INFORMED AND COMMUNITY-ENGAGED RESTORATION OF ST. PIERRE WETLAND
A UNIVERSITY OF MICHIGAN PROPERTY

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Executive Summary

St. Pierre Wetland is a 130-acre wetland property owned by the University of Michigan (UM) and managed by the School for Environment and Sustainability (SEAS). An assessment done in 2017 by the Huron River Watershed Council (HRWC) identified the prairie fen on the site as highly ecologically valuable, noting encroachment by invasive species, including glossy buckthorn. Renewed interest in the site, and the need for restoration, brought attention to the lack of use by UM affiliates since its acquisition in 1975, as well as a lack of positive relational development with surrounding communities. Our master's capstone team project was formed in January 2022 to create a culture of stewardship and increase trust between stakeholders, uphold the research and education mission of the property, and protect the biodiversity and ecosystem services of the wetland. To inform our recommendations and actions toward these goals, we took three main approaches:

1) Conduct an assessment of realistic opportunities for engaging both external stakeholders and UM users with St. Pierre wetland, and implement feasible engagement activities,

2) Increase understanding and awareness of the site using remote sensing data to assess and analyze plant species distributions, and analyze plant species distributions.

3) Design and implement informed and community-engaged experimental invasive species removal in a way that both meets research and education needs and contributes to site restoration.

Community-Engaged Stewardship

Though we had originally intended to involve stakeholders in a collaborative adaptive model of restoration, our research and experience guided a much more informed approach to community engagement on a university-owned property that is not open to the public. We use a variety of sources to provide the most informed analysis of the situation to date. We review the historical and current barriers to the use and management of the wetland site, identify key stakeholders and opportunities for engagement along a spectrum, and bring to light the challenges unique to engaging with and within a higher education institution. With this more complete understanding of the situation, we share the ways we succeeded in engaging with both UM and external stakeholders (from meetings, gatherings, and agreements, to the production of outreach materials such as site visit protocols, a Story Map, and a wetland educational flier), provide specific recommendations for future opportunities, and general lessons relevant for others seeking to increase stewardship on sites with complex collaboration and access situations.

Remote Sensing Data Analysis

In an effort to raise awareness and inform the conservation and restoration of St. Pierre Wetland, as well as meet the property's mission of supporting research and education, we applied remote sensing techniques as an efficient and effective method to learn about the biophysical characteristics of the property. Specifically, we used Light Detection and Ranging (LiDAR) derived Digital Elevation Model (DEM), associated indexes, and multispectral imagery to assess and classify the current plant species composition of the wetland. We also assessed the reliability of using high resolution remotely sensed data, in combination with field verified data and geospatial applications, by running an accuracy assessment of the image classification model used to estimate species distribution. We then used multivariate techniques to assess the relationships of species distributions to other physical features of the site. This work demonstrates the applicability and resourcefulness of remote sensing techniques to better understand a wetland.

Invasive Species Removal

Invasive species such as glossy buckthorn, Frangula alnus (F. alnus), pose a particular threat to the community structure of a groundwater-fed prairie fen on the St. Pierre Wetland property. To address the encroachment of F. alnus while meeting St. Pierre Wetland's education and research mission, we developed and initiated experimental removal treatments of F. alnus in high-priority areas. Our research plan was informed by a review of published research and extensive consultation with experienced practitioners through focus-groups, follow up discussions, and site visits. Due to limited literature and practitioner investigation of non-herbicide methods of removal, we chose to test the effectiveness of two alternative removal methods: buckthorn baggies and cutting shrubs below the water level. We established experimental plots at St. Pierre to test these methods and collected data to prime future students for evaluating the effectiveness of the treatments. In an effort to include stakeholders in this work, we invited SEAS students and staff, main stakeholder representatives, and community members from the homeowners associations adjacent to the wetland to participate in the removal treatments in February and March of 2023.

Summary of Recommendations

Based on all of our research and experiences, we recommend the following as priorities for faculty, staff, students, and practitioners involved in future work with St. Pierre Wetland:

1) To build on efforts to engage both the UM community and external stakeholders in St. Pierre stewardship and learning:

a. The Facilities Manager, faculty, and students must continue to **refine and regularly update** the site policies and protocols we created. For consistency and stronger documentation, integrate these documents across **all other SEAS properties**.

b. Due to the transient nature of academic bodies at higher education institutions, SEAS leadership and staff must **regularly communicate research and education opportunities** at SPW. Engaging the learning community will support the goals of the school for the education and development of its faculty and students as well as fulfill the goals and mission of the property.

c. Continue initiating **meetings between external stakeholders and the Facilities Manager** in order to build trust and strengthen communication channels.

d. Reinforce the role of **"power volunteer"** for select external stakeholders to have conditional access to the wetland, and consider institutionalizing the role; intentionally engage them in restoration work being done at SPW.

e. Work with offices at UM to **complete a written use agreement** between the Shan-Gri-La and Bass Ridge HOAs to protect access long-term.

f. Pursue additional **funding opportunities** available for wetland restoration, preservation, and research.

g. I**nvest in relationships with other HOAs** along the Chain of Lakes (outside of Bass Lake) to ensure restoration and preservation goals align with the stewardship culture they may have already established.

2) To further the application of remote sensing techniques, data, and geographic information systems:

a. **Monitor the behavior and estimate the rate of expansion of invasive species** such as hybrid cattail (*Typha x glauca*) and buckthorn (*F. alnus*).

b. Perform further multivariate analyses such as a **multivariate linear regression** to **determine which** independent **variable most significantly influences species distribution**.

c. Emphasize the use of **open-source data and applications** to increase awareness of, familiarity with, and accessibility to high-quality data sources.

d. Include a **variety of variables** in analyses and **consult practitioners/professionals** on what methods they use to derive and analyze remote sensing data.

3) **To continue experimental and community-engaged restoration work on site:**

a. Collect data on or before summer 2024 on the effectiveness of the **buckthorn removal experiment treatments** implemented in winter 2023, including recovery of the native plant community and expanding to other variables such as soil chemistry.

b. Continue regular biannual **photo monitoring** from established points of the wetland.

c. Initiate projects oriented toward **removal of other invasive species**, especially *Phragmites australis* and hybrid cattail (*Typha x glauca*), to prevent their spread and invasion into new areas.

d. **Create a Master's project team January 2024 - April 2025** to carry out the next phase of research, restoration, and engagement recommendations above (proposal provided in Appendix F. *Proposal for 2024 St. Pierre Wetland Master's Project*).

Acknowledgements

First, thank you to Dr. Sheila Schueller, our faculty advisor, for your unwavering support, creative problem solving, and wise guidance. This project would not have been possible without your vision for the St. Pierre Wetland and your forward momentum.

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Thank you to Kris Olsson of Huron River Watershed Association for helping to initiate this project and partnering with us to keep it moving forward. We also appreciate the conservation practitioners who attended our Practioner's Circle to provide valuable advice about buckthorn removal, especially Billy Kirst, founder of Adapt Community Supported Ecology, for leading a natural landscaping event. And thank you to all of the students and their guests who helped us to remove buckthorn at St. Pierre – we could not have established our experimental plots without you!

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Chapter 1: Introduction to St. Pierre Wetland: Problems and Opportunities

1. Potential for Collaborative Adaptive Management of Wetlands

Freshwater wetland ecosystems hold significant ecological importance for their unique and varied hydrology, vegetation, and fauna. As a product of their unique composition, these communities provide a number of ecosystem services. Wetland plants are responsible for filtering pollutants from rainwater and runoff via sedimentation, plant uptake, litter decomposition, soil retention, and microbial processes (Johnston, 1991). This filtration capacity supports the functions of other ecosystems within the same watershed. Wetlands are also highly productive and provide valuable carbon sequestration services (Bernal & Mitsch, 2011). Michigan's freshwater wetlands are inherently valuable for their biodiversity, including a wide range of emergent, submergent, and terrestrial species, and for the habitat they provide to a number of rare and endangered species (Cohen et al., 2014).

Wetland ecosystems are an important focus of contemporary conservation efforts in Michigan. These efforts are driven by a desire to preserve the ecosystem services and biodiversity found within wetlands, as there has been a 4.2 million acre decline in glacial wetland ecosystems in Michigan since European Settlement (Gourby, 2016). Some of this decline can largely be attributed to the success of woody and non-native species in the absence of critical system disturbances. Wetland ecosystems in Michigan have historically relied on natural disturbances, such as beaver damming and fire carryover from adjacent ecosystems, to suppress encroaching woody species and facilitate seed bank expression (Cohen et al., 2014). Other causes for wetland loss include habitat conversion, modification, and fragmentation via anthropogenic activities such as development, installation of drain tiles, and other degrading and destructive practices (Cohen et al., 2014).

Given that Michigan wetlands are dynamic systems embedded in landscapes with people, Collaborative Adaptive Management (CAM) provides a useful framework to effectively approach wetland conservation in Michigan. CAM approaches interweave practitioner knowledge and credible science with the experience and values of stakeholders and managers to make more effective management decisions (Scarlett et al., 2013). CAM best practices include setting clear overarching goals and concrete measurable objectives, employing tools and incentives to facilitate participation and foster collaboration, implementing protocols to promote shared learning and manage uncertainty, and committing to monitoring and adapting a management regime over time (Susskind et al., 2012). All of these practices provide guidance for approaching conservation in complex systems and could be key for the long-term viability of wetlands in a mosaic of public and private land.

2. Site and Client Background

St. Pierre Wetland is a 130-acre wetland property— one of six properties owned by the University of Michigan and managed by the School for Environment and Sustainability. It is located on the northern undeveloped shoreline of Bass Lake, 14 miles northwest of Ann Arbor (Figure 1.1). The site was donated in 1975 by Sam and Angeline St. Pierre to be used for teaching and research in wetland ecology, stream biology, and other aquatic ecology topics.

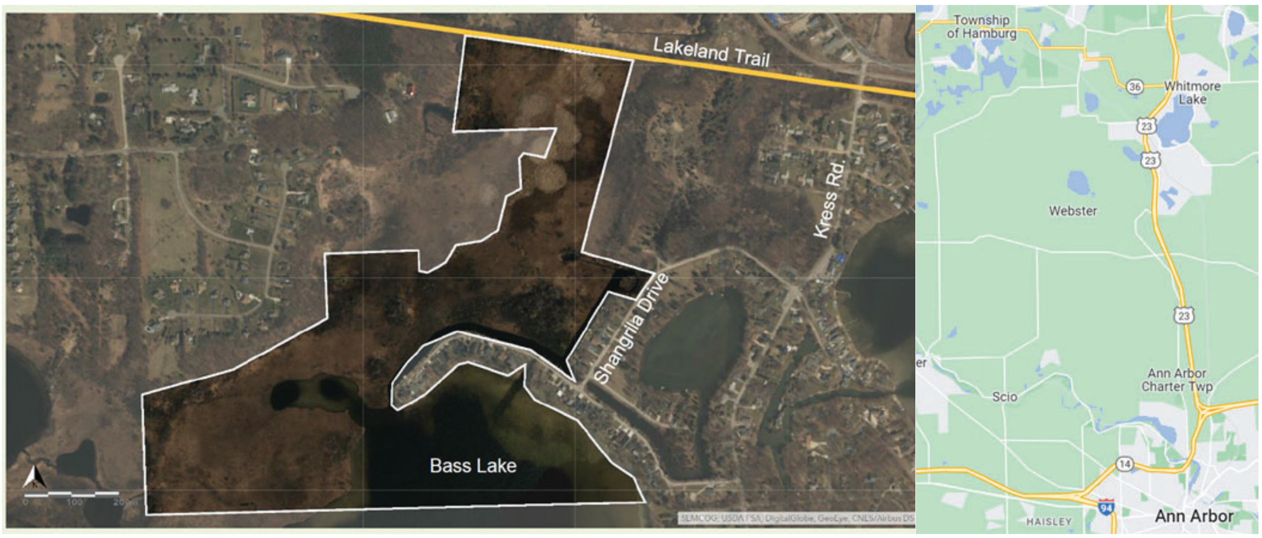

Figure 1.1. St. Pierre Wetland Property Boundary - image from St Pierre Wetland Capstone Project Proposal; location of St.Pierre wetland (Map Data @2023 Google Maps).

Ecologically, the site is important to the biodiversity and water quality of its watershed due to its range of species and vegetative zones. Given that it is an undeveloped shoreline on Bass Lake, the wetland likely serves as an important vegetative buffer protecting the water quality of the lake (SEAS Property Committee, 2017). The Huron River Watershed Council (HRWC) identified the site as having high ecological value based on an on-the-ground ecological integrity assessment conducted in 2017, awarding it a score of 134 out of 171 possible points (HRWC, 2017). The assessment identified a wide range of biodiversity in emergent and submergent vegetation spread throughout several sub-communities, including an emergent marsh, a forb and wildflower area, a prairie fen, and a shrub area (HRWC, 2017). The HRWC noted that the fen was of particularly high quality, but there were pervasive invasive plant species in the wetland, with glossy buckthorn encroaching on the north and northwest sides. Followup visits with HRWC and SEAS lead to a request in March of 2019, for Cardno, an environmental and engineering consulting firm, to provide an estimate for buckthorn removal on site. Through a site visit, they estimated the density of glossy buckthorn in different areas of the wetland and recommended cutting the buckthorn and painting the stumps with herbicide, which is the industry standard. They identified 90 acres needing treatment (roughly 70% of the site), with an estimated cost of $60,041 (Duke, 2019). This was outside the scope of available funding for SEAS property management.

In addition to invasive plants, a lack of relationships between stakeholders poses a challenge to effective property management. Stakeholders include University faculty and staff, neighboring landowners, local environmental organizations, township board members, and others. The property has not been actively used by SEAS faculty or students for research or education. Public access to the site is prohibited, as it was deeded to the University for private use, but there is considerable local interest and appreciation for the site, and footpaths are evidence of ineligible public use of the property for recreation or lake access.

While public access to the site is problematic for disturbing natural communities or research work on the wetland, there has been public interest in positive interactions with the property. Several neighbors, members of local government, and nonprofit organizations have reached out to the University at different times in the past with requests to engage in stewardship with or related to the property. For example, neighboring communities that appreciate the natural beauty of the wetland have expressed strong concern for controlling the spread of invasive species. Some have also shown a strong interest in how the property fits into the larger connected waterways of the area and the green infrastructure that protects downstream drinking water sources.

In summary, St. Pierre wetland is a high-quality University-owned natural area within a populated watershed that faces three major problems:

1. The presence of invasive species threatens biodiversity and ecosystem services in the wetland
2. The wetland receives little attention from SEAS faculty, staff, and students for its intended research and education use
3. The lack of connection with the public for stewardship efforts has led to harmful disturbance of the property and untapped potential for supportive relationships

A recent study of all six SEAS properties identified similar problems across all sites and recommended a variety of general approaches to address them, including collaborative land management partnerships, where properties could be jointly managed with other land conservation organizations, volunteer stewardship, a model where volunteers could help watch over the properties and act as liaisons to SEAS Facilities, and increased awareness and engagement with faculty and students (DeYoung et al. 2020). Specifically, for St. Pierre Wetland, a community engagement approach was recommended, to provide a model for other properties and other private-public partnerships.

3. Project Goals and Objectives

The current problems identified at St. Pierre wetlands present an enormous opportunity for an effective public-private partnership. The collaborative and adaptive management of St. Pierre wetlands could serve as a model for community engagement, education, and restoration for the larger landscape and other wetland areas. The goal of this project is to realize this potential and put previous ideas into implementation, moving beyond recommendations. Specifically, we aim to contribute to the following three goals for the site:

A. Preserve the biodiversity and ecosystem services of St. Pierre Wetland

B. Create a culture of stewardship and trust among stakeholders

C. Uphold the intended use of the property for research and education

While these broad goals can continue to guide activities on this site beyond this project, we aimed to accomplish the following specific objectives in support of all three of our goals:

1. Initiate on-site restoration in a way that is evidence-based, experimental, and adaptive.
2. Build awareness of the wetland's value among Shan-Gri-La HOA and other neighbors surrounding the wetland.
3. Engage in activities that cultivate trust between SEAS property management and community members.
4. Promote faculty and student engagement on the wetland through research and/or classes.

4. Report Overview

Chapter 2 Challenges and Opportunities for Community-Engaged Stewardship of a University-Owned Property, explores our experiences with hindrance and success while creating a lasting and meaningful sense of community stewardship for a privately-owned property. We discuss how to navigate the obstacles that arise from the complex nature of a large institution and how we overcame our particular barriers to site access. Critically, we describe the ways in which we were able to connect different stakeholder groups through a range of community engagement opportunities. The lessons learned here are applicable to a wide variety of situations where there is a dire need to inform community members about the ecology of a privately-owned property or easement.

Our work in Chapter 3 Using Remote Sensing Data to Inform Wetland Restoration, outlines the process of using spatial analysis and modeling tools to create a clear understanding of what remote sensing data can tell us about the state of invasive species at St. Pierre Wetland. We determine species composition by performing a supervised classification, using field data and spectral signatures captured through Light Detection and Ranging (LiDAR). We further delineate the property by conducting photo interpretation through the analysis of site-relevant leaf-off color infrared (CIR) imagery, LiDAR-derived Digital Elevation Model (DEM) indexes, and National Agriculture Imagery Program (NAIP) imagery. The methods we outline in this chapter are widely adaptable for investigating the presence of invasive species and developing restoration plans based on the findings.

In Chapter 4 Toward Informed Restoration and Stewardship of St. Pierre Wetland: Experimental Removal of Invasive Glossy Buckthorn, we discuss our process for selecting and establishing experimental treatments of assessing the knowns and unknowns for glossy buckthorn, specific to prairie fen communities. We outline our findings from relevant literature on buckthorn removal practices and studies to identify gaps in research, which we then used to guide our conversations with local practitioners about their experience with addressing buckthorn on sites in Michigan. Both of these areas of insight informed our final experimental treatments, cutting glossy buckthorn below the current water level and applying “buckthorn baggies” to cut stems. We detail our experimental setup, process, data collection, and next steps comparing these treatments to cut-only complexes. Lastly, we provide thoughts on what a continuation of this project will look like and how its outcome can inform wetland restoration at the property and beyond.

5. Project Significance

Through this project, we developed community engagement methods and an evidence-based invasive species management and monitoring plan that benefits stakeholders in numerous ways. For SEAS, these deliverables provide a more realistic model for the management of other owned properties and increase opportunities for courses and research to utilize the high-quality wetland for research and professional development. SEAS and Program in the Environment faculty and students can directly participate in stewardship planning and implementation, gaining hands-on and practical experience and knowledge in restoration and community engagement.

Our initial engagement with external stakeholders has allowed us to build productive, trusting relationships between public stakeholders and the University of Michigan. We have given HOA residents an opportunity to engage with student activities on and off-site and outreach events and materials to gain a deeper understanding of how their land functions ecologically as a part of the Huron River watershed. In collaboration with The Stewardship Network, we shared the lessons we learned from this project with a broader community to help inform conservation and restoration practices at sites beyond St. Pierre Wetland. Our experimental approach and monitoring plan on invasive species removal can be leveraged for other wetland habitats needing invasive species control, and our experience navigating public-private relationships can be referenced to encourage collaboration among stakeholders in other landscapes with similar social and legal dynamics. Finally, initial restoration work conducted on St. Pierre Wetland can lead to positive impacts in the larger Huron River watershed by providing a model for sustainable, informed, and engaged restoration practices that benefit regional hydrology and biodiversity.

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CH.2

CHALLENGES AND OPPORTUNITIES FOR COMMUNITY-ENGAGED STEWARDSHIP OF A UNIVERSITY-OWNED PROPERTY

Chapter 2: Challenges and Opportunities for Community-Engaged Stewardship of a Universty-Owned Property

1. Purpose and Audience

St. Pierre Wetland (SPW) is a university-owned field property in Southeast Michigan with untapped potential for collaborative, research-based stewardship. Owned by the University of Michigan (UM) and managed by the UM School for the Environment and Sustainability (SEAS), the site is closed to the public in order to protect its mission of research and education. Many local stakeholders have expressed interest in the wetland, and faculty and students have proposed projects and improvements to the site, but the research and education mission of SPW remains largely unmet. Meanwhile, invasive plant species are encroaching on the biodiverse prairie fen within the site. Engagement between relevant internal and external stakeholders is key to effective long-term use and management of the wetland. Engagement can range from simple matters such as site access, to more complex on-site collaborative management and monitoring, which is possible only after relationships have been built.

In this chapter, we first explore the historical and current barriers to the use and management of the wetland site. We introduce key stakeholders, illustrate how partnering with them could assist in overcoming some of those barriers, and consider various forms of engagement along a spectrum of community engagement. We then delve into the challenges unique to engaging with and within a university through a synopsis of academic research on the operational systems of higher education organizations, as they relate to our experiences. With this more complete understanding of the situation, we share the ways we succeeded in engaging with both UM and external stakeholders. We also provide specific recommendations for future students and faculty who wish to continue to engage stakeholders around stewardship of SPW. The barriers and solutions to the use, management, and community engagement of St. Pierre Wetland are not unique to this site, and so can provide a valuable roadmap for others seeking to increase stewardship on sites with complex collaboration and access situations.

2. Barriers to the Use and Management of St. Pierre Wetland

I. St. Pierre Wetland in the Context of Other SEAS Properties

Field properties once played a key role in the SEAS curriculum, but a reduction in use of field properties has occurred over time, alongside a reduction of administration-level investment. Obtained by the University of Michigan in 1903, Saginaw Forest was the first field property to be managed by SEAS (at the time: School of Natural Resources, SNR). SNR students and faculty established forest plantation plots which served as a rich student resource for hands-on learning about silviculture for the following decades. By 1930, SNR had acquired three more properties (Stinchfield Woods, Newcomb Tract, and Ringwood Forest), and established forestry plantations on these properties as well.

As the school's focus transitioned from silviculture to sustainability, all SEAS properties have seen a decline in both student and faculty use and funding (Grese et al., 2017). SPW is one of six properties currently owned by SEAS (the four mentioned above, as well as Harper Preserve). A master's project report highlights the decline in funding for SEAS properties: "From 1965 to 1985, staffing dedicated to the properties declined from two permanent and up to twenty temporary employees to only three student caretakers…, largely due to budgetary constraints" (Johnson et al., 1986, p. 1). In 1986, SNR's goal was to manage its properties with "zero net cash flow from SNR funds," and the report explored possible ways for SNR to manage the properties to maximize funds for site maintenance (Johnson et al., 1986, p. 1). Today, the SEAS Buildings and Facilities Manager (one full-time staff position), manages all six properties (1,761 acres total), as well as two leased properties on Central Campus, and the Samuel T. Dana Building. Two part-time student caretakers live onsite in Stinchfield Woods. As we understand it, there are no funds allocated for ecological restoration of the six properties, though basic maintenance of infrastructure and trails is to some extent supported, and is supplemented by funds from the Dana Building and Operations budget. However, we were not able to verify this information.

II. Historical and Current Use of St. Pierre Wetland

In the nearly fifty years since it was donated for research and education to UM (in 1975), St. Pierre Wetland has seen minimal student and faculty use. The current FM, who started in 2014, is not aware of any specific individuals using the property for research or education in her eight years in the role (S. Fernandez, pers. comm.), and even though a previous Professor of Fisheries and Aquaculture did report visiting the site, he did not use the site for teaching or research (J. Diana, pers. comm.). The only documented use of the property in the first 10 years after its donation was a productivity study conducted by a Resource Ecology class (as noted in a previous master's project report, Johnson et al., 1986).

Compared to Saginaw Forest and Stinchfield Woods, SPW has likely been overlooked in part because of access issues and its ecosystem type. The property is not open to the public, and is bordered by water and private land, so there is no university-owned land access. Instead, UM users would need to transport boats from a storage area at Newcomb Tract (located eight miles away) and enter the site via Bass Lake. This process is enough to deter some faculty from visiting SPW, especially when they have other, easier to access, wetlands to choose from (M. Kost, pers. comm.). Further, as a wetland, SPW did not meet the needs of forestry studies that had been the focus of other sites at the time that it was donated. It appears that these factors contributed to SPW's absence from regular course activity. Today many faculty and students are not aware of it or its potential for teaching and research purposes (Grese et al., 2017).

Beyond on-site research or coursework, there has also been a lack of active management of the wetland on the property. The properties' mission is research and education, and there are no dedicated funds or staff specifically to implement routine management or ecological restoration. Nonetheless, many recommendations have been made for management and even community engagement on the property. We will discuss those next, and some of the reasons they have not been implemented.

III. Failure to Implement Recommendations and Plans

Despite a lack of on-site work, several students and faculty have written recommendations for SPW (Box 2.1). These existing plans and reports vary in their detail for the wetland's use and management, and are generally ecologically informed, but do not take the reality of financial and practical barriers into account, and so have not been implemented to date. For example, a management plan created by students in the winter 2019 EAS 501 Restoration Ecology course lays out a multi-tiered site management and community engagement plan, and a 2020 master's project report (DeYoung et al., 2020) recommends creating a dock on the wetland and a shed to store boats. However, the allocated funds and land accessibility are not adequate to carry out either of these plans. In 2017, the Interim Dean charged a Properties Committee, including several faculty members and the FM, to present a vision for the future use of the school's six properties. Their report looks at models from other universities and emphasizes a need for reinvestment in the properties and administrative changes, such as hiring a Properties Manager (Grese et al., 2017). These recommendations were also not implemented, likely because they ran counter to the existing staff and budget structure for the properties, and even with new leadership, altering that structure was not perceived as a research or education priority.

Box 2.1. Reports by faculty and students with recommendations for use and management of St. Pierre Wetland, organized chronologically

- A master's project report, examining alternative management strategies to determine low- to no-cost management options for all six SEAS properties.

  Johnson, R., McManus, P., Murray, C., Sturtz, E., & Supers, S. (1986). Management Planning for a Fragmented Property. https://deepblue.lib.umich.edu/handle/2027.42/114676

- A team of faculty reviewed all six SEAS properties and presented a vision for their future use and management to SEAS leadership.

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- Student work within a Restoration Ecology class (EAS 501), detailing an ecological management plan for the site.

Bismack, A. & Roake, R. (2019) St. Pierre Wetland Restoration Plan. https://drive.google.com/file/d/1pd-xYz6DIXJXBQ4X9X03h4eUWJzpLm14/view?usp=sharing

- A master's project report, which lays out a vision for future management of SEAS properties, and measures carbon sequestration on SEAS properties in the context of university-wide carbon neutrality goals.

DeYoung, M., Ding, Z., Li, Z., O'Brien, L., Siciliano, P., & Van Haitsma, C. (2020). Creating a Vision for SEAS Properties. http://deepblue.lib.umich.edu/handle/2027.42/154880

Other recommendations have not been implemented because they lack knowledge of the site and its designated use. Both DeYoung et al. (2020), and Bismack et al. (2019) recommend a community workday on the wetland, in which SEAS students as well as community members participate in on-site restoration. This fails to recognize that the wetland was deeded as private property, and thus, inviting the public for on-site work presents possible liability and messaging issues. Further, the 2020 masters project suggests creating a trail from the Lakeland trail to SPW to increase faculty and student access to the wetland. However, the mandate of the FM is to uphold the property's research and education mission, which includes protecting the land from trespassing that can lead to inappropriate use and disruption of experimental plots. Thus, from an administrative perspective, a clear property access point right off a frequently traveled public trail is directly counter to the property's mission. This recommendation highlights a disconnect in understanding the consequences of public access to the site, and the different perspectives of academic and operational arms of a university – another topic we will return to later.

We have identified numerous possible barriers to explain the historical lack of on-site activity at SPW (Box 2.2) so that we can begin to better understand how to realistically navigate those barriers toward a goal of both upholding the property's mission of research and education as well as its ecological value. In the next section, we present an argument for how engagement with key stakeholders outside of UM may address some of these barriers, especially the lack of capacity for ecological restoration.

Box 2.2. Why is SPW underutilized and unmanaged?

- Access
  - Lack of university-owned land access
  - Difficult to find information about where and how to access
  - Not being open to the public limits possible access routes; routes must not encourage unauthorized visitors
  - Getting there requires a 30 minute drive from UM Central Campus (no public transportation to the site)
  - Other easier to reach wetlands are available for coursework
- Awareness
  - Lack of awareness of St. Pierre Wetland among faculty and students
  - Wetlands not a historical curricular focus of the school
  - Lack of site-specific information to inspire on-site research or education
- Capacity and coordination
  - Lack of funds for ecological management
  - Lack of dedicated faculty or staff to conduct on-site ecological management or restoration
  - Lack of agreed-upon overall site management plan

3. Engaging External Stakeholders to Solve Some of the Barriers to Site Use and Management

I. Many Stakeholders Beyond UM

Though SPW is owned by UM, there are over fifteen different area stakeholders who are either impacted by or have a potential interest in the property (Table 2.1). They range from neighbors to entities working within the larger landscape or watershed, including both local government and nonprofit organizations. Several of these stakeholders have reached out to UM at different times in the past with requests to participate in the stewardship of SPW or to learn from it for stewardship of their own neighboring waterway. Several have also shown a strong interest in how the property fits into the larger connected waterways of the area and the green infrastructure that protects downstream drinking water sources. While any of these stakeholders could be part of future engagement efforts, here we elaborate on the history of a subset that have experienced some of the same barriers we identified to the use and management of the property above, but also whose strong connections to SPW have the greatest immediate potential to meet both the needs and mission of the site.

Table 2.1. St. Pierre Wetland External Stakeholders, organized by color for each type/sector: Property Neighbors, Other area residents, Local NGOs & Collaborative efforts, Government, Restoration Practitioners

External Stakeholders	Relationship with St. Pierre Wetland	Primary Contact
Shan-Gri-La HOA	• Adjacent to St. Pierre Wetland; built on former wetland. • Developed by the St. Pierre family, who donated the wetland UM in 1975. • HOA President reached out to UM in May 2018 about pursuing buckthorn removal on the wetland.	• Shan-Gri-La Facebook page • Stephen Brown, HOA President: brownsc6887@att.net
Bass Ridge HOA	• Incorporated February 1996 • Borders northwestern edge of the wetland • HOA President and SEAS Facilities Manager met in September 2022 to establish verbal agreement for UM affiliates to access wetland through HOA property	• Max Nettleton, HOA President: (810) 355-4350 maxn@chartermi.net

External Stakeholders	Relationship with St. Pierre Wetland	Primary Contact
Portage, Base, and Whitewood HOA	• Spearheaded an invasive weeds study for the entire Chain of Lakes in 2015 that led to the creation of a 5 year Chain of Lakes Improvement Project. • Stated online they believe a lake improvement program needs to continue.	• HOA website • Facebook Page HOA Contact Information: mail@pbwoa.org (734) 474-3141 • Summary of Improvement Project
Cordley Lake HOA	• Actively pursuing shoreline restoration on Cordley Lake and interested in working with SEAS masters project students on water quality and invasive assessment and education (submitted master's project proposal in 2018). • Terri and another resident attended the Adapt gathering at Shan-Gri-La HOA.	• Cordley Lake HOA website • Terri Wilkerson, HOA President terri@a3homes.com (734) 355-7799
Lakeland Trail Users	• The northern section of St. Pierre Wetland is visible and runs directly along this popular biking/walking trail. Hamburg Township Supervisor offered to fund signage for wetland education along the trail.	• Brighton Recreation Area DNR website
Huron River Watershed Council	• Conducted bioreserve assessment summer 2017. • Initiated stewardship hikes on site and connected stakeholders, leading to the creation of this masters project.	• HRWC website • Kris Olsson, Watershed Ecologist kolsson@hrwc.org
The Stewardship Network	• Involved in stewardship hikes organized by Huron River Watershed Council.	• TSN website • Rachel Muelle, Program Manager rmuelle@stewardshipnetwork.org
Mohican Lake Collaboration	• Collaborative effort with the vision to protect critical wetland habitat surrounding the Huron River Portage Chain of Lakes. • Partners include some of the stakeholders listed here - the Huron River Watershed Council (HRWC), Ducks Unlimited (DU), Hamburg Township - as well as Golden Drake Realty (GDR), Livingston Land Conservancy (LLC), and Michigan United Conservation Club (MUCC).	• Sara Thomas sarathomas427@gmail.com • Craig Kivi, GDR craigpkivi@gmail.com

External Stakeholders	Relationship with St. Pierre Wetland	Primary Contact
Ducks Unlimited	• Mission to conserve waterfowl dependent habitat. • Employs remote sensing for conservation and preservation purposes. • Work alongside USFWS updating the National Wetland Inventory using remote sensing data and geo spatial tools. • Provided high quality remotely sensed data and wetland delineation methodologies, which we adapted for our own analysis.	• Mat Halliday, GIS/Remote Sensing Analyst mhalliday@ducks.org (734) 623-2000 • National Wetland Inventory
Hamburg Township Supervisor	• Involved in stewardship hikes organized by HRWC. • Offered to fund signage for SEAS about the wetland for community education.	• Pat Hohl, Township Supervisor pathohl@hamburg.mi.us (810) 222-1116
Washtenaw County Public Works Division	• Managed the 5 year Huron River Chain of Lake Improvement Project.	• Summary of Improvement Project • Evan Pratt, P.E., Water Resources Commissioner: drains@washtenaw.org
State of MI EGLE	• Controls the permitting process for water treatments in Michigan.	• Inland Lakes & Streams Protection
Invasive Species Management Practitioners	• Range of private and government practitioners in the area working on wetland restoration and invasive species management. • May lack the capacity to take an experimental approach or implement adaptive management monitoring to inform best practices.	• See Appendix A. Record of Stakeholder Interactions
Stantec (formerly Cardno)	• Restoration consultants. • Visited St. Pierre wetland with area stakeholders and completed an estimate for buckthorn removal on St. Pierre Wetland in 2019.	Stantec Ecosystem Restoration • Shawn Duke shawn.duke@cardno.com • Robin Burke robin.burke@cardno.com

St. Pierre Wetland connects with the Pinckney Chain of Lakes, which is surrounded by dozens of homeowners associations, two of which directly border the wetland itself (Figure 2.1). Bass Ridge Homeowners Association to the northwest was built more recently and incorporated in February 1996 with approximately 40 homes. They maintain a wood chip trail for members to use that loops along the northwestern edge of the wetland property. Shan-Gri-La Homeowners Association (SGL HOA) to the east of the property has a much deeper history with the wetland, even extending to the origin of the property itself. When Samuel St. Pierre acquired the property in the early 1950's, most of the site was wetland. Inspired by his time in Florida, Mr. St. Pierre envisioned a community of single-story, pastel-colored houses along a network of canals. Crews dredged the eastern section of the wetland, altering the hydrology of the wetland in ways that are still evident today. Construction halted with Mr. St. Pierre's death in 1963, leaving his widow, Angeline St. Pierre, living on the property. The Clean Water Act, passed in 1972, restricted development on wetlands and marked an end to construction. Current SGL HOA members speculate that Mrs. St. Pierre might have donated the wetland to UM in 1975 to rid herself of the tax burden of owning land that could not be developed.

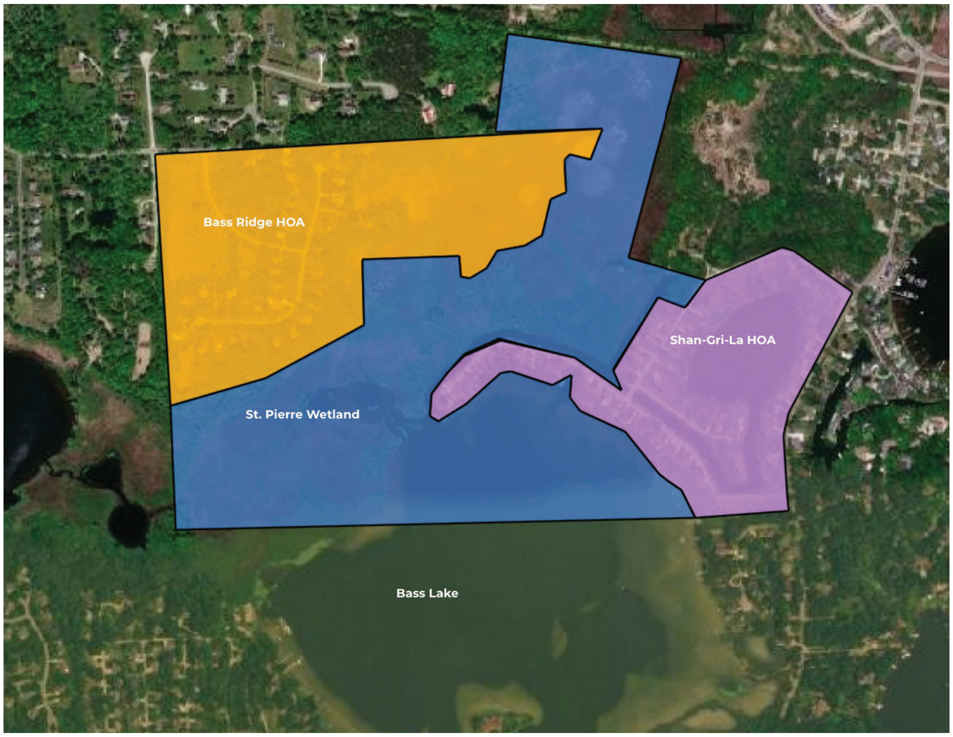


Figure 2.1. St. Pierre Wetland is bordered by Shan-Gri-La HOA on the east, and Bass Ridge HOA on the northwest. Source: Esri, USDA FSA | Esri Community Maps Contributors, Province of Ontario, SEMCOG, © OpenStreetMap, Microsoft, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, US Census Bureau, USDA

The Shan-Gri-La neighborhood is a key stakeholder of SPW not only because of their history, but also their interest in the ecological health of the area. The current neighborhood consists of approximately 85 houses, many dating back to the 1950's development, which line the northeast corner of Bass Lake and southeast corner of the wetland. As a designated "No-Wake" lake directly connected to an intact wetland, Bass Lake is considerably less developed than surrounding lakes. Many residents chose SGL HOA for its natural features and peaceful character, and they value the surrounding wetland and its wildlife, including wood ducks, softshell turtles, frogs (D. and B. Wenzel, et al., pers. comm), and even freshwater jellyfish (Coffee, M., 2022). Led by HOA president Stephen Brown, the community engages in stewardship by treating the canals to remove the invasive plant Eurasian millefoil (*Myriophyllum spicatum*) and pulling weeds manually from their shared park during their annual meeting. Mr. Brown is also engaged in other local restoration efforts through another key SPW stakeholder - the Huron River Watershed Council.

The Huron River Watershed Council (HRWC) was instrumental in raising UM's internal awareness about St. Pierre Wetland. As Michigan's oldest environmental organization established in 1965, HRWC monitors the Huron River Watershed, of which SPW is a part. In an effort to survey areas within the watershed for biodiversity and water quality, HRWC's watershed ecologist, Kris Olsson, conducted a bioreserve assessment of SPW in the summer of 2017. Initial visits for the assessment involved the FM and a SEAS faculty member, Dr. Sheila Schueller. Having documented the high quality fen prairie on site, and the encroaching invasives, Ms. Olsson coordinated follow-up visits in the winter of 2018 and 2019 with a broader set of stakeholders, including Mr. Brown from the Shan-Gri-La HOA, as well as representatives from The Stewardship Network (a regional collaborative), Hamburg township, and local restoration consultants from the company Cardno (now Stantec). Recommendations and a proposal with an estimate to remove invasives on site failed to be implemented at that time due to some of the same barriers discussed above, particularly a lack of dedicated funding for ecological restoration work on site. Proposed alternatives to contractor removal raised the logistical barriers of involving the public on private property (as a volunteer event) or of involving students who were not certified in herbicide use.

The Stewardship Network (TSN) continued to be a key stakeholder in efforts to acquire a grant for regional funding in collaboration with the university to cover the costs of restoration at SPW. Conversations to decide on funding and collaboration possibilities involved several faculty members and the facilities manager throughout the fall of 2021. While TSN interest and support remained, efforts to formally jointly submit a grant proposal with SEAS were discontinued, as it was determined that overhead costs would be too high and UM could only provide matching funds in the form of student or faculty involvement.

In the winter of 2022 this master's project was initiated with the intent of navigating previous challenges to site use and management together with core stakeholders - the Shan-Gri-La HOA, HRWC, and TSN - as clients with UM. A major focus of the project has been understanding how engagement with these and other external stakeholders could proceed in ways that overcome some of the previously named barriers to site use and management.

II. Potential Benefits of Engaging With External Stakeholders

Many of the barriers contributing to the underuse of SPW are a result of a lack of resources and of proactive conservation management, problems that can be addressed by the interested stakeholders through the application of community engagement methods. Engaging with the nationwide networks of TSN and with leaders in local government through HRWC could provide additional resources for funding, support, and resources to accomplish preservation activities such as removing invasive species that are beginning to undermine the ecological quality of the site. Support for creating and implementing a management plan could also be provided through experts and volunteers in TSN and HRWC.

Another benefit of community engagement is the potential to address inappropriate use and trespassing on SPW. A makeshift boardwalk of planks connecting the Bass Ridge HOA trail to the wetland, constructed within the past five years, and boats stored on the edge of the wetland both indicate that people outside of UM have been using the site (S. Brown, pers. comms.). A priority for the SEAS Facilities Manager is to protect the property in order to prevent disruption of research activities, as well as reduce liability. A similar value of protecting the wetland is shared by the HOAs and HRWC in order to prevent possible ecological degradation of the site. The proximity of both Shan-Gri-La and Bass Ridge HOAs allows activity to be noticed by the residents, and they could report directly to the FM. Knowledge that the property is actively being watched may also deter unwanted activity.

Working with the HOAs is also necessary for access. Accessing SPW by either land or water requires permission to go through private HOA property. While other actions, such as parking on public streets or working on the wetland, do not require permission from the HOAs, it is beneficial to engage the surrounding communities through respectful and proactive communication. This demonstrates UM as a good neighbor and may also ultimately have positive ramifications for other UM projects, events, and properties. Given the evident benefits of community engagement to address many of the barriers to the use and stewardship of SPW, we next address what forms this engagement could take.

III. A Spectrum of Community Engagement Options

Models of community engagement can vary widely along a spectrum from one entity informing or directing the others to multiple entities sharing leadership and decision-making

(Figure 2.2). Within that spectrum, there are many specific models of engagement that can be applied depending on the ecosystem, types of stakeholders, and situations (Table 2.2). For example, collaborative adaptive management and stakeholder participation are frameworks that actively engage stakeholders in all levels of decision making and implementation, placing them on the collaborate-empower side of the spectrum. Approaches such as citizen science and the knowledge deficit model aim to share information with and gather select information from stakeholders, falling on the inform-consult-involve side of the spectrum.

Table 2.2. Examples of Community Engagement Models, arranged from highest level of engagement (Empower) to lowest level of engagement (Inform), in reference to Figure 2.2 Community Engagement Continuum.

Examples of Community Engagement	Description	Sources
Collaborative Adaptive Management	A responsive management plan where decisions are based on scientific knowledge and all stakeholder experiences.	• LoSchiavo et al., 2013 • Susskind et al., 2012 • Scarlett, 2013
Knowledge Co-Production	Stakeholders setting flexible yet clear management goals by incorporating multiple forms of knowledge, including (but not limited to) Traditional Ecological Knowledge (TEK), personal lived experience, scientific research, local knowledge, and tacit or implicit knowledge.	• Norström et al, 2020 • Raymond et al., 2020
Stakeholder Participation	Shared stakeholder control of decision making through a variety of engagement methods that requires active participation throughout the entirety of implementation.	• Luyet et al., 2012 • Reed, 2008
Citizen Science	Allowing non-experts to join scientific research for the purpose of collecting large quantities of data that could not be accomplished otherwise and/or to informally educate them in science literacy and scientific methods.	• Kullenberg & Kasperowski, 2016 • Roche et al., 2020 • Sauermann et al., 2020 • citizenscience.org
Knowledge Deficit Model	One way flow of knowledge or information from experts to non-experts in an1 effort to change attitudes, beliefs, or behaviors.	• Scheufele, 2013 • Sturgis & Allum, 2004 • Suldovsky, 2017

	INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
GOAL	To provide stakeholders with balanced and objective information to assist them in understanding the problem, alternatives and solutions.	To obtain stakeholder feedback on analysis, alternatives and/or decisions.	To work directly with stakeholders throughout the process to ensure that their concerns and aspirations are consistently understood.	To partner with stakeholders in each aspect of the decision from development to solution.	Shared leadership of community-led projects with final decision-making at the community level.
STYLE	"Here's what's happening."	"Here are some options, what do you think?"	"Here's a problem, what ideas do you have?"	"Let's work together to solve this problem."	"You care about this issue and are leading an initiative, how can we support you?"

Figure 2.2. Community Engagement Continuum (from the Tamarack Institute's Index of Community Engagement Techniques)

Although each model of engagement has specialized elements, common themes appear. All encourage societal participation in scientific processes. They also include built-in internal feedback loops for reflection, are flexible to provide opportunities for changes to be made, and emphasize the necessity of thorough planning and clear communication. There are underlying tones of understanding where and how power is held and utilized within established processes and groups. Community engagement models also require a substantial amount of time and resources, and, depending on the project, can be ongoing indefinitely. The nature of working with people offers many opportunities for frustration and challenges, to the point where some question whether community engagement is even worth implementing (Irvin & Stansbury, 2004; Susskind et al., 2012). However, we do see that it is being done successfully and the benefits are evident (LoSchiavo et al., 2013; Roche et al., 2020; Susskind et al., 2012). In order for community engagement efforts to succeed, leaders, scientists, and decision-makers must commit to doing it well and investing the appropriate amount of resources from the start. There is no one-size-fits-all model, and any form of community engagement is difficult. Choosing the right method simply means deciding which model or combination of models will be the most effective to carry out a project's specific goals and is most appropriate for engaging the unique community involved. Our choice of community engagement with key stakeholders will require an understanding of one more major situational challenge of working at SPW - the university institution itself.

4. Challenges of Working With a Higher Education Institution

While community engagement might overcome some of the barriers and increase university use and stewardship of SPW, progress cannot be made without first understanding the larger barriers that are unique to working within the context of a higher education institution. As a property owned by UM and managed by SEAS, SPW is part of a large and complex university system that consists of three campuses, encompassing 19 undergraduate, graduate, and professional schools and colleges within the Ann Arbor campus, a myriad of online degree programs, and many research centers and institutes. Because SPW is part of a university system, any actions or decisions related to the property must account for the structure and processes of that system. Here we outline what we learned, both through experience and from research on higher education systems, about the unique features of working within and with a university. These include an appreciation of decision-making and power structures within their system of "organized anarchy," as well as the outcomes of having parallel administration and academic components. Understanding these unique features empowers any change agent to recognize the most realistic and feasible paths to navigate a university setting more effectively, and, at a minimum, can ensure that well-intentioned actions do not backfire.

I. Organized Anarchy and the "Garbage Can Model" of Decision Making

Large, Research 1 (as classified by the Carnegie Foundation) flagship universities like the University of Michigan are identified as having an "organized anarchy" model of organization (Birnbaum, 1988). Put simply, an organized anarchy is the opposite of a centralized bureaucracy, which operates the way that we might expect an organization to function. In a traditional bureaucracy, employees have clear roles with designated authority and explicit hierarchies, and organizational goals take priority over individual goals (Barlosky, 2010). In contrast, organized anarchy is not driven by overarching, organizational goals, but is instead the result of "the

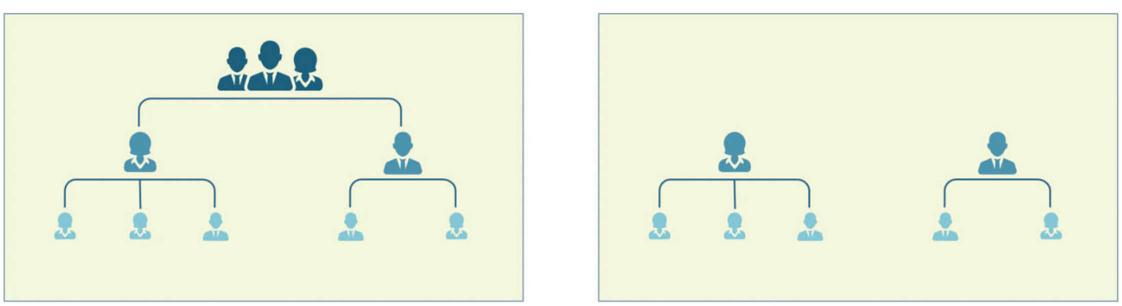


Figure 2.3. A traditional bureaucracy (left) compared with an organized anarchy (right). While organized anarchies have elements of bureaucracy, organized anarchies contain many bureaucracies with competing mandates rather than a central decision-making authority.

autonomous actions of many individuals and organizational subgroups responding to their own perceived interests or to the pressures of the market" (Birnbaum, 1988, p. 166). Organized anarchy cannot be represented by an organizational flow chart, because authority is fluid, depending on the situation and the actors present. For example, due to their appointment to a committee to find a new dean, a faculty member may have a high level of authority in that situation, but a low level of authority when it comes to funding decisions.

In addition, the different components of organized anarchy are loosely, rather than tightly, coupled (Birnbaum, 1988). A tightly coupled system is deterministic; a change in one element has direct effects on another element. For example, in a tightly coupled university system, the administration decides to emphasize DEI, and as a result, students, staff, and faculty are required to complete an online DEI training, and new DEI classes are offered in the course catalog. In a loosely coupled system, however, a change in one element travels through many other elements, and while these other elements change in response, they also retain some of their original traits. In this way, organized anarchy is probabilistic. Continuing the above example, the administration in a loosely coupled university system decides to emphasize DEI. To instate a mandatory DEI training, they must coordinate with the administration of every school and college within the university, and with the human resources department for staff and faculty. Administrators will need to track compliance, with limited enforcement mechanisms. Departments will require funds to hire new faculty to teach DEI classes, which they will seek through grants

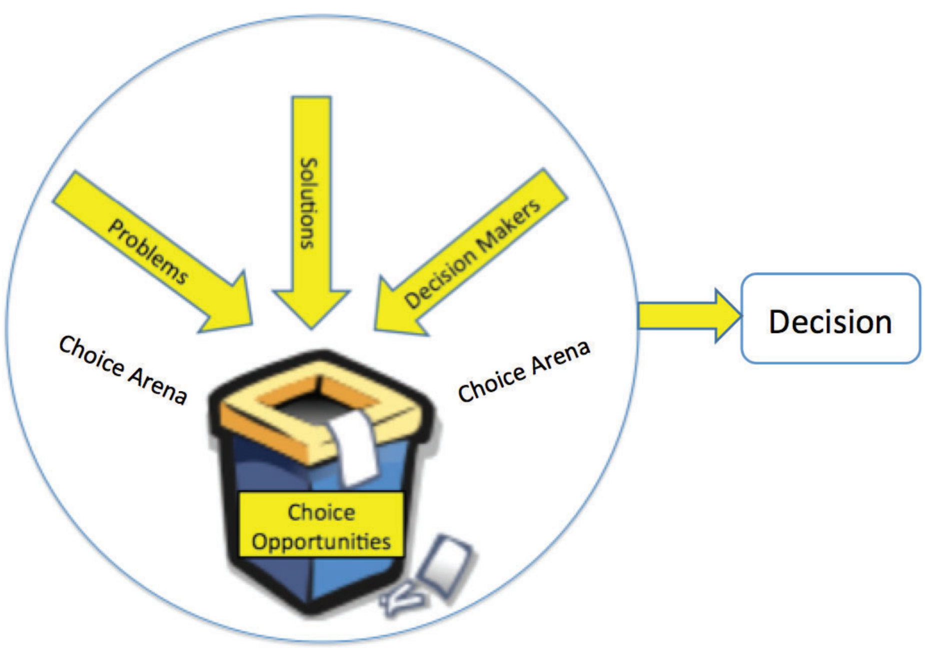


Figure 2.4. The "garbage can model" of decision making.
Garbagecansarefun [author] (2018), CC BY-SA 4.0 via Wikimedia Commons

and endowments. The many necessary adjustments hamper the university's ability to pivot, and it may be a matter of months to years before DEI courses are offered. The complex response of each group within the system thwarts any simple cause and effect.

In an organized anarchy it is ambiguous who has the power to make a decision in a given situation, which gives way to a unique decision making process known as the "garbage can model" of decision making (Cohen, March, and Olsen, 1972; see Figure 2.4). Conventional practice dictates a linear path to decision making: formulate a question, collect data, analyze the data, and choose the option that maximizes benefit. However, in the "garbage can model," problems, solutions, and decision-makers all exist independently of each other. They come together in the "garbage can" or choice opportunity (e.g. a meeting of the Board of Regents). The solution that is eventually paired with a problem is not necessarily the result of analysis and deliberation, but an outcome of whatever happens to be in the "garbage can," including which decision-makers are present, the solutions they are aware of, and the other salient events at the time. Our team experienced the "garbage can model" firsthand, when we engaged multiple decision-makers to seek land access to St. Pierre Wetland (Box 2.3).

Box 2.3. How do we get in? The "garbage can model" in action:

In the "garbage can model" of decision making, problems, solutions, and decision-makers pour into the garbage can, forming a mix of entities. These items jostle around in the can, as decision-makers attempt to connect problems with solutions. When a connection is made that enough decision-makers agree to, the paired problem-solution emerges as a decision. The following is an example of how this process played out iteratively in our attempts to access SPW.

The choice opportunity ("garbage can"):

A series of conversations (email, zoom, phone, and in person) held between January 2022 and September 2022.

The problem:

How to enter SPW. St. Pierre Wetland can only be accessed by boat or by walking through private property.

First proposed solution:

Use Stephen Brown's boats to access the wetland.

Our advisor had known Mr. Brown, the neighboring HOA president and one of our primary project clients, over the course of four years of investigating the property. Mr. Brown offered student use of his own canoe and kayaks, and though we would eventually need land access in order to continue our work and involve more SEAS students and faculty, our advisor and the team thought this was a good short-term solution to access the site.

The FM recognized that this may raise liability issues, and ran our solution past UM's legal team, the Office of the Vice President and General Counsel (Legal). Legal rejected our proposal to use Mr. Brown's boats, due to the mismatch of using private property to conduct university business, and the possibility for liability if anything were to happen during our use of the boats. However, Legal did propose another solution.

Second proposed solution:

Use SEAS-owned boats to access the wetland.

This was logistically challenging, and involved loading boats from another site onto our personal vehicles, driving eight miles to the site, unloading and launching the boats, and repeating the process in reverse to return them. In addition, professors mentioned that they would not bring students to a site where boats were necessary for access (M. Kost, *pers. comms.*). At this point, we decided that it was time to shift our attention to gaining land access, and our advisor proposed a new solution to the FM.

Third proposed solution:

Create a Memorandum of Understanding (MOU) between the Bass Ridge HOA and UM SEAS, to grant SEAS students and faculty permission to walk across HOA-owned property to access the wetland by land.

The FM recognized that this fell in the realm of UM's Real Estate Department (Real Estate), as well as Legal, so she brought in Real Estate as an additional decision-maker. However, Real Estate discouraged the use of a formal MOU, as these are legally binding documents, which can be quite limiting and may have unforeseen consequences. Given that Legal and the FM did not see the need for land-based access, the solution to use SEAS-owned boats remained as the only supported option.

To address the limitations of a lack of land access, our advisor brought in new decision-makers connected to SEAS: the Academic Dean (AD) and the Director of Budget and Administration (DBA). The DBA suggested that the FM consult Legal, rather than Real Estate, regarding an MOU, and that we frame the situation in terms of risk. Accessing the wetland by boat is relatively high-risk, involving all of the risks associated with watercraft, plus the issue of students transporting boats on their personal vehicles. The group agreed that Legal may be more likely to agree to an MOU when framed as replacing a high-risk activity with a low-risk one (land access). The FM returned to Legal with this new framing, and Legal understood the need for land access, but supported a different solution than an MOU, that they had not considered necessary earlier.

Fourth proposed solution:

A written, informal use agreement between the Bass Ridge HOA and UM SEAS, to grant SEAS students and faculty permission to walk across HOA-owned property to access the wetland by land.

While Real Estate was not on board with an MOU, they agreed to a written, informal use agreement, noting that unwritten agreements can be problematic with turnover in the parties involved (as they had experienced at a different property).

Finally, with approval from all parties, we had found a solution that was ready to emerge from the “garbage can” and enter reality. The FM reached out to the President of Bass Ridge HOA, and in September 2022 we received verbal permission from the president of Bass Ridge to use the HOA’s trail and property to access the wetland. That agreement has yet to be made into a written agreement, as the decision of wording and process required review and involvement by more parties. Nonetheless, we had, through the garbage can model involving multiple decision-makers, achieved a solution to access the wetland in a way that was feasible and minimized risk.

The literature is clear; an organized anarchy is not a negative or ineffective structure. Rather, organized anarchy is "the functional response of an institution faced with multiple and conflicting demands on attention, priorities, and performance" (Birnbaum, 1988, p. 167). This unique system allows an institution to support values or beliefs without the need to engage in institution-wide change. In the case of SPW, the university as a body can state the mission of research and education on university-owned properties without an obligation to create the structural change that might be needed to achieve that mission.

There are several additional ways we see features of an organized anarchy in play at St. Pierre Wetland. The first is that the UM owns SPW, yet it has no management plan, no dedicated funds for stewardship, and no stated goals for the property beyond supporting research and education. Having such minimal goals and purpose for a property is not a likely situation in any system other than an organized anarchy where goals can be ill-defined (Birnbaum, 1988). A forest owned by a federal agency, for example, would be required to have a management plan. A private corporation would be obliged to shareholders to manage its land to ensure a profit or minimize capital loss. By contrast, the university holds the wetland property as if it were a static asset (that requires no upkeep), rather than a living ecosystem. Also characteristic of an organized anarchy, UM did not decide to purchase the SPW site; it acquired the property by chance. That is, instead of a decision preceding an action, the action came first, and University leadership created a rationale for owning the wetland to fit one of their pre-existing missions. Birnbaum (1988) describes this process: "The institution discovers what it prefers by seeing what it has already done, rather than by acting on the basis of preferences" (p. 155).

II. Ambiguous Power Structure

The fluid authority characteristic of organized anarchies described above, also leads to a uniquely ambiguous power structure, a feature of universities that we observed in public communication efforts related to St. Pierre Wetland. While the FM is formally tasked with managing SPW, the SEAS Communications (SEAS Comms) department is the designated voice of SEAS. After developing materials about SPW to share with the public, we sought approval from both parties, and found that they sometimes had conflicting advice, due to different philosophies. For example, we were planning to share a post about student activities on the wetland on the Shan-Gri-La HOA's Facebook page, but the FM saw it as a possible opportunity for the public to leave negative comments. Her hesitancy was understandable given past negative experiences on other SEAS properties. SEAS Comms, on the other hand, encouraged proactive communication with the public as a way to avoid potential misunderstandings, and so approved the Facebook post, while the FM only approved the post after additional edits. In a later conversation, we learned that there were additional authorities to consult before creating signage for UM properties. The FM informed us that approval by SEAS Comms was not enough, and that we would need approval from the overarching UM Communications Department and the Architecture, Engineering, and Construction division of UM Facilities and Operations before being able to post signage. We ping-ponged back and forth between these authorities, and eventually came to realize that there is no one entity with final authority in this matter; they are each separate entities on an equal level in charge of overlapping domains.

The ambiguous power structure of universities can make it especially difficult for individuals outside of UM to navigate the system in order to meet their needs. When SGL HOA President Stephen Brown notified UM of the glossy buckthorn dominating the wetland, he addressed his email to a general UM address, as he had no way of knowing which entity within UM managed the site (a result of no signage and no UM presence on the site). His initial email went unanswered, he reached out to other entities within the university, and, roughly one year after his first contact attempt, he was connected with the FM – the individual specifically in charge of managing that property. When they did finally interact, both parties benefited from the meeting: the FM listened to Mr. Brown's concerns about glossy buckthorn, and Mr. Brown informed the FM of the makeshift boardwalk that had been assembled on the property. A similar disconnect occurred between the UM and Samuel St. Pierre's granddaughter, when property rights came into question, though the parties were not able to reach the same positive resolution (see Box 2.4).

Box 2.4. Ambiguous power structure can sour relationships

The impacts of an ambiguous power structure were illustrated in a 2014 encounter, involving the UM and two SGL HOA residents. Mr. St. Pierre's granddaughter and her husband (hereafter referred to as descendants) reside in Samuel and Angeline St. Pierre's original house from the 1950's, which borders the SPW. When Angeline St. Pierre donated the property in 1975, she included an outlot – a small rectangular lot protruding from the parcel – which essentially connected the wetland to Shangrila Drive (though still required crossing water). This outlot contained an island, which was a favorite spot for boaters within the SGL HOA. While most of the island fell within the parcel donated to UM, two strips along the shore of the island were kept in possession of SGL HOA, likely with the intent to allow SGL HOA members continued partial access to the island (see Appendix B. St. Pierre Outlot Information). This situation, in which property ownership and rights were unclear, laid the groundwork for miscommunication.by walking through private property.

Figure 2.5. A patchwork of land ownership between UM and Shan-Gri-La HOA. Lot -015 is owned by the Regents of the UM, and the triangles labeled "outlot" and -990 belong to Shan-Gri-La HOA.

The descendants' property borders the canal near this island, and they, along with other SGL HOA members, had been using the island casually for decades. They would park their boats along the shore of the island to enjoy the wildlife, which they invited with bird feeders and wood duck houses. In order to better enjoy these activities, they had cleared some brush along the edges of the island (D. and B. Wenzel, *pers.comm.*). In 2014, the descendants reached out to UM, seeking approval for several improvements to the island, including erecting a pavilion. In response, UM sent a staff member to inspect the island and then instructed the descendants to remove all bird feeders, wood duck houses, and other items from the island, and not to enter the island. UM threatened legal action if the descendants failed to comply (D. and B. Wenzel, *pers.comm.*). In addition, the employee who had inspected the island did so without giving the descendants advance notice, and without being seen or introducing themself. This lack of transparency partially eroded the descendants' trust in UM.

The University of Michigan's ambiguous power structure is reflected in the fact that the Facilities Manager, the most relevant university entity (as manager of the SPW, which contains the island), was not included in the exchange, and only learned of it after the fact (S. Fernandes, *pers.comm.*). The failure to introduce the FM into the situation demonstrates a missed opportunity for relationship building; instead of connecting Mr. St. Pierre's descendants with the appropriate liaison, UM remained a faceless entity. Without this relationship, there is a lack of closure to the situation. The descendants are unsure of their options to improve the sections of the island that they do own, those sections of property are being used far below their potential, and they have not reached out to UM again because of the negative interaction they experienced nine years ago (D. and B. Wenzel, *pers. comm.*).

III. Two Parallel Structures: Administrative and Academic

Another key feature of higher education institutions, which complicates the use and management of St. Pierre Wetland, is that universities are composed of two separate groups with different value systems and different structures of authority: administrative and academic. The administrative side includes professional subgroups and staff that support the school's operations, while the academic side includes faculty, lecturers, and students that are concerned with education and/or research. The administrative side strives for smooth operations, hierarchical bureaucracy, and risk reduction, while the academic side tends toward experimentation, autonomy, and collegiality. These disconnects can make it challenging for the academic and administrative sides to work in tandem, slowing down the process of institutional change (Birnbaum, 1988). We saw these differences and their consequences play out in our experiences on SPW.

On the administrative side, the structure tends to resemble that of a traditional bureaucracy, with a clear hierarchy in which those with greater authority make decisions and coordinate activities (Birnbaum, 1988, p.10). In our interactions with multiple individuals on the operations/administrative side, the individual checked with their superiors or with other administrative departments before responding to an inquiry we made. In addition, the FM, as well as other administrative entities that we worked with, valued written protocol and checklists regarding a variety of subjects and situations. We co-produced several checklists with the FM to ensure clear communication about our operations on the site, and to pass that system on to the next users. A lack of such protocols on the academic side has led to a lack of, for example, sharing of data or information about properties, especially with faculty and student turnover.

Birnbaum (1988) labels the academic side as "collegial," in that it is "a community of colleagues (p.87)," marked by mutual respect and autonomy. The authority structure is mainly egalitarian and consensus-based: decisions are often made in committees or an academic senate and publications are peer-reviewed. This leads academics to possibly move forward without considering a need to consult with other authorities. It should be noted, however, that even within the collegiality of the academic side there are strong hierarchies. Lecturers and tenured faculty, for example, will differ in their ability to fund students, be on grants, or vote on faculty decisions. This means that even considering only the academic side, the specific faculty member who heads efforts on sites like SPW can make a significant difference as to what can be accomplished.

The differences in values and operations between the administration and academic structures help to explain the differences in understanding how to approach access to SPW. We needed to cross private property to gain access to the wetland. The administrative side's primary goal is to keep the university operating smoothly, and therefore places a high value on minimizing risk and liability, in this case as it affects the property's mission. Following the hierarchical structure of the administrative side, the FM reached out to her supervisor, the Office of the Vice President and General Counsel, and the UM Real Estate Department for direction on how to proceed with access in order to ensure long-term operation of the property. Our advisor, a professor and part of the academic side, initially saw wetland access quite differently. The land was donated to UM for the purpose of research and education, and we were UM students using the land for both, so it seemed we should be able to easily access it by simply checking with the residents of the private property through which we needed to pass. This is a more collegial, autonomous approach to the situation more typical of academics.

The disconnect between administration and academics is also evident in the disregarded recommendations and plans written by faculty and students for SPW that we discussed above; they were made by the academic side and yet their implementation needed broad support from the administrative side. It is likely that students and faculty failed to account for the limitations of the property, not — for the most part— because they were ignorant of the rules, but rather because they underestimated the rules' importance. For example, the parties on the academic side who suggested a community workday were likely aware that the property was not open to the public, but assumed that this barrier could be easily overcome. However, the administrative side may see it as a liability for any non-UM affiliated individual to set foot on the property, and further, as a risk that is not worthwhile if it does not support the property's mission. Understanding that these different and equally legitimate viewpoints and values are at play, can completely change the way we choose to move forward effectively.

The above factors, including the anarchical structure, ambiguous authority roles, and differing values of academic and administrative arms of a university, make it difficult for a higher education institution to make changes. Often, as ideas encounter repeated barriers, inertia sets in and a decision is not made at all (M. Shriberg, pers. comm.). In our efforts to establish a research project on St. Pierre Wetland, we met with barriers throughout the process, and continued to seek creative ways around them. In sharing these barriers and the organizational forces behind them, we hope to empower future change agents to partner with universities around environmental stewardship, both of St. Pierre Wetland, and of other valuable natural sites.

5. A Realistic and Effective Approach at St. Pierre Wetland

We have identified some of the known barriers to the management and use of St. Pierre Wetland, as well as the benefits of engaging key external stakeholders, but also the unique challenges of working with and within a university system. Despite the barriers we encountered and adjustments we had to make, a strength of SPW is that multiple organizations and individuals value the ecological health of the land and the communities surrounding it. Even though the process looked different than expected, our goal remained the same: to continue building relationships and trust between stakeholders in order to create momentum for future stewardship.

I. Key Lessons to Navigate Barriers and Implement Community-Engaged Stewardship of a University-Owned Property

Given our understanding of the relevant opportunities and challenges, it is clear that only some methods of stakeholder engagement can be applied successfully to SPW, at least in the near term. Knowing this empowers current and future efforts to be more effective. Therefore, we have identified key lessons in how to approach engagement efforts that both meet the mission of the property while being feasible within the university system. We hope that these lessons help future change agents to more effectively and amicably navigate complex partnerships and land with limited access, both within the specific setting of UM and for any practitioner working within an anarchical institution.

The following lessons are organized so that the first level of bullet points are general suggestions for practitioners. The sub-points are specific to UM affiliates seeking to do research and education or continue restoration and conservation efforts at St. Pierre Wetland.

a. Lessons for navigating an institution with a structure of organized anarchy:

- Recognize there is no one person who has the authority to make a given decision.
- Get a lay of the land to understand the parties involved, their perspectives, and their desired outcomes for the situation.
- Strengthen relationships with involved internal parties, especially direct connections, to foster understanding and trust.

- Do not let one party's refusal put an end to your efforts. Another decision maker can have just as much say in the situation, so either continue looking for someone who will partner with you or bring other decision makers into the situation.
- Funding is not as straightforward as it seems. Budgets are closely tied to the mission of the organization and are decided the previous year. Every action must be proven to support the mission. External funding may be of limited use, because the institution may not want to be held to specific stipulations, or a grant's net value may be negative.
    - For SEAS properties, restoration that is not externally funded will be limited to a research or education activity and is unlikely to achieve large-scale restoration.
    - Working with the SEAS development office could be a way to find a private donor willing to fund ongoing contractor costs for large-scale restoration.
- Although restoration and ecosystem management are long-term endeavors, key players will come and go, due to the cyclical nature of a university. To ensure project continuity, tailor efforts to fit existing systems and processes.
    - Within SEAS, modify projects at SPW to fit within semester long classes (four months), a masters project cycle (sixteen months), a faculty research project, or plan for overlap between multiple groups to continue work for longer periods of time.
        - Initiation for projects must come from the faculty and students. Look for interest among faculty teaching subjects such as ecology, conservation biology, hydrology, remote sensing, aquatic life, plant studies, indigenous ecosystem management, community engagement, etc.
        - Involve student groups such as SEAStheWetlands in projects or to lead ongoing restoration activities.
        - Get buy-in from tenured faculty who can help support efforts through their greater voting and funding power within the academic community.

b. Pursuing community engagement for institution-owned property that is closed to the public:

- Referring to the Community Engagement Spectrum (see Figure 2.2), realistic engagement of community members will use techniques that fall within Informing and Consulting, and possibly Involvement. This ranges from project leaders taking stakeholder needs into account in decision making to consulting selected individuals for input which may or may not influence decisions.
    - For SPW, we originally hoped to pursue a Collaborative Adaptive Management

approach to engagement (see Table 2.2). However, as we navigated university barriers, we experienced that it is difficult for an anarchical institution to effectively play the role of equal partner with external stakeholders.

      - A Knowledge Deficit Model approach falls within the Inform portion of the Engagement Spectrum. This may be sufficient for educational outreach and making connections between external stakeholders.
      - A Citizen Science approach falls within the Consult and Involve portions of the Engagement Spectrum. This may assist with ongoing management and observation, but only for select "power volunteers" as the property is not open to the public. We expand on the concept of "power volunteers" later in this section.

- Clearly communicate a designated contact person for community members, and foster positive relationships between university representatives and community leaders.
    - SEAS Facilities Manager (FM) is the designated contact person for community members surrounding SPW. Make an effort to include the FM in all events involving community members.
- Be intentional in your communication with stakeholders, in order to manage expectations.
- Consider stakeholder and project member workload and availability. Higher education institutions and working professionals have different annual schedules and work load cycles. Be mindful of expectations around involvement and capacity.
    - For SPW, the involvement of stakeholders outside of UM must be restricted to a select group of FM-approved individuals, which we refer to as "power volunteers."
        - Foster good relationships with HOA community members.
        - Continue physical work on the wetland; neighbors like to see that the land is being used and cared for.

II. Accomplishments and Future Opportunities

As we navigated the opportunities and challenges surrounding the management of St. Pierre Wetland, we implemented appropriate engagement activities in line with project goals. Table 2.3 below highlights our accomplishments, the stakeholders involved in each, and opportunities to continue engagement.

Table 2.3. Current and Future Engagement with Stakeholders. Stakeholders organized by color for each type/sector: Restoration Practitioners, Property Neighbors, and SEAS Affiliates.

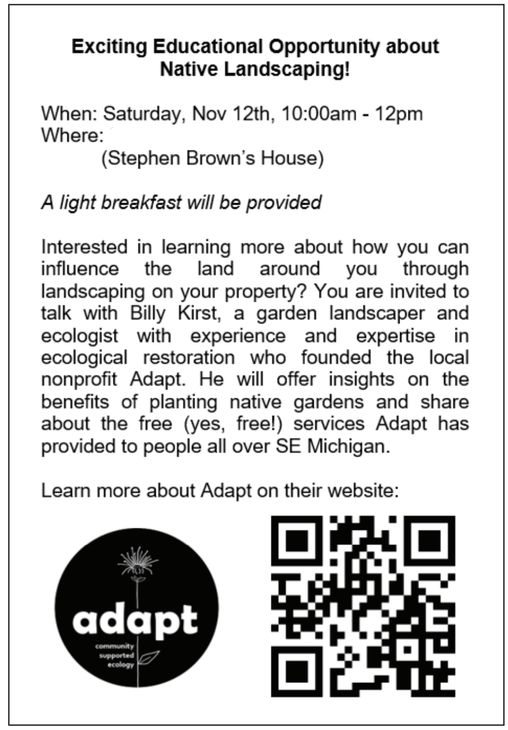
Stakeholders Engaged	Engagement Achieved	Future Engagement Opportunities
Area restoration practitioners	Held interactive conversations with approximately 20 practitioners to discuss best practices and research needs on buckthorn removal (See Chapter 4: Toward Informed Restoration and Stewardship of St. Pierre Wetland: Experimental Removal of Invasive Glossy Buckthorn).	Conduct Professional Stewards Hike at SPW in summer 2024 to view treatment effects.
	Presented to practitioners at the TSN annual conference in February 2023.	Future masters project groups continue to present each year and learn from other practitioners presenting on related topics.
Community surrounding SPW	Project team attended SGL HOA annual meeting (June 2022) to establish relationships and learn about neighbors interests and concerns.	Future masters students attend SGL HOA annual meetings to update the community on restoration progress and projects.
	FM established verbal agreements with SGL and Bass Ridge HOA for UM affiliates to use properties to access the wetland during particular site events. Student team established a relationship with a Bass Ridge HOA member who allowed us to park in front of her property.	Pursue written use agreements to preserve arrangements in the event of staff or leadership turnover. Solidify agreement with FM for community "power volunteers" to access wetland to monitor for plot disturbance. Be mindful and follow protocol when parking, in order to maintain a positive relationship with Bass Ridge HOA (see Appendix C. Logistical Site Use Guidance and Protocols for UM Faculty and Students).
	Organized meeting between ecology-oriented natural landscapes nonprofit Adapt and HOA members to educate about ecological restoration in landscaping. Members from SGL, Bass Ridge, and Cordley Lake HOAs attended (see Appendix A. *Record of Stakeholder Interactions*).	Connect with other HOA's along the Chain of Lakes (see Table 2.1)

Stakeholders Engaged	Engagement Achieved	Future Engagement Opportunities
Community surrounding SPW	Created and distributed an educational wetland flier to residents along Bass Lake (see Appendix D. *Wetland Educational Flier*).	Update flier as needed and share with the broader community around Chain of Lakes.
SEAS affiliates	Created visiting protocols and site access maps to support SEAS administration (see Appendix C. *Logistical Site Use Guidance and Protocols for UM Faculty & Students*). Created a digital version of the SEAS Research Form in Google Forms and shared it with the FM as an option to use for easier distribution and information storage.	Assist FM in streamlining protocols for SPW and other properties SEAS manages.
	Conducted site visit with Mike Kost (SEAS Lecturer and Associate Curator at MBGNA) for plant identification and ecological community restoration insights.	Connect with Mike Kost and other students in Ecological Restoration and Monitoring student organization starting 2023 to learn about restoration and conservation.
	Created the Storymap: A Guide for UM Users to provide a virtual tour and share key site features with faculty and students.	Continue to distribute the Storymap among faculty and students. Update the Storymap to reflect any changes to the site.
	Completed remote sensing analysis of SPW under oversight of SEAS professor Shannon Brines within the course EAS 652 GPS and Geospatial Field Technologies (see Chapter 3 Remote Sensing).	Continue monitoring invasive species at SPW, broadening scope to purple loosestrife (*Lythrum salicaria*), non-native Phragmites australis, and non-native cattail (*Typha latifolia* and *Typha x glauca*).
	Completed workday event to create experimental buckthorn removal plots at the prairie fen in SPW with the assistance of a volunteer group of SEAS students in March 2023.	Student volunteers, fall students (i.e. EAS 509 Ecology, EAS 546 Herbaceous Flora, etc.) and/or power volunteers follow up on research plots in summer and fall of 2023, and continue to oversee annual photo monitoring and future restoration work.

Stakeholders Engaged	Engagement Achieved	Future Engagement Opportunities
SEAS affiliates	Completed student design and implementation of experimental buckthorn treatment at SPW (see Chapter 4 Toward Informed Restoration and Stewardship of St. Pierre Wetland: Experimental Removal of Invasive Glossy Buckthorn). Uploaded our report to mfield, a data hub for all UM field properties.	Initiate another master's project team (see Appendix F. Proposal for 2024 St. Pierre Wetland Master's Project) to collect data on effectiveness of treatments and continue restoration research efforts, exploring other topics of further research, and continue other community engagement opportunities. Continue to upload relevant data and reports to mfield, a data hub for all UM field properties (https://mfield.umich.edu/st-pierre-wetland).
	Connected with SEAS faculty and shared opportunities for research and education at the wetland.	FM organizes annual site visits for faculty (and potentially students) to see the site, meet power volunteers, and to communicate correct processes and goals for SPW.
	Connected with Society of Wetland Scientists student chapter, SEAStheWetlands, and invited them to workday event.	Encourage SEAStheWetlands to use the wetland for field work and regular meetings. UM chapter advisor is Kurt Kowalski (kkowalski@usgs.gov).

Our accomplishments listed in Table 2.3 above were successful because of the way they were scaled to fit within appropriate engagement avenues. For example, recalling the engagement continuum (see Figure 2.2), we adjusted our original expectations of collaborating with HOA members for participation in on-site restoration to informing them about the benefits of ecosystem restoration and engaging with key power volunteers, who, with FM approval, can continue to access the site and assist in monitoring efforts. We also hosted an off-site event to connect stakeholders with a local organization, Adapt: Community Support Ecology, that provides free services and educates people about the importance of native plants (see Figure 2.4). Concurrently, we created an educational flier targeted specifically to residents along Bass Lake designed to not only educate about wetlands, but to also inform how individual actions within the same ecosystem have a wide impact (see Appendix D. *Wetland Educational Flier*). As noted in Table 2.1, many of the other HOA's along the Chain of Lakes are already participating in restoration activities outside of UM, and they would likely readily participate in further opportunities for restoration at SPW.

Another example of how we scaled our engagement activities is the methods we used to inform faculty and students of research opportunities on the wetland. Due to the barriers to access and liability concerns, we were not able to host stewardship hikes for faculty and students onsite. Instead, we created and shared the Storymap as an introductory tool showcasing the site. We clearly documented the new access points and also created written protocols for visiting the site with the goal of making it as simple as possible for students and faculty to visit the wetland (see Appendix C. *Logistical Site Use Guidance and Protocols for UM Faculty & Students*). In addition to being stored in Deep Blue, these guides will be linked (with access restricted to UM affiliates) in our project website to make this information as accessible as possible.



Exciting Educational Opportunity about Native Landscaping!

When: Saturday, Nov 12th, 10:00am - 12pm
Where:
(Stephen Brown's House)

A light breakfast will be provided

Interested in learning more about how you can influence the land around you through landscaping on your property? You are invited to talk with Billy Kirst, a garden landscaper and ecologist with experience and expertise in ecological restoration who founded the local nonprofit Adapt. He will offer insights on the benefits of planting native gardens and share about the free (yes, free!) services Adapt has provided to people all over SE Michigan.

Learn more about Adapt on their website:

Figure 2.6. Invitation to Adapt event distributed to HOA members

We hope our efforts have laid a foundation for future students and faculty to pursue further attempts at greater levels of community engagement. Subsequently, we strongly recommend the following as key steps for the next project team.

III. Key Next Steps

- Strengthen **relationships between UM SEAS faculty and staff and Bass Ridge HOA**
  - This relationship is essential, as we access SPW through their land.
  - This includes following **parking protocols** (see Appendix C. *Logistical Site Use Guidance and Protocols for UM Faculty and Students*) and making respectful, proactive contact with neighbors whose homes we park near.
- Work with offices at UM to complete a **written use agreement** between UM SEAS and Bass Ridge HOA. This statement would grant permission to SEAS affiliates to access Bass Ridge's private trail from the road, N. Bass Ct.
  - Possible parties to be involved: SEAS FM, Max Nettleton, UM Office of the Vice President and General Counsel (Legal), UM Real Estate Department, Stephen Brown, and others.
  - Offer Bass Ridge something in return for the access they grant, with the goal of

building a relationship, rather than a one-way exchange.

- Reinforce the role of "**power volunteer**" and designate specific individuals as power volunteers. We recommend Stephen Brown, President of Shan-Gri-La HOA.
    - Work with the FM to define the power volunteer's role and responsibilities, in writing.
    - Intentionally engage power volunteers in restoration work at SPW.
- Faculty and students pursuing future projects on SPW must be respectful of the local community and the unified efforts they are developing for whole Chain of Lakes ecosystem management. Do so by **investing in relationships with other HOAs** along the Chain of Lakes to ensure stewardship goals align with the culture already established, contributing to their work in ways that add value and promote dignity.
- Facilities Manager, faculty, and students must continue to **refine and regularly update** the site policies and protocols we created. We strongly urge **integrating these documents into SEAS properties management for all six properties.**
- Because of the transient nature of higher education institutions, SEAS leadership and staff must **regularly share opportunities** at SPW with faculty and students. Doing so will support the property's mission of research and education.
    - Future **master's project students** will also be key to building SEAS involvement in St. Pierre Wetland.
- Pursue **funding opportunities** available for wetland related activities and research (see Appendix G. *List of Possible Funding Sources*).

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cH.3

USING REMOTE SENSING DATA TO INFORM WETLAND RESTORATION

Chapter 3: Using Remote Sensing Data to Inform Wetland Restoration

1. Purpose and Audience

Assessing species and habitats on the ground through field work is essential for understanding a site and planning for restoration, but it can also be time-consuming and challenging for organizations with limited capacity. Remote sensing data, captured by satellite and airborne monitoring sensors, is a powerful source of existing information that can be used to raise awareness and inform the conservation and restoration of a site. Through the utilization of remote sensing derived data, we will demonstrate the usefulness of spatial analysis and modeling tools in facilitating ecological research, planning, and wetland restoration of St. Pierre Wetland in southeast Michigan.

After introducing remote sensing as a valuable spatial analysis tool, this chapter describes the following research steps we took:

1. Assess current plant species distribution at the St. Pierre Wetland by performing a supervised classification, using field data and spectral signatures captured through leaf-on CIR National Agriculture Imagery Program (NAIP) imagery, and further delineate the property by conducting photo interpretation through the analysis of leaf-off color infrared (CIR) imagery, Light Detection and Ranging (LiDAR) derived Digital Elevation Model (DEM) indexes, and leaf-on natural color NAIP and leaf-off Orthorectified imagery of Livingston County, MI.
2. Test the accuracy of a geospatial algorithm in identifying select species based on existing remote sensing and ground-truthed data.
3. Test the relationships of species distributions to other physical features of the site using multivariate analyses (hierarchical cluster analysis and principal component analysis).

These analyses can inform potential research and stewardship activities at the St. Pierre Wetland, while also providing technical guidance for any practitioners or researchers, who are already familiar with basic geospatial platforms and tools, and are seeking to use remote sensing data to achieve a deeper understanding of their site.

2. Introduction

From distances beyond Earth's atmosphere to heights less than 400 ft above its crust, remote sensors are used to detect and collect electromagnetic (EM) energy that is reflected and emitted from Earth's surface. Remote sensing technology has provided a practical, timely and cost effective approach to analyzing complex geographical terrain and inaccessible ecosystems. The range of sensor systems, including aerial photography, satellite imaging, multispectral and hyperspectral scanners, and high spatial and spectral resolution, have made remote sensing a valuable tool in understanding the diversity of Earth's surface on a broad scale (Joshi et al., 2004).

Remote sensing data, combined with geographic information system (GIS) techniques, are an efficient and effective way for collecting, processing, and relaying information. Remote sensing derived information has been used to inform practices, management and policy within various organizations. For example, Ducks Unlimited, a 501(c)(3) nonprofit organization committed to conserving waterfowl dependent habitats, utilizes remote sensing using hyperspectral and multispectral imaging for identifying and mapping (digitizing) these habitats, discrimination wetlands by type in order to update the National Wetland Inventory, alongside the US Fish and Wildlife Service (Ducks Unlimited | U.S. Fish & Wildlife Service, 2022). Though there are a plethora of applications of remote sensing tools and derived information, the employment of remote sensing is commonplace for fields including geography, geology, archaeology and forestry (Remote Sensing and GIS | Planning Tank, 2018). Additionally, land-use practices such as agriculture use remote sensing to monitor and inform decisions including crop placement, irrigation management and fertilizer distribution (Mary, 2021). The data collected using remote sensing imaging are rendered through geographic information techniques, allowing for the translation of information across sectors.

We chose to harness the applicability of remote sensing to better understand St. Pierre Wetland (SPW), a 130-acre University of Michigan (UM) research and education field property in Southeast Michigan that is located within a larger wetland complex (see Chapter 1: *Introduction to St. Pierre Wetland: Problems and Opportunities*). Field work to assess species and habitats on the ground is essential for understanding a site and planning for restoration, but it can also be time-consuming and challenging for organizations with limited capacity. To inform research, education, and restoration on site, we used remote sensing data and multivariate analysis to address the following research questions for SPW:

1. What is the current plant species distribution at St. Pierre Wetland?
2. Can remote sensing be used to accurately detect and differentiate between species of St. Pierre Wetland?
3. What are the relationships of species distributions to other physical features on the site?

3. Methods and Results

I. Description of Provided and Created Data Layers

Data utilized in this multivariate analysis were provided by Ducks Unlimited Great Lakes Regional Office, as they use them within their own conservation practices. Data included the most recently updated wetland polygons from the National Wetland Inventory (2016), an orthometric CIR Mosaic dataset in the form of TIFFs, and the Digital Elevation Model of Southeast Michigan. From these provided datasets, we carried out a variety of geospatial processes within ArcGIS Pro to extract additional information describing vegetation concentration and productivity, and we created a final dataset that summarized the topographical characteristics and vegetation composition of 159 palustrine emergent wetlands within Livingston County, Michigan. Below, we briefly describe each data layer (both provided and created layers) used within this analysis and have provided a data summary table (Box 3.1). In the following section we outline the methods used to extract data from these layers.

Table 3.1. Data summary table.

Data	Specifications	Souce
USA NAIP	CIR Imagery Projected Area Extent (m): Cell Size X: 0.29999999999998533 Cell Size Y: 0.29999999999998533 Number of Bands: 3 Cell Type: Unsigned Char Cell Depth: 8 bit Spatial Reference: WGS 1984 Web Mercator (auxiliary sphere)	NAIP Registry of Open Data on AWS
Orthoimagery	Livingston County, Michigan Acquisition: March 28, 2015 through April 28, 2015 Published: October 2015 Format: TIFF/TFW Tile Size: 2500 ft x 2500 ft Number of Bands: 4 Cell Type: Unsigned Char Cell Depth: 8 bit Resolution: 0.5 ft (6 inch)	Ducks Unlimited, GLARO

Data	Specifications	Souce
Orthoimagery	Spatial Reference: NAD_1983_HARN_StatePlane_Michigan_South_FIPS_2113_Feet_Intl_feet Vertical Accuracy: N/A	Ducks Unlimited, GLARO
Livingston_3m_ DEM (Original)	Livingston County, Michigan Projected Area Extent (m): Top: 251,235.614465 Bottom: 210,057.614465 Left: 649,946.326106 Right: 691,871.326106 Cell Size X: 3 Cell Size Y: 3 Number of bands: 1 Cell type: Floating point Cell depth: 32 bit Spatial Reference: NAD 1983 (2011) Michigan GeoRef (Meters)	Ducks Unlimited, GLARO
DEM (indices)	Livingston County, Michigan Project Area Extent (m): Top: 247,040.563300 Bottom: 211,034.505100 Left: 652,005.853300 Right: 678,996.007100 Cell Size X: 2.9999059464265057 Cell Size Y: 2.99975491127217 Number of Bands: 1 Cell Type: Floating Point Cell Depth: 32 bit Spatial Reference: NAD 1983 (2011) Michigan GeoRef (Meters)	Ducks Unlimited, GLARO

Data	Specifications	Souce
SEMCOG Polygons	Spatial Reference: WGS 1984 Web Mercator (auxiliary sphere) XY Resolution: 0.0001 Meters	Ducks Unlimited, GLARO
SEMCOG_ NAIP_2020	Projected Area Extent (m): Top: 5235609.936621 Bottom: 5225814.012527 Left: -9351038.711466 Right: -9330825.137239 Cell Size X: 5.299836 Cell Size Y: 5.297958 Number of bands: 3 Cell type: Unsigned Char Cell depth: 8 bit Spatial Reference: WGS_1984_Web_Mercator_Auxiliary_Sphere	NAIP Registry of Open Data on AWS
Reprojected SEM-COG	Projected Area Extent (m): Top: 218,181.435700 Bottom: 211,341.730800 Left: 664,234.440000 Right: 678,996.007100 XY Resolution: 0.0001 Meters Spatial Reference: Projected Coordinate System: NAD 1983 HARN Michigan GeoRef (Meters)	Ducks Unlimited, GLARO

a. Color Infrared Orthoimage (provided)

An orthorectified image (orthoimage) is a raster image processed from vertical aerial images where optical distortions from the sensor system and changes in terrain due to sensor view angle have been removed (ESRI, 2016). The resulting image layer provides both the characteristics of an image and geometric qualities of a map, linking pixels with the appropriate x and y coordinates, functioning as a cartographic base for displaying, generating, and modifying associated digital planimetric data.

This raster dataset, consisting of 8-bit, 4-band (R, G, B, and NIR) color orthoimagery, was used to delineate vegetation. Altering the band combination from 1, 2, 3 (Natural Color) to 4, 1, 2 (CIR) we were able to distinguish between urban land use, vegetation and water with greater contrast between vegetation types (GISGeography, 2014). Comparing Figure 3.1 and 3.2, the visual differences among land cover types are exacerbated when changing the band combination from Natural Color (Figure 3.1) to CIR (Figure 3.2). Though we utilized orthoimagery for vegetation classification, additional applications of orthoimagery include, but are not limited to, environmental impact assessments, disaster management, flood analysis, soil erosion assessment, groundwater and watershed analysis, and the detection of physical features or attributes not possible at ground level.

b. Digital Elevation Model (provided)

The Digital Elevation Model (DEM), also known as a Digital Terrain Model (DTM) represents bare Earth as a topographic surface, excluding trees, buildings, and any other surface objects. This information was collected by an active remote sensing system known as Light Detection and Ranging (LiDAR). From the DEM, layers (indices) were rendered using geoprocessing tools within ArcGIS Pro and python scripting (Macleod, 2018). These indices describe different characteristics of the imaged topography.

c. Slope (provided)

Slope, an important DEM derived indice, measures the degree or steepness of incline from the maximum rate of change of elevation between a specific location and its surroundings. Measured and displayed in radians, this layer can be used to further analyze Earth's surface topography. Low radian values will appear dark, indicating a relatively flat surface, whereas higher radian values will appear light in color and may provide additional insight on the surface texture of the area of interest.

d. Topographic Position Index (provided)

The Topographic Position Index (TPI) was created using the focal statistics spatial analysis tool. This tool was used to calculate the mean (average) of values for each cell location of the DEM raster within a specified neighborhood. The output focal statistics raster or TPI provides a generalized topographic profile, distinguishing high and low elevation. For example, a high focal mean value may indicate the crest of a hill, whereas a low focal mean value may indicate the trough of said hill.

e. Compound Topographic Index (provided)

The Compound Topographic Index (CTI) layer is helpful when modeling water flow accumulation as a function of upstream contributing area and slope (calculated by percent rise). CTI is a metric of potential ground wetness and can be used to identify areas in which water is

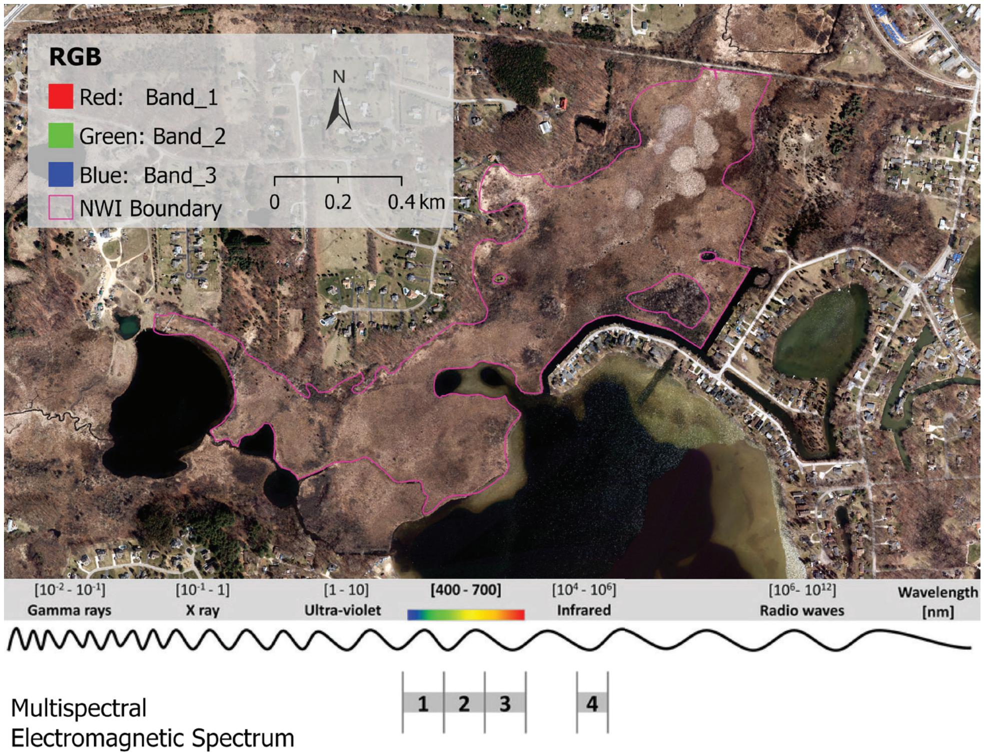


Figure 3.1. Orthoimagery of Livingston County, MI, centered on SPW with a natural color band combination of red (1), green (2), blue (3) indicated at the bottom of the figure.

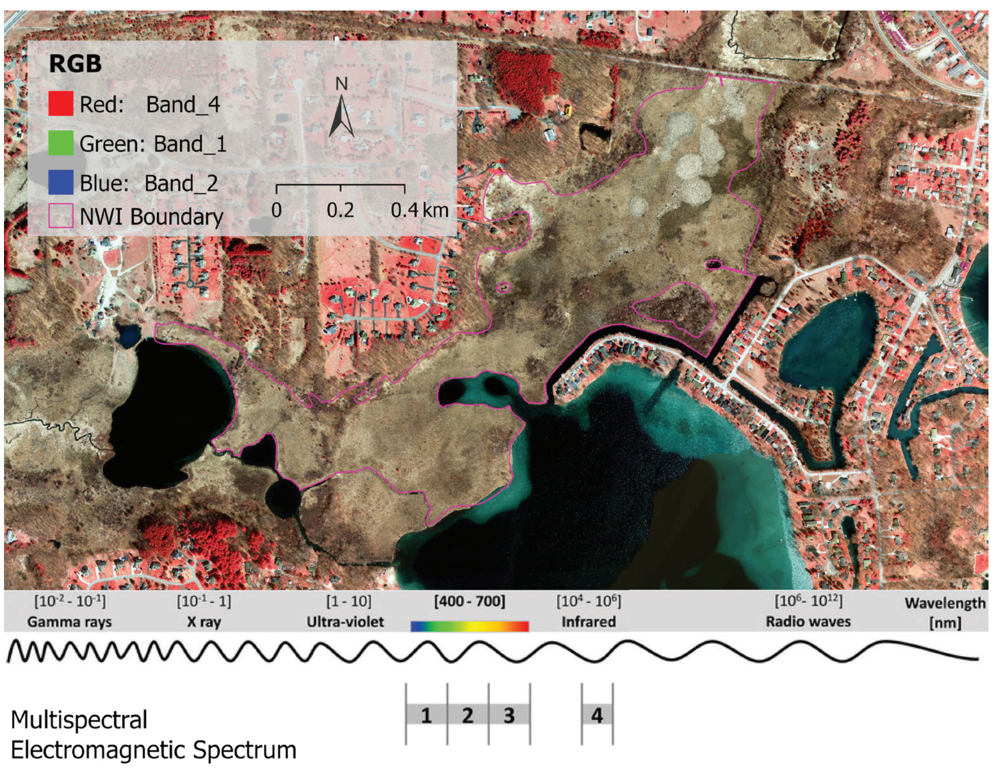


Figure 3.2. Orthoimagery of Livingston County, MI, centered on SPW with a CIR band combination of red (4), green (1), blue (2) indicated at the bottom of the figure.

most likely to accumulate, often highlighting scarification of the landscape that is not captured in other DEM derived indices. Prolonged exposure to water is a key factor in determining soil type, influencing soil properties such as texture, moisture and organic content. This affects the distribution of vegetation, varying with moisture gradients and soil conditions. Small CTI values are typically found along ridgelines while large values may indicate valley bottoms and basins (Buttrick et al., 2015).

f. Stochastic Depression Analysis (provided)

A Stochastic Depression Analysis (SDA) identifies topological depressions while accounting for errors and uncertainties within the DEM raster (Aranda et al., n.d.). An SDA layer, in combination with additional spatial analyses, can further illuminate depressions and, therefore, be used to locate depressional wetlands within the study area.

g. Maximum Height (provided)

Maximum height (maxheight) captures the maximum height of an element on Earth's surface, measuring the height or distance between the ground, represented by the DEM, and the top of an object (Wasser, Leah et al., 2021). For example, canopy height can be derived from this layer, providing a measurement (m) of how far above the ground the top of the canopy is. This information was collected using LiDAR.

h. Hillshade (created)

The DEM surface raster was altered using the Hillshade spatial analyst tool within ArcPro. This Hillshade layer provides a better idea of elevation difference and textural components of bare Earth by considering the illumination source angle and shadows. This layer can be used for delineating boundaries that may be difficult to identify using the CIR image or DEM.

i. Normalized Difference Vegetation Index (created)

Using a multispectral raster, the Normalized Difference Vegetation Index (NDVI) describes the greenness or estimated productivity of vegetation within a specified zone by calculating the difference between the red band and near infrared band (two of the four spectral bands that compose the CIR image). NDVI values range from +1.0 to -1.0. Low values (<= 0.1) may indicate barren rock, sand, or snow. Moderate values (0.2 - 0.5) may indicate areas of sparse vegetation. High values (0.6 - 0.9) may indicate dense vegetation at their peak growth stage (Remote Sensing Phenology | U.S. Geological Survey, 2018). Overall, the range of NDVI values can be used to estimate vegetation type, abundance, and health on a large scale.

j. Species Classification Image (created)

A predictive image is generated using the Image Classification Wizard within ArcGIS Pro. This spatial analysis tool, guided by you and the information you feed it, uses maximum likelihood estimation to delineate your area of interest, identifying variance in land-use and/or spe-

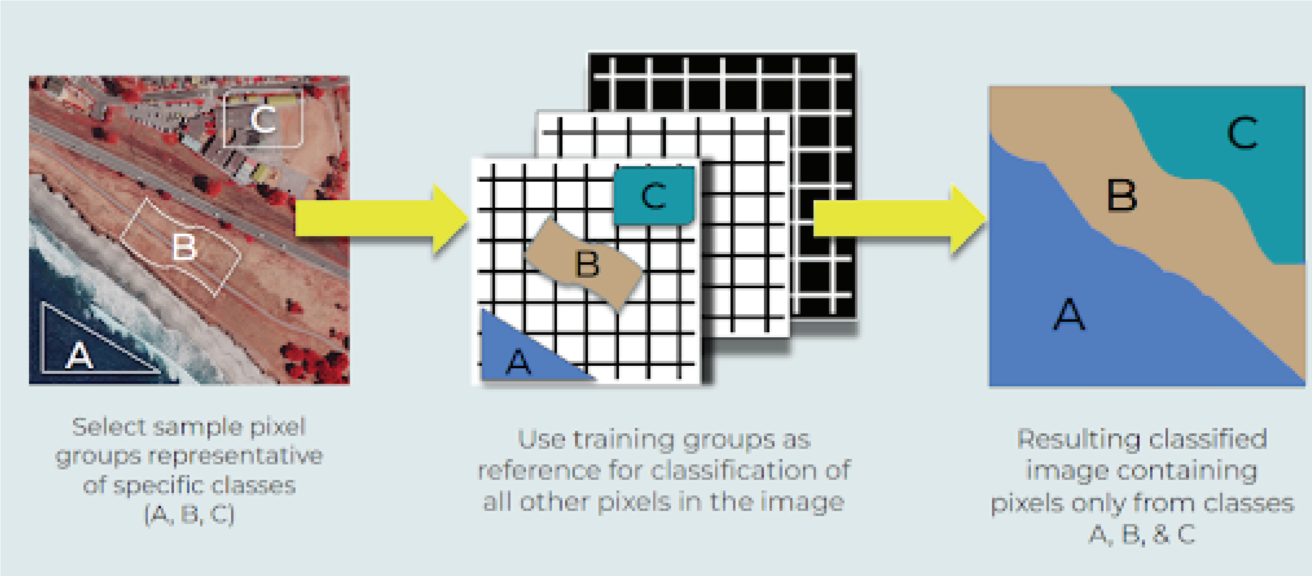
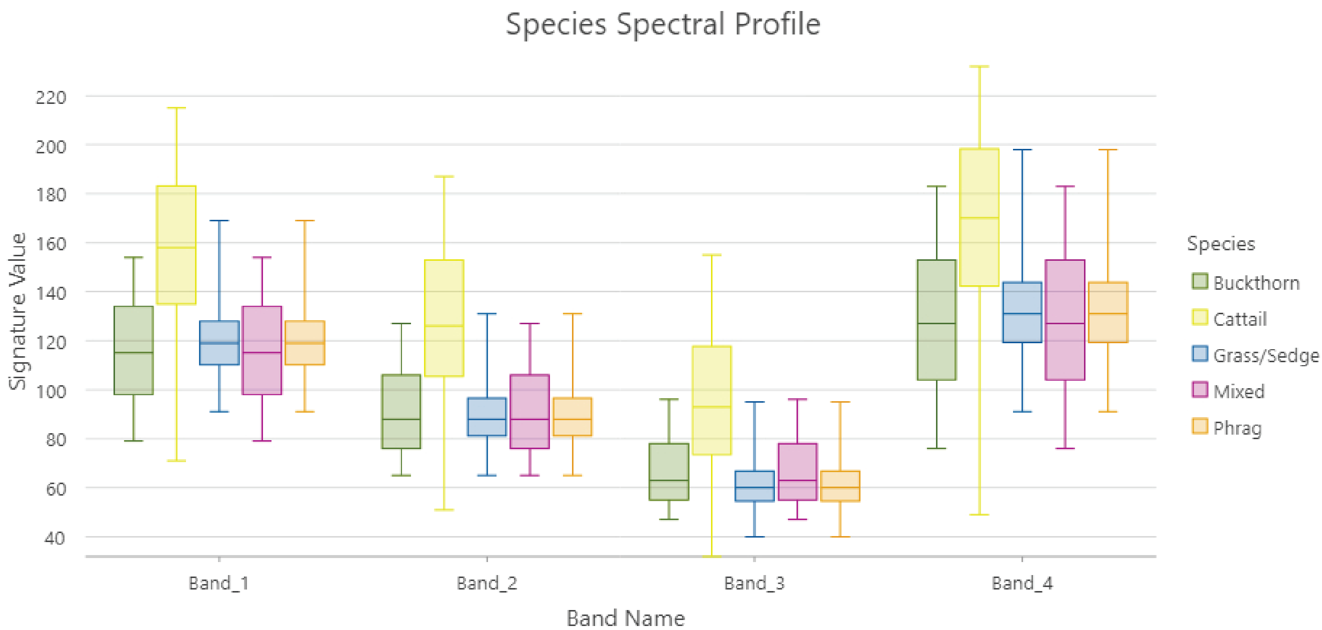


Figure 3.3. Breakdown of how the image Classification Wizard utilizes maximum likelihood to summarize the spectral signatures of individual cells within specified polygons.

cies composition. This process, demonstrated in Figure 3.3, requires the user to identify areas of interest within polygonal features of which the maximum likelihood algorithm will use differences in spectral signatures to delineate the landscape. For example, the variance in spectral signature among vegetation classes can be visualized in Figure 3.4. Differences among spectral signatures can be further understood by comparing the signature value increase when changing the imagery band combination from natural color (Figure 3.4.a) to CIR (Figure 3.4.b).

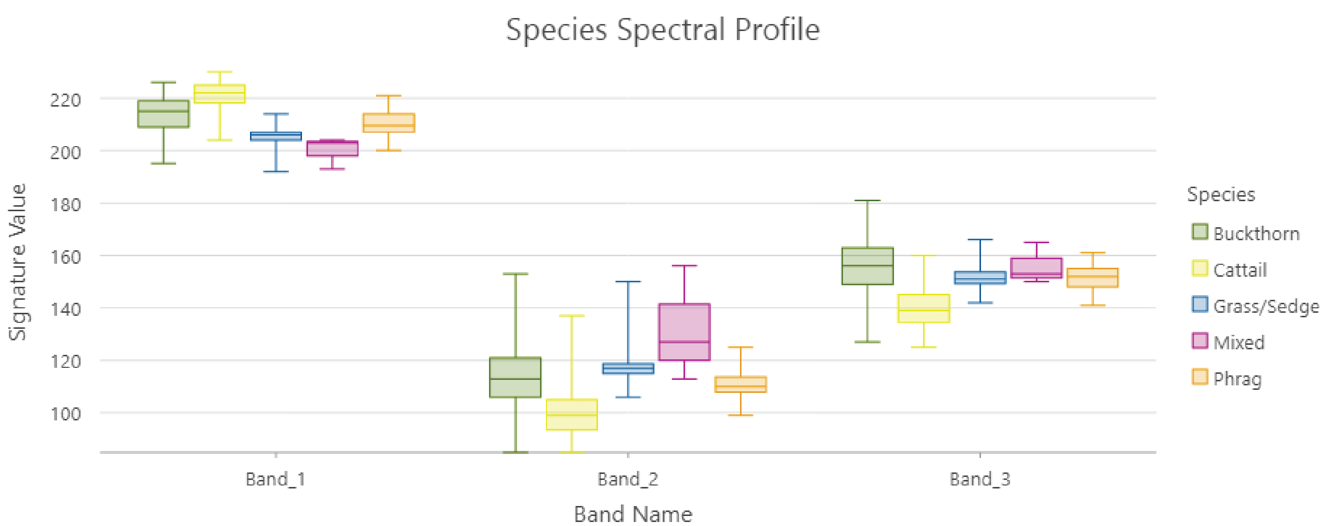
k. Verification Points (created)

In order to provide the Image Classification Wizard with accurate species information we had to conduct field work at St Pierre Wetland. Prior to visiting the property, we used ArcGIS Online to drop points where we believed clusters of certain species may be present (cattail, phragmites and buckthorn). In the field, we used ESRI Field Collector, a GPS based data collection mobile application, to direct us to each point of interest. On October 30, 2022, a total of 14 verification points were collected in the field for analysis (Figure 3.6), identifying cattail, phragmites and buckthorn. On March 20, 2023, we collected an additional 18 verification points using a Bad Elf Flex external GNSS receiver, identifying areas of mixed vegetation, buckthorn, cattail and grass/sedge. Employing this GPS in the field allowed for us to collect points with horizontal accuracy of approximately 0.013 cm and vertical accuracy of approximately 0.021 cm. Unfortunately, due to difficulties in the field, over half of the positions collected relied upon our Integrated (System) Location Provider (iPhone GPS) resulting in a horizontal accuracy of approximately 5 m and a vertical accuracy of approximately 9.5 m. Despite the positional error discrepancies, we utilized the ground truthed data to inform our supervised species classification.



Created using CIR Orthorectified Imagery (2016) and filed verification points (2023).

Figure 3.4.a. A spectral profile of specified species within SPW, produced using CIR Orthoimagery (2016) and field verification points (2023). Visually, you will observe differences among species signature values within each band but notice that the greatest signature values are recorded in band 4 (NIR).



Created using NAIP CIR Imagery (2016) and field verrification points (2023).

Figure 3.4.b. A spectral profile of specified species within SPW, produced using CIR NAIP Imagery (2016) and field verification points (2023). These spectral signatures were recorded using a CIR band combination of (red(4), green(1), blue(2)). The increase in spectral reflectance (signature value) when placing the NIR information in the red band (identified by band_1) influenced our team's decision to conduct our analysis using a CIR band combination.

I. National Wetland Inventory Polygons (provided)

Using the National Wetland Inventory (NWI), we extracted 159 wetland polygons within Livingston County, MI, where our area of interest is located. These wetlands were chosen specifically because they are similar to that of St. Pierre Wetland was necessary in ensuring a large enough sample size to run multivariate analyses.

II. Research question 1: What is the current plant species distribution at St. Pierre Wetland?

Having provided a brief description of the data types used within this analysis, we now provide the methods by which the data were collected, including detailed descriptions of where (specific platform) and how (step by step) we extracted information from the datasets provided by Ducks Unlimited (DU). An overview of the data sources are given below as a visual aid, as well as a simplified breakdown of the data extraction methods (Figure 3.7). The purpose of providing this level of detail is so that others may follow along and/or conduct similar analyses.

i. Polygon retrieval

Funded by the Southeast Michigan Council of Governments (SEMCOG), DU, in collaboration with US Fish and Wildlife Service, have been contributing to updating the NWI by identifying and digitizing wetlands within many Southeastern Michigan Counties. Provided access to these files by DU, we filtered the wetland segment layer by Palustrine Emergent Wetlands with seasonal prolonged inundation (PEM1C), the same wetland classification type as the SPW. After filtering the dataset for PEM1C, we used the boolean expression to select all PEM1C wetlands within the village that SPW is located, Pinkney, MI (village in Livingston County, MI). We then exported these results (159 wetland polygons) to a new shapefile so that the topographical characteristics and species composition could be summarized for further analysis.

Figure 3.5. Photograph taken in a cattail stand at SPW while collecting verification points (10/30/2022 at 1:30 pm).

Figure 3.6. Map of verification points collected at the SPW (10/30/2022). Top subset image captures our view through a cattail stand looking into the middle of the wetland, while the bottom subset image is directed towards Bass Ridge HOA.

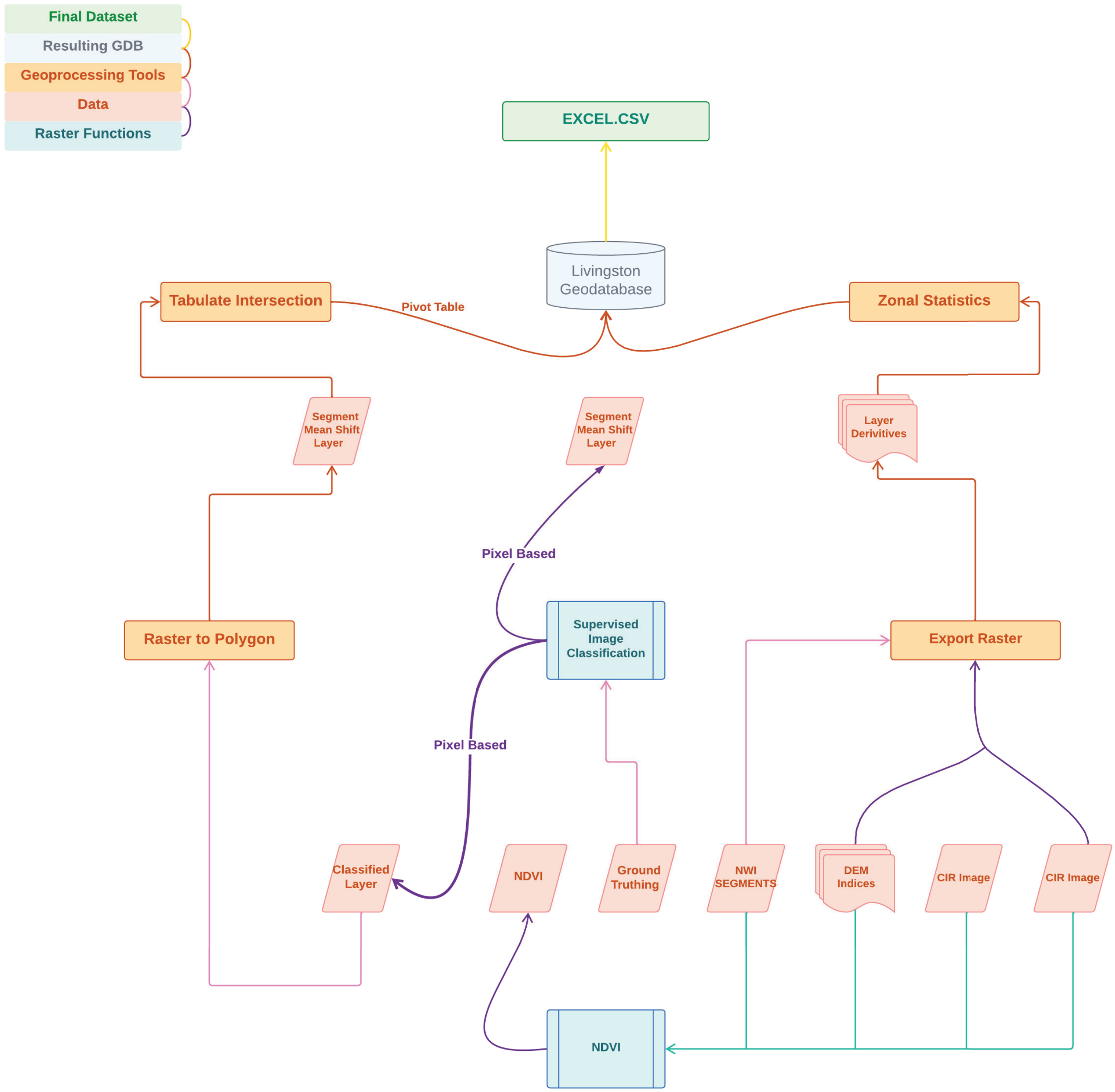


Figure 3.7. Flow chart breaking down the processes used to extract data for our analysis.

ii. Mosaic Construction

Before we could begin extracting the zonal information for each of our polygons, we needed to rebuild the Livingston County Mosaic dataset. Though it is not difficult to download mosaic datasets, the connections linking the geotiffs to the built mosaic often break when transferring the files from one source to another. Below, we have provided the steps we took to rebuild our mosaic dataset. The final compilation image was used for visual interpretation (CIR, bands 4, 1, 2) of moisture presence, vegetation vigor, and categorical information at each site.

Steps for rebuilding the Livingston County Mosaic dataset

1. You will need to create a new File Geodatabase in which you will construct a new Mosaic Dataset. For our purposes, we left all settings default.

2. Within your newly constructed Mosaic Dataset, you will import the raster image geotiffs, calculate the pyramids and statistics and build overviews with default settings.

    a. When you add rasters (geotiffs) to your mosaic dataset it gives you the option to build pyramids, statistics and overviews, but that usually fails or produces distorted results.

Once the mosaic was complete, we changed the original band combination from natural color (1, 2, 3) to CIR (4, 1, 2) to inform our photo interpretation and data extraction process.

iii. Deriving Layer Information

Large datasets, such as the one built for this study, have proven difficult to work with because they drastically slow down tool execution within spatial modeling and programming platforms. These factors can be problematic when deadlines are to be met and, therefore, one should approach similar situations with well formulated strategies/methodologies to limit wasted effort and lost time. Depending on your priorities and available data, we would recommend any extraction method that can preserve area while supporting your primary goal. In an attempt to moderate the time needed to run functions in the future, we exported all rasters data, clipping to the geometry and extent of the wetland polygons. This resulted in raster layers that only held information relevant to each individual polygon.

Steps for extracting rasters:

1. Select the raster layer of interest in your contents pane. Right click and select data and export raster. A new pane will appear, ready for you to define your parameters.

2. Within the "Export Raster" pane:

a. Choose where you would like to store the output raster dataset. Select the coordinate system that matches that of your polygons. You will need to specify the four coordinates that will define the extent of the bounding box used to clip the raster. For our purpose, we chose the SEMCOG wetland polygons for the clipping geometry. In order to derive information about the topography and spectral characteristics of each wetland, we chose to maintain the clipping extent, automatically adjusting the raster size and cell size. If the output raster size is too large for export, the column and row boxes will turn red. This was a common theme when exporting rasters to our desired extent, requiring us to adjust the cell size accordingly. Additionally, you will need to assign the common pixel type (8 bit Unsigned), set your NoData value to zero, and select your desired output format (GRID or TIFF).

This data management tool allowed us to extract the cells of each raster layer that correspond to areas defined by the wetland polygon geometry, returning an output raster containing the cell values extracted from the input raster. This process was carried out for each of the DEM raster indices using the same wetland polygonal mask as the extraction boundary and extent. These layers were used later to enhance the species classification process, reducing the processing time.

The next step in compiling data for analysis was to create a table that summarized the values of each raster layer (DEM indices and CIR image) within the zones of the wetland dataset. This table was created using the image analysis tool "Zonal Statistics to Table" which is described as follows:

Zonal Statistics to Table:

1. Within the Zonal Statistics to Table pane, you will select the dataset that defines your zones or areas of interest. For our purposes, we chose the SEMCOG polygonal feature layer as the Input Feature Zone Data. We defined the Zone Field to Object_ID as that field is unique to each wetland feature. You will then select the raster that contains the values you are interested in statistically summarizing such as the DEM indices, and choose an output location for this information. The final step is to select the statistic type to be calculated, of which we chose the mean. There are many other modifications one can select on the panel but for our purposes, we left everything else as default.

Using the spatial analysis tool "zonal statistics as table," the zonal statistics of each raster layer was carried out consecutively. All rows and columns of each attribute table were copied

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Figure 3.8. Formula used to calculate NDVI within a raster dataset that includes information collected in the NIR spectral range. NIR – reflection in the near-infrared spectrum; RED – reflection in the red range (visible light) of the spectrum.

to clipboard and pasted in separate excel pages to keep our working space organized. An additional excel page was created for the construction of the final dataset that we would then be saving as csv and reading into R Programming.

Calculating Normalized Difference Vegetation Index:

The Normalized Difference Vegetation Index (NDVI) is an additional element that we believed would better inform the species classification results and overall analysis. Using the NAIP CIR multiband output raster layers, created through the Export Raster portion of our methods, we calculated the relative biomass of each wetland polygon/feature zone by running the NDVI Color Map Image Analysis function. This function summarizes the relative biomass or greenness of vegetation by calculating the difference between the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band, using the following formula (Figure 3.8).

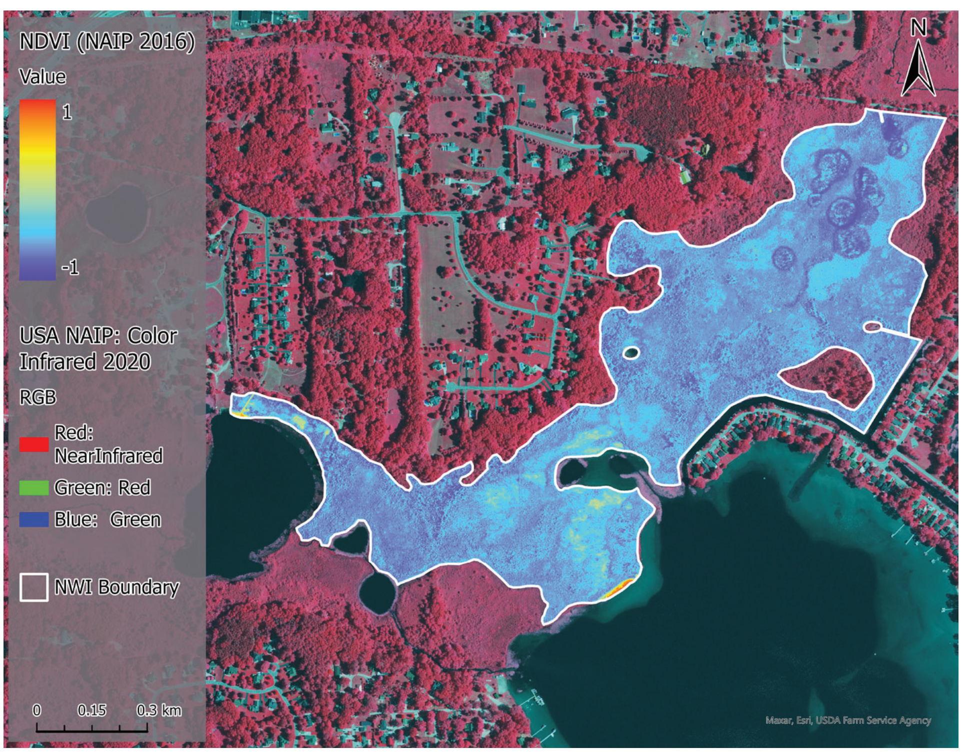


Figure 3.9. Map describing the relative biomass of SPW during peak growing season in 2016. The calculated NDVI (2016) raster layer overlays the NAIP CIR imagery (2016). We can see that NDVI for this specific year ranges from approximately 0 to -1.

Steps for NDVI Color Map:

1. Having selected the CIR multiband raster layer within your contents pane, you will open Raster Functions located in the image tab of your ribbon. You will find the NDVI function under Analysis. There is an option to create a NDVI Color Map but that does not produce a scientific output.

2. Within the NDVI raster function pane you will input your raster of interest and specify which bands hold NIR and Red spectral information. For your analysis, we selected the NAIP CIR 2016 raster file (3 band: 4, 1, 2) that had been extracted earlier. The appropriate bands were identified and the scientific output was checked so that the resulting NDVI raster values would range from -1 to 1.

The resulting NDVI layer, summarizing vegetation vigor, was used to inform species classification through photo interpretation. We ran zonal statistics on this layer but the produced values were not included in the MVA as the NDVI statistical summarization only described the mean NDVI value of each polygon. In order for this information to be beneficial to our overall MVA, we would have needed to, within the wetland polygon boundary, transform the species classification raster lay into polygonal features and then run zonal statistics on NDVI within said features. This would allow us to determine relationships between NDVI values and specific species classes, if any existed. However, we did use the NDVI layer as a photo interpretation aid and as reference data for training our image classification algorithm.

iv. Image Classification

To complete the data extraction process, the species composition of each wetland/feature zone was determined by employing the Image Classification Wizard. The information used to classify species included photo interpretation by toggling between leaf-off CIR and leaf-on NAIP imagery of SPW (refer back to Figures 3.1 and 3.2) to delineate deciduous and evergreen species, ground truthing data collected through site verification points and the utilization of image classification tools. We suggest familiarizing yourself with the information needed to employ the Image Classification wizard, considering the format and data type required for maximum likelihood image analysis. Additionally, we recommend determining which image classification tools you will use to produce the required information to ensure a structured workflow.

Image Classification Tools

The image classification tools are presented on the top ribbon along with the Image Classification Wizard. Each tool returns an informative output to be used as input data when running the Image Classification Wizard. These tools guide the user through the image classification process, providing space for the user to make modifications per their priorities.

Segment Mean Shift

The segment mean shift tool is most often used for object-based image classification where pixels in close proximity and similar spectral characteristics are grouped together as a segment. Segments that are similar in shape, spectral signatures and spatial properties are grouped together as objects (Understanding Segmentation and Classification—ArcGIS Pro | Documentation, n.d.) and can then be classified by the user, representing the features of interest within the analysis. For our analysis we utilized the segment mean shift tool to create a reference raster layer for our supervised pixel-based image classification.

Steps for segmenting an image:

1. Having selected the image you wish to segment within your contents pane, you will navigate to the imagery tab within your ribbon and select "Segmentation" in the classification tools drop down.

2. Within the image classification pane you may adjust the parameters according to the amount of detail that characterizes your features of interest.The Spectral Detail parameter control allows one to specify the mean shift algorithm's attention to spectral differences and similarities between classes. Spectral detail values range from 1.0 to 20.0, where 1 is little to no detail and 20 is extremely detailed. Since the discrimination between classes increases with the spectral detail, we selected a spectral detail value of 18 as our interest was to more accurately differentiate between species. Similar to the spectral parameter, Spatial detail values range from 1.0 to 20.0, where 1 is little to no detail and 20 is highly detailed. We chose a spatial value of 10 so that the resulting segmented image would have a more smooth and more generalized spatial composition. The minimum segment size in pixels depends on the input raster, merging segments smaller than your minimum mapping unit with their best-fitting neighbor segment. We chose a minimum segment size of 40 pixels.

A lot of trial and error accompanies this process, but previews of the final segmented image are provided so that the spatial and spectral detail of the desired output can be easily altered. The final segmented raster image was later used as the reference layer for our supervised pixel-based classification, informing the maximum likelihood algorithm of the neighboring pixel clusters, to enhance performance.

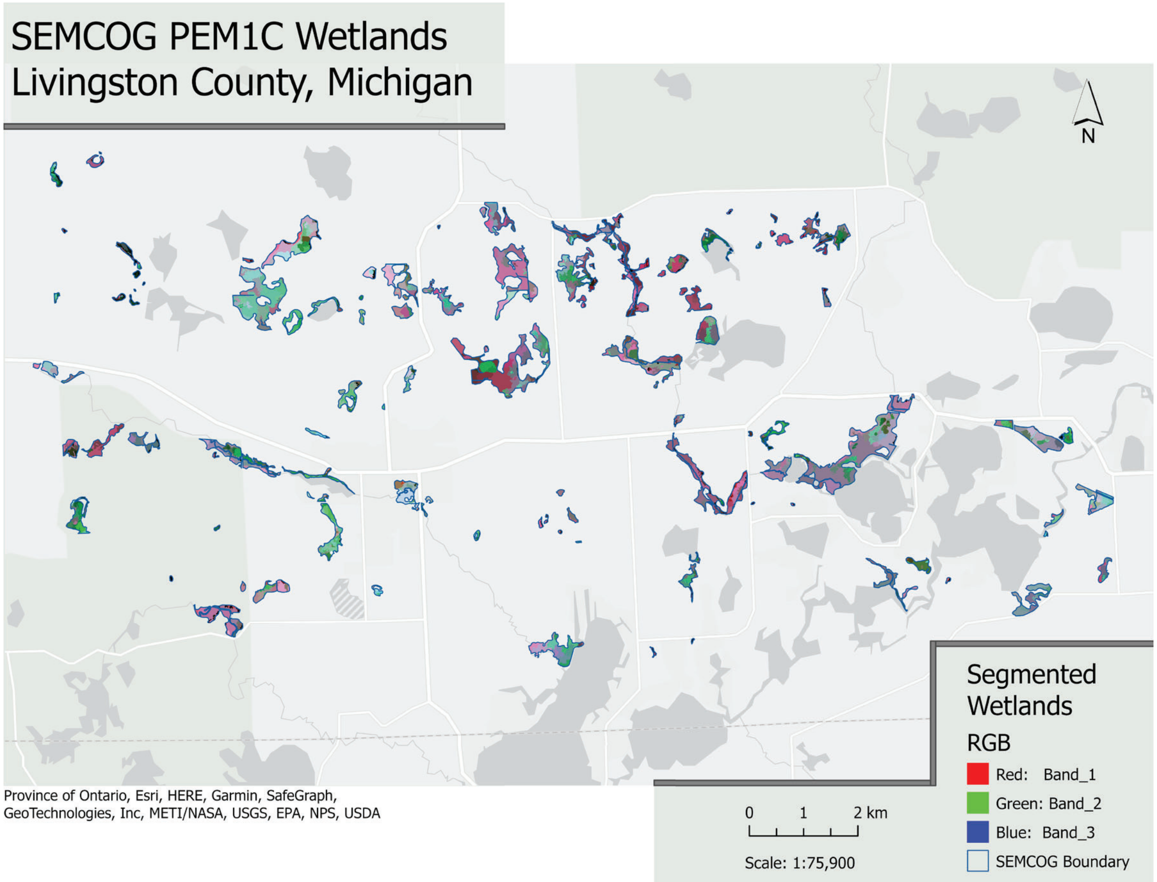


Figure 3.10. An overview map capturing the 159 wetland polygons included in this analysis. Segmented parameters: spectral resolution (18), spatial resolution (10), minimum segment size in pixels (40); NAIP CIR (2020) and SEMCOG wetland polygons.

Collecting Training Samples

Collecting training samples involves grouping together pixels that represent a specific feature of interest by means of polygons, lines, or points. The pixels assigned to that feature are then statistically compared to all of the pixels within the image. The classification algorithm will use this information to delineate the image based off of the pixel values that define each specified feature.

1. Having selected the image you wish to classify within your contents pane, you will navigate to the imagery tab within your ribbon and select “Training Samples Manager” in the classification tools drop down.

2. You may create, upload or utilize the default classification schema. Interested in delineating vegetation, we created a custom schema of our desired classes (buckthorn, cattail, grass/sedge, mixed and phrag). Using the schema, we drew training sample polygons for each species class, informed by our species verification points. The training polygons can be seen in Figure 3.11. These class specific polygons were used in our supervised pixel-based species classification.

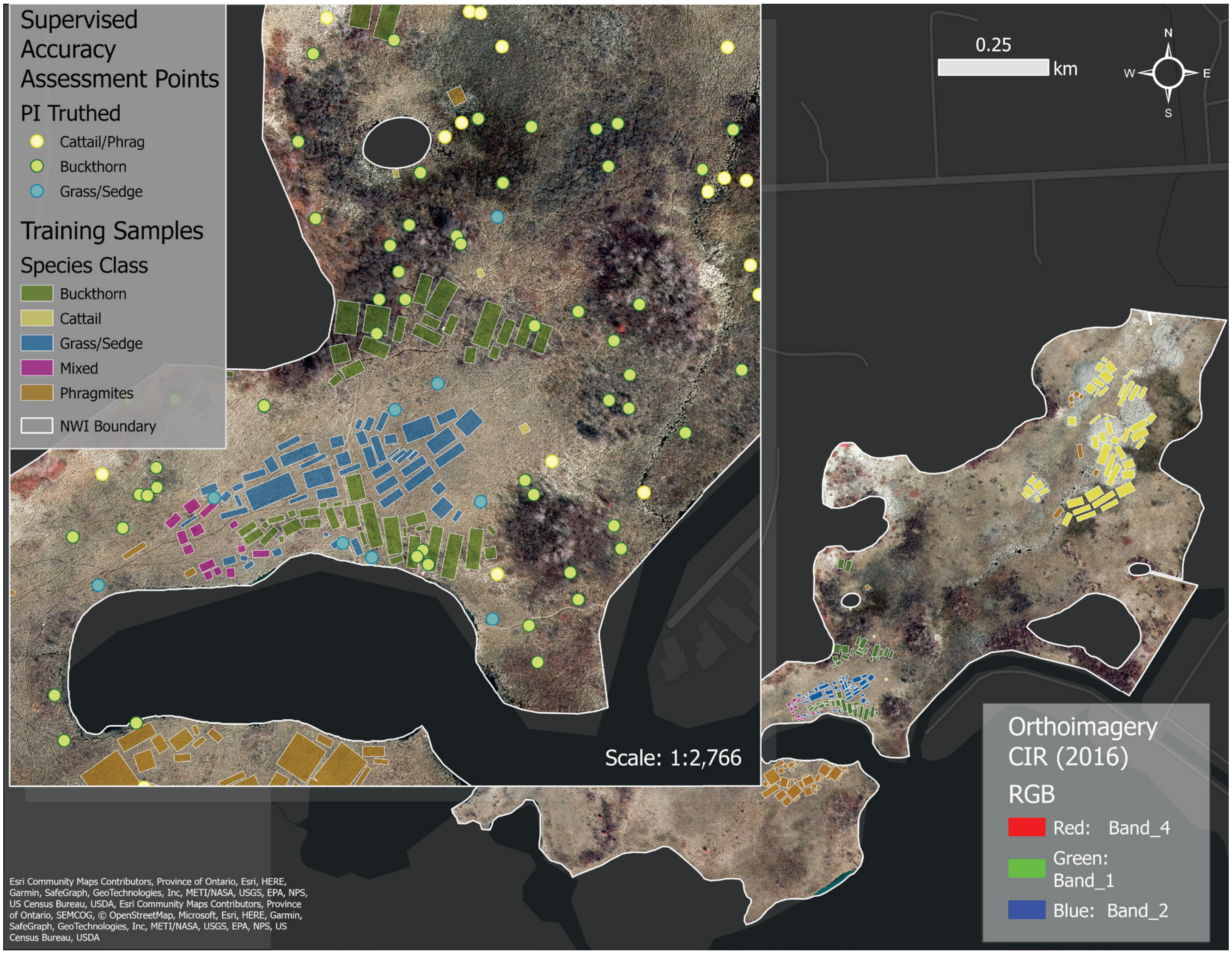


Figure 3.11. An inset map of SPW highlighting the training sample polygons from our analysis. Supervised accuracy assessment points are included to compare the spatial and spectral characteristics between the training samples and the points produced for the confusion matrix. This information overlays CIR ortho imagery (2016), clipped to the geometry and extent of the SPW boundary polygon.

Image Classification Wizard

Below, we have detailed our steps and reasoning. This may be utilized as an example if you are interested in conducting a spatial analysis similar to ours.

1. Classification Method – ‘Unsupervised’ does not require training samples and, therefore, is less tasking for the user. This classification method can be less accurate at delineating species and is therefore used to create your segmented image. ‘Supervised’, dependent on the training samples, requires more of the user’s time to draw and assign polygons to class/subclass values but will result in a more accurate delineation of species.

    a. The Supervised classification method was used to create the species classification image, relying on training samples informed by ground truthing points and photo interpretation.

2. Classification Type – Pixel-based classification is carried out on a per-pixel basis while object-based is performed on the localized neighborhood of pixels.

    a. We used object-based classification to create our segmented image (reference raster layer) to enhance the maximum likelihood algorithms ability to delineate species of SPW.

3. Classification Schema – There are existing schemas that identify land-use types but, for our purposes, we created our own. You must assign a unique numeric value to each of your specified classes. For example, the assigned values are as follows.

    a. Parent class = Cattail/Phrag (10) Buckthorn (30) and Grasses/Sedge (70).

    b. Subclasses = Grass/Sedge (20), Cattail (40), Phrag (50) and Mixed (60).

4. Output Location – Choose your desired location/geodatabase to store the output classification image.

5. Segmented Image – Input your segmented image.

    a. Refer to the top portion of Figure 3.12.

6. Training Samples – Input training samples.

7. Reference Data – Input the NDVI raster dataset for your area of interest.

8. Train your image classifier – Run with default setting using the Maximum likelihood classifier.

9. Once your image classifier is trained you may evaluate whether you would like to modify any of your input variables and their associated values or merge subclasses with parent classes.

a. When deciding whether we should modify any of our input variables, we referenced Figure 3.4.b. Analyzing band_1 (red(4)), we can see that there are similar signature values between cattail and phrag, and grass/sedge and mixed. Given these similarities, we merged the subclasses with their associated parent class to simplify our classification (Figure 3.12).

Cattail + Phrag → Cattail/Phrag

Grass/Sedge + Mixed → Grasses/Sedge

The final function to be run within ArcGIS Pro so that we may complete the dataset needed for the multivariate analysis (MVA) is the Tabulate Intersection geoprocessing tool. This tool computes the relationship between two or more variables, using cross-tabulation (a contingency table analysis) to calculate areas between two datasets, and qualitatively describes the relationship among multiple variables to define the area of interest.

Before you can begin to tabulate the intersection of species classes and wetland polygons, you must convert the species classification information from a raster dataset to a polygonal feature class using the “Raster to Polygon” conversion tool.

Tabulate Intersection:

1. Once you have conterted your classification raster dataset to a polygon feature class, you will navigate to the “Tabulate Intersection” analysis tool.

2. Willin the tabulate intersection pane, you will specify what areas you would like to summarize. For our purposes, we used the wetland polygons as our input zone features and their unique object ids as zone fields. Interested in calculating the species composition (area) of each wetland, we used the species classification polygonal feature class (converted raster dataset) as our input and specified our desired attribute and sum fields.

a. Class Fields – Class Name (species classification names)

b. Sum Field – Shape Area

c. Output Units – Acres

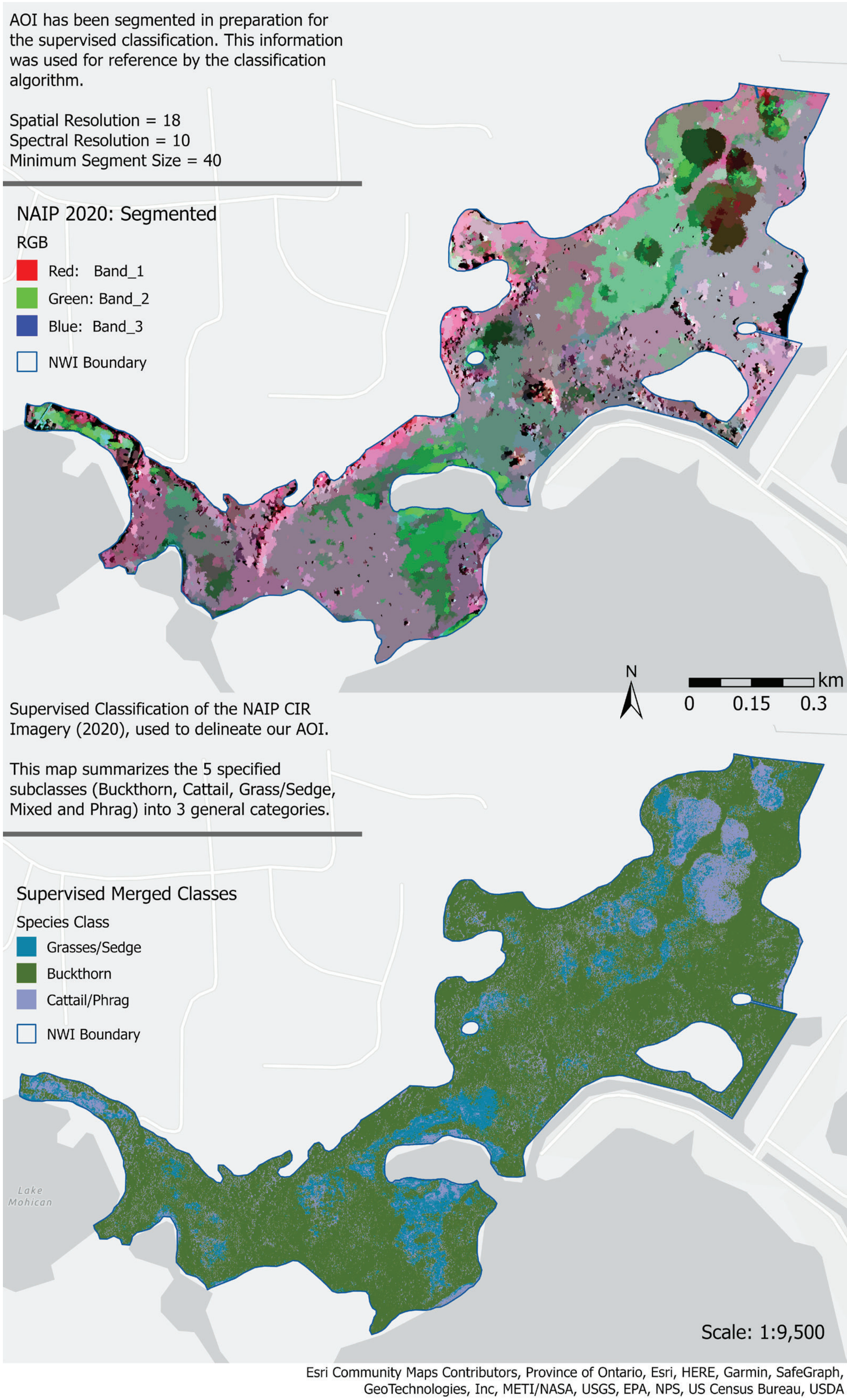


Figure 3.12. Top portion: A map of the segmented mean shift classification; Bottom Portion: A map of the final species classification after merging classes with similar spectral values. Location: SPW

The resulting table was then pivoted using the data management tool "Pivot Table" to reduce redundancy and calculate the proportion of each species class relative to the individual wetland acreage. This information was copied and pasted into the final MVA dataset. We saved this dataset as a .csv file in our project working folder where we would set our working directory for the MVA.

Results: Current Plant Species Distribution

Using the information gathered through the methods described above, we have classified the current (2020) species composition of SPW. We found that, of the 197.2 acres of land (captured within the NWI PEM1C boundary), buckthorn accounts for ~70%, cattail ~19%, and grasses/sedge ~11%.

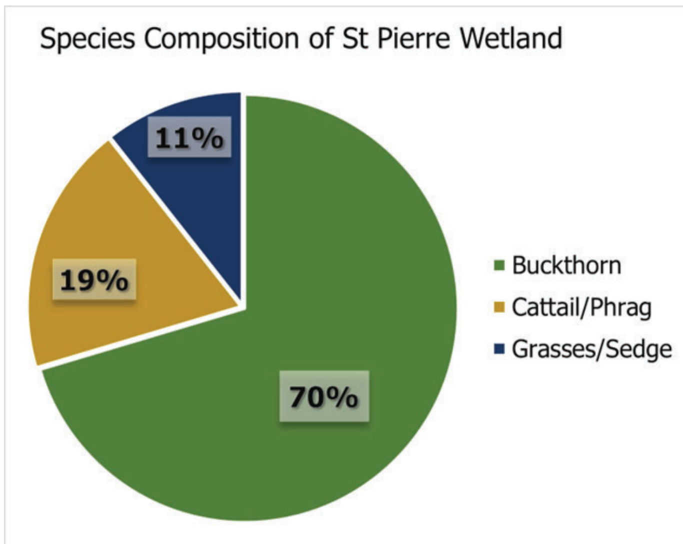


Figure 3.13. A pie chart displaying the resulting species composition from our supervised pixel-based classification. The percentages have been rounded up. The raw acreage results are, buckthorn (138.87 acres), cattail (37.50 acres), and grass/sedges (20.84 acres).

II. Accuracy Assessment: Can remote sensing be used to accurately detect and differentiate between species of St. Pierre Wetland?

Having demonstrated that remote sensing can be used to estimate the species distribution of our area of interest, we wanted to further understand our results and determine the accuracy of this information. To assess the ability of the classification algorithm in identifying select species, we conducted an accuracy assessment within ArcGIS Pro. We have detailed the process and the results below.

Performing an Accuracy Assessment

Equipped with the species classification results, custom schema and training samples polygons, we created accuracy assessment points using the Accuracy Assessment Point image analysis tool. This tool considered the above information and generated 500 random points, equally distributed to our specified species classes through the stratified random sampling strategy. The resulting accuracy points were provided in a dataset that included an empty feature column label as 'ground truthed.' You must then verify each point through photo interpretation and assign the correct class value. The complete dataset, including the accuracy points and ground truthed points, will then be used as the input dataset for confusion matrix.

Performing a confusion matrix (contingency table) is common practice when assessing the accuracy of a model. This matrix, seen in Figure 3.14, assesses the overall accuracy of the classification as well as the accuracy of the user (map viewer) and the producer (map maker). The overall accuracy provides us with the proportion of reference sites that were mapped correctly. The user's accuracy column provides us with Errors of Commission, describing the proportion of sites that were incorrectly classified (false positives), while the producer's accuracy column provides us with Errors of Omission, describing the proportion of reference sites that were omitted from the final classified raster (false negatives). The Kappa statistic, seen in the bottom right corner of Figure 3.14, provides an overall assessment of the accuracy of the classification.

Reviewing Figure 3.14, there was an overall accuracy of 56% meaning that 283 of the 500 reference sites (accuracy assessment points) were mapped correctly. The Kappa statistic of 21% indicates that the final classification map is highly inaccurate. Given the low accuracy results and high commission and omission error, the summarized species composition and map of the SPW are misleading and should be considered gingerly.

ClassValue	Cattail/Phrag	Buckthorn	Grasses/Sedge	Row Total	Useres Accuracy	Kappa
Cattail/Phrag	51	32	22	105	49%	
Buckthorn	87	224	59	370	61%	
Grasses/Sedge	18	0	8	26	31%	
Column Total	156	256	89	501		
Producers Accuracy	33%	88%	9%		56%	
Kappa						21%

Figure 3.14. Confusion Matrix used to assess the accuracy of the supervised pixel-based species classification.

III. Research question 3: What are the relationships of species distributions to other physical features on the site?

Having assessed the ability of our application to delineate specific species, we wanted to ascertain whether there were any existing relationships among their distribution. With 9 variables (including acres) describing varying aspects of the wetlands topography and species composition, we conducted a multivariate analysis to determine whether any relationships existed within our data.

i. Preparing for Statistical Analysis

After completing the data extraction and collection methods above, we analyzed relationships among the spatial variables using multivariate analyses in R studio (Cluster and Principal Component Analysis), in order to see what the clusters of related variables could tell us about how species assemblages could be predicted by remotely sensed physical characteristics on site. The R scripts used to carry out these analyses are available…

Similar to any statistical analysis, we first needed to clean our data, organize variables and remove any zero/na values. The goal was to create a dataset that will be of most use to our analysis, storing data variables in individual columns and wetland polygons (collection sites) within rows. From this point forward, we will refer to the PEM1C NWI wetlands included in this analysis as 'sites'. Again, these wetlands were most similar to SPW, meaning they experience similar inundation periods and prominent species.

We initially compiled all of the data collected through our extraction process within ArcGIS Pro including "all" zonal statistics of the DEM indices and tabulated intersection of species concentrations for each site. Instead of subsetting the data within R, we chose to upload the clean/organized dataset created within excel as a .csv. This dataset included the mean values of each explanatory variable for each site.

ii. Preparing for and Running Cluster and Principal Component Analysis

In preparation for running a cluster analysis and principal component analysis on the uploaded dataset, we wanted to visualize the data to assess 1) whether there were any strong correlations among the explanatory variables and 2) check the normality of the data. Multicollinearity was checked visually by creating a pairs plot of the independent variables, grouped by wetland class (Figure 3.15). The pairs plot describes the pairwise relationships between different variables.

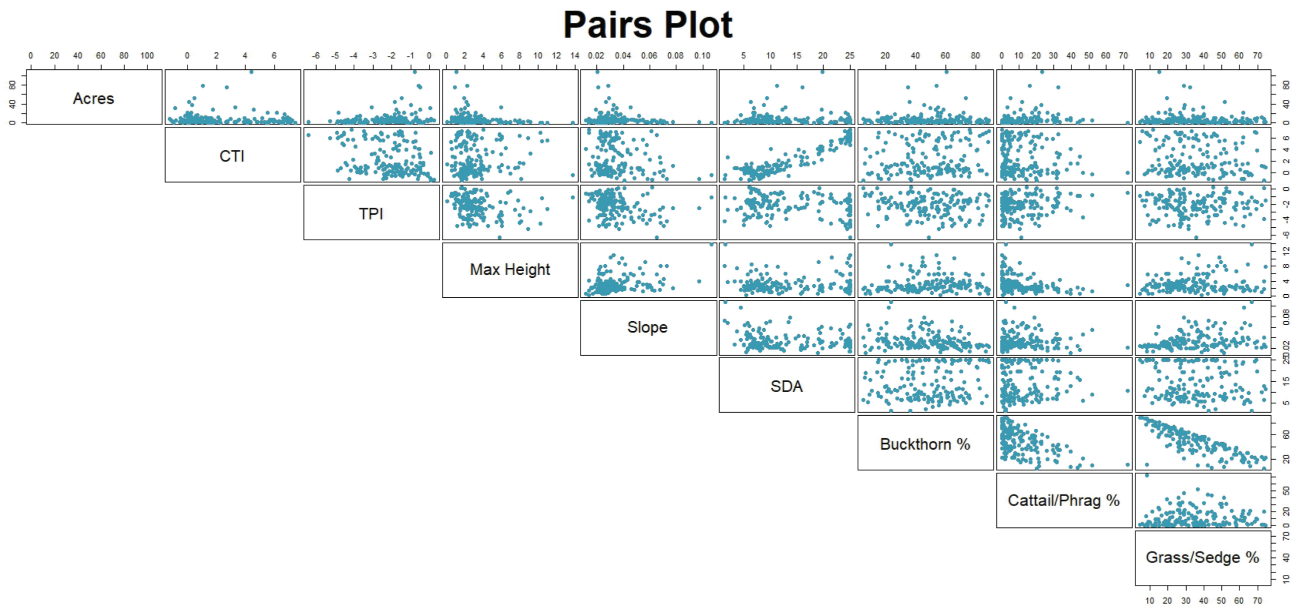


Figure 3.15. Pairs plot describing the multicollinearity among variables. Relationships that standout initially include CTI and SDA, Buckthorn % and Grass/Sedge %, and Buckthorn % and Cattail %.

Scaling and Removing Variables

Though we visually concluded that there were a few variables with collinear relationships, we chose to remove acres so that we could better assess the dataset as a whole, given such a large variance in acreage per wetland polygon. We subset the mean dataset to exclude acres as a variable. We then scaled the data, encouraging normalization by equally weighting values across all independent variables. Boxplots were created to visually compare the unscaled variance of data to the scaled variance. This graphical comparison supported our decision to scale the data, meeting the assumption of data normalization (Figure 3.16).

Cluster Analysis

To ascertain which, if any, of the independent variables may have an influence on species composition, we determined existing relationships among sites. We accomplished this using hierarchical clustering to quantify the pairwise relationships between variables and identifying patterns within the dataset. This route of MVA allows us to not only analyze the variables in the columns but determine the relationships among the rows. This agglomerative clustering, also known as a bottom-up clustering method, is used to group objects by similarity, successively merging each cluster into one large cluster. The results are presented in a tree-like structure known as a dendrogram, as the main cluster branches into descending groups. To preface, refer to Figure 3.17.

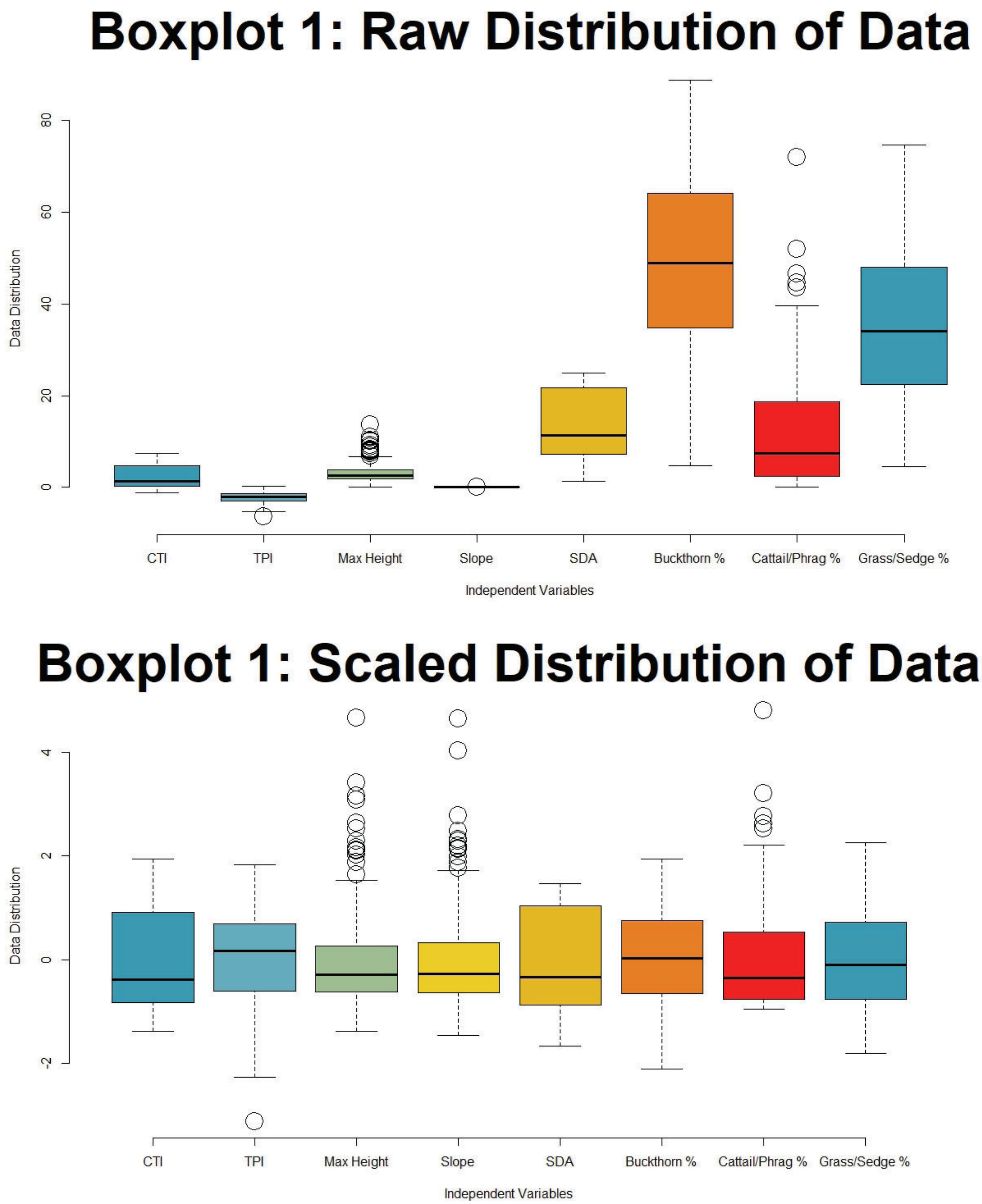


Figure 3.16. Comparison of data normality using box plots (top – raw data; bottom – scaled). There is a significant difference in data normality between the raw data (not normal) and the scaled data (normal).

We must first calculate the dissimilarity or distance between the rows of our dataset using a distance measure. For this study we employed the Euclidean distance measure, storing the result in a vector to be used for hierarchical clustering. Using 'hclust', we input the distance vector and assigned the 'complete' agglomerate linkage method to calculate the distance between clusters. The method 'complete' calculates the distance between two clusters by the maximum value of all pairwise distances between elements in cluster 1 and elements in cluster 2.

An alternate function for grouping elements to identify patterns within your dataset is the function 'pvclust.' This method calculates values for hierarchical clustering through bootstrap resampling and returns the associated p-values for each cluster. This function allows you to assign the hierarchical clustering method and method of distance measure. Figure 3.18 is the resulting dendrogram that, unlike Figure 3.17, displays the p-values of each cluster. The red boxes highlight the clusters with the highest significance (p-values <0.05).

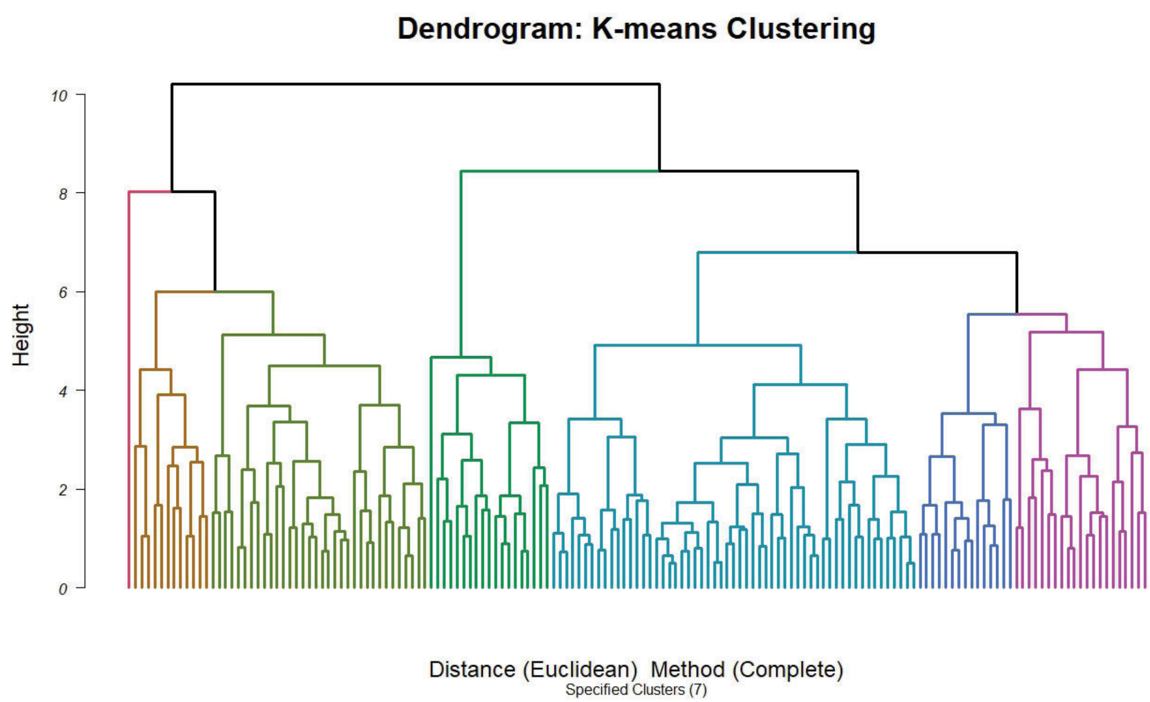


Figure 3.17. A dendrogram, used to visually display the results of hierarchical clustering (a bottom-up clustering method). Created using hclust().

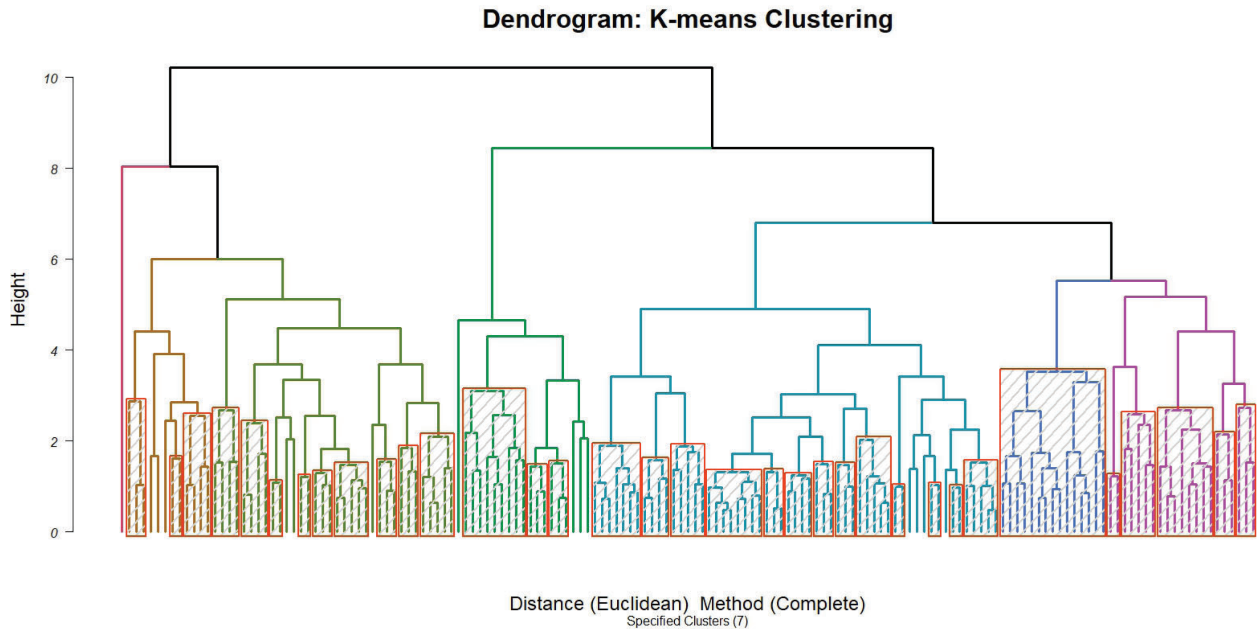


Figure 3.18. A dendrogram displaying the results of our hierarchical cluster analysis. There are 33 significant clusters indicated by the red boxes.

Though Figure 3.18 informed us of significant similarities and differences among sites, we wanted to determine the optimal number of clusters. We performed the gap statistic to minimize the number of clusters (k) needed to explain the variance in data among sites. The results, seen in Figure 3.19, suggest that the optimal number of clusters is 7. To further explore this finding, we visually assessed the data with varying k values (Figure 3.10). Symbolized by convex ellipses, the varying k values (k-mean values: 2 - 7) overlay principal component biplots. We will return to the analysis of this figure in the next MVA section.

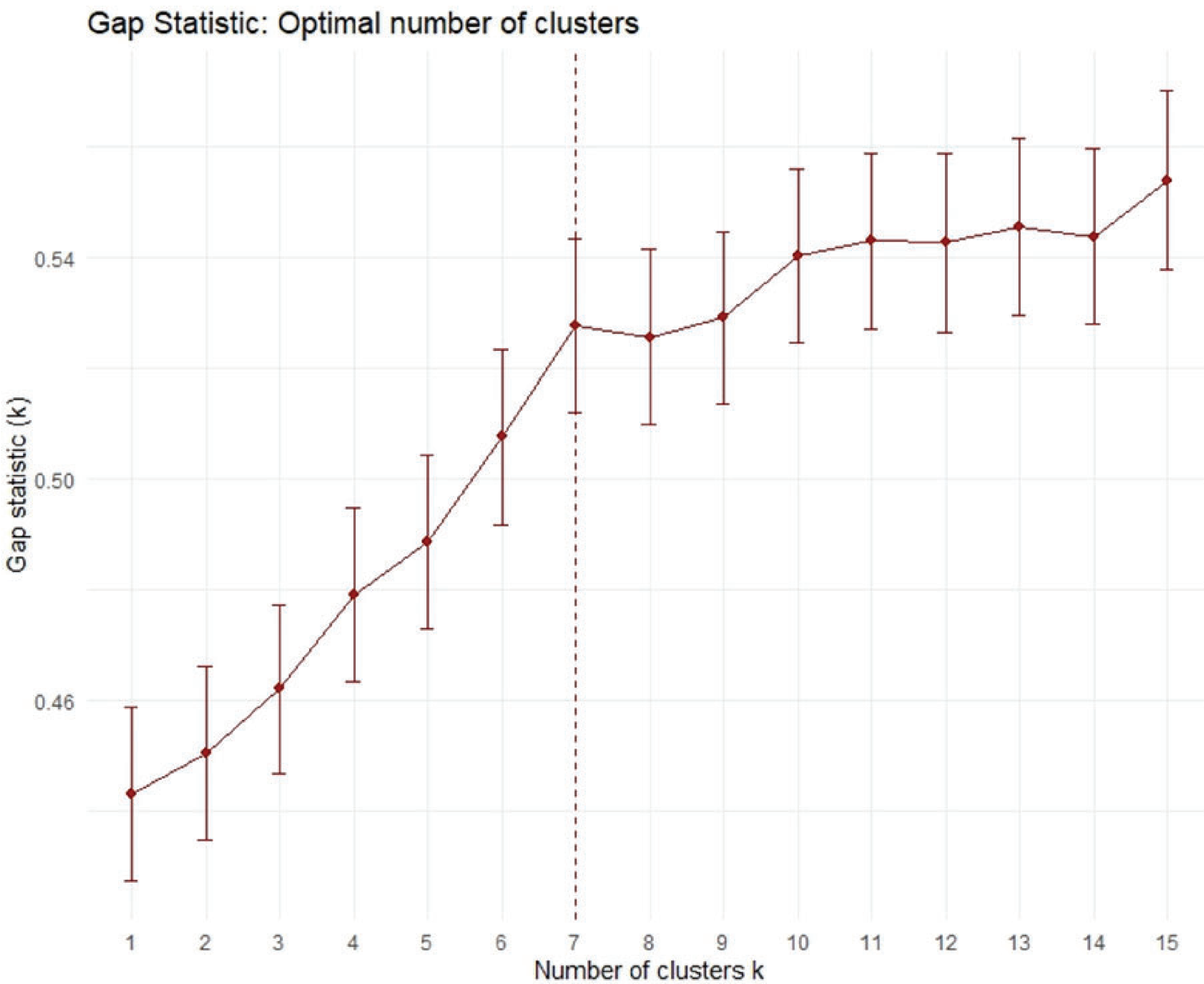


Figure 3.19. Resulting graph of the gap statistic performed within R. The optimal number of clusters (k) determined by the gap statistic function is 7, indicated by the perpendicular dashed line, with a gap statistic of approximately 0.53.

Principal Component Analysis

To understand which independent variables may be driving the significant clustering of sites, we used Principal Component Analysis (PCA). PCA is an additional MVA technique used to assess linear relationships between explanatory variables and describe overall data variance. Unlike cluster analysis, principal component analysis reduces the dimensionality of your dataset by grouping variables based on linear combinations to describe the data variance. This process creates new explanatory variables, referred to as principal components (PCs), that capture as much of the variance in the dataset as possible by grouping independent variables. When analyzing data, PCs can be thought of as axes that represent the direction and angle that best describe/explain the data variance.

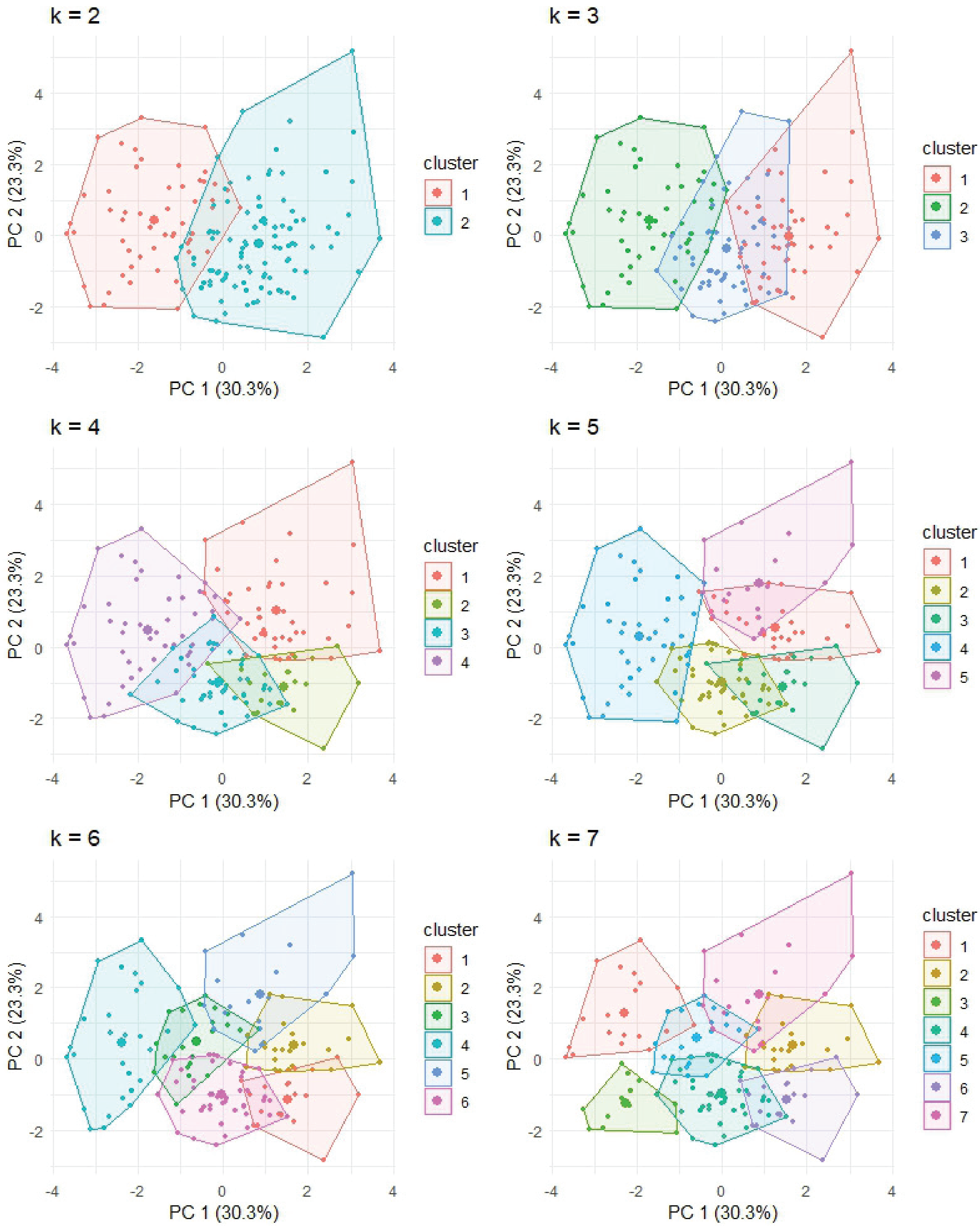


Figure 3.20. A map series displaying hierarchical clusters of data with varying k values, indicated by the convex ellipses. These clusters have been superimposed on principal component biplots. We will refer back to this figure when we discuss our principal component analysis.

As mentioned previously, before running any type of MVA we prepared our dataset by using subset() to remove acres as a variable and scaled the dataset so that each variable would have a mean of 0 and a standard deviation of 1. Using this primed dataset, we began our analysis by calculating the PCs and then viewed the summary of the PCA results (Figure 3.21). Though the summary was informative, we wished to create a visual (Figure 3.22) that would describe the threshold at which additional PCs would no longer greatly contribute to the explanation of data variance. One can visualize the result of the PCA by creating a scree plot.

The PCs reduction of dimensionality allows for a clearer visual expression and straightforward interpretation of the data variance explained by the PCs. Though the creation of a scree plot is useful in visually identifying the number of PCs needed to explain the variance in data, one is unable to assess any additional characteristics that would be beneficial in understanding the dataset. By creating a biplot (Figure 3.23) we can visualize the variance explained by principal component 1 and principal component 2, and make note of any patterns that may occur within the dataset. Additional information resulting from the PCA can be summarized using a well labeled biplot (Figure 3.23), which can display information regarding loadings that can be interpreted by arrow length and direction.

Importance of components	PC 1	PC 2	PC 3	PC 4	PC 5
Standard Deviation	1.555913	1.365208	1.295542	0.934105	0.777595
Proportion of Variance	0.302608	0.232974	0.209804	0.109069	0.075582
Cummulative Proportion	0.302608	0.535582	0.745386	0.854455	0.930037

Figure 3.21. PCA Summary – Four principal components are needed to explain the overall variance in data among sites (cumulative variance: x>80% of variance). Proportion of variance: PC1 (~30%), PC2 (~23%), PC3 (~21%), and PC4 (~11%).

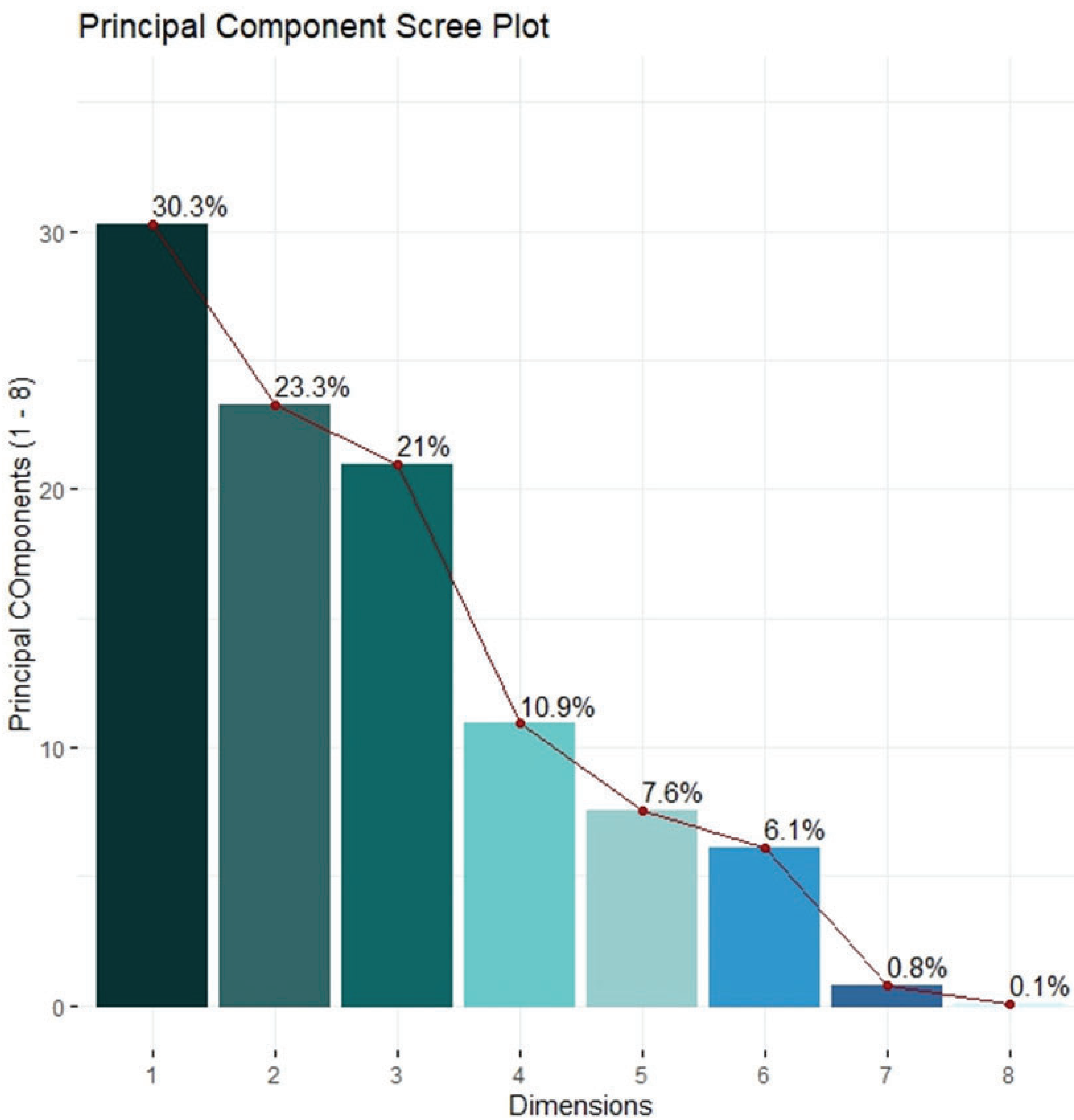


Figure 3.22. This plot portrays the variance explained by each of the PCs resulting from the PCA, and allows one to visually determine how many PCs would be used to describe the variation in data. The number of PCs needed can be located where the scree plot significantly drops.

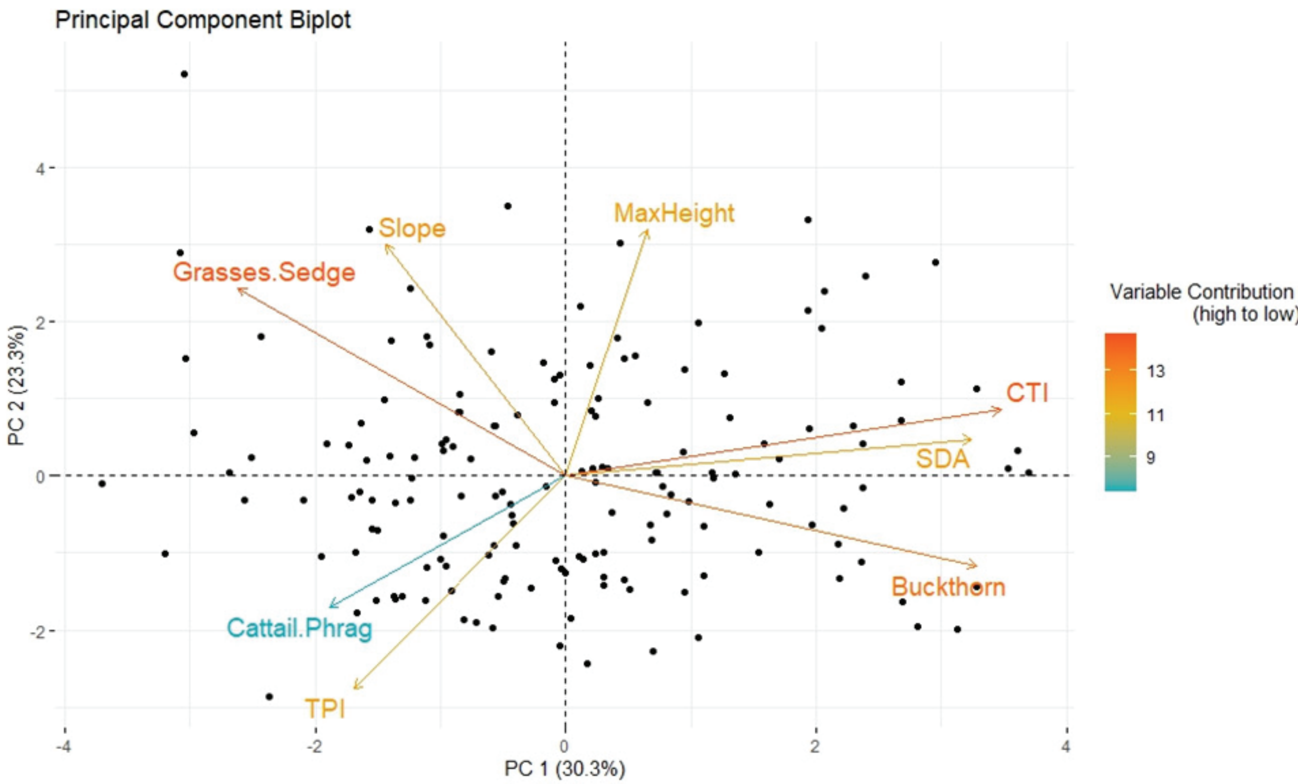


Figure 3.23. Biplot of PCA describing PC1 and PC2.

iii. Interpreting the MVA Results

Cluster Analysis

Figure 3.17 represents the results of the euclidean measured bottom up (Complete) method of hierarchical clustering using hclust(). Sites are represented where the branches of the dendrogram meet the x-axis. Though these figures provide some insight into the relationship among sites, we chose to run an alternate method that would create clusters based off of significant relationships (Figure 3.18).

The pvclust dendrogram, seen in Figure 3.18, displays the p-values of each cluster. The red boxes highlight the clusters with p-values less than 0.05, indicating the clusters are comprised of sites that are most significantly similar to one another. Since there were 33 significant groupings, we conducted a gap statistic as a cluster reducing method to determine an optimal number of clusters. The gap statistic results, seen in Figure 3.19, suggest that 7 clusters are needed to explain the variance in data among sites. This implies that the sites clustered together share significant similarities with one another and each cluster is significantly different from the other. Further analysis is needed to determine what topographic and vegetative characteristics they have in common.

Principal Component Analysis

The PCA results, performed using princomp(), detail the individual ability of principal components to explain data variance as well as the cumulative proportion of variance. Since PCA is a dimension reducing technique, we want to explain our data with a fewer number of variables than we started with. When running this analysis you want to have enough principal components to describe a cumulative proportion of ~80% (majority of variance). As seen in the summary chart (Figure 3.21), PC 1 explains the majority of the variance by 30%, while PC 2 explains 23%, PC 3 explains 21%, and PC 4 explains 11%, for a total cumulative proportion of ~85%. The Scree plot (Figure 3.22) visually describes the number of PCs needed to explain the majority of the variance within the dataset, indicated around PC 4 where the downward sloping line begins to level. This visualization supports the PCA summary results.

Examining the PCA biplot (Figure 3.23), we can see that the percentage of variance explained is indicated along the x and y axis. Visually, without any imposed means of grouping, it is difficult to identify which side of the plot the majority of points lie. To enhance our understanding of the relationships among our data, we overlaid hierarchical clusters with k-mean values ranging from 2 - 7. In Figure 3.20 we can see that there are significant similarities and dissimilarities among sites that we could not initially identify within Figure 3.23.

In effort to further understand the independent variables' influence on our data, we compared the findings from the k-means clustering and the PCA biplot. Given the optimal number of clusters is 7, we aligned the associated k-means cluster graph with that of the PCA biplot (Figure 3.24). Again, the direction and length of each arrow is important when considering the level of influence an independent variable has on a cluster of sites. Below, we have broken down the information gathered from this comparison.

1. Independent variables with the greatest contribution to data variance include CTI, Grasses/Sedge and Buckthorn.
2. Independent variables that moderately contribute to data variance include SDA, Max Height, Slope and TPI.
3. The independent variable that contributes the least to data variance is Cattail/Phrag.
4. Independent variables that contribute to the variability in data variance explained by principal component 1 include Max Height, CTI, SDA, and Buckthorn.
5. Independent variables that contribute to the variability in data variance explained by principal component 2 include Slope, Grasses/Sedge, Cattail/Phrag and TPI.

6. CTI and SDA influence sites within cluster 1, Buckthorn influences sites within cluster 3 and Max Height influences sites within cluster 2.
7. Cattail/Phrag and TPI influence sites within clusters 4 and 7, while Grasses/Sedge and Slope influence sites in clusters 5 and 6.
8. Positive relationships exist between Slope and Grasses/Sedge, CTI and SDA, and Cattail/Phrag and TPI.
9. Negative relationships exist between Buckthorn and Cattail, Buckthorn and Grasses/Sedge, TPI and Slope, TPI and Max Height, TPI and CTI, and TPI and SDA.

Understanding what the explanatory variables are and what they measure/represent is important for the overall interpretation. For example, positive TPI values represent locations that are at higher elevation than the average of their surroundings, while negative TPI values represent locations that are lower and values near zero represent relatively flat areas. Information regarding the explanatory variables included in this analysis can be found in the beginning of this chapter.

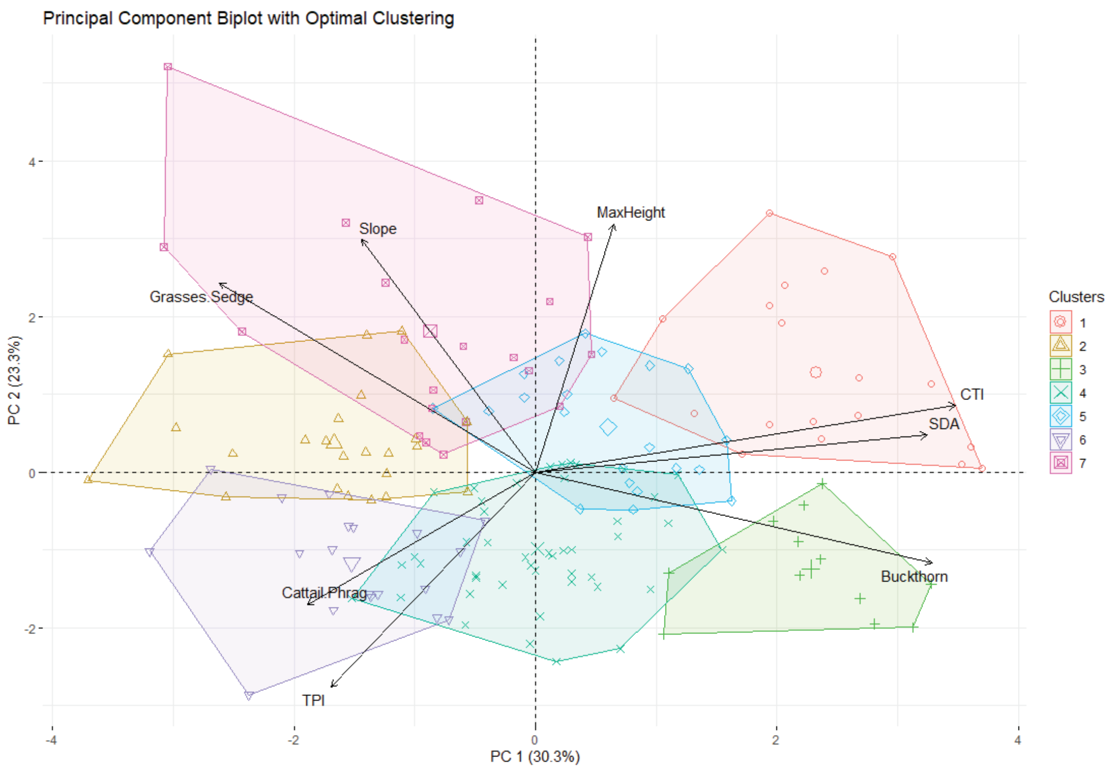


Figure 3.24. Comparing PCA results, loading contributions and k-means clustering. The PCA biplot (bottom image), excludes site points, displaying only the loadings (independent variables) symbolized by the arrows.

4. Discussion and Conclusion

Though remote sensing data are most commonly used to track land-use change and aid in the expansion of agricultural practices, they can also be extremely valuable to raise awareness and inform the conservation and restoration of a site. Inspired by the wetland conservation applications of remote sensing by Ducks Unlimited, we chose to use high spectral resolution imagery and professionally designed methodologies to deepen our understanding of St. Pierre Wetland for restoration purposes, to provide an example for other students, researchers, and practitioners passionate about improving conservation efforts.

Within our analysis, we performed a supervised pixel-based classification to describe the species composition of St. Pierre Wetland. The classification process was guided by our photo interpretation and delineation of remotely sensed data including CIR orthoimagery, NAIP CIR imagery, LiDAR derived DEM indexes and additional spatial layers created in ArcGIS Pro. The confusion matrix described the model as having an overall accuracy of 56%, correctly classifying 283 of the 500 accuracy assessment points. The low overall accuracy in combination with the kappa statistics of 21% implies that the final species classification map does not appropriately represent the composition of vegetation at SPW. This classified map, though flawed, can be referred to lightly when drawing relationships among but should be improved if trying to dr

The model's accuracy was relatively low, resulting in an overall classification accuracy of 56%. The Kappa statistic (Figure 3.14) describes the resulting species composition map to be merely 21%, meaning that the map erroneously represents the distribution of species of SPW. Factors that may have attributed to the low accuracy include but are not limited to:

1. Reference data (Segmented NAIP CIR 2020)

   We could have created a composite band raster that would have provided a greater variety of information to enhance the maximum likelihood algorithms' ability to correctly link spectral signatures to their correct class.

2. Classification of SPW during peak growing season (NAIP CIR Imagery 2020)

   The NAIP CIR Imagery lacked variation in spectral signature values among species. We could have performed the classification using CIR ortho imagery (leaf-off imagery) to inform the classification algorithm of coniferous and deciduous (evergreen) vegetation within SPW.

3. Too much emphasis on the spectral detail of the segmented image

   When adjusting the spatial and spectral parameters for image segmentation (to create our reference data layer), we could have decreased the spectral detail ($x<18$) and increased the spatial detail ($x>10$) and minimum segment size ($x>40$)

to reduce the 'salt and pepper' effect within the classification. The resulting segmented image would have had more defined boundaries among vegetation of SPW, aiding in the overall classification process.

4. Number of training polygons for each class

   We could have provided the classification algorithm with more species specific information by increasing the number of training polygons used to summarize spectral signatures of our specified classes.

5. Accuracy assessment ground truthing process

   The process of checking/ground truthing 500 accuracy assessment points was conducted through photo interpretation and relied upon the analyst's perception instead of field verified data. This increased the number of false negatives accounted for in the confusion matrix (Figure 3.14).

6. One photo interpreter

   The classification accuracy may have improved if there were more GIS analysts involved in species identification, allowing for quality assurance and quality control.

Though the accuracy of our species classification was lower than desired, this analysis demonstrates that remote sensing data can be used to characterize land-use or vegetation composition with information provided by field verified data. Unfortunately, our inferences, detailed below, can not be seriously considered due to species composition accuracy. For the purpose of this analysis, our inferences will illustrate how one would interpret the results of a multivariate analysis if the classification was reliable.

The cumulative information, synthesized from the numerous sources of remotely sensed datasets, was further analyzed using multivariate statistical techniques including hierarchical clustering and principal component analysis. We concluded that the optimal number of clusters needed to explain the significant relationships among sites was 7. CTI and SDA influence sites within cluster 1, Buckthorn influences sites within cluster 3 and Max Height influences sites within cluster 2. Cattail/Phrag and TPI influence sites within clusters 4 and 7, while Grasses/Sedge and Slope influence sites in clusters 5 and 6 (Figure 3.24). We found that the majority of variation in sites can be attributed to PC 1, where sites are influenced by Max Height, CTI, SDA, and Buckthorn percentage. The variation in sites attributed to PC 2 are influenced by Slope, Grasses/Sedge percentage, Cattail/Phrag percentage and TPI. Positive relationships exist between Slope and Grasses/Sedge, CTI and SDA, and Cattail/Phrag and TPI. For example, the positive correlation between two variables means that as TPI rises so will the percentage of cattail/phrag. Negative relationships exist between Buckthorn and Cattail, Buckthorn and Grasses/Sedge, TPI and Slope, TPI and Max Height, TPI and CTI, and TPI and SDA. For example, given the negative correlation between two variables, we can conclude that areas experiencing high concentrations of cattail will have lower concentrations of buckthorn while areas with high concentrations of buckthorn will have low concentrations of cattail/phrag and grasses/sedg. You would expect greater slope values to accompany positive TPI values but the biplot of the PCA results suggest otherwise. Using the biplot we see that positive slope values result in negative TPI values and a lower proportion of cattail than buckthorn. These results contradict the definition of TPI but, after analyzing the maps, we can visually identify areas we know to be cattails that are interpreted as higher in elevation. This may be due to the concentration of cattail resulting from its clustered growing patterns and the satellites inability to fully penetrate the cattail stand or that our classification map inaccurately captures the distribution of species of SPW.

Combining our knowledge of slopes within depressional areas and the likelihood of water to accumulate in low lying areas, we can infer that within palustrine emergent wetlands of Livingston County, MI, there will be a greater abundance of cattail in depressional areas with less slope where water is likely to accumulate. As one would move out of the depressional area we would see an increase in slope and therefore an increase in buckthorn percentage. These observations support the tendency of different vegetation species to disperse according to moisture gradients. To test this hypothesis we would need to improve our classification accuracy and perform additional multivariate analysis.

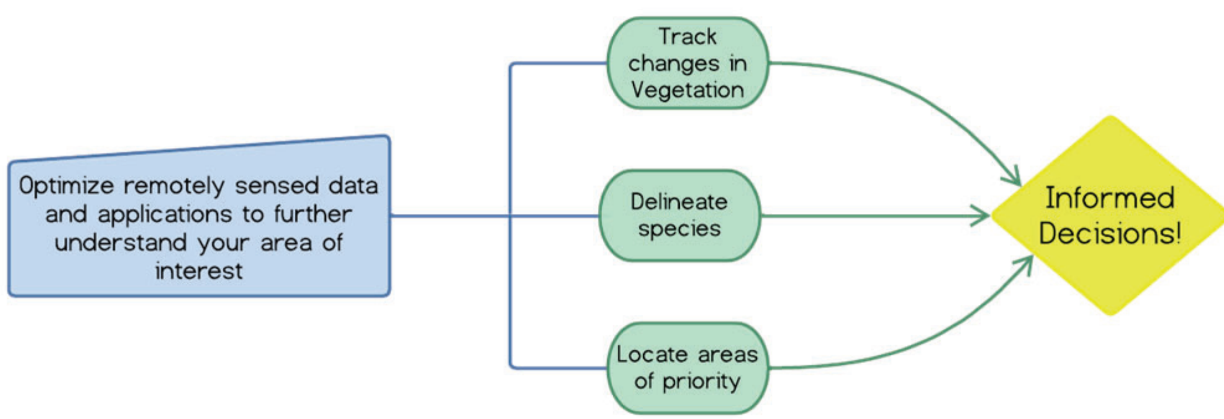


Figure 3.25 Flow chart illustrating how remote sensing can be used to inform decisions.

Remote sensing has greatly enhanced our familiarity with St. Pierre Wetland, allowing us to draw relationships between wetland types, species composition and topographical characteristics. We hope that through this demonstration, other students, researchers and practitioners will apply remote sensing and optimize its capabilities. Examples utilizing remotely sensed data include but are not limited to approximating species composition, tracking vegetation succession or land use change over time, and locating areas of interest that may require immediate intervention. All of these application examples can be used to inform ecological stewardship and restoration practices of not only wetlands, but any area of interest. For a simplistic summarization of the above information please refer to Figure 3.25.

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ch.4

TOWARD INFORMED RESTORATION AND STEWARDSHIP OF ST. PIERRE WETLAND: EXPERIMENTAL REMOVAL OF INVASIVE GLOSSY BUCKTHORN

Chapter 4: Toward Informed Restoration and Stewardship of St. Pierre Wetland: Experimental Removal of Invasive Glossy Buckthorn

1. Purpose and audience

Wetlands have enormous ecosystem service and biodiversity value, and restoration efforts are often required to address the numerous threats to this value. Property reports from recent years revealed that the University of Michigan-owned St. Pierre Wetland is affected by several invasive species. Glossy buckthorn, *Frangula alnus* (hereafter, *F. alnus*), poses a particular threat to the community structure of a groundwater-fed prairie fen on the property. No known restoration efforts had been made before 2023, and the encroachment of invasive species on the property has been increasing. To conduct informed restoration of a wetland site while meeting St. Pierre wetland's education and research mission, we developed and initiated a research plan for experimental removal treatments of *F. alnus* in high-priority areas. In this chapter, we provide the rationale for prioritizing buckthorn removal, review and synthesize best practices from existing published research and focus groups with experienced practitioners, describe our experimental restoration approach at St. Pierre Wetland, and provide recommendations for continued restoration and monitoring at this site. We aim to provide relevant information and models to University of Michigan faculty and students to continue this valuable work at St. Pierre, as well as all stewards involved in regional freshwater wetland restoration.

2. Why prioritize buckthorn removal to restore wetlands

Freshwater wetlands are uniquely susceptible to invasive species, which can outcompete native vegetation and threaten community structure and function (Angeloni et al., 2006). Because they occur in low-lying portions of a landscape, wetlands receive seeds, sediments, and nutrients in the runoff and streams from the surrounding watershed. Sediment that accompanies incoming invasive seeds provides a growing medium and can cover native species. Invasives can also take advantage of nutrients in fertilizers in runoff from neighboring developments, allowing them to exceed the growth rates of native plants (Zedler & Kercher, 2004). Once established, exotic invasive species adversely affect soil moisture, pH, carbon and nitrogen cycling, and microbial activity (Heneghan et al., 2006).

Shrubs in the buckthorn family, Rhamnaceae, are among the most pervasive and negatively impactful invasives of freshwater wetlands and surrounding uplands in the northern Midwest. Like other members of the buckthorn family, *F. alnus* (previously *Rhamnus frangula*) is native to Eurasia and North Africa and was brought to North America in the 1800s as a hedgerow shrub due to its ability to form dense thickets (Barnes & Wagner, 1981; Maine Department of ACF, 2023). While initially successful in its use as a hedgerow plant and in revegetation projects, *F. alnus* became naturalized and was an invasive species in North America by the 1900s (Michigan EGLE, 2014). *F. alnus* can be confused for the closely-related *Rhamnus cathartica* (hereafter, *R. cathartica*) is a similarly problematic invasive in North America, though the two are distinguishable by a number of physical traits (Table 4.1).

Table 4.1. Characteristics for identifying *Frangula alnus* and *Rhamnus cathartica* (Michigan Department of Natural Resources, 2012a, 2012b).

Trait	*Frangula alnus*	*Rhamnus cathartica*
Common names	Breaking buckthorn, alder buckthorn, European alder buckthorn, tallhedge buckthorn	European buckthorn, Hart's thorn, European waythorn
Height	Up to 6m	Up to 7m
Leaf arrangement	Opposite	Alternate
Leaf margin	Serrate	Entire
Bark color	Gray-brown	
Bark	Glossy	Matte
Stem patterns	Many stems that break off to favor a central trunk in maturity	One central stem

Several factors enable members of the buckthorn family to persistently invade natural landscapes in Michigan and beyond. In addition to growing quickly to form dense thickets, they resprout vigorously when cut back. Without a secondary treatment, resprouting makes controlling buckthorn a difficult task for land managers. Another feature that makes non-native members of the Rhamnaceae invasive is that nearly fifty species of native birds have adapted to consuming buckthorn berries (Craves, 2015). Seed dispersal through bird droppings allows *F. alnus* and *R. cathartica* to invade new areas. Because buckthorn seeds can persist in the seed bank under moist conditions for an average of six years, it is difficult to eliminate *F. alnus* from natural communities once they reach fruit-bearing maturity (Illinois Natural Preserves Commission, 2007). Prairie fens are particularly vulnerable to buckthorn invasion, as their characteristic tussock sedge hummocks provide microhabitats that may be conducive to buckthorn seedling establishment (Fiedler & Landis, 2012; Peach & Zedler, 2006).

F. alnus's ability to tolerate wet conditions to a greater degree than *R. cathartica* makes it a considerable threat to the ecological stability of wetland communities (Kozikowski, 2016; Kurylo et al., 2015). While *R. cathartica* remains in drier upland areas, *F. alnus* can proliferate in wetland environments, shading out native species and causing changes in wetland hydrology (Fiedler & Landis, 2012). The rapid growth of this woody species, which can be exacerbated by fertilizer runoff from human developments, requires a significant water uptake (Huron River Watershed Council, 2017). As a result, the soils in buckthorn-invaded wetland communities begin to dry out. Soil conditions can become dry enough such that they are intolerable for certain native wetland species, which can affect a wetland's ability to capture and process pollutants. The capacity to filter contaminants, including nitrogen, phosphorus, and mercury, is essential for maintaining wetland community structure and the quality of water that feeds into adjacent natural ecosystems and human communities (Land et al., 2016; Zillioux et al., 1993). The social and ecological significance of how *F. alnus* can alter ecosystem processes calls for a closer examination of the state of buckthorn on the St. Pierre Wetland property.

Of the invasives found at the St. Pierre Wetland site, *F. alnus* has been identified as the most pressing issue to address. An ecosystem assessment of the property conducted by the Huron River Watershed Council (HRWC) in 2017 found a variety of non-native forbs, grasses, shrubs, and trees that threaten the ecological function of wetland ecosystems in Michigan (Huron River Watershed Council, 2017; Suzan Campbell et al., 2010). Out of the invasives recorded in the HRWC report (Table 4.2), *F. alnus* is considered a primary concern, because of its extent but also, especially its encroachment of the high quality prairie fen located on the southeast side of the property. The HRWC report notes that fertilizer runoff from the housing development upslope of the site may be fueling *F. alnus* growth on the northwest side of the prairie fen (Huron River Watershed Council, 2017).

Table 4.2. Invasive species noted in the 2017 HRWC Bioreserve Assessment of St. Pierre Wetland.

Common Name	Scientific Name
Autumn Olive	*Elaeagnus umbellata*
Glossy Buckthorn	*Frangula alnus*
Honeysuckle	*Lonicera maackii*
Purple Loosestrife	*Lythrum salicaria*
Norway Maple	*Acer platanoides*
Mullein	*Verbascum thapsus*
Reed Canarygrass	*Phragmites australis*
Multiflora Rose	*Rosa multiflora*

3. How has the abundance and distribution of buckthorn changed over time at St. Pierre Wetland?

While there is little institutional documentation of *F. alnus* at St. Pierre Wetland before the 2017 HRWC report, other sources affirm that the property's landscape has changed significantly since ownership passed to the University of Michigan's School for Environment and Sustainability (SEAS) in 1975. Longstanding members of the Shan-Gri-La Homeowners Association, located on the southeast side of the property, reported during Shan-Gri-La's annual meeting on June 4, 2022, that the wetland has changed significantly over the past several decades. Historical and current photos taken overlooking the site from Shan-Gri-La reveal the difference in F. alnus abundance (Figure 4.1). Satellite imagery also demonstrates trends in the property transitioning from various wetland community types to more woody-plant dominated shrub-carr communities (Figure 4.2). Together, historical satellite imagery and oral history of the site support that there has been an increase in buckthorn abundance at St. Pierre.

Figure 4.1(a). Photo of the wetland as seen from the Shan-Gri-La neighborhood, 2008. Courtesy of Stephen Brown.

Figure 4.1(b). Photo of the wetland as seen from the Shan-Gri-La neighborhood, June 2022.

Figure 4.2(a). Google Earth satellite imagery of the wetland, April 1998. Figure 4.2(b). Google Earth satellite imagery of the wetland, March 2021.

Following the HRWC Bioreserve Assessment report and an increased concern by SEAS facilities management about the presence of *F. alnus* on the property, staff from Stantec (formerly Cardno) produced baseline data of buckthorn's presence and a quote for its removal in 2019. Walking the site, they mapped the approximate boundaries of stands of both *F. alnus* and R. cathartica that were categorized by "low", "moderate", and "high" densities based on visual interpretation of stem density (Figure 4.3). They categorized buckthorn presence on 63 acres as "low" density, 12.6 acres as "moderate", and 13.5 acres as "high" density, for a total of 89.1 acres out of the 130 total acres of the property. The two "high" density areas noted in the report were those closest to adjacent housing developments. They identified a total of 90 acres in need of treatment (roughly 70% of the site), with an estimated time commitment of 45 days and cost of $60,041 (Stantec, 2019). No action was taken on this proposal, as it was outside the scope of SEAS funding available for property management (See Chapter 2: *Challenges and Opportunities for Community-Engaged Stewardship of a University-Owned Property*.)

Based on current trends, St. Pierre Wetland is in need of an evidence-based and adaptive restoration plan for the site that focuses particularly on *F. alnus* in the prairie fen. The species is present throughout the site and has increased in population over time, and is likely affecting the wetland hydrology of the property, segmenting and encroaching on the existing wetland (Figure 4.4). The prairie fen is a unique and valuable ecosystem to protect, but no restoration efforts have been taken up at the site to date.

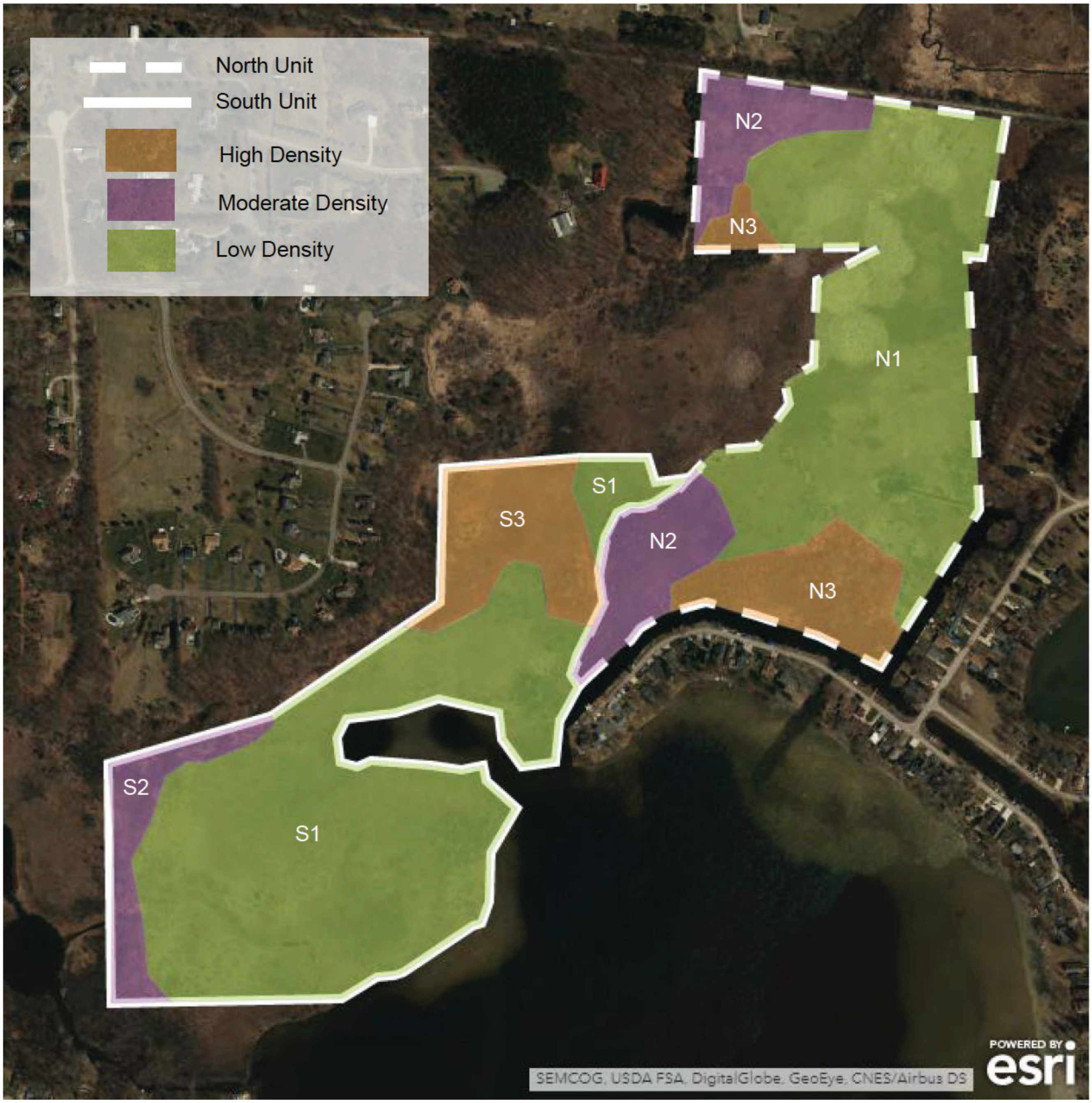

Figure 4.3. Stantec estimate of buckthorn management units at St. Pierre Wetland, 2019.

Figure 4.4. Clockwise from top left: facing north across the prairie fen, a photo, a depiction of the height and density of buckthorn on the north side of the prairie fen, the buckthorn stand along the canal between Shan-Gri-La HOA and the property.

4. What are best practices for buckthorn removal based on published materials?

I. Peer-Reviewed Literature: Herbicide

Applying herbicide is the most widely reported buckthorn control method in the literature. "Cut stump herbicide" (cutting the buckthorn stems to ground level and painting the stumps with glyphosate-based herbicide) is a preferred approach for effectively killing specifically *F. alnus* in wetlands (Nagel et al., 2008). Other research suggests that herbicide can be effective, in combination with girdling, when applied to a single stem of a *R. cathartica* stem complex (Pergams & Norton, 2006). In studies focused on wetlands, papers typically report applying a 50% mix of wetland-approved glyphosate with water to treat cut stumps (Frappier et al., 2004; Reinartz, 1997). Another study defaulted to an herbicide mixture of 20% glyphosate when applying a secondary treatment to resprouts (Nagel et al., 2008). Corace, et al. (2008), supported the efficacy of lower concentrations of glyphosate, specifically 1.25%, 2.5%, and 5%, to treat resprouts of previously cut mature plants in an upland area (Corace et al., 2008). Studies using herbicide treatment for buckthorn vary in scale from individual stem complexes to 25m^2 plots. Research with larger plots studied removal effects on soil characteristics, biodiversity, and tussock microhabitats, (Fiedler & Landis, 2012; Heneghan et al., 2006) while research by stem complex and smaller plots focused solely on mortality rates (Croft, 2022; Pergams & Norton, 2006).

II. Non-herbicide Approaches and Management Guides

Outside the realm of research centered on herbicidal approaches to controlling buckthorn are a spread of experimental treatments and management recommendations that have either few to no documented replicated results or no experimental data at all. Several guides for buckthorn management recommend girdling the stems, that is, cutting through the phloem of the stem to cut off energy flows to the roots (Missouri Department of Conservation, 2023; Upper Thames River Conservation Authority, 2023). We could not find peer-reviewed evidence supporting this method, but we did find a journal providing guidance using the frilling technique. This technique involves making a series of downward angled cuts that are made completely around the tree, leaving the partially severed bark and wood attached at the bottom (Figure 4.5) (Stelzer 2006).

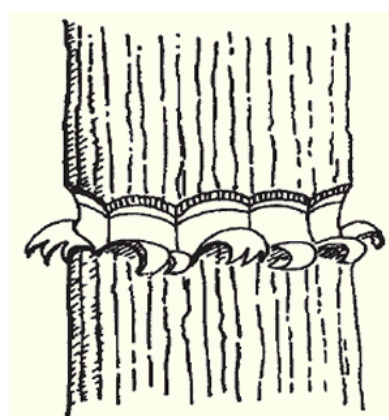

Figure 4.5. Frilling technique used as a woody plant removal method (Stelzer 2006)

Other gray literature mentioned that controlled burns would be an effective way to remove buckthorn (Illinois Natural Preserves Commission, 2007), but this was not supported by experimental work in Indiana that found an increase in all stem size classes of *F. alnus* after both of two burns (Post et al., 1989). Buckthorn Baggies, black plastic baggies that can be ordered in various sizes online (see https://www.buckthornbaggie.com/), claim to kill buckthorn by covering cut stems and blocking light for an extended period (Figure 4.6). The only published work testing the effectiveness of bags is a thesis that reports that bags can prevent resprouting in 80.7% of the stems and that there is a positive correlation between stem diameter and the survival rate of buckthorn stem complexes (Croft, 2022). To date there are no peer-reviewed research publications on the impacts of Buckthorn Baggies.

Figure 4.6. The Original Buckthorn Removal Baggie (https://www.buckthorn-baggie.com/)

5. What are best practices for buckthorn removal based on experience?

I. Introduction and Methods

Upon finding that the body of literature on buckthorn removal approaches is limited, we decided it would be beneficial to learn directly from practitioners who have hands-on experience with the management and removal of invasive buckthorn species. To gain this perspective and better inform on-site treatments and monitoring at St. Pierre Wetland, we consulted with practitioners individually and also hosted two online focus groups in 2022 on Tuesday, May 3rd (9:00 - 10:30 am ET) and Wednesday, May 11th (12:00-1:30 pm ET) (hereafter referred to as the first and second meeting, respectively). Knowing practitioners' best practices for buckthorn removal (and how those differed for *R. cathartica* vs. *F. alnus*), along with other potential methods of interest they would like to see tested, was most interesting to us.

For the focus groups, we developed a list of 45 practitioners to invite from 35 public and private organizations active in the Midwest and also encouraged them to invite others within their professional network. There were eight practitioners present at the first meeting, and seven at the second, with one practitioner attending both meetings; Figure 4.7 shows the represented organizations focused on conservation, restoration, and stewardship initiatives.

Based on our research objective and what we learned from the literature, we prepared closed and open-ended questions (see Box 4.1) ahead of time to learn about each person's familiarity and experience with buckthorn removal and long-term monitoring, what they consider as successful, and what alternative methods they have either seen used or been curious about trying. Upon review of the information gathered, we synthesized key takeaways to inform recommendations for buckthorn removal at St. Pierre, but also to serve as a reference for the larger community of practitioners sharing and using the information on buckthorn management.

Figure 4.7. Organizations represented in focus groups

Box 4.1: Closed and open-ended informal interview guidance questions

One set of poll questions focused on practitioners' familiarity with the topic by asking:

1. How many years of experience do you have in removing *F. alnus*?

   [>5 years, 1-5 years, <1 year]

2. How often are you able to share/learn about effective invasive species removal practices from other practitioners?

   [Very often (several times a year), at least once a year, less than once per year, This is the first time!]

The other set focused on practitioners' experience with removal by asking:

1. From your experience, which of these approaches is most effective to reduce/remove *F. alnus* over time?

   [pull, cut stump, cut stump & herbicide, foliar herbicide, fire/torching, other, not sure]

2. To what extent do you think *F. alnus* and *R. cathartica* removal practices are similar?

   [The same, somewhat similar, different, or very different, not sure]

These closed-ended questions were followed by open-ended informal interview guidance questions, focused on exploring what alternative approaches they might use toward long-term wetland recovery:

1. What have you wanted to try but have not?
2. What have you heard might work, but are not sure?
3. What about building biotic resistance or resilience versus just removal? Have you seeded or planted native plants in your restoration efforts?

Finally, we asked about their perspectives on long-term monitoring and success:

1. How long do different methods take for successful removal and restoration?
2. What does success look like? (metrics) By when?

II. Focus Group Results and Key Recommendations

Key information gathered from the focus groups is shared in sections a - d below. Additional information gathered on girdling from an individual consultation with a practitioner is included in section d.2.

a. Practitioner experience and opportunities for sharing

Both focus groups opened with poll questions focused on practitioners' familiarity with the topic. When asked how many years of experience they have in removing *F. alnus*, 41% of respondents had more than 5 years of experience, 39% had 1 - 5 years of experience, and 20% had <1 year of experience (respectively). With 80% of attendees having 1 or more years of experience with removing *F. alnus*, it was clear they had a strong collective experience that could help inform our initiatives for St. Pierre Wetland.

Since the events were a unique opportunity associated with our project, we asked attendees how often they can share and/or learn about effective invasive species removal practices from other practitioners; the responses were as follows in Table 4.3:

Table 4.3. Focus group response for how often attendees can engage with other practitioners on invasives removal practices

Level of engagement	Response rate
Very often (several times a year)	*59%*
At least once per year	*35%*
Less than once per year	*0%*
This is the first time	*6%*

When asked what opportunities they've had in the past for engagement with other practitioners, attendees shared a variety of ways in which they've interacted with others about invasive species removal practices. Overall, they encouraged others to seize opportunities to engage with other professionals of similar fields as often as possible to further their education, network, learn new perspectives, etc. Thus, the focus groups were considered a valuable opportunity for connecting with a community of practice on buckthorn removal and outcomes.

Recommendations for connection:

Attend conferences (e.g.Stewardship Network Conference (https://conference.stewardshipnetwork.org/)

—

Join online webinars

(e.g. webinars by the Natural Areas Association

—

Engage with others on online platforms such as Instagram

—

Seize opportunities to have 1:1 discussions with others through organized activities

b. *R. cathartica* vs. *F. alnus* Approaches: Prioritize fruiting shrubs?

Since *R. cathartica* and *F. alnus* are closely related - with only slight differences such as the size and ripening of the rounded fruit, leaf structure, and flower structure - it was generally agreed upon to not treat them differently for invasive removal. However, one key difference is that *R. cathartica* is dioecious, meaning it has individual plants with male or female flowers, and only the females will bear fruits. A recommendation was to prioritize removing the fruiting individuals (female, fruiting plants) since it would reduce the seed bank, but removing all individuals was the more feasible and common approach.

c. The most effective approach to buckthorn removal: cut stump and herbicide with specifics on its application

Similar to the literature, a majority of practitioners (77.5%) agreed that the most effective approach to reduce and/or remove *F. alnus* over time is applying herbicide to cut stumps. Unlike the literature, they provided much more informed guidance on the specifics of applying this method, including cut height, wetland use, time of year, and what to do with leftover cut biomass. Important takeaways and recommendations are as follows:

- Cutting stumps:
    - Cut as low as possible while maintaining visibility to the stump (a shorter stump has less distance for the herbicide to travel to the roots and is thus more efficient).
    - If herbicide treatment cannot be done on the same day as the cutting, make the cuts higher so that the stumps are easier to locate at a later time.

- Upon return for herbicide application, cut each stump as low to the ground as possible before it is treated.

- Herbicide:
    - A wetland-approved herbicide is the best option for St. Pierre Wetland.
        - Garlon 3A is specifically recommended because it contains Triclopyr, which is approved for use in waters in the state of Michigan.
    - Only use one type of wetland-approved herbicide for the entirety of the site to eliminate the need to clean and change out equipment between applications.
    - Mix in a blue tracer dye with the herbicide to improve the visibility during application to cut stumps.

Key Recommendations for "cut stump and herbicide" method:

Cut as low as possible if applying herbicide immediately; if applying later, leave a cut high enough to be able to rediscover the stump

—

Use only a wetland-approved herbicide in both wet and dry areas for any site with standing water present

—

Optimal timing to apply method in a wetland is winter season with frozen ground; avoid spring (growing) season

—

Handle cut biomass either by repurposing it (e.g. firewood) or by creating brush piles that will undergo a prescribed burn

- Timing:
    - Winter season is ideal for cutting stumps and applying herbicide on a wetland site because frozen ground makes it easier to move around and minimizes disturbance to the dormant native vegetation.
        - While a 1:1 dilution ratio is generally recommended for herbicide mixed with water, applying the herbicide at full strength or adding a little bit of RV auto freeze specifically (not auto antifreeze or other types) during winter can keep the liquid from freezing in the applicator.
    - The least optimal time for application is during the spring season since herbicide would move up into the leaves and push out during the plant's growing season, rendering it ineffective.

   - This approach could be done in the summer and autumn seasons once plants have leafed out around the first of June, but it would be unideal with the terrain no longer being frozen.

- Handling cut biomass:
   - Leftover buckthorn biomass could be reused in ways such as for firewood or as mulch after cutting it with a wood chipper, as long as there are no longer fruits/seeds remaining that could lead to a risk of spreading the species further (another reason to cut in the winter).
   - Cut brush could also be left where it falls or piled up in stacks on site.
      - If cutting in the winter season, stacks could be formed and burned on-site via a professionally controlled burn.
      - Brush piles could be left intentionally for providing valuable habits (e.g. snakes), and an experiment could assess that value.
   - Important considerations:
      - A risk associated with forming brush piles and leaving them on site is the potential for regrowth to still occur for some cut individuals beneath the piles.
      - Piles should be formed in designated areas where they are not obstructing access to the area for future monitoring and maintenance tasks.

d. Alternative spproaches: foliar spray, girdling, plastic baggies, burning, native seeding

i. Foliar spray

Several practitioners reported using foliar spray (spraying the leaves of growing plants with herbicide instead of applying herbicide to a cut stump) when a plant has a trunk roughly narrower than a finger's width since it would not be wide enough when cut to draw in enough herbicide to kill the root system. If surrounding plants being hit and killed by the spray is a concern, cutting the plants intended to be sprayed and waiting a few months for them to re-sprout in a bushier form is a suggested strategy. It is easier to target buckthorn individuals in a bushier form and is thus safer for the surrounding plants.

ii. Girdling

Focus group attendees acknowledged girdling as a potential method to consider for removing larger *F. alnus* or *R. cathartica* individuals. Comments on its use were limited, but a key benefit shared is that it does not immediately result in cut stems that must be removed or handled. To understand this method further, we consulted with a practitioner more experienced in girdling after conducting the focus groups.

We learned that it is vital for effectiveness to make a cut that is not only deep enough to go through the cambium layer but also is a complete 360-degree circle around the trunk of a tree to ensure the plant cannot continue to get the flow of nutrients, water, and energy from the xylem and phloem. Additionally, for an effective cut, it is recommended to cut the cambium at least a quarter of an inch wide and not cut deeper than the cambium layer since cutting into sapwood or heartwood can prompt resprouting.

We were also advised to only girdle a plant if the stem is greater than or equal to 5 cm in diameter as anything smaller than that would be better off being cut through entirely. The tools recommended for cutting are either a hatchet (common for the frilling technique) or a hand saw (Figure 4.8). For individuals that are not much greater than 5cm in diameter, the use of a chainsaw is not advised since one is more likely to run the risk of cutting through the plant unintentionally. A chainsaw, however, could be a considerable option for older individuals that have much larger stem diameters.

A recommendation made for monitoring effectiveness is to check for resprouting and/or remaining healthy branches on a girdled individual the following year; if one or the other is present, the girdle can be considered ineffective. Since girdling can entail years of monitoring wounded individuals, it may not be an appropriate method for short-term restoration goals. However, if the site one is working on has longer-term goals, it may be a good option for the management of buckthorn.

iii. Plastic baggies

Practitioners in both focus groups were familiar with buckthorn baggies, and a few have used them in their own buckthorn removal efforts. One practitioner estimated a 75 - 80% success rate in using them for killing buckthorn plants around vernal pools where it is not ideal to use herbicide. They advised zip-tying the baggies for security and emphasized how important it is for them to remain fanned out at the bottom to prevent resprouting from the base of the stem. To improve the likelihood of effectiveness, it was also suggested to establish a plan for monitoring the placement of the baggies during their use so that any that have been compromised are fixed or replaced (e.g. if debris cause the skirt to be pushed in, requiring an adjustment). As for the duration of use, at least one year was advised with another suggesting leaving them on designated plants for many years.

Success was found using black baggies in open areas and on individuals ranging from 12-15 feet high, but it came at a cost. Those having applied this method shared that the process requires more time and resources than they typically can allocate since it requires resources for both the setup and removal of the bags. They also shared that the cost associated with applying

Figure 4.8. Common Buckthorn Girdling with a handsaw (image via staticflickr.com)

this method can be very expensive, especially on a larger scale, when considering the materials and personnel needed.

iv. Burning

An agreed-upon management tool among practitioners for handling cut *F. alnus* and *R. cathartica* biomass on a site is to burn it on-site via a professionally controlled burn, either in stacks or spread out on the ground. A few suggested doing so in the winter when the ground is frozen, with another adding that it is optimal to conduct a burn when the weather is dry so that heat is generated more quickly. When asked what they've wanted to try, but haven't yet, as it pertains to fire management, an additional consideration brought up was the use of a cover crop such as rye as fuel for a prescribed burn. Suggested for sites with muck soils where buckthorn was present for years before it was later removed, this can be an effective approach for killing new seedlings and sprouts because of the heat produced when the cover crops burn.

When considering using fire along with other removal alternatives, practitioners also emphasized that the timing and order of treatments will vary based on the site. Burns conduct-ed ahead of other treatments can kill off a large number of plants quickly, reducing the number of plants that need to be killed by other means, whereas areas with low grassy vegetation may require another method to be applied first to ensure enough "grassy fuel" is present to keep the fire moving throughout the designated burn area. In the latter case, it is best to start with a manual/mechanical form of control and wait 1 - 3 seasons for sedges to grow before conducting a prescribed burn. Additional tips from practitioners with first-hand experience in conducting prescribed burns at St. Pierre Wetland included various methods of placing cut material strategically to assist with burning techniques, such as creating piles or spreading it on the ground before a burn.

v. Native seeding and monitoring for native recovery

Practitioners agreed that for the ecosystem management of sites with a strong native seed bank, additional seeding is not necessary; and that, in any case, it is important to monitor and foster native species' success after conducting invasive species removal. Not all native species that emerge may be considered "good" for prairie fen communities, so there may be a need to control aggressive species that could outcompete the desired native plants. One method of aggressive species control that a practitioner suggested for a site with less of a native seed bank is sowing in wild rye (*Elumus canadensis*, a perennial grass native to Michigan) as a cover crop. Since wild rye can burn hot enough to potentially kill surrounding buckthorn seedlings and sprouts during a controlled burn, it can help native species compete.

When discussing improving native plant success and monitoring, the practitioners suggest waiting at least one year after buckthorn removal before furthering restoration efforts. Native vegetation should show itself by then, as it is expected that native plants will grow naturally as the sunlight reaches the areas that were previously shaded. From there one can assess further actions such as additional removal if there are invasive resprouts or the planting of new native seeding if there are bare patches that could allow for new invasives to move in if not managed. Native species that practitioners recommended for potential seeding and/or planting at a prairie fen are listed below in Table 4.4. A clear message from practitioners is that if there is high confidence in the native seed bank present on site, seeding natives is not likely necessary; making monitoring the site post-removal an important step in both invasive and native monitoring.

In addition to new plant growth, soil chemistry should also be monitored post buckthorn removal treatment. One practitioner shared that invasive removal methods are likely to lead to a change in soil chemistry over time and that two specific aspects worth monitoring to assess improved soil health are nitrogen and emodin levels. Buckthorn leaf litter has high nitrogen content compared to other littler types, which can lead to the rapid mineralization of nutrients that can alter the fertility of the soil (Heneghan et al. 2002). Emodin is also produced and released by *R. cathartica* (occurs in leaves, fruit, flowers, bark, and roots), and leaf litter decomposition can result in the leaching of emodin into the surrounding soil (Sacerdote et al. 2014). Emodin is considered harmful because it has known biological and physiological effects in birds and mammals, including abortive and neurological effects, predation and feeding deterrence, and immunosuppressive and vasorelaxant effects (Sacerdote et al. 2014).

Table 4.4. List of native species that practitioners recommend seeding and/or planting in a prairie fen.

Species	Species Photo
Whorled yellow loosestrife *(Lysimachia quadrifolia)*	
American water-willow *(Justicia americana)*	
Tag alder *(Alnus incana)*	
Native Dogwoods *(Cornus florida, foemina, ammomum, sericia)*	
Poison sumac *(Toxicodendron vernix)*	

Nannyberry *(Viburnum lentago)*	
Ninebark *(Physocarpus opulifolius)*	
Bog Birch *(Betula pumila)*	
Prickly-ash *(Zanthoxylum americanum)*	
Buttonbush *(Cephalanthus occidentalis)*	
Swamp rose *(Rosa palustris)*	

Images courtesy of the University of Michigan Herbarium (https://lsa-miflora-p.lsait.lsa.umich.edu/)

6. What research can be done at St. Pierre wetland to both achieve restoration and improve practice?

Based on our research of removal methods in theory and in practice, it is clear that different methods can be appropriate in different situations. The “cut stump and herbicide” method is a considerable option for a large-scale site with plants that have matured but still have a trunk diameter < 5 cm. The foliar spray could be most effective for a site that has a lot of younger individuals with small trunk sizes and where it would not harm surrounding native plants. Girdling can be effective for sites with individuals > 5 cm in diameter and where removal can take time. Using buckthorn baggies may be a great option for a small-scale site. Burning and native seeding are good options to consider as additional management tools combined with another method.

The overall restoration goal at St. Pierre is to protect the biodiversity and ecosystem service value of the wetland, while also meeting the research and education mission of the site. Thus, it makes sense for us to take an experimental approach that tests the ability of different methods to minimize the threats to site hydrology and native biodiversity. This means focusing on buckthorn removal, but in a way that limits additional disturbance to the site. It must also be feasible and applicable to the site and within the logistical challenges of access and limited capacity. Considering all of this, at least for the first phase of experimental work, we decided not to test the following as treatments:

- **Girdling**. The only area of the property with individuals >5cm in diameter is near the property boundary and is composed of densely growing common buckthorn. Those larger stems mostly exist within buckthorn complexes (clusters that contain more than 1 buckthorn, with individuals that are both >5cm and <= 5cm), which means access to girdle the larger stem cannot be obtained without cutting all of the smaller stems around it, which would just resprout. Furthermore, this area is a low-value site and the dense thicket may be serving the role of deterring public accvess to the site.

- **Fire**. A proper prescribed burn would require a contractor for which at this time there is a lack of funding. It would also require building trust and understanding with the neighboring community before implementation.

- **Herbicide**. Even though “cut stump and herbicide” is the most commonly suggested removal method, its outcomes are relatively well documented already, and herbicide alternatives are less studied. Furthermore, in a movement that mirrors some of the pushback on herbicide use more broadly, students from the University of Michigan (UM) have been advocating the elimination of the use of herbicides on campus (https://www.rewild.org/rewild-your-campus), further highlighting the need to explore alternatives, especially on University property. The rich native plant community of St. Pierre wetland also indicates a need to avoid the risk of potential negative impacts of herbicide on non-target plants, seed performance, and soil, which are well documented (e.g., Biggerstaff and Beck, 2007; Rokich et al., 2009; Wagner and Nelson, 2014; Schuster et al. 2020). Finally, in terms of feasibility, herbicide application requires certification, and while there is a limited capacity for trained individuals to conduct work at St. Pierre, there are many potential volunteers.

I. Research Question

a. What is the effectiveness of non-herbicide removal methods on buckthorn control and native plant restoration?

Black baggies are an herbicide alternative removal method that practitioners are familiar with, but for which there is a lack of data on effectiveness. Many practitioners we talked to were interested in the effectiveness of black baggies in preventing resprouting or being used in small-scale applications where herbicide use was counter-indicated. Croft's (2022) thesis work is the only published assessment of black baggy effectiveness, and while his study showed an average 80.7% mortality rate of buckthorn over a 7-month treatment period, it also indicated enormous site variation in effectiveness (from 33.4 to 97.5%), lacked data on the level of resprouting in plants not killed by the treatment, and on what happened over longer time periods. The author speculated that water availability might have caused variation among the two study sites, and interestingly the treatments were conducted on the upland R. cathartica, and did include data on F. alnus, which is the greater threat to wetlands. St.Pierre wetland provides an opportunity for a long-term and systematic study of the effectiveness of the black baggies not only on F. alnus removal, but also on long-term native plant recovery, and with the added variable of proximity to water, given that it is on the shoreline of Bass Lake. From this research, we hope to develop best practices and applications for baggy use. Given the concern over the sustainability of invasive species removal methods, we also decided to conduct a smaller pilot study on the effectiveness of non-plastic bags (made of heavy-duty paper bags) that use the same principles of blocking light to the cut stem.

II. Experimental buckthorn removal methods

a. Plot setup

We set up six 4x10 meter treatment plots in an area of the fen where F. alnus density was relatively consistent, where removal would have the highest potential restoration value, and perpendicular to the shoreline so that we could compare subplots near and far from the water (Figure 4.9). We intentionally chose the location for the treatment plots based on recommendations to prioritize connectivity of undisturbed areas within the prairie fen (M. Kost, personal communication, August 8, 2022). Per conversations with practicing researchers, we chose to keep the individual plot sizes small— 4m x 10m— to minimize disturbance in the plot when removing shrubs and to ensure that subplots are accessible from the plot edge (L. Petri, personal communication, July 15, 2022). The six plots were split between 3 alternating treatments:

1. B: Buckthorn Baggie
2. C: Control (cut-only, high)
3. T: Cut-Only (low)

The control plots are a cut-only treatment with stumps cut at the same height as the stumps for the baggie plots so that bagged resprouting can be compared with the continued growth of cut-only plants, but also to test the effect of experimental treatment disturbance (and the skirt of the bag) on surrounding native plants. The cut-only treatment plots, where *F. alnus* stems are cut as low as possible, compares F. alnus stem mortality with stems in the baggie treatment plots, while also assessing the possible hydrological stunting of F. alnus growth when low-cut in a wetland system (M. Kost, *pers. comm.*).

We further subdivided each plot into 4 equally sized quadrants (Figure 4.10) to study additional factors of interest:

- The effect of adjacency to a particular treatment (e.g. the effect of the cut-only treatment being adjacent to the baggie treatment).
- The effect of proximity to water; since one edge of the entire row of plots is closer to the shoreline of Bass Lake than the other.

Figure 4.9. The six 4 x 10 meter buckthorn removal experimental plots were mapped at their location on site near the water's edge of Bass Lake (data points were taken using a Bad Elf GNSS receiver with positional accuracy within a few cm).

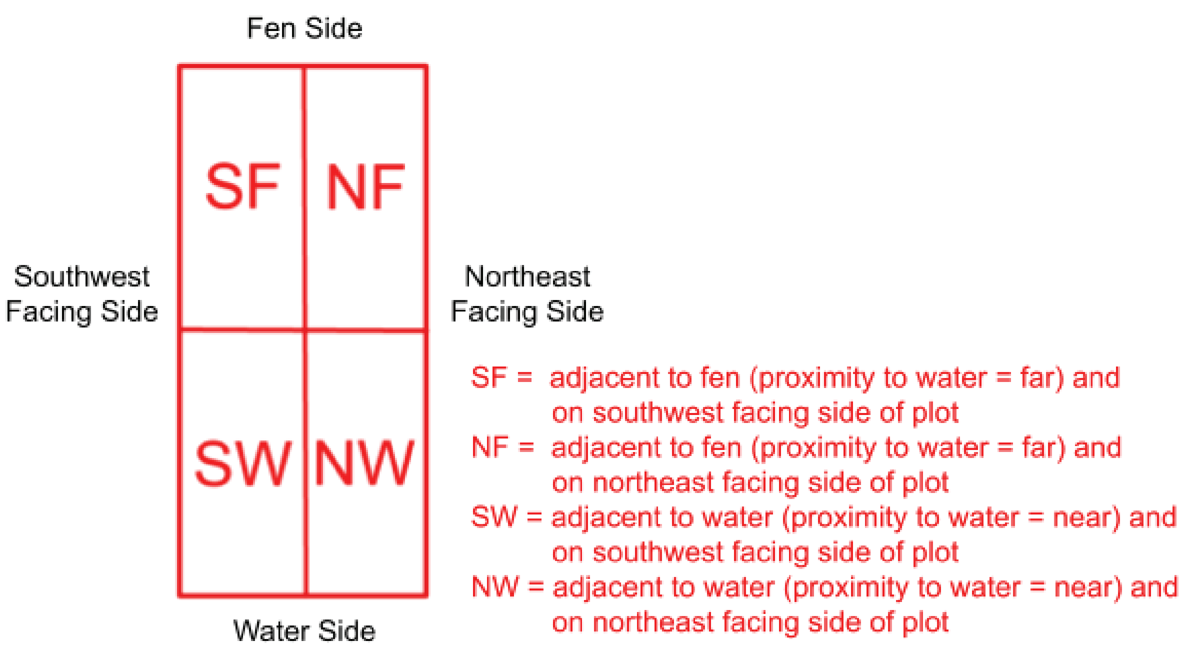

Figure 4.10. A 4 x 10 meter buckthorn removal experimental plot showing subdivision into 4 quadrants labeled SF, NF, SW, and NW according to its proximity to either the fen or water and the direction the plot sides are facing.

We marked the corners of the plots with rebar stakes driven .5m into the ground to ensure they could resist disturbances from wildlife and weather, marking only one rebar stake per plot with a metal tag and orange paint at the base to be able to check against the plot treatment maps when revisiting plots. Due to a concern with surrounding untreated buckthorn interfering with treatments due to the potential for seed to fall within the plots, we chose to high-cut all *F. alnus* stems within one meter of the plot boundaries to create a surrounding buffer.

b. Treatments

For the control treatment, C, we simply cut back all *F. alnus* stems, living and dead, to approximately 10cm from the ground, using a clear ruler to measure the height. We primarily used loppers to cut stems, but also used a folding hand saw for stems >5cm in diameter. The 10cm height was determined as it was an appropriate height at which to cut stems for applying baggies for the buckthorn baggie treatment (B). We used the following standard operating procedure for this treatment after cutting all stems:

- Before measuring a stem or stem complex, check to see what stems are within the complex. The complex is defined by which stems appear to originate from the same hummock or within a 20cm diameter from the estimated center of the hummock.

- Using the clear ruler, measure the diameter (in cm) of each living stem in the complex and record it on a datasheet for the plant ID associated with the stem complex (e.g. For C plot 1 (C1), the first stem complex in the "SF" quadrant (quadrant ID: CSF1, plant ID: CSF1-1) would be labeled CSF1-1-1)

For plots with the buckthorn baggie treatment, B, in addition to cutting stems back in the same manner as for the control treatment (C), we covered stems with buckthorn plastic baggies (see Box 4.2, below) and secured the baggies with metal wire and metal staples at the base (See Figure 4.11). We used the following standard operating procedure for the bagged treatment after stems had been cut:

- Before applying a baggie, decide which cut stems and/or complexes you want to place a baggie over. In some cases, it may make sense to place a smaller bag over a single stem or complex, but in others, it may be best to place a wider bag over multiple stems and/or complexes.

- Pick a baggie out of the size options that is best suited for the chosen stem(s) and/or stem complex(s).

- Measure the diameter (in cm) of only each living stem and record it on a datasheet for the plant ID that is to be associated with the plant (e.g. For B plot 1 (B1), the first stem or stem complex in the "SF" quadrant (quadrant ID: BSF1, plant ID: BSF1-

1) would be labeled BSF1-1-1).

- Write the Plant ID (e.g. BSF1-1) on a white waterproof laser jet label with a black paint marker and let it dry for a minute (Appendix E. d. F*ield Research Material Checklist*).
- Place the chosen baggie over all of the live stem(s), and also dead stems if necessary for a more secure fit
    - If the baggie is of appropriate width, but is too tall for a proper fit on the stem(s), roll up the sides of the baggie (as shown in Figure 4.12) until a more secure fit is achieved.
    - Ensure that the baggie is fanned out at the bottom so that it is flush with the ground since doing so is important for covering the root system of the plant(s) and keeping light from getting to the plant(s).
- To ensure that the bag will remain secure:
    - Use 16 gauge galvanized utility metal wire - cut to an appropriate length associated with the baggie you are applying it to - to secure the bag to the stem or stem complex (as shown in Figure 4.11).
        - To secure the wire around the bag, make the wire taut and twist it (as shown in Figure 4.14) so that it is not able to come loose. Wear cut-resistant gloves that are thin enough to allow for the dexterity needed to twist the wire.
        - If there is an excessive length of wire left over after it has been twisted, the extra length can be bent and pressed into the ground for added security. If there is not enough wire length to reach the ground, bend it down toward the ground to avoid sharp ends sticking out (Figure 4.14)
    - Use a heavy-duty metal landscape staple (stake) to secure the bag to the ground (Figure 4.13). For the wide baggie size (24″ Wide x 18″ High) or baggies where improved security is needed (e.g. if a baggie skirt does not lie flush on the ground as desired), place two stakes on opposite sides of the baggie skirt
- Place the label with the Plant ID associated with the plant on the bag toward the top where it is visible and lays flat on the bag. Readjust the label (as needed) to ensure it is placed properly (see Figure 4.12). Rub your thumb over the label once properly placed to ensure adhesion to the bag.

Figure 4.11. buckthorn plastic baggies secured to the base of the stem or stem complex with a 16 gauge galvanized utility metal wire.

Figure 4.12. A plastic baggie of size 11 1/2" x 11 1/2" with the sides of the bag rolled up to ensure a proper fit on the stem(s) of the plant it was placed on and with a Plant ID label added to the bag during treatment so it is visible and lays flat on the bag.

Figure 4.13. A heavy-duty 20 gauge landscaping stake used to secure a buckthorn baggie to the ground.

Figure 4.14. 16 gauge galvanized metal wire tied around baggies to secure them to the stem. The left and middle picture exemplifies proper tautness and twisting of the wire with excess length pushed into the ground. The picture on the right exemplifies how shorter excess wire lengths should be bent toward the ground.

For the cut-only treatment, T, we simply cut back all *F. alnus* stems, living and dead, as low as possible to the ground so that the possible hydrological stunting of *F. alnus* growth when low-cut in a wetland system (M. Kost, *pers. comm.*) could be assessed. We primarily used loppers to cut stems, but also used a folding hand saw for stems >5cm in diameter. We followed the same standard operating procedure noted above for the control treatment, C, after cutting all stems, with the only difference being the naming convention used for recording data (e.g. For T plot 1 (T1), the first stem complex in the "SF" quadrant (quadrant ID: TSF1, plant ID: TSF1-1) would be labeled TSF1-1-1).

Box 4.2 Supplies Used in Experimental Setup

- 16 gauge galvanized metal wire to make sure that each stem or stem complex within the treatment plots are labeled. Purchased at a hardware store in the Ann Arbor area.
- Stringliner mason's line to establish plot and subplot edges. Purchased at a hardware store in the Ann Arbor area.
- 6″ 20 gauge landscaping stakes to secure the mason's line to hummocks at the plot and subplot corners and to secure baggies to the ground. Purchased at a hardware store in the Ann Arbor area.
- Stake flagging to make the corners of plots distinct during field work days. Purchased at a hardware store in the Ann Arbor area.
- 1.27cm x 45.72cm rebar stakes to secure the corners of the plots more permanently once plot setup was complete. Purchased at a hardware store in the Ann Arbor area.
- Avery waterproof labels to mark buckthorn baggies with distinct plant complex IDs. Purchased online.
- Black paint marker to write the plant complex ID on each tag. Purchased at a hardware store in the Ann Arbor area.
- Buckthorn Baggies (ordered through the Buckthorn Baggie site https://www.buckthornbaggie.com/order). They come in 3 size options: 11.5″ wide x 11.5″ tall (original), 18″ wide x 24″ tall (heavy duty), and 24″ wide x 24″ tall (heavy duty). To determine what quantity to order for each bag size, we first counted the number of buckthorn individuals and complexes for the B treatment plots, measured their approximate diameters, and then compared the measured diameters to the diameters associated with each baggie based upon the circumference of each baggie type opening.
    - Original Buckthorn Baggies (11 1/2″ X 11 1/2″)
        - Circumference of opening = 23″

- Diameter = 7.3″
- Heavy Duty Baggies (18″ Wide x 24″ High)
  - Circumference of opening = 36″
  - Diameter = 11.5″
- Heavy Duty Baggies (24″ Wide x 18″ High)
  - Circumference of opening = 48″
  - Diameter = 15.3″

To refine our treatment standard operating procedures and to plan logistics for conducting the remaining treatments during the field research work days, several members of our team conducted the B1 baggie treatment on the morning and afternoon of February 18th, 2023. We organized the field research work days with the goal of engaging student volunteers and HOA members in learning about the ecological significance of the property and providing a hands-on stewardship activity. We spoke to ecology and conservation classes to recruit interested students, who signed up for the field research work days using a google sign-up form (Appendix E. a. *Field Research Workday Interest Form*).

With the help of fifteen student volunteers from UM SEAS, two HOA members, and two UM SEAS staff and faculty, we applied treatments T1, C1, and C2 on March 12th, treatment T2 and a quadrant of treatment B2 on March 18th, 2023 (Figure 4.15), and the remaining quadrants of treatment B2 on March 20th and 23rd 2023 (Figure 4.16). We met with volunteers off-site and carpooled to Bass Ridge HOA, then hiked along the HOA trail to the wetland. Prior to volunteers arriving, two team members organized the appropriate materials for each plot treatment, including sheets for recording data, in large blue tote bags, which we placed at each plot. Once volunteers arrived on site, we spoke with the group about the site's history and ecological importance, the theory behind treatments, the processes for applying treatments, and the data collection protocol before dividing the group into plot teams, each led by 1-2 of our group members. Two volunteers were responsible for collecting and piling cut stems from the plots, and a team member answered questions and ensured that all the groups had enough supplies. Please refer to Appendix E.a - E.h for all materials used to organize the Field Research Workday.

Figure 4.15. Photos of team members and volunteers participating in the field research work days

Figure 4.16. Photos of the B2 baggie treatment plot, with top photo showing the completed plot and the bottom picture showing the plot as the treatment was being applied.

After the field workday events, we sent out a form for participants to provide feedback about their volunteer experience. Generally, students were happy to have gotten the opportunity to learn about the site and participate in active restoration efforts at a SEAS property. One student reported, "It was great to get out into the wetland and do some hands-on work with a clear science goal. As a SEAS student, this was one of the only opportunities I had for fieldwork this whole semester! It was a great hands-on wetland and invasive species removal experience … It really was a highlight for me this semester." Improvements that volunteers offered focused on time management, encouraging volunteers to wear warmer or more pairs of socks and the efficiency of carpooling.

c. Handling of cut stems post-treatment

To manage the build-up of cut stems within plots, we decided to pile cut stem brush outside of the high-quality prairie fen. As noted by practitioners, an ideal location for piling brush would be one accessible by foot, within the property boundary, and where inhibiting the growth of native species is not a concern. It is also important that the location is a reasonable distance from the experimental treatments to reduce the time and effort necessary to move the brush. A location on-site that met these conditions and is on either side of the footpath used for access is shown in Figure 4.21 below. This location has dense buckthorn cover with minimal native vegetation, is accessible off of the footpath used to access the site, and is no greater than 150m away from the experimental plots.

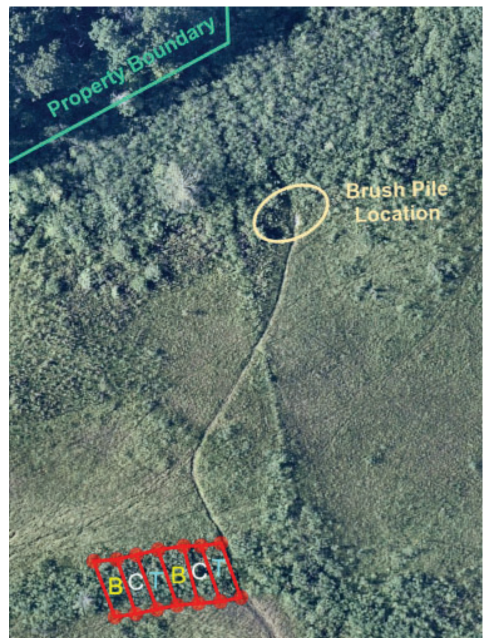

Figure 4.17. Location of brush piles for cut *F. alnus* stems on either side of the access path at St. Pierre Wetland.

d. Response Variables and Monitoring Protocol

We have laid out the following timeline for recording response variables to assess each treatment's effectiveness. All data will be recorded in the datasheet we used to capture information during treatment setup.

1. **Summer 2023** (conducted by a "power volunteer" from adjacent HOAs, a student volunteer, and/or Sheila Schueller):

   a. **Bag condition**: There are obvious concerns about leaving "research waste" at the site, so it is important to regularly check if any bags come loose (and to know to what extent this undermines treatment effectiveness). Monitor B and P treatment plots to document damage to buckthorn baggies, including whether the bag has slipped, torn, been visibly tampered with, or come off the stem complex to any extent. Record this information in a column, "bag condition", according to the complex with the corresponding naming convention. Any affected bags will not be fixed, as this will give the team a sense of their actual practical effectiveness.

b. **Resprouting**: Locate complexes and record the number and length of resprouts of each complex for all treatments, without removing bags.

2. **Fall 2023** (Students in EAS 509, Restoration Ecology &/or Herbaceous Flora):

   a. **Bag condition** as above

   b. **Resprouting**: Locate complexes and record the number of resprouts and length of each resprout of each complex for all treatments, without removing bags.

   c. **Vegetation**: Monitor subsample plots for surrounding plant response variables

      i. Total native diversity

      ii. Percent cover

      iii. Presence of indicator species tbd

      iv. Number of new buckthorn stems

3. **Spring/Summer 2024** (new St. Pierre master's project or thesis students):

   a. **Bag condition** (as above), the remove bags and assess:

   b. **Resprouting** (as above)

   c. **Vegetation** (as above and additional measures such as FQI)

   d. Mortality: Record by the stem and stem complex - dead stems may show discoloration of wood, bark separation, and splitting of heartwood. All individual stems must be dead and no resprouts can be present for a stem complex to be classified as dead.

4. **Spring/Summer 2024** (new St. Pierre master's project or thesis students):

   a. **Bag condition** (as above), the remove bags and assess:

   b. **Resprouting** (as above)

   c. **Vegetation** (as above and additional measures such as FQI)

d. **Mortality**: Record by the stem and stem complex - dead stems may show discoloration of wood, bark separation, and splitting of heartwood. All individual stems must be dead and no resprouts can be present for a stem complex to be classified as dead.

e. Data management and sharing protocol

The following outlines how data from this study will be managed and shared:

- Data associated with every plant ID will be kept in a datasheet and that file will be shared here and with edit access to Sheila Schueller
- GIS data of the location of each plot replicate (plot point data shown in Figure 4.9 above) will be accessible to the University of Michigan members through ESRI ArcOnline as well as on Mfield.
- This chapter will be shared with local practitioners who gave their input in the focus groups and through personal communication in emails to them and by sharing our project website
- Photo Monitoring points (see Figure 4.18 below) will be accessible to the University of Michigan members through ESRI ArcOnline as well as on Mfield.

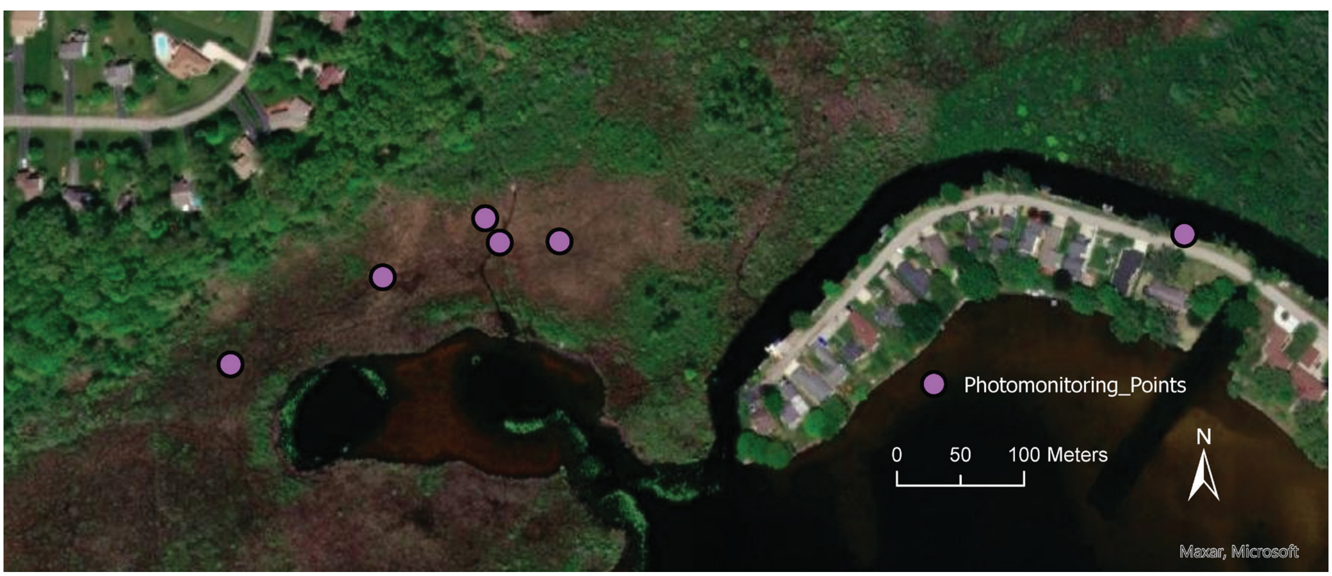

Figure 4.18. Photo monitoring points captured on-site using ESRI ArcGIS Field Maps.

7. Continuing evidence-based adaptive restoration at St. Pierre: High priority recommendations

We have designed and implemented an informed experimental buckthorn removal experiment for St. Pierre Wetland. The value of this effort depends on continued investment following this project's completion in April 2023. Below we outline three priority next steps.

I. Ensure the implementation of the data collection plan detailed above

This will mean engaging volunteers and students, and critically, enlisting a Master's project team (or thesis student) for January 2024 - April 2025 to carry out the next phase of research and engagement (See Appendix F. *Proposal for 2024 St. Pierre Wetland Master's Project*).

II. Expand the treatments and response variables to further inform practice, including measuring other response variables and other invasive species

We recommend future student research groups investigate the efficacy of a compostable "Buckthorn Baggie" for smothering cut *F. alnus* stem complexes. This entails using several layers of yard waste bag material, secured by hemp or jute twine, to prevent any light from reaching the complex. Complexes should be cut and data should be recorded as they were for the Buckthorn Baggie treatment that we used. If successful compared to the Buckthorn Baggies, practitioners could apply the compostable bag treatment without necessarily needing to remove the bags, which will break down after several years.

Soil chemistry or hydrology are several additional key response variables that could be added to existing treatments, as these are likely to be affected by the buckthorn. Targeted herbicide treatment of cut stumps could be added or replace the cut-only treatment if it is deemed necessary for comparison or for control of resprouting stems. Larger plots with complete buckthorn removal, as capacity allows, could also be used to assess impact on local vegetation and conditions, and increase restoration impact.

Beyond research on buckthorn, there are opportunities to explore restoration methods and impacts with several other species on the property. The presence of the common reed, Phragmites australis (hereafter, P. australis), and hybrid cattail, *Typha x glauca*, should be monitored in coming years and considered for future restoration efforts at St. Pierre. *P. australis*, identified from native *Phragmites* by the bluish tint to their leaves, is a perennial grass that grows to be at least 2m tall and is crowned with a large seed head. Hybrid cattail shares characteristics of narrowleaf (*Typha angustifolia*) and broadleaf (*Typha latifolia*) cattail, making them indistinguishable from native cattail at a distance. *P. australis* and hybrid cattail are high-priority invasive species at St. Pierre because of their capacity to rapidly reproduce and dominate a landscape once established at a site (M. Kost, personal communication, August 7, 2022). While neither species was listed as present in the 2019 HRWC report, both *P. australis* and hybrid cattail have been noted in team visits to the site during 2022. Hybrid cattail has been noted within the northeast section prairie fen and may be present elsewhere on the property. The Matthaei Botanic Garden's Associate Curator stressed monitoring and removing hybrid cattail populations because of its proximity to the prairie fen and ability to quickly dominate the landscape (M. Kost, personal communication, August 7, 2022). The bloody glove method is recommended as an efficient - though herbicide reliant - option for preventing hybrid cattail from spreading further (M. Tu & J. M. Randall, 2003).

A stand of *P. australis* is present where St. Pierre wetland meets the eastern end of the inlet of Bass lake, extending south from the southwest border of the prairie fen. Strategies recommended for managing *P. australis* include foliar herbicide sprays, prescribed fire, and mechanical treatment, but further investigation is needed to determine which treatment is most appropriate for the site (Michigan Department of Environmental Quality, 2014). Staff and students at SEAS may connect with the resources and knowledge of the Phragmites Adaptive Management Framework through Great Lakes Phragmites Collaborative to develop an informed approach to addressing the species at St. Pierre. Given the importance of maintaining the structural and ecological integrity of the prairie fen and the site at large, it will be important for proper literature review and consulting with practitioners to guide any efforts to control other invasive species on the property.

III. Continue photo monitoring efforts at the wetland

Photo monitoring provides an on-the-ground visual comparison to track changes in the composition and position of invasive species. Photos taken from the photo monitoring points in spring, summer, and fall will illustrate the rate at which community structure changes with advancing invasives, particularly *F. alnus.* Understanding the pace at which invasives encroach on the prairie fen will help future stewards at St. Pierre to adapt restoration recommendations for the site in the event that particular invasive species become more critical to address.

While satellite imagery and visual estimations from the 2019 Stantec report paint a broader picture of buckthorn coverage on the property, the extent to which buckthorn has dominated sections of the property came into focus during site walkthroughs the spring and summer of 2022. To bridge the gap between the relative densities identified in the Stantec report and the reality of the issue, we established photo-monitoring sites and protocols. These include photos to track buckthorn growth on the north side of the prairie fen, one directed toward the buckthorn stand between Bass Lake and the prairie fen, and one directed at the east side of the prairie fen (Figure 4.22). We used a GIS layer in the ArcGIS Field Maps application to record the location of each photo point and attached both a photo for photo monitoring and a photo of the marker by which the photo was taken. The first photos were taken on October 22, 2023. In the point description, we documented the direction, in degrees, in which the photo was taken. We also added detailed directions to ensure future photographers can find the point. To avoid leaving permanent markers, we used natural markers— cedar trees, a buttonbush shrub, and an existing stake— to identify our photo monitoring locations. Per the NRCS guide to photo monitoring, photos were taken at eye level, ensuring that the sky makes up a consistent proportion of the composition for easy replication (NRCS, 2023). Once we took photos, we developed photo point maps that include points' names, landscape references to match future images to initial data points, and the date that photos were taken.

To provide key insight into stakeholders' view of the site, on October 22, 2022, we also established a photo monitoring location within the Shan-Gri-La Homeowners' Association, where the HOA president took a photo from his dock looking across the canal to the property in 2008. We were prompted to do so by the stark difference in the extent to which buckthorn obstructed the view of the wetland between this initial data photo and the visits to the site in the spring of 2022. The historical photo also gave us a sense of what changes homeowners have seen over time as St. Pierre's restoration efforts have fallen by the wayside. Because the photo was taken previously without any notes of location or direction, we were limited when matching our photo to a copy of the original image. These photos, as well as ones taken from Bass Lake, will both inform property managers of the conditions of the site and demonstrate how the site appears to the public, in particular HOA. Biannual photo monitoring, in the spring and fall of each year, will create visual baseline data to track the progression of invasive species at priority sites on the property, and the photo monitoring point from the perspective of Shan-Gri-La can lend understanding to the perspective of the HOA members, a critical component of long-term community-engaged stewardship efforts.

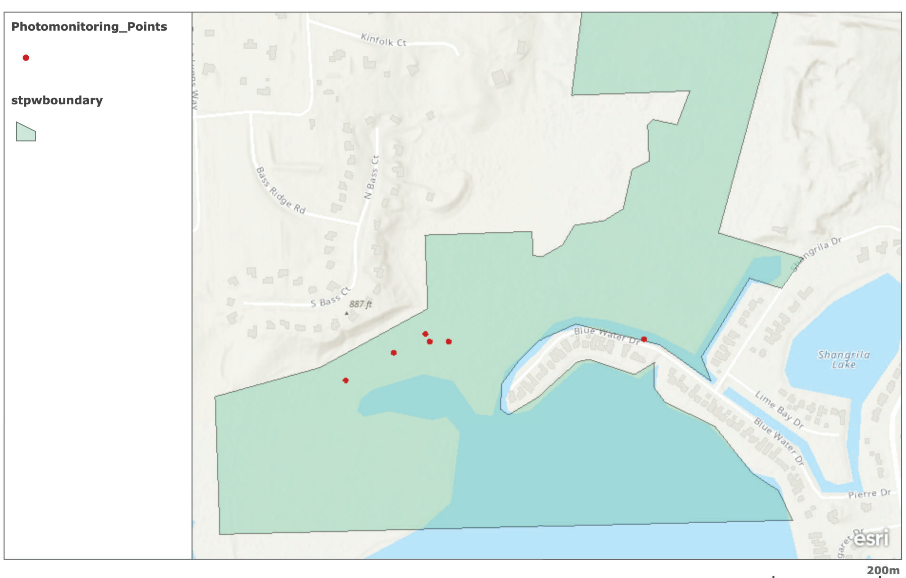

Figure 4.19. A map of photo monitoring locations

IV. Integrate fire as a future restoration practice for long-term site management

Fire is a natural part of Michigan's fen ecosystems, maintaining open conditions and helps many native plants to thrive; in its absence, invasive plants and tall trees and shrubs tend to dominate and crowd out native fen plants (Kost, 2009). Thus, working with trained professionals to reintroduce fire is an option for future efforts to control invasive species and restore vital ecological processes at St. Pierre Wetland. Techniques that could be employed at St. Pierre Wetland for invasive species impression include conducting prescribed burns (Figure 4.20), burning brush piles, and spot-burning invasive plant seedlings such as F. alnus and R. cathartica (Kost, 2009).

In planning to introduce fire to the site, there are key factors to consider. To minimize impacts to fire-sensitive species: the seasonal timing of the burn, heat intensity, rate and direction of flame spread, cloud cover, temperature, and relative humidity (Kost, 2009). An additional consideration is the timing of when fire practices are employed in a prairie fen community. It is suggested that periodic fire with a recovery interval may be best for maintaining plant diversity because yearly dormant-season burning leads to greater dominance by graminoids and a cumulative loss of forb diversity (Kost, 2000). With regards to social considerations, there will also need to be open communication with members of both HOAs regarding timing and what neighbors should expect.

Figure 4.20. Prescribed fire to control shrub encroachment (Photo by Kelly Bougher, Spring 2018).

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Appendices – some only available to umich users

A. Record of Stakeholder Interactions

  a. (This will be a record of people who we spoke with in regards to this project, in order to avoid unnecessarily duplicating communication efforts)

B. St. Pierre Outlot Information

C. Logistical Site Use Guidance and Protocols for UM Faculty and Students

D. Wetland Educational Flier

E. Field Research Workday materials

  a. Field Research Workday Interest Form

  b. Field Research Workday Schedule

  c. Field Research Workday Logistics

  d. Field Research Workday Material Checklist

  e. Task Checklist for Workday Coordinators

  f. Field Research Workday Preparation Materials

  g. Field Research Workday Safety Briefing

  h. Field Research Workday Advertisement Slide

F. Proposal for 2024 St. Pierre Wetland Master's Project

  a. (A proposal outlining the purpose and activities of a master's project involving the wetland, to run from January 2024 to April 2025)

G. List of Possible Funding Sources

H. Species Classification Accuracy Assessment - Confusion Matrix

I. Multivariate Statistics within R Studio - R Scripts

J. StoryMap Guide to St. Pierre

  a. Feedback For Reviewers

A. Record of Stakeholder Interactions

Record of Stakeholder Interactions

The record is intended to inform future stakeholder outreach efforts made by the 2024-2025 master's project team. We hope that this record enables future students to pick up where we left off.

See the contact list at the end of the document for more information.

Spring & Summer 2022

Practitioner's Circle - May 3, 2022
Name and organization:

- Becky Hand - City of Ann Arbor Natural Area Preservation (NAP)
- Michael Hahn - NAP
- Frederick Sechler - Native Plant Trust
- Billy Kirst - Adapt, Community Supported Ecology
- Paul Buzzard - Washtenaw County Conservation District
- Spencer Kellum - The Stewardship Network
- David Mindell - PlantWise, LLC
- Lais Petri - PhD Student, UM SEAS

Team contact: Kim Heumann

Practitioner's Circle - May 11, 2022
Name and organization:

- Steven Parrish - Matthaei Botanical Garden
- Jessica Ableson - Genesee Cooperative Invasive Species Management Area (GiLLS CISMA - Genesee, Lapeer, Livingston, and Shiawassee counties)
- Pete Blank - The Nature Conservancy, Northwest Ohio and Southeast Michigan
- Michelle Beloskur - Midwest Invasive Plant Network
- Rachel Hackett - Michigan Natural Features Inventory Office (MSU)
- Katie Grzesiak - Michigan DNR
- Billy Kirst - Adapt, Community Supported Ecology

Team contact: Kim Heumann

San-Gri-La Annual HOA Meeting June 4, 2022

- Stephen Brown - SGL HOA President, project client
- Sucila Fernandes - UM SEAS Facilities Manager
- Steven McKenna - SGL HOA Resident
- Cindy & Steve Smith - SGL HOA Resident
- Mike Bonk - SGL HOA Resident

Site visit, August 7, 2022

- Mike Kost - Associate Curator, Matthaei Botanical Gardens; Lecturer at SEAS

Team contact - Liam Connolly

Site Access conversations, July - September 2022

- Ciara Comerford - Associate General Counsel, UM Office of the Vice President and General Counsel (UM Legal Team)
- Chris Allen, Executive Director of Real Estate, UM Real Estate Office

Team contact - Sucila Fernandes (Sucila communicated directly with them)

Fall Semester 2022

Meetings and correspondence re public communication and flier, April - October 2022

- Carole Love - Executive Director, Communications, Marketing, and Outreach - SEAS

Team contact: Sheila Schueller

Adapt Event - November 12, 2022

- Billy Kirst - Adapt, LLC
- Stephen Brown - President, SGL HOA
- Margaret and Matt Compton - SGL HOA residents, recently arrived
- Ginny Maturen - SGL HOA Board Secretary and resident
- Terri Wilkerson - Cordley Lake HOA
- Gwynne Jennings - Cordley Lake HOA

Team Contact: Kim Heumann

Winter Semester 2023

Interview about past interactions with UM regarding St. Pierre Wetland - January 11, 2023

- Debbie Wenzel - Granddaughter of Samuel St. Pierre, SGL HOA resident
- Barry Wenzel - Husband of Debbie, SGL HOA resident
    - *Debbie and Barry had a negative interaction with the UM around use of St. Pierre about 10 years ago. (See report). Feel free to check back in or give them updates, but do not interview them about this incident, as we have already done so. (Can ask to verify information in our report).*

Team contact: Rachel Kaufmann

Contact regarding parking, March 2023

- Gina Wilson - Bass Ridge HOA Resident
    - *Gina was interested in the work we are doing on the wetland, and she allowed us to park in front of her property. This situation became complicated by neighbors complaining about blocking access to driveways and mailboxes. I recommend reaching out to Gina, but if you park in front of her house you must clearly understand where it is and is not okay to park. (See Site Checklist and Protocols for parking guidelines).*

Team contact: Rachel Kaufmann

People involved in our "Buckthorn Removal Workdays" - March 12 and 19, 2023

Workday 1 - March 12

SEAS students:
- Jamie Brackman
- Sara Thiessen
- Anna McAtee
- Sally Phipps
- Emma Fagan
- Allegra Baird
- Evelyn Faust
- St. Pierre Master's Project Team

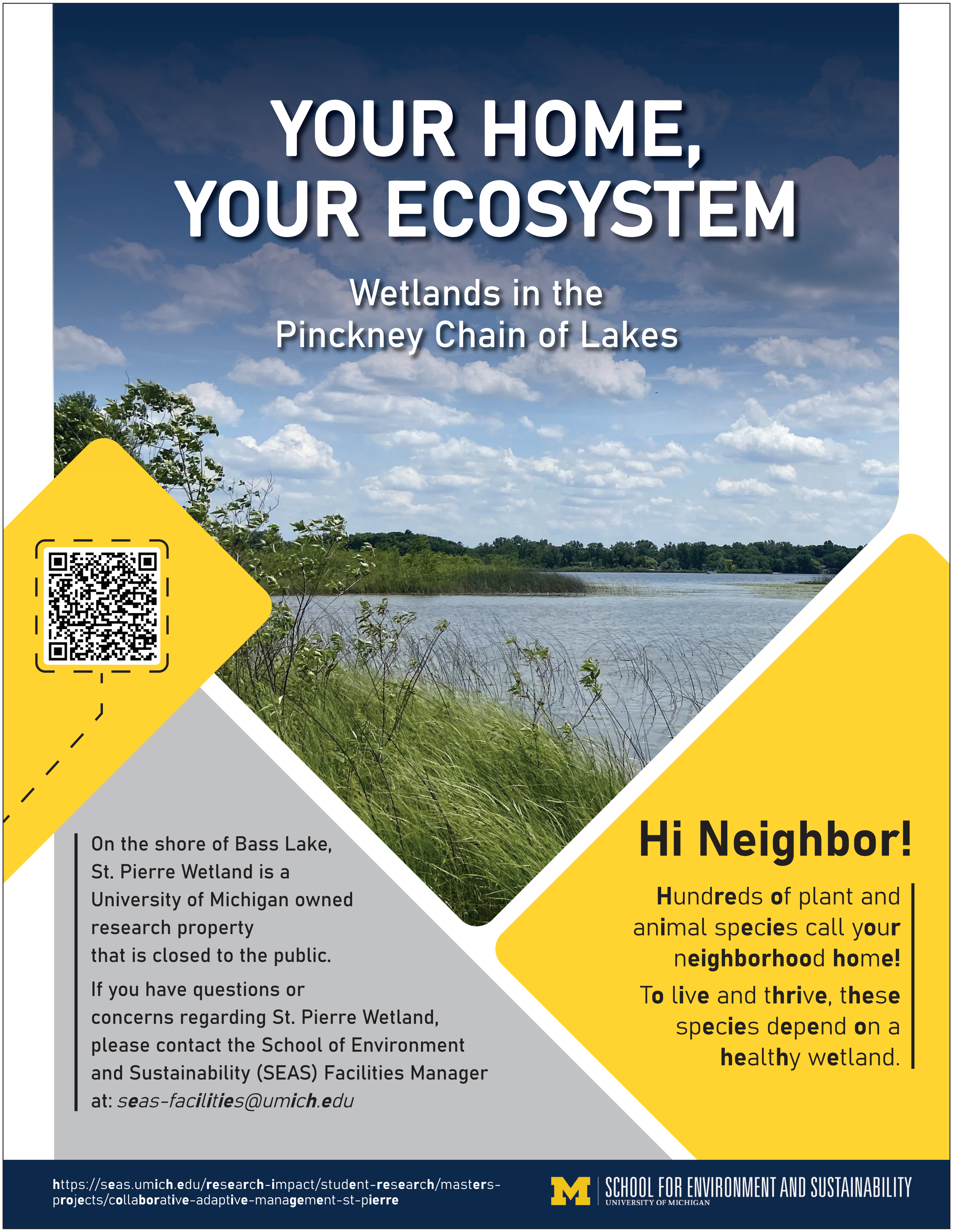
Others:
- David Pounta
- Stephen Brown
- Sucila Fernandes
- Sheila Schueller

Workday 2 - March 19

SEAS students:
- Esther Chiang
- St. Pierre Master's Project Team

Others:
- Yuen-Lin Tsau
- Derik Heumann
- Lance Riegle
- Stephen Brown

D. Wetland Educational Flier



What are wetlands?

- Wetlands are areas where soil is saturated with water for extended periods of time. A variety of wetland types are found throughout Michigan, including bogs, swamps, marshes, and fens.
- The St. Pierre wetland is an ecosystem that includes marsh as well as prairie fen, and supports a unique and diverse set of plants and animals.
- Learn more about Michigan's wetlands here: *https://www.michigan.gov/egle/public/learn/wetlands*

Why are they important?

Healthy wetlands carry out many important functions, such as:

- Filtering out pollutants (heavy metals, plant litter, etc.).
- Retaining soil and decreasing land erosion, especially by stabilizing shorelines and dampening wave impact during storms.
- Providing habitats for animal shelter and reproduction. More than one-third of endangered species depend on wetlands.
- Reducing flooding by collecting and slowly releasing stormwater.
- Storing large amounts of carbon in soil and plant mass, keeping it out of the atmosphere.

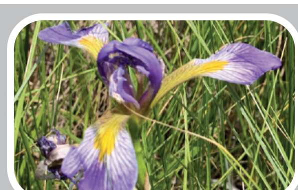
Risks to Wetland:

- Non-native plants can degrade wetland habitats. They often spread quickly, pushing out native plant species and changing the way water moves in the ecosystem.
- Fertilizers or herbicides applied outside of the wetland can easily reach the wetland through runoff and stormwater drains. Fertilizers can spur the growth of algae and non-native plants, and herbicide is not plant-specific and can impact desired native plants in the wetland.
- Trampling or creating worn paths in wetlands can break up root mats, disrupt the flow of water, or facilitate the spread of non-native and invasive species.

You can be part of the solution:

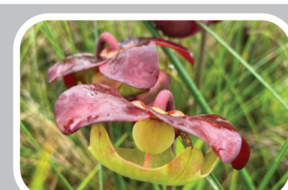
- Plant native plants on your property to promote healthy and diverse ecosystems!
- Use natural fertilizers, such as compost or manure, and use sparingly. While natural fertilizers are better than the alternative, they can still have a negative impact when overused.
- Eliminate or limit herbicide use. If herbicide is necessary, use a selective herbicide rather than a broad-spectrum one. Refresh yourself on how to use it correctly and only use the minimum effective amount.

Lesser fringed gentian
(Gentianopsis virgata)



Southern Blue Flag
(Iris Virginica)

Sensitive Fern
(Onoclea Sensibilis)



Pitcher Plant
(Sarracenia purpurea)

https://seas.umich.edu/research-impact/student-research/masters-projects/collaborative-adaptive-management-st-pierre

SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY
UNIVERSITY OF MICHIGAN

E. Field Research Workday materials

a. Field Research Workday Interest Form

St. Pierre Wetland Experimental Restoration: Student Volunteer Sign Up Form

Use this form to **sign up to attend** an experimental plot set up at St. Pierre Wetland on **Sunday, March 12th, 1-4pm** (backup date March 19th). Here are some details for you to know:

This event is organized by a SEAS Master's Project team working on informed and community-engaged restoration of a SEAS-owned property. St. Pierre Wetland is located just 25 minutes north of Ann Arbor in Pinckney, MI along the Chain of Lakes (click here for a map). It has a beautiful prairie fen and undeveloped shoreline. Invasive plants such as buckthorn are beginning to alter the site's hydrology and biodiversity. You will be a part of setting up plots that will be monitored over time to test the effectiveness of different buckthorn removal methods.

On-site activities will include: learning about the site and species, walking along a woodchip trail and on uneven terrain in the wetland, measuring and cutting small buckthorn shrubs at the base using hand tools such as loppers, applying a novel non-herbicide alternative treatment of buckthorn baggies, and moving and positioning brush piles.

Please complete the form below to secure your spot! ***Space is limited and available on a first-come-first-serve basis.***

* Required

1. Email *

____

2. First Name *

____

3. Last Name *

____

E. Field Research Workday materials

a. Field Research Workday Interest Form

4. Email *

____

5. School and Degree/Specialization *

Check all that apply.

- [ ] SEAS - ESM
- [ ] SEAS - GDS
- [ ] SEAS - BEC
- [ ] SEAS - Sus Sys
- [ ] SEAS - Sus Dev
- [ ] SEAS - EJ
- [ ] SEAS - EPP
- [ ] SEAS - MLA
- [ ] Other: _______________________________

6. Do you have prior experience identifying and removing buckthorn? *

Mark only one oval.

- ( ) No prior experience
- ( ) I have done some removal, but might need identification help
- ( ) I have plenty of experience removing buckthorn
- ( ) Other: _______________________________

E. Field Research Workday materials

a. Field Research Workday Interest Form

7. St. Pierre Wetland is about a 30-minute drive northwest of Ann Arbor (click here for map). There may be space in a van, but it is not guaranteed. We will also help organize a carpool. Please share your preferences below so we can plan transportation for the day. *

Check all that apply.

- [ ] I will drive myself
- [ ] I will drive myself and volunteer to take others (please note how many can ride with you in the "other" field)
- [ ] I would like to ride with someone in their personal vehicle
- [ ] I would like to ride in the van
- [ ] Other: ______________________

8. We will supply safety supplies such as eye protection, gloves, and vests. If you need gloves supplied for you, what size do you wear? *

Mark only one oval.

- ( ) Small
- ( ) Medium
- ( ) Large
- ( ) I'll bring my own gloves!

9. I understand I may be working with handheld manual tools. (Instructions on proper use and safety will be given on the day of the event.) *

Mark only one oval.

- ( ) Yes
- ( ) No

E. Field Research Workday materials

a. Field Research Workday Interest Form

10. I understand I will be outside for a few hours in Michigan in March and will dress appropriately to stay warm and dry (coats, hats, waterproof warm boots). More reminders on proper clothing will be sent out before the event. *

Mark only one oval.

- Yes
- No

11. If we have to cancel the March 12th event because of weather, are you also available for the backup day March 19th? *

Mark only one oval.

- Yes
- No

12. Are you able to lift 50lbs? *

Mark only one oval.

- Yes
- No

13. What do you hope to gain out of this experience?

____

E. Field Research Workday materials

a. Field Research Workday Interest Form

14. Please let us know if you have any other questions, concerns, or ideas about the event.

Thank you for your commitment to restoration research and education on a SEAS property!
We understand that plans can change due to illness, or other things outside of your control. **Your registration here is a commitment and we plan the event around the number of people coming and driving, so please let us know at least 24 hours before the event if you need to cancel by emailing** stpwetlands22@umich.edu

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Google Forms

E. Field Research Workday materials

b. Field Research Workday Schedule

Time	**Activity**
Noon	2 team members arrive at STPW to prep the plots, organize tools, collect a buckthorn stem for identification
11:45	2 team members meet at Dana (Back of building) to load waders into a designated team member's car
12:15	Carpoolers Meet at Church Street Garage, drive to Lakeland Trail Head
1:00 - 1:15	● Solo drivers meet at Lakelands Trailhead - *Rachel* ● Carpoolers arrive at Lakelands Trailhead - *Kim, Sheila, Alice Zhou* ● Stephen and Sucila meet us at Lakelands Trailhead - *Steve has confirmed, waiting on confirmation from Sucila* ● Put on waders ● Give directions to Bass Ridge, hang tags to drivers - *Rachel* ● Share info on timing of return and who folks are returning with (just so we don't end up with not enough seats to drive people back) - *Kim/Rachel*
1:15-1:30	Carpool to Bass Ridge HOA Park and enter wetland ***We want time in HOA to be as short and* quiet *as possible + Make sure all cars have hang tags & are not in front of parking lots***
1:30-1:45	Walk to the wetland via HOA trail - Point out *hazards*
1:45- 2:00	**Gather by the plots** *1 team member* - orientation (limber-up circle) *2 team members* - Buckthorn identification, demonstration on removal, safety talk, then distribute tools
2:00 - 3:30	Work time
3:30 - 3:45	wrap up and gather tools; provide snacks
3:45 - 4:00	Walk back to vehicles - *On the way (at end of wood chip trail in snow) - do snow angels in the snow to clean off waders as much as possible*
3:45- 4:00	*From HOA to Lakeland; get waders back*
4:15 - 4:45	Travel back to AA
4:45-5:15	*Any/all available - moved waders back into waders closet neatly; leave all supplies to dry out on lab benches*

Field Research Wokday Logistics

Gathering Materials/Tools/Equipment:

- Organize time before the event for gathering all materials/tools/equipment needed
    - Coordinate a time to get materials from on campus resources
        - EAS 509 Lab (contact SEAS faculty)
        - SEAS Properties Manager (contact SEAS staff)
        - Matthai Botanical Garden and Nichols Arboretum (contact MBGNA staff)
- Plan a time to purchase materials that can't be borrowed ahead of the event, having at least one designated team member store and transport the materials on the day of the event

Parking:

- For those needing to carpool from the Ann Arbor campus, meet at Church Street Garage
    - Once carpoolers are in vehicles, drive to the Lakelands Trail Trailhead parking lot (0 M-36, Pinckney, MI 48169)
- Prior to any carpool to the site access point, all visitors to the site should first meet at the Lakelands Trail Trailhead parking lot (0 M-36, Pinckney, MI 48169)
    - At this location, sign liability waivers and put on waders
- Maximum number of vehicles that can fit on that street = 5 vehicles
    - For event: limit parking to **max of 5 vehicles** on the street near the site entrance in the HOA community
        - If more than 5 vehicles are needed for transportation of people to the event, carpool from the Lakelands Trail Trailhead parking lot (0 M-36, Pinckney, MI 48169)

Walking to Site:

- Plan on it taking **10 min** to travel via carpool from the Lakelands Trail Trailhead parking lot (0 M-36, Pinckney, MI 48169) to the site access point at Bass Ridge HOA (Bass Ridge, Hamburg Township, MI 48169)
- Plan on it taking **20 min** to travel via carpool fromthe site access point at Bass Ridge HOA (Bass Ridge, Hamburg Township, MI 48169) to the wetland

E. Field Research Workday materials

d. Field Research Workday Material Checklist

Field Research Workday Material Checklist

Tools/Equipment

- **Clippers/pruning shears** - use: cutting small buckthorn branches [qty: 5]
  - 
  - Where to get the item: Borrow from MBGNA and team member(s)
- **Loppers** - use: cutting large buckthorn branches [qty: 8]
  - 
  - Where to get the item: Borrow from MBGNA and team member(s)
- **Hand saws** - use: cutting buckthorn stem or girdling large buckthorn[qty: 5]
  - 
  - Where to get the item: Borrow from team member(s) and EAS 509 lab
- **Sled** - use: transportation of materials [qty: 1]
  - 

  - Where to get the item: Borrow from team member(s) (if available)

E. Field Research Workday materials

d. Field Research Workday Material Checklist

- **Bungee Cords** - use: secure materials during their transportation [qty: 2]
  - 
  - Where to get the item: Borrow from team member(s)
- **Masking tape** - use: label tools and equipment [qty: 1]
  - Where to get the item: Borrow from team member(s) or EAS 509 lab
- **Sharpies** - use: mark marking tape, along with other needs [qty: 2]
  - Where to get the item: Borrow from team member(s)

Materials for Plots

- **Black Paint markers** - use: mark waterproof labels that are placed on baggies [qty: 2]
  - 

  - Where to get the item: Purchase from a hardware store
- **Orange flagging tape** - use: marking quadrants and/or plants [qty: 1 roll]
  - 
  - Where to get the item: Borrow from EAS 509 lab

E. Field Research Workday materials

d. Field Research Workday Material Checklist

- **Orange Mason Line Reel** - use: marking quadrants [qty: 1- 500ft roll or 2 - 250ft rolls]
    - 
    - Where to get the item: Purchase from a hardware store
- **Buckthorn baggies** - use: covering buckthorn plants [qty: 330]
    - 
    - Where to get the item: Purchase online @ https://www.buckthornbaggie.com/order
        - Options:
            - Original Buckthorn Baggies (11 1/2" X 11 1/2") - qty: 230
            - Heavy Duty Baggies (18" Wide x 24" High) - qty: 25
            - Heavy Duty Baggies (24" Wide x 18" High) - qty: 75
- **16 gauge galvanized metal wire** - use: securing baggies onto plants [qty: 1]
    - 

    - Where to get the item: Purchase from a hardware store

d. Field Research Workday Material Checklist

- **Combination wire pliers with cutter** - use: cutting and bending metal wire [qty: 2]

  - Where to get the item: Borrow from team member(s)
  - Alternative option:
    - 2 wire pliers
    - 2 wire cutters

- **6” 20 gauge landscaping stakes** - use: securing baggies or mason line [qty: 250]

  - Where to get the item: Purchase from a hardware store

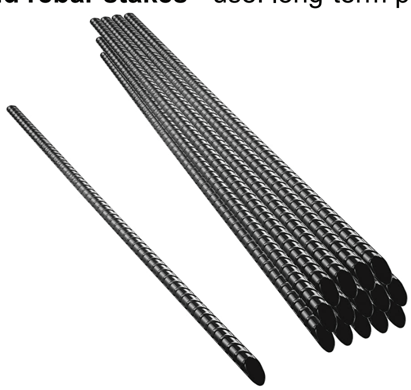
- **Waterproof labels** - use: labeling buckthorn baggies [qty: 300]
  - Where to get the item: Purchase online or from an office supplies store
  - Specific recommendation: Avery waterproof, oil and tear-resistant labels

E. Field Research Workday materials

d. Field Research Workday Material Checklist

- 

- **Scissors** - use: cut mason line, along with other needs [qty: 2]
  - Where to get the item: Borrow from team member(s)

- **Ground rebar stakes** - use: long-term plot markers [qty: 20]
  - 
  - Where to get the item: Purchase from a hardware store

- **Transect Tape** (in meters) - use: layout plot boundaries and measure other distances as needed [qty: 2]
  - Where to get the item: Borrow from EAS 509 lab

Materials for Data Collection

- **Data collection sheets** - use: record data [qty: 100]
  - Where to get the item: Print datasheet created online

- **Clipboards** - use: hold datasheets [qty: 6]
  - Where to get the item: Borrow from EAS 509 lab

- **Pencils/Pens** - use: record data [qty: 6]
  - Where to get the item: Borrow from team members

- **Digital calipers** - use: measure buckthorn stems [qty: 5]
  - Where to get the item: Borrow from EAS 509 lab

- **Batteries for digital calipers** - [qty: 5]
  - Where to get the item: Purchase from a store or borrow from EAS 509 lab

E. Field Research Workday materials

d. Field Research Workday Material Checklist

- **Small clear rulers** (with centimeter measurements) - use: measure stem cut heights and stem diameters [qty: 6]
  - Where to get the item: Borrow from EAS 509 lab

PPE/Safety Items

- **Tub to keep all safety gear in** [qty: 2]
  - Where to get the item: Borrow from SEAS facilities
    - One for safety glasses
    - One for safety vests
- **Safety glasses** [qty: 15 (regular), qty: 15 (over glasses)]
  - Where to get the item: Borrow from SEAS facilities
- **Safety vests** [qty: 30]
  - Where to get the item: Borrow from EAS 509 lab
- **Safety gloves** (cut-resistant) [qty: 30]
  - Borrow a variety of sizes (S, M, L, and XL)
  - Where to get the item: Borrow from SEAS facilities
- **Metal binder clips for pairing safety gloves** [qty: 30]
  - Where to get the item: Purchase from a store
- **First Aid Kit** [qty: 2]
  - Where to get the item: Borrow from EAS 509 lab or from team member(s)
- **Liability Waivers**
- **Copy of safety protocol**

Logistics/Other Items (borrowed from or created by team members)

- **Paper towels**
- **Tick Key**
- **Extra pens/pencils**
- **Rubbing alcohol** (to aid with poisonous plants)
- **Hand sanitizer**
- **Snacks** (include a gluten-free option)
- **One-gallon water jug** (backup option for hydration)
- **Trash bags**
- **Spare socks** (have on hand in case someone gets water in their shoes)
- **Box of hand & toe warmers**
- **Spare winter hats**
- **Maps of the site** (print out ahead of the event for anyone carpooling to the HOA site access location)
- **Car hang tags/signage** (for any cars carpooling to and parking at the HOA site access location)

Task Checklist for Workday Coordinators

Before getting to the site

- Tasks to be completed by ***2 weeks before*** the event
  - Visit the site to set up plot boundaries and count the buckthorn within them so that materials can be gathered or purchased accordingly
  - Recruit volunteers for participation in the workday
    - See “Field Research Workday Interest Form,” appendix item E.a
    - See “Field Research Workday Advertisement Slide,” appendix item E.h
- Tasks to be completed by ***1 week before*** the event
  - Visit the site a week out from the event to:
    - Mark the boundaries and quadrants of the plot
    - Assess conditions to determine what outerwear and footwear needs to be recommended for people to bring (e.g waders if the water level has risen)
    - Remove any materials that may be present on-site for trial purposes that are no longer needed
  - Make sure all items on the material list (see ”Field Research Workday Material Checklist,” appendix item E.d) are accounted for, and there is a plan to transport them
    - Refer to “Field Research Workday Logistics,” appendix item E.c)
  - Send out a reminder email to volunteers with site & safety information (see ”Field Research Workday Preparation Materials,” appendix item E.f)
    - Weather check (look up predicted weather online) a week out and provide a “heads up” of anticipated weather conditions for the day in the reminder email
      - Include what clothing they should wear given the weather conditions
        - Footwear
          - If frozen:
            - Durable boots
              - Make sure to wear warm socks and/or bring toe warmers
          - If not frozen, but the water level is low (not above ankle height):
            - Waterproof boots
              - Muck boots are preferable if you have them
              - Otherwise:

                - Tall rain boots
                - Tall hiking boots
            - If not frozen, but the water level is high (above ankle height):
                - Clothing that can be worn with waders
                    - Waders will be supplied by the team
                - Waders if you have them, but not necessary as they will be provided by the team
        - Other
            - If cold (below 50F)
                - Insulated winter Jacket
                - Insulated gloves
                - A warm/insulated hat that covers your ears
                - Optional: scarf or buff for extra warmth
            - If warmer (above 50F)
                - Light jacket
                - Non-insulated gloves
    - Include clear parking instructions (for parking logistics details, refer to "Field Research Workday Logistics," appendix item E.c)

- Tasks to be completed the ***day before*** the event
    - Conduct a final weather check (look up predicted weather online) > 24 hours before the event start time and cancel (via email) no later than 24 hours ahead of the event start time if the weather is predicted to be hazardous
        - Hazardous weather conditions that warrant cancellation:
            - Temperature is below 0 F (frostbite is a risk at this temperature)
            - Windchill causes the temperature to drop below 0 F (frostbite is a risk at this temperature)
            - Snow is expected at > 1 inch
            - High winds equal to or greater than 30 mph
            - Ice on roads is anticipated
            - Blizzard anticipated that could reduce driving visibility
    - Print out extra liability waivers, maps of the site, car hang tags/signage, and a few copies of the workday schedule (see "Field Research Workday Schedule," appendix item E.b)

E. Field Research Workday materials

e. Task Checklist for Workday Coordinators

Upon arrival at the site

- Carpool site (Lakelands Trail Trailhead parking lot (0 M-36, Pinckney, MI 48169)
  - Check-in volunteers
  - Have liability waivers signed
- HOA site access location
  - Ensure car hang tags/signage are displayed in all vehicles parked at this location (not needed for the carpool site)
- Wetland site (in the field)
  - Unpack & sort materials (see "Field Research Workday Material Checklist," appendix item E.d)
    - Items to handout
      - E.g. Tools/Equipment, Materials for Plots, PPE/Safety
    - Items to have on hand
      - E.g. Other Items
    - Other Items for Coordinators
      - Clipboard with extra liability waivers
      - Maps of site
      - Copy of safety protocol
  - Have an orientation talk, including an on-site safety briefing (see "Field Research Workday Safety Briefing," appendix item E.g)

While on-site

- Check-in with volunteers to ask if they need anything (e.g. help, instruction, water)
- Keep track of time, calling out the time on occasion for participant awareness
- Designated team members (see "Field Research Workday Preparation Materials," appendix item E.f) will perform quality control of methods (e.g. circulating the plots, checking in on volunteers) and take pictures during the event

At end of the workday/when wrapping up

- Ask volunteers to pair gloves (using provided metal binder clips) and put them into the designated container
- Have volunteers deposit other safety/PPE items into the designated container
- Collect all tools/equipment and leftover materials used for the plot treatments
- Offer volunteers any remaining water and/or snacks
- Get a group photo

e. Task Checklist for Workday Coordinators

- Check-out volunteers
- See volunteers off and thank them (if not riding with them)
    - If applicable, share about future workday opportunities

<u>After the workday</u>

- On-site
    - Finish packing up materials and load them into team member vehicles
    - Search for and collect trash that needs to be deposited off-site
- Off-site
    - Put away materials from the workday (see Field Research Workday Material Checklist," appendix item E.d)
        - Tools/equipment
        - Leftover materials for the plots
        - Safety/PPE
        - Other
    - Send a follow-up email to volunteers (see "Field Research Workday Preparation Materials," appendix item E.f)
        - If taken, include a group workday photo in this communication

Field Research Workday Preparation Materials

Emails:

Email Draft - Promoting Event

Subject: Wetland Restoration Workday Opportunity for Date (Duration time)

Body of Email:

St. Pierre Wetland is a SEAS-owned private property that is home to a variety of plants and animals and offers important ecosystem services and biodiversity value within southeast Michigan. However, invasives such as glossy buckthorn (*Frangula alnus*) are threatening the biodiversity in the wetland, and restoration efforts are required to address them.

That is where you come in!

Please come out and join us for a great learning and stewardship opportunity at St. Pierre Wetland on Date from Time. You will get first-hand experience in restoration by being part of experimental research testing the effectiveness of different buckthorn removal methods at this unique site.

This work will involve about x hours of time outdoors, walking on uneven ground and using tools such as loppers and hand saws, as well as cutting, dragging, and piling brush. We will provide the tools, site background, snacks, and other essentials to make volunteering a great experience for you - you should bring your own water bottle, clothes to stay warm and dry, and your enthusiasm for engaging with nature in an impactful way!

It is essential that you sign-up for the Field Research Work Day in advance rather than just show up! This allows us to prepare for your involvement.

Sign-up for the Field Research Workday restoration opportunity here

Questions prior to signing up?

Please email one of our Stewardship Day coordinator(s) at:
- Team member [name]: [email]
- If applicable, add additional team members

We hope to see you out there this winter!

[INSERT SITE PHOTO(S) HERE]

Cheers,

The UMich SEAS St. Pierre Wetland Team

Email Draft - Send to Event Registrants Before Event

Subject: Experimental Restoration Workday Day Info – Sunday, March 12th (1 - 4 pm)

Hello wetland stewards!

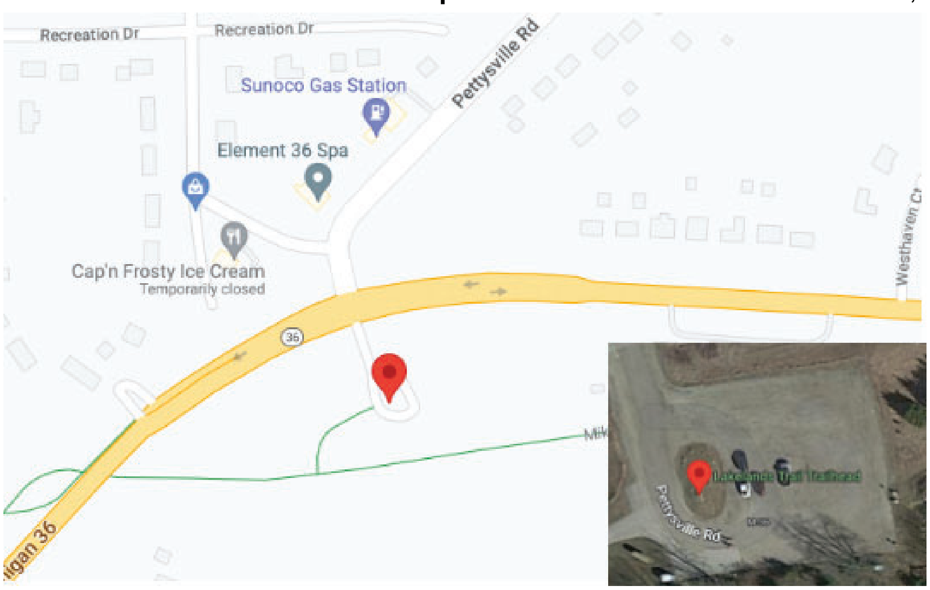
Thank you for signing up for the Experimental Restoration Workday at St. Pierre Wetland on Sunday, March 12th! We look forward to hosting you for a great day of learning about the wetland ecosystem and buckthorn removal practices while engaging in stewardship on-site.

Where & when to meet:

Please arrive on time. Due to the site logistics, it can be difficult, or nearly impossible, for those arriving late to safely and successfully join the group.

For those carpooling (needing a ride or driving others):
Please meet outside the Church Street Parking Structure (525 Church St, Ann Arbor, MI 48104) at **12:15 pm.** (Free street parking on Sundays). Our teammate [name] will meet you there, her phone number is x. If you indicated a willingness to drive others in the carpool, please have your car ready by having cleared your seats and a full tank of gas.

For those driving alone:
Please meet at this address **at 1:00 pm**: Lakelands Trail Trailhead - 0 M-36, Pinckney, MI 48169



We will meet at this parking lot first and will carpool to the site together because there is limited parking at the site.

We will depart from the site around 4:00 pm, so plan on **arriving back in the Ann Arbor area around 4:45 pm**.

What to wear & bring:

- Include this bullet point if the ground is frozen: **Sturdy closed-toe shoes are required**, and shoes that are also **waterproof are recommended**.
- Include this bullet point if the ground is not frozen and waders are not provided because the water level is below ankle height: **Sturdy closed-toe boots that are above the ankle and waterproof are required**
- Include this bullet point if the ground is not frozen and waders are to be provided because the water level is above ankle height: **Waders will be provided (can bring your own if desired), wear clothes and socks that will fit and are comfortable with worn with waders**
- Please dress to be comfortable working outdoors in cool weather for the project's duration. Base layers and thermal socks (e.g. wool) are recommended, as well as a winter hat.
    - Bring at least one extra pair of socks that can be changed into if needed
- We will be supplying PPE (e.g. gloves, safety glasses) and any tools that are necessary. If you have a favorite pair of gloves or safety glasses, feel free to bring them.
- Bring a full water bottle. There will also be some snacks (including a gluten-free option) available, and you are also welcome to bring your own.

More Info:

- There are **no restrooms on-site**, so please use a restroom before you arrive.
- As of today, [day of week of event, e.g. Sunday]'s forecast is cloudy, and temps will be around [degree]F. If we must reschedule the workday due to weather, we'll send an email by [time at least 24 hours before the event start time] on [date of the day before the event]. Our backup date is Day of Week, Month Day (time of event, e.g. 1 - 4 pm).
- If you have questions before the workday or need to cancel, please inform team member(s): email(s) - cell phone number(s).

We look forward to working with you at St. Pierre Wetland! With your help, we will make important progress in restoring the area.

Thank you,
The SEAS St. Pierre Wetland Team
Laura Gumpper, Liam Connolly, Alice Colville, Kimberly Heumann, Rachel Kaufmann, and Xu Zhou
Advisor: Dr. Sheila Schueller

Email Draft - After Event

Subject: Thank you for volunteering at the St. Pierre Wetland Workday!

Hello all,

Thank you for volunteering at our Workday event at St. Pierre Wetland on day of week! Due to your efforts, we established experimental restoration plots that will inform buckthorn removal practices used in the future to maintain the site.

We really enjoyed meeting you all while working on-site together and hope that you had a meaningful experience.

We will keep you updated on our continued work at St. Pierre Wetland, and will let you know if any future opportunities for volunteering on the wetland come up!

In the meantime, feel free to check out our site for the great restoration work going on at the site! [link here]

Please reach out with any follow-up thoughts or questions, and have a great week!

Cheers,

The SEAS St. Pierre Wetland Team

Email Draft - Cancellation & Rescheduling of Event

Subject: *NOTICE: Field Research Workday re-scheduled due to weather*

Body of Email:

This message is to inform you that the Field Research Workday volunteering event has unfortunately been **RESCHEDULED** due to anticipated severe weather. The safety of attendees and coordinators must always come first.

We sincerely apologize for any inconvenience this may cause and hope to be able to work with you on the backup date, [backup date].

If you cannot attend the new date, *please let us know*.

If you have any further questions or concerns, please do not hesitate to contact our coordinator(s) below:

- Team member [name]: [email]
- If applicable, add additional team members

Thank you for your understanding, we look forward to seeing you at the rescheduled event!

Regards,

The SEAS St. Pierre Wetland Team

E. Field Research Workday materials

f. Field Research Workday Preparation Materials

Team Roles:

Define the roles and responsibilities of team members hosting the event:

Role	Team Member 1	Team Member 2 (If Needed)	Responsibilities
Overall Workday Leader	[Name]	[Name]	Ensures that our team is ready for the workday, organizes site visit prep days, delegates responsibilities to other team members, makes sure that our team is on track according to the schedule. Designs tasks so that volunteers can effectively participate in the workday
Experimental Design Leader	[Name]	[Name]	Makes final decisions about experimental design and communicates info about experimental design to the team.
Logistics Leader	[Name]	[Name]	Tracks who has been invited, who is attending, organizes carpools
Outreach/Recruitment	[Name]	[Name]	Talk with Steven and Max; pitch workday to classes. Revise and distribute Google Form for registration
Event Communication (Pre and Post)	[Name]	[Name]	**Pre:** Send out emails communicating carpool info, preparation, and rescheduling information; and send out additional communication about rescheduling due to cancellation, if it happens. **Post**: Send out a thank-you email, including (if available) additional educational materials and knowledge on volunteer events elsewhere
Tools Manager	[Name]	[Name]	Responsible for assembling materials for the day. Decides which tools are needed for the workday, how many, and where to get them from (first choice - MBGNA). Inventory tools before the workday, gather them at the end of the day and make sure none are lost.
Volunteer Leaders	[Name]	[Name]	Lead introduction to work, show volunteers how to ID glossy buckthorn, demonstrate hand tool use, (give tips for how not to lose tools), perform quality control of methods during the event (circulate the plots, checking in on volunteers), close out the day
Orientation Talk	[Name]	[Name]	Introduction, go through the schedule, safety brief, mention taking pictures

E. Field Research Workday materials

f. Field Research Workday Preparation Materials

Sucila Communicator & Safety Manager	[Name]	[Name]	Keeps track of liability forms, has urgent care number saved and is prepared to drive anyone in case of emergency. Makes sure everyone is accounted for at the beginning and end of the day.
Plant Identification	[Name]	[Name]	Help guide plant identification for GBT (in support of Volunteer Leaders) and be a resource for curious volunteers during the day.
Photographer	[Name]	[Name]	Take pictures during the event

g. Field Research Workday Safety Briefing

Field Research Workday Safety Briefing

- Overview of the site & weather conditions anticipated
    - Boardwalk: Be careful walking on the boardwalk, it may be slippery
    - Debris: watch out for woody debris that may be on the boardwalk and/or on the site, be careful to avoid tripping over it
    - Weather:
        - Cold temperatures:
            - Keep your hat and gloves on to stay warm and protect yourself from frostbite
            - Will provide hand/toe warmers & winter hats upon request
        - If going to be windy, give volunteers a heads up
    - How frozen/wet the ground is:
        - If wet, be careful as you walk throughout the wetland
            - Try to avoid stepping in areas that are visibly deep to avoid the risk of getting water in your boots
            - If you get water in your shoes, let us know and we can provide you with spare socks
- Overview of Safety/PPE items available
    - See the “PPE/Safety Items” section within the “Field Research Workday Material Checklist,” appendix item E.d
- General field safety: uneven footing, branches, sunburns
    - Mention sunblock is available
- Dehydration
    - Remind volunteers of the importance of drinking water
    - Mention water is available
- Over-exertion
    - Mention that it is important for injury prevention not to overdo it and not to do a task you are uncomfortable with, are unfamiliar with, or aren’t physically able to do
- Irritating plants (poison sumac)
- Mention that rubbing alcohol is on hand if needed

g. Field Research Workday Safety Briefing

- Overview of the use of the tools/equipment
  - Show a demonstration of the proper use of tools
  - Reminders about how to keep one another safe
    - Keep PPE on
    - Keep a safe distance from others
    - Be careful with the handling of sharp tools (saws, loppers)
  - Sharp tools (saws, loppers). Keep a safe distance, use PPE

E. Field Research Workday materials

h. Field Research Workday Advertisement Slide

Student Opportunity: Sunday, March 12th, 1-4pm (backup date March 19th). Experimental restoration plot set up at St. Pierre Wetland

- **Organized by SEAS Master's Project team working on informed and community-engaged restoration of a SEAS-owned property**
- **St. Pierre Wetland** - 25 minutes north of Ann Arbor
  - High quality prairie fen and undeveloped shoreline
  - Invasive plants such as buckthorn beginning to alter the site's hydrology and biodiversity
- **Goal**: Set up plots that will be monitored over time to test the effectiveness of different buckthorn removal methods
- **On-site activities:**
  - Learn about the site and species
  - Walk woodchip trail and uneven terrain in the wetland
  - Cut and measure small buckthorn shrubs
  - Apply novel non-herbicide alternative treatment of buckthorn baggies
  - Move & position brush piles

Click on this form **or follow the QR code** for more information and to **sign up.**
Space is limited and available on a first-come-first-serve basis.

F. Proposal for 2024 St. Pierre Wetland Master's Project

Note: This is a first draft of the 2024-2025 project proposal. It is meant simply as a spring-board for future efforts.

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UM-SEAS MASTER'S PROJECT PROPOSAL SUBMISSION FORM

UM-SEAS Master's Projects are applied research projects for client organizations addressing a sustainability research need or related problem, over a one-and-a-half-year timeframe, with teams of approximately five graduate students spanning multiple disciplines of study within the SEAS master's degree program. Teams receive back-end support through a UM/SEAS faculty advisor while working directly with client organizations. Projects for this cycle of students will be reviewed in fall of 2023. Those advancing will begin in January 2024 and will be **completed by April 2025**

For full consideration, email this completed form (all responses below) to: seas-projects@umich.edu by the date posted in email communications and online at:
https://seas.umich.edu/research-impact/student-research/masters-projects

Part 1 – Title of Proposal and Client Basic Information

(*Please answer each bullet*)

- Proposed Master's Project Working Title / Topic: **Collaborative Experimental Restoration of St. Pierre Wetland**

- **Client Organization Name:** Matthaei Botanical Gardens and Nichols Arboretum
- Client Website:

- **Secondary Client Organization**: Shan-Gri-La Homeowners Association
- Secondary Client Website:
https://www.facebook.com/Shan-Gri-La-Homeowners-Association-177480195940802/

- **Additional Client/Partner:** The Stewardship Network
- Website: https://www.stewardshipnetwork.org/

Project Contacts Information:

- Name: Mike Kost (Or other staff member)
- Title: Associate Curator, Matthaei Botanical Gardens; Lecturer at UM SEAS
- City: Annn Arbor
- State or Country: MI
- Phone: (734) 647-7704
- Email: michkost@umich.edu

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- Name: Stephen C. Brown
- Title: President, Shan-Gri-La Homeowners Association
- City: Lakeland
- State or Country: MI
- Phone: (734)-604-4582
- Email: brownsc6887@att.net

- Name: Rachel Muellle
- Title: Project manager, The Stewardship Network
- City:
- State or Country: MN
- Phone:
- Email: rmuelle@stewardshipnetwork.org

Check all that apply:
___ I am a SEAS student
___ I am a SEAS/SNRE alum
___ I am a U-M faculty member, School/Department:
___ I am a staff member of a potential client organization
___ Our Organization has been a Master's Project client in a previous year
___ Other (please specify):

- **Primary Project Location(s)** : Ann Arbor, MI

Part 2 – Proposal Advisor Status

(*Please answer each bullet*)

- Have you identified a potential SEAS Faculty Advisor(s)? If so, list Faculty member(s):

Sheila Schueller - schuel@umich.edu - Conservation & Restoration Theme Course

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Part 3 – Summary of Project Proposal

(*Please answer each bullet*)

Include a brief overview and a detailed response to each of the topics outlined below. Please be as specific as possible.

- Goals & Objectives: What will this project accomplish?

St. Pierre is a 130-acre wetland property managed by the School for Environment and Sustainability on the northern undeveloped shoreline of Bass Lake within Livingston County in Hamburg Township, 14 miles northwest of Ann Arbor. This site was donated in 1975 by Sam and Angeline St. Pierre to be used for teaching and research in fisheries, wetland ecology, stream biology, and other aquatic ecology topics. There are two communities neighboring the site: the Shan-Gri-La Homeowners Association on the east side with a canal between the site and the neighborhood, and Bass Ridge Homeowners Association on the northwest side. Part of the northern part of the property borders a popular biking and walking trail, the Lakelands Trail, which offers open views of St. Pierre Wetland. The landscape surrounding Bass Lake has additional wetlands and waterways, and includes the Huron River Chain of Lakes, a series of nine connected lakes along the main branch of the Huron River.

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In 2017 the Huron River Watershed Council completed an on-site field assessment of the property because it ranked high in ecological value based on watershed-level GIS data. The field assessment found that the parcel includes a pristine prairie fen of very high ecological quality, and that overall the wetland scored in the top ten of all wetlands in the watershed. Invasive species are pervasive, however, with cattails, purple loosestrife, and glossy buckthorn encroaching on the north and northwest sides, close to the neighboring developments.

This site faces three major problems:
1) The threat of invasive species makes the need for site stewardship urgent, or it is likely to degrade to a point that is more difficult to restore,
2) It is currently underutilized by SEAS classes and researchers, failing to meet its teaching and research mission, and
3) Neighboring community members and local nonprofit organizations are invested in the site's ecological health. In addition, neighbors play a key role in allowing students/faculty to access the site, and in preserving the ecological health of the site. The 2023 master's project initiated relationships with several stakeholders that should be continued and built upon, to the benefit of all involved.

- **Theoretical Justification, Social Benefit, or Significance:** Why is this research important? What is the real-world impact of the proposed research?

- **Specific Activities & Duration:** What research methodologies are appropriate to tackle the proposed research question? Is the scale of proposed research reasonable for a (part-time) year and a half project for ~5 students?

To address the threat from invasive species:
- Continue the established glossy buckthorn removal experiment and data collection from the previous (2023) master's project.
    a. Assess the efficacy of baggies and other treatments, and recalibrate the experiment as needed.
- Explore options for removal of glossy buckthorn on larger scale, either through student workdays, community involvement from 'power volunteers,'or conservation practitioners
- Possibility to inventory presence of other species, both native and non-native (phragmites, red-osier dogwood, cattail)
- Create a restoration plan or broader management plan for the St. Pierre Wetland

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To increase usage by SEAS students and Faculty
- Involve students in the restoration efforts detailed above
- Continue to increase awareness among faculty

Engage surrounding community members
- Build upon established relationships and structures
    - Continue to establish several trusted community members as "power volunteers" with access to the site
    - Continue to refine site access procedures and establish a written informal agreement
- Use the resources and expertise of the Matthaei Botanical Gardens to involve community members in restoration efforts in a way that is acceptable to all parties involved.

- Integrative Approach: How does the proposed research integrate the skills of disparate team members to generate an effective final product/output?

- Key Words/Themes (Please add here any broad and specific topic descriptors):

Please check each specific SEAS program areas where expertise is needed. To meet SEAS standards for an interdisciplinary project, your proposal must include substantive work from multiple fields of study. For specific details about these disciplines, please review info web-links of each below:

✓ Behavior, Education, and Communication
✓ Ecosystem Science Management – Conservation Ecology
___ Environmental Justice
✓ Environmental Policy and Planning
✓ Geospatial Data Sciences
___ Landscape Architecture
___ Sustainability & Development
___ Sustainable Systems

- **Role** (Please briefly describe the role for each area of expertise selected above. Include 2-3 sentences for each discipline you selected. Include all key skills/expertise necessary for a master's project team to successfully complete this project):

Identify Expected Products
(*Please answer each bullet*)

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Include a detailed description of the final output of the project team and its value to the client organization.

- Deliverables: What documents/products/reports will the team deliver upon completion of this project?

- Implementation: How will project outputs be used by your organization? Will the project team's recommendations be shared with a broader network/audience?

Part 4 – Student Benefits, Privacy and Additional Values Impact

(*Please answer each section below*)

Professional Career Development Benefits (Identify skills, knowledge, and contacts that students can expect to develop by working on this project, as well as any other potential career-related benefits—such as opportunities to present findings at a professional conference or meeting, professional networking opportunities with client and partner organizations, individual/group publications, job openings or organizational growth outlook, etc.):

Funding Sources (Note if funding is potential or confirmed as well as the amount, if known. While not a requirement, bringing project funding boosts a proposal's likelihood to advance. Funding can also take the form of paid internships for one more student team members):

Privacy Considerations (Optional: if you have specific privacy concerns related to your proposed research topic, please indicate below)

___ My organization has its own IRB and/or rules about doing internal research.

___ We will require a non-disclosure agreement (NDA) for some portion of work related to this project. [Note that data or back-end information can be included but that a final report will be publically available via University of Michigan online publication medium.]

Values (CSR) and Diversity, Equity & Inclusion (DEI) Statements

Please provide here any Corporate Social Responsibility (or similar) Statement from your organization, or provide as a link or attachment:

Please provide here any Diversity, Equity & Inclusion (or similar) Statement from your organization, or provide as a link or attachment:

How does your project proposal align with or advance your above (if provided) CSR or DEI statements or initiatives?

Possible Funding Sources

1. Society of Wetland Scientists: Wetland Restoration Student Research Grant
2. Institute for Social Research: Next Generation Initiative | Institute for Social Research
3. National Fish and Wildlife Foundation: Conservation Grants
4. Department of Ecology: Water & Shorelines Grants
5. Environmental Protection Agency: Federal Funding for Wetlands
6. Fish and Wildlife Service: F23AS00163 - Aquatic Invasive Species Grants to Great Lakes States - Fiscal Year 2023 Great Lakes Restoration Initiative

Consider the Wetland Mitigation Banking Program through the Natural Resources Conservation Service U.S. Department of Agriculture

Potential UM-Affiliated Groups to Partner with

1. Ecological Restoration Student Group at MBGNA: led by Mike Kost
2. SEAStheWetlands: The Society of Wetland Scientists North Central Chapter Student Chapter at the University of Michigan

H. Species Classification Accuracy Assessment - Confusion Matrix

ClassValue	Cattail/Phrag	Buckthorn	Grasses/Sedge	Row Total	Useres Accuracy	Kappa
Cattail/Phrag	51	32	22	105	49%	
Buckthorn	87	224	59	370	61%	
Grasses/Sedge	18	0	8	26	31%	
Column Total	156	256	89	501		
Producers Accuracy	33%	88%	9%		56%	
Kappa						21%

SEMCOG Data Analysis – STPW Masters Project ’23

Acolvill

2023

R Markdown

Preparing for multivariate analysis

```
# Load necessary packages
setwd('C:\\Users\\alice\\OneDrive\\Desktop\\capstone')
head(library(wesanderson))
```

```
## [1] "wesanderson" "stats"       "graphics"    "grDevices"   "utils"
## [6] "datasets"
```

```
head(library(ggplot2))
```

```
## [1] "ggplot2"     "wesanderson" "stats"       "graphics"    "grDevices"
## [6] "utils"
```

```
head(library(FactoMineR))
```

```
## [1] "FactoMineR"  "ggplot2"     "wesanderson" "stats"       "graphics"
## [6] "grDevices"
```

```
head(library(factoextra))
```

```
## Welcome! Want to learn more? See two factoextra-related books at https://goo.gl/ve3WBa
```

```
## [1] "factoextra"  "FactoMineR"  "ggplot2"     "wesanderson" "stats"
## [6] "graphics"
```

```
head(library(MVA))
```

```
## Loading required package: HSAUR2
```

```
## Loading required package: tools
```

```
## [1] "MVA"        "HSAUR2"     "tools"      "factoextra" "FactoMineR"
## [6] "ggplot2"
```

```
head(library(pvclust))
```

```
## [1] "pvclust"    "MVA"        "HSAUR2"     "tools"      "factoextra"
## [6] "FactoMineR"
```

```
head(library(dendextend))
```

```
## Registered S3 method overwritten by 'dendextend':
##   method       from
##   text.pvclust pvclust
```

```
##
## ---------------------
## Welcome to dendextend version 1.17.1
## Type citation('dendextend') for how to cite the package.
##
## Type browseVignettes(package = 'dendextend') for the package vignette.
## The github page is: https://github.com/talgalili/dendextend/
##
## Suggestions and bug-reports can be submitted at: https://github.com/talgalili/dendextend/issu
es
## You may ask questions at stackoverflow, use the r and dendextend tags:
##   https://stackoverflow.com/questions/tagged/dendextend
##
##  To suppress this message use:  suppressPackageStartupMessages(library(dendextend))
## ---------------------
```

```
##
## Attaching package: 'dendextend'
```

```
## The following object is masked from 'package:stats':
##
##     cutree
```

```
## [1] "dendextend" "pvclust"    "MVA"        "HSAUR2"     "tools"
## [6] "factoextra"
```

```
head(library(vegan))
```

```
## Loading required package: permute
```

```
##
## Attaching package: 'permute'
```

```
## The following object is masked from 'package:dendextend':
##
##     shuffle
```

```
## Loading required package: lattice
```

```
## Registered S3 method overwritten by 'vegan':
##   method     from
##   rev.hclust dendextend
```

```
## This is vegan 2.6-4
```

```
## [1] "vegan"      "lattice"    "permute"    "dendextend" "pvclust"
## [6] "MVA"
```

```
head(library(cowplot))
```

```
## [1] "cowplot"    "vegan"      "lattice"    "permute"    "dendextend"
## [6] "pvclust"
```

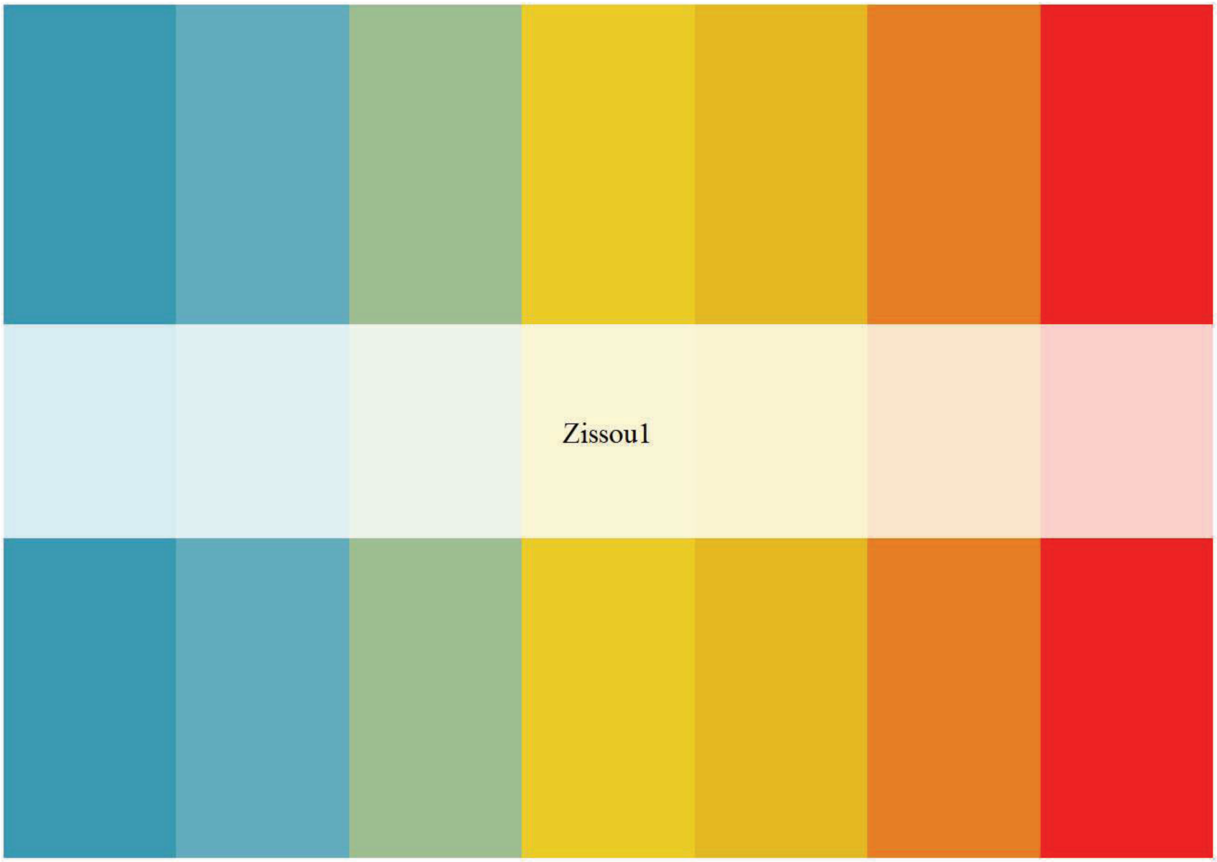
```
head(library(cluster))
```

```
## [1] "cluster"    "cowplot"    "vegan"      "lattice"    "permute"
## [6] "dendextend"
```

```
#set working directory
setwd('C:\\Users\\alice\\OneDrive\\Desktop\\capstone')

### Load in data
data = read.csv("SEMCOG_DATA.csv")

dat.m <- data.frame(data, header = TRUE)
```

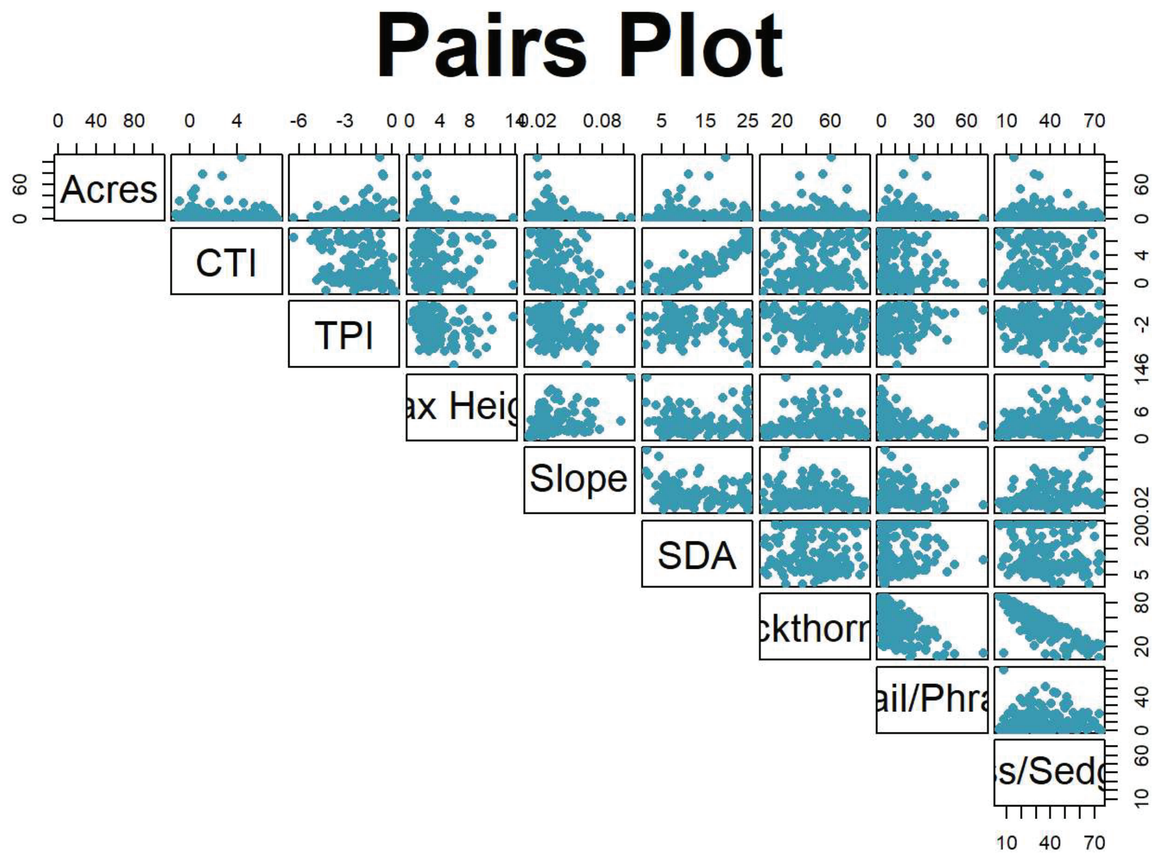
```
# Created color palette
# Choosing color for points
pal <- wes_palette("GrandBudapest2", 7, type = c("continuous"))
pal
```


```
pal2 <- wes_palette("Zissou1", 7, type = c("continuous"))
pal2
```

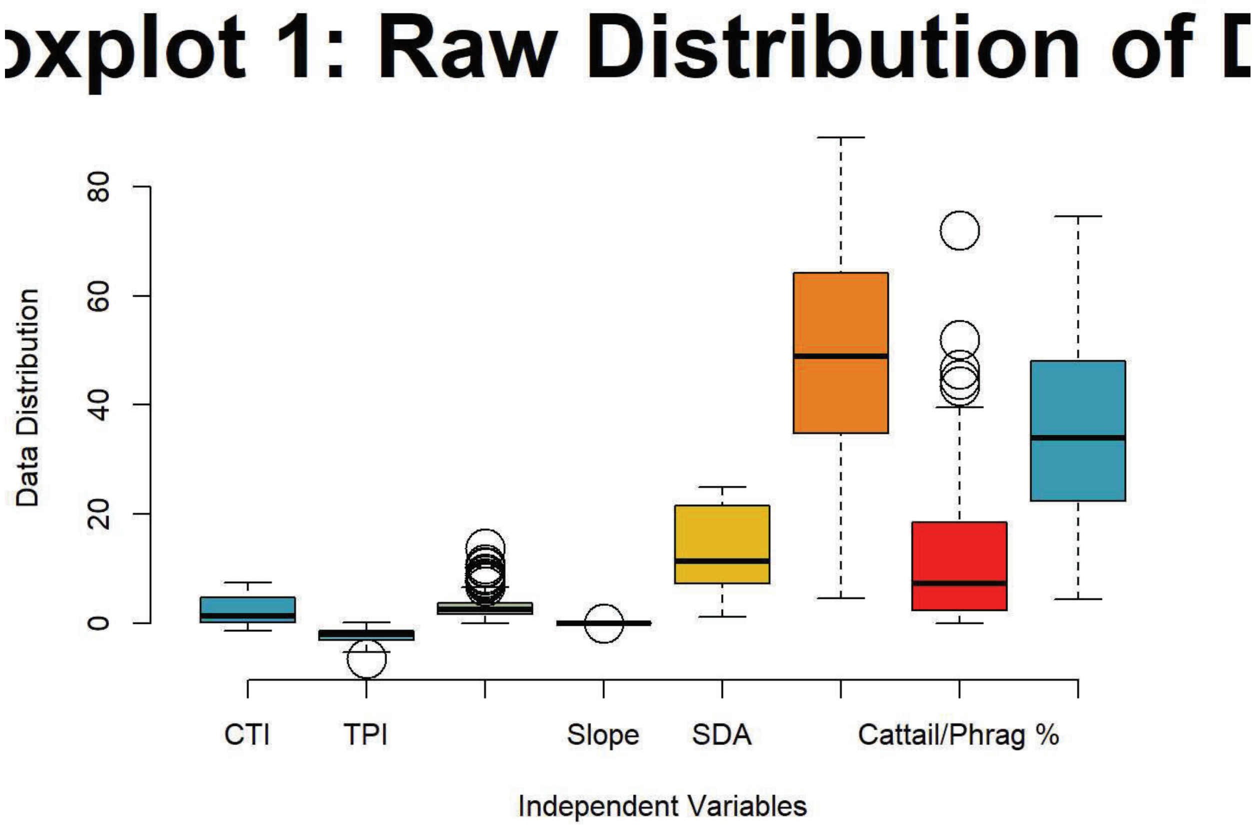



```
# pal2[1]
```

```
### Pairs Plot to visualize collinearity
pairs(dat.m[2:10], col ="#3B9AB2", pch = 16, lower.panel = NULL, gap = 0.3, labels = c("Acres",
"CTI", "TPI", "Max Height", "Slope", "SDA", "Buckthorn %", "Cattail/Phrag %", "Grass/Sedge %"),
cex.labels = 2, main = "Pairs Plot", sub = "Visualizing the pair-wise relationships amoung all v
ariables", cex.main = 3, cex.sub = 2)
```

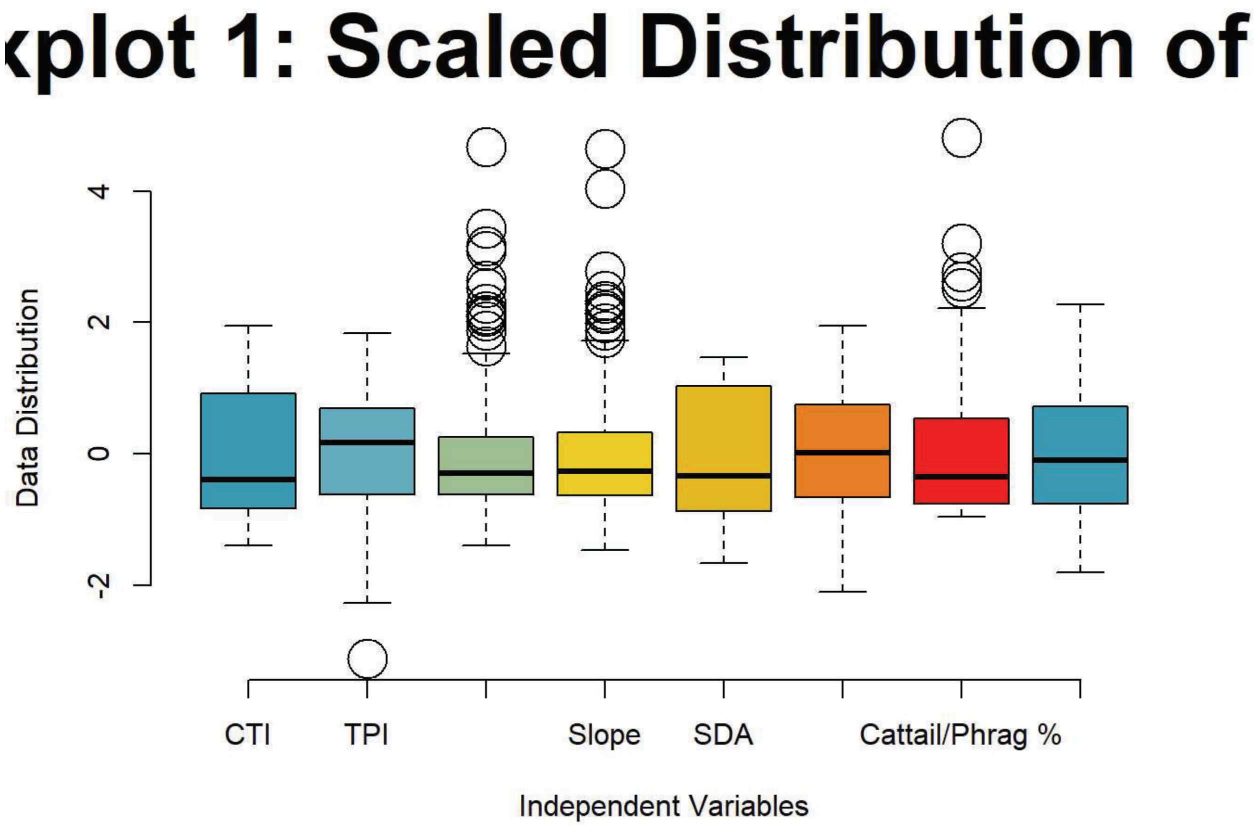



```
#Subsetting data to remove Object ID and Acres
#Scaling Data -- will be compared to raw data
scale_dat <- (scale(dat.m[,3:10]))

# Creating boxplots for comparison
# Raw data distribution
boxplot(dat.m[,3:10], repel = TRUE,
        main = "Boxplot 1: Raw Distribution of Data",
        cex = 3,
        col = pal2,
        xlab = "Independent Variables",
        ylab = "Data Distribution",
        frame = FALSE,
        names = c("CTI", "TPI", "Max Height", "Slope", "SDA", "Buckthorn %", "Cattail/Phrag %",
"Grass/Sedge %"), cex.main = 3)
```




```
par(cex.lab=3) # is for y-axis

par(cex.axis=3) # is for x-axis
```

```
# Creating boxplots for comparison
# Scaled data distribution
boxplot(scale_dat, repel = TRUE,
        main = "Boxplot 1: Scaled Distribution of Data",
        cex = 3,
        col = pal2,
        xlab = "Independent Variables",
        ylab = "Data Distribution",
        frame = FALSE,
        names = c("CTI", "TPI", "Max Height", "Slope", "SDA", "Buckthorn %", "Cattail/Phrag %",
"Grass/Sedge %"), cex.main = 3)
```




```
par(cex.lab=3) # is for y-axis

par(cex.axis=3) # is for x-axis
```

Principal Component Analysis

```
# PCA on scaled data
pc_s.dat <- princomp(scale_dat, cor = T, scores = T)

# Summary
summary(pc_s.dat)
```

```
## Importance of components:
##                           Comp.1    Comp.2    Comp.3    Comp.4    Comp.5
## Standard deviation     1.5559132 1.3652078 1.2955415 0.9341051 0.7775953
## Proportion of Variance 0.3026082 0.2329741 0.2098035 0.1090690 0.0755818
## Cumulative Proportion  0.3026082 0.5355823 0.7453858 0.8544548 0.9300366
##                            Comp.6      Comp.7       Comp.8
## Standard deviation     0.70078730 0.249678403 0.0791513924
## Proportion of Variance 0.06138786 0.007792413 0.0007831179
## Cumulative Proportion  0.99142447 0.999216882 1.0000000000
```

```
# Results
# Extract variable results
pca_var <- get_pca_var(pc_s.dat)
pca_var
```

```
## Principal Component Analysis Results for variables
##  ===================================================
##   Name       Description
## 1 "$coord"   "Coordinates for the variables"
## 2 "$cor"     "Correlations between variables and dimensions"
## 3 "$cos2"    "Cos2 for the variables"
## 4 "$contrib" "contributions of the variables"
```

```
# Looking at contribution of variables to principal components
head(pca_var$contrib)
```

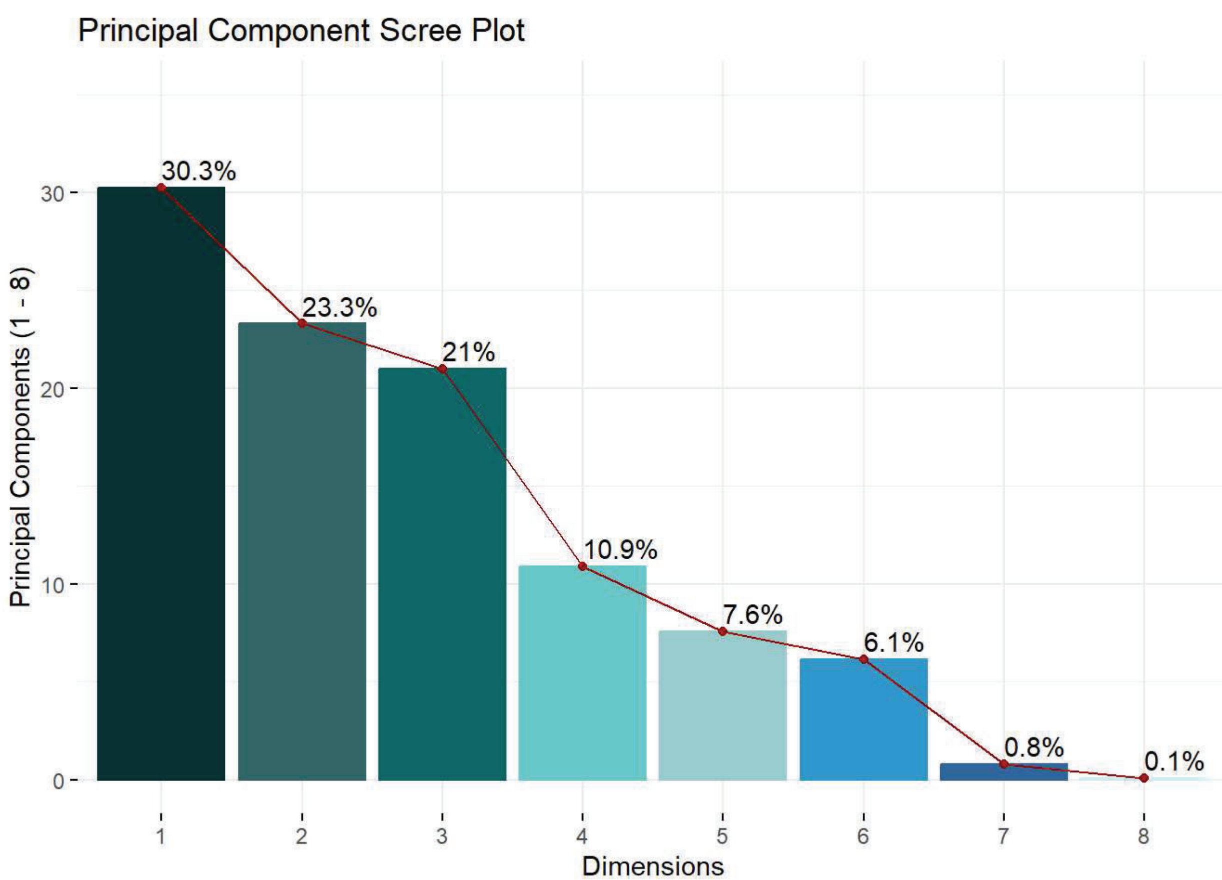
```
##                Dim.1      Dim.2        Dim.3      Dim.4        Dim.5     Dim.6
## CTI       24.5790391  1.9374793 18.928913920  0.3843143  0.755516181  2.319573
## TPI        5.8393661 20.1655714  0.007641019 21.9226044 32.225148044 19.628754
## MaxHeight  0.8627446 26.8933665  5.378271639  2.1229105 45.623418565 18.972284
## Slope      4.2145443 23.6151590  1.431979437 21.9548457  2.370359738 46.405440
## SDA       21.3572574  0.6033211 24.685571797  0.2903572  1.522896301  3.155686
## Buckthorn 21.9223321  3.5903636 22.998626139  0.2912189  0.004228543  2.181983
##                  Dim.7        Dim.8
## CTI       51.077667128  0.017497051
## TPI        0.207921451  0.002993429
## MaxHeight  0.066019750  0.080984436
## Slope      0.000615586  0.007056354
## SDA       48.372427874  0.012482403
## Buckthorn  0.008098397 49.003149589
```

```
# Looking at which individuals (wetland sites) are explained by pcs
pca_ind <- get_pca_ind(pc_s.dat)
head(pca_ind$coord)
```

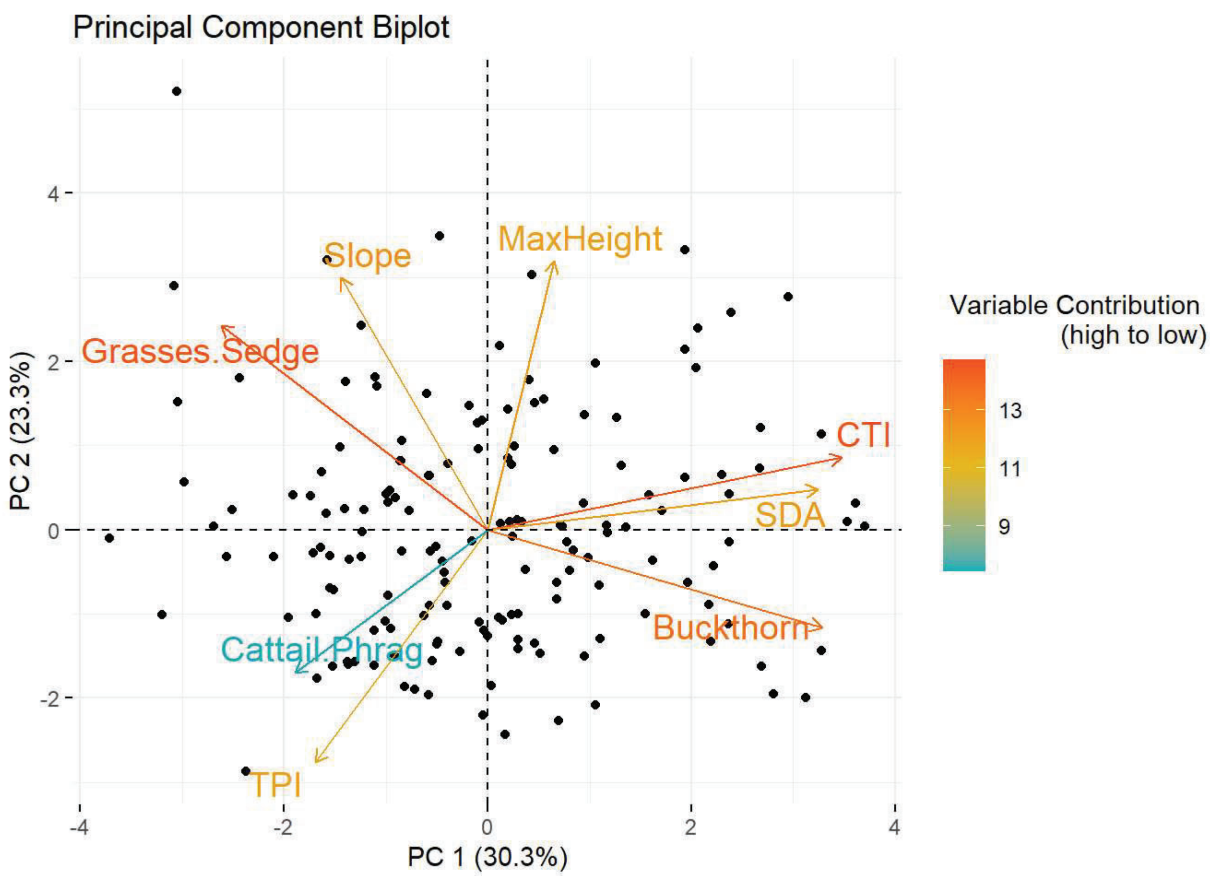
```
##          Dim.1      Dim.2      Dim.3        Dim.4       Dim.5       Dim.6
## 1  2.21983580 -0.4263985  0.7344335  0.267603616  0.34565193  1.21672561
## 2  0.98354349 -0.3274269 -1.2260606  0.045472609 -0.43699728 -0.20115665
## 3 -0.42744983 -0.5073645 -1.5484808 -0.001172821 -0.21154090  0.33140480
## 4 -0.57925091  0.6425131 -1.7354877  0.614658014  0.53220096 -0.08865966
## 5  0.64810628  0.9443088 -0.2015194  0.125848032  0.05045957  0.37024888
## 6 -0.09308581  0.9574743  0.5910527 -0.186026637  0.65378193 -0.06547602
##        Dim.7        Dim.8
## 1 0.2780485 -0.054359801
## 2 0.0786380 -0.045520357
## 3 0.2055647 -0.019476455
## 4 0.1350810  0.074119947
## 5 0.2329509  0.001615285
## 6 0.1027088 -0.048235931
```

Creating visuals for PCA analysis

```
# Scree plot to visualize PC's
fviz_eig(pc_s.dat, addlabels = TRUE, ylim = c(0, 35), geom = c("bar", "line"), barcolor = c("#00
3333","#336666","#006666","#66cccc","#99cccc", "#3399cc", "#336699" , "#ccffff"), barfill = c("#
003333","#336666","#006666","#66cccc","#99cccc", "#3399cc", "#336699" , "#ccffff"), linecolor =
"#990000", ncp = 20, cex = 2, main = "Principal Component Scree Plot", cex.main = 3, ylab = "Pri
ncipal Components (1 - 8)")
```



```
# PCA Biplot
fviz_pca_biplot(pc_s.dat, repel = TRUE, geom = "point", geom.var = c("arrow", "text"),
                col.ind = "black",
                col.var="contrib",
                gradient.cols = c("#00AFBB", "#E7B800", "#FC4E07"),
                title = "Principal Component Biplot",
                cex.main = 3,
                legend.title = " Variable Contribution
                (high to low)",
                xlab = "PC 1 (30.3%)",
                ylab = "PC 2 (23.3%)",
                labelsize = 5)
```



Cluster Analysis

```
# Hierarchical Clustering -- Complete Method and euclidean distance
# Using PVCLUST() to group individuals by significance (topographic characteristics)

pvcl_s.dat <- pvclust(t(scale_dat[,1:8]),
                      method.hclust = "complete",
                      method.dist = "euclidean",
                      use.cor="pairwise.complete.obs",
                       r=seq(.5,1.4,by=.1))
```

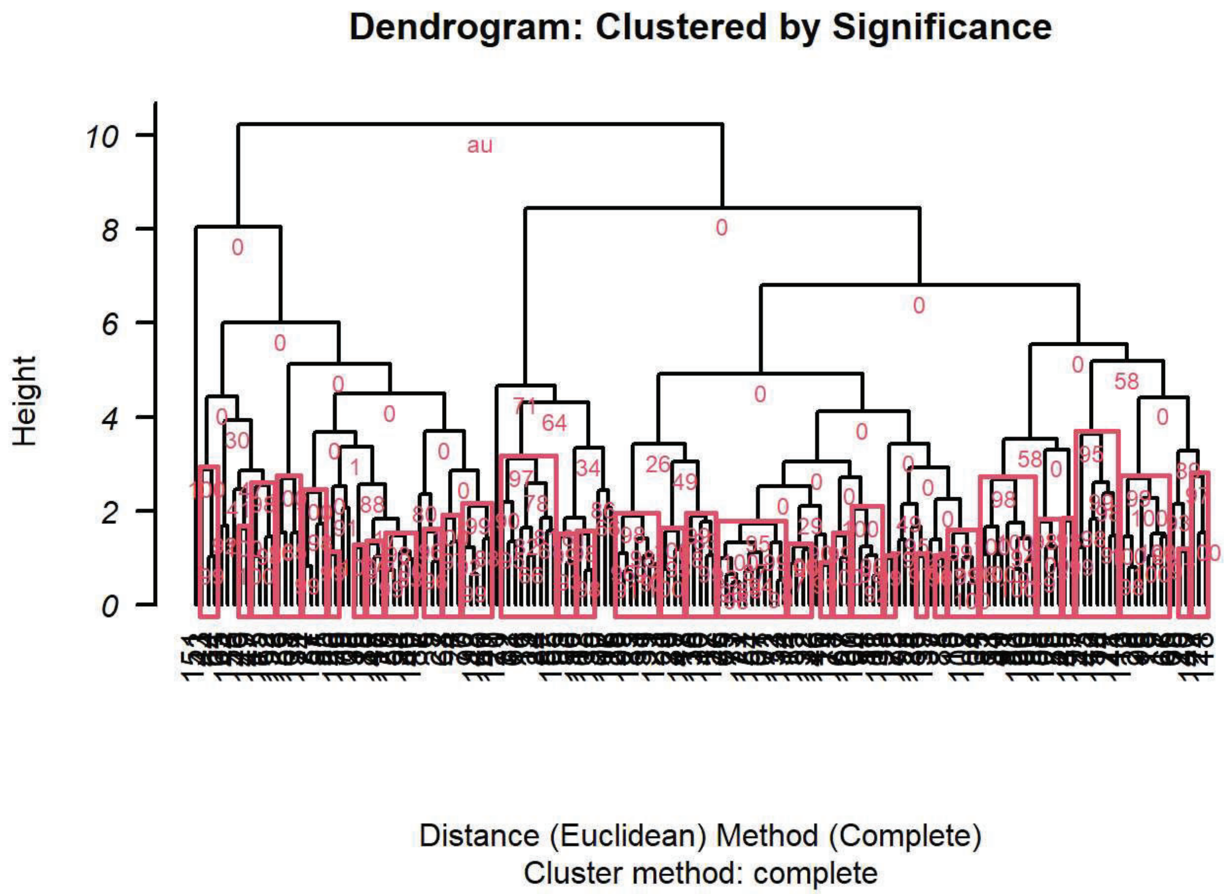
```
## Bootstrap (r = 0.5)... Done.
## Bootstrap (r = 0.62)... Done.
## Bootstrap (r = 0.75)... Done.
## Bootstrap (r = 0.88)... Done.
## Bootstrap (r = 1.0)... Done.
## Bootstrap (r = 1.12)... Done.
## Bootstrap (r = 1.25)... Done.
## Bootstrap (r = 1.38)... Done.
```

```
# PVCLUST summary
summary(pvcl_s.dat)
```

```
##         Length Class           Mode
## hclust    7    hclust          list
## edges     9    data.frame      list
## count     8    data.frame      list
## msfit   158    mslist          list
## nboot     8    -none-          numeric
## r         8    -none-          numeric
## store     8    -none-          list
## version   1    package_version list
```

Creating visuals for Cluster analysis

```
# Storing the results as a dendrogram for future use

# Plotting the cluster dendrogram
plot(pvcl_s.dat, cex = 1, lwd = 2, hang = -4, float = 0.01, cex.pv = 0.75, print.pv = c("au"), p
rint.num = FALSE,
     main = "Dendrogram: Clustered by Significance", xlab = "Distance (Euclidean) Method (Comple
te)", font.axis = 3, las = 1)

ask.pvcl <- par()$ask
par(ask = TRUE)

# Imposing boxes of clusters that have significant relationships (alpha grater than 0.95)
pvrect2(pvcl_s.dat, pv = "au",
       type = "geq",
       alpha = 0.95,
       lower_rect = .5, max.only = TRUE, lwd = 2.5, lty = 1)
```

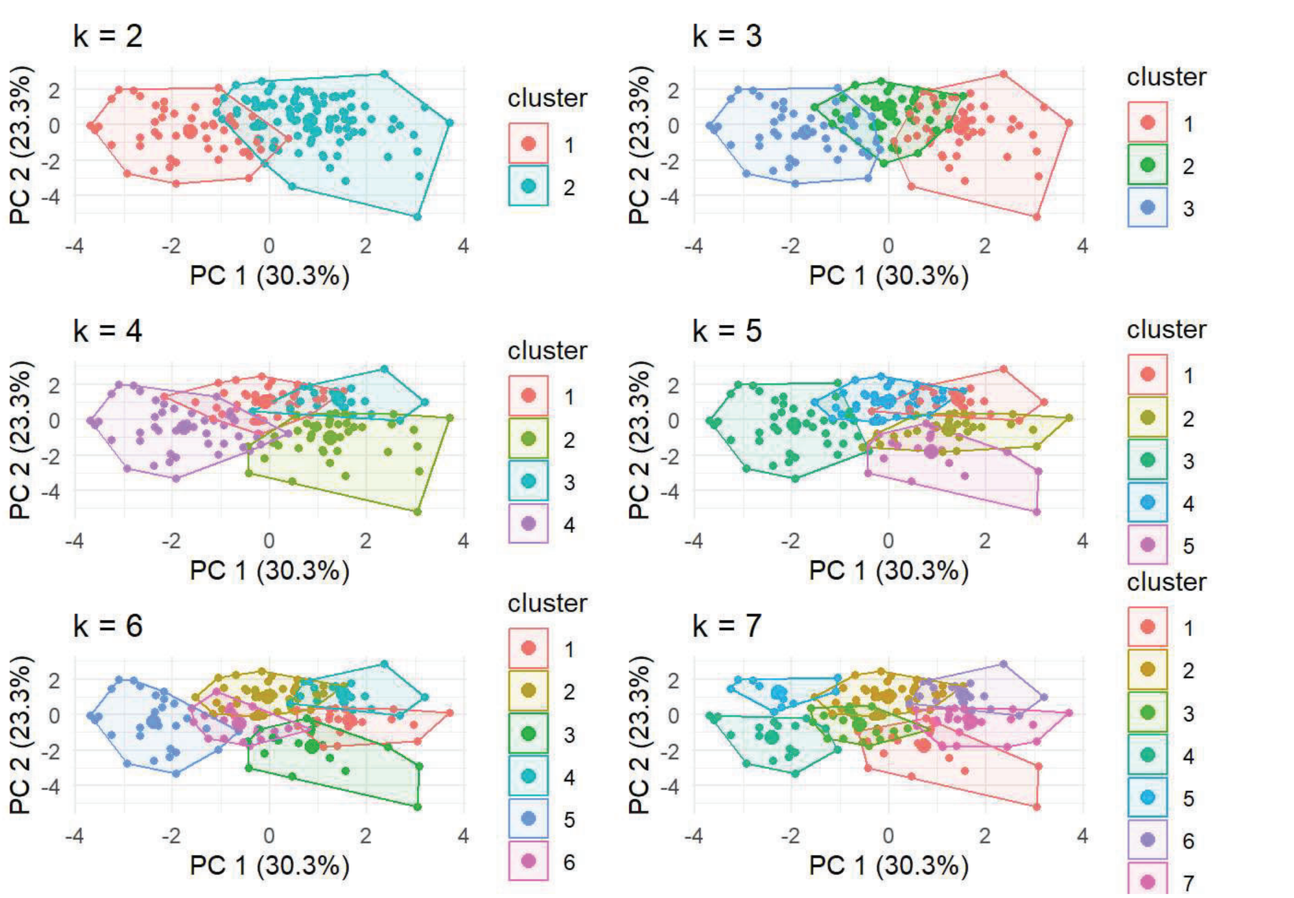

Dendrogram: Clustered by Significance
Height
0
2
4
6
8
10
au
Distance (Euclidean) Method (Complete)
Cluster method: complete

Determining optimal number of clusters

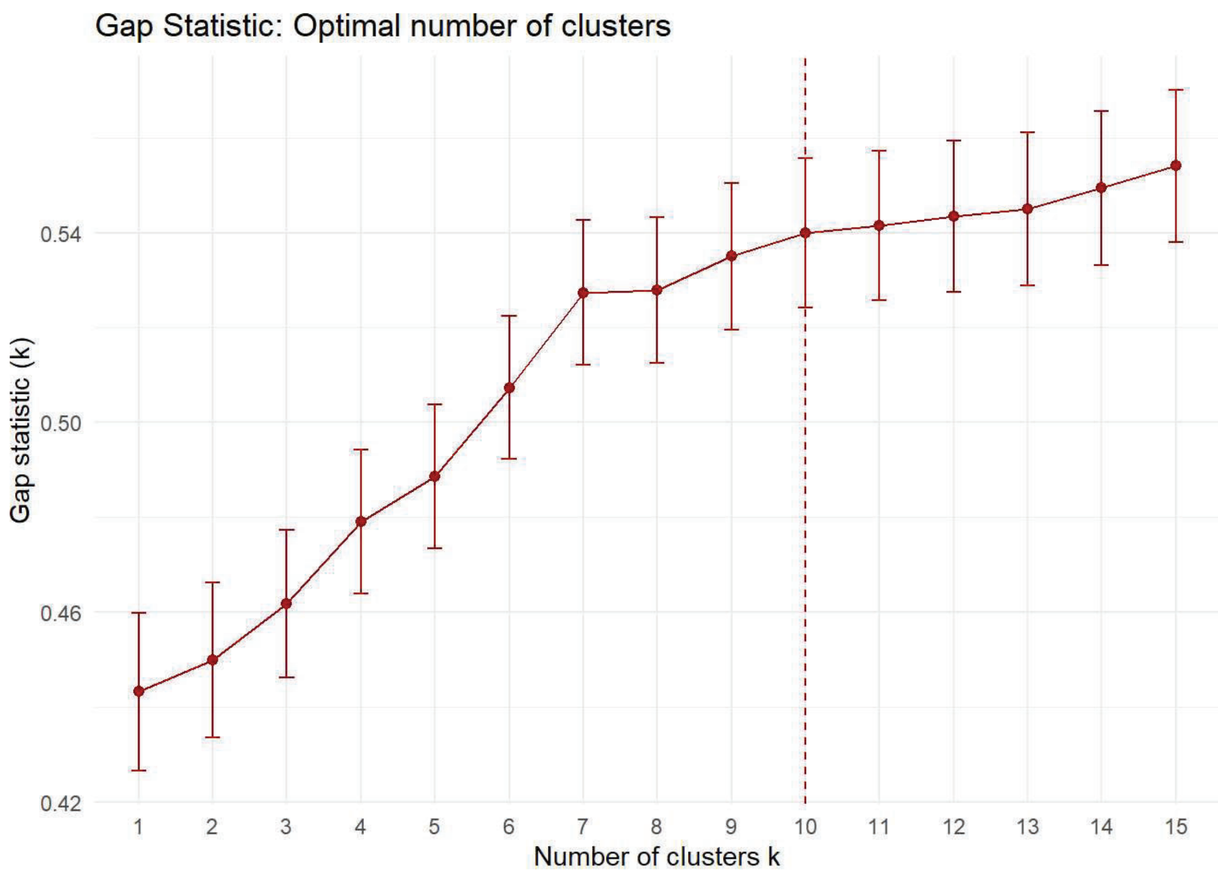
```
# Calculating k-means to determine optimal number of clusters --
# Visualize the distribution of sites within each cluster

km2 <- kmeans(scale_dat, centers = 2, nstart = 30)
km3 <- kmeans(scale_dat, centers = 3, nstart = 30)
km4 <- kmeans(scale_dat, centers = 4, nstart = 30)
km5 <- kmeans(scale_dat, centers = 5, nstart = 30)
km6 <- kmeans(scale_dat, centers = 6, nstart = 30)
km7 <- kmeans(scale_dat, centers = 7, nstart = 30)
km8 <- kmeans(scale_dat, centers = 8, nstart = 30)
km9 <- kmeans(scale_dat, centers = 9, nstart = 30)

p1 <- fviz_cluster(km2, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 2")
p2 <- fviz_cluster(km3, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 3")
p3 <- fviz_cluster(km4, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 4")
p4 <- fviz_cluster(km5, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 5")
p5 <- fviz_cluster(km6, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 6")
p6 <- fviz_cluster(km7, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
```

```
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 7")
p7 <- fviz_cluster(km8, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 8")
p8 <- fviz_cluster(km9, data = scale_dat, ellipse.type = "convex",
                   geom = c("point"), reprel = TRUE,
                   show.clust.cent = TRUE, ellipse.level = 0.95,
                   ellipse.alpha = .1, pointsize = 2, shape = 20, main = "PC K-Means Cluster Plo
t", outlier.color = "black",
                   xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)") + theme_minimal() + ggtitle("k
= 9")
```

```
# Plot the kmeans clustering within a grid (vertical format option for report)
plot_grid(p1, p2,
          p3, p4,
          p5, p6, nrow = 3, ncol = 2)
```

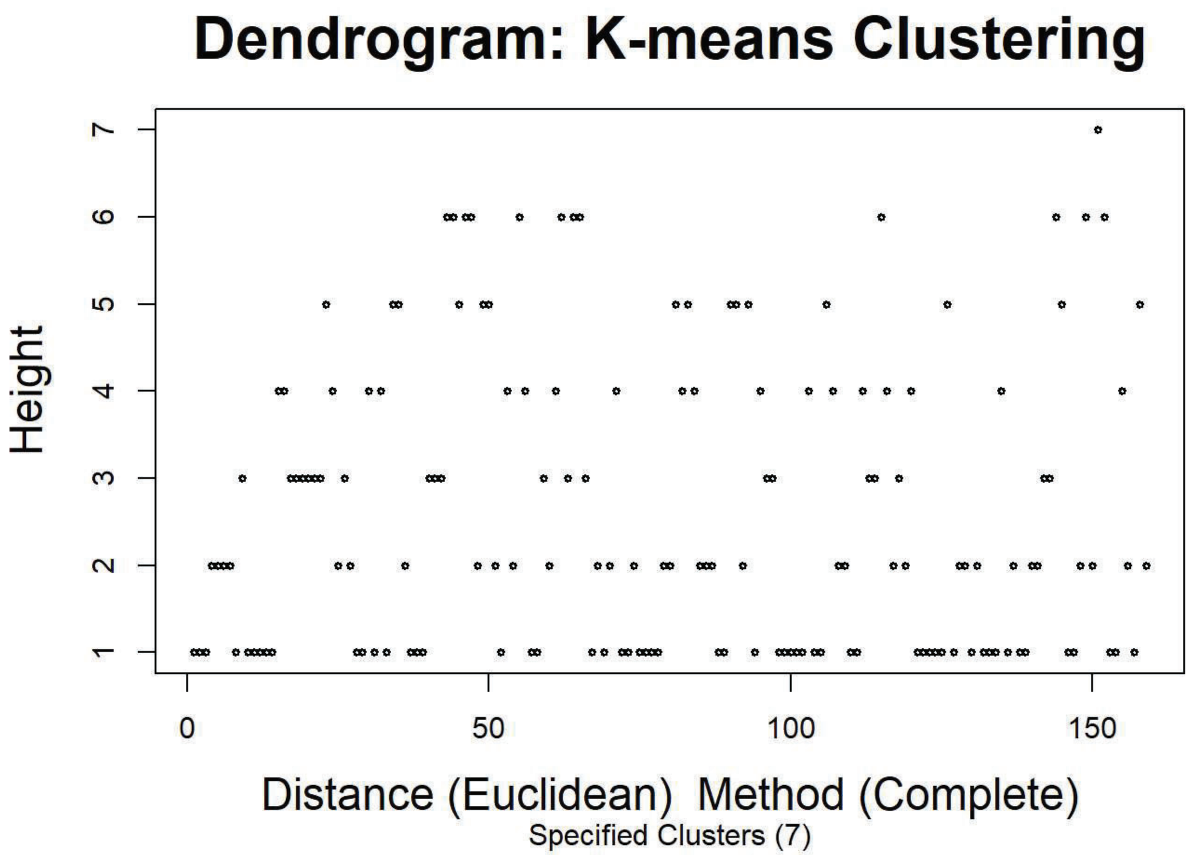


```
# Using gap statistic to determine the optimal number of clusters needed to explain the signific
ant variance in data
gap_stat <- clusGap(scale_dat, FUN = kmeans, nstart = 30, K.max = 15, B = 500)
fviz_gap_stat(gap_stat, linecolor = "#990000") + theme_minimal() + ggtitle("Gap Statistic: Optim
al number of clusters")
```

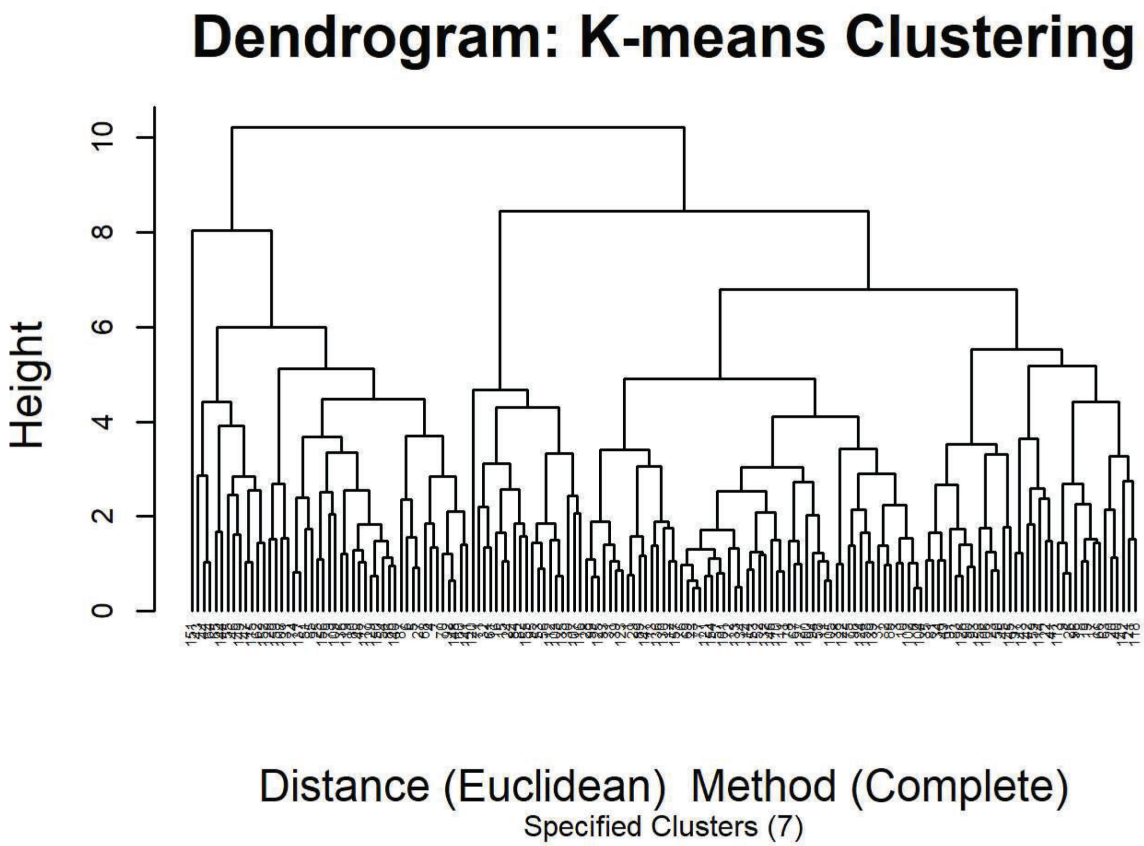



```
# Compute dissimilarity matrix with euclidean distances
d <- dist(scale_dat, method = "euclidean")


# Hierarchical clustering using Ward's method
res.hc <- hclust(d, method = "complete", members = NULL)
hcdend <- as.dendrogram(res.hc, labels = FALSE)

# Cut tree into 7 groups
grp <- cutree(hcdend, dend_heights_per_k = 7, k = 7,
  use_labels_not_values = TRUE,
  order_clusters_as_data = TRUE,
  warn = dendextend_options("warn"),
  try_cutree_hclust = TRUE)
```

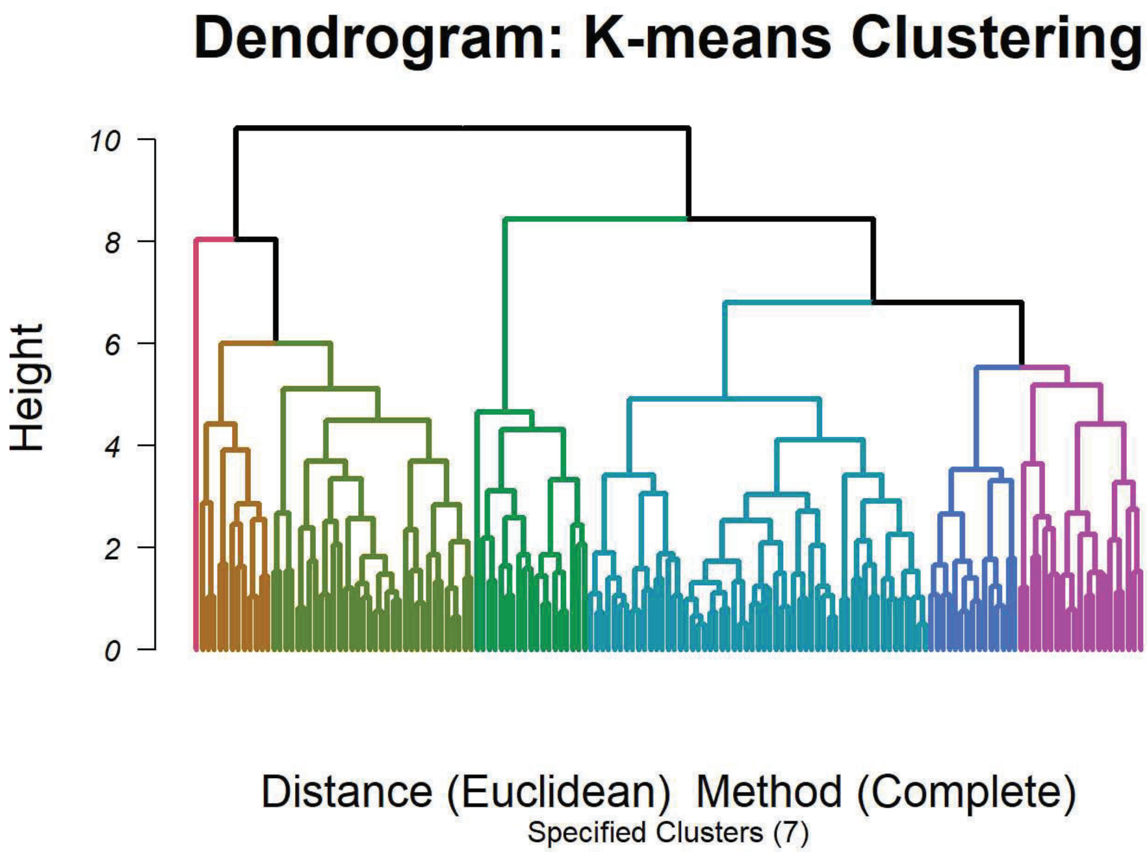
```
# Plotting the cutree hclust/dendrogram
plot(grp, cex = 0.5, lwd = 1.5,
     main = "Dendrogram: K-means Clustering", xlab = "Distance (Euclidean)  Method (Complete)",
sub = "Specified Clusters (7)",
     cex.main = 2, cex.lab = 1.5, ylab = "Height")
```



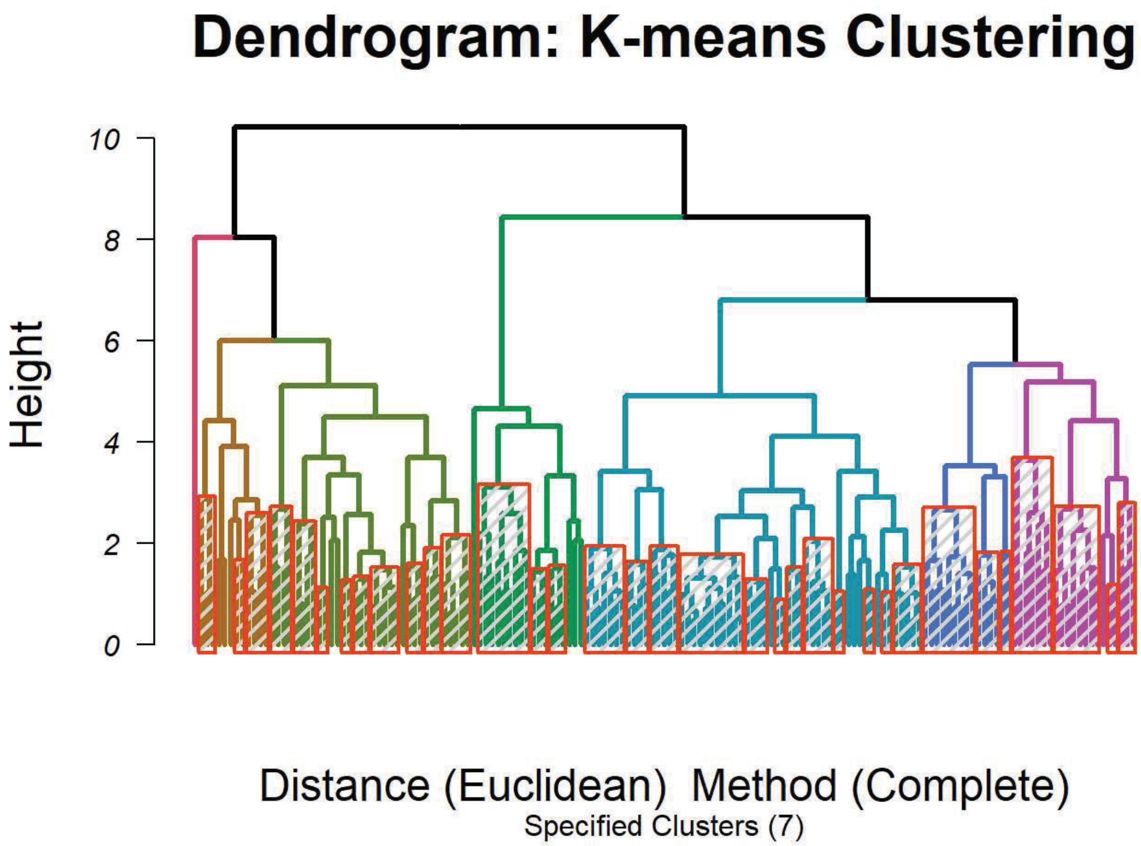

```
# Visualize
# plot tree -- original with site values on x-axis
plot(res.hc, cex = 0.5, lwd = 1.5, hang = -2,
     main = "Dendrogram: K-means Clustering", xlab = "Distance (Euclidean)  Method (Complete)",
sub = "Specified Clusters (7)",
     cex.main = 2, cex.lab = 1.5, ylab = "Height")
```




```
# Clustered by colore
colored_dendro <- (color_branches(hcdend, k= 7))

# Plotting dendrogram by optimal clusters using variation in color
# with desired labels/formatting
plot(colored_dendro%>%
  set("branches_lwd", 3), leaflab = c("none"), main = "Dendrogram: K-means Clustering", xlab =
"Distance (Euclidean)  Method (Complete)",  sub = "Specified Clusters (7)", cex.main = 2, cex.la
b = 1.5, ylab = "Height", font.axis = 3, las = 1)
```




```
# Plotting dendrogram with significant relationships, colored by optimal number of clusters
plot(colored_dendro%>%
  set("branches_lwd", 3), leaflab = c("none"), main = "Dendrogram: K-means Clustering", xlab =
"Distance (Euclidean)  Method (Complete)",  sub = "Specified Clusters (7)", cex.main = 2, cex.la
b = 1.5, ylab = "Height", font.axis = 3, las = 1)
pvrect2(pvcl_s.dat, pv = "au",
       type = "geq",
       alpha = 0.95,
       lower_rect = .5, max.only = TRUE, lwd = 2, lty = 1, col = "lightgrey", border = "orangere
d2", density = 15)
```



Summarizing the principal component analysis

```
# summary table
summary(pc_s.dat)
```

```
## Importance of components:
##                           Comp.1    Comp.2    Comp.3    Comp.4    Comp.5
## Standard deviation     1.5559132 1.3652078 1.2955415 0.9341051 0.7775953
## Proportion of Variance 0.3026082 0.2329741 0.2098035 0.1090690 0.0755818
## Cumulative Proportion  0.3026082 0.5355823 0.7453858 0.8544548 0.9300366
##                            Comp.6      Comp.7       Comp.8
## Standard deviation     0.70078730 0.249678403 0.0791513924
## Proportion of Variance 0.06138786 0.007792413 0.0007831179
## Cumulative Proportion  0.99142447 0.999216882 1.0000000000
```

Analysing clusters attributed to PC1 and PC2

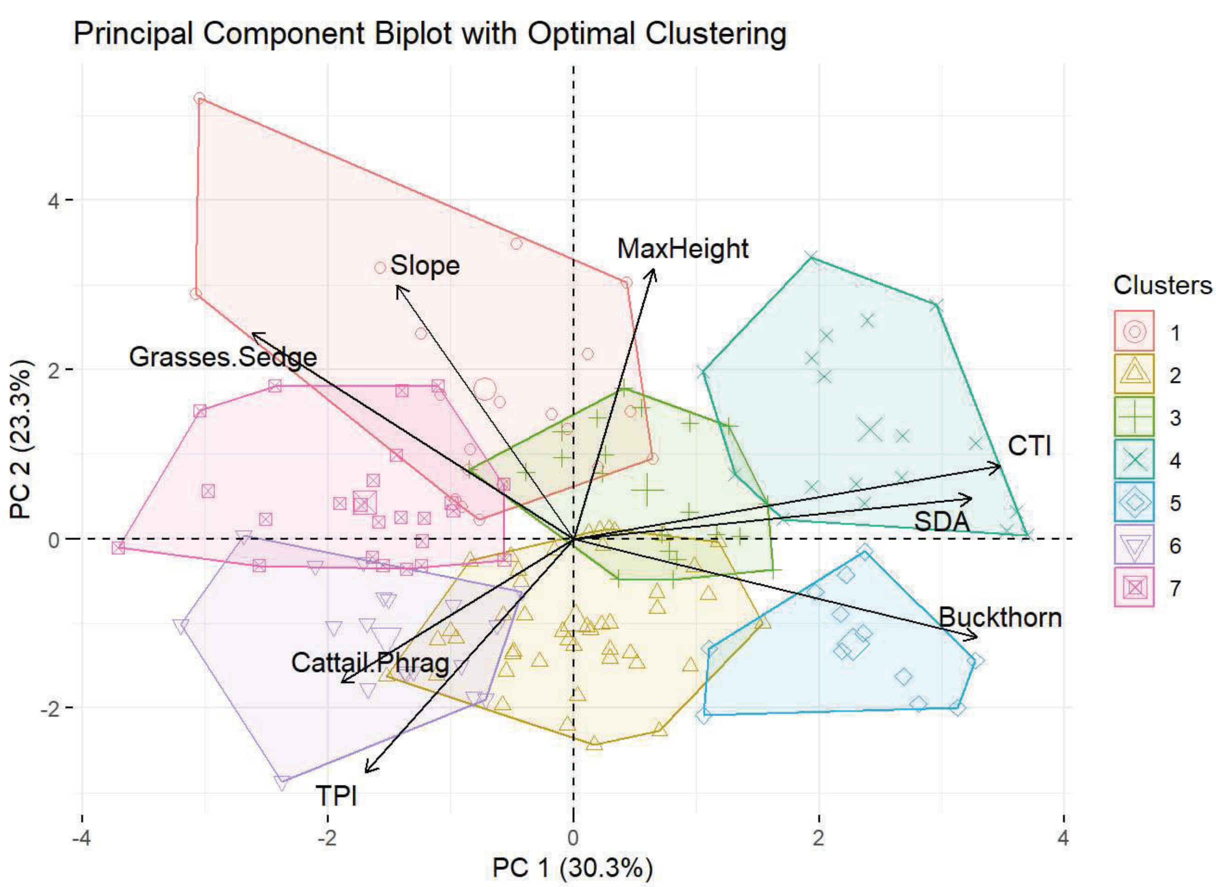
```
# Creating a biplot displaying only the variables and their contribution
biplot_contrib <- fviz_pca_biplot(pc_s.dat, repel = TRUE, geom = c("", ""), col.var="contrib", g
radient.cols = c("#00AFBB", "#E7B800", "#FC4E07"), title = "Principal Component Biplot", cex.mai
n = 3,legend.title = " Variable Contribution
                (high to low)",xlab = "PC 1 (30.3%)",ylab ="PC 2 (23.3%)")

# Checking the class of the plots
biplot_contrib%>%class
```

```
## [1] "gg"     "ggplot"
```

```
p6%>%class
```

```
## [1] "gg"     "ggplot"
```

```
# Combining plots
fviz_pca_biplot(pc_s.dat, label = ("var"), habillage = km7$cluster, addEllipses = TRUE, ellipse.
type = "convex", geom = "point", show.clust.cent = TRUE, ellipse.level = 0.95, ellipse.alpha = .
1, repel = TRUE, pointsize = 2, col.var = "black", title = "Principal Component Biplot with Opti
mal Clustering", legend.title = "Clusters", xlab = "PC 1 (30.3%)", ylab = "PC 2 (23.3%)")
```



J. StoryMap Guide to St. Pierre

a. Feedback For Reviewers

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