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Master's Thesis

The effect of common reed (*Phragmites australis*) expansion on plant species diversity

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DIPLOMA THESIS ASSIGNMENT

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Engineering Ecology
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Thesis title

The effect of common reed (Phragmites australis) expansion on plant species diversity

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Objectives of thesis

The aim of the thesis is to evaluate the effect of common reed expansion on plant species diversity in wetland communities in its native range and compare these results with the studies examining the effect of common reed in non-native range.
The thesis will include evaluation of field data collected by own author in Velký Tisý littoral vegetation, where the common reed is recently expanding in some parts. It will also include the review of studies dealing with common reed expansion in non-native range. The main hypothesis is that sites with expanding Phragmites in native range will have negative effect on plant species diversity and will remember sites in its non-native species range, whereas the sites with its stable occurrence or retreat in will maintain species diversity.

Methodology

The author will use the long-term data on Phragmites expansion/retreat in Velký Tisý littoral vegetation. At each plot, which will be distributed evenly along the littoral zone, she will collect data on current Phragmites cover, rate of Phragmites expansion (from historical data) and plant species diversity. She will use the historical aerial photographs for characterizing of changes in Phragmites dominant vegetation. She will model the effect of current Phragmites cover and historical expansion/retreat on species diversity. She will compare these results with the studies performed in non-native range of common reed.

The proposed extent of the thesis

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Bhattarai, G. P., Meyerson, L. A., & Cronin, J. T. (2017). Geographic variation in apparent competition between native and invasive Phragmites australis. Ecology, 98, 349-358.

Chambers, R. M., Meyerson, L. A., & Saltonstall, K. (1999). Expansion of Phragmites australis into tidal wetlands of North America. Aquatic Botany, 64, 261-273.

Minchinton, T. E., & Bertness, M. D. (2003). Disturbance-mediated competition and the spread of Phragmites australis in a coastal marsh. Ecological Applications, 13, 1400-1416.

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Declaration

I declare that I have worked on my diploma thesis titled "The effect of common reed (*Phragmites australis*) expansion on plant species diversity" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break copyrights of any their person.

In Prague on 30.03.2023

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The effect of common reed (*Phragmites australis*) expansion on plant species diversity

Abstract

The current research was conducted to analyze the impacts of common reed (*Phragmites australis*) expansion on plant species diversity in the national nature reserve *Velký and Malý Tisý* located in the South Bohemian region between the towns of Lomnice nad Lužnicí and Třeboní, Czech Republic from January 2022 to January 2023. Two hypotheses were proposed: 1) plant species diversity does not depend on the expansion of *Phragmites australis* and 2) density, height, distance, and canopy openness of native *Phragmites* stand are related to plant species richness. Data was collected from 30 buried poles placed next to *Velký Tisý* fishpond in three steps: (1) canopy openness was determined using gap light analysis, (2) *Phragmites* expansion trends were measured by determining stand distance, isolated distance, height on point, and isolated height, and (3) plant diversity was assessed through a vegetation survey and identification with the departmental herbarium and density was determined using a simple point count method. The results revealed that canopy openness was significantly less in the areas where *Phragmites* are densely grown and vice versa. However, a linear regression model revealed that the species richness decreased by 1.293 for every unit increase in stand distance, while it increased by 0.349 for every unit increase in canopy openness. Additionally, every meter of height on the point caused a decrease of 6.28 in the species richness index. The vegetation survey identified 80 plant species, and the detailed diversity index was calculated. The canonical correspondence analysis (CCA) showed that height on point, stand distance, and canopy openness had a significant influence on species composition. *Tripleurospermum inodorum*, *Myosotis palustris*, and *Trifolium hybridum*, preferred to grow in areas with high canopy openness. Conversely, *Persicaria minor*, *Juncus effuses*, and *Chenopodium polyspermum* were shade-tolerant species that thrived in areas with low light under the foliage of *Phragmites australis*. The permutation test for CCA showed that all factors were strongly correlated and equally affected species composition ($p \leq 0.05$). So, It is conclusion that native *Phragmites* had a significant of an impact on plant variety in higher densities. However, native *Phragmites* are safer and healthier to propagate in controlled and normal densities. In order to preserve the ecological balance, the stand density and height of *Phragmites* must be manipulated.

Keywords: *Phragmites australis*, Canonical Correspondence Analysis, expansion, plant species diversity, Gap Light Analysis, canopy openness, stand distance, height on point

Vliv expanze rákosu obecného (Phragmites australis) na druhovou rozmanitost rostlin

Abstrakt

Současný výzkum byl proveden za účelem analýzy dopadů rozšíření rákosu obecného (Phragmites australis) na druhovou diverzitu rostlin v národní přírodní rezervaci Velký a Malý Tisý nacházející se v Jihočeském kraji mezi městy Lomnice nad Lužnicí a Třeboní, Česká republika od ledna 2022 až leden 2023. Byly navrženy dvě hypotézy: 1) druhová diverzita rostlin nezávisí na expanzi Phragmites australis a 2) hustota, výška, vzdálenost a otevřenost zápoje původního porostu Phragmites souvisí s druhovou bohatostí rostlin. Data byla sbírána z 30 zakopaných kůlů umístěných vedle rybníka Velký Tisý ve třech krocích: (1) byla stanovena otevřenost koruny pomocí analýzy mezerového světla, (2) byly měřeny trendy expanze fragmitů určením vzdálenosti porostu, izolované vzdálenosti, výšky v bodě a izolovaná výška a (3) diverzita rostlin byla hodnocena pomocí vegetačního průzkumu a identifikace s oborovým herbářem a hustota byla stanovena pomocí jednoduché metody bodového počítání. Výsledky ukázaly, že otevřenost zápoje byla výrazně menší v oblastech, kde jsou hustě pěstovány fragmity a naopak. Lineární regresní model však odhalil, že druhová bohatost se snížila o 1,293 při každém zvýšení vzdálenosti porostu, zatímco vzrostla o 0,349 při každém zvýšení otevřenosti zápoje. Navíc každý metr výšky bodu způsobil pokles indexu druhové bohatosti o 6,28. Průzkumem vegetace bylo identifikováno 80 druhů rostlin a byl vypočten podrobný index diverzity. Kanonická korespondenční analýza (KKA) ukázala, že výška v bodě, vzdálenost porostu a otevřenost zápoje měly významný vliv na druhové složení. Tripleurospermum inodorum, Myosotis palustris a Trifolium hybridum, preferované k růstu v oblastech s vysokou otevřeností zápoje. Naopak Persicaria minor, Juncus effuses a Chenopodium polyspermum byly druhy odolné vůči stínu, kterým se dařilo v oblastech se slabým osvětlením pod listy Phragmites australis. Permutační test pro KKA ukázal, že všechny faktory spolu silně korelovaly a stejně ovlivnily druhové složení ($p \leq 0,05$). Z toho vyplývá, že původní fragmity měly významný vliv na odrůdu rostlin ve vyšších hustotách. Nativní Phragmites jsou však bezpečnější a zdravější pro šíření v kontrolovaných a normálních hustotách. Pro zachování ekologické rovnováhy je nutné manipulovat s hustotou porostu a výškou fragmitů.

Klíčová slova: Phragmites australis, Kanonická Korespondenční Analýza, expanze, druhová diverzita rostlin, Analýza Mezerového Světla, otevřenost zápoje, vzdálenost porostu, výška v bodě

Table of Contents

Introduction ... **1**

1. Background ... 1

2. Thesis objectives and hypothesis ... 2

 2.1 Research's Aim ... 2

 2.2 Research objectives ... 3

 2.3 Research hypothesis ... 3

Literature Review ... **4**

1. Overview of plant invasion ... 4

 1.1. Plant-soil feedback ... 4

 1.2. Steps of invading ... 4

2. *Phragmites australis* distribution and variability ... 5

 2.1. Species distribution ... 5

 2.2. Species variability ... 6

3. *Phragmites australis* biology ... 7

 3.1. Serving as a nitrogen sink ... 7

 3.2. Stand above-ground biomass ... 7

 3.3. Role of Phragmites australis in decomposition ... 7

 3.4. Reproduction of Phragmites australis. ... 8

 3.5. Seeds ... 8

 3.6. Rhizomes, role in the expansion ... 8

 3.7. Thriving capacity ... 9

4. Invasion processes ... 9

 4.1. Successful Invasion Strategies of Phragmites australis ... 9

 4.2. Role of nature in Phragmites invasion ... 10

 4.3. Invasion history of Phragmites australis ... 10

 4.4. Invasion in the USA ... 11

 4.5. Altering the region's feature ... 12

5. Effect of *Phragmites australis* on biodiversity in the native and non-native range ... 12

 5.1. Effects of Phragmites on plant diversity and habitat quality ... 12

 5.2. Herbivores and insects feeding on Phragmites ... 14

 5.3. The role of Phragmites australis for other trophic levels ... 15

6. Socioeconomic factors and Conservation management ... 16

 6.1. Socioeconomic factors ... 16

 6.2. Conservation management in Phragmites stands ... 17

Methodology ... **18**

1. Study Area ... 18

2. Data and used materials 19
2.1. Light effect.. 19
2.2. Phragmites australis expansion/reiteration.. 20
2.3. Plant species diversity.. 20
3. Statistical Analysis.. 20
Results 22
1. Species richness measures 22
2. Testing hypothesis 22
3. Factors affecting species richness on plots 22
4. Ordinations.. 24
Discussion and recommendations.. 27
1. Discussion.. 27
2. Recommendations for nature conservation practice 29
Conclusions 31
References 32
Appendix 42
Appendix I: Geographic features of the study points... 42
Appendix II: Numeric variables collected during data collection (primary data).............. 43
Appendix III: List of Plant Species found in study locations 44

List of Figures

Figure 1: Map of the study area ... 18
Figure 2: Canopy photos on the point ... 19
Figure 3: Dependency of species richness from expanded stand distance from the point ... 23
Figure 4:Dependency of species richness from canopy openness on the point ... 23
Figure 5: Dependency of species richness from the height of Phragmites on the point ... 24
Figure 6: Effect of environmental factors on species composition (Full Species Names Listed in Appendix III) ... 25

List of tables

Table 1: Richness index on each plot: ... 22
Table 2: Results of the test ... 22
Table 3: Permutation test ... 26

List of abbreviations

GLA: Gap Light Analysis

CCA: Canonical Correspondence Analysis

Introduction

1. Background

Wetlands ecosystems have a critical role in maintaining the balance of our planet. A distinguishing feature of these is the existence of standing water and the support of a diverse array of species. Wetlands perform a variety of important ecological functions, including the cycling of carbon and nitrogen (Gaberščik et al., 2020). Plants and microorganisms have a crucial role in enabling and supporting these essential ecological processes (Shahid et al., 2018). These types of ecosystems provide food and water supplies, regulate hydrology by mitigating the effects of flooding, desiccation as well as soil erosions, filter and degrade pollutants as well as encourage soil growth along with nutrient cycling (Langergraber & Masi, 2018). Numerous essential functions may be significantly impacted by invasive plant species that impact the wetland ecosystems by decreasing biodiversity and interfering with the nutrient cycle (Ehrenfeld, 2003).

Invading plant species frequently create monocultures in wetlands, which increases primary production, adds more plant litter, and upsets the nutrient cycle (Choudhury et al., 2018). Although the impact of plants on the soil they inhabit varies among species, invasive plants have been observed to alter soil conditions in a way that favors their growth and dominance, creating a positive plant-soil feedback loop (Bardgett & Van Der Putten, 2014; Berg & Smalla, 2009; Crocker et al., 2017). In US invasive species were mostly introduced in the Laurentian Great Lakes in reaction to human settlement in the 1800s (Whyte et al., 2008). Over 180 species are currently thought to be invasive, and they are replacing native species (Ricciardi, 2006). They are made up of 42 percent plants and 86 percent of people were born in Europe. *Phragmites australis*, is a perennial grass that has spread fast over the northeastern US over the past 150 years and is a particularly hazardous invasive plant species near the Great Lakes (Saltonstall, 2002).

Phragmites are one of the wetland plant genera with the greatest global distribution. Since ancient times, people have used the genus of plants found in wetlands called reeds (*Phragmites*). It is a *Phocaea* grass that is tall, slender, and extremely productive, with above-ground biomass of up to 30 tones per hectare per year (Köbbing et al., 2014). In Quebec, Canada, during the 1960s, a significant *Phragmites* invasion was noted. Currently, over 95% of all *Phragmites* colonies can be found in Quebec, with the exotic genotype dominating in both roadside and wetland colonies (Lelong et al., 2007). The majority of North America is home to it. The most recent genotype of *Phragmites* is aggressive, displacing local plant populations and becoming an invasive species in a number of states (Quirion et al., 2018). *Phragmites australis* can currently be found in various locations, including the lower 48 states, southern regions of Canada, and other areas. However, it is absent from Alaska and Hawaii (Swearingen & Saltonstall, 2010). An increasing population of invasive *Phragmites* may replace several native plant species imposing a serious threat to biodiversity (M. N. Uddin & Robinson, 2017). That's why studying invasive species populations in their natural habitats is crucial to determine whether they have the capacity to reduce wetland habitat diversity over a lengthy period of time. It is crucial to understand how they affect the variety of other native species in wetland ecosystems as well as the mechanisms that affect how they compete with one another. We can see communities of invasive species from other places inside their native ranges, with varying population dynamics. Some populations are growing, which is consistent with invasive processes occurring beyond the range boundaries of some species. Some maintain the status quo or are collapsing, thus may show, which factors may limit the potential for species invasion.

This study focuses on the effect of native *Phragmites* expansion on plant species diversity in its native ranges. Observations were conducted in the national nature reserve Velký and Malý Tisý, in the natural range of *Phragmites australis*. Due to the various status of stands of *Phragmites australis* (i.e., expanding, retreating, and stable) in the natural habitat in a fish pond, we could compare the effects of *Phragmites australis* on the diversity of vascular plants under different population dynamics. At the same time is considering the main factor influencing on plant's growth is the light effect on each site. The results of conducted research will be compared with previous studies of the effect in native and non-native ranges.

2. Thesis objectives and hypothesis

2.1 Research's Aim

- Evaluate the effect of *Phragmites* expansion on plant species diversity in wetland communities
- Provide suggestions on the management of *Phragmatis* diversity in order to keep the balance of other plants species on the site

2.2 Research objectives

- Review the effects of *Phragmites australis* on the diversity of vascular plants in the native and non-native range
- Test the effects of *Phragmites australis* on the diversity of vascular plants in the native populations under different common reed stand dynamic
- Compare the results gained from the empirical study (objective 2) with the review on the effect of *Phragmites australis* in the non-native range (objective 1)

2.3 Research hypothesis

Two hypotheses were proposed. The first hypothesis was that plant species diversity does not depend on the expansion of *Phragmites australis*. The second hypothesis was that the density, height, distance, and canopy openness of the native *Phragmites* stand would be positively or negatively related to the richness of the plant species:

- How expansion of *Phragmites* in *the* native range will affect plant species diversity on sites?

H0: Plant species diversity does not depend on the expansion of *Phragmites australis*.

H1: Expanding of *Phragmites australis* effects on plant species diversity in the studied area.

Literature Review

1. Overview of plant invasion

1.1. Plant-soil feedback

Plant species influence host plant survival via a reciprocal interaction known as plant-soil feedback PSF, This can also impact the composition and functioning of soil biota communities (Kulmatiski et al., 2008). The influence of plant-soil feedbacks (PSFs) on host plants is determined by various factors, including both positive elements such as nitrogen-fixing bacteria, mycorrhizal fungi, and other advantageous organisms, as well as negative elements like soil-borne diseases, parasites, and herbivores present in the soil environment (Klironomos, 2002; Reinhart & Callaway, 2006). Plant-soil feedbacks (PSFs) have an impact on the survival of exotic plant species (Van der Putten et al., 2013). Exotic plant species may have less beneficial characteristics compared to closely related native species. For example, they may have weaker associations with beneficial organisms, or they may be more susceptible to attack by local natural enemies due to the effects of plant-soil feedbacks (PSFs). This indicates that the native soil community is capable of resisting invasive species (Callaway et al., 2013; Gribben et al., 2017). As opposed to closely related native species, invasive plants may offer more or less favorable PSFs, which could result in dominance for the invader through relative protection from natural predators. (Keane & Crawley, 2002).

1.2. Steps of invading

The First step of invasion consists of crossing a geo-graphic barrier, which is often assisted by human activity. To effectively expand a species', range Multiple chances must exist for populations to endure alteration along with reaching a new living place, a condition referred to as high pressure of propagation (Lockwood et al., 2005; Richardson et al., 2000). Several individuals who have been released into a new area are measured by the invasion pressure. This method considers both the number of individuals released and the frequency of release events to assess invasion pressure (Lockwood et al., 2005).

Theoharides & Dukes, (2007) stated that the second step of invasion is colonization. In the new colonization of a species, it must face some biotic obstacles. While temperature is a rough filter for many invasive species, light, nutrition, and moisture are other important factors in deciding whether an introduced species will survive. The disturbance that eliminates native vegetation and provides nutrients may enhance the likelihood of successful colonization by increasing the chance of transfer (Leishman & Thomson, 2005; Minchinton & Bertness, 2003). Additionally, high pressure contributes to colonization success, as it may prevent the extinction of tiny imported populations by constantly replenishing the region with viable propagules. If the introduced species successfully colonize a location and reproduces, establishing a self-sustaining population without the aid of humans, The invasion enters the establishing phase. (Theoharides & Dukes, 2007).

Davies et al., (2009) observed that a species must be able to obtain sufficient nutrients for growth, maintenance, and reproduction throughout this stage, as well as locate gametes for outcrossing and have a sufficient lifespan to reproduce. The self-sustaining population within the introduced area is said to be "naturalized" (Richardson et al., 2000). During this stage, invasive species often have advantages in competition, such as fast growth rates and the ability to release chemicals that inhibit the growth of other species (allelopathy), which reduces the overlap of their habitat with native plants. This benefits the invasive species (Theoharides & Dukes, 2007). Non-competitive interactions can also aid in the succession of imported species. The enemy-escape theory, i.e., to help imported species in their new habitat, it has been suggested that introduced species should be kept in their adversaries' range. (Wolfe, 2002).

2. *Phragmites australis* distribution and variability

2.1. Species distribution

Phragmites australis is a flowering plant with one of the widest distribution ranges in the world, found on every continent except for Antarctica (Sheng et al., 2021). It is a wetland plant that may thrive in fresh, brackish, or salt water (Gu et al., 2020). The word "*Phragmites*" is taken from a word (Greek) "Phragma," which means fence or barrier, aptly characterizing the thick monotypic stands these give (Shaheen et al., 2019). It is found all over the majority of North America. The latest genotype is violent which displaced local plant populaces, making *Phragmites* an invasive species in a number of states (Quirion et al., 2018). Today, *Phragmites australis* can be found in southern Canada, the lower 48 states, and other places. Alaska and Hawaii don't have it. Genetic analysis has revealed the existence of three distinct lineages of *Phragmites* in the US. One of these lineages is native and only found in the US, another occurs in both North and South America, while the third is invasive and non-native. In the past, the native endemic lineage (known as *Phragmites australis* ssp. *americanus*

Saltonstall, *Peterson*, and *Soreng*) was widespread and commonly found throughout Canada and most of the United States, except for the southeastern region spanning from Texas to Florida and north to South Carolina. However, it still persists in the western United States.. The native lineage, which was once widespread in the eastern United States, has largely been replaced by the invasive lineage. Several significant rivers on Maryland's eastern shore, which is a part of the Chesapeake Bay watershed, have some remaining populations. Native *Phragmites* are still present in many natural areas of the Midwest and West of the United States, and recent evidence suggests that they are actively spreading to new locations. It has been determined that *Phragmites australis* subspecies berlandieri Saltonstall & Hauber, (2007) represents the "Gulf Coast lineage." Its range is limited to the southernmost states, and southern Arizona and California have both received introductions of it. Whether it originated in the United States or moved north from populations in Mexico and Central America is unclear at this time. *Phragmites australis'* invasive lineage most likely came from Europe. Currently, *Phragmites* can be found throughout the continental United States and in the southern regions of six Canadian provinces. The invasive lineage has been identified near the Mississippi River delta in the southern United States, where it overlaps with the Gulf Coast lineage, and there is a possibility that it may spread to other regions along the Gulf Coast. However, its distribution in regions south of the United States is not yet known (Swearingen & Saltonstall, 2010)**.**

During the 1960s the invasion of *Phragmites* on large scale was noticed in Quebec, Canada. Within less than 20 years, there was a significant shift from a majority of native genotypes to a complete dominance of the invasive genotype in Quebec. At present, the invasive genotype dominates over 95% of common reed colonies in Quebec, with a high abundance observed along roadsides. Notably, even colonies in marshes are now controlled by the non-native genotype (Lelong et al., 2007).

2.2. Species variability

There are currently four recognized species of *Phragmites*: 1) *Phragmites australis (Cav.)* T. ex S., 2) *Phragmites japonicus* S., 3) *Phragmites karka (Retz.)* T. *ex* S., and 4) *Phragmites mauritianus* K. (Diazgranados et al., 2020; Saltonstall, 2016). Out of the four recognized species within the genus *Phragmites*, only *Phragmites australis* has a worldwide distribution (Saltonstall, 2016). Despite extensive research on common reeds in North America, their taxonomy is considered outdated. There are currently three distinct lineages of *P. australis* in North America, including a native lineage previously designated as *P. australis* subspecies *americanus* (Saltonstall et al., 2004), a Gulf Coast lineage previously designated *P. australis* var. *berlandieri* (E. Fourn.) (Saltonstall & Hauber, 2007), and an exotic lineage. On the basis of morphological features and chloroplast DNA markers, the imported lineage is distinguished. There is evidence that the imported lineage is varied in comparison to the indigenous lineage (Plut et al., 2011).

3. *Phragmites australis* biology

3.1. Serving as a nitrogen sink

Phragmites may serve as a nitrogen sink. When *Phragmites* are eliminated, nitrogen removal decreases temporarily. For instance, certain common reed herbicidal application locations discharged up to 7 kg per ha per year of nitrogen as a result of usage. The capacity of *Typha* and *Spartina* wetlands to immobilize a greater quantity of nitrogen is attributed to their increased foliage (above-ground) biomass (Findlay et al., 2003).

3.2. Stand above-ground biomass

These may touch a height of six meters, however, are mostly seen from 2 to 4 meters in height (Dash et al., 2021). It is capable of reaching plant densities of up to 300 culms per square meter (Hara et al., 1993). It may cover a large area; for example, about 30,000 of Delaware's 90,000 total tidal marsh acres are covered by *Phragmites* (Hellings & Gallagher, 1992). *Phragmites* can produce up to 3223 ± 204gm^2 aboveground ash-free dry weight (AFDW) in August. while in the post-season, the average amount of biomass was estimated at 1494 ± 92 SE AFDW gm^2) during November (Windham, 2001). *Phragmites* have the potential to be a highly productive energy crop and source of chemical feedstock, owing to their high yields and availability. According to reports, it can produce up to 4.4-6.9 kilograms of biomass per square meter each year, helped by its ability to endure the winter (Garrido et al., 2017).

3.3. Role of Phragmites australis in decomposition

P. australis not only increases net primary output but also seems to decrease decomposition. Because *P. australis* litter decomposes slowly, it has a direct impact on an ecosystem: for example, In a freshwater lake with shallow depths, it took approximately 242 days for *Phragmites australis* leaves to reach 50% breakdown, while the stems took 574 days to achieve the same level of breakdown. (Warren et al., 2001). Additionally, *Phragmites australis* indirectly slows down decomposition rates by providing shade to the soil and reducing its temperature (Windham & Lathrop, 1999). The accumulation of litter in wetlands can fill in holes in the substrate, resulting in a smoothing of micro topography and elevation of the soil surface. This process can alter the hydrology by lowering the level of water in wetlands (Able et al., 2003; Weinstein & Balletto, 1999; Windham & Lathrop, 1999).

3.4. Reproduction of Phragmites australis.

Phragmites australis can reproduce both sexually and asexually, which enables them to spread and expand rapidly, colonize new regions, and retain a high level of genetic variety while also forming stands of locally adapted clones that are well adapted to the surrounding environmental situations (Kettenring et al., 2016). Although sexual reproduction is not considered the main propagative approach of *P. australis*, there is increasing evidence that seed reproduction is critical for colonizing new regions (Belzile et al., 2010; Kettenring & Mock, 2012).

3.5. Seeds

Seeds, which were previously believed to be largely not viable, were subsequently discovered to have greater sustainability than formerly informed. *Phragmites* spreads mostly via seeds (Shearin et al., 2018). McCormick et al., (2010) discovered a 25-fold increase in *Phragmites* cover in Chesapeake Bay, Maryland, between 1971 and 2007. By comparing the genetics of adjacent stands that are not linked by rhizomes, it was shown that this increase in cover was mainly due to seed dispersal. Irrespective of seeds' viability, stems allow them to produce vast mono-cultures by colonial growth once established.

3.6. Rhizomes, role in the expansion

Rhizomes promote the horizontal expansion of the plant, offer supports structurally, as well as permit reserved storage (Packer et al., 2017). These expand straight at a rate of up to four meters per year, getting depths of up to two meters. Those which are vertical, allow for the development of buds necessary for culm growth (B. Liu et al., 2014). *Phragmites'* physiological responses vary according to water depth. Rhizomes get fewer resources in deeper water due to the need for higher culms. Vretare et al., (2001) discovered that *Phragmites* grow slower and have a reduced capacity to spread in deeper water than they do in shallower water.

3.7. Thriving capacity

The capacity of this grass to thrive at varying wetland depths is attributed to venture-induced removal or transmission that enables O_2 to be transported into the rhizomes through broken branches (Mauchamp et al., 2001). It was reported that *Phragmites* species have the capability to ventilate efficiently up to three hundred percent as compared to the local species (Tulbure et al., 2012).

4. Invasion processes

4.1. Successful Invasion Strategies of Phragmites australis

Albert et al., (2015) gave the following strategies for the successful and safe invasion of *Phragmites australis* based on their closed meta-analysis of various research.

1. Developing effective control tactics requires an understanding of the relative contributions of sexual reproduction and vegetative proliferation to the dissemination and establishment of exotic plants. *Phragmites australis* is considered one of the most invasive species in North America, providing a good example of this phenomenon.

2. Albert et al. (2015) conducted a study to investigate the propagation of *Phragmites australis* in roadside ditches at its northern distribution limit in North America. The researchers utilized in situ field observations and two genetic analysis techniques, microsatellite markers (SSR) and genotyping by sequencing (GBS), to gather evidence. This was the first time these techniques have been used in combination for this purpose.

3. In an area where *Phragmites* are already widespread, field investigations revealed the process of establishing new populations is aided by both seeds and plant fragments. A higher number of individuals originating from plant fragments survived the second year in comparison to seedlings. However, newly established individuals were primarily (84%) produced from seeds instead of fragments.

4. The presence of high genetic diversity among the stands of common reed in marsh and highway areas suggested that sexual reproduction played the main role in dispersal. A single stand had the vast majority of genotypes, and sexual reproduction is the sole explanation for the considerable genetic variety seen. One clone made up half of the examined stands, indicating that vegetative growth was the primary method of local spread. It is likely that all the stands under investigation were initially created by genetically distinct individuals because the modest percentage of SSR genotypes

that were first believed to be shared between distant stands turned out to be distinct (as revealed by GBS data).

5. According to his research, the *Phragmities* relies on long-distance seed dissemination in marshes and along roadsides, although seeds and plant fragments both aid in short-distance dispersal along roadways, at least in areas where the species is already common. This invader's success in North America appears to be due to a reproduction strategy that combines the benefits of sexual reproduction with vegetative proliferation. Additionally, this study demonstrates how the GBS strategy significantly lowers the risks connected with using a constrained number of markers. Ecologists working with an increasing number of invasive species of which few have been found to carry microsatellite markers will find this method particularly very helpful.

4.2. Role of nature in Phragmites invasion

Minchinton, (2002) stated that along with human disturbances, natural disturbances such as storms promote the spread of *P. australis*. For example, during an El Nio year, *P. australis* produced 30% more shoots, 25% higher shoots, and substantially more flowers than the previous year in coastal brackish marshes of southern New England. Similarly, Wilcox, (2012) reports that the natural decline of Lake Erie in the 1990s is believed to be responsible for the fast-spreading of imported *P. australis*. Thus, *P. australis* benefits from its broad environmental tolerance and its capacity to exploit nutrient contamination and physical stress through fast growth and an increase in canopy cover.

4.3. Invasion history of Phragmites australis

Two genotypes of *Phragmites* are currently present in the United States. The records from fossils indicate that the native genotype has been existing in the southwestern region of the United States for at least 40,000 years. However, in the last 150 years, its distribution and abundance have significantly increased, especially along the Atlantic coast (Saltonstall, 2001). Whereas, it is believed that non-native genotypes of *Phragmites australis* may have been introduced to North America within the last 200 years (Chambers et al., 1999). *Phragmites australis* was identified as a non-native, invasive species in North America in 2002 and has since become one of the most challenging species to manage in wetlands (Saltonstall, 2002). Paleo-ecologically, it is suggested that there has seen its population burst during the last one hundred and fifty years, establishing itself as a landscape component. A novel *Phragmites* genotype prevalent in Eurasia is currently invading local wetland communities with native genotypes across the United States, almost eradicating the native genotype in Southern New England (Williams et al., 2019). Due to this aggressive genotype, many states along the United States Atlantic Coast and upper Midwest have classified *Phragmites* as invasive (Meyerson et al., 2009). The invasive genotype spreads in disturbed wetlands and may even overgrow areas where wetland vegetation was completely removed by human interventions (Saltonstall, 2002). This plant has the potential to diminish plant species diversity (League et al., 2007), change hydrology (Y. Liu et al., 2021), and detract from an area's socioeconomic worth (Durant et al., 2020).

4.4. Invasion in the USA

The cause of their invasive behavior in the USA was the addition of a new genotype which was declared as aggressive and disturbed the environment significantly during the past hundred and fifty years. And another solid reason for their existence with more density is the lack of their biological predator (Tewksbury et al., 2002). It is thought that the introduction of a novel genotype resulted in the species being extra violent as well as well suited to the environment of the US. Since 1960, there has been a significant shift in genotypes throughout the US. Local species are nearly extinct in some areas and are thought endangered in some areas of the US (Saltonstall, 2002). These novel genotypes seem to favor an unstable environment that has aided the expansion of the US.

These may spread at a rate of up to 20% each year. Plants are more likely to proliferate in environmentally distressed regions where another plantation has been removed, hydrologic modifications have been made, dredging has been done, or greater sedimentation has occurred (Hudon et al., 2005). Distressing lakes, rivers, and canals wetlands as well as changing tidal systems to the extent that more than half of the wetlands have been lost or disturbed, has helped its growth and expansion. If the expansion and size of the population are observed, it can be concluded that it is still in the growth and expansion phase and may attain a great population and it is going through a populace boom (Warren et al., 2001). *Phragmites'* new aggressive genotype population expansion may also be linked with the disruption related to the construction of any roadway systems, as well as housing as well in industrialized regions (Tulbure & Johnston, 2010).

4.5. Altering the region's feature

Common reeds may change the physical features of a region due to their large accumulated heaps of dead foliage debris, slow rottenness rates than other species for instance *patens* species, as well as tenfold the aboveground biomass of adjacent short grasses species (Windham, 2001). Topographic relieving is usually not as much as 1 cm inside *Phragmites* populations. In contrast, shortgrass communities have an 8-centimeter topographic relief (Lathrop et al., 2003). The micro-topographic alterations have the potential to affect the hydrologic flow across a region along with isolating some tidal zones. It was discovered about this common reed is a dominant species in a number of 1st as well as 2nd order intertidal streams. As soon as these streams turn blocked, trophic transmissions of prime along with minor produce within tidal schemes may be harmed (Capotosto & Wolfe, 2007; Lathrop et al., 2003).

5. Effect of *Phragmites australis* on biodiversity in the native and non-native range

5.1. Effects of Phragmites on plant diversity and habitat quality

Along North America's Atlantic Coast, salt marshes are being forcefully encroached upon by the reed *Phragmites australis* Cav. More than 90% of the variance in *Phragmites* cover between marshes was accounted for by shoreline development, which is defined operationally as the elimination of the woody vegetation surrounding marshes. The removal of woody vegetation from marsh edges may improve nitrogen availability and decrease soil salinities, which would facilitate *Phragmite's* invasion. The development of the shoreline was found to be strongly associated with decreased soil salinity and increased nitrogen availability, which was found to be significant factors in the increased growth of *Phragmites*. The study showed that soil salinity accounted for 64% of the variation in *Phragmites* cover, while nitrogen availability accounted for 56%. When considered together, these factors explained 80% of the variation in the success of the *Phragmite's* invasion. *Phragmite's* dominance in developed salt marshes led to a nearly three-fold reduction in plant species richness, according to both univariate and aggregate (multidimensional scaling) studies of plant community composition. The results of this study show how crucial it is to keep habitat borders intact in order to conserve natural communities, and they also give an example of the crucial role local conservation may play in maintaining these systems (Silliman & Bertness, 2004).

5.1.1. Impact of native Phragmites on ecology

The introduced lineage showed a lower occurrence of clonal growth; therefore, it seems unlikely that this is the main factor contributing to its reputation for invasiveness in the area under investigation. The introduced stands were more clonally varied in each marsh system. The native *Phragmites* lineage has a higher tendency for clonal growth in regional areas, which could potentially explain why it is more resistant to displacement by invasive species (Douhovnikoff & Hazelton, 2014). So, that's why native *Phragmites* have minimal impact on colonial diversity and population but nonnative *Phragmites* tend to replace native flora gradually as, all populations with low levels of *Phragmites* density had found significantly higher values of species richness, evenness, and the Shanon-Wiener index. Lower diversity and mono-specificity were present at higher densities of exotic *Phragmites* (M. N. Uddin & Robinson, 2017).

5.1.2. Impact of invasive Phragmites on ecology

The presence of this common reed results in a decrease in total plant variety as well as diversity (Meyerson et al., 2009). Lathrop et al., (2003) reported its expansion that was observed in Delaware (9.59 hectares per year) and New York (5.37 hectares per year). Another way the common reed affects other plants badly is its accumulated biomass that forms a carpet on the surface of the soil, this mat surface stops the light and absorbs it, depriving the other growing plants. *Phragmites*, which are often higher than the vegetation it invades, are able to establish themselves as a better competitor for sunlight (Vymazal & Březinová, 2016). Cluster analysis of resultant data grouped inhabitants spatially with distance along the river, with one exception. It indicated a distinct source of propagules for the populations on the main stem of the river and those on the Muddy River, a branch, significantly separated them. Transects across large *Phragmites* stands revealed changes with distance in three of the four populations, showing that stands are made up of a small number of closely spaced clonal individuals or a large number of individuals mixed together. Molecular variance analysis depicted the component separating the populations on the two rivers at 1.71 percent of the data set's variance. The preponderance of variation occurs within populations among individuals, suggesting that the populations are relatively closely linked and that metapopulational variation is minimal. This could indicate that populations have mostly been established through vegetative propagules or that the range of this plant has recently expanded (Keller, 2000). It was noticed that the population density of Typha in Indiana state has decreased from 39 to 13 culms/m^2 in ecological competition due to the increasing population density of invasive *Phragmites* in the same habitats (Chun & Choi, 2009).

All populations with low levels of *Phragmites* density had significantly higher values of species richness, evenness, and the Shannon-Wiener index. Lower diversity and mono-specificity were present at higher densities. With varying levels of *Phragmites* density, significant changes in soil characteristics were observed. The effects of population density on water content, dehydrogenase activity, and microbial biomass (C, N, and P) were found to be interdependent, but no significant effects were observed on pH, electrical conductivity, phenolic, organic carbon, and spore density. The study also clarified how mycorrhiza associations and biomass development interfered with the native plants' ability to compete by reducing their biomass and mycorrhiza associations. Overall, our findings imply that *Phragmites* density greatly influenced ecologically significant changes in soil and vegetation characteristics, including mycorrhiza capacity. Through the disruption of the functional connections between those variables, such changes may play a significant role in the *Phragmites* invasion process (M. N. Uddin & Robinson, 2017).

5.2. Herbivores and insects feeding on Phragmites

Nearly twenty-six herbivores feed on this plant in the US and Europe, there are one hundred and seventy (Allen et al., 2015). A moth named *Rhizedra iutosa* is reported to damage this common reed which is a stem borer, it was found in the Atlantic USA and England (Southern). *Rhizedra iutosa* gives its eggs within desiccated culms throughout the autumn. In the mild season of spring, this hatching is started. Then its larva goes to the rhizomes inside, ultimately killing the reed. Nevertheless, this moth has a tiny populace in the United States, which is deemed insufficient to substantially decrease *Phragmites'* expansion (Tewksbury et al., 2002). To achieve biotic control of this common reed, newer species must be introduced or existing species must be increased (for instance the stem-boring moth-like *Rhizedra iutosa*) (Casagrande et al., 2003). Without the threat of herbivores or predators, exotic species may devote more energy to development than defense (Blossey & Notzold, 1995). Indirectly, species that reproduce asexually or without relying on pollinators may have an advantage during the initial stage of the establishment (Richardson et al., 2000; Theoharides & Dukes, 2007).

5.3. The role of Phragmites australis for other trophic levels

Birds are not the only wetland biota that may be obstructed by the invasion of *P. australis*. The alterations brought about by the *P. australis* invasion have the potential to disrupt critical invertebrate food sources, thus affecting the avian food supply. There are only a limited number of insect species known to feed on *P. australis* in North America, with fewer than ten identified so far. However, the insect density within *P. australis* stands can still be high, and susceptibility to the plant may vary depending on the specific macroinvertebrate taxon involved (Chambers et al., 1999). There are plentiful to abundant snails, amphipods, and isopods in the habitat of *P. australis* in North America, and their abundances are similar to those in resident marsh vegetation (Fell et al., 1998). This could be attributed to the fact that *P. australis* provides a more favorable habitat for herbivorous invertebrates to graze. Patch of *P. australis* has been shown to have a high density, which correlates with a high snail population. In a Lake Erie coastal marsh, macroinvertebrate populations were found to be comparable amongst *P. australis*, *Typha* spp., and native plants (Holomuzki & Klarer, 2010). Additionally, reports from salty environments show that the presence of *P. australis* does not seem to have an impact on the abundance and diversity of invertebrates (Able et al., 2003; Warren et al., 2001). However, a study conducted on tidal marshes showed that *Spartina alterniflora* supported a higher abundance and species richness of larger invertebrates compared to *P. australis* (Angradi et al., 2001). Common reed habitat seems to sustain a sufficient number of invertebrates within marsh systems, implying that any reported impacts on water birds are not merely a result of changes in the quantity of invertebrates' food available to them.

Numerous water birds, such as herons, egrets, Least Bitterns, and American Bitterns, consume a considerable amount of fish (*Botaurus lentiginosus*). The invasion of *Phragmites australis* has the potential to impact fish as a food source for birds, due to its ability to fill up open-water pools and decrease the level of standing water inside marshes. However, studies have shown that the species composition and quantity of fish in *P. australis*, *Typha angustifolia*, and treated *P. australis* vegetation remained statistically similar (Fell *et al*., 2003). Numerous research on fish usage in *P. australis* has taken place in tidal marshes, with particular stress on *Fundulus heteroclitus* (mummichog), a tiny, saline-tolerant killifish. *Fundulus heteroclitus* is plentiful in *P. australis*, which allows fish to feed effectively, and there are no apparent variations in the size of adult *F. heteroclitus* that forages in *P. australis* vs those that forage in other plants (Chambers et al., 1999; Fell et al., 2003). Additionally, these fish may effectively lay and hatch eggs in *P. australis,* but the low juvenile abundance indicates that P. australis may not be an ideal nursery environment. *P. australis,* however, does not seem to have a harmful impact on young fish, including *F. heteroclitus,* or on bigger fish, according to previous research with fish communities (Able & Hagan, 2000). Fish may utilize *P. australis* stands during the day in freshwater lakes in Germany since the long stems offer cover for feeding birds (Okun & Mehner, 2005). Overall, variations in fishes' usage of *P. australis* seem to be minor, despite the fact that few researchers have concentrated on freshwater fish populations. The exact correlation between *P. australis* and the fish population is not fully comprehended, but it appears that *P. australis* can provide an adequate amount of fish. As a result, any alterations in bird usage of the marsh are unlikely to be caused solely by changes in fish availability.

In accordance with Capotosto & Wolfe, (2007), the moving of ducks as well as herons, big birds, and animals are obstructed due to the almost impenetrable barrier that *Phragmites* create. In contrast to the more varied *Spartina* marshes, the absence of a diverse plant population causes danger to animals (Iriti & Faoro, 2007). In comparison with the short grass species other than the common reed in Connecticut marshes ruled by *Phragmites* had a substantially reduced diversity of bird species. In Connecticut, species like egrets, herons, sandpipers, and terns are absent from these grass stands, but are abundant in other kinds of grasses growing in wetlands (Benoit & Askins, 1999).

6. Socioeconomic factors and Conservation management

6.1. Socioeconomic factors

Opinions on the effect of *Phragmites* on socioeconomic variables vary in different areas. While some people see *Phragmites* as a non-productive plant, others admire the reed for its potential to be utilized as a raw resource (Haslam, 2003; Ludwig et al., 2003). The invasion of the exotic lineage has been blamed for the rapid proliferation of *Phragmites* into saline tidal wetlands on the US East Coast, however other causes including commotion (Bart & Hartman, 2000; Minchinton & Bertness, 2003) and anthropogenic modifications within wetlands (Johnston et al., 2008; Maheu-Giroux & de Blois, 2007; McNabb & Batterson, 1991) or on adjacent upland areas (King et al., 2007; Minchinton & Bertness, 2003; Tulbure & Johnston, 2010) would be a serious problem.

Phragmites may obstruct vistas and access to water, detracting from a property's economic worth (*State of Ontario's Natural Resources Report | Ontario.Ca*, n.d.). Based on regression models predicting current *Phragmites* cover and spread rates in Virginia, it is projected that created wetlands may become completely covered in 40 years. To guarantee that these newly formed wetlands do not become infested with *Phragmites*, it is recommended that they be monitored for a minimum of ten years, which has cost implications (Havens et al., 2003). Croplands next to each other may be lost as a result of *Phragmites'* spread, resulting in agricultural production reductions (*State of Ontario's Natural Resources Report | Ontario.Ca*, n.d.).

6.2. Conservation management in Phragmites stands

Several management measures have been undertaken in an attempt for halting its spreading. Cutting and burning have been shown to limit growth merely when done properly; otherwise, plant densities are enhanced (Al-Gburi et al., 2018). In the United States, biologically controlling measures, natural or imported, have revealed limited efficacy (Tewksbury et al., 2002). Flooding, which is often combined with cutting, has been proven to be efficient in depriving its rhizomes of oxygen availability. It's not a permanent viable solution, owing to the inherent complexity and logistics. Herbicide application is the most frequent and effective technique of control (Bonello & Judd, 2020). Still, repeated herbicidal treatments are required, and some herbicides used to control *Phragmites* have been shown to be deadly to frogs and other non-target plant species (Relyea, 2005).

Methodology

1. Study Area

The study was conducted in, the national nature reserve *Velký and Malý Tisý* (49° 3'29.87"N, 14°43'20.43"E), which is located in the South Bohemian region between the towns of Lomnice nad Lužnicí and Třeboní, Czech Republic. There are eleven sizable fishponds on the nature reserve. But the information was gathered from 30 buried poles that were placed alongside the *Velky Tiys* fishpond as described in the study area map (Figure 1). The reason for the choice was easy accessibility and the visible targeted problem. The area was managed by allocating different points at the location of 30 years old dug-in poles about 2 meters long. After 30 years we analyzed the expansion/retreating of *Phragmites* from each point.

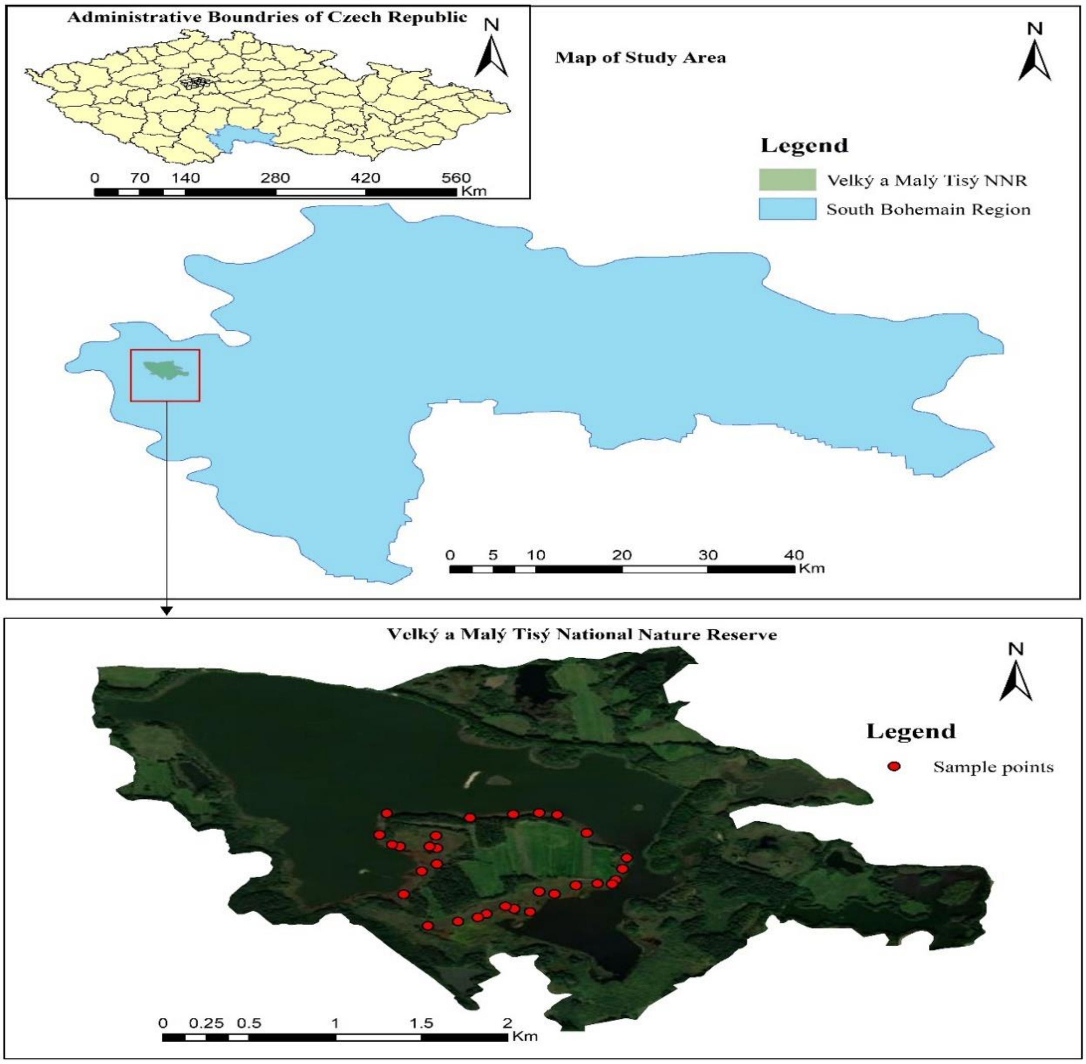

Figure 1: Map of the study area

2. Data and used materials

In the current study, the data collection phase was divided into the following three parts: analyzing light effect; evaluating expansion/reiteration of *Phragmites;* information about other plant species on sites. The geographic features of the study points are represented in Appendix I.

2.1. Light effect

For the purpose of analyzing the light effect, the following data was gathered:

- Coordinates of points: longitude (long), latitude (lat), elevation (ele);
- Canopy photographs: digital hemispherical photographs were taken using the bracketing function of the camera (Figure 2).

A clear difference can be observed in both photographs. In the first photo high canopy openness can be examined due to the partly spread of *Phragmites*, whereas in the second photo, the canopy openness is significantly less because of the dense growth of *Phragmites*. In other words, more amount of *Phragmites* comes with less canopy openness.

Figure 2: Canopy photos on the point

On the basis of these photographs light effect was analyzed by using the software "Gap Light Analyser" – GLA version 2.0. Using Gap Light Analyses, the following information was obtained: Direct transmission, Diffuse transmission, Total transmitted radiation, and Canopy openness. Canopy openness is the main light factor that we used later in modeling.

2.2. Phragmites australis expansion/reiteration

To evaluate the expansion/reiteration of *Phragmites* following measures were carried out

- Stand distance: dense-growing length of *Phragmites* from the point

- Isolated distance: total growing length *from* the point which also includes a partial spread of *Phragmites*

- Height on point: height of *Phragmites* on the point

- Height isolated: height of *Phragmites* after expansion/retreating

Stand distance, Height on point are the main factors of expansion which were later on used in analyses. Mentioned numeric variables collected during data collection (primary data) are represented in Appendix II.

2.3. Plant species diversity

To analyze plant species diversity on each site was conducted vegetation sampling method. All plant species were determined in all 30 littoral sites of the fishpond. The area of plots was taken in a 5-meter radius from each dug-in pole. The identification was done using a departmental herbarium. The density of each plant species was taken through a simple count method and plant cover for each plant was estimated in percentage. A list of plant species found in study locations is represented in Appendix III.

3. Statistical Analysis

Different statistical tools were used to test the following hypotheses:

H0: Plant species diversity does not depend on the expansion of *Phragmites australis.*

H1: Expanding *Phragmites australis* effects on plant species diversity in studied area.

We discovered diversity indices for each site (package "vegan" was installed) before testing the effects of factors on plant diversity. In the "R" program, the dependence of richness indices from various factors was determined. A general linear model with one dependent (Species richness index) and three independent variables (Canopy openness, Height on point, and Stand distance) was developed to test the hypotheses. We can assess whether or not the decline in diversity indices caused by the expansion of *Phragmites* is significant based on the P value. For summarising species diversity data ordinations technic - “Global multidimensional scaling” was used which is a precise method for representing the collected data.

Results

1. Species richness measures

Species richness was determined in each block separately by using the Community ecology package “Vegan” through “R software” of statistics and the results reveled that plot number 24 showed a significantly higher species richness index (33) ($p \leq 0.05$) relative to other plots. Whereas plots no. 5, 2, 23, 26, and 30 were significantly less diverse and dominated by *Phragmites*. Richness indexes were found heterogeneous properties between different plots as depicted in Table 1.

Table 1: Richness index on each plot:

Point N	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***	***21***	***22***	***23***	***24***	***25***	***26***	***27***	***28***	***29***	***30***
Richness index	*22*	*8*	*4*	*13*	*2*	*15*	*18*	*15*	*17*	*15*	*24*	*28*	*28*	*21*	*7*	*4*	*21*	*5*	*4*	*4*	*9*	*2*	*1*	*33*	*5*	*2*	*12*	*18*	*3*	*2*

2. Testing hypothesis

A general linear model was developed to analyze the effects of *Phragmites'* natural range expansion on plant species diversity on specific sites. Richness (the dependent variable) and the following three independent variables were used to create the model: Height on point, stand distance, and canopy openness. There was a substantial relationship ($p \leq 0.05$) between species richness and *Phragmites* expansion and light conditions as depicted in Table 2.

Table 2: Results of the test

Coefficients	**Estimate**	**Std. Error**	**Z value**	**Pr (>│z│)**
Intercept	2.224599	0.490576	4.535	5.770E-06
Stand distance	-0.06971	0.012503	-5.575	2.48E-08
Canopy openness	0.009087	0.005982	1.519	0.129
Height on point	-0.06315	0.088404	-0.714	0.475

3. Factors affecting species richness on plots

In the current study dependency of species richness on different plots from the expansion of *Phragmites australis (*height of *Phragmites* on the point and expanded stand distance from the point*)* and light effect (measured canopy openness on plots) was analyzed through a linear regression model. Canopy openness was lowest in plot no 29 (25.75%) and was highest in plot no. 7 (89.38%). Where the plots showing the dependence of species richness on various factors accordingly: Stand distance, Canopy openness, and Height on point are shown in Figure 3,4,5.

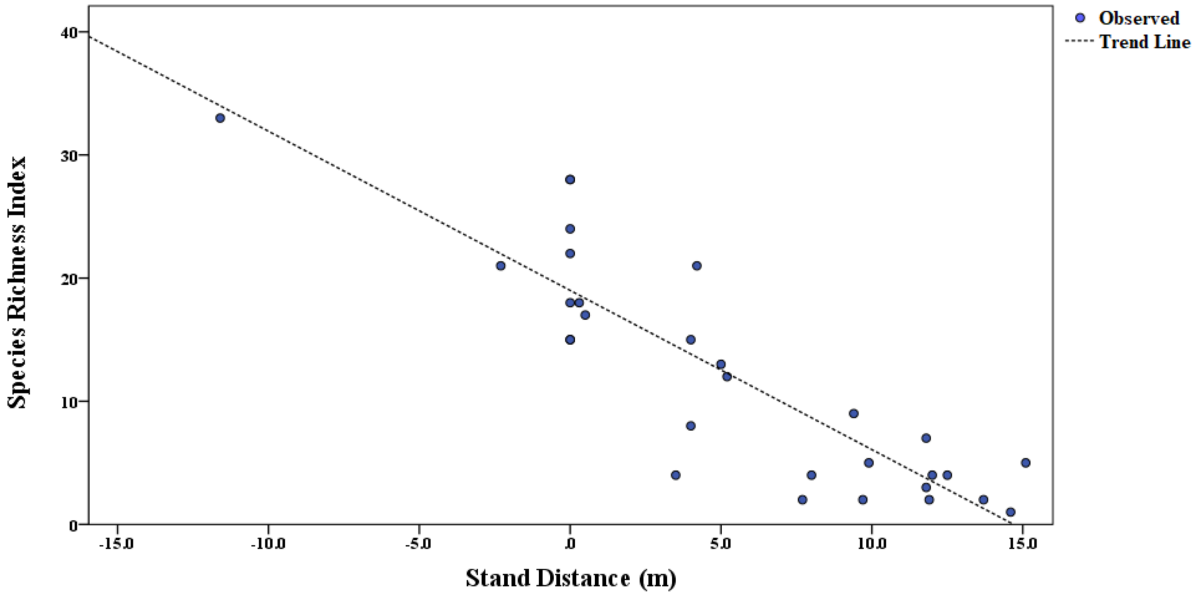

Figure 3: Dependency of species richness from expanded stand distance from the point

The curve estimation through the linear regression model in Figure 3 makes it abundantly evident that there is a meaningful negative relationship between the specie richness index and stand distance. The species richness index decreases by 1.293 for every unit of stand distance.

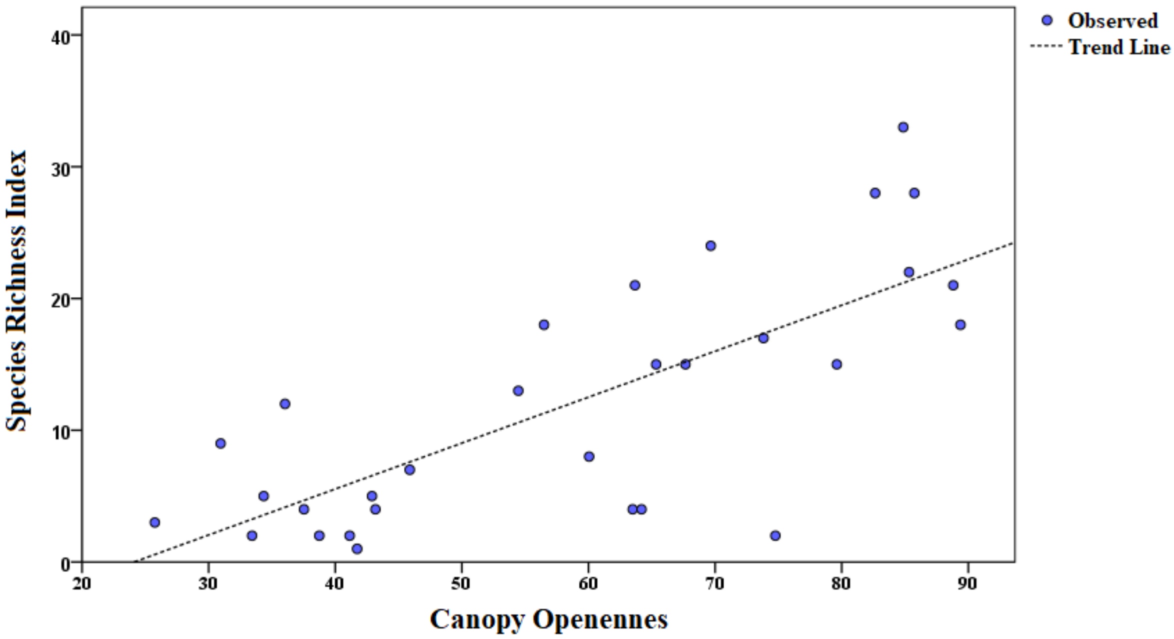

Figure 4:Dependency of species richness from canopy openness on the point

However, The curve estimation through the linear regression model in Figure 4 clearly shows that there is a direct link between the index of species richness and canopy openness. The species richness index rises by 0.349 for every unit increase in canopy openness.

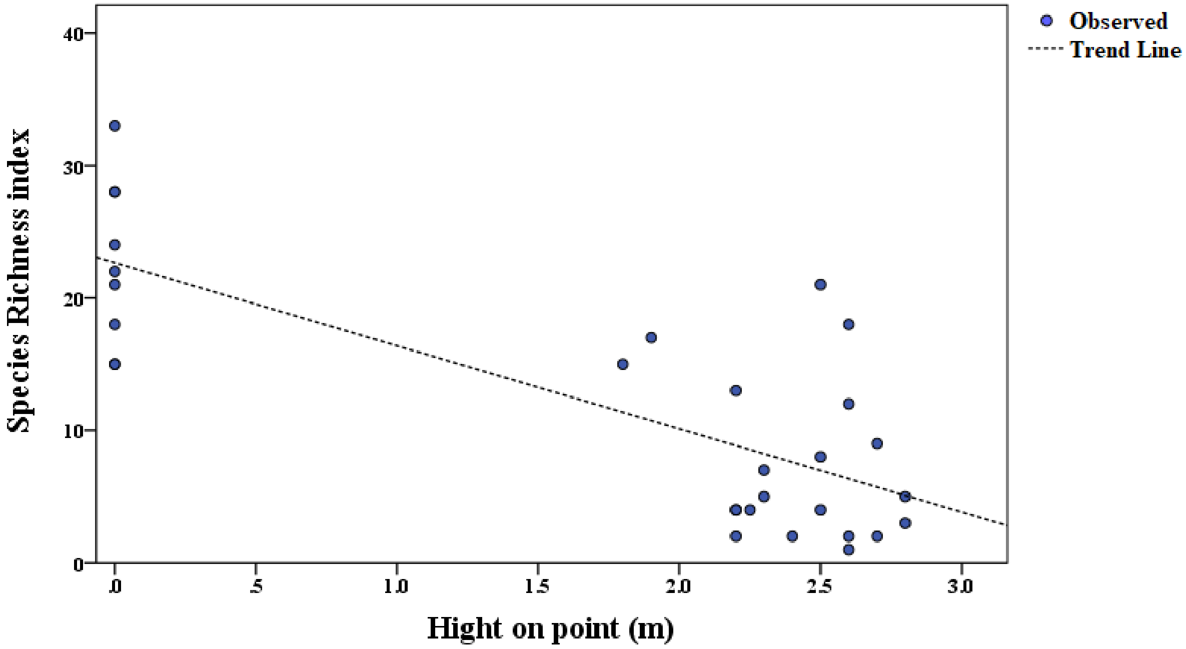

Figure 5: Dependency of species richness from the height of Phragmites on the point

The curve estimation using the linear regression model in Figure 5, however, demonstrates unequivocally that the relationship between the index of species richness and Height on point is inverse. Every meter of Height on the point that is added causes the species richness index to decrease by 6.28.

4. Ordinations

In the vegetation survey, 80 plant species from all 30 plots were identified. Table 1 displays the diversity index for all 30 plots. To further, summarize the community data and represent the response of particular species to environmental factors ordinations technics were used. Canonical correspondence analysis (CCA) plot, showing the influence of environmental factors such as height on point, stand distance, and canopy openness on species composition (black arrows; Figure *6*). The analysis was performed based on the 53 most important plant species (codes highlighted in red). Full name of codeded species showen in Appendix III. Most species such as *Tripleurospermum inodorum*, *Myosotis palustris, Trifolium hybridum,* and others prefer to grow on sites with high Canopy openness. However, *Persicaria minor*, *Juncus effuses* and *Chenopodium polyspermum* are shade-tolerant species and can thrive with the low amount of light under the foliage of *Phragmites australis*.

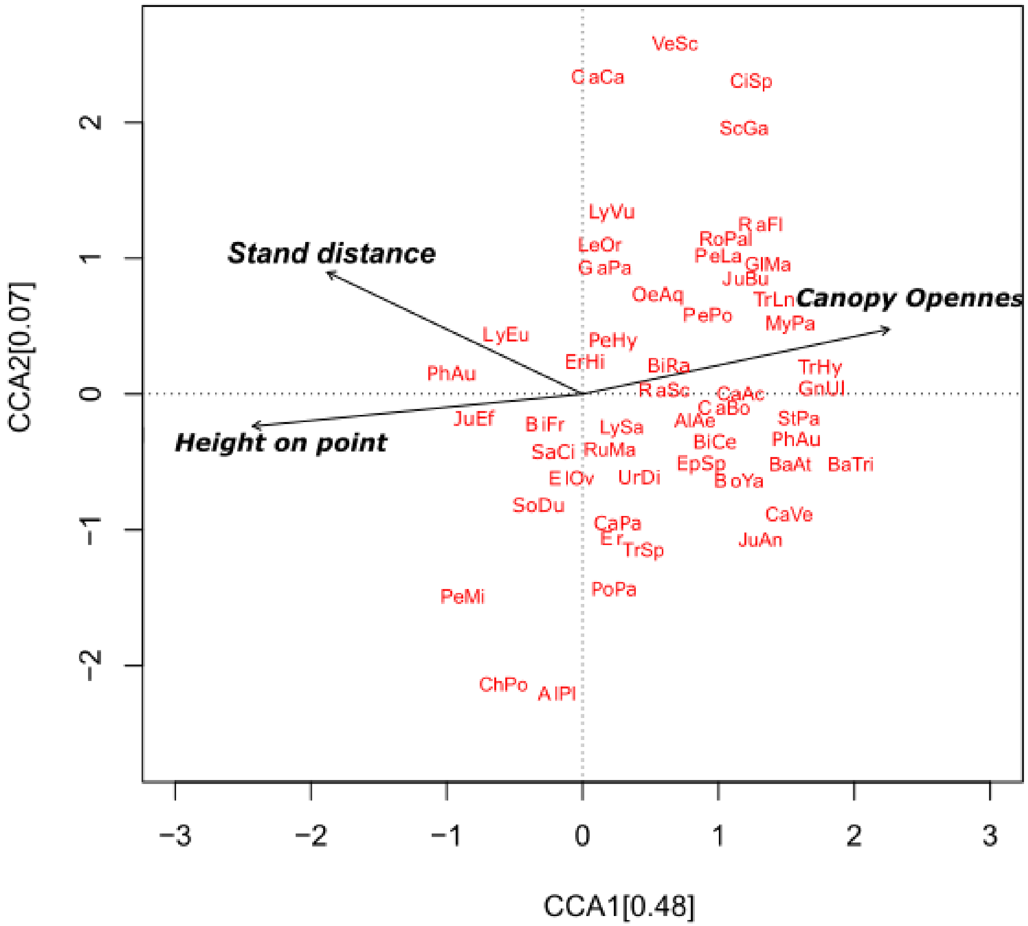

Figure 6: Effect of environmental factors on species composition (Full Species Names Listed in Appendix III)

In addition, to evaluate the significance level of environmental factors was run permutation test for CCA. The analysis was significant overall at $p \leq 0.05$ as depicted in Table 3. All mentioned factors are strongly correlated and almost equally affect species composition.

Table 3: Permutation test

Coefficients	Estimate	F value	Pr (>│F│)
Stand distance	0.30308	6.1090	0.001
Canopy openness	0.20277	4.0871	0.002
Height on point	0.12168	2.4527	0.012

Discussion and recommendations

1. Discussion

My study on the effect of native *Phragmites australis* on plant diversity provides information on the complex relationship between the population dynamic of expansive species and plant species diversity and contributes to the discussion on *Phragmite's* impact on the surrounding wetland ecosystem, specifically in the Czech Republic. *Phragmites australis*, a highly expansive and competitive species, have the ability to alter the physical, chemical, and biological characteristics of the environment in which it grows, which in turn can have significant impacts on other species (M. D. N. Uddin & Robinson, 2017). The objective of this study was to examine the impact of native *Phragmites australis* on plant diversity under distinct circumstances. The study is significant as it is the first to examine the relationship between *Phragmites* population dynamic in wetlands (i.e., consequences of its expansion or retreat) and its effect on species diversity and composition. Using data on the history of retreat and expansion of the native *Phragmites* zone, this study directly shows the effects of *Phragmites* on plant species diversity and composition in relation to its canopy openness, plant height, and canopy dynamics, as well as providing ordinations of these parameters.

Our findings suggested that *Phragmites australis* through the ability to modify environmental factors such as light penetration create conditions that are more favorable for its own growth and reproductive success but can cause other plants to retreat (Rudrappa et al., 2007). However, this change in the environment can also have significant impacts on other species, both positively and negatively, depending on the species' ability to perform under altered conditions (B. Liu et al., 2014). For example, some species may benefit from increased light levels and nutrient availability, while others may be negatively affected by changes in water levels or compete for resources with *Phragmites* (Farrer & Goldberg, 2009). The previous research conducted by Tulbure et al., (2012) in North America found that populations of non-native *Phragmites* had denser growth patterns and more aged culms compared to stands of native *Phragmites*, resulting in higher competitive pressure on the other plant species in a community. The results of my study, which analyzed the canopy openness of native *Phragmites* using Gap Light Analysis (GLA), extend these findings. My results suggest that expansive *Phragmites* stands exhibited lower levels of canopy openness and the species richness index decreased by 0.349 for every unit decrease in canopy openness. The results are consistent with a meta-analysis conducted by Windham & Lathrop, (1999) on the effects of *Phragmites* invasion on plant diversity showed that *Phragmites* negatively affected plant diversity in wetlands across North America. Furthermore, Chambers et al., (2003) suggested that *Phragmites* invasion significantly reduced plant diversity and altered plant community composition in wetland ecosystems. Another study by Saltonstall et al., (2004) found that non-native *Phragmites* had a negative impact on the diversity and abundance of native plant species in coastal marshes. The study also found that *Phragmite's* invasion resulted in a shift in plant community composition towards a few dominant species.

Another study by Rooth et al., (2003) found that *Phragmites* invasions can lead to changes in soil conditions, which in turn can facilitate the growth of other species. However, these results are inconsistent with those of Tulbure et al., (2012) and Rudrappa et al., (2007), who found that non-native *Phragmites* have a high range of canopy openness and increased plant diversity. It is important to note that the negative impact of *Phragmites* on plant diversity is a significant conservation issue, especially in their native range, and more research is needed to fully understand the complex relationship between invasive species and their impact on ecosystem diversity.

The negative linear association between invasive species and species diversity in a given area is a typical trend that can be altered by various environmental factors. For example, soil moisture levels can affect the performance of invasive and native plants. Studies have shown that *Phragmites*, a non-native plant species, have a greater competitive advantage over other plant species in aquatic ecotypes with high moisture levels compared to terrestrial ecotypes (Lachavanne & Juge, 1997; Li et al., 2014). Conversely, native plants perform better than invading species under conditions of lower soil moisture (Daehler, 2003).

Shoreline development in New England has been found to reduce soil salinity at the high marsh-terrestrial boundary and increase nitrogen availability in low marsh habitats (McClelland & Valiela, 1998). This shift has facilitated the initial establishment and clonal expansion of *Phragmites* in marshes, leading to a predictable change in community composition and a reduction in marsh plant richness (Chambers et al., 1999; Minchinton & Bertness, 2003). The competitive overgrowth by *Phragmites* is predicted to cause the extinction of all high-marsh plant species, with only the more potent competitor, *Spartina alterniflora*, remaining on the seaward edge of marshes where pore water salinities are highest and *Phragmites* expansion rates are reduced (Silliman & Bertness, 2004).

Our findings on the relationship between the *Phragmites* and species diversity in a given area align with previous research (Daehler, 2003; Lachavanne & Juge, 1997; Li et al., 2014). The current findings show that the very high density of *Phragmites* had a negative linear association with plant diversity. However, there is a complex association between *Phragmites* stands and other plant species, with lower coverage and higher biodiversity indices associated with higher plant height and historical dynamics of *Phragmites* stands. Interestingly, the retreat of *Phragmites* was associated with the expansion of certain species such as *Carex acuta, Glyceria maxima, Juncus bufonius,* and *Veronica scutellata*, but it does not impact the density of some species such as *Persicaria hydropiper*. These findings provide further evidence that historical *Phragmites* dynamics play a crucial role in shaping species diversity and composition (Silliman & Bertness, 2004). It would be interesting to explore this relationship in future studies to shed light on the impact of invasive and expansive species on ecosystem functioning and biodiversity. But native *Phragmites* are frequently credited with being the catalyst for local-scale biodiversity increases (Sax & Gaines, 2003) similar to our findings. When the density of *Phragmites* was low to moderate in the native *Phragmites* area, plant diversity increased. Once the cover was exceeded, a negative impact of *Phragmites* density on local species diversity became apparent (Y. Liu et al., 2021). In this case, *Phragmites* are capable of encroaching into nearby areas and displacing other wetland plant species, decreasing the system's overall plant diversity (Galinato & Van der Valk, 1986; Szczepanska & Szczepanski, 1982; Weisser & Parsons, 1981). *Phragmites australis* has the potential to displace other plants, which may have been thought to be more important for wildlife as food or cover, by forming monocultures. Nevertheless, it can also serve as a critical soil stabilizer and as a nutrient sink for wastewater treatment before release. (Brix, 1987; Bushmann, n.d.; Gersberg et al., 1986; House et al., 1994)

2. Recommendations for nature conservation practice

The following recommendations can be made based on the current study regarding the management of *Phragmites*. We can consider either supporting or reducing the population, depending on the population's history and its impact on diversity. To help the population spread, propagation, and field establishment procedures can be developed (Ailstock et al., 2001; Eleuterius, 1974; Stout, 1977). To reduce the population, breaking up the top layer of the soil or fire can drastically decrease the density of *Phragmites* in the immediate future. This seemingly drastic management restarts wetland succession and allows less competitive species to regenerate and rebuild populations, increasing in higher species diversity (Ailstock et al., 2001). This shows that although *Phragmites* has a high growth rate and rapidly replace native plant diversity, their population is relatively easy to manipulate through management.

More research is needed to make informed decisions regarding this plant species, including investigating its biology and ecology. Specifically, research should focus on the ecological and physical changes to its habitat that have likely contributed to its recent expansion.

The impact of anthropogenic soil disturbances on the growth of *Phragmites* compared to other wetlands vegetation should also be studied. There is evidence that a highly invasive non-native ecotype of *Phragmites* has emerged in several regions of North America and this ecotype may benefit from anthropogenic disturbances.

The effectiveness of traditional marsh management techniques, such as seasonal flooding or marsh burning, should be evaluated to determine if they contribute to the competitive tactics of *Phragmites*. Increased runoff and urban expansion can also impact hydrological conditions and should be considered.

Studies have shown the effect of native and nonnative *Phragmites* on plant diversity and density, but more research is needed to understand how they interact with local fauna for making batter management decisions.

To assess the impact of *Phragmites* on diversity and composition, it is recommended to compare historically stable *Phragmites* stands with sites where *Phragmites* have retreated. This comparison will determine whether species are reoccupying the sites after *Phragmites* retreats, indicating that the sites are still suitable for typical wetland species. Alternatively, if the sites are not similar in species diversity and composition, it may suggest that environmental conditions have changed and the sites are no longer suitable for typical wetland species, which would have negative implications for conservation.

Conclusions

The supreme purpose of the study was to examine the influence of *Phragmites* on the diversity and composition of plants. Specifically, the study aimed to determine the response of native *Phragmites* to plant diversity and to investigate the relationships between *Phragmite's* stand characteristics, their population history, and plant species richness in a community.

Two hypotheses were proposed. The first hypothesis was that plant species diversity does not depend on the population history of *Phragmites australis*. The second hypothesis was that the density, height, and canopy of the native *Phragmites* stand would be negatively related to the richness of the plant species. The results indicate that native *Phragmites* had a negative impact on plant diversity but only in highly expansive stands with dense canopy, density, and height.

The study highlighted the importance of manipulating *Phragmite's* stand in order to maintain the ecological balance and promote plant diversity. The findings of this research offer novel perspectives on the correlation between *Phragmites* and plant diversity and propose additional areas for investigation to comprehend the fundamental mechanisms that regulate this correlation. The investigation of the impacts of *Phragmites* on the local fauna, the evaluation of the natural dynamics of *Phragmites* stands, and the comparison of sites where *Phragmites* are historically stable with sites where *Phragmites* have retreated may also crucial for further studies. The ultimate goal of these tasks would be to better inform *Phragmites* management strategies for nature conservation.

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Appendix

Appendix I: Geographic features of the study points

Study points	Latitude	Longitude	Elevation (m)
Point 1	49.05265	14.71857	428.7116
Point 2	49.05427	14.71952	430.6139
Point 3	49.05476	14.7203	432.3334
Point 4	49.05586	14.72031	433.8003
Point 5	49.0567	14.72026	431.8605
Point 6	49.05597	14.71995	432.4807
Point 7	49.05598	14.71837	432.9943
Point 8	49.05609	14.71798	431.7883
Point 9	49.05677	14.71731	431.7809
Point 10	49.05827	14.7177	431.3015
Point 11	49.05797	14.72204	436.0485
Point 12	49.0582	14.72431	434.5565
Point 13	49.05829	14.72565	441.3434
Point 14	49.05818	14.7266	437.3724
Point 15	49.0569	14.72814	434.1789
Point 16	49.05518	14.73024	431.205
Point 17	49.05442	14.73002	431.8535
Point 18	49.05364	14.72965	433.2551
Point 19	49.05338	14.72946	432.888
Point 20	49.05339	14.7287	429.8384
Point 21	49.05328	14.72757	431.4521
Point 22	49.05269	14.72646	430.241
Point 23	49.05285	14.72566	429.8971
Point 24	49.05142	14.72519	430.663
Point 25	49.05166	14.72434	431.5117
Point 26	49.05181	14.72388	430.6381
Point 27	49.05129	14.72292	433.5994
Point 28	49.05106	14.72245	432.6982
Point 29	49.05078	14.72141	432.7059
Point 30	49.05048	14.71985	431.2147

Appendix II: Numeric variables collected during data collection (primary data)

Study points	Canopy openness, %	Growing height of *PhAu* from the point, m	Total growing height of *PhAu* from the point, m	Hight of *PhAu* on the point, m	Hight of *PhAu* after expansion/retreating, m	Total plant cover estimation, %
Point 1	85.32	0	1.6	0	0	80
Point 2	60.05	4	8.2	2.5	1.9	95
Point 3	63.49	3.5	6.2	2.2	1.7	94
Point 4	54.46	5	7.9	2.2	1.9	96
Point 5	74.76	11.9	14.3	2.2	2	100
Point 6	65.34	4	6	1.8	2.4	96
Point 7	89.38	0	3.7	0	0	95
Point 8	79.61	0	7.2	0	0	96
Point 9	73.82	0.5	5.8	1.9	1.9	90
Point 10	67.66	0	3	0	0	80
Point 11	69.66	0	10.4	0	0	85
Point 12	82.64	0	4.1	0	0	85
Point 13	85.74	0	1	0	0	90
Point 14	88.81	-2.3	1.3	0	2.3	80
Point 15	45.88	11.8	15.2	2.3	2.5	100
Point 16	43.17	8	9.8	2.2	3	97
Point 17	63.67	4.2	5.9	2.5	3	95
Point 18	34.35	15.1	26.9	2.8	2.8	96
Point 19	37.53	12.5	14	2.5	2.1	95
Point 20	64.19	12	15.3	2.25	2.3	100
Point 21	30.95	9.4	11.9	2.7	2	100
Point 22	38.74	9.7	12.5	2.7	2.5	100
Point 23	41.73	14.6	18.2	2.6	2.3	97
Point 24	84.86	-11.6	1.8	0	2.35	75
Point 25	42.9	9.9	10.9	2.3	2.5	96
Point 26	41.14	7.7	8.8	2.4	2	95
Point 27	36.03	5.2	7.3	2.6	1.7	85
Point 28	56.49	0.3	4.6	2.6	2.6	90
Point 29	25.75	11.8	14	2.8	2	97
Point 30	33.43	13.7	14.8	2.6	3	100

Appendix III: List of Plant Species found in study locations

Sr. No.	List of Species	Short name	Sr. No.	List of Species	Species code
1	***Acer sp.***	AcSp	41	***Juncus effusus***	JuEf
2	***Agrostis stolonifera***	AgSt	42	***Leersia oryzoides***	LeOr
3	***Alisma plantago-aquatica***	AlAq	43	***Lemna minor***	LeMi
4	***Alopecurus brachystylus***	Albr	44	***Limosella aquatica***	LiAq
5	***Alopecurus aequalis***	AlAe	45	***Lycopus europaeus***	LyEu
6	***Barbarea stricta***	BaSt	46	***Lycopus***	LyLy
7	***Batrachium aquatile***	BaAq	47	***Lysimachia vulgaris***	LyVu
8	***Batrachium trichophyllum***	BaTr	48	***Lythrum salicaria***	LySa
9	***Bidens cernua***	BiCe	49	***Myosotis palustris***	MyPa
10	***Bidens frondosa***	BiFr	50	***Myosoton aquaticum***	MyAq
11	***Bidens radiata***	BiRa	51	***Oenanthe aquatica***	OeAq
12	***Bidens sp.***	BiSp	52	***Oenanthe***	OeOe
13	***Bolboschoenus yagara***	BoYa	53	***Peplis portula***	PePo
14	***Calamagrostis canescens***	CaCa	54	***Persicaria hydropiper***	PeHy
15	***Callitriche palustris***	CaPa	55	***Persicaria lapathifolia***	PeLa
16	***Carex acuta***	CaAc	56	***Persicaria minor***	PeMi
17	***Carex bohemica***	CaBo	57	***Phalaris arundinacea***	PhAr
18	***Carex hirta***	CaHi	58	***Phragmites australis***	PhAu
19	***Carex pseudocyperus***	CaPs	59	***Plantago uliginosa***	PlUl
20	***Carex vesicaria***	CaVe	60	***Poa palustris***	PoPa
21	***Chenopodium polyspermum***	ChPo	61	***Poa trivialis***	PoTr
22	***Cirsium sp.***	CiSp	62	***Ranunculus flammula***	RaFl
23	***Deschampsia caespitosa***	DeCa	63	***Ranunculus sceleratus***	RaSc
24	***Eleocharis ovata***	ElOv	64	***Rorippa palustris***	RoPa
25	***Epilobium obscurum***	EpOb	65	***Rumex maritimus***	RuMa
26	***Epilobium palustre***	EpPa	66	***Salix cinerea***	SaCi
27	***Epilobium sp.***	EpSp	67	***Scutellaria altissima***	ScAl
28	***Erechtites hieraciifolius***	ErHi	68	***Scutellaria galericulata***	ScGa
29	***Erechtites***	ErEr	69	***Setaria sp.***	SeSp
30	***Erigeron annuus***	ErAn	70	***Solanum dulcamara***	SoDu
31	***Galeopsis sp.***	GaSp	71	***Sorbus aucuparia var. aucuparia***	SoAu
32	***Galinsoga parviflora***	GaPa	72	***Spirodela polyrhiza***	SpPo
33	***Galium aparine***	GaAp	73	***Stellaria palustris***	StPa
34	***Galium palustre***	GaPa	74	***Trifolium arvense***	TrAr
35	***Glyceria fluitans***	GlFl	75	***Trifolium hybridum***	TrHy
36	***Glyceria maxima***	GlMa	76	***Trifolium sp.***	TrSp

37	***Gnaphalium uliginosum***	GnUl	77	***Tripleurospermum inodorum***	TrIn
38	***Iris pseudacorus***	IrPs	78	***Urtica dioica***	UrDi
39	***Juncus articulatus***	JuAr	79	***Veronica scutellata***	VeSc
40	***Juncus bufonius***	JuBu	80	***Veronica serpyllifolia***	VeSe