous Fire Areas (HFA) to identify poles where potential wildlife ignition was a greatest concern. Field data were used to validate the wildlife electrocution risk model and assess retrofit and mitigation practices. The model will be used to focus wildlife electrocution mitigation efforts on the highest-risk poles in the most vulnerable fire areas.

Environmental Concerns in Rights-of-Way Management 13th International Symposium

BACKGROUND

Wildlife contacting overhead powerlines and substations is a leading outage cause for many utilities, but the risk of fire ignition caused by wildlife electrocutions is less understood. Wildlife interactions are an important problem for electric utilities for both reliability and risk management reasons. The potential for wildlife-caused ignition is particularly grave in the seasonally arid western states and on older utility systems that were historically designed with limited protections against negative wildlife interactions.

Black Hills Energy (BHE) partnered with EDM International, Inc. (EDM) and Lakeside Environmental Consultants, Inc. (ECI) to review the company's past wildlife-caused outages and assess such outages as potential wildfire ignition causes. This voluntary process started in 2019 with an assessment of BHE's vegetation management (VM) program and expanded into a study to review company-owned electrical equipment, wildlife, and associated wildfire risk. The primary goals of the original project were the protection of capital infrastructure investments and increased system resiliency. The enlarged scope expanded to include environmental stewardship through natural resources protection and wildfire risk reduction.

Black Hills Energy Context

Black Hills Energy is a diversified energy company based in Rapid City, South Dakota. Black Hills Energy 's electric utilities provide service in Colorado, Montana, South Dakota, and Wyoming, and serve approximately 218,000 customers in more than 60 communities, and own 1,481.5 MW of generation and 8,899 miles of electric transmission and distribution lines. Each day, BHE works to enhance the safety and reliability of the electric utility system to deliver safe and reliable energy. This includes taking proactive steps to maintain and upgrade the system to protect against negative wildlife and vegetation interactions and prevention of wildfire. The electric service area of BHE commonly experiences extreme weather conditions including severe storms and episodic drought, leading to an elevated vulnerability to wildfire. Black Hills Energy strategically assesses and enhances the safety and reliability of the electric transmission and distribution system, prioritizing infrastructure maintenance, upgrades, and replacement to mitigate identified risks.

Black Hills Energy is a member of the Edison Electric Institute (EEI) and the Avian Power Line Interaction Committee (APLIC). These organizations provide a collaborative environment where environmental professionals in the electric utility industry can share best practices and new research to reduce the possibility of bird interactions with electric utilities. In 2011, BHE adopted an Avian Protection Plan (APP) that has been endorsed at all levels, from field technician to senior management. The APP provides structure and procedures to facilitate BHE compliance with applicable avian and wildlife laws, regulations, and permits. The APP is aligned with industry best management practices and APLIC and United States Fish and Wildlife Service (USFWS) recommendations (APLIC and USFWS 2005). The plan states that BHE will document bird mortalities and injuries; poles and lines with high risk of wildlife interaction; and high-risk nests as well as provide information, resources, and training to improve employees' knowledge and awareness of APP requirements. Black Hills Energy has also certified that all new facilities will provide avian-friendly clearances and that the company will retrofit or modify infrastructure (APLIC 2006) where a protected bird has died or been injured to prevent future incidents. Black Hills Energy regularly joins public and private organizations in programs and research to reduce detrimental effects of bird interactions with powerlines.

Wildlife interactions with overhead electric distribution equipment are unavoidable and responding to and retrofitting for wildlife-caused outages reactively can weigh heavily on planned resources. However, BHE has found there is a strong business case for proactively making sensible and appropriate infrastructure investments, especially when those investments can demonstrate risk reduction.

Wildlife Electrocutions as Fire Ignition Risk

Powerlines can inadvertently ignite fires (Short 2014; Collins et al. 2016; Keeley and Syphard 2018) when high winds cause energized wires to contact one another (Sutlovic et al. 2019), or when vegetation falls into, grows into, and/or bridges conductors (Short 2014; Texas A&M University 2014), creating sparks. Wildlife-powerline interactions can cause fires if bird nest material bridges conductors and ignites (Burgio 2014). The focus of this study was animal electrocution, which can occur when birds or other wildlife make phase-to-phase or phase-to-ground contact (EPRI 2001; APLIC 2006). An electrocuted or shocked animal may fall to the ground smoldering or in flames (Lehman and Barrett 2002; Guil et al. 2017; Dwyer et al. 2019; Kolnegari et al. 2020; Barnes et al. 2021; Fenster et al. 2021), the incident may trip an expulsion fuse that emits sparks and superheated debris (Coldham et al. 2011), or the incident may cause damage that results in a downed powerline (Idaho State Journal 2019).

Every wildlife electrocution results in one or more "thermal events" as a result of the current anomaly. In most cases, no ignition occurs because the thermal event does not contact flammable material or the flammable material does not catch fire. However, each thermal event represents a risk, and the scale of the cumulative risk is roughly proportional to the number of thermal events. National wildlife-powerline ignition data indicate that ignition is most likely in seasonally dry climates, where grasses and shrubs grow profusely in the wet season and then become highly flammable in the dry season (Barnes et al. 2019). Although only a small percentage of electrocutions results in ignition, fires caused by wildlife interactions with overhead powerlines are both a national (Dwyer et al. 2019; Barnes et al. 2021) and a global concern (Vargas 2016; Guil et al. 2017; Kolnegari et al. 2020).

Wildlife-powerline interactions are a specific fire ignition concern in the Great Plains and the Western United States (Barnes et al. 2019). Public data from the California Public Utilities Commission (2018) indicate that a single investor-owned utility experienced an average of 411 ignitions per year from 2014–2016. Wildlife was responsible for 46 ignitions/year (11%), making it the third most common cause behind equipment failure (147 ignitions/year, 36%) and vegetation (116 ignitions/year, 28%). On another California distribution system, five out of seven powerline-associated fires were caused by bird electrocutions in 2017, comprising 23% of all ignitions in the service area (Dwyer et al. 2019). Wildlife ignitions are largely preventable, as electrocution mitigation practices are well established (APLIC 2006) and have been proven to reduce wildlife outages (Hamilton et al. 1989; Heck and Sutherland 2014; Fenster et al. 2021).

Proactive electric utilities like BHE seek strategies to harden their power systems to prevent accidental fires through system-wide wildfire mitigation programs. EDM International hypothesized that records of wildlife-caused outages could help to identify potential ignition points for wildfires. A better understanding of electrocution risk could help determine whether wildfire mitigation programs should address wildlife contacts, and if so, where, based on spatial modeling.

OUTAGE ANALYSIS

From 2015 through 2020, BHE experienced an average of 491 wildlife outages per year. Of these, 27% were attributed to birds, 35% attributed to mammals, 38% were unknown animals (not attributed to a specific type of wildlife), and 1% attributed to snakes or another non-bird, non-mammal group. Birds were associated with a total of 786 outages, 475 of which listed an avian species or group; 82% of which implicated non-native invasive birds (e.g., Rock Pigeon [*Columba livia*], Eurasian Collared-Dove [*Streptopelia decaocto*], European Starling [*Sturnus vulgaris*]) that are not federally protected under the Migratory Bird Treaty Act [1918]). Mammals were associated with 1,020 outages, of which tree squirrels were responsible for 92%, followed by raccoons (5%) and various other species (3% total).

Most of BHE's known wildlife-contact records were associated with tree squirrels (14–29" length) (Schwartz and Schwartz 1976) and European Starlings (16" wingspan, 8.5" head to tail) (Sibley 2000). Both are relatively small, suggesting phase-to-ground contacts may be more common than phase-to-phase contacts. These species are often found in urbanized locations and frequently use utility poles and wires.

Only a small proportion of electrocutions trigger system protection devices, thereby causing an outage. In another study, Dwyer and Mannan (2007) found that less than 10% of documented raptor electrocutions were associated with outages recorded by the utility's outage management system (OMS). Kemper et al. (2013) found that, at most, 6% of raptor electrocutions caused an OMS-documented outage. Outside of North America, an even smaller proportion of actual electrocutions may be documented by the OMS. In Iran, Kolnegari et al. (2020) documented 57 avian electrocutions, but none were associated with an OMS outage.

Although each of these studies focused on bird electrocutions, the likelihood of a wildlife electrocution causing an outage should be similar for mammals and other wildlife.

The low OMS detection efficiency of electrocutions has important implications for our understanding of wildlife ignition risks. Based on these studies, the number of OMS-documented wildlife outages should be multiplied by 10.0 or 16.7 to more accurately scale electrocutions or potential ignition incidents on a North American distribution system. Even these multipliers could be conservative because (1) not all electrocutions that caused outages were properly attributed to wildlife in the OMS (Dwyer 2022; EDM International and Pers. Comm. 2022), and (2) multiple thermal events can result from a single electrocution.

Based on these peer-reviewed studies, BHE's documented 491 wildlife outages/year likely represented at least 4,907–8,178 electrocutions annually. Based on the extent of BHE's distribution network, this translates to a rate of 0.70–1.17 electrocutions/mile each year. The scale of this wildfire ignition risk was higher than previously appreciated by the project team and could be somewhat higher if some outages caused by wildlife were recorded as "unknown" (EPRI 2001).

In an effort to confirm or refute these findings, the BHE-specific estimates were benchmarked against a peer-reviewed nationwide estimate based on independent avian electrocution datasets. Loss et al. (2014) conducted a statistical meta-analysis of previous peer-reviewed studies to estimate the frequency of avian electrocution across the United States. They found that 11.8 to 49.2 million birds were annually electrocuted nationwide, with a median estimate of 0.03 birds/distribution pole (95% confidence interval: 0.005-0.062 birds/pole). This would equate to a median estimate of 0.60 bird electrocutions/mile each year (CI: 0.10-1.24). In North America, birds comprise

48% of distribution outages attributed to a specific wildlife group (EPRI 2001). Therefore, the median estimate for all wildlife would be 1.25 electrocutions/mile each year (CI: 0.21-2.58) across the United States (Figure 1).

The BHE-specific electrocution estimate of 0.70–1.17 electrocutions/mile was just 56–94% of the nationwide median estimate of 1.25 electrocutions/mile. However, the nationwide confidence interval brackets the BHE-specific range, lending credence to the initial analysis. Although the project team initially considered estimates of BHE electrocution rates too *high*, the subsequent comparison to national electrocution rates suggested that BHE's electrocution rates were substantially *lower* than most distribution operators. One explanation for BHE's comparatively low electrocution rate may be the 2011 adoption of an APP, in which BHE committed to the installation of wildlife mitigation on the overhead system. Avian Protection Plan implementation may well have reduced wildlife outages relative to other utilities from 2015 through 2020, thereby improving service reliability for customers, reducing potential ignitions, and increasing conservation efforts.

We fully acknowledge that the estimates of the BHE electrocution rate based on Dwyer et al. (2007)/Kemper et al. (2013), and Loss et al. (2014) throughout the U.S. are highly speculative. In both cases, these estimates rely on piecing together data from a small number of available studies across wildlife species, systems, and regions. Both estimates rely on a series of assumptions and connections that are, at best, inexact, imprecise, and subject to study biases. Although we have little confidence in the ultimate accuracy of either estimate, we see value in presenting both—with the underlying logic, for two reasons. First, we believe the estimates correctly suggest that wildlife electrocution is more frequent than widely acknowledged, and therefore an important potential ignition cause that can be mitigated.

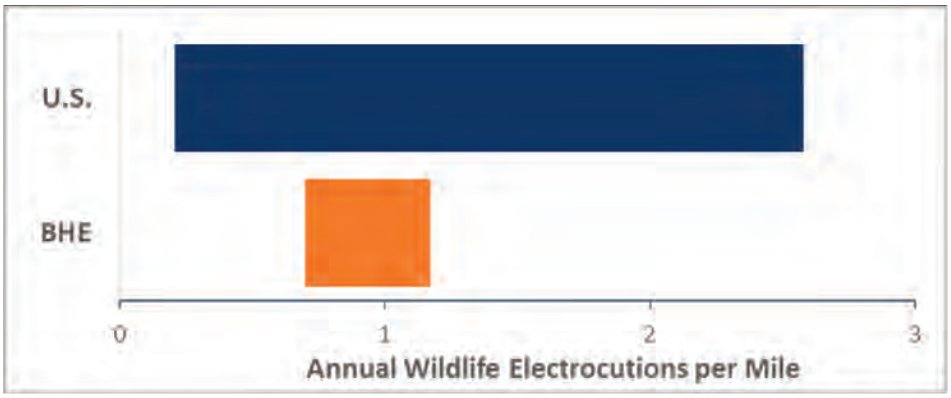

Figure 1. The estimated range for BHE wildlife electrocutions is at the low end of the 95% confidence interval for electrocutions nationwide.

Second, we believe publishing these provisional estimates could spur further study that might help lead to more accurate and more precise estimates that account for regional-, habitat-, species-, and system-related differences. Further research would facilitate more targeted and more effective mitigation, which would benefit all stakeholders.

Outage analysis findings were important on several levels. First, they suggest wildlife electrocution is more prevalent than most distribution utilities understand, as is associated wildfire ignition risk. Second, although BHE likely experiences fewer wildlife electrocutions than most U.S. utilities, portions of its service territory are susceptible to wildfire, magnifying the potential risk of any thermal event. Third, wildlife mitigation could appreciably reduce BHE's ignition exposure, if strategically focused on poles in high fire-risk areas that posed an elevated wildlife electrocution risk.

WILDLIFE ELECTROCUTION IGNITION RISK MODELING

Electrocution risk is unevenly distributed on BHE's distribution system, and a small percentage of high-risk poles generally pose a disproportionate electrocution risk for wildlife (Harness and Wilson 2001; Schomburg 2003; Cartron et al. 2005; Mojica et al. 2022). Similarly, the risk of wildfire is spread unevenly across the landscape based on vegetation type, fuels loading, and a myriad of other factors, as is the likelihood of catastrophic consequences, such as loss of human life or large-scale property damage. Poles in high wildfire-risk areas having high wildlife electrocution risk can be considered poles with high wildlife ignition risk. These poles can be prioritized for further field investigation and potential retrofitting and mitigation to reduce overall wildlife electrocution risk and, subsequently, fire risk.

In previous work, BHE and its consultants developed a geospatial Hazardous Fire Area (HFA) rating schema that quantifies and categorizes wildfire risk specific to the landscape and human population in BHE's service territory, using high-quality, publicly available data curated from various sources, including:

- Vegetation cover and the Scott and Burgan 40 Fire Behavior Fuel Models from the interagency LANDFIRE program
- Topographic data from the United States Geological Survey
- Historical weather patterns from the National Weather Service
- Long-term simulations of large wildfire behavior from the United States Department of Agriculture and United States Forest Service
- Community data from the United States Census Bureau and Department of Energy

The HFAs were compiled and weighted to match local variables for

BHE's service area and a geographic information system (GIS) was used to delineate the HFA polygons according to six risk classes (HFA classes), ranging from "zero" (impervious areas) to "very high." These HFA classes are normalized descriptors of the various factors affecting wildfire initiation, spread, intensity, and difficulty of control on the landscape, as well as potential damage consequences relative to human population development and BHE assets.

If wildlife electrocution risk could be accurately assigned to BHE distribution poles based on existing GIS attributes, it would be a simple matter to combine the electrocution risk dataset with HFA modeling to identify poles and circuits where wildlife mitigation would be most beneficial. The starting point for the wildlife electrocution risk assessment was a statistical electrocution risk model published by Dwyer et al. (2013), which predicted pole-specific avian electrocution risk based on the number of jumpers, number of conductors, presence of high grounding (categorical), and presence of habitat for species of interest (categorical). The final model output is an electrocution risk index between 0.00 and 1.00, with high values indicating a greater relative risk of electrocution than low values.

The Dwyer et al. (2013) model was originally developed to assess electrocution risk for birds. The model predicts that electrocution risk increases as poles become more complex (e.g., greater number of exposed jumpers, increasing number of phases, and exposed ground contact points) and when located in favorable habitat. The same factors are relevant to non-bird wildlife species. Historical outage data provided by BHE showed many mammal-associated outages were associated with complex equipment poles. Therefore, it was determined that the model could be used for other wildlife. Because the most frequently electrocuted species are found in a wide range of habitats, nearly the entire BHE service territory was considered good habitat in the context of the model.

Figure 2. Example map showing synthesized general pole configuration

The electrocution risk model was originally developed for field use. This project sought to scale up and batch apply the risk index equation across the entire BHE system by using GIS to systematically estimate the model inputs. For this analysis, BHE provided EDM with GIS data associated with the following:

- Poles
- Overhead (OH) primary lines
- Pole-mounted equipment, by type

First, retired and proposed infrastructure were removed from the dataset, along with non-primary poles (e.g., secondary poles, push poles, guy poles) and those greater than 40 feet from any OH primary wire. Then, primary lines were split at the pole point locations and segmented by span, and a bearing (0–360 degrees) was calculated for each span. A series of spatial joins was performed to count pole-mounted equipment and summarize other information relevant to the model. Hazardous Fire Areas and LANDFIRE class also were assigned to each pole. Based on the number and bearing of associated line segments, a "general configuration" was synthesized for each pole, using the following criteria (Figure 2):

- **Terminal (Deadend)**: Pole had only one associated span
- **Tangent**: Pole had two associated spans and net difference in span bearing was less than 20 degrees
- **Angle**: Pole had two associated spans and net difference in span bearing was greater than 20 degrees
- **Intersection**: Pole had three or more associated spans

These general pole configurations were used, along with phasing and associated pole-mounted equipment, to estimate the independent variables for the electrocution risk model. The number of jumpers was estimated based on the type and quantity of pole-mounted equipment, plus an additional jumper for each primary phase on angle and intersection poles. The phase information was used to determine the number of conductors at each pole. Presence of high grounding was also estimated based on pole material (i.e., steel versus wood) and presence/absence of equipment, such as primary risers that are associated with exposed grounds. LANDFIRE class was used to assign habitat quality, but only the "barren" classification was presumed to be poor habitat for all species of interest. These four estimates were then used to apply the electrocution risk model to each pole using a Python script within the GIS to calculate values for *P*, electrocution risk index.

Model Results

The model result was a GIS pole layer (n = 128,265 poles) containing the wildlife electrocution risk index and HFA class. High-risk poles were defined as those having a relative risk index score > 0.40; poles with a risk index above this threshold have been shown to be 5.25 to 8 times more likely to be implicated in an eagle electrocution than low-risk poles (Dwyer et al. 2022; Dwyer and Mojica 2022; Mojica et al. 2022) with a risk index <0.40. The model predicted just 18% of BHE poles were high-risk poles (Figure 3). Because high-risk poles are disproportionately associated with electrocution (Harness and Wilson 2001), ongoing analysis focused on poles with risk index of 0.40 or greater.

A majority of the high-risk poles were in HFA classes Zero through Moderate (Table 1). Only 6.9% of the poles determined to be both high electrocution risk *and* located in a High or Very High HFA class. This group of poles is sufficiently targeted that it can be effectively displayed, even on a small map covering a large area (Figure 4).

Field Validation and Discussion

The GIS-based system-scale model was determined to be imperfect for two reasons. First, pole-specific arrester data was not available, which could slightly depress modeled risk because each arrester includes one jumper, which incrementally increases the modeled risk index. Second, independent model variables should account for the presence of insulation that effectively mitigates risk (Dwyer et al. 2013). For

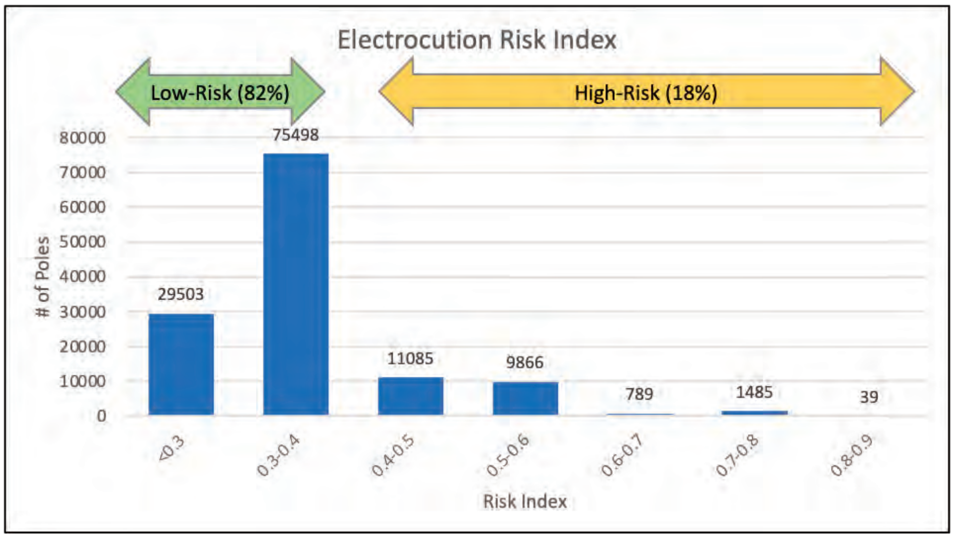

Figure 3. Histogram of modeled electrocution risk index among BHE poles

Table 1. Distibution of BHE Poles by Electrocution Risk and HFA Class

Electrocution Risk		HFA class		
Category	Risk Index Bin	Zero-Moderate	High	Very High
Low Risk	0.3–0.4	65,410	25,456	14,135
High Risk	0.4–0.5	7,485	2,373	1,227
	0.5–0.6	5,622	2,589	1,655
	0.6–0.7	435	181	173
	0.7–0.8	827	380	278
	0.8–0.9	35	3	1

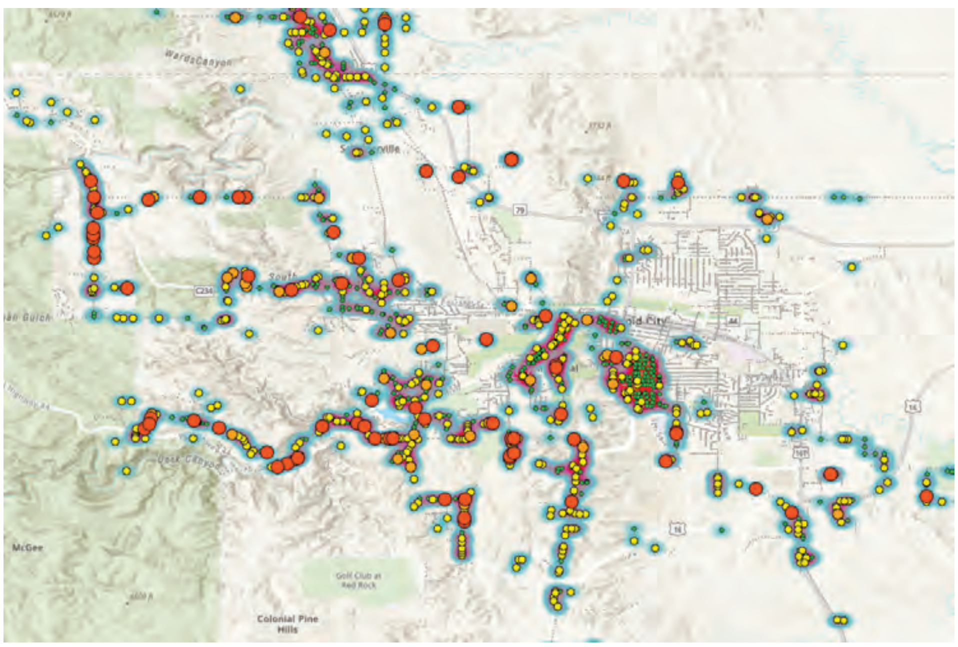

Figure 4. Example GIS map showing high-risk electrocution poles that are also in High or Very High HFA risk categories in the vicinity of Rapid City, South Dakota

example, if five of nine jumpers on a particular pole are covered and the associated equipment is capped, the appropriate jumper entry for the model would be four, reflecting the pole's actual unmitigated risk. However, because wildlife mitigation information was not available in GIS, the model assumption was zero mitigation. The ultimate model impact of these considerations was unknown, as the two factors could offset one another. The limitations in the available GIS data made it essential to validate model performance using pole data collected in the field.

Trained technicians collected data at a spatially distributed sample of 3,254 poles across BHE's 3-state service territory, emphasizing poles having high modeled electrocution risk within High and Very High HFA classes. Field data were collected with CartoPac mobile data collection platform, running an EDM-developed wildlife electrocution module. High-risk poles were color-coded based according to modeled risk to verify the full range of risk levels was sampled. The platform calculated electrocution risk in real time, based on user inputs, and allowed technicians to document primary configuration, equipment, existing mitigation, and retrofit recommendations. Digital photos of each pole were captured and compiled. Technicians also provided detailed summary comments describing typical system characteristics and wildlife protection practices in the area surveyed.

Model performance was quantified by binning field-calculated "true" risk index scores and calculating the average modeled risk index among those poles. Table 2 shows that the model performed well in discriminating between groups of low-risk poles versus groups of high-risk poles.

In addition, the GIS model successfully identified field-verified three-phase equipment poles as high risk, and poles with fewer phases or no equipment as low risk (Table 3). On average, the field-calculated risk index was lower than the modeled risk index

Table 2. Comparison of Field-Based and Model-Predicted Risk Index Scores

Field P	# Surveyed Poles	Avg. Model P
<0.3	469	0.386
0.3–0.4	1,262	0.410
0.4–0.5	707	0.497
0.5–0.6	499	0.493
0.6–0.7	77	0.517
>0.7	31	0.642

Table 3. Average Field-Calculated and GIS-Modeled Electrocution Risk Index for Three-Phase Equipment Poles, as Compared to All Other Poles

	Three-Phase Equipment Poles	All Other Poles
Model P	0.575	0.396
Field P	0.446	0.359
	n=819	*n*=2,435

for complex poles. This was partially due to the presence of wildlife insulation products, which were documented by the field inspections but assumed to be not present in the GIS model.

Even with imperfect inputs, the initial GIS-based system-scale electrocution risk model proved useful in identifying (a) high-risk poles, (b) the subset of high-risk poles that was at elevated risk of wildlife-caused wildfire ignition, and (c) the large majority of poles where wildlife ignition is unlikely because they are low electrocution risk or in a low to moderate HFA class. Although model accuracy for individual poles was fallible, accuracy for groups of poles was far better. Aggregation represents the best use case for the study, for example, identifying specific circuits with a high proportion of high-risk poles in HFAs where mitigation could be prioritized.

Field technicians observed that older poles had fewer wildlife mitigation measures, therefore, older circuits would likely be associated with greater electrocution and ignition risk. Unfortunately, this anecdotal observation could not be tested or verified because pole age was not present in the GIS dataset. Nevertheless, this finding could be incorporated as BHE uses this study to strategically implement wildlife mitigation. One process is as follows:

- Inspection data or other asset information is used to identify the oldest circuits.
- Model results are used to identify clusters of high-risk poles in high fire-threat areas on the oldest circuits. Prior wildlife outages also could be evaluated.
- The circuits or the clusters with the oldest vintages *and* the highest average wildlife risk *and* in high fire-threat areas are prioritized for mitigation.

Future projects could benefit from the use of field data to develop specific model assumptions based on pole vintage. For example, field data might show that transformer bushing covers were present on most poles installed after 1990, but only on a small proportion of poles prior to that date. A set of age-based assumptions could improve model predictions. Similarly, IOUs comprised of multiple legacy systems developed independently might find that region-based assumptions also could improve model accuracy. Final deliverables included a GIS layer containing modeled electrocution risk and HFA class for each pole. Deliverables also included the full field dataset, including pole-specific retrofitting recommendations for more than three thousand field-inspected poles. A set of tailored recommendations for effective and efficient mitigation were developed based on patterns of characteristic practices observed in the field.

CONCLUSIONS

Efforts to reduce wildlife fatalities, wildfire potential, and enhance operating reliability provide payback for utility companies by helping them to avoid the potentially costly and catastrophic impacts of wildlife-related fires, including damage to electrical equipment assets, service interruptions/power outages, and even human injuries and loss of life and property. Black Hills Energy is using results and insights from this project to refocus resources to efficiently reduce wildfire potential in and around its service territories. Black Hills Energy's first implementation step was to develop a pilot program to identify an animal and infrastructure interaction risk area for the overhead distribution system, considering wildlife habitat, pole configuration, and wildfire risks. Poles having a high electrocution risk index located within the High or Very High HFA class were a logical starting point.

Black Hills Energy is planning a pilot retrofitting project for a selection of high-risk poles near Rapid City, South Dakota, to scale costs, level of effort, time to operationalize, and potential pitfalls. Learnings from the pilot program will help BHE better plan and budget for future high-risk pole retrofitting in HFA High or Very High risk categories. Black Hills Energy plans to develop a proactive program to retrofit equipment across all service territories based on the priorities identified through this project. Black Hills Energy has already established wildfire risk evaluation requirements within the internal Distribution System Integrity Program (DSIP) and for siting work, and also intends to integrate wildfire risk assessment into other company procedures and programs.

Investor-owned utilities are accountable to customers, regulators, and shareholders. Black Hills Energy strongly believes that wildlife electrocution is an important component of wildfire risk, and that wildlife mitigation can meaningfully reduce all stakeholders' exposure to wildfire impacts. This project has helped BHE focus its efforts on a small minority of poles that, when mitigated, can disproportionately improve reliability, enhance wildlife conservation, and reduce fire ignition risk.

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Reducing Wildfire Risk, Restoring Habitat, and Protecting Wildlife by Controlling Annual Grasses

Shannon Clark, David Spak, and Harry Quicke

Keywords: Grass-Fire Cycle, Indaziflam, Invasive Grass, Restoration, Technology, Wildfire.

Annual invasive grasses such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-madusae*) continue to spread at an alarming rate throughout the Western U.S. in areas such as rangeland, natural areas, and rights-of-way (ROW). Annual invasive grasses can outcompete native and desirable vegetation and result in increased wildfire frequency and degrade pollinator and wildlife habitat. A new tool has been developed that has the potential to provide long-term control of invasive annual grasses and has the ability to restore and protect pollinator and wildlife habitats, and potentially reduce the spread and devastation of wildfires. The objective is to review existing research and available information on the impact of controlling invasive annual grasses and evaluate the multitude of potential benefits on ROW. Research trials were conducted throughout the arid and mountain west region to evaluate long-term control of invasive annual grasses, changes in vegetation, wildlife and pollinator activity, and wildfire behavior.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

Exotic winter annual grasses are some of the most problematic and destructive weeds faced by land managers in the Western U.S., occupying a large portion of perennial grasslands in western states. The most widespread is cheatgrass (*Bromus tectorum*), which has invaded an estimated 22 million ha in the Western U.S. (Duncan et al. 2004) (Figure 1).

Introduced to the U.S. in the mid-1800s, the newly completed Transcontinental Railroad provided the perfect avenue of spread for cheatgrass, as seed was transported in straw packing material and on livestock being shipped by rail (Mack 1981). While cheatgrass impacts more hectares, ventenata (*Ventenata dubia*), and medusahead (*Taeniatherum caput-medusae*) have emerged as serious threats to western lands, as these annual grasses provide no forage value and can invade areas that are typically resilient to cheatgrass invasions (Young 1992; Jones et al. 2018). Other exotic winter annual grasses of concern on rangelands and rights-of-way (ROW) include Japanese brome, red brome, feral rye, and jointed goatgrass. These invasive annuals germinate in late summer and fall, continuing root development over the winter and exploiting soil moisture and nutrients before desirable plant communities begin active growth in the spring (Mack 1981; Young 1992; Jones et al. 2018). This opportunistic growth cycle allows them to outcompete desirable grasses, forbs, and shrubs. In the past few decades, these invasive grasses have rapidly expanded into new ecoregions and elevations with warming climates and changing disturbance regimes (Abatzoglou and Kolden 2011; Wallace et al. 2015).

As annual grasses senesce early in the growing season, they produce dense mats of litter which create a continuous bed of flammable-fine fuel, promoting larger and more frequent wildfires (Fusco et al. 2019). These conditions also increase the likelihood that an ignition source (e.g., spark from a vehicle, train, utility line) will contact the combustible fuel (Davies and Nafus 2012; Fusco et al. 2016). Annual grasses are well-adapted to this fire cycle and they quickly reinvade after fire, while native plants often do not completely recover before the next fire (Davies and Nafus 2012). Eventually perennial plants are completely displaced by an annual grass monoculture. Electrical powerlines and equipment or vehicle-sparked fires are some of the main contributors to wildfires in the Western U.S., with annual grasses contributing to the fuel loads that increase the spread rate and size of these fires (Fusco et al. 2016; Balch et al. 2017). In California, equipment use and vehicles (e.g., sparks, crashes, malfunctioning equipment) caused ~ 21% of wildfires, and powerlines (e.g., fallen powerlines, debris contact, etc.) caused ~10% of wildfires from 2016–2020 (CAL FIRE 2022). Furthermore, 5 of the 10 most destructive wildfires in California history were caused by powerlines, including the 2018 Camp Fire, which is the deadliest fire in state history (CAL FIRE 2022). Although fewer fires burn in the Western U.S., wildfires are larger and burn more acreage. In 2021, 6.2 million acres burned in the 12 Western states (Alaska to Colorado), compared to <1 million acres in the Eastern states (Hoover and Hansen 2021).

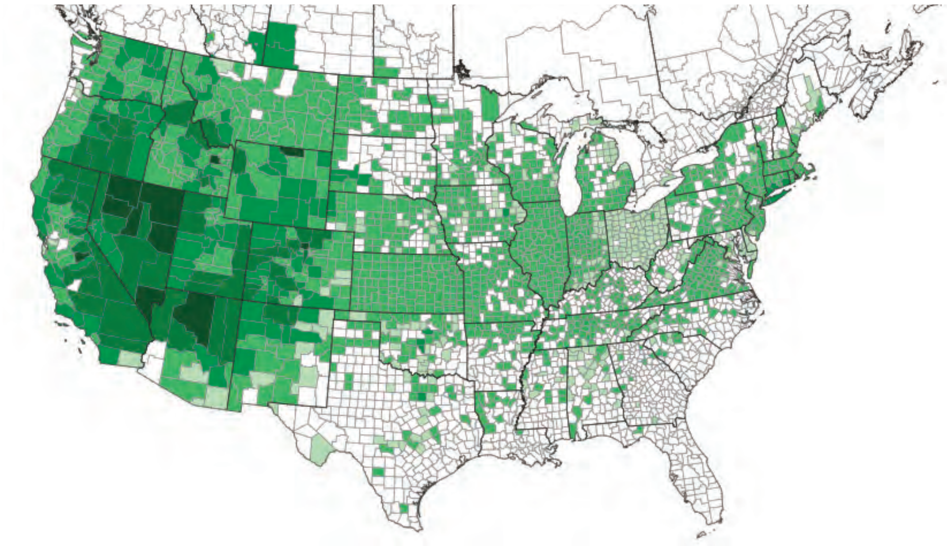

Figure 1. Current distribution of downy brome (*Bromus tectorum*) in U.S. Shades of green represent the number of instances reported by county (0 to 501+). (Source: EDDMapS)

Even without fire, when winter annual grass invasions are left unchecked, they greatly impact native ecosystems. Medusahead can reduce grazing capacity of rangeland by 50–80%, and severely invaded plant communities produce only 13% of the native plant biomass of non-invaded communities (Young 1992). Ventenata invasions in the Pacific Northwest grasslands have reduced species richness and diversity, threatening the remaining fragmented habitat of the Palouse Prairie (Jones et al. 2018). In the last few decades, ventenata has expanded into sagebrush steppe rangelands in Utah, Oregon, Montana, and Wyoming, and within the last five years, the first occurrences of ventenata and medusahead were discovered in the Great Plains Ecoregion (Jones et al. 2018).

These invasions also cause major degradation of pollinator and wildlife habitat. Greater sage grouse (*Centrocercus urophasianus*) populations have declined more than 80% over the last 50 years, putting them at risk of being listed as endangered (Shinneman et al. 2018). A major contributor to the decline is loss of habitat from annual grass-fueled fires which consume large expanses of sagebrush, a critical species that provides both food and shelter for the grouse (Shinneman et al. 2018). Additionally, habitat degradation on annual grass-invaded lands has been cited as one of the major causes of mule deer population declines (Clements and Young 1997; Shinneman et al. 2018). Reductions in small mammal abundance have also been attributed to annual grass invasions, which further impacts predators that feed on those mammals (Shinneman et al. 2018). Reductions in flowering forbs from annual grass competition reduces species richness of pollinators, especially small bees and ground nesting bees, and further compounds pollinator habitat loss (Rhoades 2016).

New annual grass invasions favor disturbed areas and long-distance spread is often attributed to animals, humans, and machinery; therefore, roadsides and other ROWs serve as a main conduit for their spread (Mack 1981; Gelbard and Belnap 2003). In Utah, cheatgrass cover was three times greater in interior communities adjacent to improved surface roads compared to four-wheel-drive tracks, while California grasslands were found to have higher frequency of annual grasses and lower frequency of native species in sites within 10 m from roads (Gelbard and Belnap 2003; Gelbard and Harrison 2003). In Eastern Oregon, there was a threefold increase in the frequency of medusahead along roadsides than in random sampling conducted off roadsides (Davies et al. 2013). An examination on the spatial relationship of roads to wildfires found that 88% of all wildfires are human caused, and of these wildfires, the majority occur within 200 m of a road (Morrison 2007). The rate of invasive annual grass spread facilitated by ROWs demonstrates the need for control in these sites to improve habitat and reduce fire risk.

Herbicides have been the most effective and affordable control option for invasive annual grasses on ROWs. Past chemical control options for annual grasses have included atrazine, glyphosate, rimsulfuron, and imazapic. These herbicides often provide adequate short-term control but lack the long-term soil residual needed to deplete the seedbank, and annual grasses often reestablish (Sebastian et al. 2016; Sebastian et al. 2017; Clark et al. 2019). These tools can also cause injury to desirable species (Sebastian et al. 2016) or are no longer labelled for use on ROWs, as in the case with atrazine.

Indaziflam is a newer herbicide option labelled for use on ROWs, including grazed areas, that provides long-term invasive annual grass control. Indaziflam is a cellulose-biosynthesis inhibitor (Group 29) and has preemergence activity on several annual grass and broadleaf weeds (Sebastian et al. 2017; Anonymous 2020). Annual grasses are especially susceptible at low-use rates (Sebastian et al. 2017). On ROWs, indaziflam is used at rates between 51 and 102 g ha^{-1} and brings a unique mode of action to these sites (Sebastian et al. 2016; Anonymous 2020). Indaziflam binds tightly to soil organic matter and stays in the top layer of the soil. Most perennial plants are not injured, as they have deeper roots established below the layer where the herbicide is active (Sebastian et al. 2017). One application of indaziflam can provide 3+ years of annual grass control, allowing enough time for desirable species to respond while avoiding reinfestation from the annual grass seed bank (Sebastian et al. 2016).

Although the impacts of invasive annual grasses are widely recognized, little information is available about the benefits of controlling these annual grasses on roadsides and utility ROWs, such as transmission and distribution lines as well as gas pipelines. Since indaziflam is the first chemical option to provide long-term control of annual grasses, a review of indaziflam research that has application to ROWs for invasive annual grass management and resulting benefits was conducted.

METHODS

Invasive Annual Grass Control and Desirable Vegetation Response with Indaziflam Applications

Several field trials were conducted across the Western U.S. to evaluate control of downy brome (*Bromus tectorum*), Japanese brome (*Bromus japonicus*), ventenata (*Ventenata dubia*), medusahead (*Taeniatherum caput-madusae*), and feral rye (*Secale cereale*) with indaziflam. These research trials also evaluated impacts to desirable species biomass, diversity, and richness. Several of these trials used small research plots (~27 m^2) established in sites classified as rangeland or natural areas. Plots were treated with indaziflam (44 to 102 g ai ha^{-1}) or other annual grass herbicides using a CO_2 - pressurized backpack sprayer (Sebastian et al. 2016; Sebastian et al. 2017; Clark et al. 2019; Koby et al. 2019; Beckley et al. 2021; Getts 2021). Hart and Mealor (2021) evaluated ventenata control and vegetation response in operational herbicide treatments applied aerially to sites ranging from 20 to 400 ha in size, while Sebastian et al. (2022) monitored operational indaziflam treatments across thirteen sites (2 to 40 ha), applied by a tractor with a boom sprayer. Across all studies evaluated, vegetation monitoring was conducted annually for one to five years after treatment (YAT). Researchers used several rangeland monitoring techniques to evaluate invasive annual grass control and desirable species impacts.

Pollinator Resource Impacts

A field trial in Boulder County, Colorado, evaluated the effects of indaziflam applications on pollinators. Plots were established on sites that had been treated with indaziflam at the rate of 102 g ai ha^{-1} (Arathi and Hardin 2021). Plots ranged in size but had at least one side measuring 100 m in length and included a paired treated and non-treated control. Evaluations were conducted in 2018 at three locations, approximately 1.5 YAT. Eight permanent 100-meter belt transects were established in both the control and treated plots at each site, in which a 1 m^2 frame was placed along the 100-meter transect at 10 meter intervals. For each frame, the type and number of flowering plant species were recorded. These assessments were conducted for a period of eight weeks, from May through September.

In a follow-up study, similar assessments were conducted across six locations in Boulder County, Colorado (Nissen et al. 2020). Two of the previous sites were used (Arathi and Hardin 2021) and four additional sites were added. Plots had been treated with indaziflam (102 g ai ha^{-1}) 2.5 to 3.5 years before the sampling period. At each site, three 50 m x 2 m transects were established in both the treated and control plots. Sampling was done starting in mid-June through the end of August, with two sampling periods at each site. Timed walks of the transects were conducted and all arthropods contacting the reproductive structure of a flowering forb within a 2-meter band along the transect were recorded. All flowering plants species and number of flowers were also logged for plants occurring within the 2-meter band along the transect.

Wildlife Habitat Impacts

To evaluate impacts of indaziflam on habitat improvement for mule deer, trials were conducted at six sites in Boulder County, Colorado, that had dense stands of mountain mahogany, four-lobed sumac, antelope bitterbrush, winterfat, rubber rabbitbrush, four-winged saltbush, and fringed sage (Sebastian et al. 2020). Areas ranging in 1 to 8 hectares in size were treated with indaziflam (102 g ai ha^{-1}) plus glyphosate during the winter, while desirable shrub species were dormant. Not all shrub species occurred in every site. Data were collected along three permanent 61-meter transects established in paired treated and non-treated plots at each site at 8 and 20 MAT (months after treatment). Shrub measurements included measuring new leader growth and recording the longest leader length for each shrub occurring along the entirety of the transect. Cheatgrass litter, perennial grass, forb, and shrub biomass was harvested from ten 1-m^2 frames randomly placed in the treated and control plots. At three sites, game cameras were used to track mule deer visitation in treated and non-treated plots, with photos taken every minute for 12 months.

Impacts of indaziflam on Northern Bobwhite quail habitat were evaluated in three sites on Bijou Ranch in Morgan County, Colorado (Marymor 2020). Indaziflam (73 g ai ha^{-1}) was applied to 0.1 ha plots using an all-terrain vehicle with a boom sprayer. Line point intercept data along established transects and biomass clippings were collected 1 and 2 YAT.

Fuels Reduction Impacts

Several trials evaluating invasive annual grass control with indaziflam have also provided information on fuels reduction that is directly applicable to roadsides. In a study conducted in Sublette County, Wyoming, applications of indaziflam (73 g ai ha^{-1}) were made aerially (helicopter) to plots ~ 2 ha in size in a randomized block design (Courkamp et al. 2022). Cheatgrass canopy cover and density were measured using a 0.5 m^2 frame placed in five locations within each plot through 3 YAT. In August 2019, an incidental wildfire burned through the study location providing visual observations of how cheatgrass treatments impacted fire behavior.

A case study was conducted at the Denver International Airport (DEN) using indaziflam combinations for invasive annual grass control on ROWs, including roadsides and natural habitats existing within transportation corridors (Seedorf 2020). Applications of indaziflam (102 g ai ha^{-1}) partnered with other herbicides for broadleaf vegetation management, were made to 54 m^2 plots using a CO_2 -pressurized backpack sprayer. Plots were established along roadsides at two sites with dense cheatgrass infestations within DEN property. Visual evaluations of weed cover and biomass clippings were conducted at 1 and 2 YAT.

RESULTS AND DISCUSSION

Invasive Annual Grass Control and Desirable Vegetation Response with Indaziflam Applications

Research trials and operational treatments have demonstrated that indaziflam can provide long-term control (>2 years) of several winter annual grasses, including cheatgrass, ventenata, medusahead, Japanese brome, and feral rye with a single application. Sebastian et al. (2016) found that treatments with indaziflam provided 83–100% cheatgrass control 3 YAT across two sites in Colorado. In a separate Colorado trial, indaziflam (102 g ai ha^{-1}) treatments provided 97–99% control of cheatgrass, feral rye, and Japanese brome at 2 YAT, with a 28- to 42-fold increase in perennial grass biomass and a 3- to 5-fold increase in forb biomass (Sebastian et al. 2017). Fall timing indaziflam (73 and 102 g ai ha^{-1}) applications on medusahead in the Intermountain Region of California resulted in 87%–94% control at 2.5 YAT (Getts 2021), while indaziflam treatments in central Utah reduced medusahead cover to <5% at 3 YAT compared to 55% cover in the non-treated (Beckley et al. 2021). Indaziflam (73 and 102 g ai ha^{-1}) treatments in the inland Pacific Northwest reduced ventenata biomass to <20 kg ha^{-1}

compared to 500 kg ha^{-1} in the non-treated, while perennial grass cover increased 1.7- to 6-fold in the treated plots (Koby et al. 2019). Both Clark et al. (2019) and Hart and Mealor (2021) found no negative impacts to desirable species richness or abundance when indaziflam was used to control cheatgrass and ventenata.

In a large survey conducted across thirteen Boulder County properties where operational indaziflam treatments were made to control cheatgrass and Japanese brome, treated sites had significant increases in species richness and average number of flowers per plant. Species richness increased by 150% (66 to 104 species) in treated sites, while increases in average flower number per plant were observed in 34 species. Rare and concern species diversity increased from an average of 2 species in control sites to 7 species in treated sites (Sebastian et al. 2022).

Both research trials and operational treatments, including treatments on ROWs, have demonstrated that long-term invasive winter annual grass control is achievable and can lead to positive impacts for desirable species. This provides an opportunity for land managers to mitigate effects from invasive annual grasses and can aid in restoration of natural habitats on ROWs. Reducing the competition from invasive annual grasses and promoting native species can lead to further ecosystem benefits, as discussed in the following sections.

There are limitations to where indaziflam should be used. Indaziflam has a longer soil residual than most other annual grass targeted herbicides. In heavily degraded sites with no remnant perennial species, indaziflam is not recommended as there is a two-year plant back time on seeding in to indaziflam-treated areas (Anonymous 2020). Spraying under these conditions can result in areas of bareground. Due to its ability to control germinating seedlings, indaziflam should also not be used in sites dominated by desirable annual species or areas with small or young perennial grasses with underdeveloped root systems (Anonymous 2020).

Pollinator Resource Impacts

A loss of habitats with diverse flowering forbs is one of the main causes for pollinator population decline. Researchers evaluating impacts on pollinators and floral resources found that long-term control of cheatgrass with indaziflam led to significant increases in flowering forb richness and alpha-diversity measures (Arathi and Hardin 2021). The average number of flowering forb species detected along a transect went from <3 species in the non-treated plots to 4 to 7 species flowering in the indaziflam treatments. These increases were seen across early-, mid-, and late-season evaluations, indicating that cheatgrass removal led to an increase in the flowering period for flowering forbs (Arathi and Hardin 2021). A continuation of the study in 2020 that tracked pollinator visitation to flowering forbs found significant increases in floral visitor richness and abundance in areas treated for cheatgrass with indaziflam (Nissen et al. 2020). Floral visitor richness was increased twofold while floral visitor abundance was increased 2.5–9x in treated plots compared to control plots. Native bees, hemipterans, lepidopterans, and coleopterans were observed more often in the indaziflam-treated sites compared to the control sites, demonstrating increased arthropod usage of the treatment areas, including by several pollinator groups. Furthermore, there was a 3.5x increase in number of flowers detected in treated plots, indicating that cheatgrass treatments led to increases in floral resources for pollinators.

Although habitat loss from human development and agriculture are main sources of pollinator decline, invasive species play a major role in reducing pollinator habitat quality in remaining habitat areas, especially invasive annual grasses which decrease the diversity and abundance of flowering forbs (Rhoades et al. 2016). Creating pollinator-friendly ROWs has been a major topic within ROW research but is often focused on eastern regions which are usually dominated by trees and large shrubs (Wojcik and Buchmann 2012). The research focus in these areas is often around the intensive management on ROWs and the return to early successional habitats to promote pollinator habitat (Wojcik and Buchmann 2012). In Western states, the habitat is dominated by grasslands and shrublands, many of which are impacted by invasive species. On ROWs within grasslands and shrublands that have been degraded by invasive annual grasses, long-term invasive annual grass control is necessary to restore and promote pollinator habitat.

Wildlife Habitat Impacts

As previously noted, habitat degradation, including invasive annual grass invasion, is listed as the number one threat to mule deer populations (Clements and Young 1997). Having healthy winter range is especially important for deer and elk as their winter diet is naturally lower in nutrients, and annual grasses further deplete the nutrient availability (Clements and Young 1997). Research in critical overwintering habitat for mule deer, elk, and other wildlife found that shrub growth increased in sites where cheatgrass was controlled with indaziflam compared to adjacent non-treated sites (Sebastian et al. 2021). Wildlife browse was increased for seven different shrub species utilized by browsers during winter months, indicating a substantial improvement to critical winter range in the study sites. New leader growth was 1.5x to 2.8x longer on shrubs in areas treated for cheatgrass, while shrub canopy volume increased 120%–400% by just 20 months after cheatgrass treatments (Figure 2). There was a 67%–648% increase in mule deer visitation to treated plots compared to non-treated plots during the critical browse months throughout fall, winter, and spring.

In research trials conducted in Northern bobwhite quail habitat on the sand sage prairies of Eastern Colorado, indaziflam treatments provided the long-term cheatgrass control necessary to promote higher forb frequency and bareground required for quail nesting and brood-rearing (Marymor 2020). At 2 YAT, there was a 3x increase in forb biomass and a 1.7x increase in bareground within indaziflam treatments. Bareground increases were due to reductions in cheatgrass litter biomass, which was near zero in treated areas by 2 YAT. As Northern bobwhite quail are in decline due to habitat loss and degradation, results from this trial demonstrate indaziflam as an option to restore quail habitat in those areas that remain by providing long-term annual grass control. Quail need abundant forbs for feeding, as forbs serve as insect habitat, while bareground allows for chick movement and ability to seek cover from predators under the taller, native grasses. Long-term cheatgrass control allowed for restoration of these critical habitat components.

The current research suggests that achieving multi year invasive annual grass control could potentially promote wildlife habitat improvement on ROWs. The creation of ROWs can cause habitat fragmentation for wildlife by disturbing areas used for breeding, protection from predators, and food resources, and create a barrier for wildlife movement (Biasotto and Kindel 2018). Unlike in the Eastern U.S. where large brush and trees are frequently managed along roadsides and utility corridors, large expanses of the Western U.S. are dominated by smaller shrubs, such as sage brush species (Shinneman et al. 2018). These shrubs provide critical habitat for both mammals and birds. Since low-growing vegetation (i.e., grasses, forbs, and small shrubs) can oftentimes be left intact on ROWs

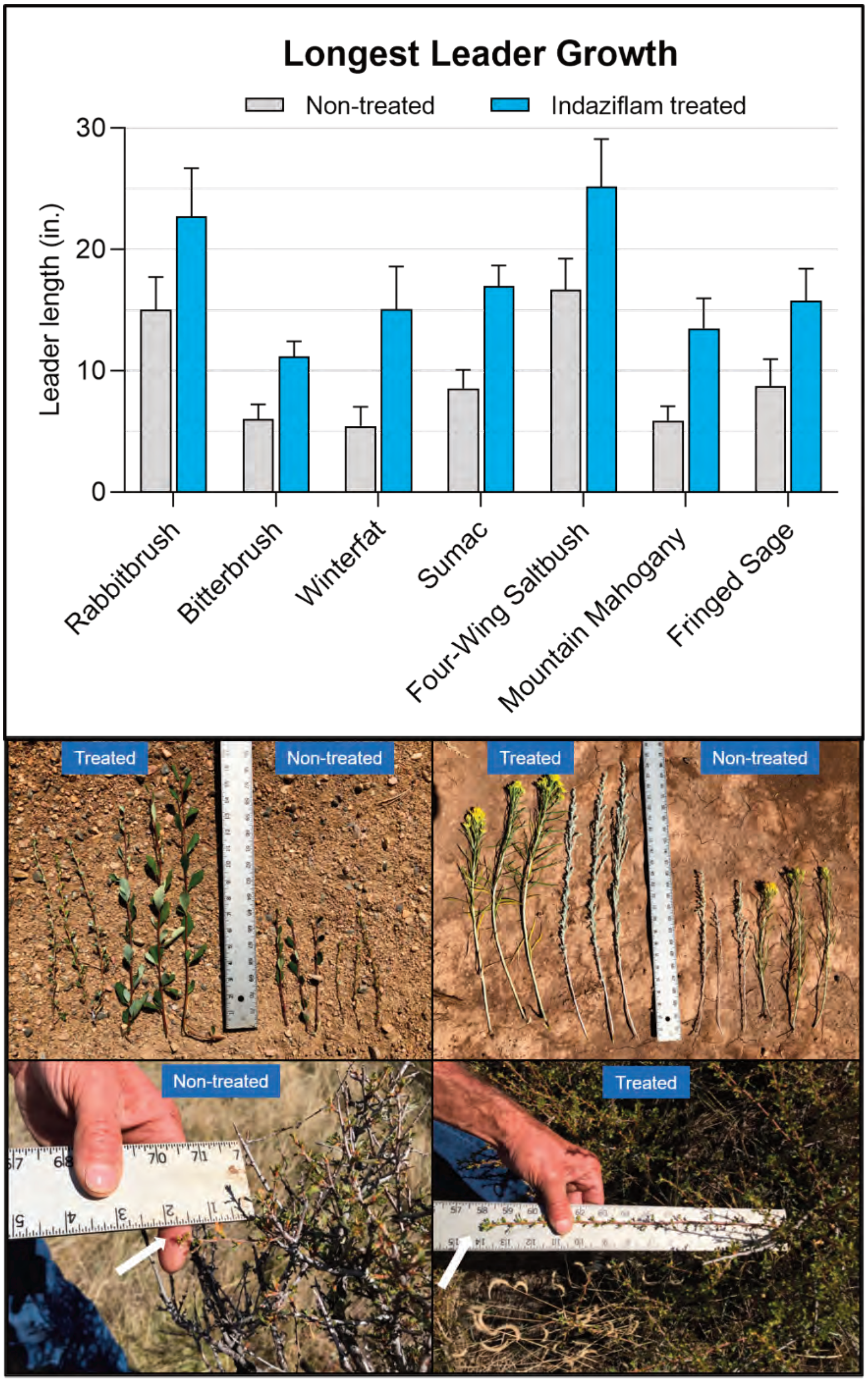

Figure 2. Average longest leader growth on shrubs in treated (indaziflam) vs. non-treated areas across six sites at 20 months after treatment. Bottom image showing representative mountain mahogany (top left), rabbitbrush and fringed sage (top right), and antelope bitterbrush (bottom) leader growth comparing treated and non-treated growth. (Source: Sebastian et al. 2020)

without causing safety issues (Dreyer and Niering 1986), promoting these vegetation types by reducing the competition from invasive annual grasses could help restore wildlife habitat in these areas.

Fuels Reduction Impacts

Arguably, the most critical reason to control invasive annual grasses on ROWs are the risks associated with fire spread. Long-term control options are needed on these sites to reduce the fine-fuel accumulation from annual grasses. A study in the foothills shrubland of Colorado evaluated the speed of litter degradation when cheatgrass is controlled long-term. Researchers found that cheatgrass litter was reduced 92% by 8 MAT, and there was 100% reduction at 20 MAT (Figure 3). On the flip side, perennial grass biomass was increased 5- to 10-fold (Sebastian et al. 2021) (Figure 3).

Seedorf (2020) found similar results on roadside plots treated with indaziflam for cheatgrass at DEN. Indaziflam treatments reduced cheatgrass cover to <5% compared to 80% cover in the control plots, while perennial grass biomass increased 5- to 10-fold at 2 YAT. This research has direct applications to reducing fire risk on roadsides, which is one of the top contributors of human-caused fires. Replacing the continuous, dry fuel layer with grasses that have more interspacing and dry out later in the growing season reduces the spread and severity of annual grass-fueled wildfires (Davies and Nafus 2012).

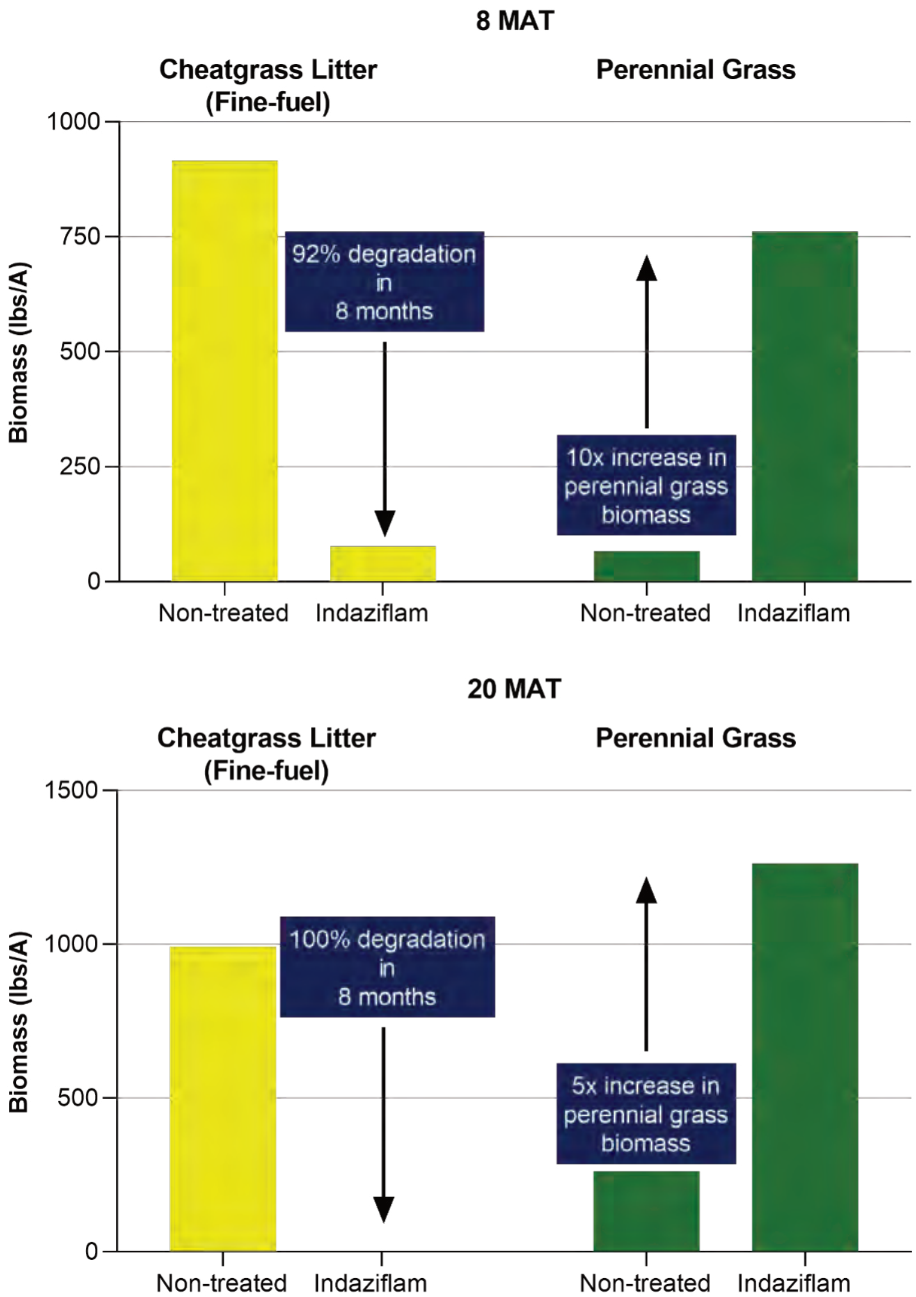

Figure 3. Cheatgrass litter and perennial grass biomass 8 and 20 months after treatment (MAT) in non-treated vs. indaziflam treated areas. (Source: Sebastian et al. 2020)

At a big sagebrush site in Wyoming, anecdotal evidence was gathered on the impact of long-term cheatgrass control to wildfire spread. Significant portions of study plots (2 ha) treated with indaziflam were left unburned when a cheatgrass fueled wildfire burned though the site 3 YAT, whereas non-treated plots were burned (Courkamp et al. 2022). Data collected two months before the wildfire showed that the cheatgrass canopy was <10% in the indaziflam-treated plots while the non-treated plots had >35% cheatgrass cover. Normalized difference vegetation index (NDVI) imagery from just before the fire, reveals more live green vegetation in the treated plots (Figure 4). These data suggest that reduction in the cheatgrass canopy in the indaziflam treatments may have influenced the behavior of the wildfire. Similar observations were made in the CalWood and Cameron Peak wildfires, which burned in October 2020 in Boulder and Larimer Counties in Colorado. Large patches of landscape that had been treated with indaziflam were left unburned or experienced more patchy burning compared to cheatgrass infested areas which burned more thoroughly (personal observations) (Figure 5).

Reducing wildfire risks on ROWs is a focus for land managers in the Western U.S., where wildfires are rampant and often spread from ROWs. This research demonstrates the ability to achieve long-term control of invasive annual grasses on ROWs to create fuel breaks and reduce the risk of fires sparked on roadsides or by utility transmission lines. The Red Cliffs National Conservation Area (NCA) provides critical habitat to the Mojave desert tortoise (*Gopherus agassizii*). In 2005, 15% of the tortoise population died in fires fueled by cheatgrass and red brome, and the population still has not recovered to pre-fire levels (Kellam 2020). The post-fire report indicates that most of the mortality occurred in open areas with high densities of cheatgrass (Kellam 2020). The Red Cliffs NCA lists treating roadsides for invasive annual grasses and maintaining firebreaks along ROWs as the number one priority in their habitat management plan to reduce fire spread (Kellam 2020). The creation of greenstrips linear strips maintained to have less-flammable vegetation in annual grass-invaded areas have been effective in disrupting the continuous fuel layer and slowing the spread of wildfire (Shinneman et al. 2018). Fuel breaks are frequently created along roadsides, as the reduced fuel combined with the bare ground of the road can prevent the fire from jumping the road and spreading (Shinneman et al. 2018). Successfully employing the use of greenstrips or fuel breaks in annual grass-invaded sites has been challenging though for land managers, as past tools for management were usually short-lived and would have to be repeated yearly (Shinneman et al. 2018). With new options available, long-term annual grass control can be achieved to create expansive networks of greenstrips or fuel breaks on ROWs.

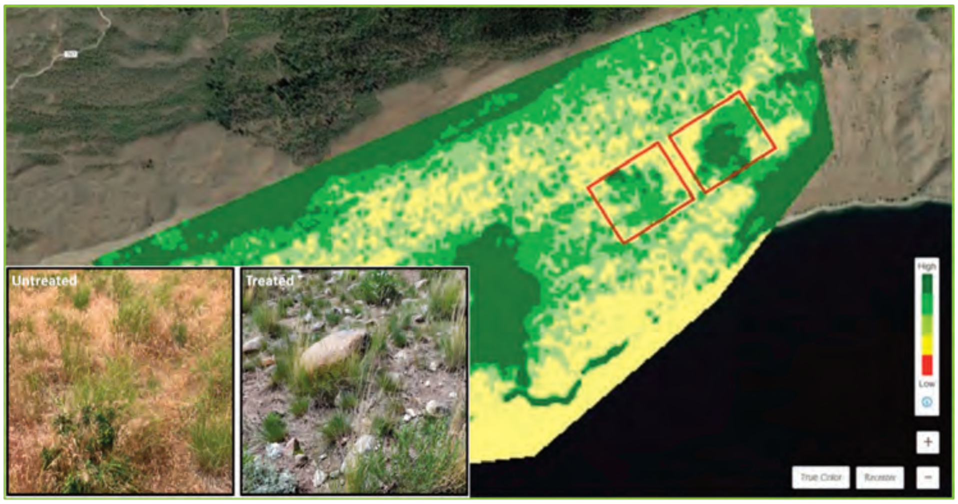

Figure 4. Normalized difference vegetation index (NDVI) imagery before Boulder Lake Fire, showing increase in live green vegetation in indaziflam-treated blocks at 3 YAT (depicted with red rectangles). Bottom left shows close up of vegetation in non-treated (left) and treated (right) plots 1.5 months before wildfire occurred. (Source: Courkamp et al. 2021)

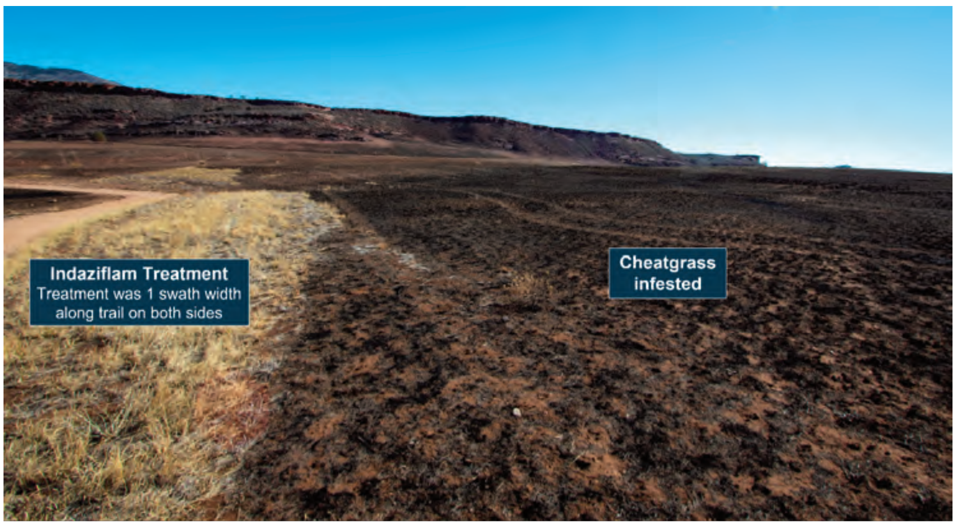

Figure 5. Photo taken three weeks after Cameron Peak Fire, showing burn severity in indaziflam-treated trail edge compared to non-treated area. The treated area dominated by perennial grass experienced a more patchy burn.

CONCLUSIONS

Annual invasive grasses are spreading at alarming rates across the Western U.S. and contributing to increased wildfires, loss in habitat, and ecosystem degradation. Indaziflam represents a newer option in the toolbox for invasive grass control, although there is no one-tool-fits-all solution in managing the vast expanse of annual grasses in the Western U.S. Focus needs to be on ecosystem restoration and an integrated weed management approach should be taken to make use of the various tools available. Long-term control of annual invasive grasses on utility ROWs has many potential benefits as described in rangeland and other non-crop settings, such as roadsides. Promoting low-growing shrubs and forbs could provide critical wildlife and pollinator habitat and is consistent with currently recommended integrated vegetation management practices on ROWs. Rights-of-ways should be treated for invasive annual grasses to reduce flammable fuel loads and create networks of fuel breaks, as powerlines and equipment (which may be accessing ROWs) are both main causes of wildfire ignitions. Overall, managing annual grasses on ROWs can aid in restoration of critical habitat while also reducing wildfire risk.

There is a need for case studies on transmission and distribution lines in the Western U.S. that have become dominated by annual invasive grasses. Studies should aim to evaluate topics such as fuels reduction, resiliency, and habitat restoration on ROWs. Application methods such as ground broadcast or feasibility of aerial applications need to be considered.

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Wildfire risk from aging or vulnerable electric utility infrastructure is quickly becoming a top priority for electric utilities, particularly in wildfire-prone Western states. Ground-based inspections have traditionally been utilized to identify defects and prioritize the maintenance or replacement of at-risk equipment. However, a ground-based approach to aboveground-level inspections has limitations and can miss critical defects only discoverable from above. Small unmanned aircraft systems (sUAS) are now being utilized to great success to improve efficiency and provide top-down views of distribution poles in wildfire risk zones. In 2019–2022, we collected hundreds of thousands of images documenting more than 40,000 poles in higher wildfire risk areas. Vulnerabilities included: rotting or split crossarms, pole-top rot and splits, loose or misaligned hardware, loose or detached ground wires, slack guys, and missing or damaged animal guards and arresters, among other defects. Many of these vulnerabilities were visible only from above and would only be efficiently discoverable via UAS. To effectively leverage sUAS technology for wildfire mitigation on distribution infrastructure, several contingencies must be considered, including sUAS model and pilot selection, GIS and data management, inspection workflow, homeowner privacy concerns, and much more. This paper will provide advice on how to plan for these contingencies.

Small Unmanned Aircraft System Applications for Wildfire Mitigation on Electric Utility Distribution Rights-of-Way

Greg Brenton and
Paul Petersen

Keywords: Maintenance, Unmanned Aerial Systems/Drones, Utility Lines.

Environmental Concerns in Rights-of-Way Management
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INTRODUCTION

There are more than 10.3 million kilometers of electric utility distribution lines across the U.S. (PES 2017). This enormous amount of infrastructure crosses a landscape that is projected to more than double its risk of wildfire property damage over the next 30 years (First Street Foundation 2022). More than 80 million properties in the U.S. are at some risk of wildfire exposure, with more than 4 million of those at extreme risk (>26% chance of wildfire damage over the next 30 years) (First Street Foundation 2022). While much of the wildfire risk is currently in the Western U.S., the Southeastern U.S. is expected to become increasingly wildfire prone (First Street Foundation 2022).

Data reported to the California Public Utilities Commission (CPUC) from investor-owned utilities in California showed that between 2014–2016, there were on average 300–600 annual fire incidents on their systems (CPUC). In Pacific Gas & Electric's (PG&E) investigations into cause, ~50% of the incidents were due to contact from an object (vegetation, animal, vehicle, balloon, etc.). The second leading cause at ~35% was equipment or facility failure (CPUC). Of equipment and facility failures, conductor and splice/clamp/connector issues were the leading causes, followed by transformers, capacitor banks, fuses, insulators, poles, lightning arresters, crossarms, guy wires, and span wires, among other equipment causes. Successful wildfire mitigation for electrical power infrastructure should involve many strategies including vegetation management, animal interaction mitigation, conductor clearance analysis, pole-loading analysis, public safety power shutoff programs during high-weather events, system hardening, application of advanced system protection technologies, and inspection for equipment defects.

Camp, Dixie, Malibu, Butte, Ruidoso, Kincade, Rice, Guejito, and Thomas are just a few of the destructive and deadly wildfires that were allegedly ignited or exacerbated by electrical power equipment over the past 15 years (CAL FIRE 2022). A 2018 study by the CPUC showed that electrical power was the third-leading cause of wildfire in California in 2017. In 2015, the CPUC reported that 149,000 acres burned in fires were ignited by electrical infrastructure—twice the acreage as the second-leading cause of ignition during that year (CPUC). In response to these fires, utilities have been fined tens, or even hundreds of millions, of dollars. It is now an imperative for electric utilities to implement cost-effective and efficient means of wildfire mitigation across their systems. To accomplish that, electric utilities need to better understand their vulnerabilities to fire ignition risk at a pole-by-pole level. Small unmanned aircraft systems (sUAS) can help with that.

Small unmanned aircraft system virtual inspection has recently begun to be utilized by many electric utilities across the U.S. Significant advantages of sUAS over crewed aircraft include the improved safety profile (often only necessitating one or two staff in the field, working from the safety of the ground away from energized equipment) and a drastically reduced cost of equipment. Lastly, the ability to take images a few feet from structures and equipment offers much better defect discovery, especially from above.

In a recent survey (Dwyer 2022) with several electric utilities that have tested or recently implemented sUAS programs, several challenges were often cited when trying to scale efficient and cost-effective sUAS programs. Chief among those challenges included recurring sUAS program funding; waning excitement for programs; personnel conflicts for sUAS roles; a bias for traditional inspection; reluctance from existing LiDAR/mapping personnel or contractors to accept sUAS; homeowner interactions (positive and negative); data storage and management; airspace rules and delays; and misaligned expectations about program deliverables.

Our objective is to share our findings on structuring an efficient and scalable sUAS-enabled virtual inspection program to discover equipment defects and create actionable reporting for electric utilities to mitigate wildfire risk along distribution rights-of-way (ROW). Our approach is based on four years of substantive data collection (40,000+ distribution poles) and inspection via sUAS from 2019–2022. Through this work, we have improved both our data collection and inspection efficiency and effectiveness. We compare advantages and disadvantages of different inspection methods and detail how to build and scale a sUAS inspection program for wildfire mitigation.

METHODS

Inspection Strategies

Prior to sUAS technology and high-resolution cameras on crewed aircraft, aboveground-level, ground-based patrols were the best strategy for discovering equipment defects on distribution structures. A ground-based strategy has several advantages compared to either crewed aircraft or sUAS. Primarily, a trained inspector has the potential to both spot defects in the field and investigate further, should a defect be spotted. Additional benefits of ground-based inspections are the ability to see the structure in three dimensions (compared with a 2D image) and identify unanticipated vegetation or ROW clearance issues. However, many defects are difficult to detect from a ground-based vantage point, including pole-top rot, crossarm damage, loose or disconnected hardware, damaged or corroded insulators, and loosened or damaged conductor ties (Images 1–4). A bucket truck used in conjunction with ground-based patrol can remedy some of these limitations but adds significant cost in equipment and time, and is not practical in difficult access areas.

Virtual inspection enabled by imagery collected using crewed aircraft or sUAS holds significant advantages to a "boots-on-the-ground" approach and can often significantly reduce the time needed for traditional inspection methods, like ground or foot patrol, climbing inspection, vegetation patrol, and crewed aerial inspection. Among the benefits of virtual inspection are an increased safety profile; increased efficiency for hard-to-reach structures; faster inspection rates; better view of a structure's top; better detection of certain types of defects; leveraging a distributed work force; the ability to share images and get input from others; more effective use of inspector time (e.g., less time in transit); repeatability by building a photo archive and change-detection; and an opportunity for artificial intelligence (AI) to create efficiencies and greater accuracy.

Crewed aircraft has more recently availed itself to high-quality overhead inspection due to technology improvements in high-resolution imagery, such as 100MP and 150MP cameras and the ability to collect light detection and ranging (LiDAR) data at the same time. This approach has several advantages, including a 2–3x efficiency in number of structures captured (400–1,000+ per day with helicopter vs. 150–250+ per day with sUAS), as well as gathering data for multiple uses (i.e., vegetation management, pole modeling, etc.). However, the increased cost of crewed aircraft (including crew, equipment, and sensors), the higher flight profile necessary for safety (thereby reducing the resolution for fine defect discovery), and the reduced safety profile of crewed aircraft relative to sUAS make this approach challenging for many utilities focused on discovering equipment defects specifically for wildfire mitigation.

Image 1. Pole-top rot

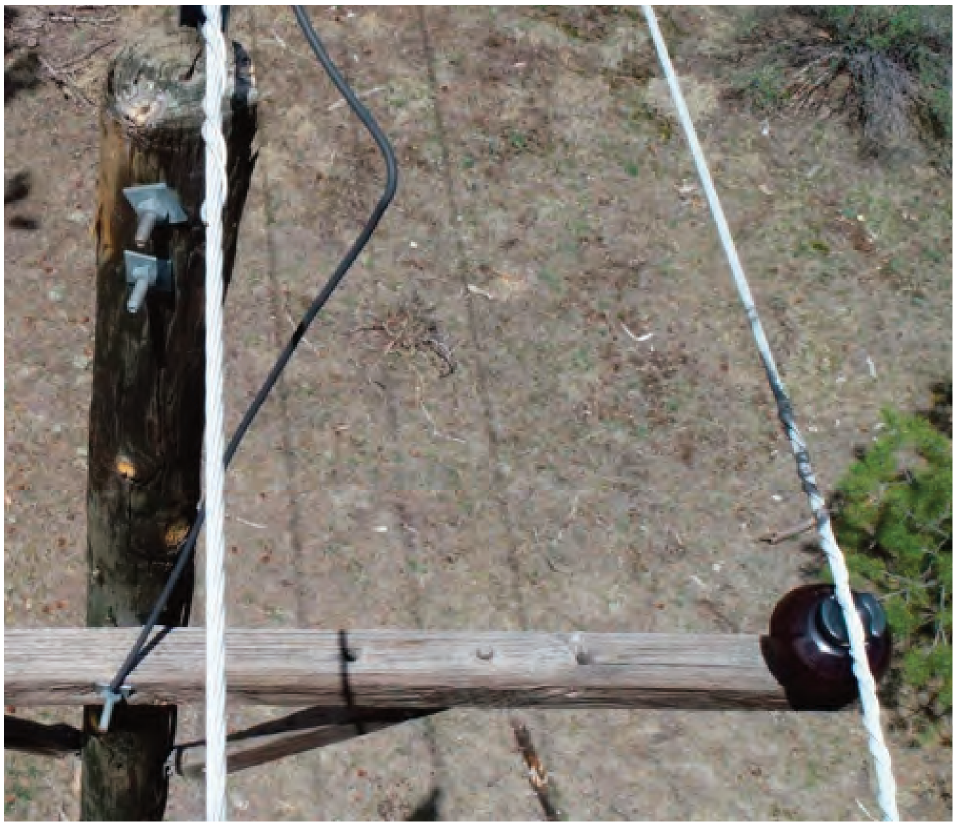

Image 2. Loose neutral blown onto primary and broken tie strands

RESULTS

After more than 40,000 structures flown, inspected, and reported, the following is our primer on structuring an effective sUAS virtual inspection program.

Pre-Flight and In-Field

A successful UAS program first and foremost depends on decent utility infrastructure data. Pole ID and location data from the utility needs to be provided to a geographical information systems (GIS) team member, where it can be input within a database system to be efficiently viewed and used by sUAS pilots, inspectors, project managers, end users, and the GIS team for ongoing support. There are enormous benefits of using one centralized system to accomplish all team functions. We have found particular success with Esri ArcGIS Portal. The platform allows all project staff to work seamlessly together from area planning to in-field data collection via sUAS, to inspection, and finally to apps and actionable reporting (Figure 1).

Once pole location data is loaded within the ArcGIS Portal, customer notifications are critical to conduct sUAS operations with as minimal distraction and negative interactions as possible. While negative homeowner interactions are expected given privacy concerns with this emerging technology, our experience has shown that notifications shortly before sUAS operations have helped to alleviate negative customer interactions.

Small unmanned aircraft system pilot selection is the next critical step in a successful program. Hiring contractors can often be a great approach for an organization that isn't ready to hire and devote full-time sUAS pilots to a project. However, maintaining data collection efficiency with dedicated staff pilots allows all downstream inspection and reporting to operate with a more reliable queue of images/structures to inspect, therefore allowing for more efficient staffing and deliverable expectations internally or for a client.

Image 3. Pin backing out—no cotter pin

Image 4. Damaged crossarm

Small unmanned aircraft system aircraft selection is a topic that could be covered extensively. Fortunately, for organizations looking to implement efficient sUAS programs, there is now a wealth of high-quality, affordable, and reliable "prosumer" models to choose from that work for enterprise-level electrical utility applications. Many smaller quad-copter sUAS models are a great choice for this kind of operation. If you are just starting a program, selecting a model that has a 20 megapixel or greater resolution camera is ideal. Their cost ($2,000–$10,000) presents a relatively minimal investment and offers resiliency in the event of an aircraft crash, especially given the proximity flying of distribution sUAS work. This allows both lower repair costs, as well as less risk to sensitive electrical equipment if contact is made with the aircraft.

Controlled airspace was cited as a concern or impediment to some utilities pursuing comprehensive UAS operations (Dwyer 2022). The Federal Aviation Administration (FAA) has continued to streamline authorization with its Low Altitude Authorization and Notification Capability (LAANC). There are several FAA and LAANC compatible mobile and desktop applications (e.g., Airmap, Kittyhawk) that allow a pilot to receive automatic authorization while in the field within seconds. For military airspace, temporary flight restrictions, or within a 0 ft LAANC cell (i.e., on/adjacent to airport grounds), the FAA provides authorization through a manual submission and review process within the *FAADroneZone.faa.gov* website, where pilots and organizations also register their aircraft. Most approvals take a few days to a couple of weeks.

After obtaining these prerequisites of good data and software, customer notifications, pilot and aircraft selection, and airspace approval, in-field data collection may commence with a higher degree of efficiency. For wildfire mitigation, we've seen success with a series of five images per distribution pole (oblique full-length photos from both front and back, oblique "top third" photos of conductors/equipment from front and back, and a nadir pole-top image) (Figure 2). While vegetation sometimes precludes 360-degree viewing, nearly all poles are able to be effectively inspected via sUAS. For poles that are obscured by vegetation, we have leveraged a hotstick-mounted, GPS-enabled digital camera. Over four years, and by streamlining our process, we have determined that pilots can capture an average of 150–250 poles a day with this strategy. This makes it possible for a very small team of pilots to image significant portions of an electric utility's territory per year, accommodating a recurring inspection strategy of an entire system.

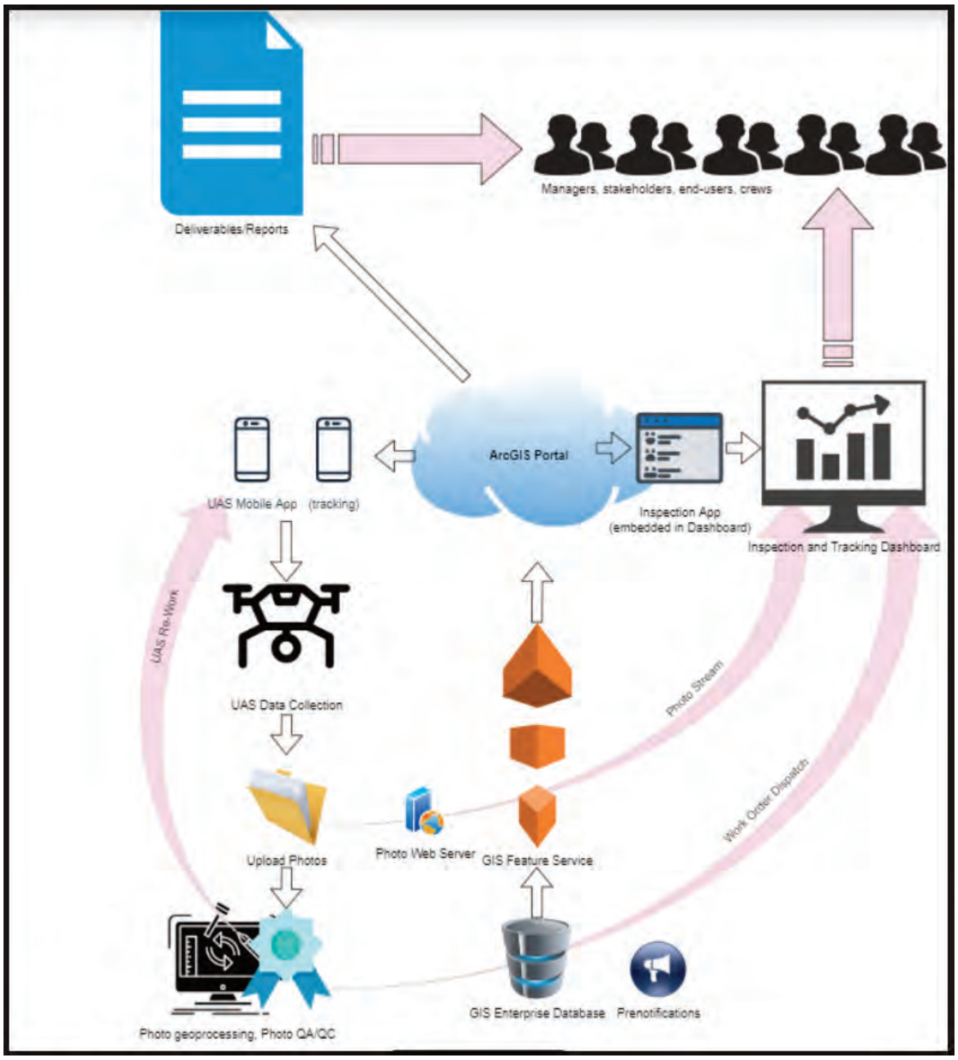

Figure 1. Small unmanned aircraft system wildfire mitigation workflow

After each in-field sUAS collection day, the pilot transfers imagery to a shared network drive through a secure VPN. Once the transfer is complete, the GIS team moves the imagery into the post-collection and inspection phase via the ArcGIS Desktop and Portal software (Figure 1). The imagery is also backed up at this time.

Post-Flight and Inspection

An essential step after image upload is a GIS team member providing QA/QC to establish: (1) that the correct poles were imaged and any missed poles can be flagged for follow-up in the field and (2) that the images are joined correctly to the pole ID for inspection. Some locations in the field will have 2–4 poles in a tight grouping, making it difficult to distinguish which photos are of which pole. A GIS specialist will group and "join" those photos to the correct structure type (primary, secondary, etc.). This "join" is done through a series of Python scripts, which saves time over the duration of a project and also helps to standardize the process. Once images have gone through QA/QC and joined to each pole ID, they are then assigned to an inspector.

One of the benefits mentioned of virtual inspection is finding and onboarding inspectors that allows for a decentralized and even part-time workforce of linemen to inspect and report on defects. They are connected to the centralized database through an ArcGIS Portal dashboard app, and can view and enlarge images, flag defects, and generate reports all within the app. Each pole is typically given a rating based on the severity of the defect(s) (i.e., immediate action, pole with defect, pole ok, etc.), along with the inspector's notes. That report is then generated and emailed directly to the project manager as well as the client/utility for repair in the field.

With five photos per pole at 20MP each, and an average of 150–250 poles per day, folder sizes can average 15–30 GB per pilot, per day. Data storage then becomes a significant consideration. Having dedicated server space of at least 5–10 TB is a good starting point for a project that involves more than 10,000 poles per year.

Based on analysis of a subset of more than 40,000 poles that we have imaged via sUAS and inspected in higher wildfire risk areas (primarily constructed prior to the mid-1980s), 30–50% of structures have at least one defect present. Poles that necessitated a replacement were 4–8%, and 1–2% of inspected poles had a critical defect in need of immediate attention.

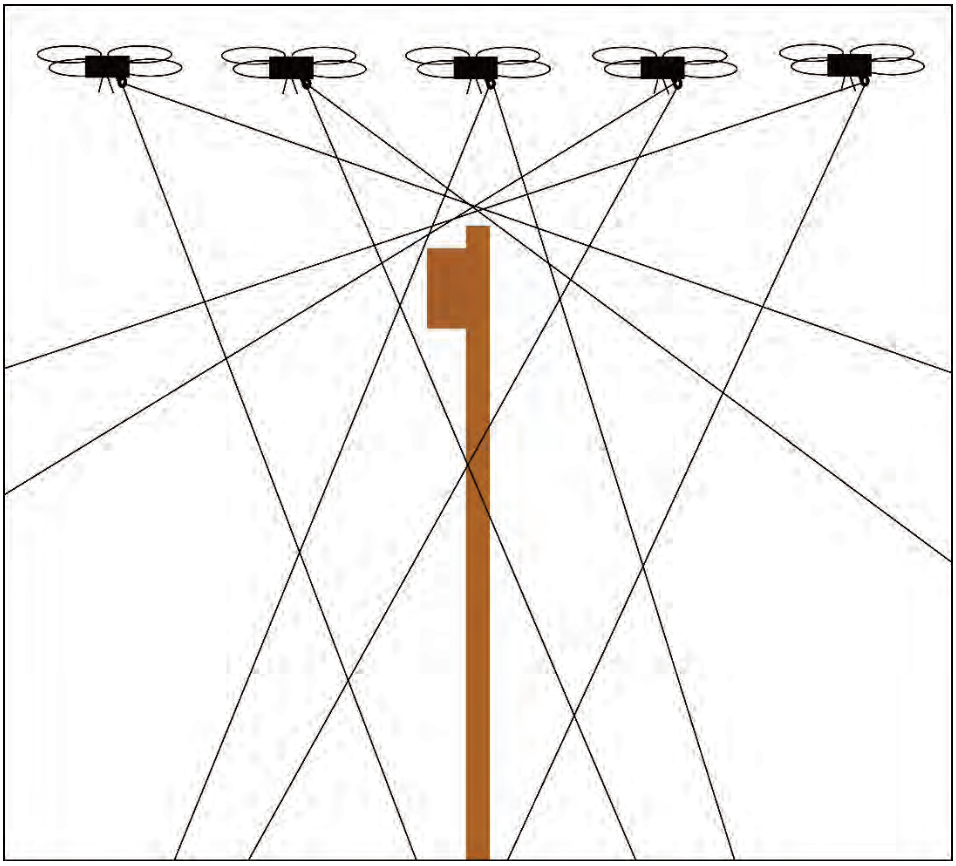

Figure 2. Small unmanned aircraft system image capture for distribution structure

Furthermore, we've improved our own process from time of flight to time of report delivery, a critical metric for the ability to provide timely and actionable insight. Over four years, we have reduced flight to report delivery by more than 50%. Similarly, inspection time per pole has been improved significantly due to the integration of imagery and reporting, all within the ArcGIS Portal dashboard.

DISCUSSION

This entire UAS virtual inspection workflow, from pre-flight GIS to reporting, is not without its investment in time and money, as well as the need for a highly capable team. But as the process has continued to improve, we've proven the feasibility of reducing the overall cost of defect-focused distribution wildfire inspection to a level comparable with most ground-based inspection approaches, and more cost-effective than crewed aircraft inspection. Most importantly, we've been able to provide higher detection rates of critical defects.

CONCLUSIONS

For defect detection related to wildfire mitigation, sUAS has been shown to be an efficient and effective method of capturing data to help address this increasingly growing area of risk. Small unmanned aircraft systems can be a key strategy in "inspection stacking" to combine new technologies with existing inspection processes and personnel. As electric utilities continue to increase adoption of sUAS for inspections, it is realistic to anticipate growing pains with adapting emerging technologies to existing infrastructure and processes. As with all advancements in the industry, a continued effort towards process improvement, defined expectations, and a dedicated team is required to achieve success.

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AUTHOR PROFILES

Greg Brenton

Greg Brenton has more than 3,000 hours of UAS flight time in electric utility ROWs, including within restricted airspace. He is a Part 107 FAA-Certificated Commercial Small Uncrewed Aircraft Systems Pilot, a Level 1–sUAS Certified Infrared Thermographer, and a UAS Pilot with EDM International, Inc. Brenton's electric utility UAS experience has covered tens of thousands of distribution poles in higher wildfire risk areas, thousands of transmission structures, imaging for joint-use inventories, orthomosaic mapping, post-construction inspections, and thermal imaging and analysis.

Paul Petersen

Paul Petersen has been working as a GIS Consultant since 2003. He has experience in a diverse array of GIS functions and platforms, including project management, database design, mobile data collection, cartography, analysis, photogrammetry, web design and web maps, and scripting. Petersen joined EDM International in 2011 and currently oversees GIS and mobile data collection work. He provides analytical and management support for geospatial projects related to gas and electric facility inventory and inspection, asset management, avian risk assessments, and utility development and construction.

Understanding the Wildfire Litigation Process: Rights and Remedies of Litigants

Charles Lally and
Lawrence J. Kahn

Keywords: Laws, Legal Cases, Liability, Rights-of-Way (ROW), Utilities, Wildfires.

A substantial proportion of the most damaging wildfires in many U.S. states originated from tree and powerline conflicts. The enormity of these disasters includes personal injury and death claims, massive property loss and damage, economic loss, and a variety of other claims and cross-claims brought by thousands of plaintiffs against utilities and their contract partners, and sometimes even direct actions against their officers and directors. At least one of these disasters led to the largest bankruptcy proceedings in American history. With the potential for both civil and criminal liability, as well as class actions, the end result is some of the most complicated litigation ever experienced anywhere in the world, which requires handling by experienced counsel with a deep understanding of mass torts, practice and procedure, fire investigation, insurance coverage, and utility vegetation management (UVM), as well as other complex areas of the law. The use of the principle of inverse condemnation to hold utilities accountable for the damage, regardless of negligence, was previously a tool utilized only in California, but other Western states are beginning to consider applying this as a tactic to hold utilities accountable for massive damages claims. This paper analyzes the rights and remedies of various parties and investigates the question of whether government itself shares some of the responsibility and liability for the losses experienced by claimants.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Trends in Wildfire Frequency and Severity

Over the last 30 years, the total average frequency of wildfires in the United States has declined slightly, while the total average area affected by wildfires has ballooned significantly (Hoover and Hanson 2022). There can be significant variation year over year; for example, the 2014 wildfire season was unusually mild, with less than 4,000,000 acres burned, while seven other fire seasons in the 2010s saw more than 8,000,000 acres burned. Two of those seasons (three, including 2020) burned an unprecedented 10,000,000 acres (Hoover and Hanson 2022). Considering that "a small percentage of fires account[] for the vast majority of acres burned," this data indicates that the largest wildfires are doing more damage every year, and that even though there may be fewer wildfires, the ones that do develop are significantly more destructive than they have been in the past (Hoover and Hanson 2022).

It comes as no surprise that aridity and drought conditions are very strongly correlated with the amount of land burned by wildfire in a given year (Juang et al. 2022). Disturbingly, among the largest and most destructive fires, dry conditions have an exponential influence on the total burned area (Juang et al. 2022). Wildfires expand along their continuously combusting perimeters, or fire fronts. Larger fires will have larger fire fronts, leading to a "strong tendency for large fires to grow faster than small fires" under any conditions (Juang et al. 2022). As previously noted, the long-term rise in wildfire-burned area cannot be accounted for by a rise in the number of individual fires. This rise also cannot be accounted for by longer, as opposed to faster, burns (Juang et al. 2022). In other words, as conditions dry and a region enters a period of drought, the largest wildfires spread at an exponentially faster rate.

Table 1. Yearly Percentages of All Individual Fires That Were Caused by Utility Infrastructure and All Acres Burned by Wildfire from Utility-Related Fires

Year	% of Incidents	% of Acres Burned	Citation
2010	4.72%	3.51%	CALFIRE. 2010. Wildfire Statistics, 12, 18.
2011	4.61%	3.20%	CALFIRE. 2011. 2011 Wildfire Statistics, 16, 22.
2012	8.62%	3.85%	CALFIRE. 2012. 2012 Wildfire Statistics, 16, 25.
2013	8.77%	39.19%	CALFIRE. 2013. 2013 Wildfire Statistics, 16, 25
2014	7.84%	0.35%	CALFIRE. 2014. 2014 Wildfire Statistics, 15, 24.
2015	7.80%	0.35%	CALFIRE. 2015. 2015 Wildfire Statistics, 15, 24.
2016	9.59%	1.12%	CALFIRE. 2016. 2016 Wildfire Statistics, 16, 25.
2017	11.76%	53.37%	CALFIRE. 2017. 2017 Wildfire Statistics, 16, 25.
2018	8.48%	23.22%	CALFIRE. 2018. 2018 Wildfire Statistics, 16, 25.
2019	9.85%	64.45%	CALFIRE. 2019. 2019 Wildfire Statistics, 16, 25.
2020	9.57%	4.07%	CALFIRE. 2020. 2020 Wildfire Statistics, 18, 27.

The Southwestern U.S. is currently gripped by the worst drought in at least 1,200 years (Williams et al. 2022), and it is being predicted that drought conditions there may persist until 2030 (Williams et al. 2022). Accordingly, the conditions that create the largest, deadliest, and most damaging wildfires can be expected to dominate the Southwestern U.S. for the foreseeable future. The 2020s are shaping up to be an extraordinarily dangerous decade for people living in wildfire-prone regions, and those in the Southwestern U.S. need to be prepared for wildfires that may be as intense as those that have been experienced in the Western United States.

Utility Wildfire Overview and Statistics

Between 2017 and 2021, 89% of all wildfires in the United States were caused by human activity (Hoover and Hanson 2022), and many of these anthropogenic wildfires are ignited by either failed utility infrastructure or by conflicts between vegetation and such infrastructure. The most comprehensive data on this subject has been published by the California Department of Forestry and Fire Protection (CALFIRE). A portion of that data, containing the yearly percentages of all individual fires that were caused by utility infrastructure and all acres burned by wildfire from utility-related fires, is shown in Table 1. Note that these data reflect only the areas of California within CALFIRE's zone of responsibility, and do not include data outside of this area (CALFIRE 2020).

Periodically, utility wildfires may be caused by downed lines or contact with animals, but the overwhelming majority of these fires are sparked by contact with vegetation (CALFIRE 2020). In one particularly devastating case, contact between a tree and one of Pacific Gas & Electric's (PG&E) transmission lines caused a wildfire that destroyed most of the towns of Paradise and Concow, California (CALFIRE 2019). Dubbed the "Camp Fire," the 2018 blaze remains the deadliest in California's history and the sixth deadliest (with more than 80 deaths) in the history of the United States. The 2021 Dixie Fire—which killed three firefighters, burned approximately 960,000 acres, and destroyed 1,329 structures—was also caused by contact between vegetation and PG&E's electrical equipment and was spurred by drought conditions (CALFIRE 2022).

WILDFIRE BASICS

Ignition of Utility-Related Wildfires

Wildfires are "unplanned fire[s] burning in natural (wildland) areas such as forests, shrub lands, grasslands, or prairies" (U.S. Forest Service 2013).

Wildfires require the ready availability of “fuel and atmospheric oxygen,” as well as a “competent ignition source” (U.S. Forest Service 2013). Many natural phenomena, such as lightning, and man-made objects or activities, such as improperly extinguished campfires and smoldering cigarette butts, can be competent ignition sources.

Powerlines can become a competent ignition source for a wildfire in at least four different ways. First, components on a utility pole can become hot enough to ignite vegetation through resistance heating (Watson et al. 2021, at 133 134). Heat is always produced when electricity flows through conductive materials, but faulty connections between energized components can cause dangerous amounts of heat to build up (Watson et al. 2021). Vegetation in contact with a component experiencing resistance heating can ignite, sparking a wildfire. Second, overcurrent and overload can cause utility equipment to become a competent ignition source through a similar mechanism; instead of heat building up at the site of a faulty connection, overcurrent causes heat to build up within a conductor (Watson et al. 2021). Electrical components are only rated to operate safely up to a certain current. When that current is exceeded, heat will build up, and if the component can’t shed the excess heat, it can cause vegetation in contact with it to ignite. Third, arcs can cause ignition if the arc path intersects vegetation. An arc is a “high-temperature luminous discharge” appearing spontaneously between components with substantial voltage differences (Watson et al. 2021). Vegetation caught in an arc path will experience temperatures in the range of several thousand degrees, but they may not necessarily ignite: arcs are often brief enough that they do not pose a risk of heating vegetation to the point of ignition (Watson et al. 2021). That said, however, vegetation with a higher surface-to-mass ratio will be easier to ignite through electrical arcing, and any dead and/or dry (including dryness due to drought) parts of a tree could be more susceptible to ignition from arcing. Fourth, electrical components along a powerline or on a pole can produce sparks during a short circuit or ground fault. If the sparks encounter vegetation before they cool, they can likewise be a competent ignition source.

Wildfire Mechanics

Once vegetation comes into contact with a competent ignition source, weather, fuel, and topography dictate how the wildfire will spread (Schneider and Breedlove 2022, at 4 5). Hot temperatures, high winds, and low humidity and precipitation will aid the spread of a fire (Schneider and Breedlove 2022). Low-moisture, small-diameter vegetation will burn the fastest, and vertical arrangements of fuel will aid the spread of wildfire from the surface into the overhead canopy (Schneider and Breedlove 2022, at 5 6). Aspect (the exposure of a slope to the sun) and slope angle are the topographical features most influential on the spread of wildfire (Schneider and Breedlove 2022, at 7 8). In the northern hemisphere, southern slopes have greater exposure to the sun, and are therefore more susceptible to wildfire (Schneider and Breedlove 2022). Steeper slopes are less resistant to wildfire; fire near the bottom of a steep slope can burn upwards easily, and fire near the top can cause flaming debris to roll downhill (Schneider and Breedlove 2022).

“Fire spread is essentially the physical transfer of heat through the environment,” so good fuels will display properties conducive to absorbing heat quickly and retaining it for long periods of time (McGranahan and Wonkka). The three most important properties of plant material for their ability to spread (or resist) wildfire are their size, their moisture content, and their three-dimensional arrangement (McGranahan and Wonkka, at 8 12). The size of a particular piece of plant material, measured with reference to its diameter, is relevant because the time it will take to reach ignition temperature is directly related to its surface area to volume ratio (McGranahan and Wonkka). Larger-diameter pieces of plant material, like tree trunks and large branches, will need more time to ignite than smaller-diameter pieces of plant material, like leaves and twigs (McGranahan and Wonkka). High-moisture-content plant material will also require more time to reach ignition temperatures (McGranahan and Wonkka, at 9 11).

Finally, in a wildfire context, the three-dimensional arrangement of plant materials in nature is referred to as the “fuel bed.” “There are three broad fuel bed layers: the ground, the surface, and the canopy. A ground fire will burn material below the soil, such as peat, a surface fire will burn plant materials rooted in the ground, like grass and shrubs, and a canopy fire will burn the canopies of trees. A surface fire can become a canopy fire by traveling into the canopy along “ladder fuels,” or vertically arranged plant materials. Once a canopy fire has begun, the distance between trees will determine whether only a single tree is ‘torch[ed],’ or many trees are burned in a ‘running crown fire’” (McGranahan and Wonkka, at 11 12).

The most damaging wildfires occur during periods of low precipitation, high temperatures, and high wind. Under these conditions, wildfires will quickly burn through both living and dead vegetation. Trees may be spared during low-intensity surface wildfires, as the flame front will pass too quickly to ignite their trunks. The presence of vertically arranged vegetation, though, may provide a ladder for surface fires to reach the leaves and branches in the overlying canopy. Trees that would otherwise be large enough to survive a wildfire unaffected can be severely damaged or killed by canopy fires and provide fuel for the next wildfire to pass through the same area.

UNDERSTANDING LAWSUITS

Parties to a Utility Wildfire Lawsuit

Property Owners

Property owners can become involved in wildfire litigation when their property is damaged or destroyed in (or as a result of) a fire. After a utility wildfire, property owners may have claims against the publicly or privately owned utilities responsible for igniting such a fire. Property owners have a choice to bring these claims against either the utility directly, or alternatively, against their own property insurance companies, assuming, of course, that the policy of insurance provides coverage in the event of a wildfire. If the property owner files a claim against the insurer, then the insurer must determine if the loss was or was not covered. If a determination is made that coverage exists, then the insurer will investigate the value of the claim and will be required to pay the full amount of damage (up to the policy maximum) less any deductible, if any.

Even property owners who have received payment from an insurer through an insurance claim may seek to make a recovery against the utility, so long as they don't claim monies already paid to them. For example, underinsured property owners who have lost more than the value of the policy may seek to recover the difference (and/or any deductible they needed to pay) from the utility in a utility-originated wildfire case.

It is possible that a property owner's insurer will deny a claim for reasons unrelated to any defense the utility might have (if any). In such case, the property owner would likely bring an action against the utility for the damages suffered, and, if the property owner believes that the denial of the claim was wrongful, may also seek damages from the insurer (for wrongful denial of the claim—not the fire damage itself).

Similarly, the insurer may reject certain damages elements (in whole or in part) that are claimed by the property owner. In such case, the property owner may take or reject the insurer's offer and still pursue the utility for the difference. The property owner may also pursue the insurer for wrongful denial of claim, unfair settlement practices, or a variety of other causes of action.

Insurance Companies

If a property owner's insurer pays the property owner's claim (in whole or in part), the insurer will be subrogated to the property owner and will be able to pursue the utility that ignited the fire for amounts paid to the property owner, because in such case, the insurer will "stand in the shoes" of their insured. The insurer has the choice to sue in the name of the insurance company itself or in the name of the property owner. In the case of a large fire that impacts many property owners that were all covered by the same insurance company, an insurance company representing those property owners might have significantly more bargaining power against a utility than any individual property owner might have had, due to the aggregation of multiple claims. Insurers with aggregated claims in such cases also have the opportunity to be more efficient with their expenditures on legal fees than would have been the case if numerous individual property owners each needed to hire their own counsel to pursue claims against a utility. On the other hand, if property insurers improperly decline to honor their policies of insurance, then property owners may bring their claims against both the utility (for igniting the fire) and the insurer (for wrongful declination of coverage).

It is possible that an insurance company may be insufficiently capitalized to pay the claims of multiple holders of policies stemming from a single massive fire. In that case, the insurance company may seek bankruptcy protection. Under these circumstances, the policy holders whose insurer failed to pay them would likely proceed against the utility, while the insurance company itself might seek a claim in its own right against the utility for actions that drove it into bankruptcy.

Utility Companies

Utility companies become involved in wildfire litigation when their equipment triggers a wildfire. They will almost always be on the defensive; property owners can make claims against them for damages through a wide variety of causes of action, insurance companies can seek to recover their costs in court, and government agencies can seek to impose criminal liability, enforce binding changes to their operational policies through a court order, or recover for the cost of suppressing the wildfire. Utilities can end up in an adversarial position relative to one another if one seeks to indemnify against another, or if a wildfire ignited by one utility causes damage to property (including infrastructure) of another utility.

Contractors to Utility Companies

Many utility vegetation management (UVM) functions, such as tree inspection and tree pruning and removal activities, are performed for utilities by third-party contractors. Ordinarily, contractors in such a position owe a duty of "ordinary care" for the work that they perform, which is generally tolerant of simple negligence. However, in the UVM context, particularly in California, utilities contractually hold their contractors to a higher standard of care and will require that the contractors obtain extremely large insurance policy coverage limits that cover the utilities (as "additional assureds") as well as the contractors. If a utility-ignited wildfire is the result of contractor error (for example, because a tree that should have been pruned or removed was not addressed), then the utility would likely bring a third-party action against their own contractor for the failure, seeking to hold the contractor liable for all of the damages faced by the utility.

Ordinarily, contractors are nowhere near as solvent as the utilities that they work for, so few (if any) contractors can withstand the full financial liability of a catastrophic wildfire. Additionally, utilities ultimately need to be aware that bringing lawsuits against their own contractors that result in the financial destruction of those contractors will have a chilling effect on other contractors and their willingness to perform such work for that utility. Accordingly, utilities contemplating such action are better served demanding the surrender of the contractor's insurance policy (i.e., require the contractor's insurer to pay the maximum coverage amount), and then seek additional monies via settlement with the contractor directly (over and above the policy limit). Such a strategy would allow the utility to extract a meaningful financial contribution to be paid to the victims while avoiding the decimation of its contractor.

Government Agencies

Government agencies fall into three broad categories in the context of wildfire litigation. There are agencies who carry out fire suppression, such as CALFIRE and the United States Forest Service, who will become involved during the suppression and investigation of wildfires. They will have deployed workers and resources to combat the wildfire, as well as investigators to determine its origin and cause. They can sue to recover these costs under a variety of statutes. Some government agencies will enter litigation to impose criminal liability on the parties responsible. Finally, some legally empowered public utility commissions such as the CPUC will become involved to force utilities to make factual stipulations, change their operations and policies, and enforce damage regimes. Rarely, government agencies can even end up litigating against one another when one seeks to recover the costs of an operation from another.

Causes of Action, Generally

Like other forms of mass tort litigation, the numerous causes of action available to petitioners, respondents, plaintiffs, and defendants in a utility wildfire case reflect the wide variety of interests, responsibilities, and agreements at stake. In a civil case, common causes of action available to petitioners include negligence, trespass, and nuisance. Inverse condemnation, a legal concept deserving of its own, far more extensive, exploration, also enables property-owning petitioners to recover their costs after a wildfire. Respondents in a civil case will occasionally have access to cross-claims of explicit and implied indemnity against their fellow respondents. Electrical utilities can also be held criminally liable for sparking wildfires; in criminal cases, prosecutors can level statutory violations, allegations of air and water pollution, arson, infliction of great bodily harm, and manslaughter against corporations and their officers. The following section will examine these various legal concepts and causes of action.

Civil Causes of Action

Claims

1. Negligence. Negligence claims can arise against an electrical utility both for causing a wildfire, as well as for measures that they implement to avoid causing wildfires. The first half of this section will be devoted to explaining negligence in a wildfire litigation context, and the second half will deal with negligence claims in the course of utility companies' efforts to avoid wildfires. As an introductory note, negligence claims such as these can arise in both individual and class action litigation.

Negligence is a common law remedy with four elements: a duty of care, a breach of that duty, damages resulting from the breach, and proximate cause. Duty is a question of law, and the remaining three elements are questions of fact (*Wells v. Nespelem Valley Elec. Coop* 2020). Utility operators generally owe property owners an ordinary duty of care to prevent fires (*Wise Elec. Coop., Inc. v. American Hat Co.*, 476 S. CALFIRE.3d 671, 686,Tex. App. 2015). Utilities can end up, either explicitly or *de facto*, owing a heightened duty of care as a result of the extraordinary danger posed by power and communication lines (See Wells, 462 P.3d at 154, citing *Celiz and Sanchez' Estates v. Pub. Util. Dist. No. 1 of Douglas Cnty.*, 638 P.2d 588, 590 [Wash. Ct. App. 1981]; see also *Alderwoods [Pennsylvania], Inc. v. Duquesne Light Co.*, 52 A.3d 347, 356 [Pa. Supp. Ct. 2012], noting that no "second tier of extraordinary care" exists, but "the level of care must be proportionate to the danger involved" [citing *Stewart v. Motts*, 654 A.2d 535, 538 {Pa. 1995}]). Utility operators can breach this duty by failing to inspect and maintain their lines or by failing to appropriately address challenges caused by the vegetation within their right-of-way (ROW) (*United States v. Southern California Edison*, No. CV-19-07179 PA [SKx], 2020 WL 2542613 at *2, C.D. Cal. Mar. 23, 2020). Damages in utility negligence can come in the form of destruction of property by fire, or damage to property by smoke. These damages can be proximately caused by utility operators if they resulted from vegetation growing into, sagging onto, or striking a utility line.

United States v. Southern California Edison provides a representative example of negligence in a wildfire litigation context, as well as demonstrating the wide variety of possible claims and claimants in this field of law. *U.S. v. SoCal Edison* arose when a tree in the Los

Padres National Forest fell on power and communication lines owned and operated by SoCal Edison and Frontier Communications. This tree-to-powerline contact resulted in the Rey Fire, which burned 19,752 acres of the National Forest. Frontier's duty of care was established when it agreed to abide by California's Joint Pole Committee Routine Handbook, which required it to trim all trees that could cause Frontier's communication lines to contact SoCal Edison's powerlines, and this duty was breached when Frontier failed to inspect and remove the tree that started the Rey Fire. That breach was the proximate cause of the Rey Fire, and the Rey Fire damaged a vast swath of United States Forest Service land.

Utility companies can also be subjected to negligence claims in their efforts to avoid causing wildfires. *Gantner v. Pacific Gas & Electric Corp.* provides a salient example, although it will be discussed further in future sections of this paper (namely, the sections dealing with the effects of bankruptcy on wildfire litigation and the influence of empowered public regulatory bodies like the California Public Utilities Commission). The petitioner in *Gantner* filed a claim alleging damages as a result of negligence on the part of Pacific Gas and Electric Corporation (*Gantner v. Pacific Gas & Elec. Corp.*, 26 F.4th 1085, 1087-88 [9th Cir. 2022]). The petitioner argued that PG&E had a duty to maintain its grid in a safe condition; that it breached that duty by operating tens of thousands of miles of conductors that are highly susceptible to failure, failing to upgrade its transmission lines, and failing to prune trees around those lines. The petitioner did not actually allege damage as a result of these operational failures, they claimed that these failures made frequent Public Safety Power Shutoffs (PSPSs) a necessity (*Id.* at 1088). The petitioner's damages all relate to the loss of power during PSPS events, not from damage from wildfires. The petitioner in *Gantner* has offered a plausible theory for recovery under a claim of negligence, but the litigation has become entangled with questions concerning CPUC's authority to order such shutoffs, and no decision has been reached as of the time of the writing of this paper. The litigation, which began in Bankruptcy Court in the Northern District of California, was appealed to the United States District Court for the Northern District of California, was appealed again to the Ninth Circuit Court of Appeals, and is currently pending certification by the California Supreme Court (*Id.* at 1088-89, 1092).

2. Trespass by Fire. Utility companies incur claims of trespass by fire when fires started by their lines cause damage to property. Trespass is an unlawful interference with an owner's interest in the possession of their property. Trespass by fire results when utility wildfires prevent property owners from exercising their rights of ownership. Trespass generally has five elements: (1) the petitioner's ownership or control over the property in question; (2) the defendant's intentional, reckless, or negligent entry onto the property; (3) lack of permission for the entry; (4) resulting harm; and (5) the respondent's conduct was a substantial factor in causing the given harm (*Ralphs Grocery Co. v. Victory Consultants, Inc.*, 225 Cal. Rptr. 3d 305, 317 [Cal Ct. App. 2017] [enumerating the elements of trespass]).

Trespass can encompass a wide variety of infringements against personal and property rights, so it is worth taking the time to map the common-law definition onto a real example of trespass by fire. In *United States v. Southern California Edison*, the petitioner raised a claim of trespass by fire after the "defendants…negligently and/or in violation of the law, ignited the Rey Fire, thereby setting fire to or allowing a fire to be set to National Forest system lands." The Rey Fire "damaged and destroyed property of the United States," and resulted in the Forest Service incurring "fire suppression costs, costs to rehabilitate the area," and other expenses (First Amended Complaint ¶ 76-78, *United States v. Southern California Edison*, No. CV-19-07179 PA [SKx], 2020 WL 2542613 at *2, [C.D. Cal. Mar. 23, 2020]). The petitioner owned and controlled the land through the United States Forest Service; the respondent was negligent in their maintenance of the right-of-way and their electrical transmission equipment, and that negligence resulted in fire entering Forest Service property; this ignition was obviously unsanctioned; harm resulted when more than 10,000 acres of forest were burned and substantial resources were expended containing the blaze and rehabilitating the land; and the respondent's negligent maintenance was a substantial factor in causing those harms.

3. Nuisance. Nuisance is a closely related cause of action to trespass and negligence in the field of wildfire litigation. The burden of proving a claim of nuisance is often practically identical to proving trespass in fire or negligence, so petitioners will routinely allege two or all three (*Hensley v. San Diego Gas & Elec. Co.*, 213 Cal. Rptr. 3d 803, 806 [Cal. Ct. App. 2017]) (alleging "inverse condemnation, negligence, trespass, nuisance, trespass per se," statutory violations, and intentional and negligent infliction of emotional distress); see *Perkin v. San Diego Gas & Elec. Co.*, 170 Cal. Rptr. 3d 335, 339 (Cal. Ct. App. 2014) (alleging "inverse condemnation, trespass, nuisance," and statutory violations); see *Barham v. Southern California Edison Co.*, 88 Cal. Rptr. 2d 424, 426 (Cal. Ct. App. 1999) (alleging "negligence, nuisance, and trespass"). Nuisance, like trespass, can encompass many situations, but it generally has two elements; an unreasonable or unlawful use of property, and results in material annoyance, inconvenience, discomfort, or injury to another person. The element of injury to another person can be satisfied by a showing of interference with the use of property.

4. Inverse Condemnation. A full exploration of inverse condemnation is considerably beyond the scope of this paper, but it bears a brief explanation (Heiser 2021). Put simply, inverse condemnation allows petitioners to "recover for a physical injury to private property caused by a public improvement as deliberately designed, constructed, or maintained" (Heiser 2021). While eminent domain can allow public and private utilities to convert private property for public use in exchange for fair compensation, inverse condemnation allows private property owners to recover damages from public and private utilities for harm to property on a strict liability basis. Inverse condemnation is intended to socialize the costs to private landowners associated with the provision of public goods (Heiser 2021). Every landowner benefits from the existence of an extensive power grid, but individual landowners will be unequally affected by a utility wildfire. The regime of inverse condemnation is a powerful deterrent to risky behavior; public and private utilities can face "ruinous inverse condemnation liability" when lax maintenance and oversight leads to wildfires.

Inverse condemnation regimes are established by constitutional language barring takings without compensation for "public use." The Takings Clause of the Fifth Amendment establishes a right of action for inverse condemnation against the federal government, and the Fourteenth Amendment extends that right of action against the states (Heiser, supra note 18, at 9). The Supreme Court has traditionally adopted a "broad understanding of public purpose," such that the "public use prerequisite in the federal Takings Clause is greatly diminished" (*Kelo v. City of New London*, 545 U.S. 469, 485 [2005]; Heiser, supra note 18, at 13). The federal Takings Clause is enforceable against the states, but some states have adopted their own broader takings clauses. Likewise, some state courts have developed their own more limited definitions of public use and public purpose, and some have adopted the Supreme Court's expansive view.

Publicly owned utilities are liable for the damage that their equipment causes under regimes of inverse condemnation. Petitioners can sue public utilities for fire damage resulting from the design, construction, and, most crucially, the maintenance of public improvements, like powerlines. Utility infrastructure can suffer from faulty or defective design. For example, if a utility pole is designed in a way that allows powerlines to arc off of each other, even if only under extreme conditions or to make contact with communication lines, any damage from fires that spawn will be the responsibility of the public utility. If the utility ROW is allowed to suffer from poor maintenance, such as infrequent trimming and vegetation grows, sags, or falls on powerlines, the public utility will also be responsible.

Depending on the jurisdiction, petitioners can also recover from private utilities under a theory of inverse condemnation. This is an especially salient issue in California, where utility wildfires have been frequent and serious in recent years, and the courts have equated public and private utilities for the purpose of inverse condemnation recovery. As Professor Heiser discusses at greater length in *Floods, Fires, and Inverse Condemnation*, the court in *Barham v. Southern California Edison Co.* noted that the State of California has granted private utility companies the power to "condemn any property necessary for the construction and maintenance" of electrical plants and transmission lines (*Barham v. Southern California Edison Co.*, 88 Cal. Rptr. 2d 424, 429 [Cal. Ct. App. 1999] [citing CAL. PUB. UTIL. CODE §§ 617, 217 {1976}]). The *Barham* court concluded that "generally, condemning private property for the transmission of electrical power is a public use and inverse condemnation will apply" (*Id.* at 429-30). Although inverse condemnation is not as prominent an issue in Washington, the Washington Supreme Court ruled similarly in 1927, and reaffirmed in 1998 (*Id.* at 429-30).

Inverse condemnation is a powerful tool for petitioners because it exposes utilities to the risk of proceeding in court under a standard of strict liability. There are generally three elements to a proximate cause claim; the respondent's instrumentality, as deliberately designed, constructed, or maintained, must be involved; the petitioner's property must have suffered damages; and those damages must have been proximately caused by the instrumentality (*Id.* at 429-30). A petitioner does not need to prove any actual fault on the part of the utility, and the utility cannot defeat an inverse condemnation claim by demonstrating that the particular incident in question was unforeseeable (*Id.* at 47). In the future, state legislatures may attempt to replace inverse condemnation's strict liability standard with a reasonableness standard. They will face an uphill battle; 18 state constitutions create rights of action when property is taken for public use, and 27 more state constitutions create rights of action when property is taken *or damaged*. (*Id.* at 10 n.21; Maureen E. Brady, The Damaging Clauses, 104 Va. L. Rev. 341, 344 n.6 [2018]). Kansas and Massachusetts have statutory equivalents to the Takings Clause. *Id.* Kansas and North Carolina are the only states with no constitutional provisions prohibiting takings without compensation (*Id.* at 349 n.30). Tennessee has a constitutional Takings Clause that does not grant a right of action in state court against the state government (Huffer and Murphy, Eminent Domain in Tennessee An Attorney's Guide 28, 1992, rev. 2007). Constitutional amendments would be required to change the standard in inverse condemnation cases from strict liability to reasonableness (See Heiser, supra note 18 at 54). State courts would then face enormous difficulty adapting the reasonableness standard to fit the unique challenges and public policy considerations of wildfire litigation (*Id.* at 53).

Statutory Violations

Utility operators can find themselves in violation of a seemingly limitless number of statutory provisions after sparking a wildfire. This section will provide an introduction to the two categories of statute that utilities are most likely to violate during a wildfire, relying on codes and cases from California as a representative example. The first half of this section will discuss public resource codes, the compilations of state environmental management laws, and the second half will discuss health and safety codes, the laws which exist to protect people and the human environment.

1. Public Resource Codes: California Public Resource Code § 4435. Section 4435 of California's Public Resource Code creates a misdemeanor penalty for sparking fires, and makes the occurrence of such a fire *prima facie* evidence of negligence for the purpose of other claims and charges (*United States v. Sierra Pacific Indus.*, 879 F.Supp.2d 1096, 1110 [E.D. Cal. 2012]) (stating "where a fire originates from the use of a covered device, negligence is assumed from the very fact that the fire started"). Under § 4435, the escape of any fire from "any engine, machine, … or any other device which may kindle a fire" *prima facie* evidence of negligence, and the operator of such an instrumentality is guilty of a misdemeanor when fire spreads as a result (CAL. PUB. RES. CODE § 4435). After its addition to the California Public Resource Code in 1965, the first case to interpret the meaning of "engine, machine, … or … device" was *People v. Southern Pacific Co.* in 1983 (*People v. Southern Pacific Co.*, 188 Cal. Rptr. 913, 916 [Cal. Ct. App. 1983]). The court in *Southern Pacific Co.* determined that a train could be one such device, and that the legislative intent behind § 4435 was to shift the burden of proof onto the operators of such devices to prove that they were not negligent. In 2004, the court in *U.S. v. Southern California Edison* interpreted a hydroelectric plant "which consistently produces high voltage electricity" could likewise be a "device which may kindle a fire" for § 4435 purposes (*United States v. Southern California Edison*, 300 F.Supp.2d 964, 990 [E.D. Cal. 2004]). The most recent application of § 4435 in a utility wildfire case was *U.S. v. Southern California Edison* in 2020; in that case, the plaintiff argued that § 4435 could be invoked when "a tree fell onto communication lines and power lines" (*United States v. Southern California Edison*, No. CV-19-07179 PA [SKx], 2020 WL 2542613 at *4, [C.D. Cal. Mar. 23, 2020]). Another recent case, *Montezuma Harbor, LLC v. United States*, applied § 4435 to "hot metal fragments of a catalytic converted" (*Montezuma Harbor, LLC v. United States*, No. 2:19-cv-00831-JAM-KJN, 2021 WL 2188135, at *2 [E.D. Cal. May 28, 2021]. The issue was left unsettled pending discovery, and there have been no filings in the case since April of 2020.)

2. Health and Safety Codes

i. California Health and Safety Code § 13007

Section 13007 of the California Health and Safety Code states that any "person who personally or through another willfully, *negligently*, or in violation of the law, sets fire to…" public or private property is liable to the owner for any damages caused by the fire. § 13007 does not "establish a standard of care, but merely codif[ies] the basis of fire liability," and plaintiffs "must still establish that a fire was 'negligently' set" (*Exact Prop. and Casualty Co. v. Union Pacific Railroad Co.*, No. 2:21-cv-00928 WBS JDP, 2021 WL 2711188, at *3 [E.D. Cal. Jul. 1, 2021]) (citing *People v. Southern Pacific Co.*, 188 Cal. Rptr. 913, 917 [Cal. Ct. App. 1983]). Recall, however, that California Public Resource Code § 4435 accepts the escape of fire from any of a broad series of instrumentalities as *prima facie* evidence of negligence. Courts have interpreted § 13007 to require no affirmative actions or actual knowledge on the part of the defendant. In *Exact Prop. and Casualty Co. v. Union Pacific Railroad Co.*, the court determined that knowledge of the "conditions, circumstances, or conduct which might reasonably be expected to result in the starting of a fire" would suffice to sustain a claim under § 13007 (citing *Ventura Cty. v. Southern California Edison*, 193 P.2d 512, 515 [Cal. Dist. Ct. App. 1948]). In California Public Resource Code § 4435 and California Health and Safety Code § 13007 plaintiffs have access to a powerful tool, and defendants face a daunting obstacle. (As a closing note, two utility wildfire cases involving claims under § 13007 were recently remanded from the United States District Court for the Eastern District of California back to California state court. It will be well worth observing the progress of these cases in state court. See *Burns v. Liberty Util. Co.*, No. 2:21-cv-00647-TLN-KJN, 2022 WL 36377 [E.D. Cal. Jan. 4, 2022]; see *also Franklin v. Pacificorp*, No. 2:22-cv-00465-MCE-CKD, 2022 WL 2303974 [E.D. Cal. Jun. 27, 2022]).

ii. California Health and Safety Code § 13008

Section § 13008 of the California Health and Safety Code imposes liability for damages caused by fire when the defendant "allows any fire burning upon his property to escape to the property of another, whether privately or publicly owned, without exercising due diligence to control such fire." The language "upon his property" has a straightforward application for most individuals, and even most electrical utilities when the property in question is a power plant. However, it raises significant ambiguities when the property in question is a utility ROW. These ambiguities deepen when two or more utilities are sharing poles on a ROW, land that neither actually own. *United States v. Southern California Edison* was poised to shed light on these and other ambiguities, but the plaintiff abandoned their claim under § 13008 (*United States v. Southern California Edison*, No. CV-19-07179 PA [SKx], 2020 WL 2542613 at *3, [C.D. Cal. Mar. 23, 2020]). One co-defendant argued in their Motion to Dismiss that the § 13008 should be dropped because the plaintiff never alleged that wildfire burned on the defendant's property, nor that they "allowed" the fire to escape "without exercising due diligence." *Id.* The court may have held that a utility ROW is equivalent to the defendant's property for the purposes of liability under § 13008, and that the exercise of due diligence can include conduct occurring before the incident, such as maintenance and vegetation trimming. The court may also have decided the opposite, that § 13008 applies only to the ultimate property owner, and that "allow" and "due diligence" require actual knowledge or affirmative actions. The applicability of § 13008 to utility wildfire litigation remains unclear, but several cases spawned by the Woolsey Fire are currently underway that may clarify the situation (see Plaintiff's Complaint, *Lozano v. Southern California Edison Co.*, No. 22STCV16790, 2022 WL 1640057 [Cal. Super. May 20, 2022]; see also Plaintiff's Complaint, *Magna v. Southern California Edison Co.*, No. 22STCV15606, 2022 WL 1498669 [Cal. Super. May 11, 2022]; see *also Stack v. Southern California Edison Co.*, No. 22STCV15763, 2022 WL 1523329 [May 11, 2022]).

iii. California Health and Safety Code §§ 13009-13009.1

Section 13009 of the California Health and Safety Code allows private individuals and public agencies to recover costs that they incur in the course of suppressing wildfires. Section 13009.1 allows public agencies to recover costs that they incur investigating and compiling reports on wildfires, as well as any accounting and administrative costs that they incur under § 13009. § 13009 states that "Any person…who negligently, or in violation of the law, sets a fire, allows a fire to be set, or allows a fire kindled or attended by the person to escape onto any public or private property…is liable for the fire suppression costs incurred…and for the cost of providing rescue or emergency medical services." Similarly, § 13009.1 creates liability for "(1) The cost of investigating and making any reports with respect to the fire. (2) The costs relating to accounting for the fire and collection for any funds pursuant to Section 13009." These dual sections create a powerful incentive to engage in regular maintenance and inspection, and avoid risky operating practices.

Until recently, it was unclear whether a company could be held liable under § 13009 and § 13009.1 for negligence or violations of the law committed by their employees. The court in *Presbyterian Camp & Conference Centers, Inc. v. Superior Court* determined that § 13009 and § 13009.1 "incorporate the common law theory of respondeat superior," despite not including language to the effect of "any person *who personally or through another*" (*Presbyterian Camp & Conf. Ctrs., Inc. v. Superior Court*, 501 P.3d 211, 226 [Cal. 2021]).

Government agencies can waive their right to recover under § 13009 and § 13009.1 by entering into mutual assistance agreements with other government departments. Although this issue is rarely litigated, one such case was decided in 2015. In *Department of Forestry & Fire Protection v. Lawrence Livermore National Security, LLC*, the court held that no party to a mutual assistance agreement, a voluntary agreement between government departments to provide firefighting assistance across jurisdictional boundaries, can be held liable under § 13009 and § 13009.1, even when wildfires are negligently sparked by one of the parties (*Dep't of Forestry & Fire Prot. v. Lawrence Livermore Nat'l Sec., LLC*, Cal. Rptr. 3d 1060, 1067-68 [Cal. Ct. App. 2015]). Under the Mutual Assistance Treaty at issue, CALFIRE and the Regents of the University of California, who were operating the Lawrence Livermore National Laboratory, agreed that "no party to this Agreement shall be required to pay compensation to the other party for services rendered" (*Id.* at 1063). A wildfire occurred on the defendant's property, and CALFIRE expended roughly $90,000 suppressing it (*Id.* at 1064). The plaintiff claimed that the wildfire was the result of the defendant's negligent maintenance practices, and that their negligence should void the compensation terms of the Mutual Defense Agreement. The court dismissed the plaintiff's claims under § 13009 and § 13009.1, noting that the "unconditional" language of the agreement created no exception for instances of negligence (*Id.* at 1067).

Criminal Causes of Action

Twice in recent years, Pacific Gas & Electric have found themselves as defendants in extraordinary criminal utility wildfire cases. In the 2020 *People v. Pacific Gas & Electric Co.*, PG&E plead guilty to 84 counts of involuntary manslaughter and one count of unlawfully causing a fire in violation of California Penal Code § 452 (Superior Court of CA 2020). This case stemmed from the 2018 Camp Fire, which was ignited by a nearly 100-year-old powerline, owned and operated by PG&E (Boghani 2019). Less than two years later, PG&E's equipment sparked another devastating California wildfire; in September of 2020, the Zogg Fire ignited when a grey pine collapsed on one of PG&E's powerlines. The fire would kill four people, destroy about 200 structures, and devastate about 87 square miles of land (AP 2021). In the 2021 *People v. Pacific Gas & Electric Co.*, prosecutors have leveled a wide variety of criminal charges against PG&E; this section will use the ongoing litigation as a vehicle to survey some of the criminal charges that utility operators may face more routinely going forward. The eleven felonies that PG&E has been charged with are of particular interest, but this section will also explore the ten air pollution charges that PG&E unsuccessfully demurred from.

Air Pollution

Pacific Gas & Electric has been charged with ten misdemeanors for emitting air pollution. Five of those charges are for violations of California Health and Safety Code § 41400.1(a), which penalizes the negligent emission of "an air contaminant in violation of…any rule, regulation, permit, or order of the state board or of a district pertaining to emissions regulations or limitations" (Cal. Health & Safety Code § 42400.1[a]). Each of these charges is "punishable by a fine of up to $25,000" (Cal. Health & Safety Code § 42400.1[a]). The remaining five air pollution charges are for violations of California Health and Safety Code § 42400.3(b), which penalizes the willful and intentional emission of air contaminants, or emissions done "with reckless disregard for the risk of great bodily injury…to, or death of, any person," when a risk of great bodily injury or death actually results (Cal. Health & Safety Code § 42400.3[b]). The penalty for a violation of § 42400.3(b) is a fine of up to $125,000 (CAL. Health and Safety Code § 42400.3[b]).

Pacific Gas & Electric was charged with five violations of § 41400.1(a) for emitting "wildfire smoke and related particulate matter and ash" between the September 27 and October 1 (Criminal Felony, *People v. Pacific Gas & Elec. Co.*, No. 21-06622, at 6-7 [Cal. Super. Sep. 24, 2021]). Pacific Gas & Electric was charged with five violations of § 41400.3(b) for emitting air contaminants over the same time period, with reckless disregard for risk of serious bodily injury or death. Pacific Gas & Electric demurred to these ten claims in October of 2021 (Rittiman 2021). In May of 2022, PG&E's demurrer was denied, and in June PG&E plead not guilty to all charges (Gardner 2022).

Involuntary Manslaughter

Pacific Gas and Electric was charged with four counts of involuntary manslaughter over the deaths attributed to the Zogg Fire (Criminal Felony, *People v. Pacific Gas & Elec. Co.*, No. 21-06622, at 1-2 [Cal. Super. Sep. 24, 2021]). Under § 192 of the California Penal Code, involuntary manslaughter is the "unlawful killing of a human being without malice…in the commission of an unlawful act, not amounting to a felony; or in the commission of a lawful act which might produce death, in an unlawful manner, or without due care and circumspection." In the case of an individual (rather than corporate) defendant, involuntary manslaughter is punishable by imprisonment for 2–4 years (California Penal Code § 193.) When PG&E pled guilty to 84 counts of manslaughter in the Camp Fire case, they agreed to pay a $3,500,000 fine and $500,000 to reimburse Butte County's investigation (Penn and Evans 2020). § 193, which established the punishments for violations of § 192, does not enumerate a monetary penalty for involuntary manslaughter (Cal. Pen. Code § 193). If PG&E is found guilty of these four counts of manslaughter, there is no good way to know ahead of time what kind of penalty they might incur.

Arson

Pacific Gas & Electric was charged with seven counts of arson, in the form of violations of California Penal Code § 452(a)-(d). Pacific Gas & Electric incurred one count of violating § 452(a), which prohibits "unlawfully causing a fire that causes great bodily injury and is punishable by two, four, or six years in state prison (Cal. Pen. Code § 452[a]). Pacific Gas & Electric incurred one count of violating § 452(b), which prohibits "unlawfully causing a fire that causes an inhabited structure or inhabited property to burn" (Cal. Pen. Code § 452[a]). A felony arson conviction under § 452(b) is punishable by 2–4 years in state prison. Four of PG&E's eleven felony charges stem from counts of § 452(c), which prohibits "unlawfully causing a fire of a structure or forest land" and is punishable by sixteen months, or two or four years, in state prison (Cal. Pen. Code § 452[c]). Pacific Gas & Electric's final felony charge was for an alleged violation of § 452(d), which prohibits "unlawfully causing a fire of property" (Cal, Pen. Code § 452[d]). Violations of § 452(d) are normally a misdemeanor (Ca. Pen. Code § 452[d]). The prosecutors in *People v. Pacific Gas & Electric Co.* charged PG&E with committing the seven counts of arson during a state of emergency. Under § 454, the penalty for arson is raised to five, seven, or nine years for violations of § 452(a)-(c), and three, five, or seven years for violations of § 452(d). However, the amount of monetary penalty that PG&E could potentially incur for these arson charges remains unclear at this time.

The risk of a felony arson conviction that is tied to the death of a person should be extremely concerning to officers, directors, and managers involved in utility operations. The reason is that it is not hard to conceive of a zealous prosecutor making the leap from the felony murder by a corporation (which of course cannot go to jail) to a conspiracy involving the corporation and its officers, directors, and managers. In such case, *all* co-conspirators could be held guilty of the felony murder, and unlike the corporate party to the conspiracy, the officers, directors, and managers are all people, and people *can* be sent to jail.

CONCLUSION AND CLOSING THOUGHTS

The foregoing paper outlines many of the basics of wildfire litigation. But, as can be seen, the cases will all turn on their individual facts and the way that the law is interpreted in the jurisdiction where the wildfire occurred. The actual conduct of the litigation itself can vary, and is more convoluted and complicated. Moreover, wildfire litigation cases can last years, and this leads to complications arising from the passage of time—witnesses' memories can fade or be influenced by later events, and some witnesses may leave the jurisdiction or pass away. This makes the attorney's task much more difficult and causes the outcome of motions and the litigation itself to become rather uncertain.

As has been seen in the context of the California wildfire litigations described above, the best way to de-risk wildfire litigation is to avoid it in the first place. It is patently unreasonable to place a utility at risk of insolvency. One of the best ways to avoid utility-ignited wildfires is to address the problem caused by tree and powerline conflicts in the first place.

When trees are allowed to grow into a powerline, they create a hazardous situation for utility arborists who need to trim them back to a safe distance (the National Electric Safety Code, at NESC 218, requires that vegetation be pruned back ten feet from energized conductors to allow workers to operate safely near powerlines). In a worst-case scenario, contact between trees and powerlines can cause the trees to ignite, potentially starting a wildfire. Any tree that would, at maturity, pose a risk of contact with a powerline is a potentially problematic tree, and there are both short- and long-term options for addressing problem trees. In the short term, directional pruning can "remove branches growing towards conductors in favor of those growing away" (Elmendorf et al. 2007). Directional pruning, together with the removal of problem trees that cannot effectively be sufficiently pruned, can temporarily prevent contact between a problem tree and the powerline it threatens to contact, but it comes at the cost of requiring further pruning activities without end. Even the removal of problem trees will only temporarily solve the problem because other trees—whether naturally growing or deliberately planted—could later mature into problem trees that then require pruning or removal. Such activities can at best be viewed as an effort to maintain the *status quo* without any real hope of resolving (or even meaningfully getting ahead of) the challenge.

Relandscaping along right tree, right place principles, on the other hand, offers a longer-term solution. The risk of wildfires around electrical transmission lines can be almost entirely eliminated by deliberately planting only those trees which, at maturity, will not pose a threat of contact. No directional pruning or tree removals will be necessary if the right trees are in the right places, and there will be no risk of a tree strike, if the distance between a tree and a distribution line is greater than the height of the tree (Right Tree, Right Place [PG&E]). Deliberate planting of such shorter vegetation should be the preferred solution (leaving a bare space is an invitation for something to grow in that space). Nature abhors a vacuum, and empty space will ultimately be filled.

Relandscaping is expensive, true. But a wildfire that results in widespread death and destruction is more so and risks the viability of the utility itself. We may be at an opportune time to relandscape now. Our utility infrastructure needs to be improved in order to carry the loads that will be required as wide-scale electrification continues to replace fossil fuel-based energy. This infrastructure improvement will necessarily result in the need for construction and modification activities, and these activities will inevitably be placed in the natural world. It would be best to ensure right tree, right place vegetation choices are made now, so as to avoid future wildfire risk.

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McGranahan and Wonkka, supra note 23. (Note at 11 There are three broad fuel bed layers: the ground, the surface, and the canopy. *Id.* A ground fire will burn material below the soil, such as peat, a surface fire will burn plant materials rooted in the ground, like grass and shrubs, and a canopy fire will burn the canopies of trees. *Id.* A surface fire can become a canopy fire by traveling into the canopy along "ladder fuels," or vertically arranged plant materials. *Id.* Once a canopy fire has begun, the distance between trees will determine whether only a single tree is "torch[ed]," or many trees are burned in a "running crown fire.") pp. 8–12.

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Charles Lally is a 2023 Juris Doctor candidate at Tulane University Law School. A graduate of the University of Illinois with a Bachelor of Arts in English (with Distinction) and a minor in informatics, Lally has been extremely active in environmental law programs at Tulane, including serving as the Business Editor of the Tulane Environmental Law Journal and as Conference Organizer for the nation's longest-running student-run legal education program, the Tulane Energy & Environmental Law Summit, where he successfully produced a legal education program in March of 2022 focused on environmental litigation. Lally is passionate about protecting people and the environment from wildfire risk, and this is the first of several papers he will be publishing on the topic. He successfully completed the Utility Vegetation Management Initiative program in May 2022.

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Lawrence J. Kahn is an attorney, entrepreneur, and educator, and has advised in the environmental space for over 25 years. He earned a Bachelor of Arts from Columbia University in 1992 and a Juris Doctor from Tulane Law School in 1995. He is a Distinguished Research Fellow and Director of the Tulane Law School Utility Vegetation Management Initiative, which he founded in 2020 to provide training to law students in utility vegetation management (UVM), to conduct academically neutral and independent scholarly research in UVM and to present and publish those research findings; to serve as an unbiased advisor on law, policy and practice for the benefit of government, industry, NGOs, attorneys, public advocates and the public at large; and to assist in bettering UVM practices in order to save lives and property while improving harmony between the built and natural world.

The views expressed in this paper are those of Mr. Brannan and Mr. Kahn alone, and do not necessarily reflect the official views of Tulane University or of the Utility Vegetation Management Initiative.

13th International Symposium

Environmental Concerns in Rights-of-Way Management

PART XII

Wildlife / Wetlands / Pollinators

Assessing the Effects of Integrated Vegetation Management on Botanical and Pollinator Communities in ROW Habitats

Adam Baker

Keywords: Evaluation, Habitat, Monarch CCAA, Monitoring, Pollinators, Restoration, Rights-of-Way.

There is growing evidence that utility corridors are suitable habitat for species of conservation concern. Management of rights-of-ways (ROW) to support biodiversity, with an emphasis on pollinators, is being encouraged by various wildlife programs. One such program, the Monarch Candidate Conservation Agreement with Assurances (Monarch CCAA), invites utility companies to participate in conservation and monitoring of their managed lands to promote the health of the monarch butterfly (*Danaus plexippus*), an imperiled native insect of conservation concern. In return, lands enrolled in this program are exempt from future regulatory restrictions or limitations surrounding monarch butterfly population status. In this paper we will discuss our methods to facilitate the monitoring and compliance needs of participating utilities. This new protocol is designed to capture changes in biodiversity over time in response to integrated vegetation management (IVM) practices using keystone and indicator species. In this case study, we recorded habitat composition and quality, floral resources, number of milkweed ramets, invasive species presence, and pollinating insect diversity and abundance. This non-destructive sampling method ensures the safety of threatened species and provides insight for future management decisions. Methods used are quantitative; repeatable; compatible with Monarch CCAA and ROW as Pollinator Habitat Scorecard Tier 2; and informed by the Integrated Monarch Monitoring Program (IMMP).

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Energized rights-of-way (ROW) have long been managed to simply meet compliance needs but are now being viewed as potential habitat for insects, birds, plants, and mammals. The linear nature of ROW habitats lends to their ability to act as natural flyways. Such corridors may ease the difficulty of arduous migration routes that monarch butterflies, birds, and other animals take each year. Nectar, pollen, and seed sources present during the migration or flight periods can help fuel weary travelers along the way. Rights-of-way habitats inherently create connectivity to surrounding landscapes and can help increase biodiversity as they intersect with woodland habitats (Smallidge and Leopold 1997; Haddad 1999; Haddad et al. 2003; Komonen et. al 2013). Integrated vegetation management (IVM) can promote the growth of forbs, ephemerals, and other insect-friendly plants that act as hosts (Haddad et al. 2003). Selectively managing for native plants, which share many evolutionary traits that complement the traits of native insects, will increase insect abundance and, in turn, provide food for higher trophic levels (Ehrlich and Raven 1964; Tallamy 2009). It is important to manage or eradicate invasive, non-native species as they can suppress biodiversity by outcompeting natives. Although some non-natives may benefit pollinators by providing nectar/pollen in the short term, they eventually smother out biodiversity and often don't act as hosts for desirable insect larvae.

Conservation is needed now more than ever as insects and other organisms are experiencing mass extinctions (Wagner et al. 2020; Wagner et al. 2021). Specialist insects, which need a specific host (whether a plant or another insect) are at the greatest risk (Wagner et al. 2020; Wagner et al. 2021). One such insect, the monarch butterfly (*Danaus plexippus*), requires milkweed (*Asclepias* spp.) to complete its life cycle. This charismatic insect has garnered lots of attention because of its spectacular long-distance annual migration, which has led to millions of dollars being invested in its conservation by both public and private entities (Thogmartin et al. 2017). The loss of habitat, pesticide use, and the cultivation of glyphosate resistant monocropping systems has led to a population decline of > 90% (Brower et al. 2012; Agrawal 2019) and the recent listing of endangered status by the IUCN Red List (IUCN 2022). Similarly, bees and other pollinators are also facing decline due to habitat loss, climate change, and pesticide use (Potts et al. 2010; Mach and Potter 2017).

To combat the decline of species important to ecosystem function, a call to action from all land-use sectors to participate in conservation is necessary (Thogmartin et al. 2017). Programs such as the Monarch Conservation Candidate Agreement with Assurances (CCAA), Monarch Waystation Program, Million Pollinator Garden Challenge, and many others encourage the establishment of pollinator-centric habitat to support both the adult and larval insects. Collaboration across varying land types creates connectivity across the landscape. The Monarch CCAA, in particular, focuses on ROW habitats that are managed to support monarch butterflies (National Monarch CCAA 2022). Lands enrolled in this program are exempt from future regulatory restrictions or limitations surrounding monarch butterfly population status (National Monarch CCAA 2022).

In this paper we will discuss methods for monitoring insect pollinators, vegetation, and habitat composition in ROW to meet the compliance needs of environmental stewardship initiatives and reporting of participating entities. Continued monitoring will provide a glimpse at changes in ecosystem function under varying levels of management and reconciliation efforts.

METHODS

Sites

Ten energized ROW in the Mid-Atlantic with varying levels of IVM were monitored for biodiversity in 2021. Four transects (46 m x 3 m) were established at each site (for the purposes of this methods paper we will focus on one set of three ROW in Pennsylvania). Transects were set systematically (approximately equally spaced) along the length of the ROW management unit and randomly alternated between left/right side of the ROW, centered halfway between the ROW midpoint and edge (National Monarch CCAA 2022). For each transect, GPS coordinates were recorded. Surveys were conducted three times in 2021: late spring (May 24–June 14), mid-summer (July 11–July 31), and late summer (August 24–September 14). Counts were taken on clear, sunny days between 10 a.m.–6 p.m. with temperatures between 18–32°C and wind less than 24 kph.

Insect Surveys

Lepidoptera

On all three survey dates, butterflies (Lepidoptera) were monitored using the Pollard Walk method (Pollard 1977). The Pollard Walk utilizes an imaginary cube extending 5 m to each side, 5 m to the front, and 5 m above. The cube moves with you as you walk slowly along the distance of the transect. To avoid disturbing pollinators inside the transect, we walked outside the transect along the inner edge, capturing any butterflies inside or passing through the transect. Each walk took 2–3 minutes to complete. Butterflies that intercepted the Pollard cube during the survey were identified to family group (Hesperiidae, Lycaenidae, Nymphalidae, Papillionidae, Pieridae). Monarchs were recorded to species level.

Bees and Other Pollinators

On all three sampling dates, we surveyed bees (Hymenoptera) and other pollinating insects by walking slowly through the transect in a zig-zag pattern. Each survey walk took approximately 7–15 minutes, depending on the density of plants that were blooming. We recorded the number of large Apid bees including honey bees (*Apis mellifera*), bumble bees (*Bombus* spp.), carpenter bees (*Xylocopa* spp.) in the transect. We also recorded the number of beetles (Coleoptera), flies (Diptera), and moths (Lepidoptera) observed visiting flowers within the transect.

Vegetation

At each visit we walked the transect to count and record: (1) total number of plants in bloom, and (2) number of species in bloom.

Habitat composition/Pollinator Scorecard Tier 2 at each visit we recorded: (1) percent cover of potentially blooming plants (plants that will bloom at some point during the year); (2) total number of milkweed stems; (3) percent cover of noxious weeds/invasive plants; and (4) percent cover of trees (taller than 25 ft), shrubs (woody plant shorter than 25 ft), vines, forbs (herbaceous flowering plants), grasses, bare soil, and wetland in the ROW.

RESULTS

Insect Surveys

Butterflies, bees, and other pollinators were observed throughout the season at each of the three sites (Figure 1). Skipper (Hersperiidae) butterflies were the most abundant at site 1, whereas sulfurs (Pieridae) were the most abundant at sites 2 and 3. Honey bees (*A. mellifera*) and carpenter bees (*Xylocopa* spp.) were the most abundant bees observed at all three sites and no bumble bees (*Bombus* spp.) were observed at site 2. Flies (Diptera) and

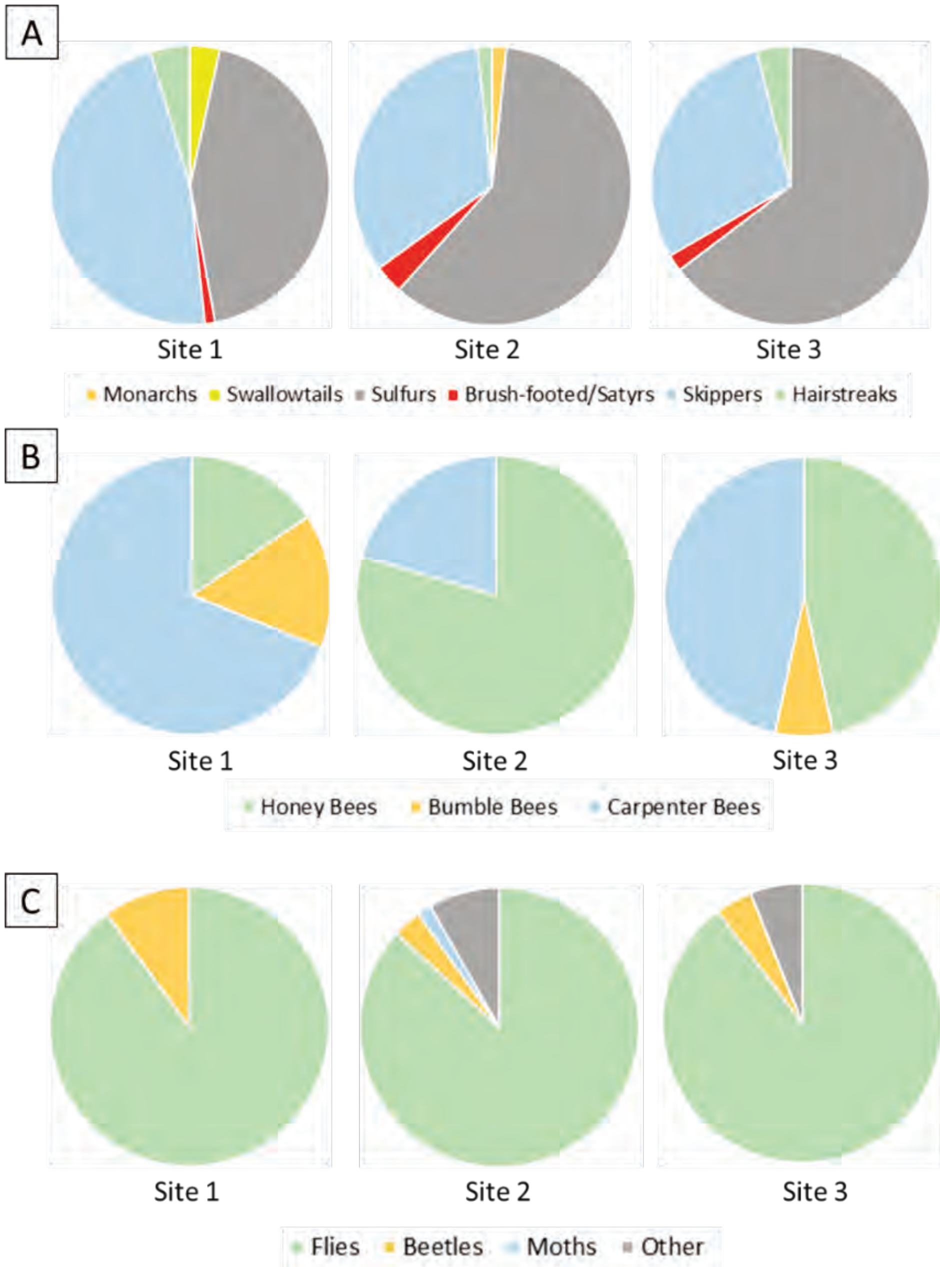

Figure 1. Proportions of pollinating insects observed in ROW habitats in 2021. (A) Lepidoptera (Monarch butterfly/*D. plexippus*, Swallowtails/Papillionidae, Sulfur/Pieridae, Brush-footed/Nymphalidae, Skipper/Hesperiidae, and Hairstreaks/Lycaenidae). (B) Hymenoptera (Honey bees/*A. mellifrea*, Bumble bees/*Bombus* spp., and Carpenter bees/*Xylocopa* spp.). (C) Other pollinating insects observed foraging on flowers (Flies/Diptera, Beetles/Coleoptera, Moths/Lepidoptera, and other pollinating insects).

beetles (Coleoptera) were the most commonly observed at all three sites, whereas pollinating moths were only observed at site 2.

Monarchs and Milkweeds

No milkweed was observed inside the transects at all three sites (Figure 2), however, 21 milkweed stems were recorded in observations from the Pollinator Scorecard Tier 2 adjacent to site 1, transect 4 (Figure 2). Monarchs were observed at all three sites during the Pollard walk or the scorecard observations.

Nectar Sources

Flowering plants were observed during all three sampling dates at every site. The greatest abundance of flowers were observed during the summer sampling date (July 11–July 31). All sites had similar floral resources throughout the year (Figure 3).

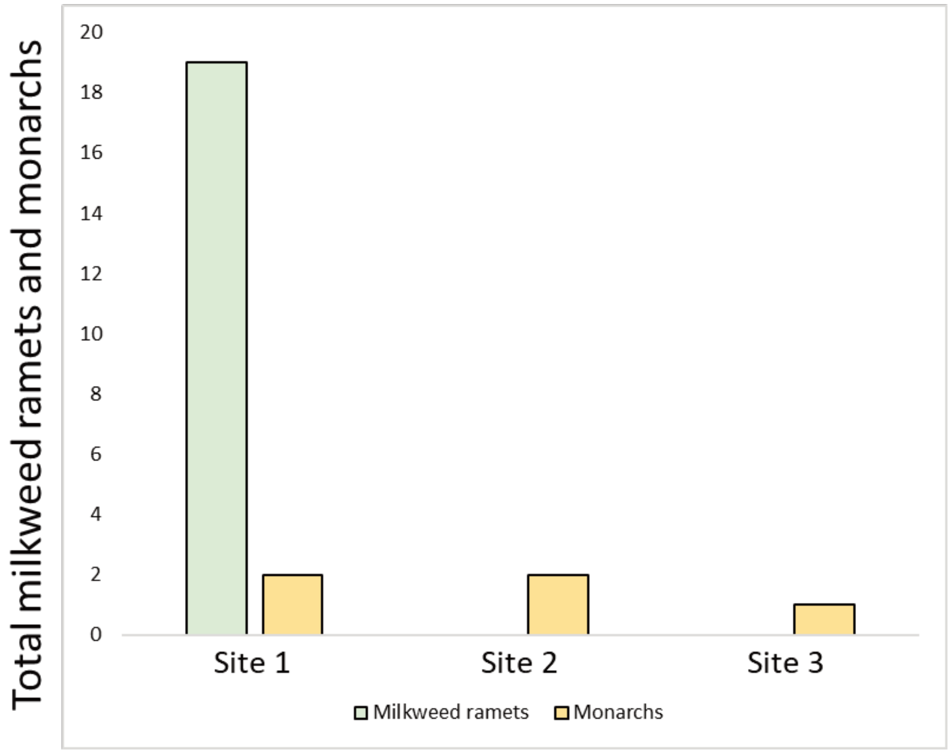

Figure 2. Total milkweed stems and monarch butterflies observed at all three sites in 2021. Data from Pollard Walk, vegetation survey, and Pollinator Scorecard Tier 2 were combined.

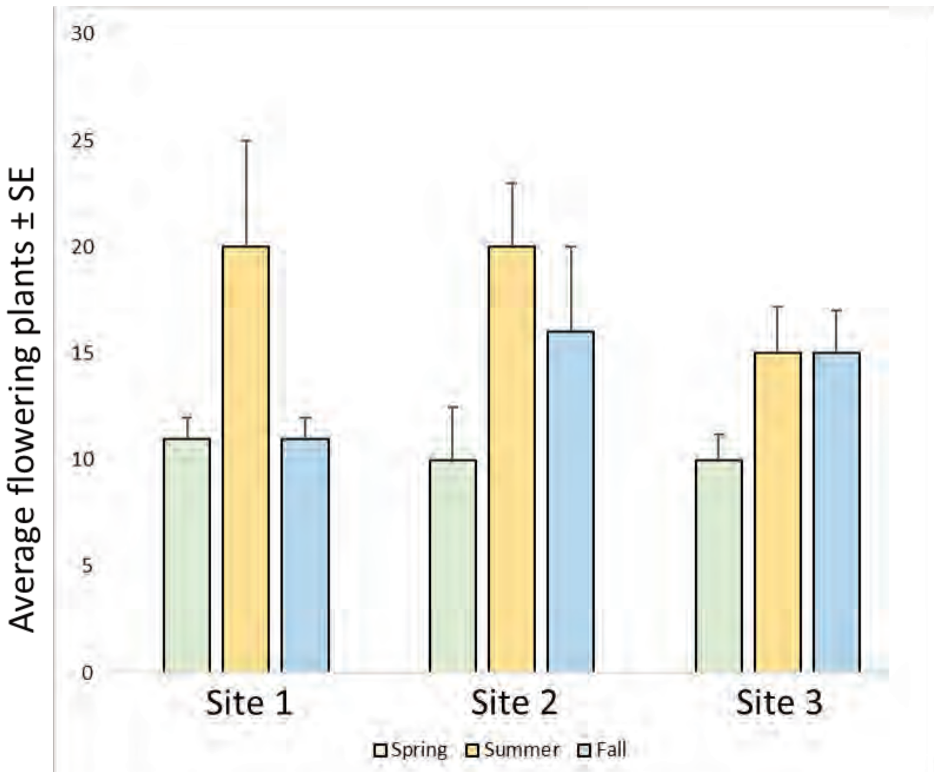

Figure 3. Average flowering plants in bloom for each site by sampling date. Data are represented as mean ± SE.

Habitat Composition

Habitat within site one was dominated by wetlands and shrubs (Figure 4). Site 2 had a good mixture of habitat types, whereas site 3 was dominated by forbs. All sites had a unique composition of habitat types.

Pollinator Scorecard Tier 2

Habitat quality ranged from moderate to improvement recommended for site 1, moderate to basic for site 2, and improvement recommended for site 3 (Figure 5). Habitat quality ratings were taken once during the season in 2021.

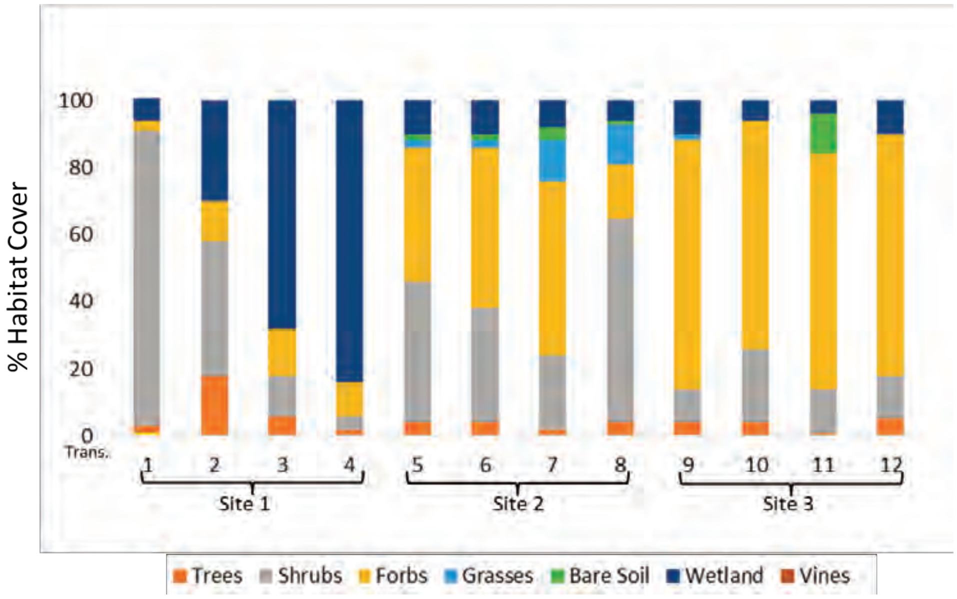

Figure 4. Proportion of habitat types at each of the four transects for all three sites in 2021

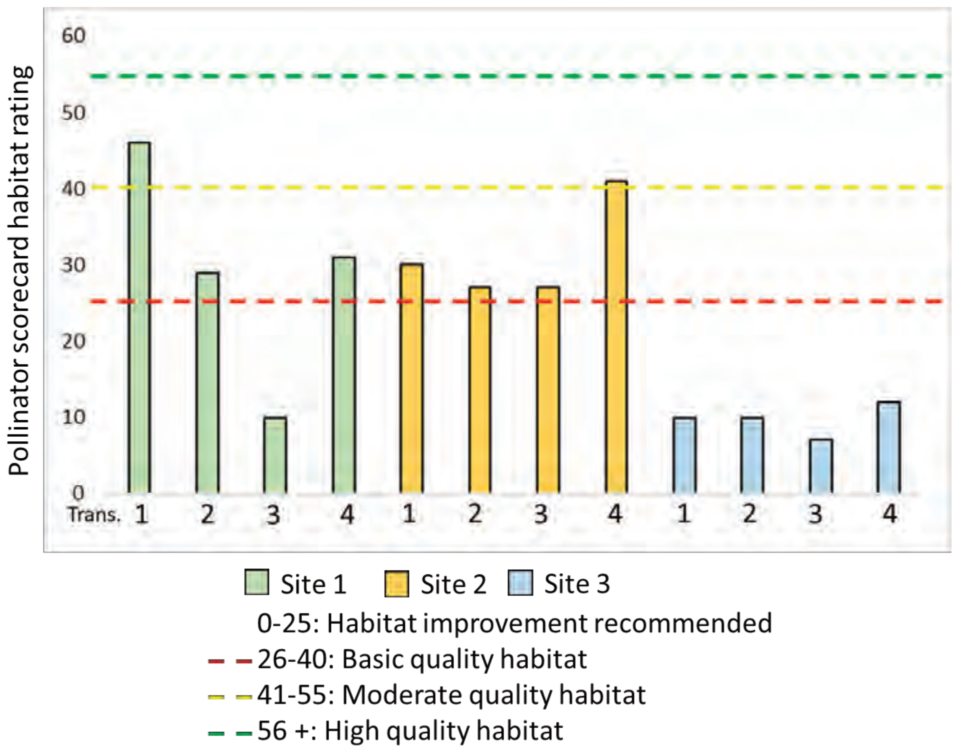

Figure 5. Pollinator Scorecard Tier 2 ratings for each transect at all three sites in 2021. Scale (red: basic quality habitat, yellow: moderate quality habitat, and green: high quality habitat) refer to points awarded by the scorecard for various landscape features.

DISCUSSION

Insects such as the iconic monarch butterfly are declining (Brower et al. 2012; Monarch Watch 2022). To combat this decline, public and private entities are participating in the establishment and monitoring of habitat for monarchs, bees, and other pollinators. In this paper we discussed nondestructive sampling methods to monitor ROW habitats to meet the compliance and reporting needs of the Monarch CCAA, IMMP, and others. Methods can be shifted to effectively meet other reporting or monitoring requirements. We monitored ROW habitats for butterfly, bee, and other pollinator abundance three times a year. In addition, we surveyed vegetation including invasive species, monarch butterfly host plants, floral resources, and habitat composition. These methods are designed to capture changes in biodiversity over time.

Butterflies, bees, and other pollinators were observed at all three sites. To enhance the resolution of future data, we will add an “other bees” category to the survey, which includes Andrenidae, Colletidae, Halictidae, and Megachilidae bees. Milkweed was observed at one of the three sites, but relatively few monarchs were observed in 2021. Longer sampling durations, more counts per season, and surveying for immature monarch larvae/eggs could provide insight on host use in ROW. As required by the Monarch CCAA (National Monarch CCAA 2022), Pollinator Scorecard data were recorded once, during the second sampling window in 2021 (July 11–July 31). Next year we will record scorecard data on all three sampling dates to provide a more accurate view of nectar and pollen resources available throughout the season. Some areas that were surveyed consisted of > 50% wetlands (Figure 4), which made their respective scores low (Figure 5).

The potential for conservation habitat on ROW is undeniable, but there are some interactions which could pose risk to wildlife. Management practices on ROW may expose pollinators and other animals to pesticides that can cause lethal and sublethal effects (Larson et al. 2013; Farina et al. 2019). Accuracy of equipment, application method, product selection, and frequency are all factors may that contribute to risk of exposure. The disturbance created and maintained in ROW creates openings of opportunistic invasive species to establish and spread into more natural areas. Those invasives are often controlled with chemical, mechanical, and cultural practices (Money 2000; Nowak and Ballard 2005). Rights-of-way near urban areas may concentrate movement of animals and increase risk of disease transmission and ecological traps (Baker and Potter 2020).

CONCLUSIONS

Although some risk is associated with establishment of habitat on ROW, the benefits far outweigh the risk. There is an opportunity to establish native species and promote biodiversity (Tallamy 2009). Proactive conservation habitat management will increase the value and abundance of floral and host resources that pollinators need to compete their life cycle. Seed mixes designed to provide season-long resources and that are compatible with native soils will provide the most benefit. Documenting biodiversity is a good first step before habitat remediation is performed. Participation in programs such as the Monarch CCAA demonstrates a commitment to preserve habitat for monarchs and other pollinators, and also provides protections for commercial entities. This 2021 season provides baseline data to assess changes in biodiversity over time, tracks successes, and informs future management decision-making.

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Biological Monitoring with Environmental DNA: Advancements, Limitations, and Moving Towards Regulatory Acceptance

Nathaniel Marshall, Jake Riley, Gabe Pelletier, and Mary Murdoch

Keywords: Bats, Biological Surveys, Environmental DNA, Freshwater Mussels, Invasive, Mitigation, Pollinators, Transportation.

Infrastructure projects routinely include biological monitoring surveys for the assessment of rare, keystone, or invasive species to support permitting efforts. Characterizing biodiversity typically requires time-intensive surveys to physically capture organisms of interest, with field crews trained in morphological identification. However, recent genetic technical advancements through the analysis of environmental DNA (eDNA—genetic material released from an organism) has become a promising tool for biomonitoring purposes. This method provides detection of organisms without the need to capture or even see them within the environment, often exhibiting increased sensitivity compared to conventional methodology. Although most progress has occurred for aquatic applications, advancements are focusing on terrestrial environments, including the collection of eDNA from air. While the breadth of eDNA research is promising, current uncertainties and drawbacks have impeded widespread regulatory acceptance of eDNA-based evidence to support permitting and project approvals. We discuss recent advancements for eDNA applications across environments and the path toward incorporating eDNA tools into linear infrastructure projects that require regulatory review. We will provide Stantec case studies and real-world examples for implementing eDNA methodology for biomonitoring surveys, and explore the development of guidelines/standards for eDNA applications to meet environmental mandates by federal and state government agencies.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Many rights-of-way (ROW) projects involve biological monitoring and surveys to support conservation and/or permitting efforts. These traditional biological surveys typically rely on observations through capture methods and morphological identification. However, many terrestrial and aquatic species are elusive, found in low density, or display morphologically cryptic features, all of which result in difficulties in successful detection. Major advancements over the past decade through the analysis of environmental DNA (eDNA—genetic material released from urine, waste, mucus, or sloughed cells) have considerably improved surveys for a wide range of taxa (Beng and Corlett 2020). The analysis of eDNA has quickly become a powerful tool for improving detection of rare and/or invasive species in freshwater systems (Rojahn et al. 2021).

The applications and implementation of eDNA methodology to address ecological and conservation issues is exponentially growing (Beng and Corlett 2020), with new sampling techniques allowing biologists to gather biodiversity measures from conventional sampling media, such as water (Marshall et al. 2022a), sediment (DiBattista et al. 2019), and soil (Marquina et al. 2019). Additionally, innovative sampling methodologies have been developed to obtain eDNA from unconventional medias, such as air (Clare et al. 2022), salt licks (Ishige et al. 2017), blood meal (Fahmy et al. 2020), snow tracks (Franklin et al. 2019), spiderwebs (Gregorič et al. 2022), and rainfall (Macher et al. 2022). These sampling strategies have proven useful across terrestrial (Leempoel et al. 2020), subterranean (Saccò et al. 2022), marine (Sanchez et al. 2022), estuarine (Hallam et al. 2021), and freshwater systems (Marshall et al. 2022a).

Compared to traditional sampling, eDNA surveys have been found to be more sensitive for detection of species at low densities (Deiner et al. 2021) and are considered less prone to morphological identification biases for species detection at any life stage (Preißler et al. 2019). Because eDNA surveying entails the collection of a mixture of genomic material from many organisms located at or near the site of sampling, this can enable simultaneous biodiversity assessments for a wide range of organisms from a single sample (Compson et al. 2020).

In addition, eDNA surveys tend to be quicker, with lower labor effort, and provide a non-destructive and noninvasive survey tool (Antognazza et al. 2019). Environmental DNA has been used as a means for early detection of biological invasions and for establishing highest probability of eradication success by detecting populations when they are at low densities (Lin et al. 2019). Typically, eDNA is considered a lower cost survey tool compared to traditional methods (Biggs et al. 2015; Qu and Stewart 2019), however cost-effectiveness of eDNA will depend on the overall project size, the sampling region, and the target taxa (Smart et al. 2016).

However, some uncertainties still need to be explored to push eDNA methodology forward. For example, detection of eDNA is largely dependent on both biological and environmental factors, and both are critical components of a proper sampling design. For example, the probability of successfully collecting DNA from the environment is related to the life history (Takeuchi et al. 2019), species behavior (Dunn et al. 2017), and population density of the target species (Baldigo et al. 2017). Thus, an eDNA sampling strategy that targets an optimal sampling season is likely to differ across taxonomic groups and between systems. Additionally, detection of eDNA can be affected by environmental conditions, such as the presence of environmental inhibitors (Lance et al. 2020), distance from source (Goldberg et al. 2016), recent rainfall (Akre et al. 2019), or presence of turbidity and sediment (Barnes et al. 2021). Currently, eDNA sampling is not well suited for addressing population status, such as sex ratios, organism size, or organism/population health (Goldberg et al. 2016), although applications for the collection of eRNA may provide better assessment of this information (Marshall et al. 2021). For some taxa, eDNA has been found to be a weak predictor of abundance or biomass of target taxa (Lamb et al. 2019), however recent work has suggested comparable measures for relative abundance estimates to that of traditional methods may be possible when factoring for allometric scaling (Yates et al. 2022).

Once eDNA samples have been collected, laboratory methodologies can use either a “targeted” species-specific approach or a “broad” community-based approach. Targeted species-specific analysis typically uses quantitative (q)PCR, or more recently digital-droplet (dd)PCR, to detect and quantify a specific DNA fragment for a species of interest. Community-based DNA metabarcoding approaches implement high-throughput sequencing (HTS) technologies (e.g., illumina MiSeq and HiSeq or Oxford Nanopore sequencers), which are capable of simultaneously identifying multiple taxa within a single sample (Compson et al. 2020). Environmental DNA metabarcoding surveys can be implemented for broad taxonomic groups (e.g., as eukaryotes [Stoeck et al. 2010] or vertebrates [Riaz et al. 2011]), or targeted specific groups (e.g., as diatoms [Vasselon et al. 2017], macroinvertebrates [Marshall and Stepien 2020], or fishes [Miya et al.

2015]), providing rapid assessments of biodiversity. Metabarcoding approaches can provide advantages over qPCR/ddPCR by broadly examining biodiversity patterns and allowing the detection of species without the a priori knowledge to test for them (Deiner et al. 2017).

Implementation by Agencies

The first examples for establishing standards for eDNA include a priority conservation species in the United Kingdom, Great Crested Newt (*Triturus cristatus*) (Biggs et al. 2015), and the highly invasive Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*) in the U.S. (Amberg et al. 2015). Since then, standards and guidelines have been developed and proposed for steps involved in eDNA collection (CSA 2021), and with qPCR assay development/validation (Thalinger et al. 2021). Within the U.S., eDNA has been proposed and/or implemented as a survey methodology for detection of aquatic invasive species (see review in Morisette et al. 2021). Environmental DNA applications are becoming a priority program across agencies, with the development of eDNA Atlas within the U.S. Department of Agriculture Forest Service (*www.fs.usda.gov/rmrs/projects/aquatic-ednatlas-project*), the 'Omics Strategy and Implementation Plan within National Oceanic and Atmospheric Administration (*sciencecouncil.noaa.gov/NOAA-Science-Technology-Focus-Areas/NOAA-Omics*), eDNA workshops developed by U.S. Fish and Wildlife Service, and the interagency eDNA Working Group (U.S. Geological Survey), just to name a few. For the future success of eDNA programs implemented for ROW-based projects, getting agency support and understanding of applications and potential limitations will be critical.

FRAMEWORK

The use of eDNA provides a fast and cost-effective survey method for complementary biological data that has the potential to improve management of linear projects. We detail four recent applications in which Stantec has implemented eDNA surveys for biological monitoring and discuss the benefits of eDNA applications for future ROW biological/ecological management. These projects span across a range of habitat and target taxa, which includes the detection of aquatic rare and threatened species, aquatic invasive species, terrestrial vertebrates, and the monitoring of pollinator diversity. We discuss these innovative sampling strategies within both terrestrial and aquatic habitats. These eDNA field studies include the use of both qPCR and metabarcoding approaches, and we evaluate eDNA performance with direct comparisons to traditional surveys. Finally, we demonstrate how the use of occupancy modeling and statistical analyses allow practitioners to evaluate probabilities of detection for target taxa, and thereby can elevate eDNA applications to the standards and expectations of traditional methods.

ENVIRONMENTAL DNA APPLICATIONS FOR RIGHT-OF-WAY MANAGEMENT

Aquatic Rare/Threatened/Endangered Species: Evaluating Community-Level Assessments

The greatest diversity of freshwater unionid mussels is found in North America, with ~300 of the 840 global species occurring in the U.S. (Williams et al. 2017). However, of those 300 species, >70% are considered endangered, threatened, or species of concern (Williams et al. 2017). Thus, monitoring and management of mussels is considered a high conservation priority, and eDNA has been demonstrated as a beneficial survey tool for this group (Marshall et al. 2022a).

In 2020, the Six Mile Dam located on the Walhonding River (an Ohio River tributary) in Coshocton County near Warsaw, Ohio, was scheduled for demolition due to structural defects causing risk for failure. The Walhonding River basin was known for extant populations of three federally listed freshwater mussels (*Epioblasma obliquata*, *Plethobasus cyphyus*, and *Theliderma cylindrica*), and thus a mussel relocation was completed within the impacted sections upstream of this dam prior to its demolition. At the same locations of the mussel rescue and relocation, Stantec conducted eDNA sampling to evaluate the effectiveness of the eDNA methodology for detecting a diverse mussel community, which included the presence of federally listed species (Marshall et al. 2022a).

Prior to the demolition of the dam, water samples upstream of the Six Mile Dam were collected for eDNA metabarcoding analysis. In total, 66 water samples were collected from 22 sampling sites across a 1.5 km reach of the river. At each site, triplicate 500 mL water samples were taken from ~10 cm above the substrate and filtered using a 47-mm diameter glass microfiber filter GF/C (nominal pore size 1.2 μm). The collected eDNA was analyzed using a metabarcoding assay capable of detecting all freshwater unionid mussels (Marshall et al. 2022a). At the same 22 sites, rescue surveys were completed using an opportunistic strategy by searching within areas that became dewatered and resulted in exposed river bottom following the dam demolition.

The mussel rescue survey resulted in 363 search hours and found >12,000 mussels across 24 species (Table 1). The eDNA survey detected the presence of 28 species, which included 22 of the 24 (92%) species found in the rescue survey (Table 1). Both survey methods detected the presence of two federally listed species from multiple sampling sites upstream of the dam (*Plethobasus cyphyus* and *Theliderma cylindrica*). The two species that were not detected with eDNA metabarcoding (*Ptychobranchus fasciolaris* and *Quadrula quadrula*) were the rarest species in the region, each found as only a single individual from the rescue survey (Table 1). Environmental DNA, on the other hand, detected four species not found in the rescue survey (*Alasmidonta viridis*, *Lampsilis ovata*, *Potamilus alatus*, and *Truncilla donaciformis*). Additionally, eDNA revealed hidden cryptic diversity within the genus *Pyganodon*, which was not able to be discerned with morphological characteristics.

To further evaluate the capabilities of eDNA sampling for freshwater mussels, a logistic regression analysis was conducted comparing detection probability comparted to mussel abundance at each of the 22 sites. Through this analysis, it was determined that eDNA displayed a 95% probability of detection when mussel density was >10 individuals per site (site size was ~150 m x ~30 m) (Marshall et al. 2022a). This suggests high sensitivity for mussel detection using eDNA metabarcoding within the Walhonding River. Additionally, by comparing species richness curves between eDNA

Table 1. Freshwater Unionid Mussel Species from the Six Mile Dam Drawdown Detected with a Conventional Rescue Survey (Listed as Mussel Abundance), and with eDNA Metabarcoding. Naming convention follows Williams et al. (2017).

Species	Common Name	Conventional (n)	eDNA
Amblema plicata	Threeridge	6812	X
Actinonaias ligamentina	Mucket	1131	X
Lasmigona costata	Flutedshell	672	X
Lasmigona complanata	White Heelsplitter	641	X
Theliderma cylindrica[a]	Rabbitsfoot	632	X
Lampsilis siliquoidea	Fatmucket	582	X
Tritogonia verrucosa	Pistolgrip	438	X
Lampsilis cardium	Plain Pocketbook	296	X
Fusconaia flava	Wabash Pigtoe	292	X
Pleurobema sintoxia	Round Pigtoe	133	X
Plethobasus cyphyus[a]	Sheepnose	127	X
Strophitus undulatus	Creeper	117	X
Cyclonaias pustulosa	Pimpleback	77	X
Utterbackia imbecillis	Paper Pondshell	76	X
Cyclonaias tuberculata	Purple Wartyback	57	X
Lampsilis fasciola	Wavy Rayed Lampmussel	53	X
Lasmigona compressa	Creek Heelsplitter	31	X
Pyganodon grandis[b]	Giant Floater	17	X
Pyganodon cataracta[b]	Eastern Floater	–	X
Pyganodon sp.[b]	–	–	X
Eurynia dilatata	Spike	5	X
Leptodea fragilis	Fragile Papershell	4	X
Ligumia recta	Black Sandshell	3	X
Villosa iris	Rainbow	1	X
Ptychobranchus fasciolaris	Kidneyshell	1	–
Quadrula quadrula	Mapleleaf	1	–
Alasmidonta viridis	Slippershell	0	X
Lampsilis ovata	Pocketbook	0	X
Potamilus alatus	Pink Heelsplitter	0	X
Truncilla donaciformis	Fawnsfoot	0	X
	Total observed species	*24*	*28*

a. Federally listed freshwater mussel
b. Mussels belonging to the *Pyganodon* genus were identified as *P. grandis* with the rescue survey, while eDNA identified three *Pyganodon* Molecular Operational Taxonomic Units (MOTUs) as *P. grandis, P. cataracta,* and a previously unnamed cryptic *Pyganodon* sp. (Cyr et al. 2007).

sampling, the mussel rescue survey, and a traditional SCUBA survey conducted in 2009, this suggests eDNA provided the highest detection of species richness with relatively low levels of field effort required (Figure 1). These results suggest that eDNA provided similar mussel community composition information to that of traditional surveys and could be completed faster and with less labor. It is important to note that eDNA cannot act as an all-out replacement of traditional methods, as mussel relocations and assessments of organism health/fitness will still require the handing of individuals. However, these eDNA results suggest a preliminary eDNA survey prior to mussel rescues can be advantageous to identify species compositions and locations of interest for presence of threatened and endangered species.

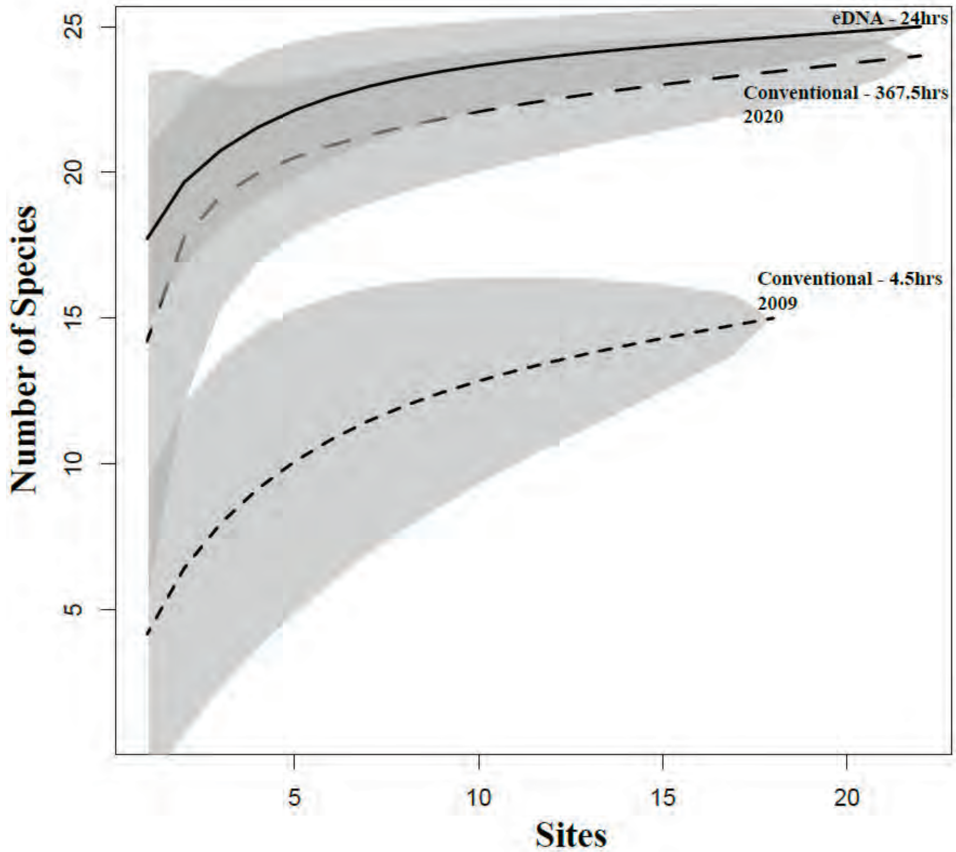

Figure 1. Species accumulation curves for the three sampling methods (2020 eDNA, 2020 mussel rescue and relocation, and a 2009 SCUBA survey). The calculated effort in search hours is listed for each survey. The black line is the estimated number of species, with grey shading representing the 95% confidence interval.

Aquatic Invasive Species: Establishing Probabilities of Detection

Hydrilla is a fast-growing, invasive rooted water plant that was first discovered in the U.S. in Florida in the 1960s. It quickly spread north and, to date, there are known infestations in Maine and Connecticut, including the Connecticut River as well as two known infestations reported in a Cape Cod pond as of 2001. In June and September of 2021, water samples were collected from 10 water bodies in Massachusetts to test for the presence of Hydrilla eDNA. At each of the 10 waterbodies, Stantec collected water samples at three sampling sites using a Niskin-type sampler and/or 1-liter bottle. At each of the three sampling sites, two 1 L samples were collected at different depths (including at the surface and near the sediment) and filtered as a composite sample. Following the analysis for the presence of Hydrilla eDNA using qPCR analysis, occupancy modeling was implemented to compare probability of detection for Hydrilla based on seasonal sampling patterns (i.e., June vs. September) using the R package eDNAoccupancy (Dorazio and Erickson 2018).

Occupancy modeling is often used in ecological surveys to account for imperfect detection of rare and/or elusive animals. For traditional surveys, these models use data collected from repeated surveys at each sampling location to estimate occurrence of a species while accounting for false-negative errors in detection. Considering eDNA is an imperfect sampling method (i.e., detection depends on successful collection of eDNA and successful molecular analysis of samples), occupancy modeling techniques are an ideal analysis to improve understanding of detection probability and estimating species presence.

Environmental DNA surveys typically collect replicate water samples per location and include subsampling within each individual water sample (i.e., qPCR replicates). Therefore, eDNA surveys typically include three nested levels of sampling:

1. Locations (primary sample units) within a study area
2. Water samples (secondary sample units) collected form each location
3. Subsamples (replicate observations) taken from each water sample

Furthermore, a multiscale occupancy model can be implemented to estimate the following:

1. Probability of target species occurrence at the location (ψ, psi)
2. Conditional probability of target eDNA occurrence in a water sample, given that the target species is present at that location (θ, theta)
3. Conditional probability of positive detection in a qPCR replicate, given that the target eDNA is present in the water sample (*p*)

Based on the framework of a multiscale occupancy model, Stantec compared the probability of eDNA detection within a water sample (*p*) between the two sampling seasons. There was a large overlap in estimated *p* values (Figure 2), suggesting sampling season did not impact the laboratory qPCR analysis. Next, the probability of eDNA collection (θ) was compared between the two sampling seasons. There was a much higher probability of eDNA collection for samples collected in June compared to those from September (Figure 3). In order to reach a 95% probability of eDNA collection, samples collected in June required four total samples per body of water, while samples collected in September required double that sampling effort (Figure 3). When accounting for our sampling design (i.e., three water samples per body of water with six qPCR replicates per eDNA sample), it was calculated June sampling displayed a 94% probability of detection, while September displayed a reduced probability of detection of only 72%. The lower rate of Hydrilla eDNA detection during the fall is likely related to decreased growing rates with lower photosynthetic processing. Similarly, previous Hydrilla eDNA surveys in Japan found that eDNA concentrations changed seasonally, with highest concentrations occurring during the summer growing season (Matsuhashi

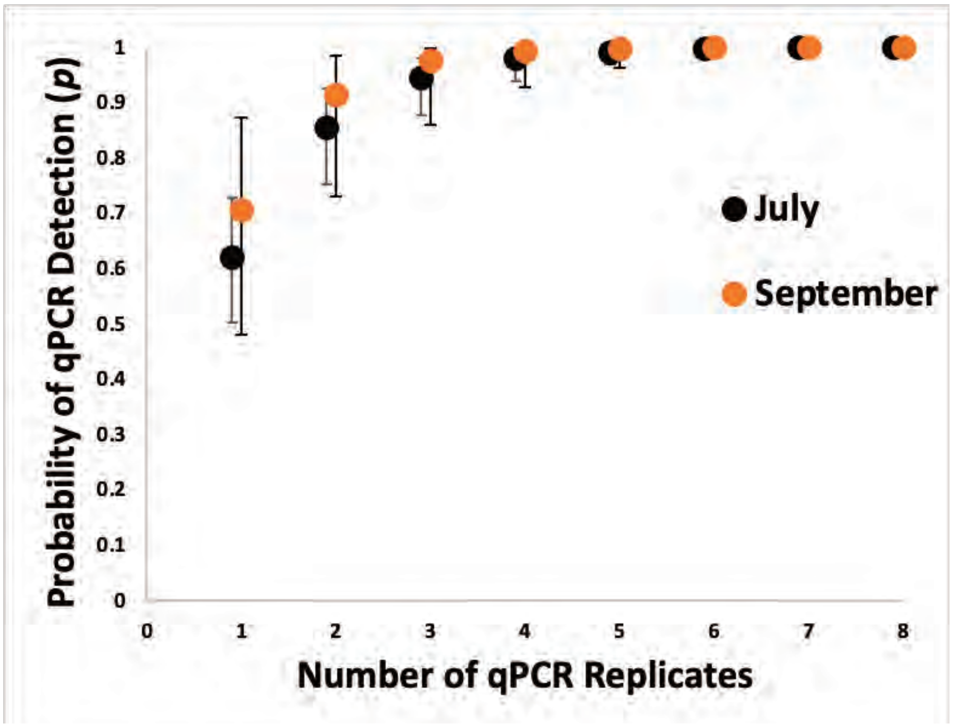

Figure 2. The probability of detection within cumulative qPCR replicates (*p*) from occupancy modeling of Hydrilla eDNA collected in July or September. Error bars represent 95% confidence intervals.

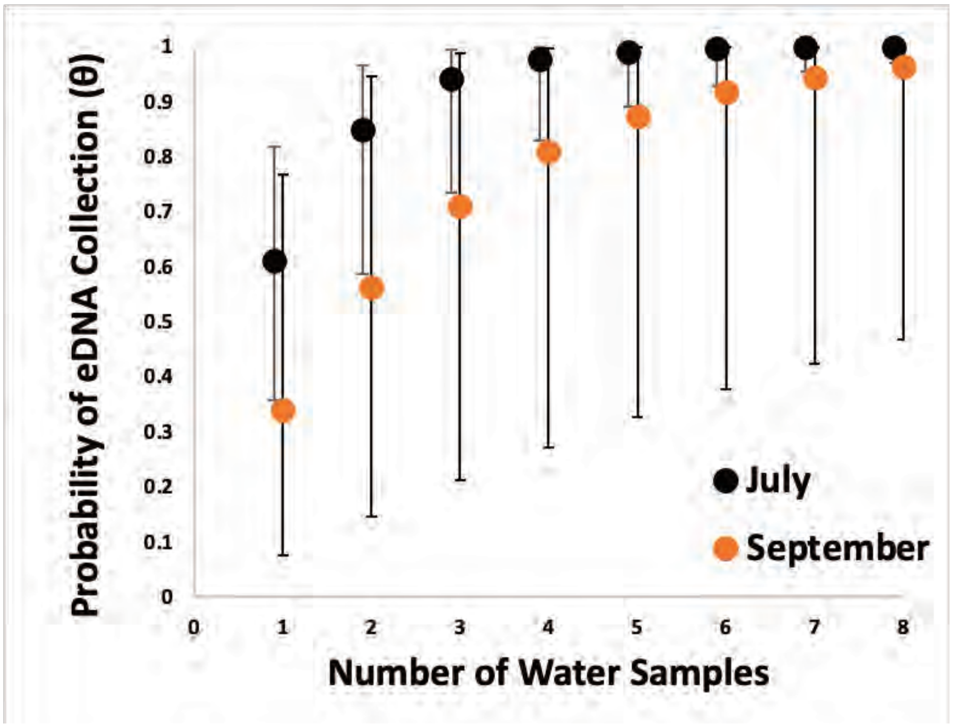

Figure 3. The probability of eDNA collection within cumulative samples (θ) from occupancy modeling of Hydrilla eDNA collected in July or September. Error bars represent 95% confidence intervals.

and Minamoto 2019). The use of occupancy modeling here allowed us to evaluate our sampling design (i.e., number of water samples in addition to the number of qPCR replicates), to provide relevant inferences in seasonality impacts on Hydrilla eDNA detection. Implementing occupancy modeling into eDNA datasets allows end users better interpretation of detection probabilities and evaluation of survey design, to potentially reduce uncertainties associated with eDNA "absence" and help design a more accurate and cost-effective sampling plan.

Table 2. Environmental DNA Samples Upland Forests with Positive Detections for Vertebrate Taxa eDNA with Community Metabarcoding Analysis (Source: Marshall et al. 2022b)

Group	Species	Common Name
Amphibians	*Anaxyrus sp.*	American toad, Fowler's toad
	Hylidae sp.	Tree frogs
	Rana sylvatica	Wood frog
	Rana clamitans	Green frog
	Notophthalmus viridescens	Eastern newt
Birds	*Sayornis phoebe*	Eastern phoebe
	Hylocichla mustelina	Wood thrush
	Passeriformes sp.	Possible Turdidae
Mammals	*Didelphidae sp.*	Virginia opossum
	Odocoileus sp.	White-tailed deer
	Prycon sp.	Racoon
	Peromyscus sp.	Deer mice
	Ursus americanus	Black bear

Moving To Land: Targeting Terrestrial Vertebrates

Biodiversity of North American temperate forest bat populations have rapidly declined, largely due to habitat loss and the lethal White-nose syndrome disease caused by the fungal pathogen *Pseudogymnoascus destructans* (Frick et al. 2020). This decline has increased monitoring efforts of bat populations and species that are protected under the Endangered Species Act (ESA) across the U.S. The analysis of DNA recovered from guano samples has been useful in identifying species and roost locations (Walker et al. 2016), however, not all bat species can be found in large roosts where guano is relatively available for collection. Instead, eDNA that is collected from water sources might provide an easy sampling methodology for the detection of terrestrial organisms relying on drinking water.

Several studies have implemented eDNA surveys for the detection of terrestrial mammals from a source of drinking water. These studies have detected a wide range of species, including coyotes (*Canis latrans*) (Rodgers and Mock 2015), invasive wild boar (*Sus scrofa*) (Davis et al. 2018), elusive jaguar (*Panthera onca*) (Wilcox et al. 2021), and even entire terrestrial mammal communities (Harper et al. 2019). Such an eDNA approach that collects water samples from source drinking water may provide the detection of critically threatened bat populations without relying on a priori knowledge of roost locations, thereby greatly improving bat monitoring and management. Stantec developed and tested a sampling strategy to detect bat eDNA from pools of water found in mixed-mesophytic forests. These pools of water act as an important water resource for bats in the area, and thus bat eDNA (i.e., saliva and hair) may accumulate within these pools following a drinking event.

Forty-seven water samples were collected from 21 pools of water in the forested uplands of the Appalachian Plateau (Marshall et al. 2022b). Environmental DNA from these water samples were analyzed using both species-specific qPCR and community metabarcoding methodologies to test for the detection of two bat species known to be in the region: big brown bat (*Eptesicus fuscus*) and eastern red bat (*Lasiurus borealis*). Through the qPCR analysis, eDNA was successfully detected from big brown bat and eastern red bat within the forested habitat, however the community metabarcoding approach failed to detect bat eDNA across any of the eDNA samples. While the community metabarcoding approach failed to detect bat eDNA, many nontarget amphibians, birds, and mammals were identified (Table 2), suggesting these pools of water can collect eDNA from a wide range of terrestrial taxa. In many regions of the U.S., state and federal agencies design wildlife water holes in strategic locations to maximize wildlife benefits, and thus these water pools provide rare opportunities to measure terrestrial biodiversity

Improving Pollinator Habitat Monitoring: Collecting eDNA on Flowers

Pollinator habitat and natural wildlife growth areas have been recognized as important management priorities to improve insect and arthropod diversity, and many state agencies have begun to provide recommendations for managing pollinator areas (such as the Ohio Pollinator Habitat Initiative). As eDNA applications continue to expand, recent studies have explored the ability to detect important pollinator species and arthropod diversity patterns from eDNA traces left on flower heads after an insect visitation (Thomsen and Sigsgaard 2018). Stantec tested community metabarcoding methods for the detection of pollinators visiting four different flower species: butterfly milkweed (*Asclepias tuberosa*), wild bergamot (*Monarda fistulosa*), false dandelion (*Pyrrhopappus carolinianus*), and black-eyed susan (*Rudbeckia hirta*). Individual flower heads for each flower species were collected and processed for traces of arthropod eDNA.

Using community metabarcoding, 154 arthropods were detected across the four sampled flower species, which included the detection of 143 insects. Additionally, differences in insect richness were found between flower species, with butterfly milkweed displaying by far the highest species richness (Figure 4). Environmental DNA from false dandelion and black-eyed susan detected far less insect species than that from butterfly milkweed and wild bergamot (Figure 4). Furthermore, there were subtle differences in the insect composition between flowers, suggesting pollinator selectivity for different flower species. This supports previous studies proposing eDNA may be useful in discerning flower-pollinator interactions (Thomsen and Sigsgaard 2018). These results are provided from a preliminary dataset, and future work is underway for analysis of eDNA samples from multiple flower species occurring across varying habitats. Still, this preliminary dataset provides insight into the effectiveness of eDNA sampling to monitor pollinator communities. There was surprisingly high arthropod diversity on just a few individual flowers, with community difference between flower species. Information on flower selection derived from eDNA detection can become an important component for establishing best practices for planning and developing pollinator habitat.

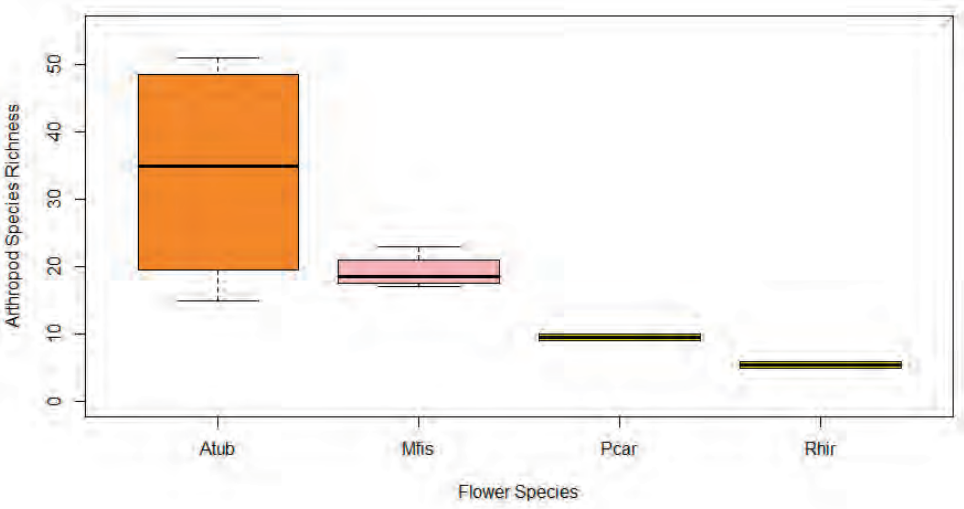

Figure 4. Arthropod species richness detected from eDNA collected on four different flower species. These flowers include butterfly milkweed (*Asclepias tuberosa* - Atub), wild bergamot (*Monarda fistulosa* - Mfis), false dandelion (*Pyrrhopappus carolinianus* - Pcar), and black-eyed susan (*Rudbeckia hirta* - Rhir).

DISCUSSION

Environmental DNA methods have greatly expanded over the past decade, and many studies have demonstrated consistency in detecting biodiversity patterns compared to traditional methods (Fediajevaite et al. 2021; Keck et al. 2022). Here we demonstrate four recent case studies that implement eDNA qPCR or metabarcoding approaches for biological surveys and/or assessments. These applications provide improved or complementary surveys for the detection of invasive species and species of concern (e.g., pollinators or federally listed species) to support conservation and/or permitting linear projects. Furthermore, eDNA methodology has shown tremendous promise for biological monitoring across both aquatic and terrestrial systems. Improved statistical models have been developed to provide better interpretation of eDNA datasets (e.g., the Hydrilla occupancy modeling demonstrated herein) and increase the accuracy and cost effectiveness of eDNA sampling survey design. The case studies presented here demonstrate how eDNA applications continue to grow, and the potential for eDNA surveys within both aquatic and terrestrial landscapes. Standardization and regulator support will continue to expand, allowing eDNA applications to be a complementary survey tool for biodiversity assessment and monitoring programs.

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Nate Marshall, PhD, is an Environmental Scientist with expertise in environmental genomic applications. Marshall has experience developing and implementing eDNA methodology for improving biological surveys. Over the past eight years, he has developed eDNA applications for early detection of aquatic invasive species and has expertise with freshwater macroinvertebrate and fish communities. His current projects include building a basis for eDNA surveys for the detection of freshwater unionid mussels, the most threatened aquatic taxonomic group in North America. This work has involved projects with clients spanning multiple sectors, including transportation, mining, oil and gas, and electric power, and across several states. As the eDNA Technical Lead at Stantec, Marshall seeks to implement genetic-based surveys as a cost-effective and efficient survey tool to aid in biological assessments under Section 7 of the Endangered Species Act.

Jake Riley

Jake Riley is a Project Manager and Certified Ecologist and with over 18 years of fisheries research and ecological experience. Riley is a technical and marketing leader, and part of Stantec's eDNA team and services by managing, executing, and providing technical input on eDNA projects, including study design, sample collection, and analysis. His other recent professional experience includes freshwater fish sampling, fisheries community and population assessments, salmonid spawning and rearing habitat surveys, fish tissue collection, fisheries water quality data analysis and literature reviews, aquatic habitat surveys, federal and state permitting, and biological assessments as consultation under Section 7 of the Endangered Species Act and essential fish habitat preparation. Marshall's prior research experience includes researching predation impediments for lake trout restoration in Lake Champlain and the Great Lakes. Riley holds a Master of Science from the University of Vermont.

Gabe Pelletier

Gabe Pelletier, AWB, is a Wildlife Biologist with five years of professional experience conducting wildlife, fisheries, and aquatic research. Pelletier is part of Stantec's eDNA team where he contributes by creating study design, leading field efforts for eDNA sample collection, and reporting on laboratory analysis. He has a Bachelor of Science in wildlife ecology from the University of Maine. A few examples of his recent project experience include environmental DNA monitoring for early detection of invasive species, studying mercury concentrations in salmonid species, and radar monitoring of bird and bat movement patterns. Examples of Pelletier's prior experience include mussel identification for a relocation project and raptor surveys to identify and protect nest locations.

Mary Murdoch
Mary Murdoch is a Vice President at Stantec and Technical Leader for Ecosystems Services in Canada. Over the past five years, she has been involved in eDNA studies in North America and Australia, across freshwater and marine habitats. Murdoch completed graduate studies in population ecology and genetics of a freshwater fish species at the University of Guelph. With more than 28 years of environmental consulting experience, Murdoch's focus is on environmental impact assessment and environmental effects monitoring, planning, and permitting for clients across all sectors. She participates in Stantec's innovation program where she is a participant and coach. She routinely presents at national technical conferences and leads Stantec's development and expansion of environmental genomics services globally.

Colored pan traps, vane traps, and sweep netting are three commonly used approaches to monitor pollinating insects such as bees, yet each approach may yield different estimations of relative abundance and diversity depending on the habitat sampled. Despite the potential importance of electric transmission rights-of-way (ROW) to these economically and ecologically important insects, few researchers have focused their attention on sampling methods within these areas. Here we surveyed bees within ROW in Central Alabama to assess the effects of collection method on estimates of relative bee abundance and diversity. We observed that blue vane traps collected more bee taxa compared to colored pan traps and sweep netting, whereas sweep netting flowering plants collected the fewest bees but documented some genera that colored pan traps and vane traps did not. Our data support the use of multiple monitoring methods within ROW to document abundance and diversity of this important group of insect pollinators.

Comparing Collection Methods for Pollinating Insects Within Electric Transmission Rights-of-Way

Anthony P. Abbate, Joshua W. Campbell, Lars Straub, and Geoffrey R. Williams

Keywords: Bees, Pan Trap, Pollinator, Rights-of-Way, Sweep Net, Vane Trap.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Many native bees and other insect pollinators within the United States are in decline (Cameron et al. 2011; Eisenhauer et al. 2019). Causes for this decline are likely multifactorial, with habitat loss, agricultural intensification, disease, pesticides, and climate change frequently blamed (Vanbergen and I.P. Initiative 2013; Koh et al. 2016). Because of the ecological and economic contributions of this group of animals (National Research Council 2007), accurate and efficient collection methods are needed to monitor native bee populations, document further declines, and to assist conservation efforts. Recent studies suggest trap type and design can affect the efficacy of collection efforts that focus on documenting insect pollinator species richness and abundance (Gibbs et al. 2017).

The most common collection methods to monitor insect pollinators like native bees include pan traps, vane traps, and sweep netting. Pan traps and vane traps are passive collection methods, usually made from plastic, that are typically placed in the environment over a set period of time, and therefore do not require constant human presence (Joshi et al. 2015). Even though each trapping method has its own sampling biases, both are often touted for their ability to capture many individuals in a short amount of time, as well as their low cost and lack of collector bias (Westphal et al. 2008; Wilson et al. 2008). Conversely, sweep netting involves mechanical collection of an insect by a scientist using a bag-shaped net and handle. Therefore, it can result in high collector bias and can be extremely labor intensive, since collections can only be made when sweeping occurs (Westphal et al. 2008). However, one benefit of targeted sweep netting is that it can provide specific pollinator-plant interactions (Cane et al. 2000; Roulston et al. 2007), and it has been shown to collect bees that are not readily captured in pan and vane traps (Roulston et al. 2007).

The United States contains 2–3 million hectare of electric transmission rights-of-way (ROW) (Russell et al. 2005). These areas have the potential to provide early successional habitat for native bees and other insect pollinators because of how they are managed for power delivery. Many electric utilities ROW land management are believed to support flowering plants (Russell et al. 2005; Hill and Bartomeus 2016; Leston and Koper 2017). Despite the importance of this habitat, methods to adequately sample native pollinators within ROW are currently unknown. Russell et al. (2005) and (2018) sampled within ROW utilizing only colored pan traps, whereas Wagner et al. (2014) used sweep netting in addition to colored pan traps. Due to the commonality of ROW throughout the United States and abroad, it is crucial to determine and compare pollinating insect collecting methods performed within and outside of ROW. Therefore, the objective of this study was to document how trap type influenced bee abundance and diversity capture rates. To accomplish this, we compared colored pan traps, vane traps, and targeted sweep netting from flowers within ROW and the surrounding forested habitat. We expected that the three collection methods would vary in the abundance and diversity of bees collected, based on data collected from other types of habitats.

METHODS

Four study sites within East Central Alabama, and belonging to Autauga, Chilton, Clay, and Tallapoosa counties, were chosen for this study. Among the sites, ROW width varied between 31–92 m. At each site, three experimental plots measuring 170 m in length (running along the ROW), each separated by 50 m, were established within the ROW. Within each experimental plot, two sets of traps, each containing a colored pan trap paired with a blue vane trap, were placed at three locations (middle of ROW, edge of ROW, 25 m into the surrounding forest), for a total of 18 of each trap type per site. Each pan trap consisted of a blue, yellow, and white pan fixed onto corrugated plastic and set on a rack system that allowed traps to be moved up as vegetation grew. Blue vane traps were also set onto a rack system so they could be placed at the same height as pan traps. Soapy water was placed into the pans and vane traps, and each trap was deployed for 48 hours/month at each site from May–October 2018, totaling 20,736 trapping hours per trap type. Following the 48-hour deployment period, the trap contents were strained and stored in a container with 75% ethanol.

Within each experimental plot per site, sweep netting surveys were conducted on the same day pan and vane traps were deployed (30 minutes per experimental plot; 10 minutes at each of the plot's three locations [middle of ROW, edge of ROW, 25 m into the surrounding forest] for a total of 12 hours of sweep netting across the four sites from May–October 2018). Sweep netting surveys meandered through each plot to target actively flowering plants (Evans et al. 2018). Insect floral visitors collected were placed in a vial and stored on ice and later euthanized, pinned, and labeled.

Differences in abundance and diversity of bees were assessed among trap type (vane traps, pan traps, sweep netting) using GLMMs, where each specimen of a specific species was considered an independent unit; trap and sampling period was included as the fixed terms; and site and transect were included as random effects. Post-hoc comparisons for all variables were performed utilizing a multiple pairwise comparisons test (Mitchell 2012).

RESULTS

A total of 5,066 flower-visiting insects were collected with pan traps, vane traps, and sweep netting (2,619; 2,283; and 164, respectively). Bees made up 50.5% of all captured insects, followed by beetles (20.9%), flies (18.8%), butterflies/moths (5.8%), and wasps (4.0%). All bees captured belonged to five families (Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae) and 30 bee genera (Figure 1). When accounting for sampling effort (the total amount of time either passively or actively sampling for insects), pan traps and vane traps performed similarly, collecting 0.13 and 0.11 insects per sampling hour, respectively. Although we spent a total of 12 hours sweep netting for insects within the four sites over 6 months, sweep netting collected on average 13.7 insects per sampling hour.

The most common bee genera collected was *Lasioglossum* (Halictidae; 48.8% of all bees collected), followed by *Melissodes* (Apidae; 18.5%), *Bombus* (Apidae; 13.6%), and *Ceratina* (Apidae; 6.7%). Despite many bee genera being successfully collected in multiple collection methods (Figure 1), each collection method varied in the abundance and diversity of each bee genera collected.

Bees within the family Apidae (including *Bombus*, *Ceratina*, and *Melissodes*) were collected in significantly higher abundances in vane traps compared to pan traps and sweep netting ($P<0.001$). Additionally, bees within the family Halictidae were collected in significantly higher abundances in pan traps compared to vane traps and sweep netting ($P<0.05$), although this was largely driven by small sweat bees in the genus *Lasioglossum*. Bees within the family Megachilidae were captured in relatively low abundances; however, significantly more individuals were captured by sweep netting compared to pan and vane traps ($P<0.05$); no difference was observed between pan and vane traps ($P>0.5$). Bees within the families Andrenidae and Colletidae were caught in very low abundances, and therefore were not included in the statistical analysis. Overall, vane traps collected a higher diversity of bees compared to pan traps and sweep netting ($P<0.05$).

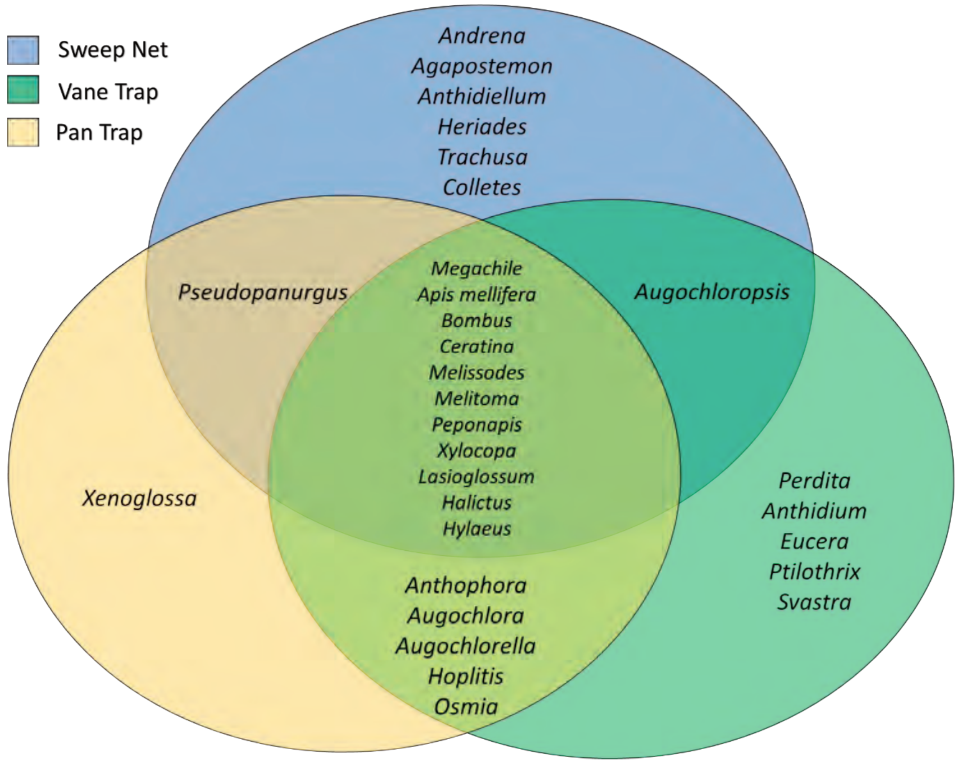

Figure 1. Venn diagram depicting the 30 bee genera collected with each collection method (pan, vane, and sweep netting) from May–October 2018 within the four electric transmission ROW sites in East Central Alabama

DISCUSSION

Numerous methods and traps designs are employed to collect flower-visiting insects, such as ecologically and economically important bees; however, pan traps, vane traps, and sweep netting are most common. Although ROW potentially contain large areas of suitable habitat for pollinators, little effort has investigated use of different trap type in these areas. Our study found that a large number of bee types reside in ROW and highlight the need for multiple trapping methods when documenting both their abundance and diversity.

Like previous studies (e.g., Russo et al. 2021), our study confirmed that ROW contain numerous insect pollinators, including bees. Similarly, results suggested that the type of monitoring method within and near to ROW could influence estimated abundance of bees just like in other habitats (Gibbs et al. 2017). Although multicolored pan traps are likely the most common of passive collection devices, our data suggest that blue vanes have many advantages: they collected more individual bees compared to pan traps, and they are easier to set up and more resistant to weather conditions. However, pan traps are not without their advantages: they are relatively cheaper and collected different types of bees compared to vane traps. For example, vane traps generally collected larger-bodied bees, whereas pan traps collected smaller ones. Previous studies have also noted this (Stephen and Rao 2005; Kimoto et al. 2012).

Our data suggest sweep netting may underestimate bee abundance. This contradicts work by Richards et al. (2011) that found sweep netting and pan traps collected similar amounts of bees, but supports Templ et al. (2019) that found reduced bee abundance during sweep netting. The drawbacks to sweep netting is that for many groups, not enough individuals were caught to make abundance inferences. However, our data suggest that collection of less-common bee groups and the collection of greater numbers of insect pollinators per unit time compared to other methods are potential advantages that warrants its conclusion, especially for work targeting bees or other insect pollinators with high conservation value.

CONCLUSIONS

Our results highlight the importance of understanding the collection biases for each collection method, as each can provide differing insect abundance and diversity results. We believe this can be overcome by utilizing multiple trap types. This is especially important when efforts are targeting specific groups of concern. Because insect pollinators are extremely important due to their contribution to critical ecosystem services (National Research Council 2007), accurate monitoring of their abundance and diversities are needed to monitor and conserve their populations. Further efforts are needed to further understand potential reasons for differences between passive trapping methods, like pan and vane traps, as future trap designs are tested.

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Joining the Monarch Candidate Conservation Agreement with Assurances: A Case Study with Vermont Electric Power Company

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Keywords: CCAA, Habitat, Monarch, Pollinator, Utility Corridor.

After experiencing nearly three decades of population declines, the monarch butterfly (*Danaus plexippus*) became the focus of the first Monarch Candidate Conservation Agreement with Assurances (CCAA), an "all-hands-on-deck" effort to improve habitat of this iconic pollinator species. Developed by the U.S. Fish and Wildlife Service, the University of Illinois, and more than 30 entities from the energy and transportation sectors, the overarching goal of this unique initiative is to encourage voluntary participation in conservation efforts on energy and transmission lands that result in a net benefit to monarch butterflies. By entering into the Monarch CCAA, participating entities commit to adopting conservation practices on a proportion of their managed lands, and in return, receive regulatory assurances that additional conservation measures will not be required if the monarch is granted protected status under the Endangered Species Act (ESA). In 2020, Vermont Electric Power Company (VELCO) joined a growing list of participating energy and transmission entities and entered into the Monarch CCAA, enrolling approximately 12,000 acres of transmission rights-of-way (ROW) across more than 1,100 kilometers (700 miles) of high-voltage electric transmission lines. In this case study, we discuss VELCO's experiences in joining the Monarch CCAA and justification for its involvement in the agreement, amid a backdrop of rising interest for pollinator protection at the national and state level. We also discuss VELCO's strategy for employing conservation measures, as well as its challenges and successes in leveraging its current land management practices to promote monarch habitat.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

The Candidate Conservation Agreement with Assurances (CCAA) for the monarch butterfly (*Danaus plexippus*) is a collaboration between the University of Illinois at Chicago (UIC), the U.S. Fish and Wildlife Service (USFWS), and more than 30 interested entities from the energy and transportation sectors.

These interested companies and organizations represent entities managing nonfederal lands for energy generation and distribution, as well as a network of individual state departments of transportation. The overarching goal of the CCAA is to encourage participation in voluntary conservation on energy and transportation lands that results in a net benefit to monarch butterflies. By entering into the CCAA, participating entities commit to adopting conservation practices within lands associated with energy and transportation infrastructure. The agreement provides participants regulatory assurances that additional conservation measures will not be required if the monarch is eventually granted protected status under the Endangered Species Act (ESA). An additional benefit of enrolling in the CCAA is that the conservation practices adopted by the participants may preclude the need to list the monarch under the ESA.

In 2020, Vermont Electric Power Company (VELCO) joined a growing list of participating energy and transmission entities and entered into the Monarch CCAA, enrolling approximately 12,000 acres of transmission rights-of-way (ROW) across more than 1,100 kilometers (700 miles) of high-voltage electric transmission lines. In this case study, we discuss VELCO's experiences in joining the Monarch CCAA and justification for its involvement in the agreement, amid a backdrop of rising interest for pollinator protection at the national and state levels. We also discuss VELCO's strategy for employing conservation measures as well as its challenges and successes in leveraging its current land management practices to promote monarch habitat.

Trends in Monarch Populations and Key Threats

Monarch is a species of butterfly that are well-known for their long-distance migration that occurs over multiple generations in North American populations. In North America, there are three known monarch populations. The Eastern and Western populations are migratory, with the greatest numbers returning to central Mexico each year for overwintering. The third population, located in southern Florida, is non-migratory as climate permits year-round nectar resources and breeding. Milkweeds (*Asclepias* spp.) are the required larval host plants for monarch caterpillars and play a critical role in the butterfly's life cycle and breeding grounds. As adults, monarchs require an abundance of flowering plants for nectar.

Monarch butterflies have experienced significant population losses over the past three decades. Researchers and citizen scientists estimate a decline of more than 80% in eastern populations and 99.4% in western populations (Xerces Society for Invertebrate Conservation). Though there are many factors driving these documented declines, habitat loss—including the loss of milkweed (their larval host plant)—is by the far the most detrimental. The applicable key threats on energy and transportation lands include:

- Threat 1: Loss of habitat resulting from land conversion
- Threat 2: Loss of habitat resulting from herbicide use
- Threat 3: Loss of habitat resulting from mowing

In December 2020, USFWS completed a thorough assessment to determine if the monarch needs ESA protection and announced that listing the butterfly under the ESA is warranted but precluded. Similarly, the Committee of the Status of Endangered Wildlife in Canada designated the monarch as endangered, but it has not been adopted into the Species at Risk Act as endangered and is not afforded protections. Conservation efforts are underway in Mexico through the Monarch Butterfly Biosphere Reserve, though there are no government-sponsored protections for monarchs. The monarch will remain a candidate species until it is determined that listing is warranted or that conservation actions, such as the CCAA, have recovered the population (U.S. Fish and Wildlife Service). At this time, the final rule on monarch status is expected to be issued in November 2024 and to become effective in December 2024.

Justification for Involvement

As managers of large real estate assets, utility companies are uniquely positioned to make significant strides towards conservation efforts that benefit monarchs and other pollinators. As a result, there is growing interest by legislators at national and state levels in policy that promotes pollinator habitat in utility ROW lands. In 2014, a Presidential Memorandum urged states to develop strategies and action plans to increase and improve pollinator habitat (The White House 2014). Specifically, the memorandum recognized that:

> "ROWs [such as transmission lines] are of particular interest for pollinator habitat because they constitute large land acreage on a cumulative basis, are generally maintained in sunny areas with low vegetation, and often extend for considerable distances, thereby potentially acting as corridors for species movements. . . . these areas can be cost-effectively managed to offer prime pollinator habitat of low-growing grasses, forbs, and shrubs."

In response to this memorandum and documented bee declines in Vermont, in 2016 the Vermont legislature ordered that an advisory group be created to study pollinator decline and established the Pollinator Protection Committee (PPC). The PPC's final report outlined recommendations to improve pollinator health in Vermont and identified habitat loss as a major threat to pollinators, advising state agencies to support practices that promote pollinator habitat (Vermont's Pollinator Protection Committee 2017). In addition, Vermont legislators have introduced and/or approved several other pollinator-related bills, including restrictions on pesticide use and the development of a Pollinator Protection Specialist position in the Agency of Agriculture, Food & Markets.

Rising interest for pollinator protection at the national and state level in Vermont underlined the importance for VELCO to prioritize pollinator conservation in the development of best management practices (BMPs). The CCAA application process provided an opportunity for VELCO to review and refine current management practices to better align with broader pollinator protection efforts at the state level and beyond.

VELCO Land Management Practices and Alignment with CCAA

Vegetation within transmission line ROW must be maintained at a height that is compatible with the safe and reliable transmission of electricity. In most cases in Vermont, this means removing tall-growing trees during initial ROW clearing, and then actively managing for a low-growing shrub and herbaceous community that does not interfere with the wires (Mercier et al. 2001; De Blois et al. 2004; Mahan et al. 2020). This is accomplished by utilizing a practice of integrated vegetation management (IVM), which VELCO employs on its ROW. Integrated vegetation management was developed to standardize practices of managing compatible and incompatible vegetation in various fields (ANSI 2008). Integrated vegetation management enables land managers to select the most appropriate treatment by site and allows for adaptive management as vegetation changes over time (Nowak and Ballard 2005; Miller 2021). Through current routine IVM practices, VELCO actively manages transmission corridors to reduce tall-growing vegetation types and promote a complex mosaic, including low-growing grasses, forbs, and shrubs. This habitat mosaic has excellent potential value to pollinators, such as monarch butterflies. A variety of management methodologies can be used to encourage the growth of a low-growing habitat mosaic over time, and there are advantages and disadvantages to each of them. VELCO utilizes three main vegetation control methodologies to control incompatible vegetation: mowing, mechanical brush removal, and herbicidal treatments.

Mowing is typically utilized in areas of high-density incompatible vegetation species and, as it is non-selective and removes all woody vegetation and any growing herbaceous vegetation, it temporarily clears the land of both incompatible and compatible vegetation. Rights-of-way are frequently mowed to "reset" or clear areas with high densities of incompatible vegetation and for transmission line maintenance and construction. Hand cutting with chainsaws is more selective than mowing and is most useful when densities of incompatible trees are relatively low or when removing all tall trees near streams or other environmental concerns is not desirable. Either type of mechanical treatment can facilitate increases in the abundance of incompatible trees over time, because these treatments promote root suckering and rarely kill deciduous tree species.

Herbicides are effective in removing specific individual incompatible plants and may also be used to allow compatible vegetation to remain and flourish, including milkweed and blooming nectar plants. Herbicide applications are highly regulated, require certified professional applicators, and are sometimes incompatible with certain land uses (i.e., organic farming) and landowner concerns. For managing ROW vegetation as habitat, herbicides provide flexibility and can aid in long-term exclusion of trees and/or invasive plants. Long-term research in ROW vegetation management (VM) indicates that selective and spot herbicide treatments are compatible with abundant and diverse populations of bees and other insects (Russo et al. 2021). It is the careful selection of site-appropriate treatment types that maintains ROW vegetation in the long term.

VELCO performs VM on a four-year cyclical basis, such that three-fourths of VELCO lands are relatively undisturbed in any given year. These ongoing practices are expected to benefit pollinators, including monarchs, as they promote open habitat with low-growing, nectar-producing herbaceous plants, including milkweed. These management practices align with conservation measures outlined by the CCAA to promote monarch populations. Thus, by enrolling lands in a CCAA, VELCO leveraged current VM practices and BMPs to join a nationwide effort to improve pollinator habitat along transmission corridors and promote public awareness for pollinator-friendly management practices. It is anticipated that conservation measures will benefit other pollinator species, such as state or federally threatened/endangered bumblebees, and align with other ongoing conservation efforts and policies.

By entering into the agreement, VELCO was granted assurances that additional conservation measures will not be required if the monarch is listed under the ESA. This affords VELCO more certainty with respect to forecasting the use of resources and expenses, assuming that an ESA listing would result in measures above and beyond those included in the CCAA, or perhaps less flexibility with respect to eligible management practices.

METHODS

Enrollment Process

Lands eligible for enrollment in the CCAA include all energy and transportation lands within the monarch butterfly's range across the lower 48 states. Eligible applicants may enroll lands at any time before an effective date of a final rule listing the monarch as threatened or endangered under the ESA. VELCO followed a four-step process to enroll in the CCAA:

1. **Pre-application outreach** to program coordinators to determine eligibility.
2. **Application preparation and submission**. In brief, application requirements include the total acreage of enrolled lands and acreage of lands proposed for enrollment, conservation measures to be undertaken on enrolled lands, a timeline, roles and responsibilities, and a plan for efficacy monitoring. Applicants are asked to provide the total estimated acreage of enrolled lands by sector within the application (Table 1). Applicants will estimate the required adopted acres by multiplying the acreage of enrolled lands by sector-specific adoptions rate(s). The resulting adopted acres are lands upon which the applicant (i.e., VELCO) implements one or more of the conservation measures for the key threats identified in this agreement. Since VELCO lands are classified as "transmission," the required adopted rate is 18% (see Table 1).
3. **Application review and approval**.
4. **Certificate of inclusion (COI) is issued upon approval of the application.** Upon the COI's issuance, the applicant becomes a "Partner" under the Agreement. VELCO's COI was issued on November 25, 2020.

Adopted Rate Approach	Transmissi on	Distributio n	Generation	Highways (Interstate, U.S., State)	Highways (County, Local)	Rail
CCAA Adoption Rates	18%	1%	9%	8%	5%	5%

Table 1. Adopted acreage rates by sector

For VELCO's adopted acres calculation, lands were excluded if they were labeled during vegetation, inventory as "agriculture" or "lawn" for a few reasons: (1) VELCO does not actively manage areas of easement with these land-use types because they are already intensively managed for compatible vegetation and (2) in most cases, these land-use types will not support milkweed.

Summary of Commitments Under the Agreement

The CCAA will be in effect for 50 years following its approval and signing by the USFWS and the UIC. Participation in the agreement is ultimately voluntary and partners can terminate their participation at any time. However, partners are asked to commit to an initial implementation period for a minimum of five years.

Partners under the agreement are required to implement conservation measures on enrolled lands, conduct tracking and effectiveness monitoring, and comply with annual reporting requirements.

Administrative fees are paid annually to the program administrator of the CCAA, UIC. Fee rates are determined based on an estimate of enrolled lands and adopted acres, with some discounts for supplemental conservation methods and early enrollment. Fees are determined annually by the UIC, based on information provided by VELCO.

Conservation Measures

Conservation measures address key threats to monarchs on energy and transportation lands by increasing milkweed and blooming nectar plants, enhancing habitat and nectar resources, and mitigating negative impacts of excessive mowing and herbicide use on habitat and nectar resources.

Ultimately, VELCO chose to adopt a suite of applicable conservation measures that largely aligned with current management practices:

1. **Brush removal to promote suitable habitat.** This management practice was a regular part of VELCO's management cycle prior to the CCAA and will continue to be implemented in the form of mechanical treatment with either hand cutting with chainsaws or mowing treatments. Brush removal addresses the limiting factors of monarch habitat availability and nectar resources by removing some or all woody vegetation and leaving herbaceous plants. Vermont Electric Power Company removes brush along 3,700 acres of transmission corridors to promote open habitat. Under the four-year rotation cycle, brush (incompatible vegetation) is cut on only approximately one-quarter of these acres (between 900–1000 acres) annually (Table 2).
2. **Suitable habitat set-asides or idle lands for one or more growing seasons.** Set-asides address a key threat to monarchs by maintaining low frequencies of disturbances in areas with suitable habitat. Vermont Electric Power Company's land management practices are on a four-year rotation, such that three-quarters of all lands are not intensively managed in a given year (Figure 1, Table 2). Any given acre of land will remain undisturbed by vegetation managers for a minimum of three years.

3. **Targeted herbicide treatment of undesirable vegetation using herbicide best management practices.** VELCO currently regularly employs ultra-low volume foliar, low-volume basal, and cut stump herbicide application methods. Herbicide is applied to hardwood tree species that grow too tall to be compatible with transmission lines. Other compatible low-growing shrubs and herbaceous plants are not sprayed. Most applications are applied with backpack sprayers. The application method is selected depending on site characteristics, such as stem densities, environmental concerns, aesthetic concerns, and landowner preferences.

In addition to these core conservation measures, VELCO chose to adopt two supplemental conservation measures:

1. Minimizing the spread of invasive species into areas of suitable habitat
2. Incorporating pollinator habitat-focused objectives into VM operations

Vermont Electric Power Company has implemented a four-year vegetation treatment cycle since 1980. Each year, VELCO foresters perform a vegetation inventory of one-quarter of the ROW for treatment the following year (Table 2).

Compliance Tracking and Biological Effectiveness Monitoring

Under the CCAA, partners must track and verify the adopted acreage across lands. There are a number of acceptable methods for compliance tracking, which may include documenting actions in a tracking log or via a geospatial record using a tracking spreadsheet; online geospatial database mapping tool; or online database entry form. Vermont Electric Power Company uses a geographic information system (GIS) application called Vegetation Inventory

Cycle #	Year 1	Year 2	Year 3	Year 4
1	Cycle 1 Inventoried	Cycle 1 acres treated Cycle 2, 3, 4 acres 'set aside'		
2		Cycle 2 Inventoried	Cycle 2 acres treated Cycle 1, 3, 4 acres 'set aside'	
3			Cycle 3 Inventoried	Cycle 3 acres treated Cycle 1, 2, 4 acres 'set aside'
4	Cycle 4 acres treated Cycle 1, 2, 3 acres 'set aside'			Cycle 4 Inventoried

Table 2. Illustration of VELCO's four-year treatment cycle. Treatments include mowing, hand cutting, and various herbicide treatments. Treatment types and amounts are determined during the inventory process, which is completed the year prior to treatments.

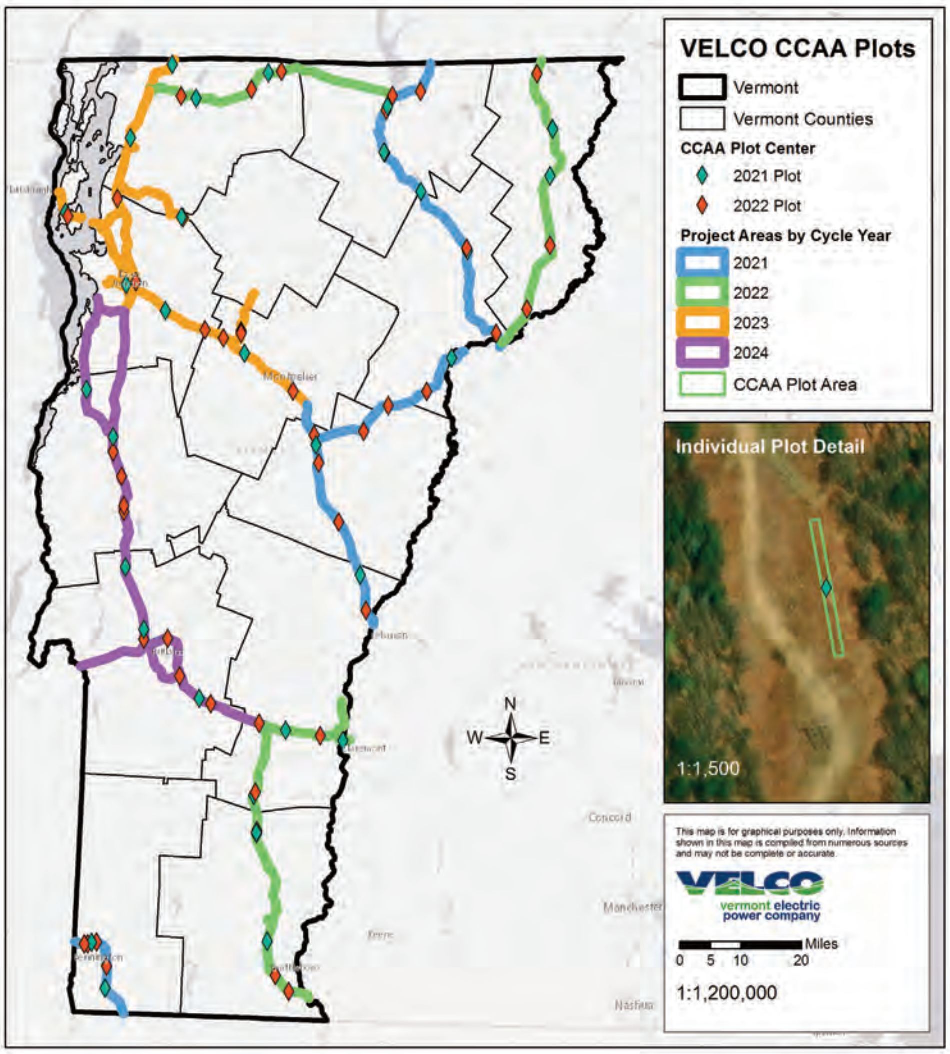

Figure 1. Map illustrating VELCO's monitoring plots and treatment schedules for vegetation management

Program (VIP) to plan, track, and organize VM activities and projects (Figure 2). Having this existing platform and data management system made it relatively simple to quantify conservation measures for the agreement. Acres with mowing and herbicide application are tracked throughout the year using VIP, and idle lands are summarized at the end of the calendar year.

To measure biological effectiveness, CCAA partners must conduct monitoring within a subset of locations where conservation measures are being implemented. The intensity of the sampling effort is determined by the number of adopted acres (Table 3). Based on VELCO's total adopted acreage, VELCO is required to visit a minimum of 30 sampling sites annually. At a minimum, effectiveness monitoring should verify that the adopted acres contain suitable habitat for monarchs. In the Northeast region, the target for habitat suitability under the CCAA is to have six milkweed stems/plot in 90% of sampled plots; however, there is no penalty if the sites do not meet this target.

Each year, VELCO randomly selects a minimum of 30 plot locations using GIS (Figure 1). In 2021, plot locations were randomly generated within VELCO ROW project areas. Each plot is 139.3 meters (1,500 square feet) in size (45.72 meters [150 feet] x 3.04 meters [10 feet]), and runs parallel to the conductor. At each of these plots, VELCO employs the Rights-of-Way as Habitat Working Group (ROWHWG) Pollinator Scorecard Tier 1, v 2.1, Midwest and Northeast U.S. Region (Appendix A). Vermont Electric Power Company employees have been granted access to use the existing Survey123 application, created by the ROWHWG, to complete the scorecard electronically. At each plot, VELCO foresters collect the following information as required by the Pollinator Scorecard: milkweed stem count, estimate of nectar resources cover, and presence/absence of monarchs and other pollinators.

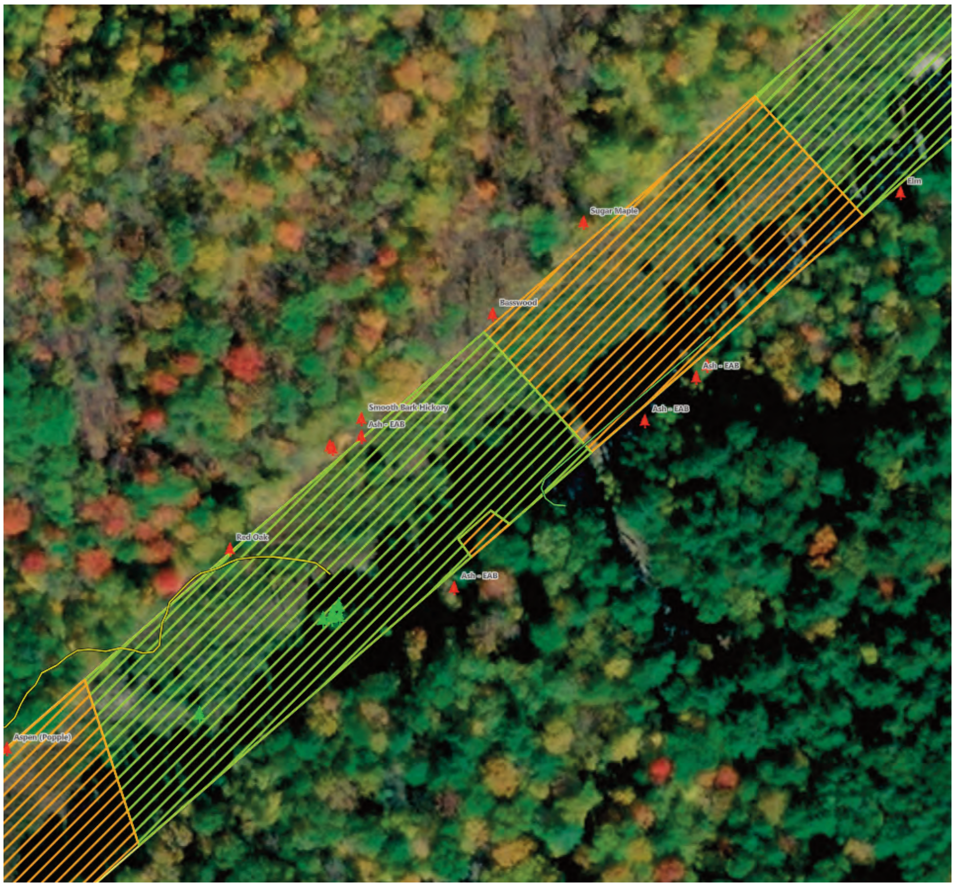

Figure 2. Example of treatments digitized in VELCO's Vegetation Inventory Program. Orange dashed polygons indicate hand cutting with chainsaws; green dashed lines refer to foliar herbicide applications; red trees are marked for removal at the ROW edge. Details of plant density, adjacent land type, and height class can be entered in each treatment's attributes.

Estimated Adopted Acres	Anticipated No. of Samples/Year
Less than 1,000	10
1,001 to 10,000	30*
10,001 to 30,000	50
30,001 to 60,000	70
60,001 or more	70

Table 3. Sampling expected for biological effectiveness monitoring
**Based on the number of estimated adopted acres, VELCO is required to conduct biological effectiveness monitoring in a total of 30 sites annually.*

Photographs are taken of each plot and uploaded using the application. Vermont Electric Power Company VM staff conduct all field monitoring and are trained to positively identify milkweed species and nectar plants, and they have access to and experience with the VIP. Monitoring is completed during normal vegetation inventory and inspections to reduce the travel burden for the task. Effort is made to visit CCAA plots during regularly scheduled field work, but ideally during the growing season (May–September).

Figure 3. Field of grasses and milkweed. This site was the only random monitoring plot in 2021 where milkweed was found.

Reporting Requirements

Partners must submit a CCAA Implementation Plan one year from the date of a fully executed Certificate of Inclusion. This plan should include the roles and responsibilities involved in implementation of the conservation measures and how the partner intends to implement the conservation measures, tracking, monitoring, and reporting required in the agreement. Vermont Electric Power Company submitted its implementation plan in January 2022.

In addition to the implementation plan, partners must submit annual compliance reports that summarize the results of conservation actions undertaken, as measured through tracking and effectiveness monitoring, compliance with the agreement, and any modifications proposed to the enrolled lands. Vermont Electric Power Company submits annual reports by January 31 each year.

RESULTS

Enrolled Lands and Adopted Acreage in 2021

Vermont Electric Power Company enrolled a total of 12,064 acres in the Monarch CCAA agreement. The adopted acres target was 2,171 (18%) of total enrolled acres. At the end of 2021, VELCO reported exceeding this target by contributing a total of 11,935 adopted acres in 2021 (98%) of enrolled lands. This was accomplished through the following conservation measures:

1. **Brush removal**. In 2021, 1,204.09 acres of brush removal was completed. This included selective mowing and hand cutting of tall woody plants.
2. **Suitable habitat set-asides or idle lands for one or more growing seasons**. Vermont Electric Power Company calculated 9,609.70 acres of land was set-aside or idle in 2021.
3. **Targeted herbicide treatment of undesirable vegetation using herbicide BMPs**. Vermont Electric Power Company calculated 1,121.45 acres of land received targeted herbicide treatments in 2021. Targeted herbicide treatments included low-volume foliar spray treatments and cut stump treatments.

Biological Monitoring

In 2021, biological monitoring for milkweed and nectar resources occurred in late fall and winter, due to challenges with staffing changes. In 30 monitoring plots, VELCO only observed milkweed in a single plot (Figure 3). That plot, however, had over 100 stems of milkweed. Almost all plots (29 out of 30) had nectar resources present. Mean cover of nectar plants across all 30 plots sampled in 2021 was 32.7%. No monarchs were observed as all 2021 monitoring was completed after the monarch breeding season in Vermont.

In visiting the random monitoring plot locations, VELCO was able to quantify some differences in vegetation among various management practices. In areas where targeted herbicide has been used for many cycles to remove incompatible tree species, there was generally a high proportion of nectar-producing, low-growing herbaceous and shrub species (Figures 4 and 5); however, this did not necessarily mean milkweed was present (Figure 6). Plots that fell within treatment areas that had been mowed in the past tended to have high cover of deciduous trees, with lower amounts of nectar-producing plants (Figure 7).

DISCUSSION

Monitoring data and observations from 2021 indicated that VELCO may not meet the target of six milkweed stems per plot in large sections of the monitored ROW. This may be due in part to: (1) the nature of the vegetation types within the ROW, (2) the history of IVM taken on by VELCO, and (3) the timing of monitoring in 2021. In many places, we manage for a low-growing shrub community or an intact herbaceous community. These vegetation communities tend to self-perpetuate, compete with, and slow the infill of incompatible taller trees, and provide important early-seral habitat for wildlife. In these areas, there are many flowering shrubs and flowering herbaceous species, but the presence of milkweed can be patchy within the habitat mosaic. The mowing regime exercised by VELCO may not be frequent enough to encourage growth and reseeding of milkweed; mowing outside of the growing season once every four years does not physically disturb milkweed plants, which may be necessary for perpetuation of milkweed (Haan and Landis 2019). Mowing annually within the growing season promotes growth of new stems, which are most attractive to egg-laying monarchs (Fischer et al. 2015; Haan and Landis 2019; Knight et al. 2019). Common milkweed (*Asclepias syriaca*), which was the most common milkweed found during VELCO's monitoring efforts, has been documented to have

Figure 4. Compatible, nectar-producing vegetation remains after a targeted foliar herbicide treatment. Brown leaves of incompatible tall trees can be seen in the background.

Figure 5. Common milkweed (*Asclepias syriaca*) present in high densities in an area of targeted herbicide treatments

significantly more monarch eggs on mowed plants compared to un-mowed plants (He and Agrawal 2020).

VELCO foresters observed milkweed in old hay fields, at the edges of mowed fields and roadsides, sporadically in herbaceous meadows, and generally in areas with little shrub cover. While new patches of milkweed may be found with further monitoring, observations align with the milkweed distribution maps and supplemental information in Thogmartin et al. (2017), where grassland, cropland, and road-edges (high-disturbance land types) supported the most milkweed. Vermont Electric Power Company's actively managed ROW primarily supports early-seral forest and shrubland habitat, habitat that provides critical nectar resources on a large scale but may not support hundreds of milkweed stems per hectare.

In implementing the biological effectiveness monitoring for the CCAA, VELCO has been able to quantify the vegetation along ROW in the context of pollinator habitat for the first time. In many cases, the data verifies observations and assumptions about VM treatments and their outcomes. For example, mowing once every four years results in cover of trees and low cover of nectar-producing herbaceous plants. In the future, VELCO plans to incorporate these data into decisions for VM and in conversations with landowners about possibilities for changing management of any given parcel.

Going forward, VELCO plans to monitor new locations each year. Reasons for this include: (1) over time, VELCO will capture a bigger picture of what the VELCO ROW looks like in terms of milkweed and nectar plants; (2) significant plot-by-plot changes in ROW vegetation are unlikely because VELCO is continuing its existing management strategy of IVM; and (3) more monitoring locations may assist in understanding milkweed distribution across the state of Vermont.

Figure 6. Nectar-producing native plants dominate the ROW in this site that has had targeted herbicide treatments to remove incompatible trees for many cycles. No milkweed was present on this site.

Figure 7. An area that is mowed once every four years is dominated by cherry, pine, and maple trees. Nectar plant cover was estimated to be between 11% and 25%, with no milkweed present.

Vermont Electric Power Company is implementing a more strategic monitoring strategy in 2022. VELCO is (1) prioritizing monitoring during the growing season, (2) restraining monitoring plots to single-treatment areas so they do not overlap management strategies, and (3) generating additional plot locations annually to understand milkweed distribution more effectively. Rather than return to the same 30 plots completed in 2021, VELCO will visit an additional 48 random locations in 2022. By adding additional plots, the VM team will have a larger dataset that inventories the entire system for milkweed and nectar resources. Because VELCO is largely collecting baseline data without drastically changing management tactics, it is unlikely that there will be dramatic shifts in vegetation cover between years.

CONCLUSIONS

Implications of and Opportunities from Joining the Agreement

Participating entities, including VELCO, have cited a number of benefits associated with the CCAA program. Regardless of size or location, participants can expect to gain regulatory assurances if the monarch butterfly is listed. For enrolled entities, regular VM activities, as well as transmission line and road maintenance and construction, can continue without them obtaining additional federal takings permits or committing to additional conservation measures. In addition, joining the agreement highlights a participant's commitment to supporting pollinator conservation, an issue that has garnered much public attention in recent years. Since land management practices may already align with the program (as in VELCO's case), the opportunities of the program may greatly outweigh any additional commitments. In this case study, VELCO leveraged current practices and strategies in joining the program and encountered specific implications and opportunities during the enrollment process.

To comply with the CCAA agreement, VELCO must collect data as part of the annual effectiveness monitoring and reporting requirement. Already having a robust system for tracking treatment acres spatially greatly simplified VELCO's ability to meet tracking requirements under the CCAA. To date, VELCO has found the monitoring requirement of the CCAA to be manageable and anticipates that the knowledge of milkweed presence or absence on the ROW will be valuable.

Vermont Electric Power Company has found value in being a member of the ROWHWG. The Working Group provides employees with handouts, BMP documents, updated literature reviews of monarch research, and a network of similar managers tackling these problems across the country. To facilitate the milkweed and pollinator monitoring process, VELCO is using the Pollinator Habitat Scorecard, the geospatial database, and the Survey123 form created by UIC. By doing this, VELCO was able to avoid additional application development and its associated costs.

Vermont Electric Power Company anticipates the benefits of signing into the agreement outweigh the potential costs and/or additional required commitments that may come with a formal ESA listing for the monarch butterfly. The visibility of adopted lands along roadsides presents an opportunity for public education, engagement, and transparency, as well as showcasing VELCO's commitment to environmental stewardship to both the public at large and other state and federal agencies. By being actively engaged in this and other nationwide conservation efforts, VELCO employees are equipped with the best available science in discussing ROW management and endangered species protection with landowners and the general public. It is expected that enrollment in the CCAA will continue to provide not only regulatory assurances but added benefits related to stakeholder relations and leveraging pollinator science toward best management practices.

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AUTHOR PROFILES

Dr. Samantha Alger, PhD

Dr. Samantha Alger is an Environmental Scientist/Pollinator Specialist at VHB where she works alongside engineers, planners, and designers to develop pollinator-friendly seed mixes, conduct endangered bumblebee surveys, and provide recommendations to clients on how to best support pollinators. Dr. Alger brings a decade of experience in applied ecological science, incorporating research, education, and outreach to improve the health of managed and wild bees. In addition to her role at VHB, she is a Research Assistant Professor at the University of Vermont, where she directs the Vermont Bee Lab and teaches beekeeping courses. Alger holds a Bachelor of Arts in biology, a Bachelor of Science in business administration, and a PhD in biology.

Devon Snyder

Devon Snyder is an ecologist turned ROW manager. For more than 10 years, she has sought to find pragmatic solutions to VM challenges. Much of this time has been spent on public land management issues related to rangeland management and disturbance ecology. She has brought her experience in ecological research and education to her position as Utility Forester for VELCO, enhancing the company's VM program through the use of GIS, data analysis, partner relationships, and public outreach. Snyder has a Bachelor of Science in environmental science and a Master of Science in natural resources and environmental science.

Ryan Scott

Ryan Scott is a Senior Ecologist with 15 years of diverse experience conducting wetland delineations and other natural resource assessments, in accordance with state and federal guidelines for various commercial, transportation, recreational, and utility projects throughout the Northeast. His experience includes wetland stormwater permitting, Phase I Environmental Assessments, supporting petitions to the Vermont Public Utility Commission for Section 248 Certificates of Public Good, and construction oversight and permit compliance for linear transmission and substation projects, commercial-scale solar and wind projects. Scott is a Professional Wetland Scientist and a Certified Professional in Erosion and Sediment Control, with his Bachelor of Arts in environmental science.

Jeffrey Disorda

Jeff Disorda is the Vegetation and Access Construction Manager with VELCO. Disorda has been managing vegetation on ROW in Vermont for 31 years, to ensure safe and reliable transmission of electricity. Vermont Electric Power Company's IVM program has always included habitat improvement as a goal. Over the years, VELCO has worked with many stakeholder partners to continuously look at opportunities and improvements on its nearly 13,000 acres of ROW. Disorda holds his Associate of Science in urban tree management.

APPENDIX A

RIGHTS-OF-WAY AS HABITAT POLLINATOR SCORECARD - *TIER 1 v2.1*
Midwest and Northeast US Region

PAGE 1 OF ____

Site Name ____________ **ROW Organization** ____________

Assessor ____________ **Assessor's Affiliation** ____________

Site Area ______ acres **Date** ______ **Start Time** ______

Monitoring Type
- ○ Baseline
- ○ Post-activity

INSTRUCTIONS
This scorecard provides a Tier 1 assessment of pollinator habitat. Tier 1 assessments provide a 'yes/no' determination of pollinator/monarch habitat. ***If using this scorecard for CCAA monitoring purposes, plot locations must be randomly selected. See Section 14.2 of the CCAA for more details.***

Plot Number ____________ **Plot Location** ____________

Plot Description (ROW type, off-ROW or facility, leased vs. owned, etc.)

REQUIRED

More than 10% cover of potentially flowering nectar plants?
- ○ Yes
- ○ No

Six (6) or more milkweed stems present?
- ○ Yes
- ○ No

OPTIONAL (in Gray)

Potentially Flowering Nectar Plant Cover
- ○ 0 %
- ○ 1 – 5 %
- ○ 6 – 10 %
- ○ 11 – 25 %
- ○ 26 – 50 %
- ○ 51 – 75 %
- ○ 76 – 100 %

Abundance of Milkweed
- ○ 0 stems
- ○ 1 stem
- ○ 2 – 5 stems
- ○ 6 – 10 stems
- ○ 11 – 50 stems
- ○ > 50 stems

Optional: Actual Milkweed Stem Count
☐ stems

Pollinators Observed
- ☐ Honey bees
- ☐ Other bees
- ☐ Monarch butterflies
- ☐ Other butterflies
- ☐ Beetles on flowers
- ☐ Wasps on flowers
- ☐ Moths
- ☐ Flies on flowers
- ☐ Other (describe):

Additional Notes

Photos (describe)

This form is intended for use within the Midwest and Northeast as defined by Figure 6-1 within Nationwide Monarch CCAA/CCA for Energy and Transportation Lands.

Lessons from the First Nationwide Conservation Agreement for Monarch Butterflies on Energy and Transportation Lands

Iris Caldwell, Megan Petraitis, Dan Salas, Michael Friedman, Caroline Hernandez, and Ben Karp

Keywords: Candidate Conservation Agreement with Assurances, CCAA, Milkweed, Monarch Butterfly, Monitoring, Nectar Plants, UIC, USFWS, Vegetation Management, Voluntary Conservation.

The Candidate Conservation Agreement with Assurances (CCAA) for Monarch Butterfly on Energy and Transportation Lands is the first nationwide agreement to promote voluntary conservation of monarch butterfly habitat. The agreement was finalized by the U.S. Fish & Wildlife Service (USFWS) and the University of Illinois Chicago (UIC) in April 2020, after more than two years of collaboration with more than 40 energy and transportation sector partners from across the U.S. The CCAA provides a means for industry participants to implement conservation commitments that support imperiled monarch butterfly populations, while simultaneously receiving regulatory protections in the event the species is listed under the U.S. Endangered Species Act, and potentially helping to avoid the need to list the species in the first place.

Since 2020, UIC and its partners have collected data on current habitat quality and conservation measures implemented as part of the Monarch CCAA program, and gathered broader lessons learned about large-scale collaborative conservation strategies. This paper focuses on two primary outcomes: participant engagement and conservation delivery. Our analysis characterizes the engagement by energy and transportation organizations to date, as well as the results of biological effectiveness monitoring to identify whether observations align with similar studies regarding monarch butterfly habitat, evaluate how well the Monarch CCAA is addressing identified conservation targets, and learn if there are regional, sector, or conservation measure-specific differences that can be observed in the data collected.

Our analysis suggests that while participant engagement has been strong since 2020, there are sector and geographic differences in terms of enrollment. In addition, participation in the Monarch CCAA program tends to motivate additional conservation actions above and beyond minimum enrollment requirements. Meanwhile, the conservation delivered by the Monarch CCAA in terms of milkweed and nectar plant abundance is at or above the biological effectiveness target levels set by the USFWS.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

In 2017, a group of energy companies and state departments of transportation in the Rights-of-Way as Habitat Working Group began collaboration on the first-ever nationwide Candidate Conservation Agreement with Assurances (CCAA) to encourage voluntary conservation for the monarch butterfly and address concerns about the potential regulatory impacts of the monarch butterfly being listed as threatened or endangered under the U.S. Endangered Species Act (ESA). More than 40 energy and transportation organizations worked closely with the U.S. Fish & Wildlife Service (USFWS), the University of Illinois Chicago (UIC), consultants, and conservation organizations over the course of two-and-a-half years to create the agreement. The *Nationwide Candidate Conservation Agreement with Assurances for Monarch Butterfly on Energy and Transportation Lands* (Monarch CCAA) was approved by the USFWS in April 2020, allowing energy companies and transportation agencies operating across the lower 48 U.S. states to enroll in the Monarch CCAA program, administered by UIC. With the approval, the USFWS issued an accompanying Enhancement of Survival permit that provides regulatory assurances for enrollees, in which no additional conservation measures will be required if the monarch is listed under the ESA.

Monarch Butterflies in Conservation Need

The monarch butterfly is one of the most iconic pollinators in North America, due to its bright-colored wings and its phenomenal migration across the continent each fall. There are two primary populations in North America: the eastern monarch population, which overwinters in Mexico, and the western population, which overwinters in California. The eastern monarch population has experienced population declines by as much as 80% over the past 40 years (Machemer 2020). The overwintering area for eastern monarchs in Mexico has decreased from a high of 13.80 hectares in 1996–1997 (Semmens et al. 2016) to less than 3 hectares in 2022 (Rendon-Salinas 2022). In the same time frame, the western monarch population has lost approximately 85% of its population, with only around 250,000 monarchs remaining out of a population that once numbered two million (Howard 2022).

Milkweeds (*Asclepias* spp.) are the sole host plant for monarchs. Monarch butterflies exclusively lay their eggs on milkweed, and monarch caterpillars only feed upon milkweed, of which there are 72 species native to the U.S. (Fallon 2019). These factors in the monarch's biology make milkweeds a critical component of habitat and conservation at both parcel and landscape scales.

Declines in milkweed abundance across the landscape, particularly in the Eastern U.S., have been correlated with habitat loss resulting from intensive monocrop agriculture and herbicide application (Pleasants and Oberhauser 2012); urban/suburban development (USFWS 2020a); other forms of land management, weather, and climate change (Lemoine 2015; Crewe et al. 2019); and the introduction of invasive species (Shahani et al. 2015). Through the Monarch Conservation Database, a system developed by the USFWS to track monarch habitat conservation throughout the U.S., individuals and organizations (including Monarch CCAA participating organizations) have reported more than 50,000 conservation efforts, totaling 2.4 million hectares (6 million acres) and contributing to the conservation of an estimated 500 million milkweed stems (Monarch Conservation Database 2021). To elevate eastern monarch numbers to the hundreds of millions that graced North America less than 30 years ago, monarch butterflies need an estimated additional 1.3 billion milkweed stems across the landscape in the U.S. (Thogmartin 2017).

In December 2020, the USFWS determined that the monarch butterfly warrants federal protection under the ESA but was temporarily precluded from listing due to other higher priority species. The USFWS is expected to publish their proposed listing rule by November 30, 2023, with a final rule anticipated 12 months later. In the meantime, the International Union for the Conservation of Nature (IUCN) placed the monarch butterfly on its Red List as an endangered species in July 2022. While an important indicator of the monarch's continued decline and conservation concern, the IUCN listing is not associated with an ESA decision and does not include regulatory requirements or restrictions to protect monarch butterflies.

Fortunately, nearly 4.8 million hectares (12 million acres) of utility corridors (Peterson et al. 2015) and 6.8 million hectares (17 million acres) of state-managed roadsides (Hopwood et al. 2015) make up a vast network of rights-of-way (ROW) (i.e., the lands adjacent to, above, or under energy and transportation infrastructure) across the U.S., much of which is managed in a state of early successional vegetation where milkweed and nectar-providing plants can thrive. Rights-of-way and other lands owned or managed by energy and transportation organizations can provide veritable highways for migratory species, like the monarch butterfly, that traverse long distances, often over habitat-barren or otherwise unfavorable landscapes. When managed for habitat, these lands can provide feeding, breeding, and nesting resources for a multitude of species facing widespread habitat loss (Midwest Association of Fish and Wildlife Agencies 2018). Compared to the surrounding landscapes, management and disturbance on ROW and other energy and transportation lands tend to be minimal and the potential for rich plant biodiversity can be greater.

What Are CCAAs?

CCAAs are formal, voluntary agreements between nonfederal landowners or land managers and the USFWS in which conservation measures are adopted for at-risk species, like the monarch butterfly. In turn, the USFWS provides assurances that, should a species be listed under the ESA, additional conservation measures beyond those in the CCAA will not be required of participants, and authorization of specific forms of take indicated in the associated permit would be in effect for the subject species. CCAAs also provide a means for industry participants to demonstrate conservation commitments that may help avoid the need to list the species in the first place.

How the Monarch CCAA Works

Nonfederal entities that own or manage energy and transportation lands in the continental 48 U.S. states are eligible for Monarch CCAA enrollment. The extent of lands that an applicant chooses to enroll are called "enrolled acres," which may comprise all or a portion of the owned, leased, and/or easement lands where they have management control. As part of their enrollment into the Monarch CCAA, organizations commit to implementing monarch conservation measures (e.g., seeding/planting beneficial floral resources, conservation mowing, targeted herbicides, habitat set-asides) on a percentage of their enrolled acres. This subset of enrolled lands where conservation measures are implemented are called "adopted acres." Adopted acre requirements are calculated for each individual organization based on a defined "adoption rate" that varies by sector type, from 1% for distribution systems to 18% for transmission systems. This variability reflects the range of potential habitat available across each sector, based on underlying land uses, expected natural land cover, and estimates made in Thogmartin et al. (2017) that are expected to provide a net benefit for monarchs. These adoption rates represent the minimum commitments expected of industry partners, although participating organizations often commit to implementing additional adopted acres above their minimum adopted acres target, which is known as "total habitat acres committed."

Applications are submitted to UIC, which serves as the Monarch CCAA Program Administrator. UIC and USFWS review the applications for accuracy and consistency with other regulatory requirements prior to issuing individual applicant organizations formal Certificates of Inclusion (CI), which extend the Monarch CCAA program requirements and incidental take coverage from the associated Enhancement of Survival permit to participating organizations. All participating organizations are required to annually track and report conservation activities on adopted acres and perform biological effectiveness monitoring.

Since 2020, UIC and its partners have collected data on current habitat quality and conservation measures implemented on energy and transportation lands across the U.S., and gathered broader lessons learned about large-scale collaborative conservation strategies. This paper focuses on two primary outcomes: participant engagement and conservation delivery. Our analysis characterizes the engagement by participating energy and transportation organizations to date as well as the results of biological effectiveness monitoring conducted by participating organizations to identify whether observations align with similar studies regarding monarch butterfly habitat, to evaluate how well the Monarch CCAA is addressing identified conservation targets, and to learn if there are regional, sector, or conservation measure-specific differences that can be observed in the data collected.

METHODS

Program evaluation of the first two years of the Monarch CCAA relied primarily on applications and annual reports completed by participating organizations. We evaluated all applications received to date as well as the annual reports submitted for the 2020 and 2021 program years to determine the enrolled acres, adopted acres, conservation measures performed, and biological effectiveness. Methods for evaluating participant engagement and conservation delivery are detailed below.

Participant Engagement

Participating organizations with fully executed CIs submit annual reports to UIC each January, summarizing the status of implementing conservation measures and the results of their biological effectiveness monitoring from the past calendar year. These reports are compiled and reviewed by UIC to assess the overall performance of the program and identify areas for improvement. In addition to annual reports, UIC utilizes an internal tracking system to estimate total enrolled acres, adopted acres, and habitat commitments (above the minimum adoption rate targets) based on applications under review.

Eleven organizations submitted an annual report for program year 2020, and 19 organizations submitted an annual report for reporting year 2021. We compiled data on total enrolled acres, adopted acres, geographic location, and conservation measures from the 2020 and 2021 annual reports. Data on organizations that are still under the application review process or did not submit an annual report in 2020 and 2021 were compiled from UIC's internal tracking system.

In order to determine enrollment trends, we plotted enrolled lands and participating organizations by state to identify geographic differences. We tracked the number of applications by type of organization to identify sector differences. We also plotted the number of applications received and CIs approved by year to compare trends over time.

Conservation Delivery

When approving the Monarch CCAA, USFWS determined that the program would "result in a net benefit to the monarch" (USFWS 2020a). This decision was based on anticipated targets of milkweed and nectar plants outlined in the agreement. We analyzed the aggregated biological effectiveness monitoring data from the annual reports to determine how well the program is meeting the anticipated targets. These analyses were performed for the Monarch CCAA program as a whole, as well as by geographic region, conservation measure, and sector.

The number of monitoring plots taken by each participating organization varies according to their specific adopted acres target. For most organizations, this ranges from 10 to 50 plots per year. Each sample plot consists of a randomly selected transect equaling 139 m^2 (1,500 ft^2) in total area. Within each sample plot, organizations must sample (at a minimum) milkweed abundance. In addition, in the Western and Southern U.S. regions, percent cover of potentially flowering nectar plants (including native and non-native species) must also be sampled (this is optional in the Midwest and Eastern U.S. region). Milkweed is recorded based on stem counts per plot. Nectar plants are recorded using a combination of estimated percent cover values, plus standardized ranges to minimize sampling bias.

In 2020, UIC informally surveyed participating organizations to gauge current biological effectiveness monitoring practices. At that time, eight participating organizations indicated that monitoring was being primarily performed by in-house staff while completing other activities in the field, and three participating organizations indicated monitoring was done by contractors. The majority of participating organizations used geospatial information systems (GIS) for tracking and monitoring. Eight participating organizations used GIS to randomly select plots before going into the field and 13 used it for tracking milkweed and nectar resources.

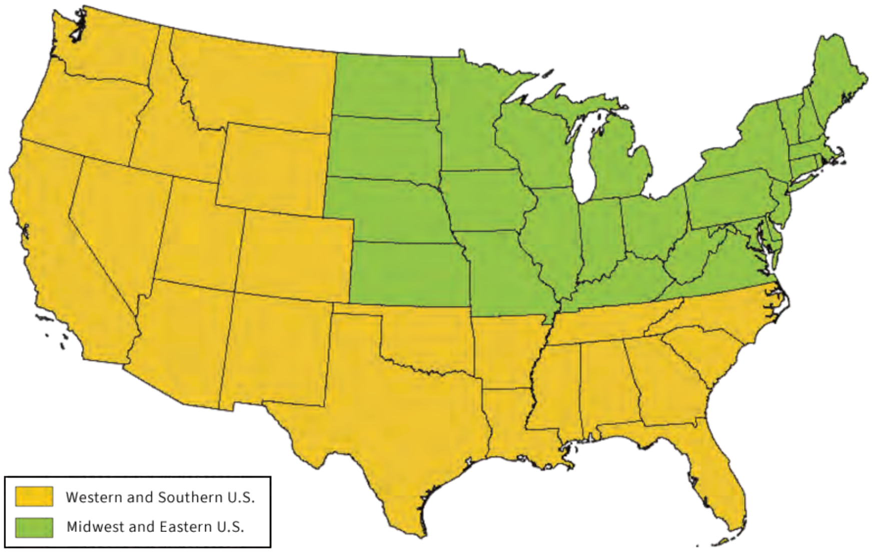

Figure 1.1. Map of monitoring regions

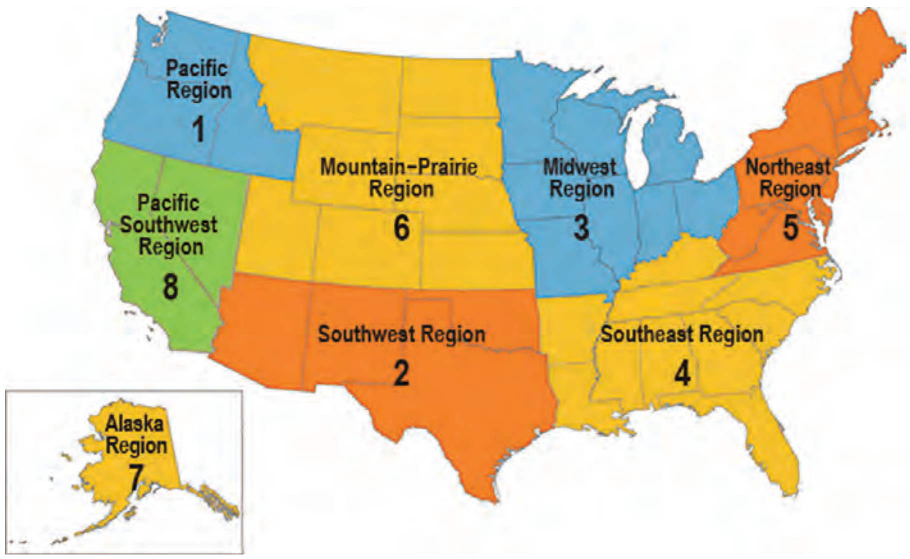

Figure 1.2. Map of subregions used in analysis. Source: USFWS.

CCAA Monitoring Data Analysis

Annual reports from 2020 and 2021 included data from biological effectiveness monitoring conducted during the calendar year, including plot information and quantitative survey values of milkweed stems per plot and percent cover of nectar resources per plot. For the purpose of our analysis, both years of data were combined because plots were primarily spatially and temporally independent samples each year (i.e., not repeated). Analysis and visualization were completed with R using RStudio 2022.07.1+554 (RStudio Team 2022).

We used the combined dataset and year subsets for analyses and visualization. Raw values for milkweed stem counts per plot were used for analysis. For nectar plants, we conducted our analysis using the midpoint value of the recorded range to avoid overestimating (or underestimating) percent cover. For example, a sampled range of 11–25% of nectar plant cover was included as 18% for the purposes of this analysis. These datasets were used to generate a series of histograms and strip plots to summarize the distribution of data and to compare between multiple qualitative variables including primary conservation measures, state, region, and subregion.

Geographic regions are defined

broadly based on Monarch-CCAA-defined monitoring regions as the "Midwest and Eastern U.S." and "Western and Southern U.S.," which were used to define minimum targets for milkweed stems per plot by region (Figure 1.1). The Midwest and Eastern U.S. range roughly corresponds with states located in the geographic range of common milkweed (*A. syriaca*). Subregions were defined based on USFWS legacy regions including the "Midwest," "Mountain-Plains," "Northeast," "Southeast," and "Southwest," as illustrated in Figure 1.2.

The Monarch CCAA specifies target goals for milkweed stems per plot based on elicited values from industry partners, analysis by Thogmartin (2017), and discussions with USFWS during the Monarch CCAA development. We analyzed the milkweed differences observed across CCAA regions and USFWS subregions, and by conservation measure.

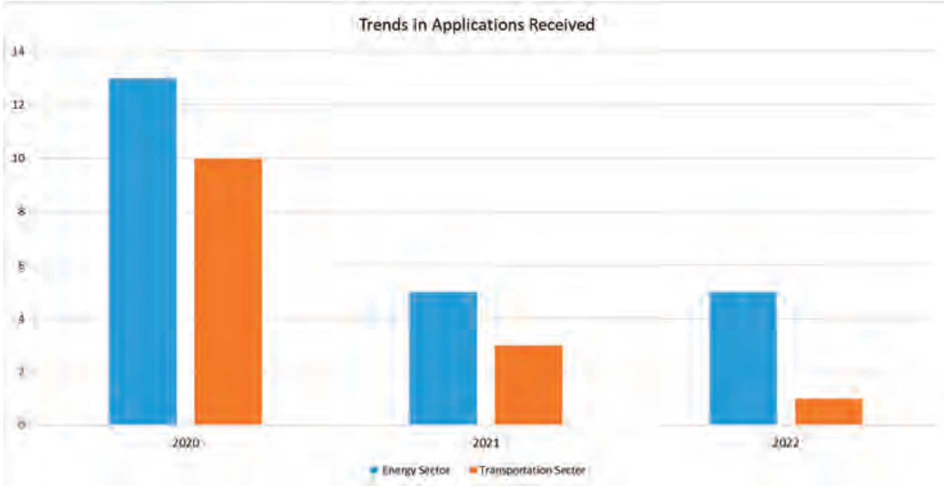

Figure 2. Trends in Monarch CCAA applications received by year and sector

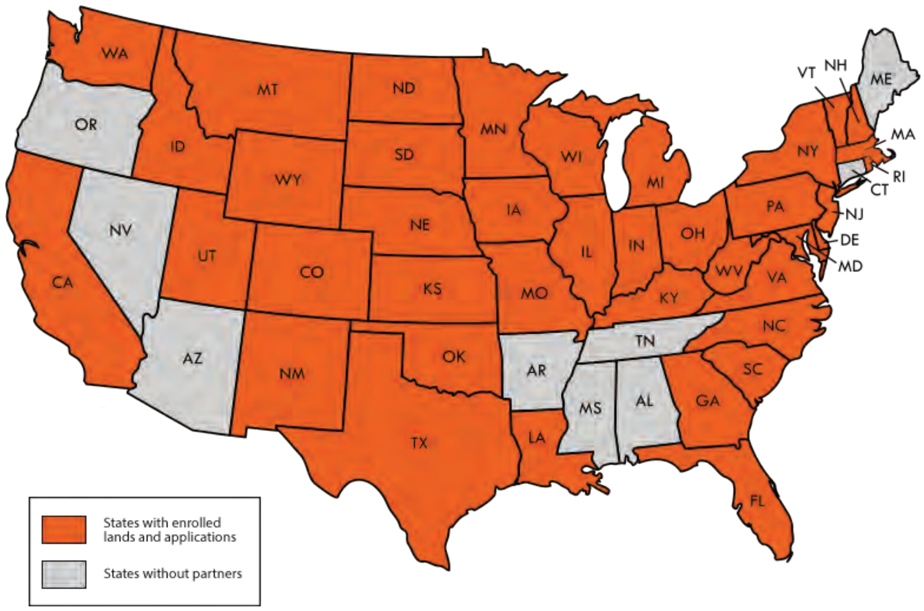

Figure 3. Map showing states with enrolled lands (orange) and those without (gray)

RESULTS

The results of our analyses of participant engagement and conservation delivery are detailed below.

Participant Engagement

As of November 2022, the Monarch CCAA has 30 participating organizations with fully executed CIs. In addition, there are seven applications from organizations at various stages in the review process. These 37 participating organizations are comprised of 23 energy companies and 14 transportation agencies. Table 1 provides high-level details of each of these participating organizations. Together, these organizations manage more than 2 million hectares (5.4 million acres) of enrolled acres and more than 331,000 hectares (818,000 acres) of adopted acres.

In 2020, the first program year, UIC received 23 applications, 13 from the energy sector and 10 from the transportation sector. In 2021, eight applications were received, five from the energy sector and three from the transportation sector. As of the time of this writing, six applications have been received in 2022, five from the energy sector and one from the transportation sector. Figure 2 shows these year-on-year differences.

Participating organizations (both those with fully executed CIs and those under application review) have enrolled lands in 39 states. Figure 3 shows the extent of enrolled lands in the Monarch CCAA and where there are still gaps in enrollment. Figure 4 shows the number of participating organizations in each state. Note: lands in Alaska and Hawaii are not eligible for enrollment.

In 2020 and 2021, participating organizations together implemented the full suite of conservation measures given in the Monarch CCAA, including:

- Seeding and planting to promote native floral resources for monarch breeding and/or foraging
- Controlled grazing to sustain early successional habitat suitable for monarchs
- Woody (non-herbaceous) brush removal to promote habitat suitable for monarchs
- Prescribed burning to sustain or enhance plant diversity
- Setting aside relatively undisturbed lands suitable for monarch habitat
- Conservation mowing to promote habitat and minimize impacts based on monarch breeding and migration activity
- Targeted application of herbicides to control undesirable vegetation, restore native/desired plant communities, and enhance suitable habitat

Conservation Delivery

The results of our analysis of conservation delivery are summarized by the primary targets of the Monarch CCAA: milkweed presence and nectar plant abundance.

Milkweed Presence

Of the 1,076 monitoring data points provided by participating organizations in 2020 and 2021, various species of milkweed (*Asclepias* spp.) were identified in 515 plots, or 48% of all monitoring plots (Figure 5). This is consistent with the sporadic distribution of milkweeds across the landscape found in other research (Zaya et al. 2017; Waterbury et al. 2019).

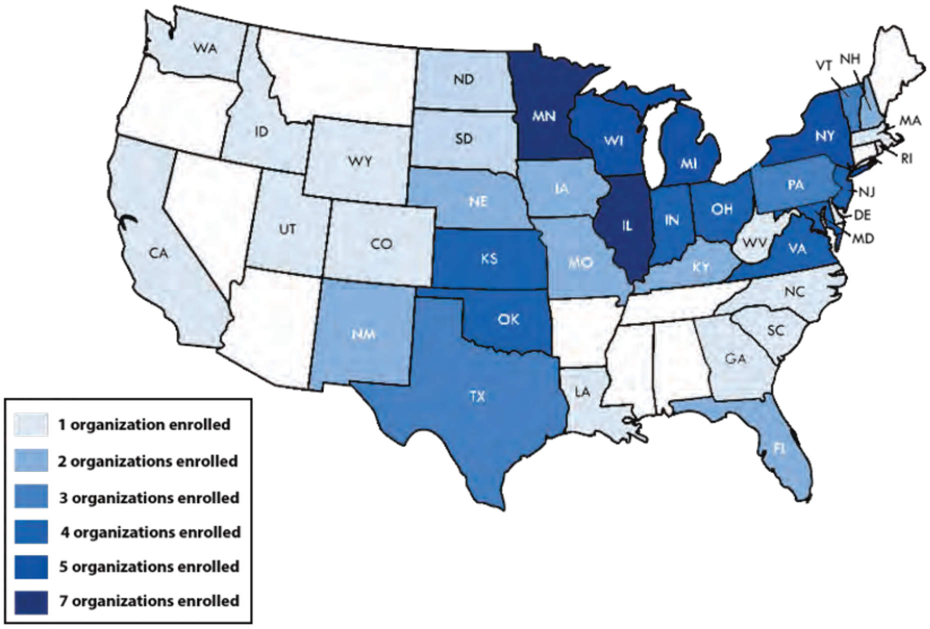

Figure 4. Map showing number of participating organizations by state

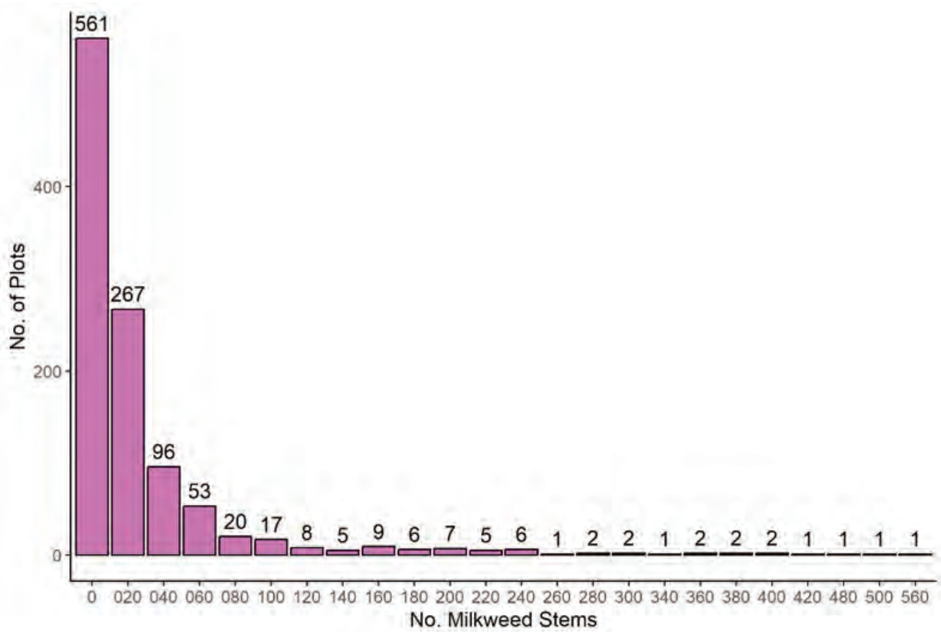

Figure 5. Frequency of milkweed counts (stems per acre) from Monarch CCAA monitoring in 2020–2021

When we analyzed milkweed presence by subregion, we found consistency in regional distribution (Figure 6). While variable, the highest amounts of milkweed were found in the Midwest, with the Mountain-Plains and Northeast being the next most abundant. Milkweed stems are reported on a per-plot basis. Plots in the Midwest, Mountain-Plains, Northeast, and

Southwest had a mean of 28.2 (n=434; SD=62.9), 7.1 (n=97; SD=14.4), 21.8 (n=261; SD=58.5), 21.0 (n=264; SD=60.7) milkweed stems per plot, respectively. Monarch CCAA enrollment in 2020 and 2021 contained limited participation in the Southeast, which does not allow for extrapolation of results in this region.

We also compared the cumulative milkweed observations to the regional milkweed stem targets identified in the Monarch CCAA (USFWS 2020a) across the two industry sectors (Figure 7). The Monarch CCAA set minimum targets for transportation and energy sectors in the "Midwest and Eastern U.S." and the "Southern and Western U.S." regions. Participating organizations in the Midwest and East aim for a target of at least 385 stems per hectare (156 stems per acre), while participating organizations in the South and West aim for at least 148 stems per hectare (60 stems per acre).

Extrapolating the milkweed stem densities from the sample plots, we found that mean milkweed counts were 2,116 stems per hectare (n=674; SD=5,095) or 856 stems per acre (SD=2,063) on transportation sector lands and 816 stems per hectare (n=402; SD=1,806) or 330 stems per acre (SD=731) on energy sector lands. While many sites have met or exceeded the Monarch CCAA milkweed stem target, many more sites have not yet reached these thresholds. Specifically, in the Midwest and East, 49% of transportation sites and 31% of energy sites met or exceeded the target. In the South and West, 30% of transportation sites and 17% of energy sites met or exceeded the target.

Natural variability is expected when conducting random sampling across such a large geographic area. While only 48% of all plots sampled contained any milkweed, the high density of milkweed suggests that when milkweed occurs on adopted acres, numbers of stems are often abundant. When we evaluated cumulative milkweed results by sector, we found that each sector individually exceeded the targets specified.

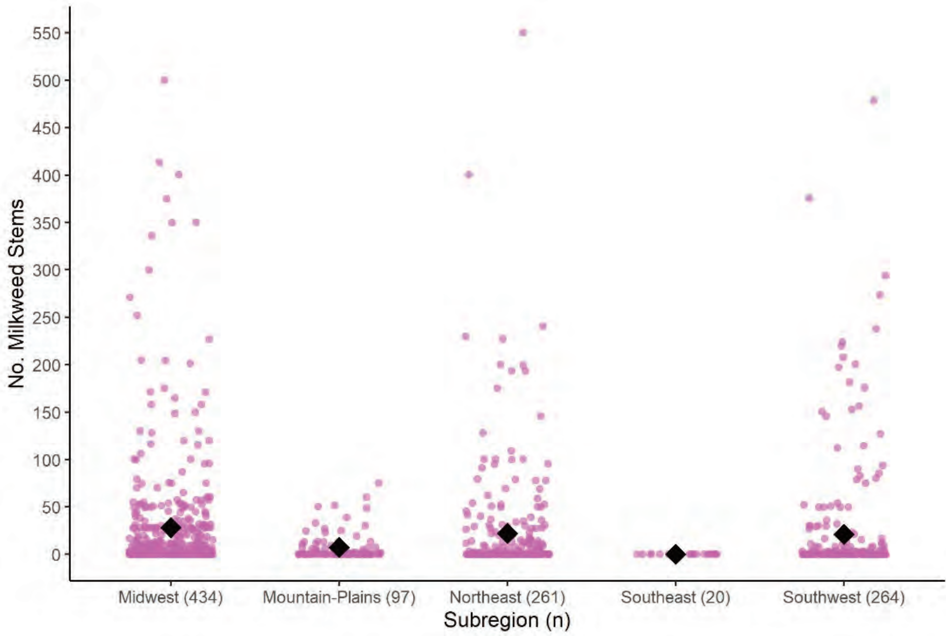

Figure 6. Milkweed counts (stems per plot) from CCAA monitoring in 2020–2021 by subregion. Black dots indicate the means of respective groups. Sample size per group is shown in parentheses (n).

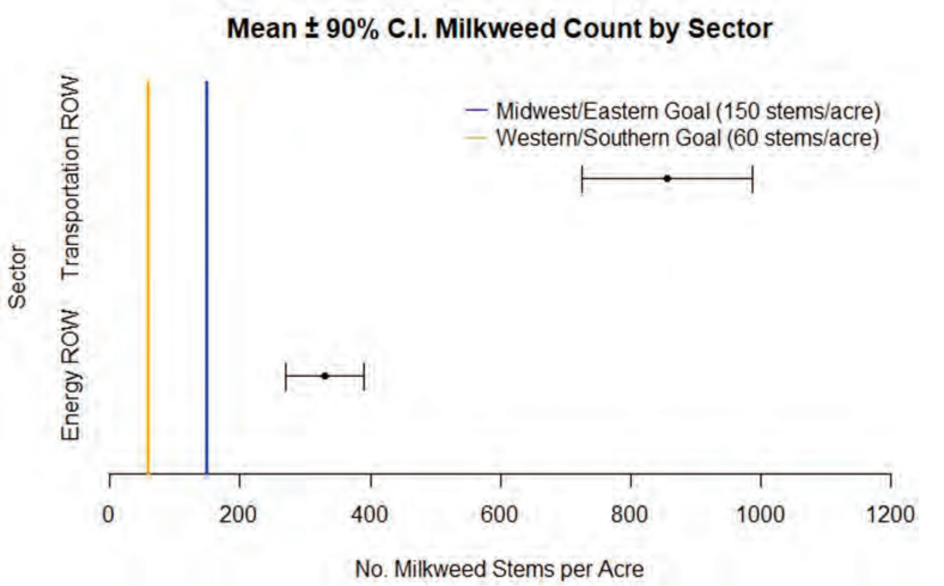

Figure 7. Mean milkweed counts (stems per acre) and 90% confidence intervals from Monarch CCAA monitoring in 2020–2021 by sector compared to targets described in the USFWS biological opinion

We also compared milkweed stem densities across plots that occurred on adopted acres with different conservation measures (Figure 8). Results were highly variable yielding means ranging from 12.6 to 64.8 stems per plot (n=708; SD=58).

While only a small sample size was available (i.e., 5 plots of 1,076), plots reporting native seeding as a conservation measure had higher mean milkweed counts (64.8 stems per plot; n=5; SD=68.0), possibly suggesting that use of diverse seed mixes may aid in re-establishment of milkweeds on adopted acres. Similarly, plots that indicated a combination of native seeding and temporary set-asides reported the next-highest values of milkweed (mean 34.0 stems per plot; n=3; SD=46.5). Sample size varied greatly between conservation measures reported. We caution that inferences regarding enhancement seeding is limited due to the small sample size. More data provided by subsequent years of monitoring will enhance comparative analyses.

However, these limited results generally align with the findings of other milkweed studies (Lukens et al. 2020) that found some milkweeds (like *A. incarnata* and *A. tuberosa*) are more likely to be present and found at higher densities when they had been planted, while other species (e.g., *A. syriaca*) may be equally likely to be present in sites where it was not planted.

Nectar Plant Abundance

Of the 1,076 data points provided by participating organizations in 2020 and 2021, 330 plots contained less than or equal to 10% cover of nectar plants (Figure 9). This represents approximately 31% of all sample plots. The remaining majority of plots exceeded the "greater than 10%" target expected of adopted acres in the Monarch CCAA.

Like milkweed, we analyzed percent cover of nectar plants by subregion (Figure 10). Even though the reported data for the Southeast indicated potentially highest levels of nectar plant cover, the data set used for that subregion is too small to be considered conclusive (similar to the milkweed analysis). Therefore, we concluded that highest amounts of nectar plant cover were found in the Northeast subregion.

Frequency of nectar plant cover was observed by Lukens et al. (2020) in the upper Midwest, where the researchers observed an average frequency of 0.45 for all flowering species observed in the study (both planted and non-planted) across all sites. By comparison, the

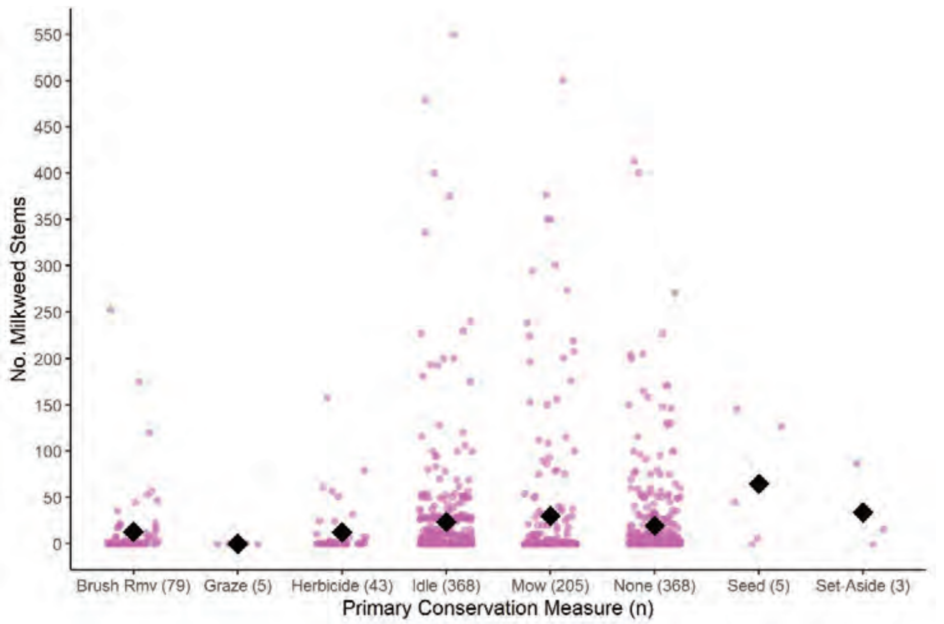

Figure 8. Milkweed counts (stems per plot) from Monarch CCAA monitoring in 2020–2021 by conservation measure reported. Black dots represent means for respective groups. Sample size per group is shown in parenthesis (n). Brush Rmv = Brush removal to promote suitable habitat; Graze = Controlled grazing to promote suitable habitat; Herbicide = Targeted herbicide treatments; Idle = Suitable habitat idle lands, or set-asides; Mow = Conservation mowing to enhance floral resource habitat; None = No conservation measure specified; Seed = Seeding and planting to restore or create habitat; Set-Aside = Set-Aside/Native Seeding.

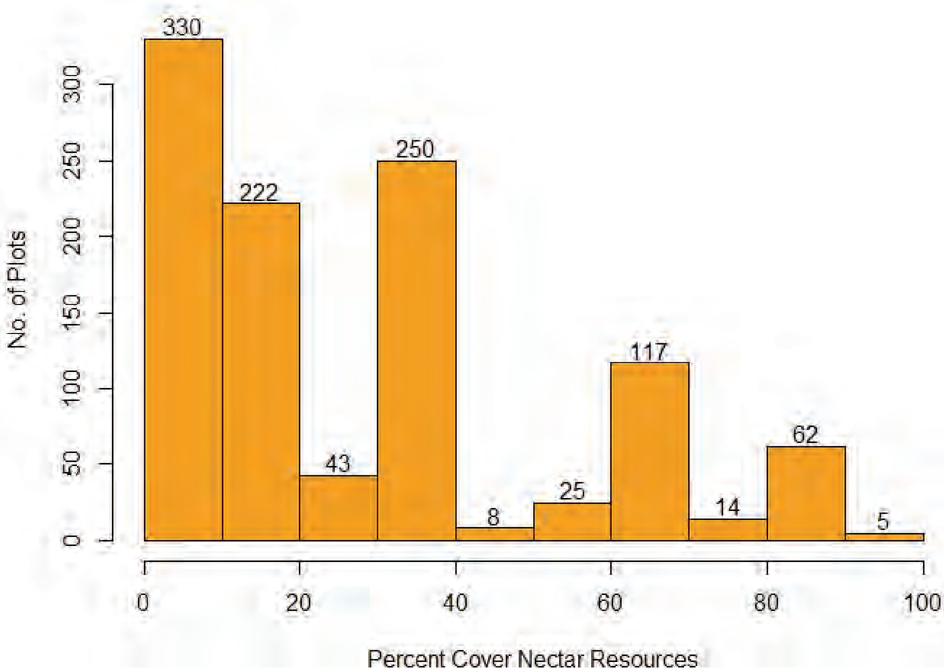

Figure 9. Nectar resources frequency (percent cover) from Monarch CCAA monitoring in 2020–2021

Monarch-CCAA-reported mean nectar plant cover for the Midwest subregion was 26.1%.

We also compared nectar plant cover across plots that occurred on adopted acres with different conservation measures (Figure 11). We observed large variations in nectar plant cover across conservation measures, with mean values between 23% and 51% cover, for most measures. One possible exception was controlled grazing, which had a mean nectar resource cover of 15.6% (SD=12.5), however the small sample size (n=5) limits what we can extrapolate from these initial results. Results indicated all conservation measures yielded nectar plants at or above the biological effectiveness target of 10% cover given by the Monarch CCAA.

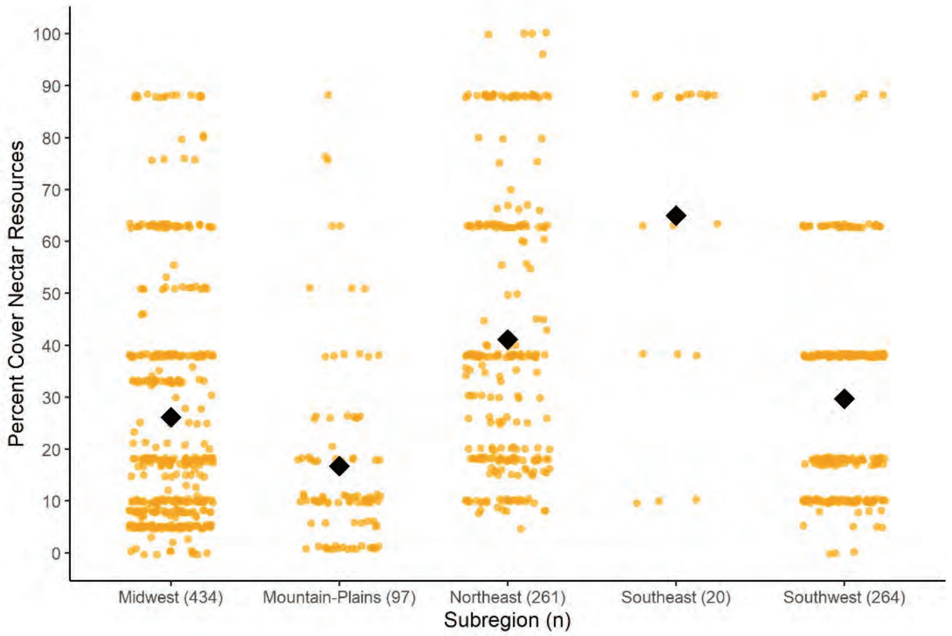

Figure 10. Nectar resources frequency (percent cover) from CCAA monitoring in 2020–2021 by subregion. Black dots represent means for respective groups. Sample size per group is shown in parenthesis (n). (n).

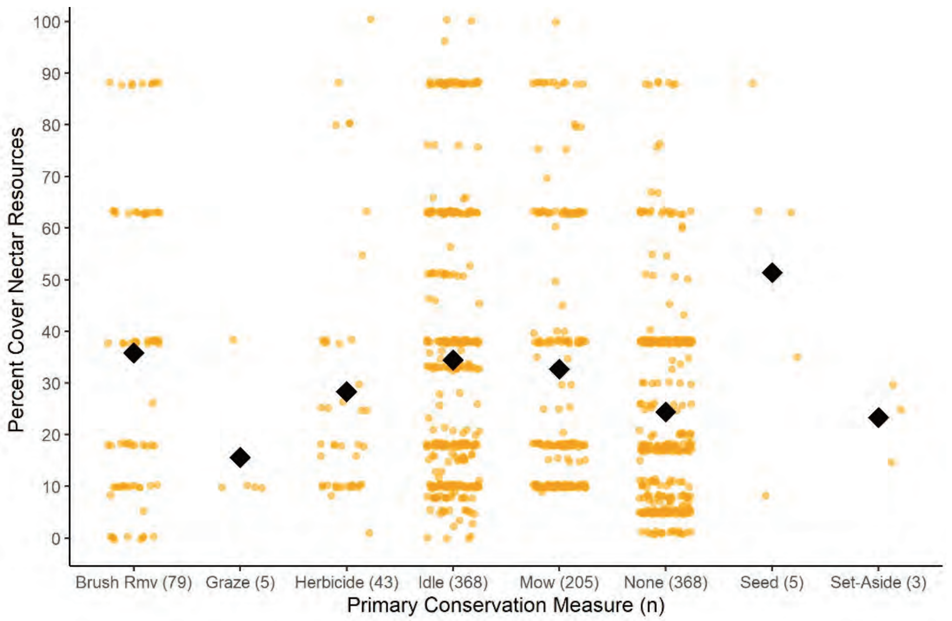

Figure 11. Nectar resources frequency (percent cover) from Monarch CCAA monitoring in 2020–2021 by conservation measures attributed. Black dots represent means for respective groups. Sample size per group is shown in parenthesis (n). Brush Rmv = Brush removal to promote suitable habitat; Graze = Controlled grazing to promote suitable habitat; Herbicide = Targeted herbicide treatments; Idle = Suitable habitat idle lands, or set-asides; Mow = Conservation mowing to enhance floral resource habitat; None = No conservation measure specified; Seed = Seeding and planting to restore or create habitat; Set-Aside = Set-Aside/Native Seeding.

DISCUSSION

Additional analysis of participant engagement and conservation delivery is given below.

Participant Engagement

Enrollment in the Monarch CCAA program during the first three years was strong. The initial spike in applications was most likely due to the momentum built among participating organizations that were involved in the development of the Monarch CCAA, in addition to a concerted outreach campaign and fee discounts used to encourage enrollment ahead of the monarch butterfly listing decision in December 2020. While the first 16 applications were evenly split between organizations from the energy and transportation sectors, participation from energy companies has outpaced transportation agencies since 2020. This difference may be due to differences in staffing, budget, and other resources available within transportation agencies, compared to private energy companies. In 2022, UIC began additional targeted outreach and technical support to assist state departments of transportation with enrollment. Based on anecdotal conversations with industry partners, we anticipate the rate of new applications from both the energy and transportation sectors will remain steady or increase through 2024, when the final ESA listing rule is expected to be finalized and, at which point, the enrollment window will close.

The geographic extent of participating organizations in the

Monarch CCAA is unprecedented, with only a handful of states in the West and Southeast without enrolled lands. However, the highest concentration of participating organizations is within the monarch butterfly's eastern migratory path. This may be due to a number of factors, including greater sensitivity of industry organizations in these regions to the potential regulatory impacts of an ESA listing; the ubiquitous nature of common milkweed across the landscape (particularly on disturbed lands such as rights-of-way); existing state and regional conservation planning efforts that have engaged energy and transportation organizations; and the high level of public awareness and interest in monarch butterfly conservation.

Thogmartin et al. (2017) estimated the milkweed restoration potential for the energy and transportation sectors as 232,183,796 stems based on a target density of 371 milkweed stems/hectare (150 milkweed stems/acre), which yields 626,446 hectares (1,547,982 acres). Based on current enrollment, participating organizations in the Monarch CCAA are contributing approximately half of the estimated potential habitat on these energy and transportation lands.

Enrollment in the Monarch CCAA has also motivated additional conservation action above and beyond what is required for the program. Many participating organizations opt to collect more detailed monitoring data, more broadly incorporate pollinator habitat-focused objectives into vegetation management (VM) plans, fund research projects, partner with local communities in conservation education and habitat projects, and implement other supplemental conservation activities.

Conservation Delivery

The results from the first two years of biological effectiveness monitoring illustrate the conservation importance of the Monarch CCAA and add to the growing body of monarch conservation research. While the dataset being created by the Monarch CCAA partnership holds potential to inform monarch conservation, there are limitations to these data that should be considered. While data is sampled according to a defined protocol using random sampling, the data are collected by a range of professionals with different skill and knowledge levels. To address this, the biological effectiveness monitoring was intentionally designed to minimize the number of variables being sampled and the degree of specialized training required.

Our milkweed and nectar plant abundance findings align with the frequency and distribution found in other research (Zaya et al. 2017; Thogmartin et al. 2017a; Lukens et al. 2020; Monarch Joint Venture 2022). These and other studies on milkweed and nectar plant habitats included various land uses and land covers. Rights-of-way are corridors that by definition span diverse landscapes. Broad alignment with other studies validates data collected by participating organizations in its consistency of findings. Mean stem densities per acre in Figure 8 reflect the variable nature of milkweed observed in sample plots. As highlighted in Figure 6, not all sample plots contained milkweed. However, when encountered, milkweed (primarily common milkweed) tends to be prolific and thereby results in a high mean density despite a lower frequency across sample plots. Similarly, approximately 29.5% of all sample plots did not contain more than 10% cover of nectar plants. This lack of nectar plant cover is suspected to be either representative of natural variability inherent to random sampling or potentially the result of "legacy" VM practices conducted by participating organizations prior to enrolling in the Monarch CCAA.

The Monarch CCAA monitoring targets were established primarily on the assumption of a milkweed-limiting hypothesis (Pleasants and Oberhauser 2012; Stenoien et al. 2016), which resulted in milkweed being the sole monitoring target in the Midwest and Eastern U.S., while milkweed or nectar plants are important habitat targets in the Southern and Western U.S. Since the initial target development, additional studies (Stenoien et al. 2016; Thogmartin et al. 2017a, b; Kinkead et al. 2019; Lukens et al. 2020) have illustrated the importance of nectar plants across the range of the monarch migration and noted that a loss of nectar plant resources could be a significant contributor to increased mortality during migration (Agrawal and Inamine 2018). Other recent studies (Moss and Evans 2022) have also highlighted potential losses in nectar plant abundance and reduced nectar production caused by increased temperatures resulting from climate change. Thus, when considering the recognized conservation value of nectar resources, combined with the nectar plant cover data supplied by Monarch CCAA monitoring to date, nectar resources could prove to be a more important consideration in the Midwest and Eastern U.S. than originally determined. In the future, incorporating these data with monitoring targets could be considered as the program adapts to improved knowledge of monarch butterfly habitat.

Our findings began to identify regional and sector-specific differences in terms of milkweed and nectar plant abundance. As enrollment increases and additional monitoring data are available, we may be able to regionalize some targets or expected net benefits. Initial findings illustrate a potential difference observed in milkweed observations among energy and transportation sectors. Anecdotally, we have observed this phenomenon in our own field observations of energy and transportation lands. It could be indicative that the differences in disturbance regimes may yield slightly different levels of milkweed presence. Energy lands more frequently rely upon herbicide applications, whereas mowing tends to be the preferred management tool used by many highway agencies. As Haan and Landis (2019) noted, milkweed was historically abundant in crop fields where manual weeding and mechanical cultivation set milkweed back but did not kill plants, which would often stimulate regrowth later in the summer. Of course, vegetation managers rely on a range of tools when using integrated vegetation management. Future research evaluating these possible differences, plus disturbance or management regimes that enhance milkweed establishment, are warranted.

While each adopted acre is different, the results shared here illustrate the range and cumulative benefits created by participation in the Monarch CCAA. In its absence, these lands would be potentially exposed to increased mowing, herbicide use, or other disturbance to monarch habitats. Thus, the Monarch CCAA provides a great example for industry engagement in a large-scale conservation partnership with tangible outcomes and results.

CONCLUSIONS

The Monarch CCAA program has yielded numerous conservation successes to date, both in terms of participant engagement and on-the-ground conservation delivery. With the monarch butterfly listing currently precluded due to higher priorities, the Monarch CCAA is one of the most important interim mechanisms for formally engaging public and private entities and creating and protecting monarch butterfly habitat at large scale. The agreement has been recognized by conservation groups, industry partners, and the USFWS for its innovative approach and significance in terms of sheer scale and cross-sector collaboration (USFWS 2020b; USFWS 2021).

The Monarch CCAA presents a unique contribution to landscape-scale conservation as well as monarch research. To date, participating organizations have collected more than 1,000 data points across 17 states. Our analysis suggests that the conservation delivered by the Monarch CCAA is at or above target levels set by the USFWS. Over time, this dataset will continue to grow, allowing for more robust data analysis. As a result, the Monarch CCAA program contributes to our knowledge regarding monarch conservation, regional and national-scale conservation needs, and the role of nontraditional working landscapes, such as ROW.

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A list of currently enrolled organizations in the Monarch CCAA can be found at *rightofway.erc.uic.edu/national-monarch-ccaa/ccaa-enrollment*.

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Table 1. Application and Certificate of Inclusion Data by Applicant

Participating Organization	Date of CI Issuance	Total Enrolled Hectares (Acres)	Adopted Hectares (Acres) Target	Habitat Hectares (Acres) Commitment	Geographical Location	Sector	Conservation Measures Committed
Organization 1	Pending Review	8,014 (19,802)	1,442 (3,564)	1,442 (3,564)	WI	Energy	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Organization 2	9/21/22	3,965 (9,798)	707 (1,746)	707 (1,746)	NY	Energy	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, seeding or planting of habitat, brush removal, prescribed grazing
Organization 3	Pending Review	5,036 (12,444)	906 (2,240)	906 (2,240)	MD	Energy	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, seeding or planting of habitat, brush removal
Organization 4	Pending Review	13,710 (33,877)	1,097 (2,710)	1,097 (2,710)	CA	Transportation	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, seeding or planting of habitat, brush removal, prescribed grazing
Organization 5	8/2/21	51,728 (127,823)	4,743 (11,721)	4,768 (11,783)	IL	Energy	Habitat set-asides or idle lands, seeding and planting, controlled grazing, brush removal, prescribed burning, conservation mowing, targeted herbicide treatment
Organization 6	5/12/21	105,018 (259,506)	2,866 (7,082)	2,866 (7,082)	MI	Energy	Conservation mowing, brush removal, seeding and planting, targeted herbicide treatment
Organization 7	9/20/22	529,709 (1,308,939)	25,248 (62,389)	25,248 (62,389)	FL, IN, KY, OH, NC, SC	Energy	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Organization 8	10/8/20	12,525 (30,950)	125 (310)	125 (310)	MN, WI	Energy	Habitat set-asides or idle lands, targeted herbicide treatments, seeding or planting of habitat, brush removal
Organization 9	11/6/20	66,709 (164,842)	8,372 (20,687)	8,372 (20,687)	KS, MO	Energy	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, seeding or planting of habitat, brush removal, prescribed burning, prescribed grazing
Organization 10	Pending Review	47,727 (117,936)	8,591 (21,228)	8,591 (21,228)	MD, NJ, NY, OH, PA, VA, WV	Energy	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Organization 11	2/4/21	219 (542)	20 (49)	44 (109)	FL	Energy	Conservation mowing, habitat set-asides or idle lands, brush removal, targeted herbicide treatment
Organization 12	5/19/21	21,766 (53,785)	1,447 (3,576)	1,447 (3,576)	GA	Transportation	Seeding and planting, brush removal, conservation mowing, targeted herbicide treatment
Organization 13	8/2/22	12,128 (29,968)	1,870 (4,621)	1,870 (4,621)	IL, IN	Energy	Seeding and planting, controlled grazing, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Organization 14	3/17/22	162,429 (401,370)	12,994 (32,110)	12,994 (32,110)	IL	Transportation	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Organization 15	6/14/21	36,094 (89,181)	2,887 (7,134)	2,887 (7,134)	IN	Transportation	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, seeding or planting of habitat, brush removal
Organization 16	10/7/21	39,930 (98,670)	7,188 (17,761)	32,966 (81,460)	MI, IA, MN, IL	Energy	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, brush removal, seeding and planting
Organization 17	4/12/21	1,594 (3,939)	80 (197)	80 (197)	MN	Transportation	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, controlled grazing, brush removal
Organization 18	11/17/20	103,672 (256,178)	8,294 (20,494)	8,294 (20,494)	MN	Transportation	Reduced/deferred mowing, prescribed fire. Additional conservation measures implemented include targeted herbicide use; brush removal (hand); brush mowing; native seeding; idle land set-asides; prescribed fire; support of pollinator/vegetation research; and pollinator surveys.

Organization 19	5/19/22	12,526 (30,952)	1,228 (3,035)	1,228 (3,035)	NY, PA	Energy	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatment
Organization 20	1/12/21	43,120 (106,551)	7,057 (17,439)	7,057 (17,439)	MA, NH, NY, RI, VT	Energy	Habitat set-asides or idle lands, targeted herbicide treatment, brush removal, seeding and planting, conservation mowing
Organization 21	Pending Review	49 (122)	6 (14)	6 (14)	MI	Energy	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatment
Organization 22	7/14/22	62,125 (153,513)	2,433 (6,011)	2,433 (6,011)	IN, KY, MD, OH, PA, VA	Energy	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatment
Organization 23	3/17/21	45,708 (112,948)	8,228 (20,331)	8,252 (20,391)	IL, IA, KS, MI, MN, NE, NM, OK, SD, TX, WI	Energy	Habitat set-asides or idle lands, seeding and planting, brush removal, targeted herbicide treatment, conservation mowing
Organization 24	10/6/20	105,278 (260,152)	8,422 (20,812)	8,422 (20,812)	OH	Transportation	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, brush removal
Organization 25	11/20/20	60,894 (150,472)	4,872 (12,038)	4,872 (12,038)	OK	Transportation	Conservation mowing to enhance floral resource habitat, suitable habitat idle lands/set-asides, targeted herbicide treatment, seeding and planting, brush removal
Organization 26	Pending Review	118 (292)	214 (531)	80 (197)	IL, WI	Energy	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Organization 27	10/5/22	3,538 (8,742)	637 (1,574)	637 (1,574)	DE, MD, NJ, VA	Energy	Seeding and planting, brush removal, habitat set-asides for idle lands, conservation mowing, targeted herbicide treatments
Organization 28	Pending Review	27,455 (67,842)	4,942 (12,212)	4,942 (12,212)	CO, ID, IL, KS, LA, MO, MT, ND, NE, NJ, NM, NY, OK, TX, UT, WA, WY	Energy	Seeding and planting, brush removal, habitat set-asides for idle lands, prescribed burning, conservation mowing, targeted herbicide treatments
Organization 29	8/3/22	5,717 (14,127)	286 (706)	291 (720)	MN	Transportation	Seeding and planting, brush removal, habitat set-asides for idle lands, prescribed burning, conservation mowing, targeted herbicide treatments
Organization 30	4/9/21	6,754 (16,690)	1,215 (3,004)	1,215 (3,004)	NJ	Energy	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, seeding and planting, brush removal
Organization 31	12/22/20	500,697 (1,237,248)	40,056 (98,980)	180,763 (446,675)	TX	Transportation	Conservation mowing, habitat set-asides or idle lands, targeted herbicide treatments, seeding and planting, brush removal
Organization 32	9/23/20	17,140 (42,354)	1,377 (3,403)	2,101 (5,191)	VT	Transportation	Conservation mowing, habitat set-asides or idle lands, brush removal, seeding and planting
Organization 33	11/25/20	4,882 (12,064)	879 (2,171)	3,966 (9,8001)	NH, VT	Energy	Habitat set-asides or idle lands, targeted herbicide treatments, brush removal
Organization 34	12/14/20	15,854 (39,175)	1,268 (3,134)	1,268 (3,134)	VA	Transportation	Conservation mowing, habitat set-asides or idle lands, seeding or planting of habitat, targeted herbicide treatments, brush removal
Organization 35	Pending Review	942 (2,327)	47 (116)	81 (199)	MN	Transportation	Seeding and planting, brush removal, habitat set-asides or idle lands, prescribed burning, conservation mowing, targeted herbicide treatments
Organization 36	7/28/22	194 (479)	17 (43)	19 (46)	MI, WI	Energy	Seeding and planting, prescribed burning, brush removal, suitable habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Organization 37	9/9/22	72,538 (179,245)	5,803 (14,340)	5,803 (14,340)	WI	Transportation	Seeding and planting, brush removal, habitat set-asides or idle lands, conservation mowing, targeted herbicide treatments
Totals: 37 Organizations		**2,207,558 (5,454,995)**	**177,671 (439,035)**	**331,400 (818,908)**			

Powerline Right-of-Way Vegetation Management and Soil-Dwelling Invertebrates: A Study of Ground Beetles at a Research ROW in Central Pennsylvania

Hannah L. Stout, Ian J. Fisher, and Carolyn G. Mahan

Ground beetles (Coleoptera: Carabidae) have long been used as bioindicators in natural and agricultural systems due to their diverse ecological roles, their ubiquity and relative abundance, and their sensitivity to environmental changes. However, the ground beetle populations of the managed early successional habitats of utility and transportation corridors are not well understood. The objective of our study was to examine the potential differences in ground beetle populations among different vegetative treatments used in integrated vegetation management (IVM) under an electric transmission right-of-way (ROW). In May 2020, at the State Game Lands 33 Rights-of-Way Research and Demonstration Area (Centre County, Pennsylvania), we installed 2x3 pitfall trap arrays in seven ROW plots, representing five different vegetation management types (mow only, low-volume foliar, high-volume foliar, low-volume basal, and hand cut only). Pitfall traps were open for 72 hours each month. By August 2020, after 288 trap hours, we collected a total of 153 ground beetles representing 45 taxa, and 7,694 individuals of other terricolous invertebrate fauna. Our findings provide a valuable glimpse into the potential effects, benefits, and/or costs of maintaining powerline ROW on ground beetle abundance, taxa richness, and diversity.

Keywords: Entomology, Ground Beetles, Rights-Of-Way (ROW), Utility Lines, Wildlife.

Environmental Concerns in Rights-of-Way Management
13th International Symposium

INTRODUCTION

Ground beetles (Coleoptera: Carabidae) have long been used as bioindicators in agricultural systems due to their diverse ecological roles, their relative abundance, and—most notably—their sensitivity to environmental changes. This family of beetles are renowned for their voracious appetite for agricultural pests, weed seeds, etc. The abundance and diversity of ground beetles have been studied in a variety of agroecosystems but also "natural" landscapes, such as forests and prairies (Spence et al. 1997; Byers et al. 2000; Pohl et al. 2007). Despite their reputation as beneficial insects within agricultural and other such "disturbed" landscapes, Carabids rely on many different habitats for breeding, feeding, and survival, and beetles of this large Family are important members of the spectrum of natural and artificial ecosystems.

Our study is part of the ongoing research conducted at the State Game Lands 33 Rights-of-Way Research and Demonstration Area (SGL33). The SGL33 research site is located in Centre County, Pennsylvania, approximately 23 km WNW of the University Park campus of the Pennsylvania State University. The SGL33 research project began in 1953, in response to public concern regarding vegetation management practices utilized at powerline rights-of-way (ROW) and their potential effects on wildlife habitat. Now in its 69th year, SGL33 is "the site of the longest continuous study measuring the effects of herbicides and mechanical vegetation management practices on plant diversity, wildlife habitat, and wildlife use within a rights-of-way" (Penn State University).

This study seeks to examine the abundance, richness, and diversity of ground beetles that roam the managed early successional habitats of SGL33. Specifically, our objective is to examine the potential differences in Carabid populations among seven ROW plots, representing five different vegetation management types (Table 1), and to provide the project's stakeholders with an analysis of ground beetle abundance, taxa richness, and diversity at SGL33, which will assist in making management recommendations for the future.

Table 1. Vegetation Treatments Used at SGL33 Research Plots

Vegetation Treatments at SGL33

Treatments Applied Every Five Years

Treatment	Description of Treatment Methods	Plots Where This Method Was Used
Mow Only (Mow)	Mechanical equipment is used to cut and mulch vegetation from the plot. This method is non-selective and is typically used to reclaim an area from tall, dense brush. The root system of mowed vegetation is not affected which frequently results in dense thickets of re-sprouted brush in areas where brush existed prior to mowing.	M4
High Volume Foliar (HVF)	A diluted herbicide solution is applied to the foliage of target vegetation using hydraulic equipment. This treatment uses a large volume of water per hectare (usually 935+ liters) and is applied on plots where incompatible vegetation is very dense and tall. Selective herbicides are used which maintain the grasses while incompatible trees and shrubs are treated. Herbicide application may be broadcast on larger areas or applied as a spot treatment on smaller areas.	F2, SF2
Low Volume Foliar (LVF)	This application method allows for selective treatment of target vegetation without impacting surrounding desirable plant species. This treatment uses the Thinvert application system whereby selected herbicides are mixed with an oil based material and applied using a unique nozzle design. This method of application results in less total volume of solution applied per hectare (typically 46 liters per hectare or less). Best suited for vegetation under 2.4 meters tall.	MH3, MH1
Low Volume Basal (LVB)	Herbicides are applied to individual target plants to selectively control trees and shrubs up to 15 centimeters in diameter without harming surrounding vegetation. This treatment uses an oil based herbicide and carrier. The mixture is applied to the entire circumference of the stem from the ground to a height of about 30 to 38 centimeters.	BLV3a
Hand Cut Only (Hand Cut)	This technique involves individually cutting target vegetation, usually with a chainsaw. All or part of the above-ground portion of the incompatible vegetation is cut. The root system of the incompatible vegetation is not affected which frequently results in dense thickets of re-sprouted brush.	HC1

source: https://sites.psu.edu/transmissionlineecology/management-practices/

METHODS

SGL33 Survey Plots

For the 2020 Carabid survey, we delineated one 50-meter length by 25-meter width survey plot at seven different vegetation treatment areas located within SGL33 (Figure 1). These seven plots represent the five different vegetation management regimes last utilized at SGL33 in 2016: "**M4**" (mow only), "**F2**" and "**SF2**" (high-volume foliar), "**MH3**" and "**MH1**" (low-volume foliar), "**BLV3a**" (low-volume basal), and

"**HC1**" (hand cut only). In May 2020, before installing our beetle traps, our original **BLV3** plot was partially and unexpectedly razed. Therefore, for this study, we delineated a new "**BLV3a**" plot in an adjacent, undamaged portion of the BLV3 management area (Figure 2).

Each of the seven plots at SGL33 contained six pitfall traps, installed in three transects of two (Figure 3). Within each transect, pitfall traps were spaced approximately 15 meters apart, and between transects pitfall traps were spaced approximately 12.5 meters apart. Trap spacing is important, as each trap needs to be separated from neighboring traps by 10–15 meters, in order to minimize "trap-to-trap interference" (Work et al. 2002). Pitfall traps on the edge of the transects were spaced approximately 5 m from the long edge of the plot, and approximately 12.5 meters from the short edge of the plot. Because of the heterogenous landscape of each plot, traps could not be positioned in the perfect grid pattern as shown in Figure 3. For all seven plots combined, there were a total of 42 pitfall traps installed at SGL33 in 2020.

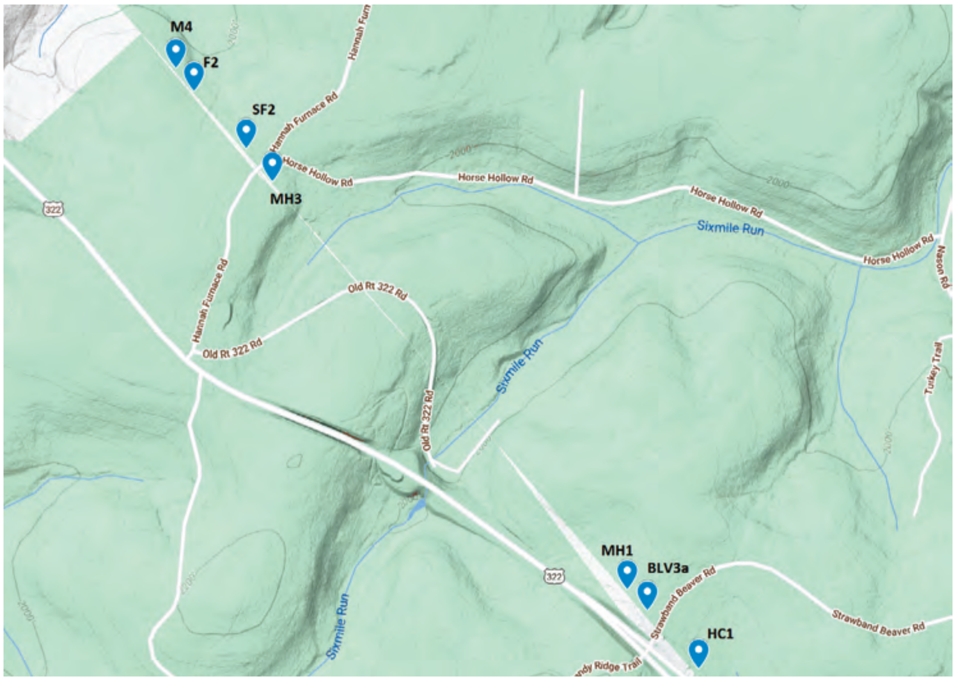

Figure 1. Locations of the seven plots sampled in the 2020 Carabidae Survey at SGL33

Figure 2. Location of the "BLV3a" plot sampled in the 2020 Carabidae Survey at SGL33

Pitfall Trap Design

Following the design used by Leslie et al. (2009), each pitfall trap (Figure 4, left) consisted of:

- **One large outer container**: 946-milliliter (32 ounce) plastic deli container (14 centimeters depth x 10.9 cm inside diameter [ID]), inserted flush with the ground. This outer container remained in the ground for the *entire season*
- **One inner trap sample cup**: 162-milliliter (5.5 ounces) plastic souffle cup (5.5 cm depth x 8.2 cm ID), placed inside the larger container
- **70 mL of preservative solution in the trap sample cup**: 1:1 mixture of food-grade propylene glycol and 70% denatured ethyl alcohol
- **One funnel**: an inverted top of a 2-liter soda bottle, inserted flush with the ground
- **One rain cover**: three 6.35 mm x 127 mm (1/4 inch x 5 inch) carriage bolts inserted into a 164-millimeter (6.48 inch) diameter plastic lid
- **Flagging** to mark each trap's location
- **Lids** for each large outer container and for each inner trap sample cup

The purpose of the smaller trap sample cup inside the large outer container was to allow for monthly removal of samples without removing or damaging the pitfall trap. The propylene glycol/ethyl alcohol mixture is nontoxic to mammals and humanely kills and preserves the invertebrates in the pitfall trap. The purpose of the funnel was to trap only small invertebrates and exclude larger animals, such as shrews or amphibians. The elevated rain cover prevents the pitfall trap from filling with rainwater (Figure 4, right).

Pitfall Trap Installation

Upon arrival at each plot, we used a 100-meter measuring tape wheel and the pitfall trap array shown in Figure 3 to measure and then "mark" the target location of each pitfall trap. We placed one large outer container at each targeted trap location before moving to measure and mark the next trap. We repeated this until all six trap locations were marked.

Using a tree planting bar ("dibble bar"), we dug at each trap location. The opening for each trap needed to be approximately 14.1 cm deep and with a diameter of 10.9 cm, so that the large outer container would sit flush or slightly lower than the level of the ground. If an opening of that size could not be dug at the targeted trap location, we searched for a more compatible area that was as close as possible to the original target location.

After the digging was complete and the large outer container was set in place, flagging was tied to tall, stable vegetation located within 1 meter of the trap. This was repeated until all six traps were ready to set at each plot.

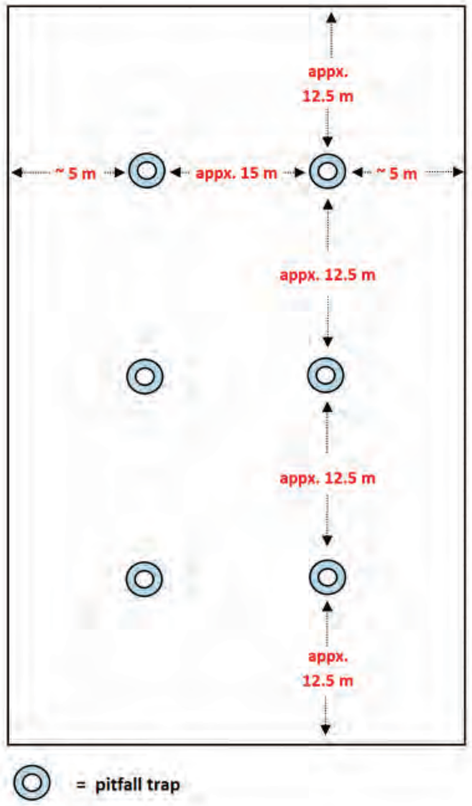

Figure 3. Theoretical pitfall trap array for each plot

Monthly Pitfall Trapping

The 2020 Carabid collections took place over the course of 13 weeks, from June 5–August 30. There were four 72-hour sampling periods:

- June 5–8 (Week 1)
- July 3–6 (Week 5)
- July 31–August 3 (Week 9)
- August 27–30 (Week 13)

Before each collection period, the sides of the inner trap sample cups were labeled with the collection week (1, 5, 9, or 13), the plot name, and the trap identifier (A–F). This same information was written on a paper label and placed inside the inner trap sample cup.

At the start of each of the four collection periods, one large outer

Figure 4. Left: Assembled pitfall trap containing preservative solution. Right: Pitfall trap and rain cover at BLV3a. (Source: H. Stout)

container was set into its hole. Approximately 70 mL of a 1:1 food-grade propylene glycol/denatured ethyl alcohol solution was added to an inner trap sample cup, which was then set inside the outer container. The inverted funnel was placed into the trap, so that the entire assembly was flush with the ground. A rain cover was inserted over the trap, pressing the carriage bolt supports into the soil until the cover was nearly flush with the ground. This was repeated until all traps at all seven plots were set.

After 72 hours, we returned to the plots in the same order as three days earlier. At each trap, we removed the rain cover and the funnel, and then the inner trap sample cup. A lid was placed on the inner sample cup, and the lidded trap sample cup was placed into a zip bag labeled with collection week and plot name. This was repeated at each plot until all six lidded trap sample cups were securely in the plot's zip bag, and until trap sample cups were removed from all seven plots.

For collection weeks 1, 5, and 9, a lid was then placed on the empty large outer container, and the large outer container was set back into the ground until the next collection period. For collection week 13, the outer container was removed and taken with all trap sampling equipment and materials to off-site storage.

Specimen Processing and Identification

The 168 trap samples were stored for approximately 2 to 4 months before processing.

Each sample cup was emptied and rinsed with denatured ethyl alcohol into a sorting tray. Pinnable beetles were removed from the tray, then washed, dried, pinned, and labeled with collection week, plot name, and the trap identifier (e.g., "Trap A"). Non-beetle invertebrates and beetles that were too small to pin were removed from the sorting tray and placed into 1- or 2-dram glass vials filled with 70–95% denatured alcohol. Each vial contained a label with the sample cup's collection week, plot name, and the trap identifier.

Ground beetles were identified to the lowest practical level (LPL). Taxonomic resources used to identify Carabids are listed in the references of this paper. All but two ground beetle specimens were identified to Species or "species group" by the SGL33 research project's entomologist. Two undetermined specimens were sent to Peter Messer, a Carabid beetle specialist at the Milwaukee Public Museum (MPM), who provided the correct IDs. These two specimens are now part of the Invertebrate Zoology Collection at the MPM (*https://www.mpm.edu/index.php/research-collections/zoology/invertebrate-zoology*). The remaining ground beetles were taken to the Frost Entomological Museum at Penn State, where the IDs were confirmed or corrected by comparing them with the museum's specimens.

Other beetles were identified to Family (or to Genus or Species if the specimen was easily recognizable). Most non-beetle specimens were identified to Order—exceptions include millipedes (Class Diplopoda), mites/ticks (Superorder Acariformes), and certain groups within the Order Hymenoptera. For Hymenoptera, easily recognizable groups, such as ants and ichneumonid wasps, were identified to Family (i.e., Formicidae, Ichneumonidae); more difficult groups, such as chalcidoid wasps, were left at the Superfamily level (Chalcidoidea).

RESULTS

After 288 trap hours, a total of 7,847 specimens—ground beetles, "other" beetles, and non-beetle invertebrates—were collected at SGL33 in 2020. The most invertebrate specimens were collected from **MH3**, and the fewest from **HC1**, but the greatest relative abundance of Carabids was at **HC1**, and the lowest relative abundance was at **MH1** (Table 2).

Table 2. Relative Abundance of Ground Beetles per Plot at SGL33 for 2020

SGL33 - 2020 GROUND BEETLES			
% GROUND BEETLES OF TOTAL SPECIMENS PER PLOT			
Plot	Total # of Ground Beetles	Total # of Specimens	Carab = % of Total
M4	16	1176	1.36%
F2	20	1291	1.55%
SF2	15	1260	1.19%
MH3	21	**1525**	1.38%
MH1	**9**	810	**1.11%**
BLV3a	15	997	1.50%
HC1	**57**	**788**	**7.23%**

Ground Beetle Abundance

In 2020, we collected 153 Carabids from the seven SGL33 plots. The most ground beetles were collected from the **HC1** plot and the fewest ground beetles were collected from the **MH1** plot (Table 2).

For all plots combined, Week 1 had the highest total ground beetle abundance of the collection season and Week 5 had the lowest total ground beetle abundance. The collection weeks in which the most Carabids were collected from each plot are shown in Figure 5.

Ground Beetle Taxa Richness

In 2020, we collected 45 ground beetle taxa at SGL33 (Tables 3 and 4). The most Carabid taxa were collected at **MH3** and **HC1**, and the fewest were collected at **MH1** (Tables 3 and 4).

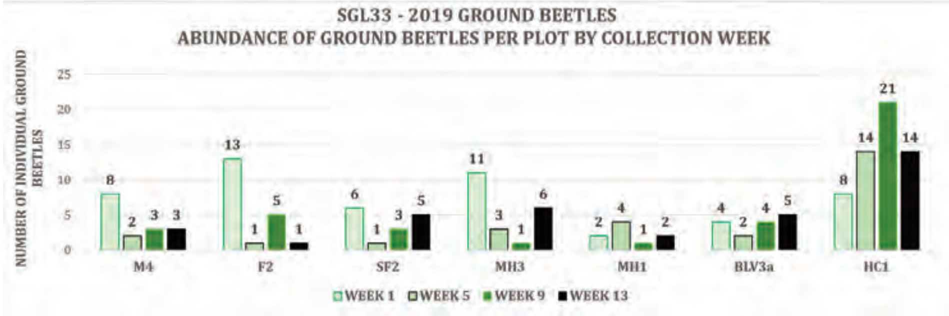

Figure 5. Abundance of ground beetles per plot by collection week at SGL33 for 2020

Table 3. Ground Beetle Taxa Present at SGL33 in 2020

MAY - AUGUST 2020 GROUND BEETLE TAXA	PITFALL TRAP COLLECTIONS (288 total trap-hours per plot) M4	F2	SF2	MH3	MH1	BLV3a	HC1	# individuals per taxon:
CARABIDAE								
CARABINAE								
Carabini								
Carabus goryi				1				1
Carabus serratus			1			1		2
Cychrini (incl. "small snail-eating ground beetles")								
Sphaeroderus canadensis					1			1
Sphaeroderus canadensis canadensis					1			1
Sphaeroderus stenostomus						1	2	3
Sphaeroderus stenostomus lecontei					1		2	3
CICINDELINAE (tiger beetles)								
Cicindelini (flashy tiger beetles)								
Cicindela sexguttata (six-spotted tiger beetle)	5	5	3	5				18
Cicindela tranquebarica (oblique-lined tiger beetle)					3			3
Cicindelidia rufiventris (eastern red-bellied tiger beetle)					1			1
HARPALINAE								
Chlaeniini (incl. "vivid metallic ground beetles")								
Chlaenius emarginatus	1	1	1				17	20
Harpalini								
Agonoleptus conjunctus		1		1				2
Anisodactylus nigerrimus				1				1
Harpalus laticeps		1						1
Harpalus pensylvanicus (Pennsylvania dingy ground beetle)		1		2				3
Harpalus rubipres				1		1		2
Harpalus somnulentus	1	2						3
Stenolophus humidus/plebejus (a species of "seedcorn beetle")	1							1
Trichotichnus autumnalis	1					1		2
Lebiini								
Cymindis americana		1						1
Lebia ornata (a species of "colorful foliage ground beetle")		1						1
Syntomus americanus	3	2						5
Licinini (incl. "notched-mouth ground beetles")								
Dicaelus dilatatus				1				1
Dicaelus dilatatus dilatatus			1					1
Dicaelus politus			1					1
Dicaelus sp. (larva)			1					1
Platynini								
Agonum nutans							2	2
Agonum palustre							1	1
Platynus angustatus						1		1
Rhadine caudata						1		1
Pterostichini (woodland ground beetles)								
Cyclotrachelus sodalis				1				1
Myas cyanescens	1							1
Poecilus lucublandus			1	3		1	1	6
Pterostichus adoxus	1					1	8	10
Pterostichus coracinus							5	5
Pterostichus mutus	2	2				2	4	10
Pterostichus novus							1	1
Pterostichus rostratus				1	1		1	3
Pterostichus stygicus			2	1				3
Pterostichus tristis				1			4	5
Sphodrini								
Calathus gregarius				1				1
Calathus opaculus		1				1		2
Synuchus impunctatus			1			1	8	10
NEBRIINAE								
Notiophilini								
Notiophilus aeneus						1		1
Notiophilus aquaticus/borealis			1					1
TRECHINAE								
Bembidiini								
Elaphropus vernicatus		2	1					3
undet. CARABIDAE larva			1	1	1	2	1	6

MAY - AUGUST 2020 GROUND BEETLE TAXA	PITFALL TRAP COLLECTIONS (72 trap-hours per plot) M4	F2	SF2	MH3	MH1	BLV3a	HC1	
								total individuals:
TOTAL INDIVIDUAL GROUND BEETLES PER PLOT	16	20	15	21	9	15	57	153
								total taxa:
TOTAL GROUND BEETLE TAXA PER PLOT	9	12	11	13	6	12	13	45

For all plots combined, Week 1 had the highest total ground beetle taxa richness of the collection season and Week 5 had the lowest total ground beetle taxa richness. The collection weeks in which the most ground beetle taxa were collected from each plot are shown in Figure 6.

Ground Beetle Diversity

Diversity Indices (DIs) are mathematical methods of characterizing the diversity of a community, beyond taxa richness. Unlike taxa richness, DIs factor in the relative abundance of each taxon. Evenness (E) is the measure of the similarity of abundances among the taxa of a community on a 0 to 1 scale; for example, a community with an equal number of individuals per taxon will have an Evenness value of 1. Evenness is an essential component of a DI.

Two commonly used DIs are the Shannon Diversity Index (H) and the Simpson's Index of Diversity (1 - D). From each of these Indices, Evenness can be calculated (e.g., Shannon's E_H and Simpson's E_D).

Shannon Diversity Index (H)

The Shannon Diversity Index (H) is a mathematical measure of diversity: it is calculated by multiplying -1 by the sum of the natural logarithms of the proportions of each taxon relative to the total number of taxa. Shannon's H accounts for both the abundance and the equitable distribution (Evenness) of taxa in a community. All taxa are weighted evenly, therefore a few rare taxa can have a strong effect on the outcome.

Shannon's DI was highest for **BLV3a** and lowest for **MH1** (Table 5).

Table 4. Total Taxa Richness of Ground Beetles per Plot at SGL33 for 2020

SGL33 - 2020 GROUND BEETLES TOTAL TAXA RICHNESS OF GROUND BEETLES BY PLOT	
Plot	**Number of Taxa**
M4	9
F2	12
SF2	11
MH3	**13**
MH1	6
BLV3a	12
HC1	**13**

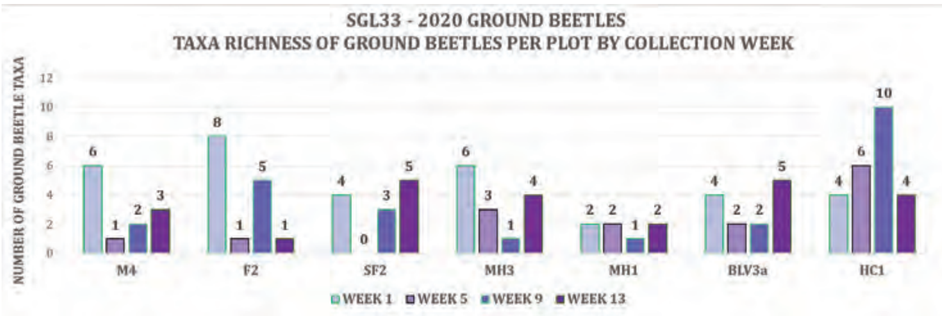

Figure 6. Taxa richness of ground beetles per plot by collection week at SGL33 for 2020

Table 5. Shannon's Diversity Index for Ground Beetles per Plot at SGL33 in 2020

2020 SGL33 GROUND BEETLES SHANNON'S DIVERSITY INDEX		
	Shannon's DI	**Evenness**
M4	1.977	0.900
F2	2.316	0.932
SF2	2.305	0.961
MH3	2.359	0.920
MH1	1.667	0.931
BLV3a	**2.458**	**0.989**
HC1	2.155	0.840

Simpson's Index of Diversity (1 - D)

Simpson's Index of Diversity (1 - D) is another mathematical measure of diversity. This index represents the probability that two randomly selected individuals from one community are of different taxa. It is calculated by subtracting 1 from the sum of the squared proportions of each taxon relative to the total number of taxa. As with Shannon's H, Simpson's Index accounts for both the abundance and the evenness of taxa in a community. Unlike Shannon's H, Simpson's 1 - D places more weight on dominant and/or common taxa, therefore a few rare taxa do not have as much of an effect on the probability.

Simpson's 1 - D was highest for **BLV3a** and lowest for **MH1** (Table 6).

Table 6. Simpson's Diversity Index for Ground Beetles per Plot at SGL33 in 2020

2020 SGL33 GROUND BEETLES SIMPSON'S DIVERSITY INDEX		
	Simpson's DI	Evenness
M4	0.828	0.646
F2	0.880	0.694
SF2	0.888	0.810
MH3	0.880	0.641
MH1	0.781	0.762
BLV3a	**0.911**	**0.939**
HC1	0.844	0.492

DISCUSSION

In 2016, the following vegetation management methods were employed at SGL33:

- Mow only (no herbicide): **M4**
- High-Volume Foliar: **F2, SF2**
- Low-Volume Foliar: **MH3, MH1**
- Low-Volume Basal: **BLV3a**
- Hand Cut Only (no herbicide): **HC1**

The fewest Carabids (Table 2) were collected at **MH1. MH1** also had the lowest relative abundance of ground beetles (Table 2) and the lowest Diversity Indices (Tables 5 and 6). This may be related to the low density and diversity of vegetation that we observed at **MH1** relative to the other six plots, or this may reflect a bottom-up effect due to a reduction in prey species that could have been brought about by vegetation management practices.

The fewest ground beetle taxa were collected at **MH1** and the most ground beetle taxa were collected at **MH3** and **HC1** (Table 4). Low-volume foliar herbicide applications were used at both **MH1** and at **MH3**, yet Carabid taxa richness differed greatly between the two plots.

The number of ground beetles, and the relative abundance of ground beetles, was greatest at **HC1** (Table 2). This is due in part to the abundance of one common species at this plot (*Chlaenius emarginatus*), and to the greater number of "woodland ground beetle" taxa (Tribe Pterostichini) at **HC1** (Table 3), a plot which provides the type of habitat in which these taxa thrive. Also, forestland Carabid communities have been shown to have higher species richness than those of agroecosystems (Leslie 2014).

Despite relatively low abundance and taxa richness at **BLV3a**, Shannon's DI was highest for this plot, which could be due to the number of "singletons" (species represented by a single individual) collected at **BLV3a**. Simpson's DI and both measures of Evenness were also highest for **BLV3a**, which strengthens the argument for this interpretation.

If the use of herbicides were to impact ground beetle abundance, taxa richness, and diversity at SGL33, then we would expect to find the most ground beetles and the most ground beetle taxa at **M4** and **HC1** and the fewest ground beetles and ground beetle taxa at **F2** and **SF2**, with intermediate abundance and richness at **MH3**, **MH1**, and **BLV3a**. This is not what we found in our 2020 collections.

Ground beetles have adapted to nearly every type of habitat: terrestrial and aquatic, woodland canopies and open deserts, coastlines, and caves. As of June 26, 2022, there are 543 known species of ground beetles in Pennsylvania (524 native, 19 adventive) (Bousquet 2012; Messer, personal correspondence, June 16 2022). The agricultural importance of Carabids—as predators of both invertebrate pests and weed seeds—has fueled significant ground beetle research in the agricultural systems of this state. The ground beetle communities that inhabit powerline clearings in Pennsylvania are not as well studied, and more research is needed. Our collection of 45 species at SGL33 in 2020 represents only 8.3% of the state's known Carabid species. For context, a two-year study of sweet and field corn farm systems in Pennsylvania used a total of 5,040 trap samples to collect 49 ground beetle species (Leslie et al. 2009). Our one-year study used a total of 168 trap samples to collect nearly the same number of species. The proximity of dense woodland habitat to our survey plots at SGL33 is likely favorable for ground beetle taxa richness. Is this richness typical for powerline clearings in the state? For powerline clearings in general?

The 2020 ground beetle survey at SGL33 was conducted prior to integrated vegetation management treatments that were administered in 2021, and a post-treatment Carabid survey at SGL33 in 2022 was conducted. We hope that these post-treatment data—and more ground beetle surveys at utility ROWs—will help us find answers to these very questions.

CONCLUSIONS

Due to their heterogeneity and relatively diverse plant communities, forests and forest edges of croplands appear to be especially important habitats for ground beetles (Leslie 2014; García-Tejero 2018). The early successional habitats that are maintained in powerline clearings, combined with the woody hand-cut plots and the ecotone of its forested edges, have been shown to provide habitat for the numerous plant and animal taxa that we have studied previously. With the data gleaned from our post-treatment ground beetle survey in 2022, we expect further insights into the habitats that SGL33 and other ROWs provide—and the potential effects, benefits and/or costs of maintaining those utility corridors on ground beetle abundance, richness, and diversity.

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Hannah L. (Cave) Stout, PhD, is a freelance Conservation Entomologist and Society for Freshwater Science (SFS)–Certified Macroinvertebrate Taxonomist based in State College, Pennsylvania. Her graduate research project for Penn State was an exploration of the "Eastern green drake" mayfly's extirpation from Spring Creek (Centre County, PA) in the 1950s, for which she earned the SFS Graduate Student Conservation Research Award in 2009. Since 2016, her primary focus is studies of insect diversity on transportation and utility ROW, but she also identifies freshwater macroinvertebrates for consulting firms based in Pennsylvania and in West Virginia. Dr. Stout is Past President of the Friends of the Frost Entomological Museum (FFEM) of Penn State University, and Past Vice President of the Keystone Water Resources Center (KWRC), and has contributed to the Spring Creek Watershed Atlas. Currently, she serves on the Board of the Association of Mid-Atlantic Aquatic Biologists (AMAAB) and is a member of the Pollinator Scorecard development team for the Rights-of-Way as Habitat Working Group (ROWHWG).

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Ian Fisher received a Bachelor of Science degree in environmental studies from the Penn State University, Altoona campus. He was the Student Marshal for the Division of Mathematics and Natural Sciences during the fall of 2021. Fisher worked as a research assistant from 2019 until 2021, examining the response of wildlife populations, including insect pollinators, neotropical migratory birds, ground beetles and herpetofauna, to integrated vegetation treatment methods in ROWs. His particular area of interest is in reptiles and amphibians, specifically snakes. Presently, Fisher is continuing his work with herpetofauna.

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Rights-of-Way Vegetation Maintenance Activities and Endangered Species Act Compliance: A Due Diligence Review Process

Andrea Sampson

Keywords: Avoidance and Minimization Measures (AMM), Bald and Golden Eagle Protection Act (BGEPA), Candidate Conservation Agreement with Assurances (CCAA), Conservation Measures, Endangered Species Act (ESA), Impact Analysis, Habitat Conservation Plan (HCP), Integrated Vegetation Management (IVM), Migratory Bird Treaty Act (MBTA), Pollinators, Section 9, U.S. Fish and Wildlife Service (USFWS), Vegetation Management.

Rules governing vegetation management in rights-of-way (ROW) are wide-ranging and dependent upon the requirements of the given regulatory authority. However, one constant is the need to comply with federal laws by avoiding unauthorized take as defined by the Endangered Species Act of 1973, the Migratory Bird Treaty Act, and the Bald and Golden Eagle Protection Act. Many states also have regulations protecting sensitive state resources. In addition, ROW are increasingly identified and leveraged for their ability to provide habitat and connectivity for a growing number of protected and at-risk species.

A robust environmental review process tailored to vegetation management projects is a customizable tool to assist in the protection of these resources. Review of projects for their potential to impact listed species coupled with the implementation of appropriate avoidance and minimization measures can greatly reduce the risk that project activities will result in unauthorized take and will ensure that ROW continue to play a role in providing quality habitat for at-risk and protected species. The creation of customized deliverables in the form of guidance documents, maps, and spatial data provide clarity for operations managers and crews and ensure the results of the review process are carried through to project completion.

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INTRODUCTION

Vegetation maintenance activities have the potential to impact sensitive resources and could cause unauthorized take of protected species. While this work often lacks a federal nexus triggering U.S. Fish and Wildlife Service (USFWS) Endangered Species Act (ESA) Section 7 consultation, Section 9 of the ESA ("Prohibited Acts") states ". . . with respect to any endangered species of fish or wildlife listed pursuant to section 4 of this Act it is unlawful for any person subject to the jurisdiction of the United States to . . . take any such species within the United States or the territorial sea of the United States" (USFWS 1973a). Take is defined by the USFWS as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct" (USFWS 1973b). Other federal laws, such as the Migratory Bird Treaty Act (MBTA) and the Bald and Golden Eagle Protection Act (BGEPA) along with a wide variety of state statutes, prohibit unauthorized take, even if that take is incidental to an otherwise lawful activity. Other regulatory authorities may also have certain standards and guidelines that drive the timing and or procedures related to vegetation management, including the Federal Energy Regulatory Commission (FERC), the Pipeline and Hazardous Materials Safety Administration (PHMSA), the North American Electric Reliability Corporation (NERC), and others.

Furthermore, utility, road, recreational, and other types of rights-of-way (ROW) provide connectivity for species via corridors between habitat patches and have the potential to provide suitable nesting, foraging, denning, migratory, and other habitat for a wide variety of wildlife. Over the last decade, ROW have been also identified as a particularly important resource to slow and/or reverse the decline of a wide range of pollinator species. As these areas are increasingly leveraged for their ability to provide habitat and connectivity for a growing number of desirable, at-risk, and/or protected species, strategies such as conservation mowing, idle land set-asides, targeted herbicide use, reseeding or reintroduction of native species, and other methods have been found to produce desirable effects. These and other practices, which often fall under the umbrella of integrated vegetation management (IVM), generate numerous benefits, including creation of habitat for a wide variety of species as well as reductions in wildfire risk, erosion, and associated impacts to water quality. These practices may also lower maintenance costs and provide a more effective vegetation management strategy (USEPA 2021).

While IVM can reduce overall vegetation maintenance costs over time, the time and effort dedicated to developing these more holistic approaches to vegetation management is not insignificant, nor are the costs that may be associated with the transition from more traditional methods. However, IVM and related practices are long-term, systemic approaches to maintaining ROW corridors, and as such, additional tools for ensuring proper implementation may be needed.

In addition, there may be trepidation around implementation of these more holistic approaches as they relate to protected species—the "if you build it, they will come" conundrum. If developing quality habitat for at-risk and protected species in the ROW is successful, how does that impact future projects? How do we ensure compliance with ESA when protected species are assumed or known to occur in the ROW?

While this conundrum could certainly apply to other activities in the ROW (operations and maintenance work, new construction, etc.), for the purposes of this paper, we will keep our focus on vegetation maintenance activities. Here we will discuss tools and approaches that will reduce the risk of unauthorized take of protected species and assist with continued adherence to the holistic, IVM-type processes that have been implemented.

METHODS

The general approach to conducting an environmental review for vegetation management activities is similar to that for other operations and management projects. However, this process assumes the following do not occur/are not necessary:

- Ground-disturbing activities: rutting, removing stumps, etc. constitute ground disturbance and could trigger Army Corps of Engineers (COE) permitting
- Crossing tribal lands
- Federal funding, authorizations, or permits
- Impacting federal lands
    - o COE-owned lands at waterways and jurisdictional wetlands
    - o USFWS conservation ease-ments
    - o Natural Resources Conserva-tion Service (NRCS) lands

These actions could trigger additional review and permitting and are not discussed further here.

Sources

Federal Species Review

The first step in the review for potential impacts to federally protected species is to evaluate the project using the USFWS Information for Planning and Consultation (IPaC) website (USFWS 2022a). Use of this tool will identify a list of species whose range intersects the project areas. These species should then be considered potentially present in the project area until further review can rule out suitable habitat and/or impacts from project activities.

An additional method for understanding the potential risks to federally listed species is to review the natural heritage data for the project area. This data can typically be found through governmental entities which partner with the NatureServe program, which is a network of biodiversity experts which collects, curates, and shares the location and ecological condition of at-risk species and ecosystems at regional, national, and international extents (NatureServe 2022a). Management and access to these data sets vary by state; a review of the NatureServe network will identify the particular administrator for each state (NatureServe 2022b). These datasets include spatial data related to known current and historical occurrences of protected species, including those listed under the ESA.

State Species Review

Depending on the state statute where the work is taking place, a review for state-listed species may also be necessary. Not all states maintain a state-based list, and not all states prohibit incidental take. However, if a review is determined to be necessary, the natural heritage data will be the best resource for this information.

Much like the IPaC review, the natural heritage data from the NatureServe program can be used to narrow the scope of potential impacts to state-listed species. Species with known records within or in the vicinity of the project areas can be more closely reviewed for the presence of suitable habitat and potential impacts.

Note that some states (e.g., Wisconsin, Minnesota) have formalized review processes that require the project proponent to submit a review to and receive a response/concurrence from the agency tasked with protected species management. This process varies greatly state by state and will depend on the statutes associated with threatened, endangered, at-risk, and sensitive resources.

Migratory Bird Treaty Act

While some regulatory bodies prohibit work during the primary window for migratory bird nesting (e.g., FERC), there may be a need to review the project for impacts to migratory birds (FERC 2013). Mowing, brushing, and tree removal may cause unauthorized take of ground- and tree-nesting birds if conducted during the nesting season. Breeding and nesting dates for birds protected under the MBTA are not always available in an easy-to-access format, particularly at the state level. Here again, IPaC can serve as a tool for identifying these windows.

When using IPaC to conduct a review of a project, the site produces a list of birds of particular concern either because they occur on the USFWS Birds of Conservation Concern (BCC) list or warrant special attention in the project location (USFWS 2021; USFWS 2022a). Currently, there are several caveats to using this data, including:

- IPaC primarily lists BCC species and does not include all species protected under MBTA.
- The dates in IPaC provide a very liberal estimate of the time frame inside which a species breeds *across its entire range*.
- IPaC lists include outlier species that may begin or end breeding/nesting several months earlier or later than the general MBTA window for that area.

Bald and Golden Eagle Protection Act

Per the BGEPA, activities that may cause disturbance to nesting eagles are prohibited in the vicinity of an active nest during the nesting season, generally January 1–July 31 (USFWS 2022b). If work cannot be avoided during the nesting season and there is reason to believe that project activities will disturb an active nest, a permit may be required. While not all vegetation maintenance projects reach the threshold of disturbance, a review of potentially suitable eagle habitat near the project areas is recommended.

While most vegetation maintenance activities will not require removal of trees large enough to support an eagle nest, it is worth noting that removal of a tree containing an eagle nest is also prohibited without a permit, even if the nest is not in use or appears abandoned.

Eagle nest data may be included in the natural heritage data, and the USFWS maintains data regarding known current and historic nests; however, the USFWS data is not publicly available. Neither the natural heritage data nor the USFWS data are comprehensive and they should not be relied upon to eliminate the potential for impacts to bald and golden eagles. Instead, the best review methods include a review of aerial imagery for suitable nesting habitat and field-based surveys conducted during the nesting season to identify active nests within disturbance distances to projects.

Review Process

Generally, once the source data is in hand, the review process is the same across species and regulations: is suitable habitat for these species present in the project areas? If so, will the activities associated with the project have impacts on these species and/or cause unauthorized take?

This review process requires a strong background in ecology, including an understanding of how suitable habitat is defined for a range of protected and at-risk species, as well as knowledge of species' spatial and temporal use of habitat(s). In-depth knowledge of the regulatory environment as it relates to protected species is also critical to the success of this review process in order to avoid over- or under-regulating the project. This includes familiarity with the details of the most recent final rules related to MBTA, BGEPA, and ESA, including species' listings, associated 4(d) rules, programmatic biological opinions, relevant Habitat Conservation Plans (HCPs), broad incidental take permits, and/or other such policies that may except certain activities or focus species' protections in specific ways.

In addition, while reviews are typically focused on threatened, endangered, and protected species, it may be desirable to include a review of public lands, sensitive waterbodies, and other sensitive resources to identify areas where vegetation maintenance activities should be further modified or restricted.

AVOIDANCE AND MINIMIZATION MEASURES

Once the initial review is complete and the potential impacts are known, conservation measures can be developed to avoid and/or minimize those impacts; these would then be applied in areas where suitable habitat is present in project areas. The most commonly used avoidance and minimization measures (AMMs) are often related to a of time-of-year restriction (TOYR). Time-of-year restrictions can be very general (e.g., avoid all work during the migratory bird nesting season) or very specific and tailored to the species (e.g., mechanical clearing is permitted only from November 1–April 30).

Other AMMs may include the following:

- A requirement to spot/target spray herbicides or restrict the use of them altogether
- Raising mower blades to ensure longer vegetation to provide increased cover and/or to prevent damage to nests, individuals, etc.
- Pre-construction survey or sweep to identify nests or individuals, or to flush mobile species, such as snakes, out of the clearing path
- Conduct some or all work under frozen conditions
- Maintenance of buffers around sensitive features
- Mosaic or patchwork mowing/brushing/clearing, where portions of the ROW are left untouched in any given year, also referred to as idle land set-asides
- Hand clearing only

If public lands are included in the review, it's possible that land managers may have additional restrictions or requirements for lands under their purview. These could include prohibiting work during hunting seasons, restricting types of tree clearing, or requiring crews to contact them prior to accessing the property.

DELIVERABLES

Deliverables are customizable for each review or per the project proponent's needs. Maps in paper and electronic format are often the primary tool used for both project planning and in-field work. Map formats can be developed in large scale (e.g., 11 x 17 or D-size maps) to assist managers and crews with the spatial nature of the restrictions. The scope and extent of the AMMs can be easily identified via symbolization and call-out boxes identifying the specific measures for that area.

Supplemental documents with tables calling out AMMs and associated map pages or other location information provide a snapshot of the restrictions and may be helpful for map review, coordination, and scheduling.

More formal documents summarizing the results of the review, including memos outlining the AMMs and any additional restrictions requested by public land managers and others, as well as memos demonstrating compliance with ESA, MBTA, BGEPA, and state regulations, can be developed for managers and project files.

There may be other conservation measures required as well if the project proponent is a partner in a Candidate Conservation Agreement with Assurances (CCAA), HCPs, or another similar program. These programs typically require commitments related to protecting habitat and may include conducting project work outside of the species' active period, encouraging native vegetation through seeding or idle-land set asides, and reduction of impacts through reducing the width of the ROW in sensitive areas (e.g., neckdowns), minimization of workspaces, or other methods. These programs also often require a survey or monitoring component as well that may have both spatial and temporal limitations or stipulations. Including these items in the deliverables, particularly the paper and electronic maps, can help reduce scheduling conflicts, ensure that areas identified for monitoring are left untouched in any given year, and streamline workflow.

Additional tools, such as web map viewers or mobile applications, can be developed to further assist coordinators or teams. More personalized tools, such as on-call guidance, can also be offered to assist managers and crews with real-time questions from the field.

CONCLUSIONS

From a purely functional perspective, there are a number of logistical and scheduling challenges in coordinating vegetation maintenance projects, including access issues, landowner concerns, and availability of equipment, among others. In addition, the need to consider and employ AMMs to prevent unauthorized take of protected species, prevent impacts to sensitive resources, and ensure the continuity and successful implementation of other measures related to IVM, CCAAs, HCPs, and other commitments can make for a very complicated project.

By clearly identifying TOYRs and AMMs on maps and project documents, a review program and the deliverables as described above can assist in long-term planning of vegetation maintenance projects. By providing an overall framework of project impacts and restrictions, managers can better plan access routes, avoid delays and/or remobilizations of staff and equipment, and coordinate with real estate and land management. It can also foster relationships with agencies and public land managers by avoiding surprise coordination and permitting needs on managed lands and reducing the risk of regulatory violations.

In addition to simplifying the overall planning and establishing efficiencies associated with vegetation management projects, this process brings more surety to project proponents regarding compliance with federal and state laws concerning protected species, their commitments in CCAAs, HCPs, and other programs, and provides an additional tool to safeguard their investments in IVM and other holistic vegetation management strategies.

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Use of Detector Dogs in Wildlife Conservation Applications for Utilities

Allison Locatell, P. Chase Bernier, and Christin McDonough

Working dogs have traditionally been utilized for a wide variety of purposes, including agriculture, law enforcement, and hunting. With approximately 50 times more olfactory receptors than humans, detector dogs have recently been employed for numerous conservation applications, beginning in the 1990s. Early detector dogs were trained to locate threatened or endangered wildlife via scent or scat. More recently, detector dogs have been utilized in a wide variety of conservation applications, including identifying spores of fungal diseases, detecting invasive species infestations in tree wood, poaching, environmental hazards, and other applications. The use of detector dogs has consistently been demonstrated to increase the efficacy of surveys while also decreasing survey time. In this case study, we demonstrate multiple applications using detector dogs for various renewable utilities, including surveys for rare wildlife and wildlife mortality. We will detail the methods we utilized to train our detector dogs, how we have used dogs in renewable utility projects, and different challenges and successes we have experienced. Additionally, we will review indicators a dog will make a successful detector dog, how dogs can contribute to the success of rights-of-way (ROW) management projects, and potential future opportunities to employ detector dogs in conservation applications.

Keywords: Avian, Bat, Canine, Conservation, Detection Dog, Rare Species, Renewable, Scat Survey, Technology, Turtle, Utility Lines, Wildlife, Wind.

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INTRODUCTION

The domestic dog (*Canis familiaris*) was first domesticated from wolves (*Canis lupus*) approximately 23,000 years ago (Perri et al. 2021). Since their first domestication, humans have continually worked to selectively breed dogs for desirable genetic characteristics and utilized these characteristics for a wide variety of working purposes. In concert with developing a wide variety of breeds for a diverse range of tasks and needs, extensive training methods have been developed in order to be able to utilize dogs for a wide range of skills. Beyond basic training (e.g., sit, stay, come, etc.), complex training regimes to harness the domestic dog's natural heightened senses, particularly smell, have been utilized.

With an olfactory system that far exceeds humans, dogs have long been deployed in a variety of fields (Kokocinska-Kusiak et al. 2021). Their macrosmatism affords them not only extraordinary olfactory smell, but also memory (Barios et al. 2014; Pirrone and Albertini 2017; Jendry et al. 2021). With their unparalleled ability to detect scents at parts per billion, or even up to parts per trillion (Johnston 1999), the use of detector canines has been rapidly embraced across multiple industries. In respect to wildlife management and conservation applications, detector dogs have been deployed for an assortment of fields, including detecting disease, poached game species, remains of deceased wildlife, and locating cryptic, rare, or at-risk wildlife (Stevenson et al. 2010). Additionally, as macrosmatics, detector dogs have been found to be more efficient at identifying wildlife in the field than humans, by both locating more wildlife and in quicker time than human counterparts (Nussear et al. 2008). Human-led field surveys for particular species can be tedious and costly, sometimes with poor results. Since a dog's olfactory sense is so superior to a human's, there is an increased interest in the emerging science of using dogs for wildlife detection.

The presence/absence surveys we implement require noninvasive, repeatable methods for locating wildlife fatalities and target wildlife species in their natural habitats. In this case study, we demonstrate how we have utilized detector dogs in two conservation applications: (1) detecting avian and bat remains from collisions with windmills and (2) surveying for rare turtles as part of pre-construction and construction monitoring efforts in Texas and Southern New England, respectively. We show how we have been able to successfully utilize human-detector dog pairs to increase our efficacy and efficiency in completing surveys for both wildlife remains and live individuals compared to independent, human-only surveyors. We discuss our processes for selecting potential detector dogs, training for conservation applications, challenges we have encountered in implementing the use of detector dogs, and how we anticipate detector dogs will be utilized for other conservation purposes in the future.

BACKGROUND

Since 2017, SWCA Environmental Consultants (SWCA) has been implementing the use of canine searchers on wind farms in Hawaii to improve our surveys and decrease overall cost effects to our clients. One way in which SWCA has used canines is for rare, threatened, or endangered turtle surveys, where canines are trained to detect specific turtle species for various rights-of-way (ROW) projects. SWCA's largest use of canines has been for post-construction fatality monitoring on wind farms where the canines are trained to find birds and bats killed due to collisions with the turbine blades.

Wind Farm Fatality Monitoring

Bat fatalities resultant from collisions with turbines number in the hundreds of thousands per year and are estimated to potentially exceed over one million in the United States and Canada (Smallwood and Bell 2020). Avian collisions with turbines are similarly detrimental, with fatalities estimated at approximately 234,000 in 2013 (Aishwarya et al. 2016).

Due to these high numbers and a push for more renewable energy sources, fatalities from turbines are of concern to generation companies, regulatory agencies, and conservationists alike. Regulatory agencies frequently require generation utility companies to report their impacts on avian and bat species at their facilities by monitoring for these fatalities and mitigating for total fatalities across an entire wind farm. Added concerns and mitigation costs occur when threatened or endangered species fatalities are likely to occur, making accurate fatality estimates a major concern for wind generation companies and regulatory agencies. However, as part of the fatality monitoring, scientists are routinely challenged with finding bird and bat remains across large areas consisting of dense vegetation, difficult terrain, and other unique challenges that can disturb carcasses and make them more difficult to find. Things like crop rotation and harvest, domestic livestock disturbance, or scavenging predators are some of the many survey challenges that can create bias factors in fatality estimates, sometimes resulting in higher mitigation costs.

Generation utility companies and regulatory agencies are considering ways to reduce these fatality bias factors. One of the ways to do this is to increase the searcher efficiency (SEEF) rates. With human searchers, this can typically be done in several ways: decreasing the distance between survey transects, increasing survey frequency, or increasing the size of a search plot. These changes can extend the survey time while not always increasing the SEEF rates significantly enough, which results in generation companies spending more money for little improvement and requires scientists to think of additional ways to decrease the bias factors in fatality estimates. Since canines have been introduced to avian and bat fatality monitoring, these SEEF rates have greatly improved, resulting in more accurate fatality estimates and faster survey times—which, in turn, can result in fewer required surveys and can save generation companies money.

Rare Turtles

In addition to utilizing canines to survey for wildlife remains, detector dogs have also been deployed to survey for a variety of rare wildlife, including reptiles (Vice and Engeman 2000; Braun 2003; Nuessear et al. 2008; Stevenson et al. 2010; and Kapfer et al. 2012). In the Northeastern United States, several organizations have recently utilized detector dogs for various fields, including pre-construction turtle surveys and research. In Massachusetts, our scientists previously deployed detector dogs to survey for eastern box turtles (*Terrapene carolina*), a rare species in Massachusetts. Eastern box turtles are a habitat generalist species (with the exception of nesting habitat) and use a variety of habitat types seasonally (Dodd 2001; Kaye et al. 2001). Eastern box turtles are primarily an upland species; however, they sometimes utilize shallow wetlands in the warmer months to maintain their body temperature and moisture (Kaye et al. 2001; Willey 2010). Typical eastern box turtle habitat includes mature upland forests, early- to mid-successional uplands, shallow wet meadows, gravel pits, powerline ROWs, and edge/ecotone habitats. Eastern box turtles nest in sandy areas with little to no vegetation and with direct exposure to sunlight. Evidence has shown eastern box turtle hibernacula to include depressions in forested areas where there is abundant coarse woody debris, high percent cover of deciduous tree basal area, presence of dense shrub cover (or early-/mid-successional growth), and naturally occurring depressions such as tip-ups (Willey 2010). This species is commonly associated with sandy, well-drained soils. The cryptic coloration on their carapace provides excellent camouflaging, making this species particularly difficult to visually locate during surveys.

For projects that may adversely impact habitats of rare turtles, regulatory authorities frequently require multiple mitigative measures to reduce permanent adverse impacts to the population. In addition to other measures, project proponents will often be required to install turtle exclusion fencing (i.e., silt fence or similar) and complete pre-construction turtle surveys within the limit of work to relocate any turtles from within the work area to adjacent suitable habitat. For projects that impact eastern box turtles in Massachusetts, pre-construction surveys to remove turtles from within the limit of work routinely require a minimum of four survey-person hours per acre of forested habitats and two survey-person hours per acre for field habitats. Additionally, many permit authorizations require turtle surveys during construction to ensure the turtle barrier remains intact and functioning as intended throughout active construction, and to relocate any turtles within the limit of work that may have been missed during pre-construction surveys.

This level of survey effort is costly, sometimes with few or no observations of the target species (“negative” survey results), particularly given the species’ cryptic nature. Using the estimates of Kapfer et al. (2012), human surveyors were able to find 22 eastern box turtles per 316.5 survey hours, whereas canine-human teams are able to find 25 turtles in only 3 survey hours. The clear demonstration that detector dogs are more efficient at finding turtles cannot be understated. Therefore, we intended to capitalize on that efficiency and utilize detector dogs to provide pre-construction turtle sweeps and construction turtle monitoring.

METHODS

Conducting biological field surveys with canines requires specific skill sets, an understanding of regulatory agency requirements, and an understanding of the current methods used for canine detection. Experienced biologists and carefully trained canines performing trial studies are needed to investigate potential improvements as well. SWCA Environmental Consultants have investigated this need for improvement by working to create a standardized detection canine program.

Canine Training

Initiating a canine program and creating a canine-handler team includes selecting the dog, obtaining target odors, and training both the canine and handler. The canine team begins with the selection of a canine. Several core characteristics in the selected canine essential for performing the work successfully include genetic working drive, environmental stability, sociability, and certain physical characteristics like stamina, size, and coat type.

Obtaining the target odor is often the next step in the process. Whether the training target odor is alive, dead, or inanimate, this comes with its own unique set of challenges. When training a dog to find live or dead animals, obtaining the specimens needed for training can sometimes require trapping and handling. Trapping, handling, or collecting protected species requires previous experience with the species and a permit issued by state or federal regulatory agencies. While training the dog to find scat of a specific species could require DNA testing on collected samples in order to ensure the scat collected for training are from the correct target species. Another hurdle with obtaining odor includes odor storage. Live specimens often can’t be held in a permit holder’s possession for the length of time needed for training. Therefore, repeated trapping, handling, and collection of odor should be done to continue the dog's training. If training a dog to find collected odor, the specimens must be stored in ways to avoid odor contamination from outside sources, as well as rotated out with new, fresh odor to maintain its integrity.

The general training and initial imprinting of the dog on a target odor can be started next. Many aspects of training take place when getting a dog field-ready, but the main step is making sure the dog can consistently identify the target odor. This process of training the dog on a specific odor is called imprinting. When the dog is introduced to target odor, it is consistently rewarded within the odor's presence, which conditions the dog into wanting to find this odor to receive their reward. As this imprinting process takes place, a specific behavior or alert on the odor is paired with locating the odor. Usually, the alert is a trained, conditioned response chosen by the trainer, like sit, down, bark, or point. The chosen trained response is what alerts the handler that the dog has found the target odor. Further training of the dog, like general obedience and safety procedures, are also done but kept separate from initial imprinting until they can be slowly combined as training progresses.

Training of the handler is required as well for the canine handler team to be field-ready. The handler should have previous canine training and handling experience, knowledge of general dog behavior, detection handling techniques, dog training practices, and odor behavior. Once teamed up, the canine and handler should prove their effectiveness as a team in both cohesiveness and performance. Once the team has proven positive, consistent results during a search, cohesiveness as a team, and demonstrated necessary obedience skills, they can be deployed on a survey.

Wind Farm Fatality Monitoring Trial Study

In order to evaluate the efficacy of utilizing detection dogs to complete fatality monitoring surveys at wind farm facilities, we selected two wind farms in Texas and compared human and canine SEEF rates. The canine handler is a seasoned field biologist and experienced surveyor for avian and bat fatalities at both wind and solar farms. Her canine partner, Moxie, is a two-year-old springer spaniel—both owned and trained by Allison Locatell, SWCA Assistant Project Manager and Fatality Search Dog Handler—for wind farm fatality monitoring. Moxie was chosen for the work because of her selective breeding as a hunting line spaniel and her inherent drive for searching. Her genetic drive for work, sociability, and behavioral stability in the field met necessary qualities required of a working canine.

Field trials for the two selected wind farms were held in the spring survey season of 2021 in three vegetation levels commonly found on wind farms in the region: no vegetation (bare ground), ankle height (low) vegetation, or knee height (medium) vegetation.

Trial surveys compared SEEF rates of a canine-handler team to a traditional human surveyor in finding bat and small bird carcasses. Our team used small bird carcasses and bat carcasses for the purpose of these trials due to their typically lower SEEF rates as compared to medium- and large-size carcasses. We used real bat carcasses as sample carcasses, collected from previous wind farm fatality monitoring efforts, and stored in a freezer for both trials. We purchased two-week-old, frozen quail (*Cotumix cotumix*) carcasses from a large animal feed company to represent the small bird carcass size class typically found on wind farms. We tagged each sample carcass with black duct tape, assigned with a unique identifier, prior to placement on a survey plot to differentiate between placed carcasses versus real fatalities.

A proctor scientist was assigned the task of placing sample carcasses within the turbine survey plots at randomly generated points, created using ArcGIS, on each wind farm. The number and type of carcasses placed for each turbine was also random to maintain a blind search for both teams. At each random point, the proctor tossed the sample carcass 10–15 feet and logged the distance and cardinal direction in which it was thrown. The proctor placed carcasses in this way to prevent the canine searcher from tracking human odor directly to each placed carcass. Both the human searcher and canine-handler team completed surveys on the same days for the same sample carcasses. The canine-handler team searched each survey plot first, primarily surveying perpendicular to the wind in a zig-zag pattern across the survey plot. The canine wore a Dogtra Pathfinder Global Positioning System (GPS) collar which recorded the canine's survey path and allowed the handler to visualize the canine's coverage on each survey plot in real time. Recovered and discovered carcasses were documented by the handler using the Collector application synced with a Geode GPS unit. All found carcasses were left in place for the human searcher who then surveyed the same turbine plot, following their designated survey transects once the canine-hander team had left the location. The human searcher also documented found carcasses in this way and left all carcasses where they were found for the proctor to collect after both teams had completed their surveys.

Twelve turbines were selected for the trial surveys at each wind farm test site. The survey plots on both test sites consisted of 100-meter x 100-meter square plots centered on each turbine, with the human searcher's transects spaced six meters apart. The survey plots at Test Site 1 (TS-1) were surrounded by active agricultural fields but contained tilled and maintained bare ground within their boundaries. We used a total of 40 sample carcasses (20 bats and 20 quail) for TS-1, since only one vegetation class was evaluated at this site. The survey plots of Test Site 2 (TS-2) were situated in livestock rangeland grazeland fields, vegetated with either low vegetation cover (ankle height) or medium vegetation cover (knee height). Some survey plots at TS-2 also contained large herds of cattle ranging in and around the survey plots during the trial. A total of 80 sample carcasses (40 bats and 40 quail) were used for TS-2, since two vegetation cover classes were evaluated at this site.

Rare Turtles

Between 2007 and 2012, we deployed one canine-handler team to survey for eastern box turtles at various sites where pre-construction and/or turtle surveys were involved, at sites throughout Massachusetts. The canine-handler team consisted of one purebred American chocolate lab canine, June, and her handler, Christin McDonough, a non-game wildlife biologist who specializes in herpetology and wetland science. June had a strong drive for detection, a high energy level, excellent fitness, and extreme sociability. All rare species surveys in Massachusetts are required to follow state-approved survey protocols and all handlers are required to be in possession of a valid Scientific Collection Permit, authorizing the permit holder to handle rare species.

The canine was fitted with a specific working vest to signal the start of the survey and communicate to the canine it was time to begin a search effort. The canine was trained to follow specified commands as well, signaling the initiation of a turtle search. In the field, the canine was allowed to roam unleashed and would indicate to the handler via a verbal cue whenever an eastern box turtle was encountered. The canine was trained to indicate for eastern box turtles using a passive indication, and no turtles were physically moved by the canine. Following successful identification of the target species, the canine was rewarded with a short game of "fetch" using a tennis ball.

RESULTS

Wildlife Strikes

The results of the trials demonstrate that the canine searcher method was more

TS-1	Carcasses Present	Found	SEEF%	Average Survey Time per Turbine
Canine	39 bats 40 quail	18 bats 24 quail	53.2%	42 min.
Human	39 bats 40 quail	6 bats 11 quail	21.5%	26 min.

TS-2	Carcasses Available	Found	SEEF%	Average Survey Time per Turbine
Canine	19 bats 20 quail	9 bats 10 quail	51.3%	20 min.
Human	19 bats 20 quail	17 bats 16 quail	84.6%	30 min.

successful than the typical human searcher method in both their SEEF rates and survey speed. On TS-1, 39 of the 40 sample carcasses placed by the proctor were still present at the time of the first search. One of the placed bat carcasses had been scavenged by a predator prior to the canine-handler team's search. Although this bat carcass had been scavenged prior to the search, Moxie showed a high level of interest at a specific location of bare ground with a small concentration of ants on one of the survey plots. This location was documented by the handler and later confirmed by the proctor as the location of the scavenged bat carcass.

Out of the 19 bat carcasses and 20 quail carcasses, the canine found 17 bats (89.5%) and 16 quail (80%), while the human searcher found 9 bats (47.3%) and 10 quail (50%). The canine outperformed the human searcher by an average of 73% on TS-1. Additionally, the canine had an average survey speed of 20 minutes per turbine while the human searcher had an average survey speed of 30 minutes per turbine.

Results for TS-2 showed similar trends. Only 79 of the 80 sample carcasses placed by the proctor were still present at the time of the first search. However, Moxie was able to detect the duct tape tag of the missing carcass which contained teeth puncture marks, indicating the carcass had been scavenged from the site. Of the 39 bat carcasses and 40 quail carcasses placed on TS-2, the canine found 18 bats (46%) and 24 quail (60%), while the human searcher found 6 bats (16.6%) and 11 quail (27.5%). The canine outperformed the human searcher by 147% on TS-2. The survey speed of both searchers also exhibited a similar trend as TS-1, where the canine completed a faster average survey speed than the human searcher. The canine had an average survey speed of 26 minutes per turbine while the human searcher had an average of 42 minutes per turbine.

Since the trials were held on active wind farms, detection of incidental fatalities were a likely possibility for both search teams. Both teams found incidental bat and avian fatalities; however, the most impressive of these incidental finds were made by only the canine. Moxie found three incidental fatalities on TS-1 that were missed by the human searcher. These incidental finds included one intact, fresh northern yellow bat (*Lasiurus intermedius*) carcass—a common species in the area that had not yet been found as a fatality by human searchers on this wind farm—and a half-buried bird and bat carcass, both of which were desiccated and decayed, thereby unidentifiable to species. On TS-2, Moxie also found four incidental fatalities that were missed by the human searcher, which included two intact, fresh Northern hoary bat (*Lasiurus cinereus*) carcasses and two partially consumed bat carcasses, unidentifiable to species. One of these partially consumed carcasses consisted of a piece of bat wing and tuft of fur smaller than 6 centimeters.

Rare Turtles

The utilization of detector dogs to survey for eastern box turtles via a canine-handler team resulted in an increase in the number of turtles found, when compared to human surveys, as well as a reduction in the amount of time required to effectively cover the work area. In order to comply with permit requirements, the typical survey-person hours (e.g., 4/acre in forest, 2/acre in field) were adhered to. However, it was our experience that the canine-handler team was able to survey a much larger area with a greater efficiency rate than the human surveyors without a detection canine. This time savings, combined with the increase in rare turtle observations, resulted in a higher success of relocating rare turtles out of the limit of work to adjacent suitable habitats, thereby ensuring the long-term protection of populations. Considering that the loss of one mature female eastern box turtle can take up to 30 years to replace within a local population, relocating as many turtles from a project work area is critical to protecting the local population.

DISCUSSION

When reviewing the practicability of deploying canine-handler teams to monitor for avian and bat fatalities, there are clear cost savings that can be recognized. However, while canine searchers have proven to be an invaluable asset on the wind farms SWCA monitors in Hawaii, our canine trials on the mainland were able to tell us that canine searchers would be more beneficial for wind farm sites containing certain environmental conditions for specific regulatory agency requirements. For example, the Hawaii wind farms are located in areas that contain two state and federally endangered bird species and one state and federally endangered bat species. With low human SEEF rates on the Hawaii wind farms resulting in large fatality estimate biases, the mitigation costs for the more difficult-to-locate bat species were extremely high for the generation utility companies in this region. However, implementing canine searchers on these Hawaii wind farms created more accurate fatality estimates, resulting in lower overall costs to the client.

The two Texas wind farms selected for the canine trials of 2021 were not located in areas containing threatened or endangered bird or bat species—making us believe that the use of a canine searcher versus a human searcher would have only improved overall cost to clients significantly enough on TS-1. Since increased SEEF rates could potentially allow for a decrease in search frequency and less field time for the search teams on TS-1. Human searchers for this site routinely monitored the wind farm for fatalities once per week in the fall, spring, and winter seasons and every two weeks in the summer season (less often in summer because of avian migration patterns). The human searchers for TS-2 routinely monitored the wind farm for fatalities once per month in all survey seasons, which was the maximum amount of time recommended between searches. The overall cost savings anticipated for TS-2 would have been due to a slight decrease in search hours each survey month, which was not viewed as a significant enough improvement in cost for a client to likely choose a canine search method over a human search method.

Additional cost saving solutions gained by using canine searchers can be seen on sites similar to TS-1, that contain agricultural fields. The survey plots of this wind farm had to be routinely maintained and free of the crops that surrounded them to ensure higher SEEF rates for the human searcher method that was used. The mowing or plowing of vegetation grown for crops or grown to support livestock is sometimes necessary in wind farm sites in order to make the area searchable by humans. However, with the use of detection canines, mowing may not be necessary. Likewise, many of our clients are required to monitor large areas for eagle fatalities. Detection canines are perfect for this task—covering more area in less time and locating targets with an exceptionally high degree of precision.

Utilizing canine-handlers to find eastern box turtles for pre-construction turtle sweeps and turtle construction monitoring has been shown to be a successful survey method in Massachusetts. The increased rate of success in locating eastern box turtles has allowed us to successfully and safely relocate a larger number of individuals from within the limits of work, a critical task to ensure the long-term survival of local populations of this species. While the regulatory requirements require a higher level of survey effort by human surveyors, such as 4 survey-person hours per acre of densely vegetated habitats, we are confident that future success with detector dogs may result in those survey-hour requirements being revised for canine-handler teams.

Lessons Learned

The case studies SWCA performed utilizing trained canines for species-specific surveys and monitoring offered several lessons learned. The biggest of these lessons was that proper canine selection is key to the success of these trials. The canine handlers of both case studies experienced scenarios in which their first selected canine was not as well suited for the demanding detection work as they had hoped. Locatell's search canine, Moxie, was the second dog she had begun training specifically for the wind farm trials. Her first dog selected was a rescued lab-bloodhound mix, adopted at the age of 4 months, that failed to exhibit the necessary working search drive required for the trials. Upon initial evaluation of her first dog, Locatell had anticipated being able to build the dog's working search drive as he matured. However, the dog's workability and stamina for a search was not well suited for the demanding workload of fatality monitoring surveys.

A similar scenario occurred with the turtle detection canine, June. June's reward for successful indication was as short game of fetch with a tennis ball. However, after several field seasons, the canine began detecting tennis balls more than turtles. In this scenario, the canine's behavior could have been corrected with additional training; however, the handler was not experienced enough to follow through with additional retraining, and resources were not as available in 2007–2012 as they are today in 2022.

One interesting observation our Massachusetts canine-handler team observed was June began detecting underground turtle nests without having been trained to do so. Her indication was the same as with detecting individual eastern box turtles: a passive indication of a bark and sit. This suggests canine detection training could be applied to both species-specific adults and eggs, including fossorial animals or nests.

The importance of proper training for both the canine and the handler cannot be overstated. Fortunately, detector dog training programs have become more popular in recent years, providing training and mentorship to the canine-handler team throughout the process. Mentorship was an essential training step for Allison because, although she had dog training experience in other areas, she had never trained a detection canine herself before the trials. Consultation with and mentorship under several professional dog handlers and trainers was beneficial for learning the necessary processes in canine detection training, odor storage, detection dog handler skills, and working canine drives and behavior. If McDonough had access to outside resources such as detection dog trainers or mentors in 2007, perhaps her canine, June, would have been able to extend her turtle-detection career.

Future Applications

Environmental detection canine teams have been conducting surveys all over the world to prevent the spread of invasive species, such as the brown tree snake (*Boiga irregularis*) in Guam (Vice and Engeman 2000), and to protect threatened and endangered species, like the eastern indigo snake (*Drymarchon couperi*) (Stevenson et al. 2010), gopher tortoises (*Goperus agassizii*) (Cablk and Hearon 2006), Wyoming toad (*Anaxyurs baxteri*), giant garter snake (*Thamnophis sirtalis*), black-footed ferret (*Musteal nigripes*), ornate box turtles (*Terrapene ornata*), Pacific pocket mouse (*Perognathus longimembris pacificus*), and Kemp's Ridley sea turtle *(Lepidochelys kempii*) nests. Elsewhere in the U.S., detection canines have been used to find Oregon silverspot butterfly (*Argynnis zerene hippolyta*) larvae, that are smaller than a grain of rice and have not been detected in the past 40 years of human-conducted surveys. Canines have also recently been used to find floating scat samples (which only float for a short period of time) of declining Southern resident orca whale (*Orcinus orca*) populations, by sniffing from the bow of a boat. Our scientists at SWCA are continually identifying new applications where dogs may be an asset to conservation work.

CONCLUSION

Domestic dogs have a long history of providing valuable services, including narcotics detection, health emergency response (e.g., high/low blood sugar, seizure onset, etc.), search and rescue, and others. With their superior olfactory receptors, dogs' sense of smell is tens of thousands of times more sensitive than humans' and they can be trained to recognize a diverse range of target odors, depending on the intended detection goals.

Not all dogs are effectively suited for detection work, and careful consideration of a dog's demeanor and drive when selecting a potential dog is of utmost importance. Ideal candidates for detection dog work are easily trainable, have a strong desire to please their handlers, and are either toy or food oriented. Of equal importance is ensuring that a potential detector dog handler is best suited as an excellent match with a potential detector dog, and that they have the patience, determination, and rigor to effectively train and work with a detector dog.

The comparative results of the 2021 wind farm canine trials clearly show distinct advantages of using a canine-handler team over traditional human surveyors. Our wind farm trials clearly demonstrated significant advantages of canine-handler survey teams over their human counterparts, echoing other studies and papers published in recent years. Beyond the efficiency improvements identifying more fatalities and completing surveys more quickly, a canine-handler team also provides a cost-effective solution for clients, lowering mitigation costs and decreasing survey frequency at a wind farm site.

The utilization of detector dogs for conservation applications is an emerging practice that is expanding across multiple sectors. Many utilities, consultants, not-for-profits, and other organizations understand the benefits of utilizing detector dogs to further their conservation goals. Utilizing canine-handlers to find eastern box turtles for pre-construction turtle sweeps and turtle construction monitoring has been successful in ensuring the long-term survival of populations of this species. The increased rate of success in locating eastern box turtles has allowed us to successfully and safely relocate a larger number of individuals from within the limits of work. While the regulatory requirements to conduct a specific number of survey hours (e.g., 4 hours/acre of woodland and 2 hours/acre of field) have still been in effect, we are confident that future success with detector dogs may result in those survey-hour requirements being revised for canine-handler teams.

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P. Chase Bernier, CWB, PWS, CERP, is a Natural Resources Team Lead with SWCA based out of their Amherst, Massachusetts, office. He holds degrees in fisheries and wildlife technologies and wildlife management, and is a Certified Wildlife Biologist and Professional Wetland Scientist. Bernier has more than 16 years of consulting experience and has worked on projects throughout the United States and abroad, including projects in Central and South America and New Zealand. Bernier has extensive experience with a broad range of rare species, including invertebrates, amphibians, reptiles, birds, mammals, plants and trees, and habitats. He has been involved in all aspects of rare species projects, including developing field protocols; directing and completing in-field surveys; analyzing and managing data; developing reports; and writing Turtle Protection Plans, Conservation and Management Plans, and Habitat Management Plans for various species.

Allison Locatell

Allison Locatell has been developing a canine-handler team capable of conducting avian and bat fatality monitoring surveys, by obtaining the training and hands-on experience necessary to perform the work. She is a member of the SWCA Scientific Leadership Program and has more than 10 years of experience performing threatened and endangered species surveys, animal handling, and monitoring. It was Locatell who prompted the creation of an SWCA detection canine program, and within the month following completion of monitoring at the North Texas wind facility and just over one year of employment with SWCA, she had acquired her own dog to begin this training. Locatell's background in pet dog and service dog training provided her with a solid foundation of fundamental knowledge and hands-on experience for training detection canines.

Christin M. McDonough

Christin M. McDonough, M.S., CWB, PWS, CESSWI, has more than 22 years of professional experience working as a non-game wildlife biologist and wetland scientist, with more than 16 years of experience at the SWCA Amherst, Massachusetts, office—where she conducts rare species surveys and research throughout New England. She is responsible for monitoring rare species using multiple methodologies, along with GIS habitat mapping and animal movement analyses. She conducts endangered species surveys, rare species habitat evaluations and mapping, vernal pool surveys, wildlife habitat evaluations, environmental permitting, wetland delineation, scientific design and technical reporting, prepares and implements rare species protection plans, and is a CESSWI Certified Construction Monitor.

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