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The characterization of riparian vegetation in agriculture drains impacted by *Phragmites australis* and drain management*:* A southwestern Ontario, Canada case study

By:

Ryan Mackenzie Graham

A Thesis
Submitted to the Faculty of Graduate Studies
through the Faculty of Science
and in Support of the Great Lakes Institute for Environmental Research in Partial Fulfillment of the Requirements for the
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at the University of Windsor

Windsor, Ontario, Canada

2023

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The characterization of riparian vegetation in agriculture drains impacted by *Phragmites australis* and drain management*:* A southwestern Ontario, Canada case study

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May 16th, 2023

DECLARATION OF CO-AUTHORSHIP/PREVIOUS PUBLICATION

I. Co-Authorship

I hereby declare that this thesis incorporates material that is result of joint research, as follows:

The manuscript forming Chapter 1, Chapter 2, and Chapter 4 of this thesis was co-authored with Catherine M. Febria. Throughout this thesis, main ideas, data analysis, and interpretation were performed by the author, and the contribution of co-authors was through theoretical knowledge input, feedback on analysis of the data, and guidance through the writing process, including revisions of the drafts.

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II. Previous Publication

This thesis includes one original paper that have been previously published/submitted to journals for publication, as follows:

Thesis Chapter	Publication title/full citation	Publication status*
Chapter 2, Chapter 3	Classifying floristic quality and levels of vegetational biodiversity provided by riparian habitats in managed agricultural drains in Southern Ontario, Canada.	Editing

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ABSTRACT

Agricultural drainage systems are important components of regional ecosystems and play key roles in ecosystem functioning. Biodiversity is a service provided by drains which is not fully understood in agriculturally dominated areas and is disrupted consistently by drain management, specifically in drains invaded by *Phragmites australis*. The objective of this thesis was to characterize the contribution of regional vegetational biodiversity provided by drainage systems, across sites representing a gradient of management frequencies. Drains were separated into management categories: Low (managed +5 years ago), Medium (managed every 3-5 years), or High (managed yearly). Plant abundance was measured and biodiversity indices (Species Richness, Simpson's, and Shannon-Wiener) were compared across the management gradient. In total, 133 distinct plant species were reported across spring and late-summer growing season surveys. Plant identifications were confirmed by local experts using a structured expert elicitation protocol. A number of environmental variables were visualized using non-metric multi-dimensional scaling (NMDS), principal component analysis (PCA), and redundancy analysis (RDA). Community composition differed across management categories, with sites under high levels of management dominated by graminoid (grasses) species. Community composition varied significantly across management categories. Biodiversity indices differed significantly across management categories, with low management sites having higher levels of biodiversity. Environmental variables did not have a strong correlation with community composition, however RDA analyses found management intensity to be the only significant variable relating to community composition. This thesis provides the first known baseline of vegetational community composition for agricultural drains across Windsor Essex. Vegetational biodiversity was dampened by regular drain management and this insight will be useful in exploring the multifunctional roles of drains in supporting biodiversity and ecosystem functions locally and regionally.

DEDICATION

This thesis is dedicated to my late-father, Kevin Neil Graham, who introduced me to and grew my love for the natural world, and my mother, Dana Elizabeth Venables, who has continued to support me throughout my time in academia and life.

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LIST OF ABBREVIATIONS

AES- Agri-environmental Schemes

BMPs- Best Management Practices

VDDs- Vegetated Drainage Ditch

ERCA- Essex Region Conservation Authority

NCC- Nature Conservancy of Canada

SOFIA - Southern Ontario Floral Inventory Analysis

FQI – Floristic Quality Index

PCA – Principal Component Analysis

DCA - Detrended correspondence analysis

VIF - Variance inflation factor

RDA – Redundancy Analysis

NMDS – Non-metric Multidimensional Scaling

HRT – Hydraulic Retention Time

GLOSSARY

Agricultural Drain – channelized water streams that exist along agricultural fields and roadsides

Agricultural Drain Management – the management of vegetation and sediment within drains, including cutting, burning, spraying pesticide, and dredging

Best Management Practice – a method of management identified to have the most effect on a desired outcome

Ecosystem Function – the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly (De Groot, 1992)

Ecosystem Services – Goods and services provided by nature (Millenium Ecosystem Assessment 2005)

Vegetated Drainage Ditch – drainage ditch with emphasis on having established vegetational communities.

Two-Stage Ditch – an engineered design of drainage ditches that includes a low bench within the ditch that can support riparian vegetation

Plant Functional Trait(s) – Plant functional traits are defined as any morpho-, physio-, and phenological plant characteristics affecting overall plant fitness through their influence on survival, growth, and reproduction (Violle et al., 2007)

Nature-based Solutions – solution to issues by using nature, or natural, alternatives

Graminoids – a group of plants with grass-like characteristics, including grasses, sedges, and rushes

Forbs – a group of herbaceous flowering plants that do not have grass-like characteristics

Shrubs – a group of woody plants growing in smaller size and small canopy cover

Trees – a group of woody plant that have growth characteristics of larger tree species and create a large canopy cover

Vines – a group of woody, and non-woody, plants that have vine-like characteristics

Aquatic – a group of plants rooted in aquatic sediments

CHAPTER 1 – INTRODUCTION

Biodiversity loss is a growing societal challenge, along with other human-induced impacts across the globe. The current UN Decade on Ecosystem Restoration (2021-2030) reminds local and global communities that measures need to be taken immediately to curb the speed of biodiversity and habitat loss. Estimates show that approximately 1 million animal, insect, and plant species are threatened with extinction globally, with the current rate of extinction being 1,000 times higher then historical rates (Balvanera et al., 2006, Pimm et al., 2014, IPBES, 2019). Starting in 1992 with the first Convention of Biological Diversity and over the last 30 years, national and sub-national governments have set goals to address some of the main factors impacting biodiversity loss. The most recent landmark agreement known as the Kunming-Montreal Global Biodiversity Framework (GBF) which committed to halt biodiversity loss through a range of measures including the conservation and restoration of 30% of lands by 2030 (COP15, 2022).

Much of the need for policy including the GBF is being driven by the widespread conversion of highly biodiverse habitats into urban and agricultural environments, a pattern seen around the world (Herzon and Helenius, 2008). Agricultural expansion and the loss of natural ecosystems can be considered the largest factor surrounding biodiversity loss, with some reports indicating that food and agriculture systems are responsible for 70% of global biodiversity loss (Davies et al., 2008, Garibaldi et al., 2017, Martin et al., 2019). Biodiverse habitats such as wetlands, grasslands, and forests have been converted into agricultural land, often complete with extensive below- and above-ground drainage infrastructure (Lind et al., 2019). While drivers of global biodiversity loss are complex, the connection to land-use changes is straightforward: we are decreasing the amount of biodiversity in the world because we are decreasing the amount and quality of habitat in which biodiversity can thrive.

In agriculturally dominated regions, the areas available for native biodiversity regeneration are relatively small. Land conversion in many of these regions has often resulted in large crop fields characterized by single treelines dividing fields and extensive networks of drainage infrastructure, leaving the only remaining areas for biodiversity to thrive to small margins that surround or divide fields. Agriculturally dominated regions look different across the world but most share similar general characteristics. Drainage infrastructure represents the modern freshwater network across agricultural regions and as a result, drain environments are highly managed, complex, and also aging, providing a challenge for societies who depend on drains for critical ecosystem services (Castellano et al., 2019).

Drainage systems are crucial habitats for biodiversity despite being heavily managed (Tscharntke et al., 2005, Ouijas et al., 2010). As such this thesis will expand the knowledge base surrounding local agricultural drainage systems and investigate their potential contribution to local regional and ecosystem services. Drain ecosystems and their influence on regional biodiversity are rarely studied but with the increasing rates of biodiversity loss, it is critical that society consider all possible areas where biodiversity can persist.

1.1 – Important ecosystem services provided by agricultural drains

The primary service provided by drains, and the reason for their creation, is the conveyance of water away from fields (i.e., flood mitigation; Moore et al., 2008). However, over time this service has impacts other aspects related to fresh water quality and quantity. Conventional farming practices, with the use of fertilizers and pesticides, have impaired water quality via the addition of chemicals and increased suspended sediments across the globe (Collins et al., 2019, Foley at al., 2005, Herzon & Helenius, 2008, Zhang et al., 2010). Runoff from fields and the movement of contaminated water has led to numerous problems for downstream environments. For example, increased nutrients from drain water have caused large eutrophication events in many regions dominated by agriculture (Cui et al., 2020, Lind et al., 2019, Stammler et al., 2008). Drains have been identified as a primary pathway of these pollutants and over the last 40 years researchers have spent a considerable amount of time attempting to reduce the downstream impacts of the movement of pollutants through this critical pathway.

Impacts from nutrient-rich water have inspired increased research on drain environments with growing research focus on the provision on ecosystem services beyond just flood mitigation. As such, drains are recognized to provide pollution mitigation and erosion control services and are regarded as both the sources of pollution but also solutions for mitigating impacts of agriculture (Kumwimba et al., 2018). Drains and their riparian habitat are considered buffer zones and numerous research projects have thoroughly studied their effects for the reduction of excess nutrients and sediment. (Lind et al., 2019). Drains, and the vegetation within them, have been studied in the realm of pollution control, and are indicated as one of the major drivers of biological processes in pollution reduction including: plant uptake, increased sedimentation, nutrient transformation, and habitat creation for microbial communities, all which can be connected to reducing contaminant levels in water travelling from drains (Cole et al., 2020, Cui et al., 2020, Kumwimba et al., 2018, Meuleman & Beltman, 1993, Moore et al., 2010, Zhang et al., 2010). In many areas, drains are the only areas for these processes to take place, and drains are now providing the services once provided by historical wetlands and other important ecosystems (Foley er al., 2005, Herzon & Helenius, 2008, Moore et al., 2010, Collins et al., 2019).

The list of ecosystem services provided by drains is extensive (Appendix 1.1) and includes the more commonly discussed flood mitigation, erosion control, and pollution mitigation, but also carbon sequestration and other services that are often overshadowed (Cole et al., 2020, Davies et al., 2009, Kozelova et al., 2020, Lind et al., 2019). While the majority of research to date has focused on how drains can mitigate agricultural pollution, recent studies have identified contributions towards riparian habitat, regional ecosystem connectivity, and regional biodiversity as additional ecosystem services provided by drains (Browers & Boutin, 2008, Bolpagni et al., 2013, Ward-Campbell et al., 2017, Lind et al., 2019, Cole et al., 2020, Tolgyesi et al., 2021). Furthermore, in agriculturally dominated regions of the globe, drain environments may be last remnant areas for biodiversity to exist.

1.2 – Drain habitat and riparian vegetational communities

Drain habitats are channelized and/or modified streams that support a combination of semi-natural environmental attributes including permanent or temporary water, aquatic substrate, and vegetated banks or margins, all of which support a variety of organisms, including pollinators, invertebrates, fish, amphibians, mammals, and birds (Herzon & Helenius, 2008, Lind et al., 2019, Martin et al., 2009, Stammler et al., 2008). The physical characteristics of a region and its drains, including soil type, size, slope, and elevation, all affect the contribution drains have to ecosystem function (Kumwimba et al., 2018). As previously mentioned, vegetation is known to play a key role in nutrient and sediment processing, but also play a large role in nature-focused ecosystem services, including habitat for animals, food, and connectivity to other ecosystems. (Herzon & Helenius, 2008, Kumwimba et al., 2018, Cui et al., 2020). Riparian habitats are considered a transition zone from terrestrial to aquatic ecosystems and provide a refuge for regional plant diversity (Bolpagni et al., 2013, Hille et al., 2017, Lind et al., 2019).

Vegetation has been highlighted as one of the main factors shaping the ecosystem services provided by drains (Cole et al., 2020, Collins et al., 2018, Martin et al., 2019). In some cases, drains have been engineered specifically to promote vegetational growth as vegetated drainage ditches (VDDs), a best management practice (BMP; Kumiwimba et al., 2018). Vegetational communities within drains have been one of the major drivers of key biological processes including plant-based nutrient uptake and transformations, increased sedimentation, and habitat creation for microbial communities, all of which can be connected to reducing contaminant levels in water travelling through drains (Meuleman & Beltman, 1993, Moore et al., 2010, Cui et al., 2020, Kumwimba et al., 2018, Cole et al., 2020).

Numerous studies have identified the importance of vegetated buffers in agricultural environments, and evidence of their efficiency at providing ecosystem services can vary across studies (non-production lands; for a review see Case et al., 2019). In a review by Lind et al. (2019), authors reported that buffer widths have differing requirements for specific environmental services. Reductions to nitrogen, phosphorus, and sediment inputs were reported to require buffer widths of nine to eleven meters to achieve 75% removal efficiency. Zhang et al. (2010) indicated that buffer widths ranging from six to eighteen meters could have ranging levels of efficiency for each contaminant. A review from Mayer et al. (2007) found that large buffers (>50 meters) provided more reductions to nitrogen levels than smaller buffers (<25 meters). Vegetation within drains can reduce water velocity and increase the time water spends in drains, known as hydraulic retention time (HRT; Kumwimba et al., 2018, Lind et al., 2019). Vegetation within drain habitats also impacts rates of sedimentation by decreasing the flow and adding physical obstructions for sediment within the water column (Moore et al., 2010).

Alongside direct plant uptake of nutrients, vegetation within drains can create habitat for microbial communities that further biodegrade pollutants and reduce their impact (Kumwimba et al., 2018, Cui et al., 2020, Rudi et al., 2020).

1.3 – Biodiversity within agriculture drainage systems

While drains and their biological communities have been extensively studied for a variety of services, only recently has their importance been examined. In Europe, the development of agri-environmental schemes (AES) was first focused on nutrient reductions but now also focuses on promoting the diversity of vegetation within drains (Primdahl et al., 2003, Blomqvist et al., 2009, Davies et al., 2009, Renouf and Harding, 2015). These government-supported programs started in 1985 and, compared to North America, research from Europe has spent more time trying to understand this dominant ecosystem type (Batary et al., 2015). Specifically for vegetational biodiversity, a study from Meiner et al. (2017) showed that drainage systems have higher levels of biodiversity when compared to meadow environments. In that study, 122 drain environments were surveyed and found 45 different species (Meiner et al., 2017). A study in the United Kingdom surveyed 154 drainage ditches and found a total of 39 plant species (Shaw et al., 2015).

While in both of those studies levels of species richness were low, an Italian study found 208 species of plants in margin habitats of agricultural regions (Bolpagni et al., 2012). Another study from Hungary found an incredible total of 512 plant species across 60 study canals (Tolgyesi et al., 2020). In North America, the number of research projects looking at biodiversity within drains has expanded greatly over the last 20 years but is still less studied compared to some areas of Europe. In Quebec, studies from Celine Boutin found significant biodiversity provided by drains (Boutin et al. 2003). Across one project surveying riparian habitats, 280 species of plant were found across 29 study sites, and when including trees, riparian habitats contained more species than habitats with just grass, forbs, and shrubs, or a combination of each (Boutin et al., 2003). Another study from Bowers and Boutin (2008) found 271 plant species in just 27 surveyed drains. More recently, a study in Ottawa found 206 species of plants across 112 sampling sites (Martin et al., 2020).

With only a few studies directly comparing levels of biodiversity in agricultural drain ecosystems to other, more natural, ecosystems, it is difficult to quantify how much drain habitats can provide to their region in terms of vegetational biodiversity. However, researchers have shown that alongside vegetational biodiversity, the animal diversity is also high in drain ecosystems (Martin et al. 2019). Among insects, Martin et al. (2019) reported 25 butterflies, 29 syrphid flies, 87 bees, 45 carabid beetles, 60 spiders, and an additional 34 species of birds. A similar study from Togyesi et al. (2021) found 55 butterfly, 219 true bug, 114 spider, and 38 bird species. A review by Lind et al. (2019) found that riparian buffers have different levels of contribution of habitat for amphibians, small mammals, birds, fish, and insects, all dependent on the size of riparian buffers and other factors. Research from across the globe is indicating that these environments are important for not only vegetational biodiversity and ecosystem services, but the diversity of a variety of living organisms.

1.4 – Importance of biodiversity for drain ecosystem services and function

Diverse ecosystems have been shown to be more resilient to disturbances, including the invasion of introduced species, as well as resilience to effects from climate change (Frankel et al., 1998, Tscharntke et al., 2005, Isbell et al., 2015, UNICEF, 2020). Multiple experiments and meta-analyses have indicated that biodiversity has a direct effect on ecosystem primary productivity, nutrient mitigation and retention, erosion control, rates of pollination, plant biomass, carbon sequestration, and more (Balvanera et al, 2006, Cardinale et al., 2011, Isbell et al., 2015, Cole et al., 2020, UNICEF, 2020).

A review by Balvanera et al. (2006) looked at 426 measures of biodiversity effects in grasslands, mostly in relation to primary producers, and found that vegetational biodiversity has positive effects on important macroinvertebrate decomposers and microorganisms responsible for nutrient mitigation. This review indicated positive effects of biodiversity on services like pest control, erosion control, and resistance to invasion (Balvanera et al., 2006). Another review, from the same research group, found positive effects of biodiversity on ecosystem services like plant products, erosion control, invasion resistance, pest regulation, pathogen regulation, and soil fertility (Quijas et al., 2010). Additionally, biodiversity of vegetation can support ecosystem services across different seasons, years, and places (Isabelle et al., 2018).

1.5 – Managing drain function and invasive *Phragmites australis*

In agricultural systems, the ability for drains to offer desired functions and services has been compromised by the presence and invasion of non-native species. Drainage practices are partially responsible. For many years, vegetational communities in drains have been cut, burned, dredged, and sprayed with herbicide to reduce the amount of influence they have on water control (Dollinger et al., 2015, Levavasseur et al., 2014, Rudi et al., 2020). These heavily modified ecosystems are then further disturbed by these management practices and these techniques have been shown to impact vegetational communities in drains (Kumwimba et al., 2018, Levavasseur et al., 2014). The importance of primary drain function of flood control remains the main reason for extensive management, as increased water in fields can greatly impact our modern agriculture systems which rely on dry soils for crop growth.

The very nature of drains themselves can also create further challenges for maintaining drain function. The nutrient rich, semi-aquatic, and heavily managed nature of these environments has allowed for the invasion of non-native species such as *Phragmites australis* (Hereafter *Phragmites;* Jodoin et al., 2007, Nichols, 2020). This plant now dominates southwestern Ontario drain environments and is one of the main reasons that drain systems must be managed. *Phragmites* is prevalent in agricultural drain systems because of its quick growing roots, large stem and leaf structure, and multiple vectors of spread (Brisson et al., 2010, Jodoin et al., 2007, Nichols, 2020). This plant has slowly spread across Canada since the early 1900s and has used drainage structures as one of its main habitats (Jodoin et al., 2007). The battle against *Phragmites* is well documented and continuous (see OPWG, n.d), but unfortunately in many circumstances it is a cycle of management and plant regrowth. Managing drains for *Phragmites* has had success, but in many circumstances dense stands of the invasive plant grow in the years following management. Managing drains is a complex issue, management is required to maintain the primary functions of drains but the management methods have impacts on other drain functions.

1.6 – Multifunctionality of drains

Perhaps due to limited evidence locally and globally, there is an underappreciation for the multifunctionality of drain ecosystems, with most research focused on identifying ecosystem services beyond water and nutrient control (Groenfeldt, 2005). A list of environmental functions provided by drains includes areas for non-production vegetation, ecological corridors, and the provision of food, water, and space for birds, insects, and mammals (Cole et al., 2019, Tolgyesi et al., 2021). Many different factors that can influence the levels of each of these functions, including the physical characteristics of the drain system, including: soil type, size, slope, elevation, and connection to other natural ecosystems (Kumwimba et al., 2018). As previously mentioned, vegetation is also known to play a key role in many of the nutrient and sediment processes, but also play a large role in ecosystem services within drains as well, including habitat, food, and connectivity to other ecosystems. (Cui et al., 2020, Herzon & Helenius, 2008, Kumwimba et al., 2018).

Many parts of the world have begun to protect these modified drainage systems with a focus on conserving the ecosystem functions provided by drains. European government programs have been developed to incentivize farmers to conserve and improve aspects of the damaged agricultural landscapes, primarily focusing initially on nutrient reductions but recently focused on biodiversity (Blomqvist et al., 2009, Davies et al., 2009, Primdahl et al., 2003, Renouf and Harding, 2015). Progress in North America and China has focused on identifying best management practices (BMPs) for drainage infrastructure and have tested out newer methods, such as creating vegetated drainage ditches (VDDs), to encourage functional nutrient and sediment processing capabilities (Moore et al., 2010, Kumwimba et al., 2018). A pattern across the agriculturally dominated regions persists, drainage systems are now considered important components of regional ecosystems and a recent movement for multifunctional drainage systems is becoming more popular.

There is a growing interest in understanding how drains can support multiple ecosystem functions. We know the challenges within these drains: the continuing need to maintain primary ecosystem function, the persistence of invasive species, and the consistent disruption from drain management to vegetational communities are connected in a variety of ways. While advances in the management of *Phragmites* has begun to produce positive results in controlling the species, management of this invasive will continue to impact the important functions of biodiversity of drains. The current, global, movement to look at nature-based solutions for issues can add to our management of drains, for exampling using species that might help fight against the domination of invasive species in these habitats. We need to further analyze how managing drains impacts the other functions provided by these habitats, how we can use nature to help in the management of drains, and we need to ensure we are beginning to look at how the effects of climate change will further impact these environments in the near future.

1.7 – Drainage systems in southwestern Ontario, Canada

Southwestern Ontario, Canada, is an excellent example of agriculturally intensified land use, specifically the Essex region. The creation of railways, roads, and massive agricultural fields have drastically impacted the environments of this region and Essex County alone has one of the most staggering rates of wetland conversion across Canada, and the world (Penfound & Vaz, 2022). According to historical records, before settlement, Essex County was a large system of interconnected aquatic environments, with the total wetland area being 83.4% of the county (Ducks Unlimited, 2010). In a 2010 survey, and after hundreds of years of settlement, the remaining wetland area was below 2% (Ducks Unlimited, 2010).

Wetlands in the region were replaced by extensive drainage infrastructure; there is now close to 3,000km of surface and sub-surface drainage corridors across Essex County (T.Dufour, ERCA, personal communication, 2022). Acres of diverse aquatic environments were transformed into fields and a complex network of drainage systems. While the region has been successful for agriculture, and flood mitigation levels are relatively high, there are still prevailing questions surrounding the benefits that drain system provide and the overall biodiversity within them. We know that a wide range of important species use these environments, but the impact of drain management is still an area needing further research.

A number of unintended consequences have emerged from this land use change, Essex County is an excellent example of the domination of non-native species including *Phragmites australis*. This region has slowly become dominated *by Phragmites* and drains here are managed frequently, sometimes yearly, to control the introduced plant. Many of the aquatic habitats in Essex County are under the pressure of *Phragmites*, however, this region is still regarded as being an area of high biodiversity (Kraus & Hebb, 2020). Essex County is home to a variety of Canada's endangered species, including over 2000 species of plants, and also contains crucial habitat for migratory birds, reptiles, and fish (Carolinian Canada, 1994, ERCA, 2000). Southern Ontario, specifically the St. Lawrence Lowlands where Essex County resides, is a very important region. This region is classified as a 'crisis ecoregion' (Kraus and Hebb, 2020). Essex County has high scores of biodiversity, high levels of threats to biodiversity, and low levels of conservation responses happening currently, with less then 5% of the total ecoregion being protected via conservation efforts (Kraus & Hebb, 2020).

1.8 – Knowledge gap

Biodiversity is declining globally, and agriculturally dominated landscapes are at the forefront of biodiversity loss. The drainage systems that have replaced natural heritage features and watercourses have become one of the last remaining areas where biodiversity can thrive (Boutin et al., 2003). The physical services of flood control and nutrient retention overshadow the ecosystem services that are provided by the high aquatic and terrestrial biodiversity in drains. In southern Ontario, the management regime used to maintain drain functions and control *Phragmites australis* has led to widespread disruption of established vegetational communities. While trying to control an invasive species, drain management has inadvertently affected the desirable vegetation communities greatly and frequent management impacts the ability for desired plants to establish (Levavasseur et al., 2014).

Drainage systems play a crucial role for regional biodiversity, yet questions persist around the role of riparian biodiversity in supporting desired ecosystem functions and services in agricultural landscapes. There is also a need for drain management because of invasive species, meaning that disturbance to vegetational communities will prevail as we fight *Phragmites.* There is a lack of knowledge on this topic, particularly on the relationship between native vegetation and *Phragmites,* and nature-based solutions in drains are relatively understudied. Exploring the relationship between native vegetational biodiversity, *Phragmites* and drain management, and the ecosystem function of agricultural drainage systems remain a knowledge gap for southwest Ontario and in particular, Essex County.

1.9 – Research objectives and hypothesis

To address this knowledge gap, this thesis will explore the relationships between vegetative biodiversity, drain management, and the drain ecosystem function in agricultural drain systems of Essex County. The vegetational communities in drains have not been studied extensively, indicating that little is known about the plant communities that reside in these drains. This research will focus on agricultural drains impacted by and managed for invasive *Phragmites* by characterizing vegetational communities across a management gradient.

This research asks: How are vegetational communities structured across low to highly managed agricultural drains? Using drain management as a proxy for *Phragmites* management this thesis will explore how attributes of drain habitats together across a management regime influence vegetational community structure to explore relationships among physical attributes and vegetational communities.
My hypotheses are:

H1. Agricultural drains actively managed for *Phragmites* will support less diverse riparian vegetational communities than infrequently managed ones.

H2. Riparian vegetational communities will be seasonally and spatially variable due to management practice and other environmental factors.

This research represents the first known vegetational biodiversity survey across drains in the region. There are global movements recognizing the importance of non-crop vegetation within these environments. Hedgerows, restored ponds, and wildflower strips have all shown benefits to agricultural practices, however, drain systems continue to be overlooked for their contribution to not only agricultural practices but regional biodiversity.

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CHAPTER 2 - VEGETATIONAL SURVEY

2. Methods

2.1 - Study location and site selection

This study was conducted in Essex County in southern Ontario, Canada (42.1727 N, 82.81189 W) which is situated in the Traditional Territory of the Three Fires Confederacy of the First Nations - the Odawa, the Ojibway, and the Potawatamie. This region is primarily clay-based soils and its geographical location between three water bodies, mild climate, and long growing season provide quality land for agriculture. Essex County is divided by extensive drain systems, containing approximately 3,000km of modified drainage infrastructure (Dufour, 2022 pers comm.). Ten agricultural drains, shown in **Figure 1**, were identified after a year-long collaboration with local farmers and study sites were only selected when permission and access to drains was granted (Febria et al. 2022). Drains size was also considered for site selection, large drains were excluded, and focus was placed to reach medium, or average, size drains.

2.2 – Created management gradient and site locations

The drain system across Essex County are heavily managed for invasive *Phragmites australis,* however, these drain systems vary in management level, or intensity. To better understand how these differing levels of management impact drain habitats, we established three primary drain management categories in this study which outline different levels of drain management intensities: low (n=4), medium (n=3), and high (n=3). Drains representing low intensity of management had not been managed in over 5 years, drains with medium intensity of management were managed last within 3-5 years, and sites with high intensity of management were drains managed every, or every-other, year. Local knowledge from farmers and landowners established a timeline for management, allowing for the classification of sites into determined categories, and local drain superintendents were consulted to reinforce knowledge on the history of drain management at each site. Alongside classifying sites into these categories, further analysis used a created “Time since managed” variable which represents the years since last management. Study sites were also categorized in two primary locations, drains directly roadside (n=6) or field-side only drains (n=4). Furthermore, for quadrats within sites connected to roadsides, quadrats were identified as road-side or field-side for deeper analysis within sites. This was done because, during management of drains, the roadside bank and stream are managed more frequently and field-side banks are often left unmanaged. During analysis of these study sites both site-wide and individual quadrats were investigated together and separately.

2.3 - Vegetation survey

During the plant blooms in spring (May-June) and late-summer (August-October) of 2021, riparian vegetational communities in drains were surveyed using a hybrid transect and quadrat approach shown in **Figure 2**. The total study reach distance was determined using a modified Ontario benthic biomonitoring network protocol, using stream width to determine total study reach. Three transects (1m wide) were established across the study reach by dividing sites into equal increments and by using random number generators to identify what location to place transects. Transects spanned the entire riparian bank, entire riparian bank referring to when riparian habitat transitioned to fields or roads. Two quadrats ($1x1m^2$) were placed within each transect, one on each bank (six quadrats per site); shown in **Figure 2**. All species within transect surveys were identified to create plant presence/absence data, and quadrat measurements, including percent cover, species count, and average height, provided estimates of above ground plant biomass and data for biodiversity indices. Study reach was determined using a combination of protocols from the Ontario Benthic Biomonitoring Network and Ontario Stream Assessment Protocol (Stanfield et al., 2017, Jones et al., 2007). In total, the study established and inventoried 117 quadrats, with only 3 being eliminated due to unsafe access or the presence of harmful plants.

2.4 - Plant identification and expert confirmation

Plant identifications were made in the field using regional plant guides, such as the Field Manual of Michigan Flora (Voss and Reznicek, 2012) and Plants of Southern Ontario (Dickinson and Royer, 2013), together with image recognition smartphone-based applications 'PictureThis' and 'Seek' by iNaturalist. If plants were unable to be identified within field, photos of key plant features were taken for identification using online native plant databases (iNaturalist; Natureserve.org) and mentioned regional guidebooks. Photos captured in the field were compared with other "research grade" photos within the iNaturalist database for further species confirmation. To maintain proper taxonomic resolution, plants within quadrats were identified to genus level. Confirming these identifications and furthering the identification to species level was done with the help from regional plant experts.

An expert elicitation procedure (Appendix 1.1) was conducted to confirm unidentified species in late 2022 and early 2023. Five local experts from Essex Region Conservation Authority (Kate Arthur and Dan Lebedyk), the Nature Conservancy of Canada (Jill Crosthwaite), and the City of Windsor (Karen Cedar and Paul Pratt), were identified as possible experts that could confirm species identification from these research projects. Excel files and PDFs of plant identifications, photos, and other plant details were sent to each expert group, who were asked to initially review the plant identifications. An in-person or virtual meeting was then scheduled with each expert and during each meeting researchers went through the identified species with experts to confirm species identification. During this process, 131 species of plants were shown to experts, and after these initial meetings experts were asked to finish the identification process on their own time, without a physical meeting. Each expert group identified plants individually and their final list of plant identification was compared with answers provided by the other experts. The most common taxonomic level was used for analyses moving forward.

2.5 – Plant abundance, functional groups, and southern Ontario floral inventory analysis

Estimates of above-ground plant biomass were calculated from the measurements taken in each quadrat. The above-ground biomass was estimated by measuring the average height of each plant, or at least five individuals, and then multiplying by the percent cover for each plant. Abundance was recorded for each species and combined for each of the plant functional groups: graminoids, forbs, vines, small shrubs, and large trees, which was then compared across sites and management regimes. These plant functional groups are relatively simple and plant species could be separated into further groups; however, the goal of identifying plant functional groups was to create a better idea of the overall functional composition of habitat provided by drains.

Confirmed plant species lists were input into the Southern Ontario Floral Inventory Analysis (SOFIA), which is a free application created by Dan Lebedyk, Biologist with the Essex

Region Conservation Authority (ERCA, 2021). SOFIA is used for summarizing and analysing floral quality in southern Ontario, and for this study was used to represent the quality of habitat provided by all of the studied drainage environments combined. SOFIA uses plant data from the Natural Heritage Information Centre (NCIS) and calculates coefficients of conservatism, coefficient of wetness, indicates values of Floristic Quality, and compares species status across national and international species rankings, and indicates the percentage of species not native to the region. Both mean coefficients of conservatism and wetness are generated using the NCIS database, and the Floristic Quality Index (FQI) is generated using Oldam et al. (1995) and Spyreas (2019). The FQI values range from 0 to 100, with scores above 35 being indicated as important floristically on a provincial scale. The mean coefficient of conservation provides a similar value, ranging from 0.00 to 10.00 with a score above 3.5 indicating floristic quality of remnant natural habitats. Lastly, mean coefficient of wetness represents the types of communities, either upland or wetland species. Values range from -5 to 5, with any positive values (0-5) being indicating the community is primarily upland species and negative values indicating dominance of wetland species.

2.6 – Biodiversity indices

Three common diversity indices were generated for comparison at each site: Simpson's Index of Diversity (Simpson, 1949), Shannon-Wiener (Shannon & Weaver, 1972), and Species richness (Scott et al., 1987). Species richness represents total species counts, whereas both Shannon-Wiener and Simpson's describe different aspects of biodiversity. Simpson's diversity ranges from 0-1 and represents the probability that two randomly selected individuals would be separate species (Simpson, 1949). A higher Simpson's value would represent higher biodiversity. Shannon-Wiener is a different diversity metric which is calculated by comparing proportions of species within each site. Values start at 0, which would represent a site with only one species, and higher values indicating more biodiverse sites.

2.7 – Environmental variables

Additional in-stream drain attributes were measured during the survey to account for any influence on vegetational communities from abiotic sources, including: water chemistry, discharge, wetted and bank full width, riparian bank width and slope, canopy cover, and other quadrat specific measurements, such as the percentages of cover for woody debris, vegetation, structure, and open soil. In-situ water chemistry was measured including water temperature (°C), dissolved oxygen (DO, mg/L), specific conductivity (µS/cm), pH, and turbidity (NTU) by using a YSI® ProDSS handheld probe. At each quadrat the percentage of vegetation, open soil, woody debris, and rock/structure was estimated to create a better understanding of riparian bank habitat. Water samples were collected and filtered to analyze nutrient concentrations using a SMARTCHEM® 170 Discrete Analyzer for further water quality data, including: nitrate-nitrite (NO3-NO2; mg/L), ammonia (NH3; mg/L), and total dissolved phosphorus (TDP; µg/L). From water samples, fluorometry of the dissolved organic matter was analyzed using a HORIBA Scientific Aqualog® and 4 main values were used: Fluorescence index (Fi), Absorbance at 254nm (abs_254), Biological index (BIX), and Humification index (HIX) (Weller, 2022). These analyses were conducted by the Organic Analysis and Nutrients Laboratory, which is a federally certified laboratory at the University of Windsor and Great Lakes Institute of Environmental Research. All measured environmental variables are listed in **Table 1.**

2.8 - Data Analysis and Ordination

2.8.1 – Biodiversity indices

Biodiversity indices, including: Shannon-Wiener, Simpson’s, and Richness were calculated from the species count recorded in each quadrat, with calculations run in RStudio (version 4.2.2; R Core Team 2022) and the *vegan* package (version 2.6.4) (Olksanen et al., 2020). Calculated biodiversity indices and plant functional group abundances were compared across sites using multiple variables, including: season (Spring, Summer), site type (Road-side, Field-side), and management regime (Low, Medium, High). All quadrats were individually compared for differences in Quadrat orientation (North, East, South, West) and overall Quadrat bank type (Roadside vs Fieldside). Plant functional groups were also compared across season, site location, and management regime. For seasonal comparisons, each test was indicated as paired during statistical analysis in RStudio since variables were connected. Normality was tested using the Shapiro-Wilk test and indicated that non-parametric tests were appropriate since all data was found to be non-normally distributed. Significance across two sample variables with Wilcoxon Rank Sum test, and variables with more than two samples was tested using the Kruskal-Wallis test and a pairwise Dunn-Bonferroni test to specifically identify site or variable differences.

2.8.2 – Non-metric multidimensional scaling

The ordination of vegetational community composition was generated and analyzed using multiple different ordination techniques in RStudio. To maintain proper taxonomic resolution, only the plant genera were explored using statistical approaches. The composition of vegetational communities was visualized using non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarities and the function *metaMDS* from the *vegan* package (Oksanen et al., 2015), from plant abundance measurements within quadrats. Hellinger transformation was done on plant genus abundances to reduce the impact of rare species found across sites. NMDS was also used with transect presence-absence data recorded within transects, to further visualize vegetational composition by using Sorensen dissimilarity. We visualized patterns within communities and analyzed significant differences across site location, season, and management regime, by using a permutational multivariate analysis of variance (PERMANOVA, 999 permutations) using the 'adonis2' function in vegan, and 'pairwise.adonis' function from Arbizu (2020). The species that could be driving distribution was explored using 'envfit' function with a 'p.max' of 0.05 to identify only species with a significant influence on ordination.

2.8.3 – Principal component and redundancy analysis

Environmental variables and conditions across sites were analysed using Principal Components Analysis (PCA) and Redundancy Analysis (RDA) using RStudio. The ordination of variables in PCA and RDA was based on a correlation matrix and before analysis all environmental variables were Log (x+1) transformed to increase normality, reduce impact from missing values, and reduce highly skewed variables. The effects of various environmental variables on vegetational communities were explored further using an RDA. RDA was chosen over a Canonical Correlation Analysis (CCA) because RDA is a further exploration of data similar to PCA and even though linear relationships between species and variables were not strong, RDA captured more variability within the data. Data were also analyzed using a Detrend Correspondence Analysis (DCA) to confirm the appropriate analysis method. Using function 'vif.cca', the variance inflation factor (VIF) was calculated and identified variables with high collinearity, which were then removed from RDA analysis. The significance of the ordination and variable was determined using ANOVA permutation tests in the vegan package and function ‘anova.cca’.

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TABLES

Table 1) All measured environmental variables, associated PCA abbreviation, area of collection within the site, study minimum-maximum vales, and average measurement for each variable across management regime.

	PCA Abbreviation	**Site Source**	**Min**	**Max**	**Mean**		
Water Chemistry					**Low**	**Medium**	**High**
Water Temperature (ºC)	Wtemp	Site	12.2	23.6	19.2	16.48	18.23
Acidity (pH)	pH	Site	6.86	8.49	7.6	7.18	7.5
Turbidity (NTU)	Turb.	Site	2.06	372.94	24.3	86.12	13.8
Dissolved Oxygen (DO) (mg /L)	DO	Site	1.42	32.23	7.18	3.84	10.37
Conductivity (µs/cm)	Cond.	Site	616	2647	915.71	1175.5	1071.7
Nitrate (mg NO_3-NO_2 /L)	Nitrate	Site	0.01	25.83	3.73	7.6	8.22
Ammonia (mg NH_3/L)	Amm.	Site	0.08	2.66	0.22	0.83	0.15
Total Dissolved Phosphorus (TDP) (mg P/L)	TDP	Site	0.012	0.31	0.13	0.06	0.12
Dissolved Organic Carbon (DOC) (mg L-1)	DOC	Site	5.35	51.2	10.11	10.41	16.99
Water Fluorometry							
Biological index	bix	Site	0.86	1.01	0.92	0.93	0.95
Fluorescence index	fi	Site	1.33	1.44	1.37	1.36	1.38
Humification index	hix	Site	3.4	8.44	6.2	5.66	5.24
Absorbance at 254nm	abs_254	Site	0.09	0.89	0.24	0.23	0.31
Drain Characteristics							
Wetted Width (m)	WetW	Transect	1.17	2.53	1.72	1.8	2.51
Bankful Width (m)	BankfullW	Transect	2.62	4.5	3.49	3.67	2.9
Discharge (m^3/sec)	DischargelD	Site	0	0.03	0.01	0.002	0.004
Average Riparian Buffer (m)	AvgRipBW	Quadrat	3.05	7.18	5.54	4.09	3.58
Average Riparian Slope (Deg)	AvgSlope	Quadrat	26.25	40.5	36.4	34.3	37.58
Average Canopy Cover (%)	AvgCCover	Quadrat	0	0.67	0.35	0.11	0.05
Average Percent Vegetation (%)	AvgPercVeg	Quadrat	38.33	55	48.09	47.5	41.94
Average Percent Woody Debris (%)	AvgPercWoody	Quadrat	2.5	20	15.07	10.13	6.25
Average Percent Open Soil (%)	AvgPercOpenSoil	Quadrat	10.83	27.5	17.08	19.16	13.05
Average Percent Rock (%)	AvgPercRock	Quadrat	0.42	8.75	2.75	4.44	5.97

FIGURES

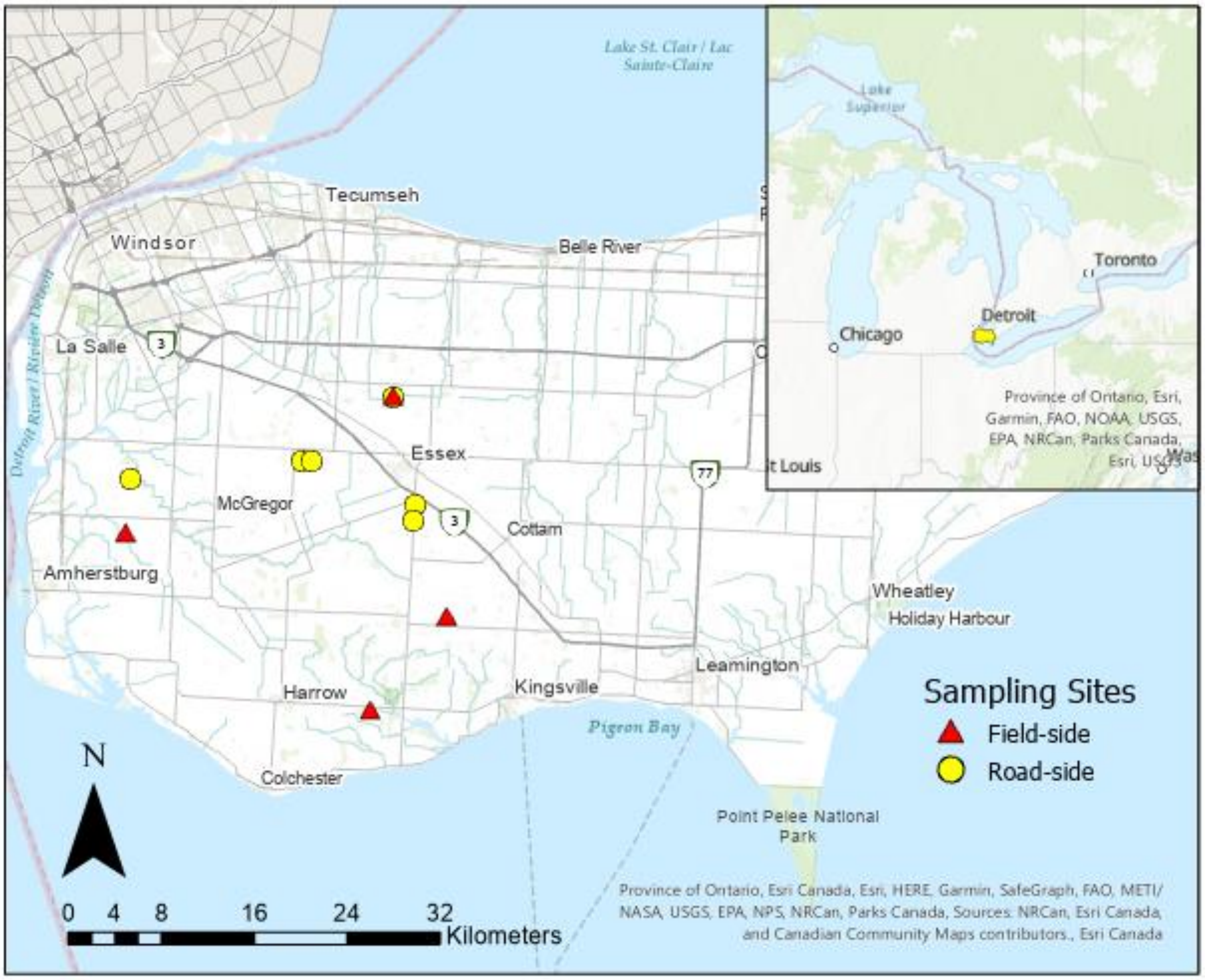

Figure 1) Map showing Windsor-Essex county in Southern Ontario, Canada. Displaying research sites, seperated by site location type; roadside (N=6, yellow circle) and fieldside (N=4, red triangle). This map was created in ESRI's ArcPRO using data from multiple sources, including: Province of Ontario, Esri Canada, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, NOAA, EPA, NPS, NRCan, Parks Canada, and Canadian Community Maps contributors.

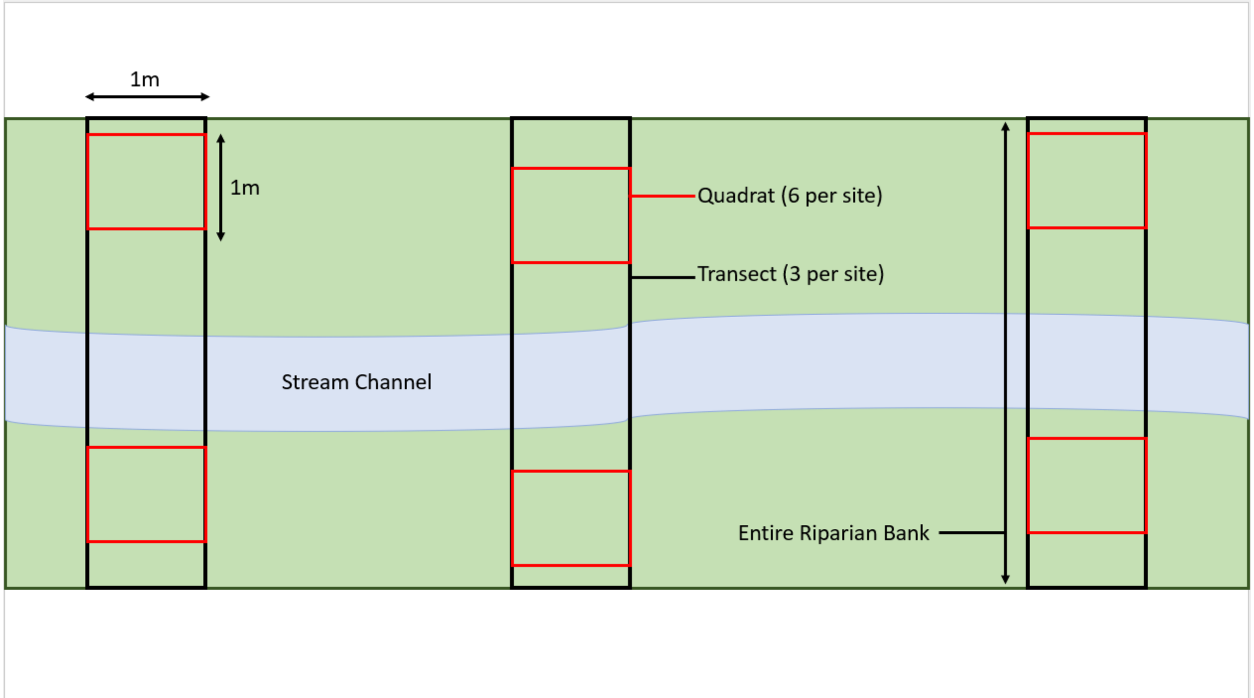

Figure 2: Conceptual diagram of study design across a drain environment, biomass data collected within red squares, representing 1x1m quadrats, black rectangles represent transects where remaining plant presence was recorded.

CHAPTER 3 – RESULTS

3.1 – Research Site Characteristics

The 10 agricultural drains surveyed in this research represent a small percentage of the total drainage environments across Windsor-Essex. Through these 10 sites, this research found a range of management intensity of frequencies**, Table 2** identifies the history of sites detailed by both landowner and municipal drain superintendents. The management history of each drain system varied among sites, however overall physical characteristics of the drain, including: size, slope, and soil type, where similar. **Table 1** shows the average environmental variables and indicates slight differences in drain characteristics across the created management gradient. Drains had similar physical characteristics however low sample size did not allow for a complete analysis of the difference between each environmental variable.

The average riparian buffer was 4.4m, however sites had buffers as small as 3m and as high as 7m. The average slope was uniform across sites with the average being 38 degrees, with only one site having large differences in slope with an average of 26 degrees. Canopy cover was low, due to the high management regimes within sites, and sites with low management had the highest average canopy cover (**Table 1**). Direct comparison and significance testing for differences in water quality and chemistry were not appropriate due to a lengthy time period across sampling events, as precipitation events and agricultural activities may have occurred between sampling, which could impact stream measurements.

3.2 – Expert validation

One hundred and thirty-one plant species were given to experts to confirm identifications. Through the expert identification process, plant identifications across expert groups were collected and compared. The expertise of each expert group varied, however of the 131 plant species given to experts, 110 of those examples had two or more expert groups confirming identifications. There were nine identifications that were removed from final species lists because of a lack of expert confirmation or because they were identified as another confirmed species (**Table 6)**. Conflicting consensus across expert groups was relatively low, with a total of 14 individual identifications having conflicting confirmation. The majority of conflict situations were one expert confirming in-field identifications and another suggesting a different species of the same genus. However, there were two circumstances where expert groups identified a completely separate genus of plant, one thistle species had experts confirm the *Sonchus* identification while another expert identified as *Cirsium*. The other example of genus conflict was a bindweed species, one expert confirmed the genus *Calysegia* while another expert group identified as *Convolvulus.*

From the 131 plant species originally identified and given to experts, 121 of those species were confirmed. A total of ten species were removed from final identification lists, including the three not identified by experts and primarily from lack of confidence in expert identification. Three of those ten species were either grass or sedge species, which our experts identified as their weakest areas of expertise. A total of 5 genera and 19 species of plants were altered throughout the expert identification protocol (**Table 5**). To reduce the burden on experts, 11 genera of plants were not included in the expert identification because of either high confidence in the identification of plants or because species were confirmed with experts on sites, shown in **Table 5.**

3.3 - Vegetational biodiversity and plant functional groups

In total, the final species list in this study found 132 different plant species spanning 104 plant genera (**Table 4).** Of the 104 plant genera, only 75 were found within quadrats and 29 were found within transects (**Table 3)**. The ten most abundant genera of plants found across all research sites, in order, were *Solidago* (Goldenrods), *Lolium* (Fescues), *Carex* (Sedges), *Cornus* (Dogwoods), *Ambrosia* (Ragweeds), *Phalaris* (Reed Canary Grass), *Vitis* (Riverbank Grape), *Symphyotrichum* (Asters), *Typha* (Cattails), and *Poa* (Meadow-Grasses). Across all study sites, 33 genera were only present at one site and two plant genera were found at all ten sites (*Lolium* and *Phalaris*) (**Table 4**). From the selected plant functional groups, this study found 19 graminoids, 73 forbacea, 15 small shrubs, 9 trees, 10 vines, and 6 aquatic, with one additional fern (*Equisetum arvense)*. The highest number of species found in one quadrat was fourteen and lowest was one. In total, twenty-one of the species inventoried in quadrats were only found at one site throughout the study.

The composition of plant functional groups also varied across study sites (**Figure 4**), however statistical comparisons were only conducted across the graminoids and forbs functional groups due to the low values of abundance for other functional categories (**Table 7**). Wilcoxon Sum Rank tests showed there were no significant differences ($p>0.05$) between the total abundance of forbs across season and location. No significant differences were found for the total abundance of graminoids across season but there was a significant difference ($p<0.00001$, $V=2$) across site locations; roadside sites had higher total abundance of graminoid plant genera. Kruskal-Wallis and Dunn-Bonferroni tests indicated there were no differences across the total site abundance of graminoids across management gradient, but there was a significant difference of total forb abundance between Low-High managed sites; drains with high levels of management had lower total abundance of forb species ($p=0.0193$, $H=0.377$) (**Table 7**).

3.4 – Vegetational community composition and quality generated by SOFIA

The results from SOFIA generate a summary of the type of vegetational communities and the habitat quality of the ten drainage sites surveyed combined. Of the 133 confirmed plant species, 56% of the species found in this study were native with 44% being introduced. When generating coefficients of conservatism, wetness, and floristic quality index, SOFIA compares only the native species values and the values when all species are considered**.** The overall value of floristic quality is relatively low, with all species only generating a score of 20.03 of 100, but when looking at only native species the FQI increases to 26.85. The mean coefficient of conservatism was also relatively low, with drains having a score of 1.74 out of 10 and with only the native species 3.12. The mean coefficient of wetness with all species was predominantly upland species (1.02). With only the native species the coefficient of wetness is slightly dominated by wetland plant species (-0.51)**.**

3.5 – Vegetational biodiversity indices across environmental variables

3.5.1 – Species Richness

The highest level of species richness found in a quadrat was 14 and the minimum was 1, the average number of species found in each quadrat was 7.36 in the spring and 4.59 in the summer (**Table 8).** Statistical analysis using Wilcoxon Rank Sum tests indicated that species richness was significantly different ($p<0.05$) across environmental variables (**Table 10**). Species richness was significantly higher ($p<0.0001$, $W=713$) in drains directly connected to fields when compared to drains connected to roadsides. Species richness was significantly higher at sites in the spring ($p<0.001$, $W=222.5$) when compared to summer. Lastly, Wilcoxon tests indicated that, like site location, quadrat bank type had significantly higher ($p<0.001$, $W=669.5$) levels of species richness when comparing quadrats located on field-side then roadside quadrats. Kruskal-Wallis tests for environmental variables with three or more conditions also indicated significant differences, but only across management regime. There were significantly higher levels of species richness across the created management gradient ($p<0.0001$) but not for quadrat bank type. Pairwise comparisons of species richness, shown in **Table 11**, using Dunn-Bonferroni methods indicated differences across management regime, specifically that richness was significant different ($p<0.0001$, $H=0.162$), specifically across the High-Low ($p<0.0001$) and High-Medium ($p<0.0001$) managed sites, but not significantly different for Low-Medium (**Table 11)**. There were no significant differences ($p>0.05$) for any of the quadrat bank placements, however, quadrats on the north riparian bank, facing south, had the highest average species per quadrat with 6.71 species (**Figure 5,Table 9)**.

3.5.2 – Shannon-Wiener diversity

Based on Shannon-Wiener diversity calculations, diversity was 2.35 in the spring and 2.10 in the summer, with the lowest diversity recorded being 0 for both seasons, due to quadrats with one species. Overall, average diversity was low across all levels of management (**Table 9**). Statistical analysis using Wilcoxon Rank Sum tests indicated significant differences ($p<0.05$) across all two sample environmental variables (**Table 10)**. There were significantly higher levels of diversity in fieldside drains when compared to roadside drains ($p<0.0001$), significantly higher levels of diversity across spring and summer sampling season ($p<0.001$), and significantly higher levels of diversity when comparing quadrat bank type, with lower diversity found in roadside quadrats when compared to fieldside ($p<0.001$) (**Figure 6)**. A Kruskal-Wallis test for environmental variables with three or more samples indicated that there were significant differences across the management gradient ($p<0.001$) but no significant differences when comparing biodiversity across quadrat bank orientation. Pairwise comparisons of biodiversity using Dunn-Bonferroni methods indicated differences across management gradient indicated that biodiversity was significant higher across the Low-High managed sites ($p<0.001$) but not differences across High-Medium and Low-Medium sites (**Table 11)**. No significant differences in diversity levels were found across quad bank placement, however the North and South facing quadrats had higher average levels of Shannon-Wiener diversity indices (**Figure 6**, **Table 9**).

3.5.3 – Simpson's biodiversity

The highest level of diversity according to the Simpson's index of biodiversity was 0.88 in the spring and 0.85 in the summer, with the lowest level of Simpson's also being 0 because of one species found within quadrats. Across all environmental variables Simpson's diversity was variable, but sites with low levels of management had the highest average Simpson's indices (**Table 6**). Statistical analysis using Wilcoxon Rank Sum tests indicated significant differences ($p<0.05$) across all two-sample environmental variables (**Table 7)**. There were significantly higher ($p<0.0001$) levels of Simpson's diversity at field-side site locations when compared to roadside, significantly higher ($p<0.01$) levels of Simpson's diversity in the spring when comparing to summer sampling, and also significantly higher ($p<0.001$; **Figure 7)** Simpson's diversity when comparing quadrat bank location, with roadside having lower levels of

Simpson's compared to field-side. A Kruskal-Wallis test for environmental variables with three or more samples indicated that there were significant differences across the management gradient ($p<0.01$) and no significant differences across quadrat bank placement. Pairwise comparisons of Simpson's biodiversity using Dunn-Bonferroni methods indicated differences across management gradient indicated that biodiversity was significant higher across the Low-High managed sites ($p<0.001$) but not differences across High-Medium and Low-Medium sites (**Table 11)**. Like the previous biodiversity metrics, the South and North Facing quadrats had a higher average of Simpson's biodiversity indices.

3.2.4 – Site comparisons of biodiversity indices

Overall, plant communities differed across season, with all three biodiversity levels being higher in the spring (**Table 4).** Sites with low levels of management had the highest average species richness according to both diversity indices (**Table 4)**. Comparing diversity across site location (roadside, field-side) and individual quadrat bank types (roadside, field-side) indicated that agricultural drains alongside fields had, on average, higher levels of all three biodiversity measures (**Table 5).** No significance tests were run on biodiversity data due to low sample size across management groupings and at sites.

The most diverse site found in was a low management field-side drain, with eight years since last management, identified as CED-001. Quadrats featured some of the highest levels of diversity based on species richness (14, 10 in the Spring, Summer, respectively) and both diversity indices (Shannon-Wiener; 2.36, 2.10 and Simpson's diversity: 0.89, 0.82, Spring, Summer, respectively). (**Table 13).** The least diverse sites were not at a single site or season, however roadside high management drains contained the lowest diversity scores. Site RVC-003, which was a high management roadside drain, had multiple quadrats with one species, generating low or zero values for Shannon-Wiener and Simpson's diversity. Without counting these quadrats, the next lowest Shannon-Wiener (0.16) and Simpson's (0.07) diversities were found at a different roadside drain with high levels management, PCR-001, in the spring. In the fall, when overall diversity was lower, the lowest levels of Shannon-Wiener (0.13) and Simpson's (0.07) were also found at PCR-001.

3.3 – Vegetational community composition

Vegetational community composition was explored using NMDS using two datasets: abundance data collected in quadrats and presence-absence data collected in transects. Both datasets were visualized using NMDS and then sites were visualized across the different environmental variables including management intensity, site location, and season for abundance data (**Figure 8),** with management and site location used for presence absence data (**Figure 9).** PERMANOVA tests indicated that vegetational communities were significantly different across management gradients (R^2=0.20, F=2.18, p=0.004) and across site locations (R^2=0.20, F=4.54, p=0.001), but not across sampling season. Pairwise comparisons of management gradients indicated that there were significantly different compositions of vegetation communities across Low-High (p=0.003) and Medium-High (p=0.012) managed sites (**Figure 8).** A total of thirteen genera of plants were indicated to be significant ($p<0.05$) in NMDS ordination by using "envfit" function (**Figure 10).** Genera *Ambrosia, Bidens, Carex, Celastrus, Dactylis, Impatiens, Lolium, Melilotus, Phalaris, Rhus, Symphyotrichum, Taraxacum,* and *Vitis,* all had significant impact on the ordination (**Table 11)**. PERMANOVA tests across NMDS ordination of presence and absence data indicated significant differences across both management gradient (R^2=0.33, F=1.8, p=0.02) and site location (R^2=0.19, F=1.96, p=0.043). However, pairwise comparisons of management gradients indicated there were no significant differences in the vegetational communities across management gradients though visually different in **Figure 8.**

3.4 – Drain water chemistry

Across the 10 surveyed sites, measured environmental variables differed but no distinct patterns emerged when comparing averages of all variables. (**Table 1**). However, average conductivity and nitrate were lowest in sites with low management. Environmental variables were visualized using PCA ordination to understand the variability in all measured environmental variables **(Figure 10).** Overall, the total variance captured across environmental variables was relatively low, with PC1 representing 23.59% and PC2 17.79%. The total variance captured within the first eight principal components reached 80% of explained variability. The small sample size and low number of values did not allow for an accurate ordination using PCA, however results from PCA can still inform other conclusions and reflection in this study. In the first principal component, water variables; DOC, TDP, Cond. and carbon signature abs_254 all have positive associations with PC1 (0.38, 0.27, 0.27, 0.37, respectively). The highest association for PC2 were Cond, AvgPercRock, and Bix (0.25, 0.31, 0.41, respectively). Ordination of PCA indicate some variables are directly related to the different management regime, **Figure 11** indicates that fluorometry variables HIX and BIX were directly related to Low and High managed sites respectively.

3.5 – Environmental drivers of vegetational community composition

Environmental variables were further explored to understand how each variable could be impacting vegetational communities. Only environmental variables with possible effects on communities were analyzed, meaning in-stream water chemistry and fluorometry, which may not have a significant impact on riparian vegetation, were removed from analysis alongside any variables indicated to have collinearity. Like PCA ordination, low variation was capture in the RDA analysis, with 31.28% captured in RDA1 and 16.14% in RDA2 (**Figure 12)**. The total inertia from the RDA was 0.6378, with the constrained ordination, representing environmental variables, was indicated to be responsible for 0.4494 of the total inertia (70% of the variance) indicating the measured environmental variables provide an influence on vegetational communities. ANOVA tests indicate that the model is significant (F=1.40, p=0.018) and also indicated that only one variable had significant impact on vegetational communities, which was the created “time since managed” variable (F=2.047, p=0.014).

TABLES

Table 2: Management history at each study site, including site details such as location, management category, and the "time since managed" variable used for RDA analysis. Management history details include both landowner and drain manager date of management, the primary group conducting the management, and type of management for each site. For the types of management, cut refers to mechanical cutting of the vegetation, dredged refers to the removal of sediment within the stream channel, and the removal of shrubs refers to selective cutting of woody shrubs growing on riparian banks.

Site Details				Management History			
Site Code	**Location**	**Management Category**	**Time since Managed**	**Landowner Date**	**Drain Manager Date**	**Primary Manager**	**Type of Management**
CED-001	Field	Low	8	2013-2019	2012-2019	Conservation Authority	Cut and Dredged
CED-003	Field	Medium	5	2016	2016	Municipality	Cut and Dredged
CED-004	Roadside	Medium	5	N/A	2016	Municipality	Cut and Dredged
PCR-001	Roadside	High	1	2020	N/A	Municipality	Cut
PCR-002	Field	Low	11	2010	N/A	Municipality	N/A
RVC-001	Field	Medium	4	2018	2016	Landowner	Cut, Removal of Shrubs
RVC-002	Roadside	High	2	2019	2019	Municipality	Cut
RVC-003	Roadside	High	1	2020	2020	Municipality	Cut and Dredged
RVC-004	Roadside	Medium	4	2017	2016	Contracted engineers	Cut
RVC-005	Roadside	Low	8	2013	2012	Municipality	Cut

Table 3) All 75 genera of plant identified and measured in quadrats: the genus, common/family name, the abundance rank for all species, and the presence or absence (1 or 0) of each genus for each management gradient classification (Low= 3, Medium = 4, High = 3)

Genus	**Common/Family Name**	**Site Abundance Rank**	**Low**	**Medium**	**High**
Alliaria	Garlic Mustard	37	1	1	0
Allium	Wild Garlic	57	1	0	0
Ambrosia	Ragweeds	5	1	1	0
Apocynum	Indian Hemp	45	1	0	0
Asclepias	Milkweeds	34	1	1	1
Bidens	Beggarticks	24	1	0	0
Bromus	Brome Grass	12	1	1	1
Cardamine	Bittercresses	72	1	1	0
Carex	Sedges	3	1	1	1
Celastrus	Bittersweets	22	1	0	0
Cerastium	Chickweeds	64	1	0	0
Chenopodium	Lambs Quarters	51	0	1	0
Cirsium	Thistle	15	1	1	1
Convolvulus	Bindweeds	27	1	1	1
Cornus	Dogwoods	4	1	1	1
Cryptotaenia	Honeworts	62	1	1	0
Dactylis	Orchard Grass	16	0	1	1
Daucus	Wild Carrot	19	1	1	1
Dipsacus	Teasels	18	1	0	1
Elaeagnus	Autumn Olive	65	1	1	0
Elymus	Wild Rye	14	1	1	1
Equisetum	Field Horsetail	42	0	1	1
Erigeron	Fleabanes	69	0	0	1
Euphorbia	Spurges	59	1	0	0
Fallopia	Buckwheats	32	0	1	0
Galium	Cleavers	26	0	1	0
Geum	Avens	17	1	1	1
Hibiscus	Flower-of-an-Hour	74	0	1	0
Impatiens	Touch-me-nots	60	1	0	0
Juniperus	Cedars	66	0	1	0
Lactuca	Prickly Lettuce	54	1	1	1
Lamium	Dead-nettles	46	0	1	0
Lathyrus	Peas	55	0	1	1

Lepidium	Peppergrasses	35	0	1	0
Lilium	Lilys	25	1	0	0
Lithospermum	Stoneseed (Puccoon)	67	0	1	0
Lolium	Fescues	2	1	1	1
Medicago	Medics	38	1	1	0
Melilotus	Sweet Clovers	44	1	1	0
Menispermum	Moonseed	49	1	0	0
Nepeta	Catnips	29	1	1	1
Oenothera	Primroses	63	1	1	0
Oxalis	Woodsorrel	56	1	1	0
Parthenocissus	Virginia Creeper	39	1	1	0
Phalaris	Reed Canary	6	1	1	1
Phleum	Timothy Grass	21	1	1	0
Phragmites	Phragmites	31	0	1	1
Physalis	Groundcherries	68	0	0	1
Plantago	Plantain	73	0	0	1
Poa	Meadow-Grasses	10	1	1	1
Potentilla	Sinquefoils	40	1	1	0
Prunella	Self-heals	50	1	0	0
Prunus	Buckthorns	61	1	0	0
Ranunculus	Buttercups	76	0	1	0
Rhus	Sumac	23	1	1	0
Ribes	Currant	71	1	0	0
Rosa	Rose	11	1	1	0
Rubus	Raspberry	13	1	1	1
Rudbeckia	Coneflowers	75	0	0	1
Rumex	Curly Dock	36	1	1	0
Salix	Willows	43	0	1	0
Sanicula	Snakeroots	48	1	1	0
Setaria	Bristlegrasses	20	1	1	1
Solidago	Goldenrod	1	1	1	1
Sonchus	Sow Thistle	30	1	1	1
Sympyotrichum	Asters	8	1	1	1
Taraxacum	Dandelions	28	1	1	1
Thalictrum	Meadow-Rue	58	1	0	0
Thlaspi	Field pennycress	70	1	0	0
Toxicodendron	Poison Ivy	47	1	1	0
Trifolium	Clovers	53	0	1	0
Typha	Cattails	9	0	1	0

Ulmus	Elms	41	1	0	1
Verbascum	Mulliens	52	1	1	1
Vicia	Vetchs	33	1	0	1
Vitis	Riverbank Grape	7	1	1	1

Table 4) Confirmed species list (including 11 species not confirmed by experts), including genus, each confirmed species, species common name, and the number of sites with genus present.

Genus	Confirmed Species	Common	Sites Present
Acer	negundo	Manitoba Maple	1
Alcea	rosea	Common Hollyhock	1
Alisma	triviale	Northern Water-Plantain	4
Alliaria	petiolata	Garlic Mustard	5
Allium	canadense	Canada Garlic	1
Ambrosia	artemisiifolia	Common Ragweed	9
Anthriscus	sylvestris	Cow parsley	1
Apocynum	cannabinum	Hemp Dogbane	3
Arctium	minus	Common Burdock	1
Asclepias	syriaca	Common Milkweed	6
Asparagus	officinalis	Wild Asparagus	2
Atriplex	prostrata	Creeping Saltbush	1
Barberea	vulgaris	Bitter wintercress	1
Bidens	cernua, frondosa	Nodding Beggarticks, Devil's Beggarticks	3
Bromus	ciliatus, erectus, inermis	Fringed Brome, Upright Brome, Smooth Brome	8
Butomus	umbellatus	Flowering-rush	2
Carex	blanda, granularis, lupulina, molesta	Common Wood Sedge, Limestone Meadow Sedge, Hop Sedge, Troublesome Sedge	9
Celastrus	scandens	American Bittersweet	1
Cerastium	fontanum	Cerastium fontanum	1
Chenopodium	album	Chenopodium album	6
Cirsium	arvense, vulgare	Canadian Thistle, Bull Thistle	9
Convolvulus	arvensis	Field bindweed	4
Cornus	amomum, drummondii, rasemosa	Silky Dogwood, Rough-leaved Dogwood, Grey Dogwood	7
Crataegus	crus-galli	Cockspur Hawthorn	1
Cryptotaenia	canadensis	Canadian Honewort	2
Dactylis	glomerata	Orchard Grass	8
Daucus	carota	Wild Carrot	9
Digitaria	sanguinalus	Hairy Crab Grass	1
Dipsacus	fullonum	Wild Teasel	4
Elaeagnus	umbellata	Autumn Olive	2

Elymus	repens, virginicus	Quackgrass, Virginia wildrye	8
Equisetum	arvense	Field Horsetail	5
Erigeron	annuus, philadelphiscus, strigosus	Annual Fleabane, Philadelphia Fleabane, Daisy Fleabane	3
Euphorbia	platyphyllos	Broadleaf Spurge	1
Fallopia	convolvulus	Black bindweed	4
Fraxinus	pennsylvanica	Green Ash	2
Galium	aparine	Galium aparine	3
Geum	laciniatum	Geum laciniatum	9
Glechoma	hederacea	Groud-Ivy	4
Gleditsia	triacanthos	Honey Locust	1
Hemerocallis	fulva	Orange Day-lily	1
Hibiscus	trionum	Hibiscus trionum	1
Hordeum	jabatum	Foxtail Barley	1
Hypericum	perforatum	Common St. John's-wort	1
Impatiens	capensis	Common Jewelweed	1
Juglans	nigra	Eastern Black Walnut	1
Juniperus	virginiana	Eastern Red Cedar	4
Lactuca	serriola	Prickly Lettuce	5
Lamium	purpurem	Red deadnettle	1
Lathyrus	latifolius	Everlasting Pea	2
Leersia	orzoides	Rice Cutgrass	1
Lepidium	campestre	Filed Peppergrass	2
Lithospermum	incisum	Narrowleaf Pucoon	1
Lolium	arundinaceum, perenne, pratense	Tall fescue, Perennial ryegrass, pratense	10
Lonicera	tatarica	Tatarian Honeysuckle	1
Ludwigia	palustris	Water Purslane	2
Lycopus	americanus	American Bugleweed	2
Medicago	lupulina	Black Medick	4
Melilotus	albus, officianalis	White Sweet Clover, Yellow Sweet Clover	6
Menispermum	canadense	Canada Moonseed	1
Morus	alba	White Mulberry	2
Nepeta	cataria	Catnip	7
Oenothera	biennis	Common Evening Primrose	5
Oxalis	stricta	Slender Yellow Woodsorrel	3
Parthenocissus	quinquefolia	Virginia Creeper	5
Persicaria	lapathifolia	Pale Smartweed	1
Phalaris	arundinacea	Reed Canary Grass	10
Phluem	pratense	Timothy Grass	2

Phragmites	australis	Phragmites	5
Plantago	lanceolata	Englished Plantain	2
Poa	compressa, pratensis	Canada Bluegrass, Kentucy Bluegrass	9
Potentilla	recta	Sulphur Cinquefoil	2
Prunella	vulgaris	Common Selfheal	1
Prunus	virginiana	Common Chokeberry	2
Ranunculus	abortivus, sceleratus	Kidney-leaved Buttercup, Cursed Buttercup	4
Rhamnus	cathartica	European Buckthron	1
Rhus	typhina	Staghorm Sumac	4
Ribes	americanum, cynosbati	American Black Currant, Eastern Prickly Gooseberry	3
Rosa	blanda, multiflora, palustris	Smooth Rose, Multiflora Rose, Swamp Rose	5
Rubus	ideaus spp. strigosus	North American Red Raspberry	7
Rudbeckia	hirta	Black-eyed Susan	2
Rumex	cripus	Curled Dock	9
Sagittaria	latifolia	Broadleaf Arrowhead	1
Salix	interior	Sandbar Willow	1
Sanicula	canadensis var. canadensis, ordata	Canadian Black Snakeroot, Clustered Sanicle	2
Schoenoplectus	tabarnaemontani	Soft-stemmed Bullrush	1
Scripus	artovirens	Dark-green Bullrush	4
Setaria	glauca var. pumila	Yellow Foxtail	5
Smilax	tamnoides	Bristly Greenbier	1
Solanum	emulans	Eastern Black Nightshade	1
Solidago	altissma	Tall Goldenrod	8
Sonchus	arvense	Field Sow Thistle	6
Symphyotrichum	ericoides, lanceolatim, novae-angliae	White Heath Aster, Panicled Aster, New England Aster	9
Taraxacum	officinale	Common Dandelion	8
Thalictrum	pubescens	Tall Meadow-rue	1
Thlaspi	arvense	Field Pennygress	3
Toxicodendron	radicans	Poison Ivy	4
Trifolium	repens	White Clover	5
Typha	angustifolia, latifolia	Nawwor-leaved Cattail, Broad-leaved Cattail	6
Ulmus	pumila, rubra	Siberian Elm, Slippery Elm	3
Verbascum	blattaria, thapsus	Moth Mullein, Common Mullein	6
Verbena	hastata, urticifolia	Blue Vervain, White Vervain	2

Vicia	villosa	Hairy Vetch	3
Vitis	riparia	Riverbank Grape	8

Table 5) List of plant species not included in expert confirmation process and reasoning.

Species	**Common Name**	**Reason**
Asparagus officinalis	Asparagus	High Confidence
Cardamine hirsuta	Hairy Bittercress	High Confidence
Cryptotaenia canadensis	Canadian Honewort	High Confidence
Robinia pseudoacacia	Black Locust	Confirmed on site with Landowner
Juglans nigra	Eastern Black Walnut	Confirmed on site with Landowner
Lactuca serriola	Prickly Lettuce	High Confidence
Lepidium campestre	Field Peppergrass	Confirmed on site with Landowner
Phragmites australis	Phragmites	High Confidence
Rudbeckia hirta	Black-eyed Susan	Confirmed on site with Landowner
Taraxacum officinale	Dandelions	High Confidence
Toxicodendron radicans	Poison Ivy	High Confidence

Table 6) Number of species that were changed throughout expert confirmation process across all created functional groups. The original number of each functional group, the number of changed genus, number of changed species, number of plants removed from final species list, and the final number of species confirmed by expert confirmation process.

	Grass	**Sedge**	**Rush**	**Forbs**	**Shrub**	**Trees**	**Vines**	**Aquatic**	**TOTAL:**
Original Number Identified	19	6	3	65	15	8	8	7	131
Plant Genus Changed	0	0	0	2	1	1	1	0	5
Plant Species Changed	3	1	0	7	3	3	1	1	19
Number Plants Removed	1	2	0	3	0	0	1	2	10
Final Number Identified	18	4	3	62	15	8	7	5	121

Table 7) Summary of analysis on plant functional groupings. First, Wilcoxon Rank Sum tests comparing the abundance of forb and graminoid functional groups across season and location. Second, results from Kruskal-Wallis test with pairwise Dunn-Bonferroni tests across management gradient.

Wilcoxon		**V**	**P-Value**	**Signif.**	
Season	Forbs	24	0.7695	ns	
	Grams	17	0.3223	ns	
Location	Forbs	24	0.0691	ns	
	Grams	2	0.00001	***	
Kruskal-Wallis		**df**	**P**	**H**	
Management	Forbs	2	0.0784	0.377	
	Grams	12	0.457	0.184	
Dunn-Bonferroni			**P-Value**	**Adj.P**	**Signif.**
Management	Forbs	Low-Medium	0.784	1	ns
		Low-High	0.00642	0.0193	*
		Medium-High	0.0218		ns
	Grams	Low-Medium	0.144	0.432	ns
		Low-High	0.0285	0.0854	ns
		Medium-High	0.495	1	ns

Table 8), Average species richness, Shannon-Wiener, and Simpson's diversity indices across sites, separated by management gradient and season; spring (above) and fall (below)

Management	**Site**	**Species Richness**	**Shannon-Wiener**	**Simpson's**
Low	RVC-005	6.5	1.24	0.57
	CED-001	10.66	1.80	0.76
	PCR-002	8.25	1.43	0.68
	RVC-001	10	1.74	0.73
Medium	RVC-004	11.00	1.83	0.77
	CED-003	10.16	1.61	0.69
	CED-004	4	0.72	0.36
High	PCR-001	5.5	0.82	0.39
	RVC-002	5.50	1.04	0.56
	RVC-003	2.33	0.46	0.25
Management	**Site**	**Species Richness**	**Shannon-Wiener**	**Simpson's**
Low	RVC-005	3.33	0.52	0.27
	CED-001	5.67	1.16	0.54
	PCR-002	5.00	0.94	0.50
	RVC-001	6.00	1.17	0.57
Medium	RVC-004	5.50	0.89	0.46
	CED-003	7.33	1.09	0.49
	CED-004	3.33	0.59	0.32
High	PCR-001	4	0.53	0.25
	RVC-002	3.66	0.80	0.45
	RVC-003	2.5	0.66	0.46

Table 9) Average Species Richness, Shannon-Wiener, and Simpson's Diversity measures across measured environmental variables and conditions, n represents number of quadrats represented in each condition.

Management Regime	**Species Richness**	**Shannon-Wiener**	**Simpson's**
Low (n=45)	6.91	1.25	0.58
Medium (n=36)	6.88	1.12	0.52
High (n=36)	3.86	0.71	0.39
Site Location	**Species Richness**	**Shannon-Wiener**	**Simpson's**
Roadside (n=72)	4.74	0.84	0.43
Fieldside (n=45)	7.93	1.38	0.63
Season	**Species Richness**	**Shannon-Wiener**	**Simpson's**
Spring (n=58)	7.36	1.26	0.57
Fall (n=59)	4.59	0.83	0.43
Quadrat Bank Placement (Orientation)	**Species Richness**	**Shannon-Wiener**	**Simpson's**
North (South) (n=35)	6.6	1.14	0.56
East (West) (n=24)	4.71	0.78	0.39
South (North) (n=34)	6.18	1.17	0.56
West (East) (n=24)	6	0.99	0.44
Quadrat Bank Type	**Species Richness**	**Shannon-Wiener**	**Simpson's**
Roadside (n=36)	3.97	0.66	0.35
Fieldside (n=36)	6.85	1.22	0.57

Table 10) Summary results from Wilcoxon Rank Sum Test comparing biodiversity measures on each two sample environmental variables.

Biodiversity Measures		**W - Test Statistic**	**P. Value**	**Significance**
Species Richness	Site Location	695	1.87E-08	****
	Season	234	0.000002362	***
	Quadrat Fieldside vs Roadside	551.5	7.327E-08	****
Simpson's	Site Location	860	0.00000208	***
	Season	1061.5	0.0004025	*
	Quadrat Fieldside vs Roadside	713	0.00001096	**
Shannon-Wiener	Site Location	764	1.639E-07	****
	Season	968.5	0.000005222	***
	Quadrat Fieldside vs Roadside	636	0.000001222	***

Table 11) Summary results from Kruskal-Wallis and pairwise comparison using Dunn-Bonferroni methodology comparing biodiversity measures across variables with three or more samples, including management gradient and across quadrat bank orientation.

Management	**P-Value**	**H-Effect**	**Pairwise (P.adj)**					
			High-Low	**High-Medium**	**Medium-Low**			
Species Richness	p<0.0001	0.161	p<0.001	p<0.001	1			
Simpson's	p<0.001	0.101	p<0.001	0.0502	0.797			
Shannon-Wiener	p<0.0001	0.132	p<0.001	0.0101	1			
Quadrat bank orientation	**P-Value**	**H-Effect**	**Pairwise (P.adj)**					
			East-North	**East-South**	**East-West**	**North-South**	**North-West**	**South-West**
Species Richness	0.176	0.0172	0.176	0.610	1	1	1	1
Simpson's	0.0323	0.05	1	0.548	1	0.504	1	0.111
Shannon-Wiener	0.0557	0.045	0.989	0.0839	1	1	1	0.214

Table 12) The thirteen plant genera indicated as having a significant influence ($p<0.05$) on the NMDS ordination. Genus of each significant species with loadings for both NMDS1 and NMDS2, alongside significant P-values (pval). Generated using function ‘envfit’.

Genus	**NMDS1**	**NMDS2**	**p-Value**
Ambrosia	-0.61299	0.390552	0.002
Symphyotrichum	-0.0196	-0.51552	0.05
Bidens	-0.43957	0.248861	0.039
Carex	0.419862	-0.65383	0.001
Celastrus	-0.44123	0.345408	0.022
Dactylis	0.289229	0.63673	0.001
Impatiens	-0.44234	0.255168	0.04
Lolium	0.472728	0.623381	0.001
Melilotus	-0.42134	0.296083	0.043
Phalaris	0.336329	-0.45319	0.021
Rhus	-0.63597	0.003124	0.014
Taraxacum	-0.56315	0.464647	0.002
Vitis	-0.50845	-0.40356	0.01

Table 13) Site Biodiversity Indices, Species Richness, Shannon-Wiener, and Simpson's, calculated at each quadrat, across Spring (A) and fall (B). Missing values at site PCR-002 are quadrats not sampled due to harmful plants.

A

	Species Richness						Shannon-Wiener						Simpsons					
	Q1	Q2	Q3	Q4	Q5	Q6	Q1	Q2	Q3	Q4	Q5	Q6	Q1	Q2	Q3	Q4	Q5	Q6
CED-001	13	12	14	9	8	9	2.01	1.68	2.36	1.36	1.60	1.85	0.82	0.70	0.89	0.61	0.72	0.82
CED-003	12	13	10	8	13	8	1.82	1.83	1.75	1.26	1.65	1.74	0.76	0.75	0.77	0.58	0.68	0.75
CED-004	4	3	5	2	8	2	0.51	0.44	0.70	0.16	1.88	0.67	0.23	0.22	0.32	0.07	0.82	0.48
PCR-001	4	2	10	4	5	9	1.15	0.16	1.61	0.51	0.52	1.00	0.63	0.07	0.70	0.25	0.25	0.47
PCR-002	10	7	10	6			1.61	1.54	1.63	0.95			0.73	0.73	0.75	0.49		
RVC-001	8	7	8	14	14	11	1.44	1.45	1.73	2.20	1.74	2.01	0.64	0.70	0.77	0.84	0.72	0.82
RVC-002	6	8	4	7	4	4	1.09	1.20	1.05	1.23	0.81	0.88	0.55	0.60	0.60	0.62	0.48	0.53
RVC-003	1	3	1	4	1	4	0.00	1.03	0.00	0.76	0.00	1.00	0.00	0.62	0.00	0.38	0.00	0.52
RVC-004	13	9	13	13	8	10	2.08	1.04	2.05	2.05	1.75	2.03	0.84	0.54	0.82	0.82	0.78	0.84
[illegible]5	3	6	4	12	4	10	0.23	1.32	0.97	2.11	1.19	1.62	0.09	0.62	0.51	0.84	0.66	0.70

B

	Species Richness						Shannon-Wiener						Simpsons					
	Q1	Q2	Q3	Q4	Q5	Q6	Q1	Q2	Q3	Q4	Q5	Q6	Q1	Q2	Q3	Q4	Q5	Q6
CED-001	10	2	10	3	6	3	2.10	0.69	1.74	0.49	1.68	0.28	0.85	0.50	0.72	0.25	0.79	0.12
CED-003	10	8	8	7	5	7	1.71	1.21	1.11	0.52	1.35	0.67	0.75	0.52	0.49	0.20	0.70	0.29
CED-004	3	4	2	4	3	4	0.15	0.97	0.13	1.18	0.18	0.93	0.06	0.53	0.06	0.67	0.07	0.54
PCR-001	2	5	3	4	2	6	0.18	0.42	0.18	0.48	0.03	1.57	0.09	0.17	0.07	0.25	0.01	0.76
PCR-002	7	4	4	4	6		0.73	1.37	0.53	1.15	0.94		0.33	0.74	0.25	0.65	0.55	
RVC-001	6	3	5	7	6	9	1.47	0.79	1.46	0.98	1.55	0.79	0.70	0.46	0.74	0.46	0.76	0.31
RVC-002	2	5	2	6	2	4	0.69	0.64	0.69	1.38	0.69	0.68	0.50	0.29	0.50	0.67	0.50	0.33
RVC-003	2	4	2	2	2	3	0.69	0.77	0.69	0.69	0.69	0.44	0.50	0.51	0.50	0.50	0.50	0.21
RVC-004	8	5	3	9	4	4	1.30	0.76	0.72	1.39	0.87	0.27	0.60	0.42	0.50	0.60	0.54	0.11
RVC-005	2	7	3	2	5	1	0.43	1.25	0.15	0.13	1.18	0.00	0.26	0.64	0.06	0.06	0.59	0.00

FIGURES

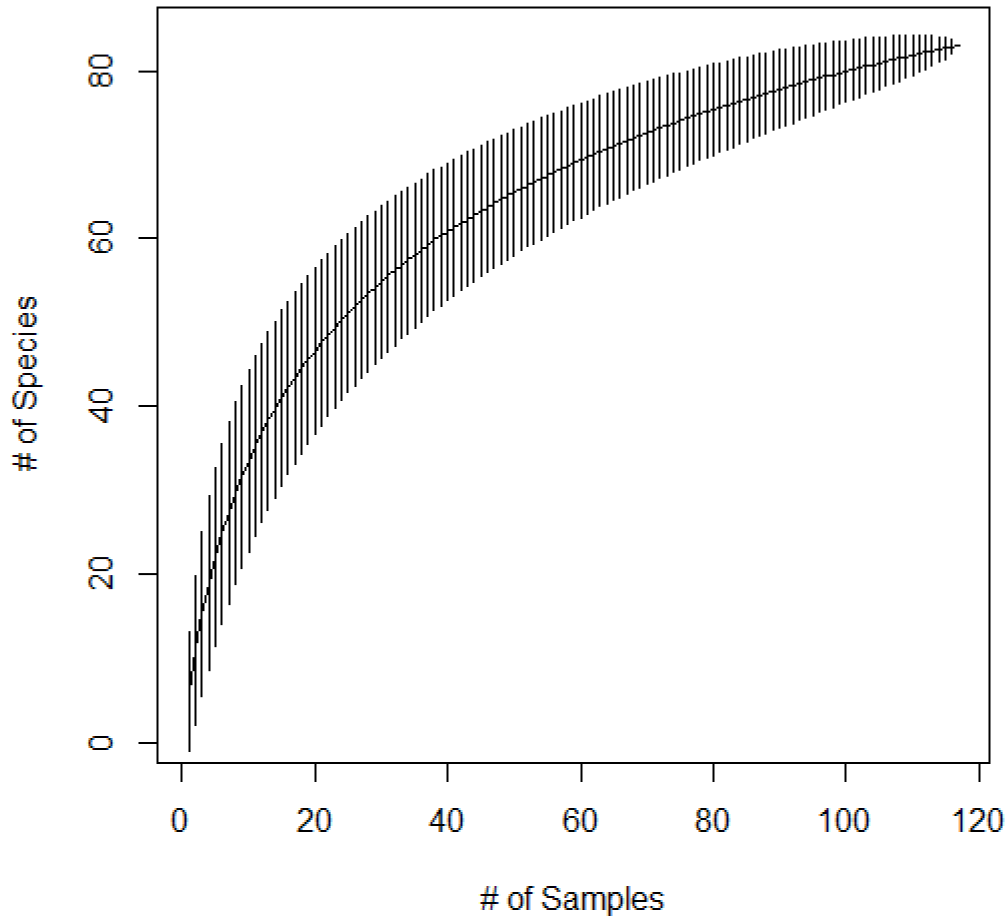

Figure 3: Species accumulation curve calculated from quadrat plant abundance data, total number of quadrat samples were n=117 and number of genera found in quadrats were 76 total, indicating adequate sampling.

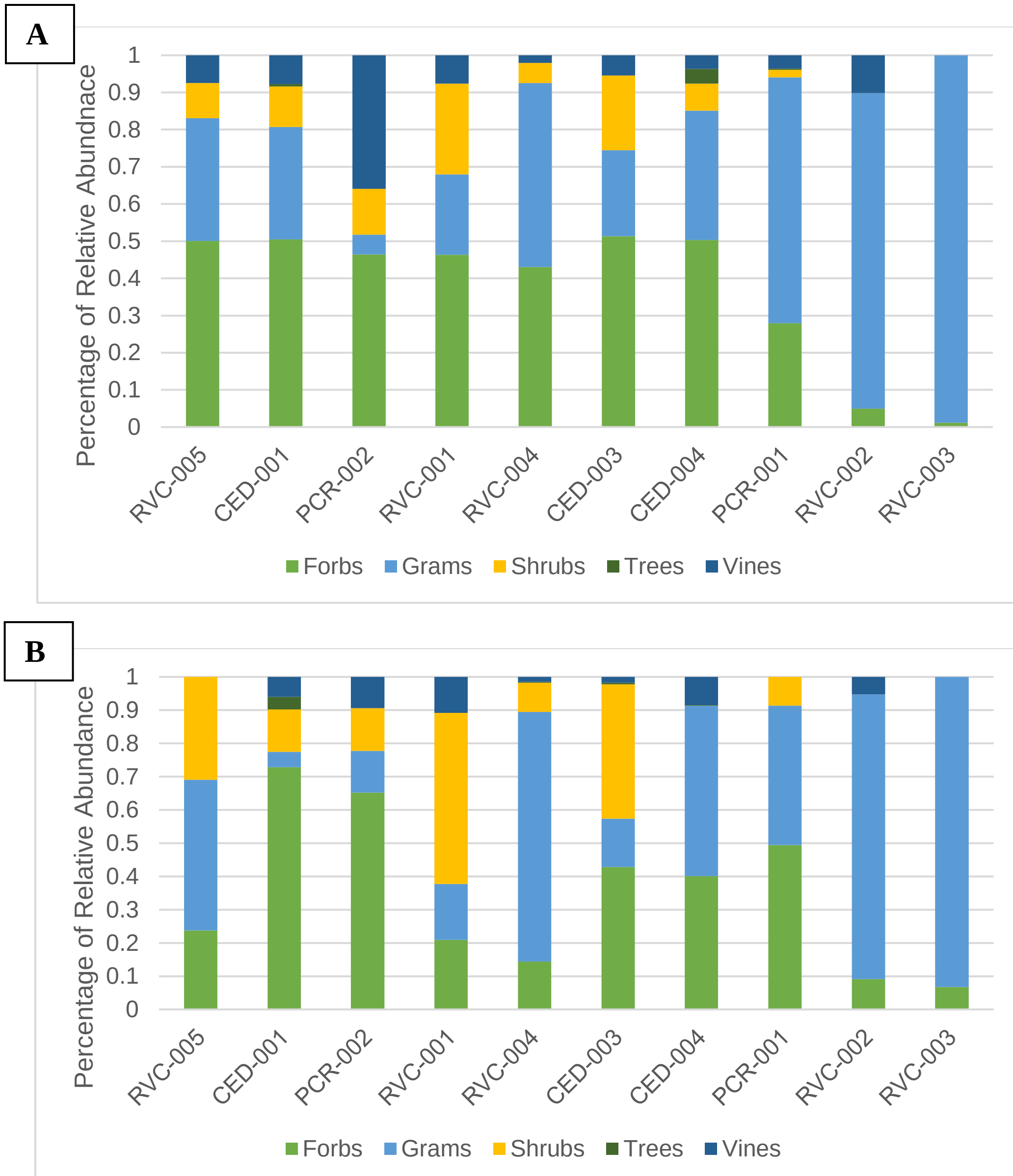

Figure 4: Bar graph representing the composition of plant functional groups (Forbs, Graminoids, Shrubs, Trees, and Vines) across all sites in both spring (A) and fall (B). Sites organized according to management gradient, with least managed sites on left. Wilcoxon Sum Rank tests showed there were no significant differences ($p>0.05$) between the total abundance of forbs across season and location. No significant differences for the total abundance of graminoids across season but there was a significant difference ($p<0.00001$) across site locations, roadside sites had higher total abundance of graminoid plant genus. Kruskal-Wallis and Dunn-Bonferroni tests indicated there were no differences across the total site abundance of graminoids, but there was a significant difference ($p=0.0193$, $H=0.377$) of total forb abundance between Low-High managed sites.

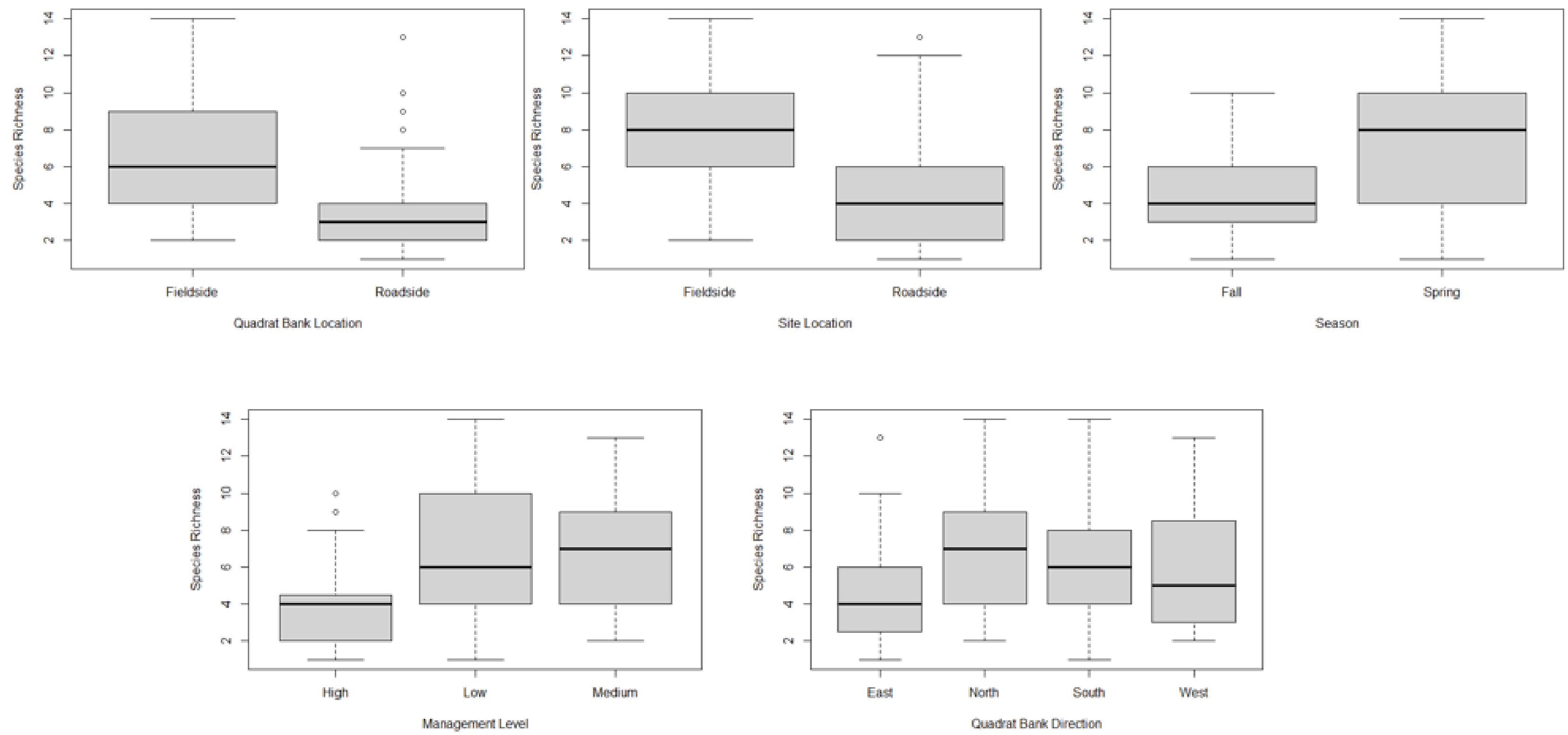

Figure 5) Box-whisker plot of species richness values across all environmental variables. Species richness was significantly different ($p<0.05$) site location ($p<0.0001$), season ($p<0.001$), quadrat bank location ($p<0.0001$) but not significant for quadrat bank placement. Pairwise comparisons of species richness across management regime indicated that richness was significant different ($p<0.0001$), specifically across the High-Low ($p<0.0001$), and High-Medium ($p<0.001$) managed sites, but not significantly different for Low-Medium with no significant difference ($p>0.05$) for any of the Quadrat Bank Direction.

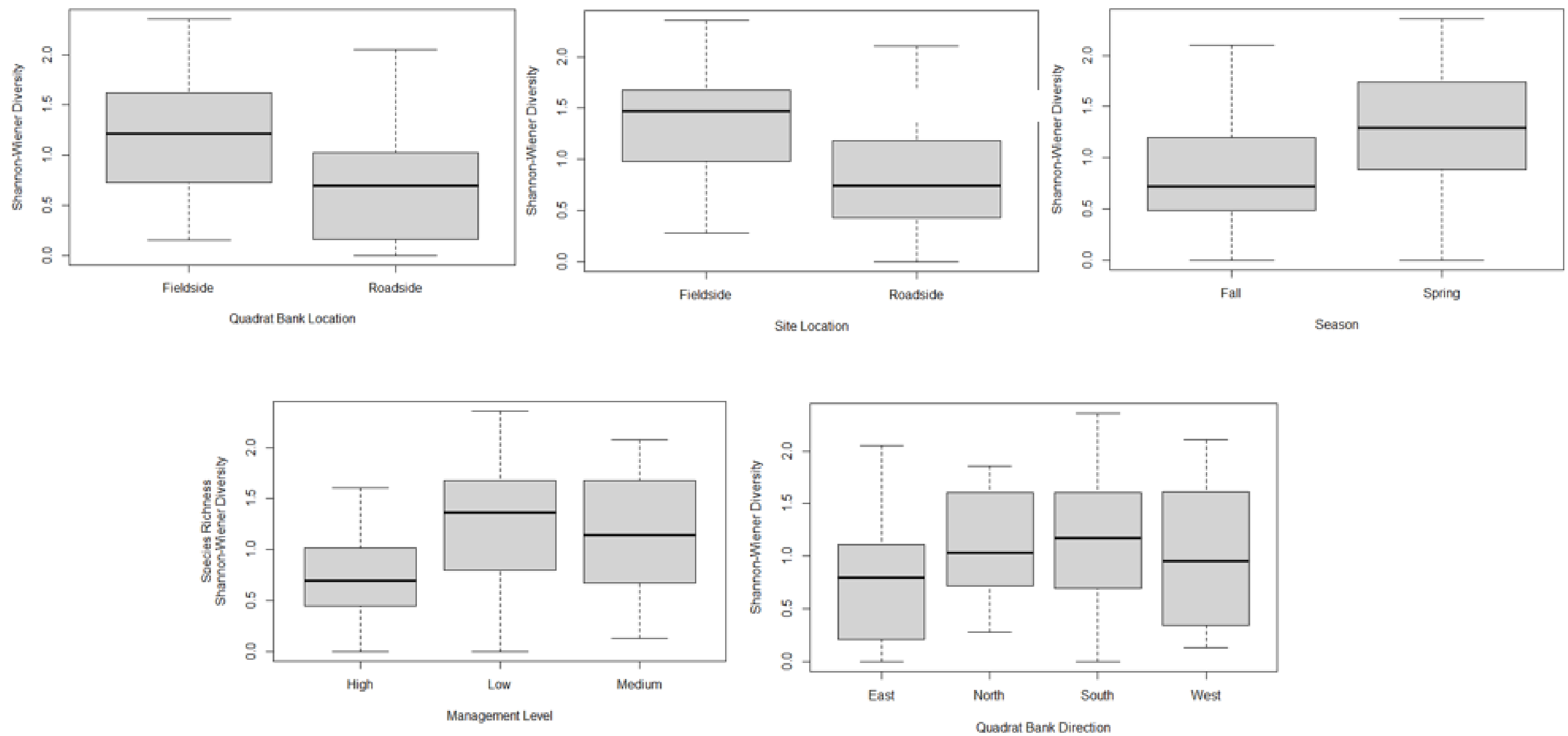

Figure 6) Box-whisker plots of Shannon-Wiener biodiversity values across all environmental variables. Shannon-Wiener diversity was significantly different ($P<0.05$) across site location ($P<0.0001$), season ($P<0.0001$), and quadrant bank location ($P<0.01$), but not for quadrat bank orientation. Pairwise comparisons of diversity across management regime indicated that levels of Shannon-Wiener diversity were significantly different ($P<0.0001$), specifically across the High-Low ($P<0.0001$), but not significantly different ($P>0.05$) for High-Medium or Low-Medium comparisons.

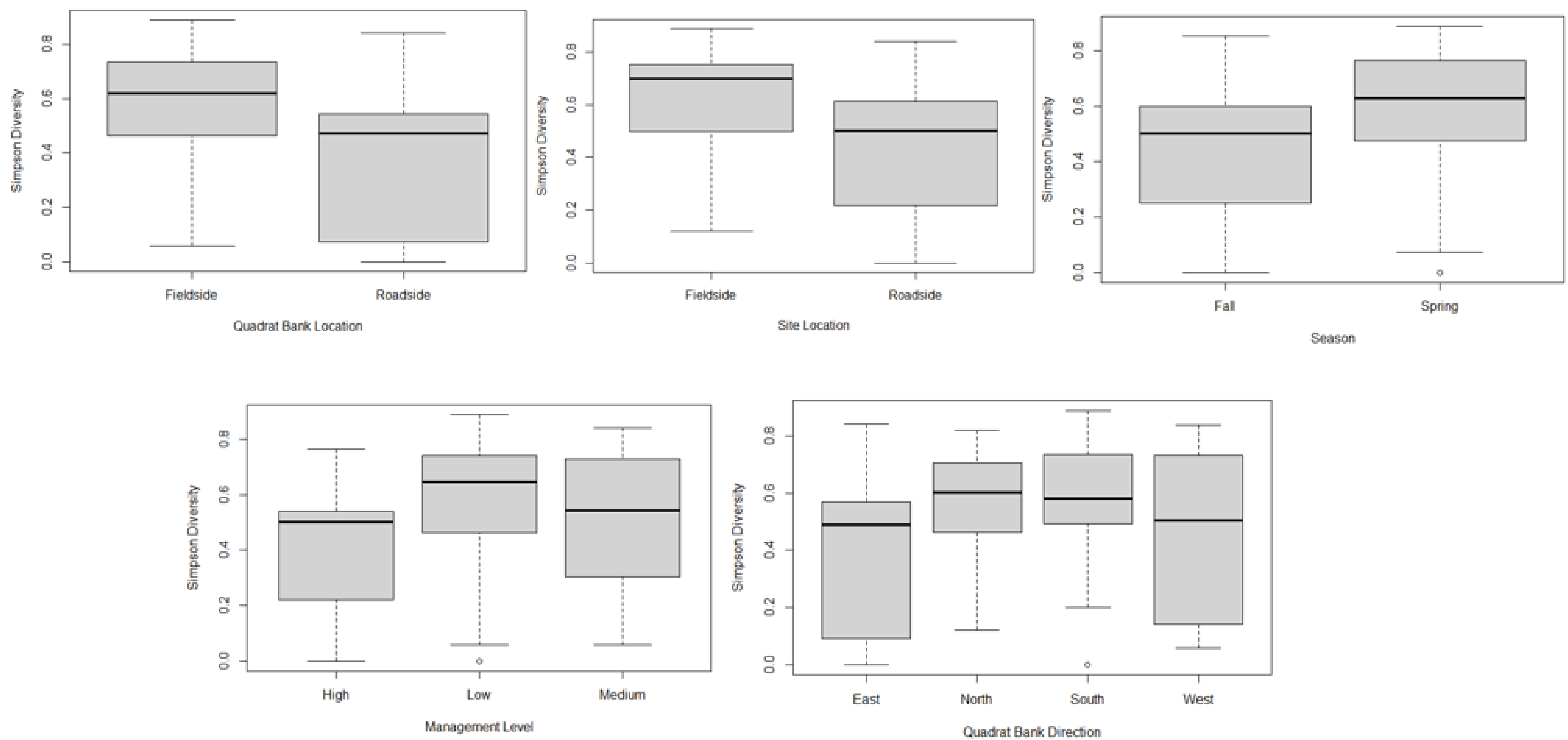

Figure 7) Box-whisker plots of Simpson's biodiversity values across all environmental variables. Simpson's diversity was significantly different across site locations ($P<0.00001$), season ($P<0.0013$), and quadrat location ($P<0.01$), but not across Quadrat bank orientation. Simpson's diversity levels across management regime showed significant differences ($P<0.001$), specifically having significant differences across the High-Low ($P<0.0001$), and High-Medium ($p=0.04$) managed sites, but not significantly different for Low-Medium

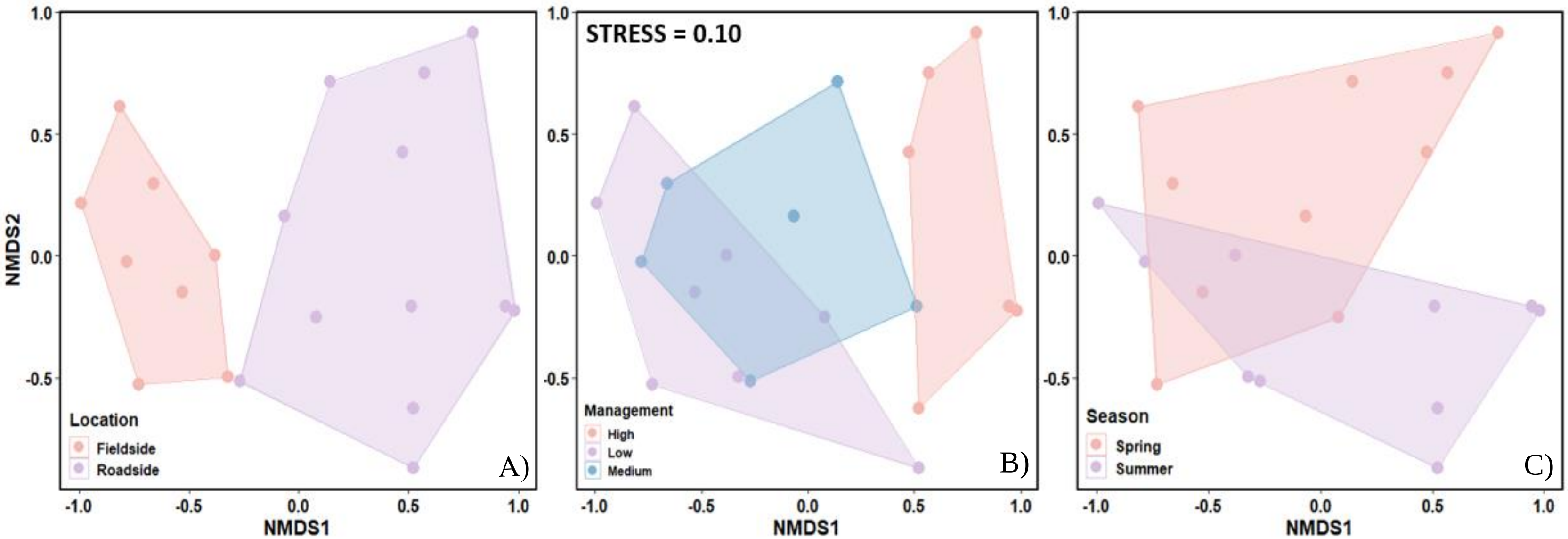

Figure 8) NMDS ordination of plant genus abundance across A) Location, B) Management, and C) Season. (Stress = 0.10). PERMANOVA analysis indicated differences across Location (R^2=0.20, F=4.54, P<0.001) and Management (R2=0.204, F=2.18, p=0.004), pairwise comparisons indicate differences specifically between Low-High management (R^2=0.22, F=3.58, P.adj=0.003) and Medium-High management (R2=0.19, F=2.45, P.adj=0.012). PERMANOVA indicated no significant difference across seasons.

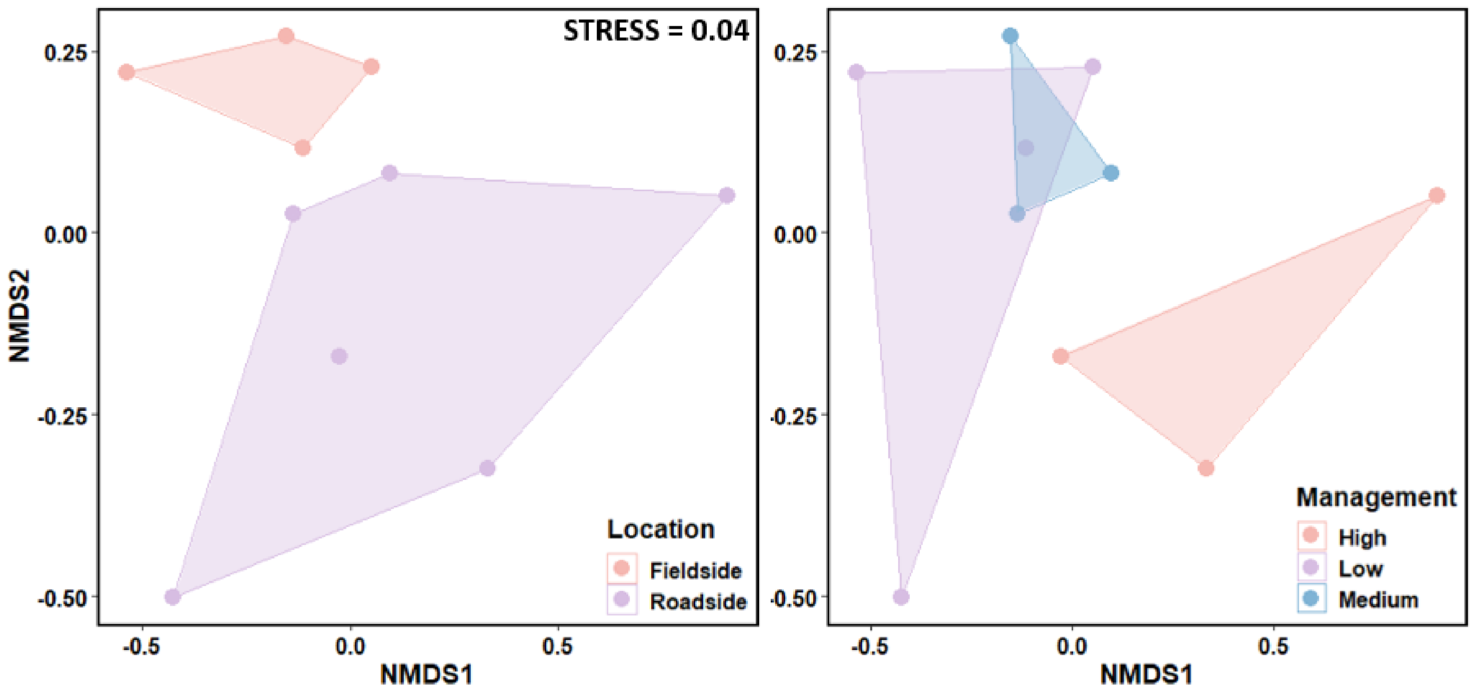

Figure 9) NMDS ordination of plant genus presence and absence across Location and Management. (Stress = 0.04). PERMANOVA analysis indicated differences across Location (R^2=0.19, F=1.968,p=0.048) and Management (R^2=0.33, F=1.8, p=0.035), pairwise comparisons indicated no significant differences when comparing any of the management gradients.

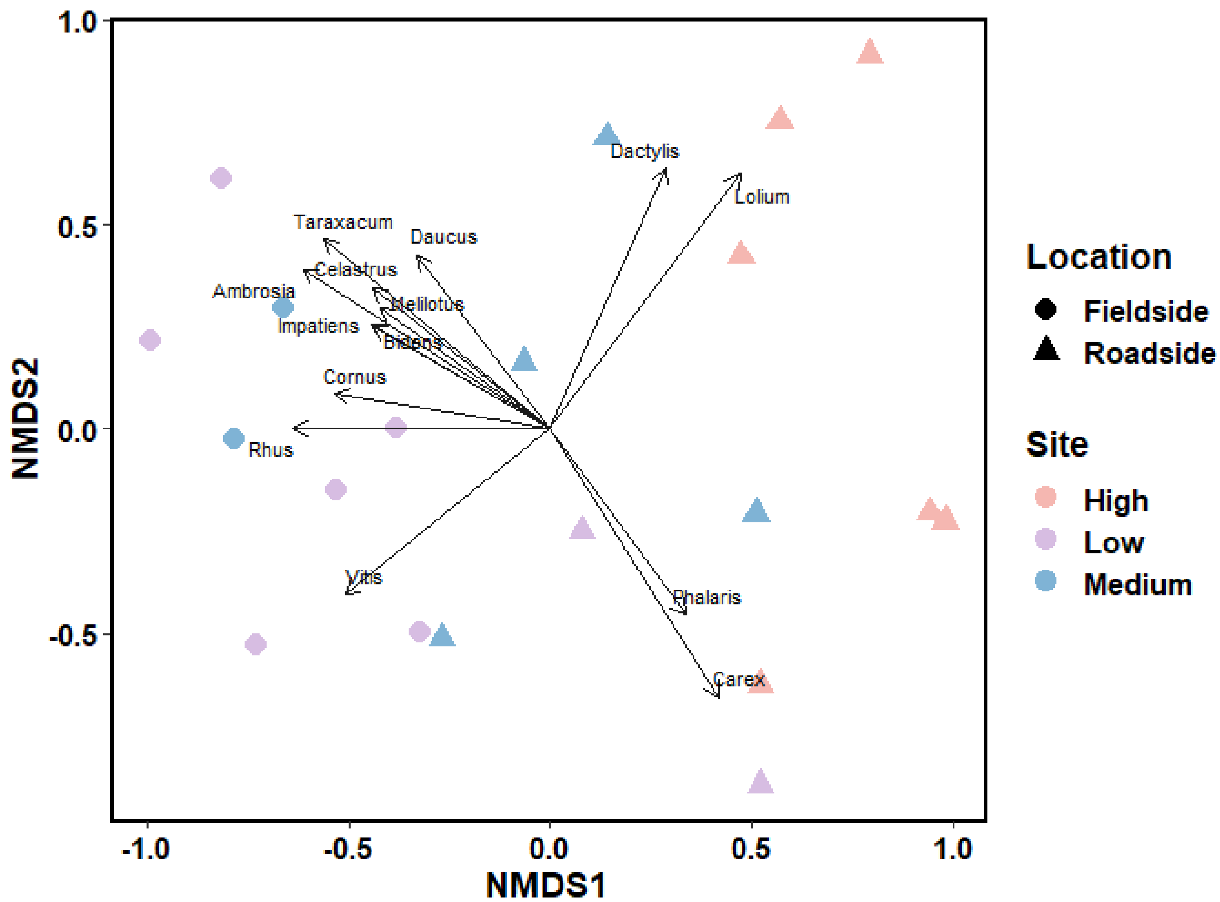

Figure 10) NMDS ordination genus abundance data of sites along management regime (Low, Medium, High), site location (Fieldside, Roadside), and plant genus indicated to have influenced ordination significantly using 'envfit' function ($p<0.05$). (Stress=0.10)

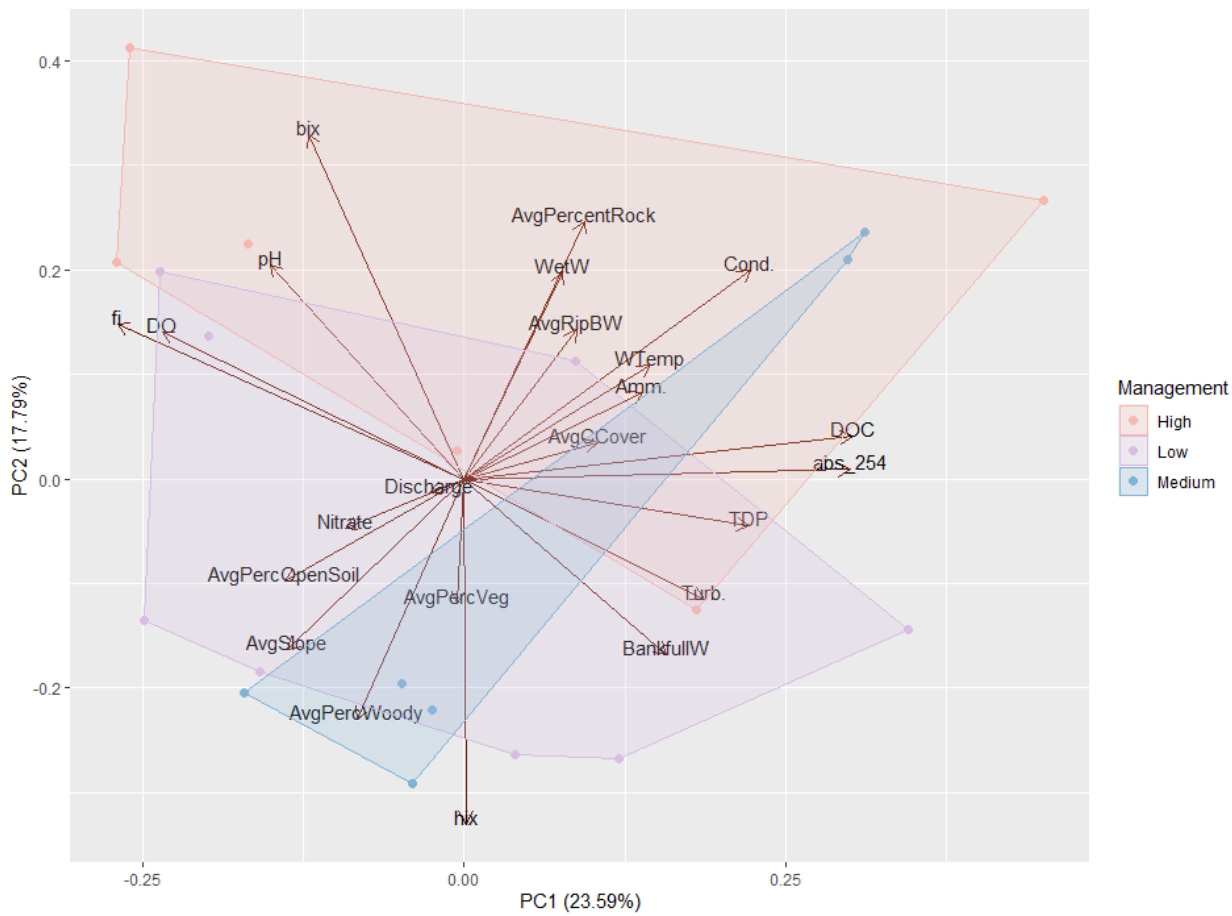

Figure 11) Ordination of environmental variables using PCA, with both spring and summer measurements for each site. PC1 represents 23.59% of the variance in the data, and PC2 represents 17.79%.

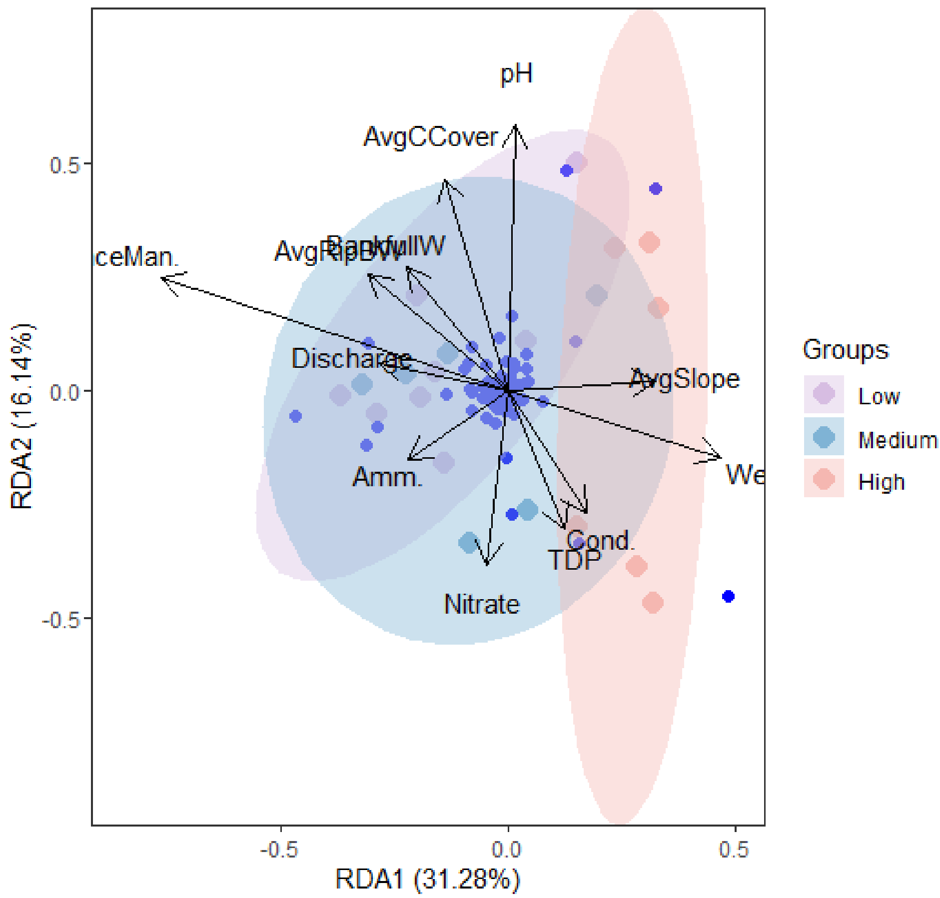

Figure 12) RDA ordination showing relationship between genus and environmental variables. Low variation was captures in the RDA analysis, with 31.28% captures in RDA1 and 16.14% in RDA2. Permutation tests indicated the model was significant (F=1.40, p=0.018) and only one variable, 'time since managed", was indicated to significantly impact communities (F=2.20, p=0.014).

CHAPTER 4 - DISCUSSION

4.1 – Vegetational biodiversity in agricultural drain ecosystems

The goal of this research was to generate a better understanding of the vegetational communities residing across agricultural drains in Essex County, southwestern Ontario. Here I presented one of the few surveys of these under-studied habitats in southwestern Ontario, Canada. Agricultural drains are recognized for their importance for ecosystem service provisioning, especially underpinned by biodiversity for a list of organisms (see Martin et al., 2019). This research provides one of the only vegetation surveys for drain habitats for the Essex region with the goal of filling critical knowledge gaps and advance further research on local biodiversity and drain management.

My thesis specifically set out to address two hypotheses:

H1. Agricultural drains actively managed for *Phragmites* will support less diverse riparian vegetational communities than infrequently managed ones.

H2. Riparian vegetational communities will be seasonally and spatially variable due to management practice and other environmental factors.

To test H1, I generated biodiversity measures, calculated abundance of plant functional groups, and used NMDS to visualize community composition. I found that all levels of biodiversity varied across the created management gradient and management affects the levels of biodiversity provided by drains. I also found that the composition of communities and functional groups was different across management levels, with higher levels of graminoids found at sites with high levels of management. The ordination of these communities using NMDS also indicated that vegetational communities are significantly different across the created management gradient, a difference that was seen in both abundance and presence-absence data.

To test H2, I used PCA and RDA to explore my measured environmental variables and attempted to test if any of the variables had a significant correlation to vegetational community composition. From PCA, we found that some measured variables were found to be more related to different levels of management levels, however no significance tests were able to run, due to low sample size, which would have identified if the measured variables were different across sites and the created management gradient. Though RDA, we found that no measured environmental variable was directly impacting vegetational communities besides the created “time since management” variable. This result, though not supported completely because of low number of sites, indicated that management has a larger impact when compared to the other environmental variables.

4.2 – Drains as important ecosystems for biodiversity

Conservation measures and policies used to address global biodiversity loss are building, and Canada as a nation has signed many agreements that lay out the framework for attempting to halt biodiversity decline, such as the global biodiversity framework (GBF). While drains are a unique ecosystem, they are often forgotten as a critical habitat for biodiversity and are usually not considered in land measurements for natural areas. The continuing recognition of the importance of drains has slowly begun to distinguish the “ecosystem” or “natural” values to these modified habitats. Drainage systems are found along nearly every field and roadside in agriculturally dominated regions, making them an abundant habitat type with a researched list of organisms that utilize them.

This research speaks to the key targets in the GBF which set out to protect what important environments remain, halt biodiversity loss, and restore remaining ecosystems, respectively (COP15, 2022). In agriculturally-dominated regions, there are few patches of important habitat, different types of land conversion that is continuing, and a large amount of drainage infrastructure that could be considered for areas needing restoration. Furthermore, the land conversion that is happening now is more from the spread of urban environments, Ontario is losing 175 acres of farmland each day from development (OFA, 2022). While the levels of biodiversity found in this study are not representative of what conservation practitioners or society may deem important or critical habitat, the growing recognition of the ability of these drains to provide the only remaining areas for biodiversity proves its importance.

4.3 – Drains as areas of vegetational biodiversity

The results from my study indicated that, despite a long history of management and modification, drain environments support varying levels of vegetational biodiversity which in turn provide habitat for other organisms (e.g., invertebrates, birds, mammals). Many of the biodiversity studies referenced in the introduction contain a range in the level of contribution to vegetational biodiversity, some studies found 45 species across 122 drain environments and others found 512 across 60 agricultural canals (Meiner et al., 2017, Tolgyesi et al., 2020). The closest research geographically was conducted in Quebec and Ottawa, these studies found 271 plant species across 81 study areas (Bowers and Boutin, 2008). In this research, 133 plant species were found in just 10 drains, creating a snapshot of the number of species that can reside within these habitats. Previous studies by Boutin et al. (2003) found that drain environments can provide areas for rare plants not found elsewhere. In this study, only two species were identified as rare or possibly rare, the first being Narrowleaf Pucoon (*Lithospermum incisum*). The second possible rare species found was unable to be identified to species because of lack of photos of specific identification features that distinguish the two species. This species is either the Hop Sedge (*Carex lupulina*) or False-Hop Sedge (*Carex Lupuliformis*), which is endangered in Canada. The only identification feature used to distinguish the two species apart is a marking along seedheads, within the larger seed cluster. While this observation was only found once throughout the study, their ability to grow in drains indicates that important species can still thrive within these heavily managed environments.

Drains have unique characteristics that allow them to provide habitat for a variety of species and plant functional types. Across this study, we found 24 graminoids, 70 forbacea, 15 small shrubs, 10 trees, 7 vines, and 6 aquatic species, with one additional fern. This is a similar combination of plant functional groups found by Bowers and Boutin (2008), who found 49 graminoids, 150 forbs, 26 small shrubs, 21 trees, 10 vines, and 15 ferns. The composition and complexity of the types of plants can provide different levels of biodiversity, and ecosystem services. This unique nature of drains provides the ability to harbor a variety of plant species, the small stream and riparian buffers still provide a wide range of plant functional types the ability to establish.

The application used to define floristic quality, SOFIA, is specifically for the Essex County region, it generated the values 'coefficient of conservation' and 'floristic quality' specifically for vegetation in this region. Data from the SOFIA suggest that the overall quality of vegetational communities within drains is low, however differences were apparent when comparing native and non-native species. In this study, only 56% of the species found were native to southern Ontario. When comparing SOFIA conservation values generated by looking at only native species scores and also across all species, these results show both levels of coefficient of conservatism and floristic quality values close to representing important habitat when looking at only native plants. A mean coefficient of conservatism of native plants was 3.02 and scores above 3.5 represent remnant, natural quality, of habitat. Floristic quality values of just native species resulted in a score of 26.85, where scores over 35 can be considered floristically important for the province. Despite almost half of these species found being indicated as introduced or invasive, these results can begin to highlight how these habitats can still provide important areas for native biodiversity.

4.4 – Managing drains and the effects on vegetational biodiversity

Drains in southern Ontario will continue to be managed to maintain water control and to reduce the impact from *Phragmites australis* (Nichols, 2020). Drains face similar challenges globally and are managed to reduce the impact from other invading species in the same way (Dollinger et al., 2015, Levavasseur et al., 2014, Rudi et al., 2020). However, in this study we identified a variety of drains with differing levels of drain management and from this we can see how the management of drains unintentionally impacts biodiversity. Across the created management gradient, the frequency or intensity of drain management greatly impacted levels of vegetational biodiversity. Though drains I sampled featured relatively low levels of biodiversity, the research sites with low levels of management featured significantly higher levels of biodiversity when compared to drains managed yearly, with high intensity.

My results showed that the vegetational communities had distinct compositions across the management gradient, sites with Low and High levels of management were significantly different from each other. The species that can grow under heavy management are primarily graminoid species, which is the functional of grass-liked plants and this is shown through the functional group comparisons and through NMDS ordination. The sites with high levels of management are influenced by graminoid species, while the other two management categories are influenced by a mix of functional group types. Ordination of both quadrat abundance and transect presence/absence show these communities have significantly different assemblages across the created management categories.

Across the created management gradient, my results indicated that both the intensity of management create disruptions to the vegetational communities residing within the drain habitat. Plant growth is significantly impacted by managing drains and if disruption to vegetational communities is high, the only plants able to grow are quick-growing species like graminoids. Graminoid species provide reduced contribution to vegetational biodiversity and overall less diverse composition of important plant functional groups, thus affecting biodiversity in drains with high levels of management. Higher biodiversity was found at sites with low levels of management. Simply put: areas that are not disrupted by dredging, cutting, or spraying support more flowering species. As hypothesized, drains with high levels of management have lower vegetation biodiversity when compared to drains with low levels of management.

A review of ecosystem services provided riparian buffers by Cole et al. (2020) indicates that there remains some uncertainty surrounding the extent to which riparian areas can provide biodiversity as an ecosystem service. This study begins to reduce this uncertainty and provides quantitative measurements of biodiversity in the region that can be compared with other ecosystems. Rarely are these drains considered ‘biodiverse’ habitats, but the small sample size in this study shows that biodiversity is still provided by drains. Across the three biodiversity measures generated in this study: species richness, Simpson’s, and Shannon-Wiener, we can see that drains still provide a range of contribution to regional biodiversity.

4.5 – Influence of measured environmental variables and management on vegetational communities

Many aspects of drain environments can influence the types, or species, of vegetational communities that reside in them. The measured environmental variables within this study did not capture a significant amount of variation between study sites, and small sample size did not allow for a full investigation into the effects each variable has on vegetational communities. Using RDA, the only variable that had significant influence on vegetation communities was the “time since management” variable, indicating that the management timeline in these environments has the largest influence on these communities. Other studies have indicated that specific environmental variables, including buffer width, slope, and canopy cover, can impact the composition of vegetational communities (Bennet et al., 2006). In this study, the buffer width and slope were relatively uniform, with only a few sites having higher slope or buffer width. Only two sites with low management had a significant amount of canopy cover from shrubs and old growth trees, and those values were still relatively low.

In this study, I compared vegetational communities across a created management gradient, as well as season and locations. My analysis showed that there are differences in the amount of biodiversity across seasons, and we found a mix of plans with differing life cycles throughout the growing season. Higher species richness, Simpson's, and Shannon-Wiener diversity indices were found during the Spring sampling period, indicating that many of the species in drains are early blooming plants. However, this inventory also found important late-summer flowering species such as Goldenrod (*Solidago*), Aster (*Symphyotrichum*), and Milkweed (*Asclepias*). Understanding when important plants within drains bloom creates a better understanding of times to manage, or areas that should be left unmanaged so plants can grow completely. *Phragmites australis* is also managed primarily before it goes to seed in late-summer, so the management of drains while late-blooming plants are still growing could have an impact on those plant species.

These results also showed there are differences in the vegetational communities depending on where the drain is located, roadside or fieldside, but also on what riparian bank side these communities are on. Roadside and only fieldside drains can be impacted by different variables, roadside would have more input of road salts and metals from vehicles, while fieldside drains could have more input from nutrients since they are surrounded by fields. In this study I found differences in the community composition and biodiversity across these variables, biodiversity was lower at roadside drains and on roadside banks across all biodiversity measures. This is most likely due to the nature of increased management in roadside drains and because of the nature of management practices. *Phragmites* reduced visibility along roadsides so the management of these drain locations is more frequent. The pattern observed via quadrat bank location was the same pattern we saw during the vegetation survey, there was less management for the drain bank opposite of the roadside. When management occurs, the roadside bank and the drain stream were managed, and sometimes the opposite drain bank was left unmanaged. This result shows that within drains if banks don't need to be managed they can provide higher levels of biodiversity, even in drains with high intensity of management.

4.6 – The ecosystem services provided by drain environments

Overall, this study showed that drains are habitat for vegetation and even though we didn't focus efforts on identifying ecosystem services provided by drains, the potential for other ecosystem services exist. For example, nutrient retention and mitigation is an important service that drains can provide, and the vegetation within drains plays an important role in reducing the impact of nutrient runoff (Cole et al., 2020, Cui et al., 2020, Meuleman & Beltman, 1993, Moore et al., 2010, Kumwimba et al., 2018). While this study did not directly measure in-stream communities that would have the greatest impact on nutrient mitigation, further research can utilize these data to begin exploring how specific communities impact this service. The low sample size and collection of water samples did not allow for any direct relation to the vegetational communities, and more variables need to be measured to better understand this relationship. Numerous studies have identified how the vegetational communities can impact nutrient mitigation, in one study indicated that grass buffers and tree buffers have different nutrient removal efficiencies (Zhang et al., 2010). Another, local, research project looking at vegetated buffers in Ontario indicated that native grass species had higher levels of nutrient retention and higher sediment trapping efficiencies (Abu-Zreig et al., 2004).

The function of nutrient mitigation can vary depending on the physical characteristics of the drain and the communities within them (Lind et al., 2019, Zhang et al., 2010). The vegetational communities can also drive macroinvertebrate and microbial communities which indirectly can impact nutrient retention. Diverse communities have been shown to have positive effects on decomposers, which directly influence the amount of carbon within streams, and vegetation can impact the microbial community primarily responsible for denitrification (Balvanera et al., 2006, Cui et al., 2020). Rates of de-nitrification from microorganisms who rely on useable carbon within streams are relying on macroinvertebrate decomposers to provide the carbon for microscopic processes (Cui et al., 2020). When reflecting on results, we can see interesting patterns from fluorometry measurements taken from water samples.

HIX as an optical carbon-based measure confirmed the presence of terrestrial based vegetation whereas BIX represents algal-derived carbon in water samples (Nolan et al., 2023, in review). Both were measured using fluorometry and describe the extent to which land and riparian carbon influence drain water quality and ecosystem processes therein. Through ordination using PCA, both fluorometry measures of HIX and BIX are directly related to sites with low and high management regime. HIX represents carbon from humic, or organic, sources and BIX represent carbon signatures directly related to bacteria. This may be due to a variety of sources of organic carbon provided by multiple plant functional groups, the presence of woody debris will be reduced when drains are dominated by graminoid species. Though research from this study on this topic is not extensive, this pattern could contribute to further research surrounding how diverse habitats contribute specific types of carbon which can be used by microorganisms. This research provides an initial look at these patterns of important carbon, and research is already underway at GLIER which attempts to understand these microorganism communities in drains further.

Other important services, more ecosystem focused, can be inferred from this study. Alongside global biodiversity, the decline of pollinators is a threat to many aspects of our society, approximately 70% of common crops require pollinators (Hopwood et al., 2015). The species list found in this study have a range of flowering plants which can be beneficial to pollinators. A review from Hopwood et al., indicated that highway roadsides can be managed for the enhancement of pollinator habitat. Although our research did not focus on pollinators, our species list can be used to understand how pollinators utilize these habitats. The vegetation within drains can also impact other important insects and macroinvertebrates. The numerous studies from Tolgyesi et al. (2021), and Martin et al. (2019), can indicate that these environments provide significant habitat for a variety of organisms. Though never measured in this project, researchers saw a variety of spiders, moths, insects, bees, birds, and mammals utilizing these habitats

4.7 – Managing drains for multifunctionality and multiple services

Multifunctionality is an important concept that has gained traction in the last 20 years, starting in Europe and Asia at the turn of the century (Groenfeldt, 2006). The primary issue surrounding drain function is that adequate water flow is required to maintain flood and water control that reduces the impact of excess water on fields (Dollinger et al., 2015, Levavasseur et al., 2014, Rudi et al., 2020). *Phragmites australis* has reduced this service for many years and will continue to dominate these habitats, even with the development of new methods of control. The drainage systems were created to help farmers, but this research adds to the growing call to manage these drains for all the provided ecosystem functions.

Though measurements from this study cannot specifically infer the effect that these vegetational communities have on invasive *Phragmites,* this research begins to develop future projects surrounding this plant. From communication with drain managers, their technicians are finding that cattails (*Typha)* re-establish in drains successfully managed for *Phragmites,* however they also indicated that farmers will require those drains to be managed further to maintain primary functions. Understanding that drains have multiple functions that impact society in different ways is crucial for understanding multifunctionality. While farmers prefer an open drain for flood control, quickly moving water filled with nutrients and sediment is harmful for downstream waterways (Collins et al., 2019, Foley at al., 2005, Herzon & Helenius, 2008, Zhang et al., 2010). This research provided insight into the vegetational communities that are directly responsible for many of the services provided by drains, including the services that can be tied to reductions in harmful pollutants from agricultural practices (Boutin et al., 2003, Gulcin & Yilmaz, 2017, Kumwimba et al., 2018, Tolgyesi et al., 2021). Further exploration specifically into these functions is required but from this research we can begin to identify benefits that would develop from managing for multifunctionality.

This study indicated that vegetational biodiversity is a service provided by these highly modified and managed habitats. While it is not initially considered an important service, this study indicated that more is needed to understand the variety of functions that are provided by these systems. With biodiversity loss, looking at vegetation within drains under the ‘multifunctionality’ scope is an extremely important area requiring further research. If biodiversity can be provided by drains, while still maintaining the important functions of flood control, nutrient mitigation, and erosion control, applying the concept of multifunctionality could improve the services provided by drains and benefit society.

4.8 – Identified knowledge gaps and future research

Acknowledging the low sample size and limited temporal scope of this study, my research surveyed less then 0.001 percent of the drainage infrastructure across Windsor-Essex, the approximate total length of all the drainage systems is longer then 3,000 kms and this project reached under 600m (Dufour, personal communication, 2022). While 10 sites, ranging in management intensity, has provided a large amount of data on plant biodiversity, this study does not represent all of the species possibly residing in drain habitats. Due to COVID-19 and lockdowns the variety of spring ephemerals may have already bloomed before I started sampling in the middle of May. Further research into this area is needed to better understand the biodiversity within these habitats, and further emphasis should be put on identifying possible stronger environmental variables impacting vegetational communities. From the ordination of both abundance and presence/absence data, both analyses showed similar composition of species and a distinct difference between Low and High managed sites. Measures of abundance in quadrats was a time-consuming effort and further research could only utilize the later approach to capture a larger sample size.

This study also surveyed primarily riparian habitat within drains, transect inventories captured in-stream species but not extensively. In attempts to understand *Phragmites australis* and the other communities that can reside in streams, future research projects will need to put larger focus on the in-stream vegetational communities. There are many unexplored variables that could impact the ability for *Phragmites* to grow, such as canopy cover and presence of other plant species occupying the same location *Phragmites* could establish. The input from drain managers indicating that cattails re-establish after management creates opportunities to explore how both of these plants are competing for the same area within drains and whether drains with the presence of cattail stands can reduce the spread or establishment of *Phragmites australis*.

This study provided some of the first insights into the ecological value of drain habitats for plant biodiversity and hints that many of these services need to be analyzed further. As mentioned above, nutrient retention is another important service that needs to be analyzed further. The two largest harmful nutrient connected to agricultural drains is phosphorus and nitrogen, future studies could utilize this data to understand what types of vegetation communities reside in drains but further research into specifically how they impact nutrients is needed. Understanding how different communities reduce sediment contaminated with phosphorus and how vegetational communities impact import microorganism habitat to increase rates of nitrogen reduction (Zhang et al., 2010, Cui et al., 2020).

4.9 - Conclusions

This thesis produced the first inventory of vegetational communities and the first quantification of vegetational biodiversity within agricultural drain systems in southwestern Ontario. Through the management gradient, I’ve shown that drain management techniques impact vegetational communities and that less managed drains contain higher biodiversity. I began to quantify the important value of drain ecosystems, not only for primary services like water control, but for areas of regional biodiversity. While environmental variables did not impact the vegetational communities as clearly as management, this study provides a method of measuring variables impacting communities which can be expanded further. Agricultural drainage systems have been historically viewed only as a way to convey water from fields and I hope this work signals other efforts to assess and halt further biodiversity loss locally and around the world.

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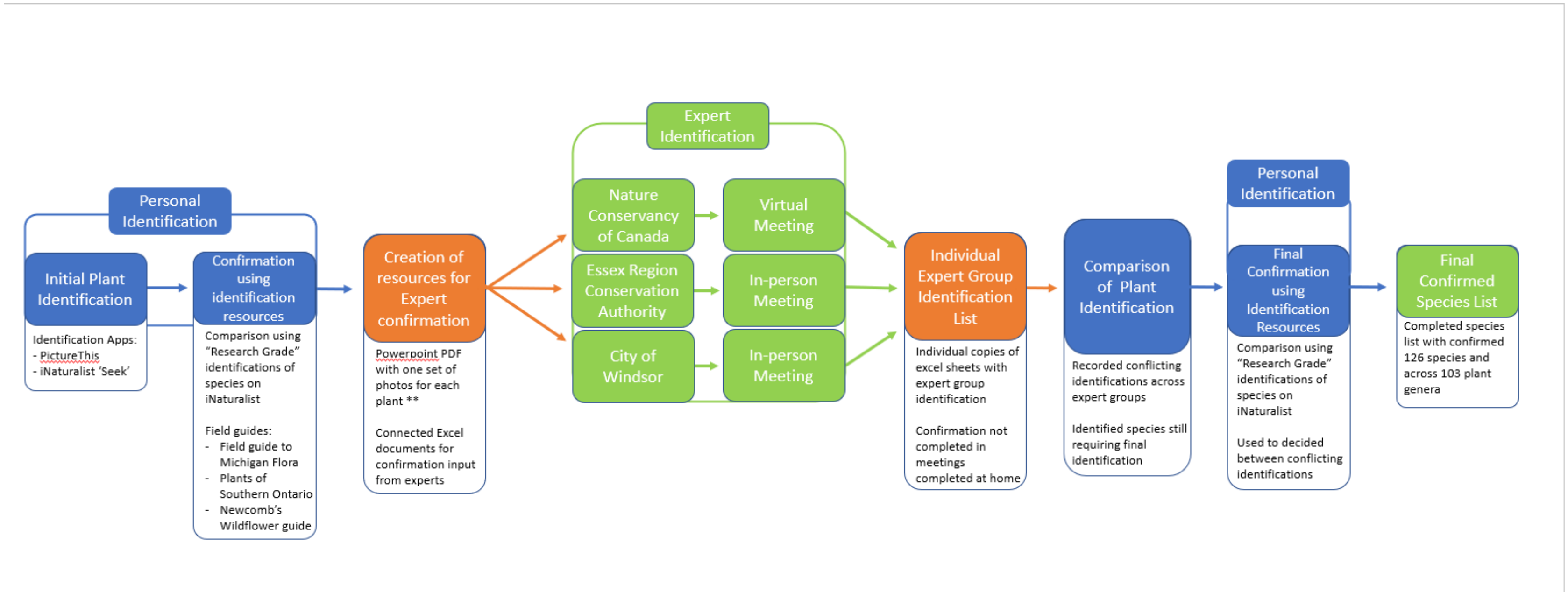
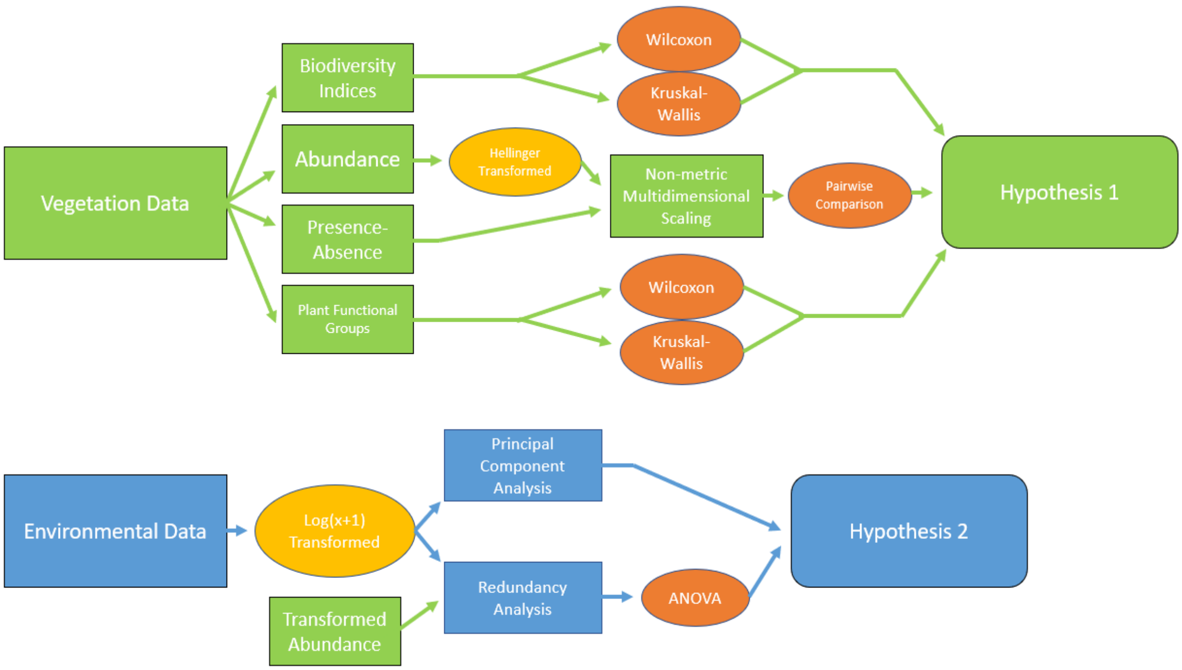
APPENDICES

Appendix 1.1) Ecosystem services provided by agricultural drainage systems, their relative location or source of each defined service, and a list of literature reviews and meta-analysis that synthesize evidence for each service.

Ecosystem Service	Provided by:	Review Sources
Nutrient mitigation	Riparian Vegetation, Microorganisms	Lind et al., 2019, Case et al., 2020, Cole et al., 2020
Erosion Control	Riparian Vegetation	Lind et al., 2019, Case et al., 2020, Cole et al., 2020
Flood Protection	Stream Area	Lind et al., 2019, Cole et al., 2020
Carbon Sequestration	Riparian Vegetation	Cole et al., 2020
Habitat	Riparian Vegetation and Stream Area	Lind et al., 2019, Case et al., 2020, Cole et al., 2020
Connectivity	Riparian Vegetation and Stream Area	Lind et al., 2019, Case et al., 2020,Cole et al., 2020
Biodiversity	Riparian Vegetation and Stream Area	Lind et al., 2019, Cole et al., 2020
Pest Regulation	Riparian Vegetation and Stream Area	Case et al., 2020, Cole et al., 2020
Cultural/ Recreation	Riparian Vegetation and Stream Area	Cole et al., 2020



Appendix 1.2) Conceptual diagram of process of expert plant confirmations, including details important in each part of the process



Appendix 1.3) Conceptual diagram of data analysis process coloured to indicate different steps or methods; green coloured shapes represent vegetation data, blue shapes represent environmental data, yellow shapes represent transformation used, and orange shapes represent statistical tests used.

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