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Mostly Harmful? Phragmites australis and Typha angustifolia in a study of the meaning of invasiveness in an abandoned limestone quarry and beyond

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Mostly Harmful? *Phragmites australis* and *Typha angustifolia* in a study of the meaning of invasiveness in an abandoned limestone quarry and beyond

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Introduction

Cliffs cast shadows over the talus slopes at their bases and wall in the flat grey basin of an abandoned limestone quarry. Compared to the lush Indiana hardwood forest around top of the cliffs, a quarry floor looks dry and desolate. Close inspection is required to reveal the life that clings to cracks and converges around temporary ponds, but once one begins to look, this strange landform is fascinating. On the floor the sun-bleached rocks are speckled with short green eastern redcedar trees paired with bone white stunted sycamores, small asters and goldenrods shoot up from the rubble, and tall *Phragmites australis* and *Typha angustifolia* stand grouped in dense clusters. Snakes hide in rock piles, killdeer camouflage their nests among the egg-like rocks, and vultures ride the currents watching for carcasses to scavenge. Life on this land is not easy, but still, life persists.

The quarry floor is in the DePauw Nature Park; a parcel of land which was donated by Hanson Aggregates after they ceased their mining activities. The park includes 520 acres of upland hardwood forest, a floodplain along Big Walnut Creek, and 10 miles of hiking trails. Before mining, the quarry floor would have been hardwood forest as well, but in 1917 humans came into the landscape and removed the plant populations while extracting tons of limestone. Bare bedrock was all that remained in that gaping hole in the surrounding forested land. The quarry seems out of place in a nature park because it is a disturbed human-made area within a park which is ostensibly meant to be filled with nature. It was actually the quarry floor which was first donated to start the DePauw Nature Park; thus, the entire park would not have existed were it not for the donation of this disturbed land. A disturbed habitat is an environment in which an event occurs that injures or kills organisms, creating opportunities for other organisms to establish populations (Bowman, Hacker, & Cain, 2017). Where does this carved out basin fit into the ideal natural world a nature park is meant to provide? Is there anything natural to be reconciled in this anthropogenic landscape? Are invasive species problematic in an environment like the quarry which is largely devoid of life? The main purpose of the quarry in the nature park could be to serve as a message for what humans leave behind when we draw resources from the land compared to nature preserves.

This project is set squarely in the disturbed landscape of the quarry floor. It was inspired by the research that I conducted in the summer of 2020 which examined pairs of species of similar forms that differed in whether they were classified as native or invasive species in Indiana. A key common factor among the plants is that they are all successfully established in the very harsh, highly fluctuating, and xeric environment of the quarry floor. That broad tolerance of quarry plants made me question the importance of the label "invasive species" in the context of a harsh environment like the quarry floor. While collecting information for my summer research project, I found that it was hard to find consistent parameters for designating a species as invasive. The definition of an invasive species from the USDA Forest Service is a non-native species that is likely to cause harm to the economy, environment, or human health in that ecosystem. Looking at this definition, there is a lot of grey area. How do scientists determine that a species is native or non-native? How long does a species have to live in an area before it can be called native? Who is assessing the likelihood of an organism to cause economic, environmental, or human health threats and how do they assess that? How are these non-native species getting to new areas? The definition of invasive species is broad, and the answers provided by invasion biology to many of these questions are arbitrary and inconsistent.

When I talk to non-scientists about my study of *Phragmites australis* and *Typha angustifolia*, they often have a negative reaction to these plants once they discover that they are classified as invasive species. Other categories of plants share the hardiness and competitiveness often associated with invasive species, and many of them do not have such a bad reputation as invasives. It is as if the label of invasiveness makes it impossible for a plant to be beautiful or useful in any way. One person even remarked on having liked the look of *Phragmites australis* in the nature park and noted it was a shame they could not enjoy the plants anymore. There is this sense that plants must be wholly reviled for their status as an invasive species. When a descriptor has such a powerful effect on a plant's reputation, it should have a clear definition.

This is all sounding very pro-invasive species, and I do not mean to discount the very real negative impacts that species classified as invasive have on the biodiversity and ecology of the regions to which they are introduced. The very same *Phragmites australis* and *Typha angustifolia* that fill in barren regions of rock in the quarry are known as notorious, noxious invasive species in many environments. The question is not whether these plants have had negative effects in many of the environments in which they grow, but rather the link of those negative effects to their status as invasive species. Do scientists need to bother proving that an invasive species is harmful in every context? Or can species that are classified as invasive be assumed to be universally harmful? I argue that the negative effects of an invasive species need to be understood in context so that management strategies can target areas where the introduction of invasive species is most likely to cause harm. Furthermore, for the term invasive species to continue to hold the significance that it currently does, it needs to be clearly defined with a set of quantitative attributes.

Purpose Statement

The purpose of this work is to study the language used in invasive species biology, to examine the meaning of the invasive label, and to apply these considerations to a geographical study of *Phragmites australis* and *Typha angustifolia*. I will explore current issues with the study of invasive species and present the kind of study for which I advocate. The implications of this work fall into politics, science writing, and resource management. Throughout the work I will be interrogating the definition of invasive species and the associated language used for plants that are called invasive. After an introduction to some of the drawbacks the presence of *Phragmites australis* and *Typha angustifolia* have been shown to have in past studies, I will attempt to put aside, until the conclusion of the paper, any preconceived biases against invasive species as a group to fully consider the questions at hand. In my studies I have found that designations authoritatively applied are not so clear as they imply. Given such a lack of clarity, I will argue that the harmfulness of *Phragmites australis, Typha angustifolia*, and all invasive species must be proven in context. Universal harmfulness cannot be assumed due to an organism's status as invasive species while this term remains ill-defined and linguistically loaded. The last section of this work will focus on the quarry floor as a landform that is undergoing primary succession which will lead to a climax community which is yet to be determined and the *Phragmites australis* and *Typha angustifolia* mapping project that I performed in the fall of 2020 and past students have undertaken in the last fifteen years.

Overview

I will begin by introducing the study site and the two focal species, *Phragmites australis* and *Typha angustifolia*. Next, the language that is commonly used in invasive species research will be explained and critiqued. Then traits associated with early successional and invasive species will be considered. Moving into the research that is more specific to the quarry floor, I will discuss some potential long-term goals for the region and how the climax community of this environment may differ from the surrounding land depending upon management decisions.

Following this is the methodology and analysis of *Phragmites australis* and *Typha angustifolia* population mapping. I will then conclude with a discussion of potential future projects in the field of invasive species research.

Site Description

This project is based in the DePauw Nature Park in Greencastle, Indiana in the portion of the quarry floor which has not undergone reclamation since abandonment. The other part of the floor, which was not included in this study, underwent technical reclamation when it was filled in with soil. Though the original quarry floor includes a region larger than that which was studied in this paper, from this point forward, I will refer to the study region as simply, the quarry floor.

The quarry was mined from 1917 to 1977 by Hanson Aggregates using blasting, steam shoveling, and water pumped from nearby Big Walnut Creek. The operations focused on utilizing the significant limestone reserves present in this area. Limestone (calcium carbonate) is the only type of rock exposed in the Nature Park. The beds of limestone at the Nature Park were deposited in a shallow continental sea during the Mississippian Period (approximately 345-350 million years ago). The study region of the quarry (quarry floor) has been abandoned with minimal restoration efforts since mining ceased in 1970 and the quarry closed entirely in 1977. [i]

The map on page 12 shows the portion of the quarry under study relative to the DePauw Nature Park. The inset map outlines the quarry floor in red. This map also contains colored portions representing the 2020 area covered by *Phragmites australis* and *Typha angustifolia,* respectively. The background imagery is from a 2018 survey of the DePauw Nature Park, and

[i] This historical information is sourced from the DePauw University website under History of the DePauw Nature Park which was provided by Professor Jim Mills.

the map was generated using ArcGIS Pro 2.6 software. The purpose of this map is to contextualize the study region. The pictures on this page were taken in the location with the corresponding numbered callouts on the map.

Figure 1.

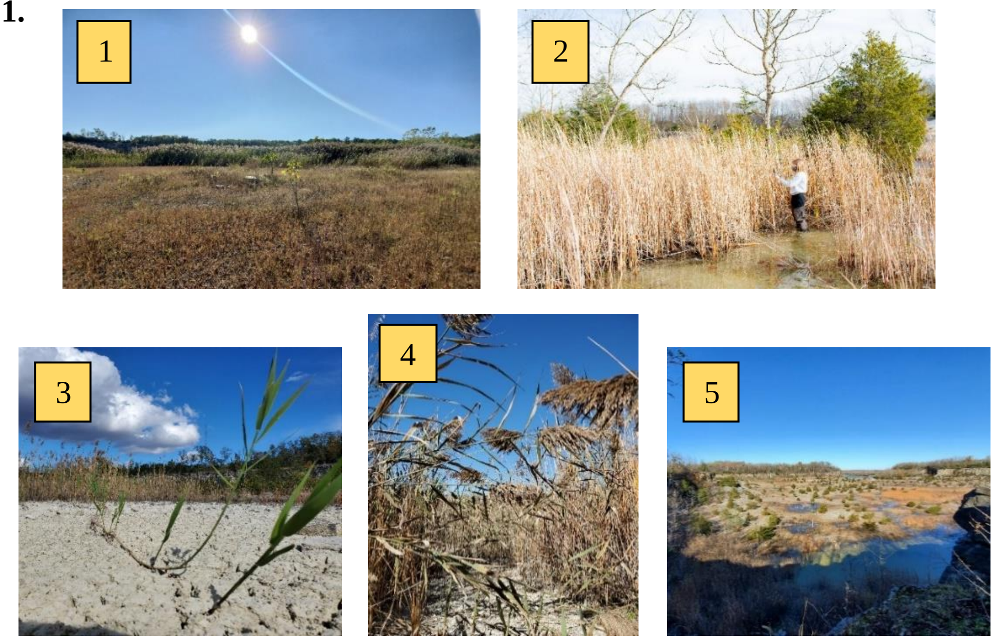


Figure 1: The picture in the top left-hand corner of this figure (1-1) is a landscape view that shows a large patch that was referred to in the field collection as the beast and is referenced in the mapping results. I took the photo on a clear-sunny day. The next photo (1-2) was taken by Brittney Way for DePauw University and it shows me (5 ft 5 in tall) in waders taking data on *Typha angustifolia* that are growing in a wet pond. The third photo (1-3) shows a runner plant stretching out from the patch of *Phragmites australis* that we called the mother patch. Runners are one type of vegetative expansion that we observe in Phragmites australis patches in the quarry floor. The fourth photo (1-4) shows tall Phragmites australis plants that are flowering. I took the fifth photo (1-5) on October 20th, 2020 from the quarry rim and looks out on the quarry floor during a period of somewhat high saturation.

Figure 2.

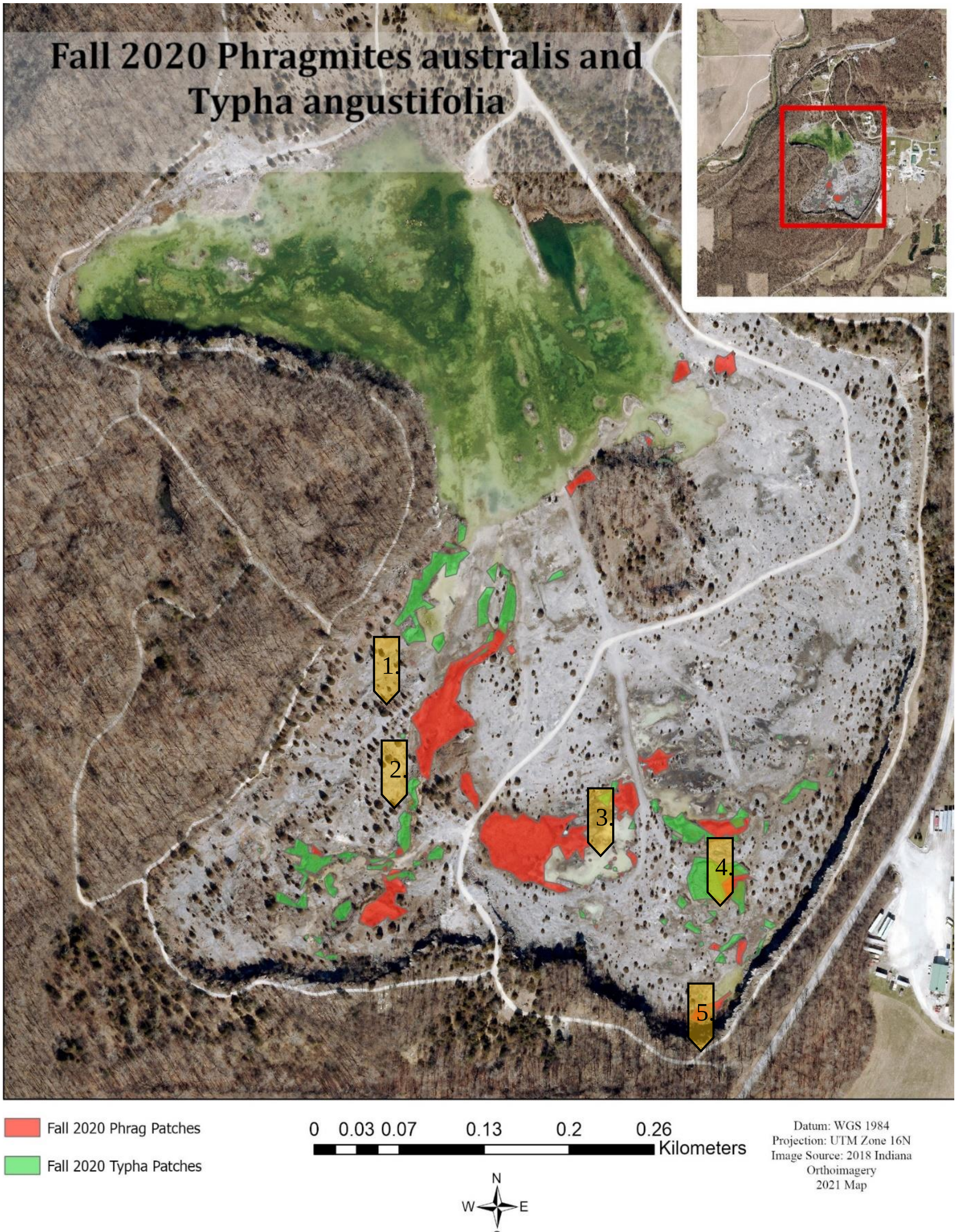


Figure 2: A map of *Phragmites australis* and *Typha angustifolia* populations in the DePauw Nature Park quarry floor

Figure 3.

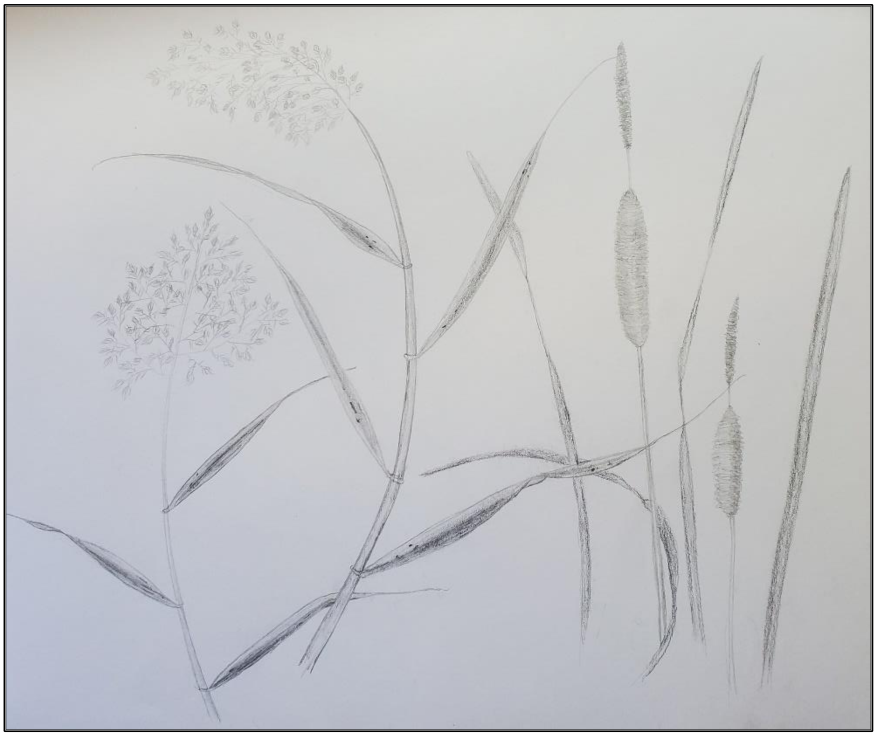


Figure 3: A sketch that I drew of *Phragmites australis* (left) and *Typha angustifolia* (right).

Species Descriptions

Phragmites australis (*P. australis* – common reed) is a tall perennial grass that is distributed throughout North America, though its native distribution is complicated. It has dense green foliage and white flowers in the summer and abundant fruits and seeds starting in the summer and ending in the fall. The mature plant height is approximately four meters. *P. australis* displays fast, rhizomatous growth and high seedling vigor, but slow seed spread rate. *P. australis* utilizes vegetative growth strategies such as rhizomes and stolons. It is adapted to multiple soil types and has high anerobic tolerance (USDA Conservation Plant Characteristics).

Typha angustifolia (*T. angustifolia* – narrow-leaf cattail) is also a perennial grass, though it is shorter than *Phragmites australis* with a mature height of approximately one and a half meters. It is native to most of Canada, but like *Phragmites australis,* is considered both native and invasive throughout the United States. *T. angustifolia* has moderately dense green foliage in the summer. It flowers in the late spring and is distinguished from other members of the Typhaceae family by the separation it has between the male and female portions of the flower as well as its narrower leaves. *T. angustifolia* also has a greater tolerance for salinity and acidity and higher shoot density and heights early in the growing season than the other *Typha* species (Shih & Finkelstein, 2008). It flowers in the late spring and the seed period begins in the spring and lasts throughout the summer. It has a rapid seed dispersal rate and rapid rhizomatous spread. It is adapted to multiple soil types and has high anerobic tolerance (USDA Conservation Plant Characteristics).

Background Information on *Phragmites australis*

Phragmites australis is a well-known invasive species in the United States and around the world. It is common in many wetland habitats and thus has been the subject of much previous research (Myerson et al., 2016). Due to its global range, the ease with which it can be grown, and its large range of ecological niches *P. australis* has been described as a model organism for studying invasive plant species (Myerson et al. 2016). Furthermore, detection of invasive *Phragmites australis* is an indicator of wetland disturbance (Saltonstall, 2002). Unlike native *Phragmites* species, invasive types displace other wetland plants, including native *Phragmites* and form monoculture stands (Ward & Jacono, 2009).

One of the difficulties researchers have found in studying this invasive *Phragmites* species is in differentiating between the native and invasive strains which are very similar in appearance (Ward & Jacono, 2009). This obstacle to positive identification leads to what Dr. Kristin Saltonstall refers to as cryptic invasion or the establishment of species that cannot be readily identified as either native or invasive (Saltonstall, 2002). It has been difficult to determine the spread and impact of invasive *Phragmites australis* around the world due to this difficulty in differentiating it from the native type. Cryptic spread of *P. australis* motivated Dr. Saltonstall's research in chloroplast DNA to identify individual strains of *Phragmites*. The results of her research revealed twenty-seven haplotypes (Saltonstall, 2002). There were eleven haplotypes identified that were native to North America alone and two that were found to be distributed more widely.

The study narrowed in on haplotype M which was found to be the most common type in North America, Europe, and Asia (Saltonstall, 2002). Haplotype M not only replaced native types in New England but was also found outside of the historical range of *Phragmites* in North America. Since haplotype M is the only type identified by Saltonstall as being distributed in southern Indiana, and the *Phragmites australis* we observe in the quarry floor forms monoculture stands, it is deducible that the *Phragmites australis* in the DePauw Nature Park is haplotype M (Saltonstall, 2002).

One question that remains unanswered about this haplotype is whether it was introduced to North America from elsewhere or if it is native. If it is native, the observed expansion in its range can be attributed to human disturbances which cause increased soil salinity, pollution, and changes in hydraulic regimes (Saltonstall, 2002). This explanation relies on the proposed heightened physiological tolerance and differences in behavior which may give haplotype M an advantage over the other native types (Saltonstall, 2002).

Background Information on *Typha angustifolia*

Typha species are increasingly considered invasive weeds in eastern American wetlands. Typha spreads quickly with both rhizomatous and sexual reproduction. They tend to form dense, monospecific stands that inhibit establishment of other species which make it possible for them to "dominate" wetlands. There are three common species of Typha in North America, *Typha latifolia*, *Typha angustifolia*, and the hybrid type, *Typha glauca*. *Typha glauca* and *Typha angustifolia* are understood to be more invasive than *T. latifolia* (Shih & Finkelstein, 2008). The species identified in the quarry floor is *T. angustifolia*; it is differentiated from the other species by its comparatively narrow leaves and the gap that can be seen between the male and female flower parts.

All three Typha species are becoming increasingly prominent in eastern North American wetlands and are considered "undesirable, weedy, or invasive" and they all display invasive tendencies in disturbed wetlands (Shih & Finkelstein, 2008). Though they have these factors in common, the range increases since 1880 for *T. angustifolia* are greater than those of *T. latifolia*, and *T. angustifolia* is considered an invasive species. More recently actualized ranges of these two species have been expanding at the same rate (Shih & Finkelstein, 2008). This begs the question as to why one species is presumed invasive and the other native.

One explanation is that the assumption that *Typha angustifolia* is invasive may be false, and alternatively it could be a native species that began to display invasive tendencies after European settlement (Shih & Finkelstein, 2008). Pollen records indicate that *T. angustifolia* may have been present in North America before European settlement but was not widespread (Shih & Finkelstein, 2008). This description of the presumed invasiveness of *T. angustifolia* is similar to that of *Phragmites australis*. For both species, it is unclear exactly where the origins lie and whether the observed increases in their distribution can be attributed to introduction or anthropogenic changes in the land.

A General Background for Invasive Species Research as a Discipline

Invasive species are generally understood to be non-native species that cause ecological, economic, and/or health damage (Inglis, 2020). There are proven drawbacks that species designated as invasive have had on the ecological health of the planet. As noted above, the two species under study themselves have been shown to have negative impacts on many of the ecosystems in which they grow. More generally, invasive species are evidenced as causing negative effects on IUCN Red List species. IUCN Red List species are those identified by the International Union for Conservation of Nature as being at risk for extinction (Verbrugge, Leuven, & Zwart, 2016). Not only can invasive species research show the harm that has been done to different ecosystems, but invasion biology can aid in predicting and preventing ecological damage (Verbrugge, Leuven, & Zwart, 2016).

Despite the benefits gained by conducting such research, it is imperative that we continue to question why we begin to examine a species' role in the environment first by invasive status (or simply by native status) instead of another feature like family, form, life history, etc. Why has native status risen to such prominence as a sorting tool for beneficial and harmful plants in the United States? There are other places, such as many European countries, where the harmfulness of a non-native species must be proved, it is not assumed. In the United States however, there is a principle of "guilty until proven innocent" for invasive species (Dahlstrom, Hewitt, & Campbell, 2011). Some may find this rhetoric odd since non-native wheat, rice, cattle, poultry, and those honeybees which we have been working so hard to protect are all highly valued (Inglis, 2020). Even the apple, so central to the image and settlement of the United States of America, is not from the Americas. Further complicating matters is that the risk assessments that distinguish invasive and non-invasive species are not consistent; this a problem that I will return to later in the section that deals with defining invasive species (Verbrugge, Leuven, & Zwart, 2016).

Language use in Invasive Species Biology

Language matters. That simple fact has become more and more evident in light of American and global politics. For example, in his first month in office, President Joe Biden moved to remove the term “alien” from U.S. Immigration laws (Shoichet, 2021). President Biden is pursuing this change because the term dehumanizes and devalues the lives of the people described (Shoichet, 2021). Alien is a familiar term to those who know the immigration policies in the United States, and to people familiar with invasive species rhetoric as well. Species are called invasives, aliens, non-native, or introduced, and once they are thus categorized, invasive species are subjected to a litany of terms that denounce their value.

I am not the first and will not be the last to call for reform in the language we use in biology. Other scientists have already called for an end to the use of the term “invasive species” due to the vilification it perpetuates and the lack of clarity surrounding the term (Inglis, 2020). The way we talk about invasive species overstates the simplicity of the phenomena being observed and builds metaphors upon that oversimplified narrative (Inglis, 2020). This section will predominantly focus on the problems associated with invasive species language, and the complexity of the categorization of an invasive species will be dealt with more in the section following this. First, I will look at nationality and impressions of invasive species, then the overlapping terms and ideas found in immigration and invasive species policies, and lastly, the use of metaphor in invasive species biology. It is the intention of this section to contextualize the importance and implications of the language we choose to use as scientists studying invasive species.

Nationalism and Invasive Species Perceptions

The use of words like invaders, foreigners, and aliens others and devalues the species it describes. The application of these words to non-human species parallels that which occurs for human migrants (Inglis, 2020). Considering this shared vocabulary between invasive species and human migration terminology, this section will explore the 2007 research of Dr. Peter Coates in which he examined the relationship between nationalism and perceptions of invasive species. His paper introduces the danger of a close correlation of opinions of human and non-human migrations which one key reason for the reassessment of invasive species terminology. Though science is typically viewed as being somewhat removed from the social and political, scientists are influenced by and contribute to the popular opinion of the times and places in which we live.

Scientists tend to use terminology and metaphors that place them squarely in the sociopolitical climate in which they work. It is commonplace in introductions to talks or articles about invasive species for researchers and speakers to describe an alien invader that is leaving the country "biologically traumatized" due to a "multinational assault" to build up to a linguistic flourish that subverts some collective expectation by ending the sentence with the revelation that no, this is not a human or extraterrestrial, but a group of plants and animals (Coates, 2007). Such scientists and politicians "Play on words and subvert familiar notions indicate that discussions of undesirable immigrants in the United States are now just as likely to include flora and fauna as they are to involve the more conventional human variety" (Coates, 2007). This device relies on the assumption that the audience will be imagining a looming human or alien threat and will be surprised at the twist. It elucidates the underlying assumption that invasive organisms and immigrants are one in the same (Coates 2007). How is it that this tacit agreement came about? How closely related are perceptions of human and non-human migrants?

Put simply, “Ideas of nationality have influenced our understandings of the nonhuman world of nature” (Coates, 2007). Starting around the second half of the nineteenth century, it was popular to bring non-native plants into new lands for cultivation. This trend was partly owing to the notion anything European was better than anything American (Coates, 2007). Such a practice may seem strange in the current context which celebrates native flora and fauna, but the popularization of the native over the “exotic” is a relatively recent trend. The rate of introductions increased quickly after World War II as international trade increased and it was around this same time that invasive species research and management started becoming popular. In 1958 Charles S. Elton used the term *invasive species* in his work managing species that affected the British economy and food supply during WWII (Janovsky & Larson, 2019). As the drawbacks of bringing “exotic” species to the U.S. became apparent toward the end of the 1900s, it was denounced and in the same stroke, native plants gained value (Coates, 2007). It was discoveries like these which helped push us into the current native-cultivar trend. During the same time-period that people in the U.S. increasingly recognized the error of their introductions of nonnative species, public opinion about human immigration also shifted based on similar ideas of the value of the native and the danger of the foreign. This xenophobic shift was further supported by the racialized science that was being produced at the time (Coates, 2007). Thus, public opinion regarding nationalism coincided with non-human species popularity. The studies and management strategies put forward by scientists may not be as objective as we assume, and even if they are, they are received by a public with preconceived notions about the value of a species based upon their origin.

Spillovers Between Science and Politics

Roderick McKenzie wrote in “The Ecological Approach to the Study of the Human Community” at the University of Chicago in the 1920’s, “Just as in plant communities successions are the products of invasion, so also in the human community the formations, segregations, and associations that that appear constitute the outcome of a series of invasions” (McKenzie, 1924). He based his work on that of a botanist and translated his rhetoric directly from his work (Coates, 2007). The absurdity of such a comparison is obvious, plant and human communities are sufficiently divergent as to make them incommensurable. Surprisingly, this comparison was not an isolated event, and there are many more examples of people using analogies from invasive species when they talk about communities of people who have immigrated to a new country. This kind of interrelation of how plants and animals move is wrong on many accounts. Not only is it moralistically reprehensible to classify people immigrating to a country as a series of invasions, but it implies that human movement is as straightforward as a plant’s and that human immigration can be understood and conceivably treated the same as the movements of plant communities.

Not all the allusions are direct, but the overlap is problematic because as people become more radically and vehemently xenophobic about invasive species, the metaphoric allusions have the potential to become increasingly violent. If one categorizes human migration and plant community establishment as being the same “problem” then the violent solutions scientists propose for the removal of invasive plants might follow the link into political discourse as well. Who is there to draw the line where the metaphor becomes unconscionable?

When scientists frame plant movements in terms that are used in immigration policy and discourse, there is a personhood imparted on flora and fauna and this can raise emotions in people (Coates, 2007). Considering the overlap in the rhetoric of these articles and political arguments about immigration, it is evident why such emotions are raised. One example of many problematic perspectives is the idea of quantifying and predicting the value added or detracted by the non-human migrants or human migrants. This valuation system is evident not only in rhetoric, but is written into our immigration policy, “just like the disputes over their nonhuman counterparts, this more familiar controversy over human arrivals has been squarely framed in terms of immigrant promise and desirability and immigrant menace and undesirability” (Coates, 2007). The following (Figure 4) is a snip from the Department of State Directory of Visa Categories. It should be noted that the category for which a migrant qualifies determines timeline, likelihood of approval, and duration of the visa. For example, an O-1 Visa for individuals with Extraordinary Ability or Achievement lasts up to three years upon initial approval and can be extended on a yearly basis. An H1-B for Specialty Occupations etc. also lasts for up to three years and can be extended for a total of six years, but applicants must enter a lotto for approval of an H1-B visa as there is a cap for the total number of these visas available in a year (USCIS).

Figure 4.

Purpose of Travel	Visa Category	Required: Before applying for visa*
Athlete, amateur or professional (competing for prize money only)	B-1	(NA)
Au pair (exchange visitor)	J	SEVIS
Australian professional specialty	E-3	DOL
Border Crossing Card: Mexico	BCC	(NA)
Business visitor	B-1	(NA)
CNMI-only transitional worker	CW-1	(USCIS)
Crewmember	D	(NA)
Diplomat or foreign government official	A	(NA)
Domestic employee or nanny - must be accompanying a foreign national employer	B-1	(NA)
Employee of a designated international organization or NATO	G1-G5, NATO	(NA)
Exchange visitor	J	SEVIS
Foreign military personnel stationed in the United States	A-2 NATO1-6	(NA)
Foreign national with extraordinary ability in Sciences, Arts, Education, Business or Athletics	O	USCIS
Free Trade Agreement (FTA) Professional: Chile, Singapore	H-1B1 - Chile H-1B1 - Singapore	DOL

Figure 4: U.S. Department of State – Bureau of Consular Affairs. Directory of Visa Categories. Travel.state.gov. https://travel.state.gov/content/travel/en/us-visas/visa-information-resources/all-visa-categories.html

Not only is the valuation system present in this somewhat cloaked language of our immigration policy, but in political speeches from prominent leaders as well. Many are familiar with some of the early quotes from former President Donald Trump regarding immigrants he deemed "undesirable"

> "They're sending people that have lots of problems, and they're brining those problems with us. They're brining drugs. They're bringing crime. They're rapists. And some, I assume, are good people"

> "It's like an invasion. They have violently overrun the Mexican border"

"Why do we need more Haitians?" (Scott, 2019).

These exclamations are not so directly tied to invasive species research, but they are built upon some of the same notions, namely normalized xenophobia and a ranked hierarchy of desirable origins for migrants (Verbrugge, Leuven, & Zwart, 2016). As Coates' article showed, perceptions of non-native species and immigrants have ebbed and flowed together. There are many parallels in the ways people view non-native biota and immigration such as the preferential treatment based on the land of origin, and European plants and people have been favored for admission to the United States. The quotes highlight where recent discourse has been regarding immigration, and we have lately been in a time of high combativeness against invasive species as well. There is harm to the use of militarized language when discussing invasive species management and this becomes apparent when politicians use it. Political polarization and radicalization can lead to terrible human consequences such as presidential suggestions of shooting migrants in the legs to slow them down (Scott, 2019). This is not to say that hate speech is born of invasive species research, but that invasive species research can add to the milieu of negativity surrounding migration, and that is not its purpose, so it should not be an outcome.

What are these Problematic Terms?

Figure 5.

Figure 5: Collection of words used to describe non-native plants from sources such as the National Parks Service and research articles (Coates, 2007).

Metaphor

Metaphoric language plays an important role in linking the scientific and the public domains. Metaphors serve to clarify concepts by creating links between the familiar and the unknown, and in so doing, they can make concepts accessible in circles that extend beyond experts in the field. Education and explanation can be aided by the use of metaphor, but a scientist or educator’s choice of metaphor is biased by the educator or researchers own experience with the topic. That bias affects how the non-expert understands the facts of the information, it is not just the learner's opinions that are affected, but their foundational grasp of a concept. The presentation of the information is itself politicized by the choice of metaphor (Verbrugge, Leuven, & Zwart, 2016).

Invasion biologists commonly choose militaristic metaphors. Though other fields in biology also use militaristic language, they use it to frame competition or predator-prey relationships between two non-human organisms. Invasive species on the other hand are framed as enemies of the environment at large. Militaristic metaphor is used more in invasive species research than in other areas of biology. According to a 2019 study by Janovsky and Larson, out of a group of applied and basic journals and invasive or other biology topics such as conservation, competition, etc., invasive species articles in basic science journals were the most likely to include militaristic language (shown as a percentage of the total articles sampled that had militaristic language), although this difference was not statistically significant. Counts of militaristic language per article were highest in this group and that difference was significant (Janovsky & Larson, 2019). Their study showed that though militaristic metaphors are used evenly across science papers, they are included in greater numbers within invasive species research articles. Verbrugges, Leuven, and Zwart in their 2016 article argue that the use of this kind of metaphor reinforces militaristic thought patterns about invasive species management (Verbrugge, Leuven, & Zwart, 2016). I agree that militaristic metaphors are overutilized in invasive species research and management strategies. Violent language does not match the preservation or conservation goals of invasion biology and should be removed from common usage in this field.

Anthropomorphism is another technique that is commonly used by scientists. Many metaphors used in biology anthropomorphize nature to make the motivations of non-human organisms more accessible (Coates, 2007). On the surface, anthropomorphism does not seem harmful. I know from experience that it can be especially challenging to convince people to care about plants or to understand that they are actors without having consciousness. Framing plant movement, growth, and defenses in terms of human thought patterns is effective for achieving that interest, but this anthropomorphic framework comes with pitfalls. The metaphors that scientists choose to use in describing invasive species inculcates plants that cannot form thoughts with malicious intent against humans (Inglis, 2020). The species have been “vilified” (Verbrugge, Leuven, & Zwart, 2016) when most villainous acts perpetrated by plants are caused by humans. Plants do not introduce and establish themselves into new areas across the globe from their roots, especially not areas with high biodiversity, humans purposefully and accidentally carry new species with us into ecosystems which are already weakened by human caused disturbance. It is not the plants that are the villains in this story.

Invasive species are framed as enemies with malicious intent. “We have deliberately chosen to depict *Phragmites* as a villain, using its marsh altering ability to affect nekton production. It is our intent to stimulate field and laboratory experiments to test the paradigm we describe” (Weinstein, & Balletto, 1999). This constitutes the use of “Strong metaphor” defined by Verbrugge et al. as one that has a call to action and a polarized setting for policy deliberations (Verbrugge, Leuven, & Zwart, 2016). The cautionary word from Verbrugge et al. is to understand that these metaphors point to solutions without fully or objectively defining the problem they are trying to solve (Verbrugge, Leuven, & Zwart, 2016). If they were to identify the problem, it would not be one of evil plants devising schemes to destroy biodiverse habitats across the world, but of a human industrial system which has long been prioritizing consumption over preservation. Negotiations with the plants will inevitably fail due to their utter inability to understand all our vehement scolding, the focus needs to shift to the drivers who can change behaviors and stop perpetuating the problem.

Conclusions

An immigrant in the United States of America is required to claim an identity as an alien on their immigration forms; understanding this positionality may clarify the problems inherent in invasive biology language. This new alien status immigrants are forced to adopt is shared with invasive species which are commonly called alien as well. Reading about invasive species, one may come across a sentence regarding the need to ramp up efforts to kill all the invasive alien species with a “shoot first, ask questions later” policy in the very same country. The same country that made immigrants check a box saying that they recognize themselves to be aliens. One way to combat this problem is to revise the language used in immigration policy, and this effort is underway. The other way to address this circumstance is to stop using such violent language in invasion biology. Even once official immigration forms cease calling human migrants aliens, the legacy of that language will continue in immigration discourse, that is why a multifaceted approach to preventing the harm our language causes is needed.

There must be a balance between using metaphor to make people care about and understand the ways they can help counteract complex biological issues and the possible harm of the chosen metaphors (Verbrugge, Leuven, & Zwart, 2016). This balance is especially important considering the synchronization between perceptions of non-native species and human immigrants over time. Another potential metaphor mistake, anthropomorphism, can muddy driver versus passenger models. Drivers cause ecological change and passengers go where ecological change has taken place. Instilling plants with human intention removes the onus from humans who are the biggest drivers of change on the planet.

Due to the xenophobia and ambiguity perpetuated in the field, some argue for an end to invasion biology altogether (Verbrugge, Leuven, & Zwart, 2016). I do not advocate for this step, but I think the gravity of this suggestion elucidates the seriousness of the language issues that persist in invasive species biology. Some basic ways to ameliorate the field are to curb the use of generative militaristic and anthropomorphizing metaphors and focus instead on specific issues caused by invasive species in context and the roles that humans play in habitat degradation.

The next section will delve further into issues of culpability by exploring what it means to be an invasive species and whether there is a clear set of characteristics that set invasive species apart from other groups.

Distinguishing Between Classifications

Invasive Species

> The USDA Forest Service defines invasive species as is a **non-native species** that is likely to cause harm to the economy, environment, or human health in that ecosystem.

I bolded non-native species because I will consider the definition of invasive species overall as consisting of two halves that together should represent all species that are deemed invasive. I will begin with this first half that is directed at an organism's native status. The labels native and non-native have been criticized for their lack of criteria, spatiotemporal specificity, and overall consistent definition and use (Verbrugge, Leuven, & Zwart, 2016).

Delineating between native and non-native species is a practice that an amateur botanist started in the 1800s. He relied upon common knowledge of whether or not humans had introduced the species in question (Inglis, 2020). The native versus invasive debate is a relatively recently developed trend that should continue to be revised to incorporate more modern research techniques and a more critical lens. Even at its beginnings, its founder acknowledged that this process was inexact and the categories difficult to define because of gaps in collective knowledge of the origins of plants (Inglis, 2020). In the United States, a common definition of native species includes only those species that were present before the arrival of Europeans to North America (Coates, 2007). Considering how little is known about pre-Columbian flora and fauna, the application of this designation is challenging. Coates also notes here that indigenous Americans migrated to North America across the Bering land bridge and they too may have brought seeds with them (Coates, 2007). For this reason, the pre-Columbian period is not the only potential cutoff for native status and the current consensus reflects a somewhat arbitrary bound.

Native status follows political boundaries, but political and ecological boundaries are not the same. Ecological boundaries limit an organism's distribution far more than any state or national borders. Even within a state, a plant or animal can thrive in one area and not in another, therefore; though it is *from that state* it truly only belongs in one habitat type (Coates, 2007). For example, an obligate wetland species such as Common Boneset (*Eupatorium perfoliatum*) is considered native to Indiana but is limited in its distribution within the state by hydrology. Eucalyptus is an introduced species in California that makes an interesting example because it is a despised *alien* to some Californians whereas others identify it as deeply and truly Californian (Coates, 2007). People's perspectives on an organism's degree of belonging vary for eucalyptus and other species depending on personal connections and perceptions of their value. If being native is a meaningful designation, there should be a right answer for each species' native status.

Invasion biologists are beginning to shift from definitions of native status based on political boundaries to ecosystem-based confines (Coates, 2007). This approach should replace political boundary usage entirely to build consensus among biologists and agree with the limitations that impact species distribution.

Given these limitations, there must be some value that invasion biologists find in considering a plant's origins that makes up for the shortcomings of how native status is determined. Richardson, Pysek, Simberloff, Rejmanek, and Mader are ecologists who in their 2008 article respond to calls to stop utilizing native status as a predictor for damage caused by a plant. These ecologists explain that knowing the native status of a plant allows for better monitoring that can prevent cryptic invasions and invasions that occur after a deceptive period of dormancy (Richardson, Pysek, Simberloff, Rejmanek, & Mader, 2008). The limitation that most concerns me from this article is that it does not adequately consider the complexity of origin. Plants are designated invasive even when their native status has not been proven.

In fact, the origins of the two focal species of this research are not known. It is possible that both *Phragmites australis* and *Typha angustifolia* are native to North America (Saltonstall, 2002, Shih & Finkelstein, 2008). The invasive species studied in this paper themselves may be native to North America, but there is no evidence that either of them is native to Indiana. The uncertainty about the origins of both plants is a major weakness in research that offhandedly identifies them as invasive. It does not change the ecological, economic, and human health impacts the plants have demonstrated, but as for the other part of the definition of invasive species that says they must be non-native, it is not known where these plants are native. Given that the native ranges of these plants are unknown, how can they be decidedly non-native anywhere?

If we do not know where the plants came from, we cannot determine how long they have been in a place. Even if we could, there is not a clear point at which an introduced species has been living in an area long enough to be considered native or naturalized in a scientific sense. In science, naturalization refers to a species' ability to form free-living populations by reproducing spontaneously and in a self-replacing fashion outside the context of cultivation (Coates, 2007). The Oxford English Dictionary entry on naturalize is

> **I.** To make native.
> **1.**
>
> **a.** *transitive*. Originally *Scottish*. To admit (a foreigner or immigrant) to the position and rights of citizenship; to invest with the privileges of a native-born subject. Frequently in *passive* †Occasionally *intransitive*.

The Scottish usage dates to the 1500s, and it came into use for plants and animals in the early 1800s (OED Online, 2021). It is worth mentioning in the spirit of interrogating our language choices that this word is also tied up in immigration jurisprudence like *jus soli* wherein place of birth determines citizenship and *jus sanguinis* wherein citizenship of the parents regardless of place of birth determines citizenship (Coates, 2007). But there is no "unambiguous point" at which an introduced species' status changes from nonnative to native (Coates, 2007). Therefore, not only can we not determine where many plants came from or when they got here, but there is also no specified length of time for which a plant must live in an area before it is considered native. The native part of the definition of invasive species is sufficiently ill-defined as to make it meaningless.

> An invasive species is a ~~non-native species~~ that **is likely to cause harm to the economy, environment, or human health in that ecosystem.**

If native status is not concrete, then the other half of the definition of invasive species must be specific to only invasive species or the term is altogether too meaningless to warrant use. Then it must be that invasive species alone cause economic or ecological damage, and/or adverse health effects in humans. That is something that is quite obviously untrue. There are “native” weeds and poisonous plants. Invasive species must then have traits that they do not share with other groups of plants which make them more likely to cause these damages if they are sufficiently different from these other groups to warrant a name. What traits are associated with invasive species? High levels of vegetative reproduction, distributions ranging widely across the world, and high levels of physiological tolerance are the traits associated with invasive species (Saltonstall, 2002). The next section deals with another group of species which shares some of these traits.

Early Successional Species

Early successional species are the first to become established in an area undergoing primary succession. Primary succession is the process of populating habitats that are devoid of life either resulting from a disturbance like the quarry or the creation of a new habitat (Bowman, Hacker, & Cain, 2017). Early successional species face many challenges to establishment and therefore, these species tend to have high tolerance to physiological stress and an ability to change their environment to make it more hospitable (Bowman, Hacker, & Cain, 2017). There are three major models that explain how early successional species make the environment more livable. One states that these organisms make it better for all species and longer-living species eventually outcompete these early species. The second and third models are both predicated on the idea that the early species make the environment less suitable for other species, but one indicates that this has no effect on the incoming later-stage species, and the other that it does have a negative effect, but that the later species outcompete the early species anyway (Bowman, Hacker, & Cain, 2017). The quarry is still in the early successional stage as plants establish in harsh conditions with few competitors. It will be important to understand how *Phragmites australis* and *Typha angustifolia* either ameliorate the environment or make it more difficult for later successional species to establish populations. In any case, following these three models, these early successional species should be replaced by later successional species as the quarry floor moves towards its climax community.

In a study conducted in Italian limestone quarries undergoing technical reclamation, (not abandoned, but managed) researchers found that the number of non-native species tended to decline with the age of the quarry, and they proposed that these species are early to mid-successional species which inevitably decline in later successional stages (Boscutti, Bozzato, & Casolo, 2017). This process was accelerated in their study by planting later successional species intentionally (Boscutti, Bozzato, & Casolo, 2017).

Some of the traits associated with primary successional species are high seed mass, fast relative growth rate, and greater plant height (Leishman, 1999). Additional seed mass gives a plant more food as it establishes itself in a harsh environment. Fast growth rate allows a plant to photosynthesize and produce offspring quickly which is especially important in a highly variable environment. Greater plant height gives the plant an increased ability to outcompete other plants for light. Fast growth rate is also associated with invasive species, and greater seed mass can increase dispersal ability which is also important for invasive species.

Again, this overlap in notable traits leads to the conclusion that the status of a plant as a successional species is not only about the qualities of the plant, and the status label is irrelevant without context. An early successional species is a matter of where and when, not as much about who. For the early successional status to be an intrinsic quality of the plant, the plant's growth patterns would need to meet some assumptions. As Leishman puts it, "If establishment ability were an intrinsic plant trait, linked to morphological or physiological traits of the plant, then we would predict that rankings of species on their establishment ability would be consistent across different neighbours" (Leishman, 1999). In her study of successional species in competition with a variety of native species, Leishman found no relationship between plant traits and establishment ability that were consistent across all treatment groups (Leishman, 1999). Thus, the underlying assumption of establishment ability as a universal plant trait or set of traits was not supported. A plant is only an early successional species in the right early successional environment, and when it is shown to be so in one place, that does not indicate that it will be in others.

Before her experiment, Leishman understood that establishment ability was closely related to the plants' seed and seedling traits, but she found that this relationship is far more complicated (Leishman, 1999). Trying to support this assumption with small numbers of species made it difficult to make generalizations about the traits that can be associated with good establishers (Leishman, 1999). Though she found that seed mass can predict 38-55% of biomass relative yield and that seedling survival is a decent predictor of establishment ability, she concluded that the relationship between plant traits and establishment ability may be context dependent due to the differences she saw when the plants were competing with a variety of native competitor plants. It is necessary to understand the mechanisms of the relationships if one wants to understand the link between traits and establishment ability (Leishman, 1999). Thus, establishment ability or the ability to be an early successional species, is not a universal quality, but another context-dependent trait. Rather than tracking individual species, it may be better to focus on the overall patterns in succession especially in comparable ecosystems.

Conclusions

Invasive species can neither be differentiated from other species by a robust knowledge of their origins nor a group of traits that are specific only to them. Therefore, the designation of a species as invasive does not imply that the plant is proven non-native nor that it holds traits that an early successional or another group of species with broad physiological tolerance might not also possess. There is value in understanding a plant's traits and origins for performing risk-assessments on introductions of new species but labeling many plants as invasive does not fulfill this goal. If the term were to have some standardized requirements for a species to be so distinguished such as a singular time cutoff for native and non-native species or a suite of traits that all invasive species must possess which is significantly different from other groups of species, the term may achieve some meaning. Rather than origin, widespread cosmopolitan distribution may be a better indicator of the risk that scientists are trying to elucidate with native versus non-native designations. Otherwise, understanding the risk of species introduction and management strategies in context can move forward without the invasive label.

Climax Community

In primary succession, vegetation layer changes and plant life history traits can be used to assess how well reclamation efforts assist the environment in recovering to be like the surrounding area (Boscutti, Bozzato, & Casolo, 2017). The final stage of succession is the establishment of the stable climax community which may or may not be like the surrounding area. The current state of the quarry floor is not the end goal for its restoration. Even if it were, it is undergoing successional changes that will continue to make its community composition change. Over time, as Boscutti et al. outlined, short lived and highly tolerant annual species tend to be replaced by longer lasting perennial species (Boscutti, Bozzato, & Casolo, 2017). In any of the successional models that I described in the early successional species section; the early species are replaced during the process of succession. What is unknown is exactly what species will replace them and whether they will be able to do so without management efforts. In order to decide what management steps need to be undertaken, not only do we need to perform research on the dynamics of the current plant communities, but the end goals for the quarry need to be determined as well. In an environment like the quarry which approximates another habitat type found in the region but not the surrounding ecosystem, is the climax community going to be the surrounding hardwood forest or another landform entirely?

While our quarry does approximate a natural landform that is found in this region of the United States, that landform is not the Midwestern hardwood forest that surrounds it. Rather, the quarry is like a glade. The term "cedar glades" has recently come to refer simply to rocky openings; the soil type in this habitat is described as rough stony land (Baskin, Baskin, & Lawless 2007). The substrate of a cedar glade is typically saturated in late autumn, winter, and early spring and experiences drought in late spring to early autumn (Baskin & Baskin, 1975). There are several of these habitat types that have been described and are similar to the quarry. These are cedar glades, xeric limestone prairies made up of predominantly little bluestem, redcedar-perennial grass savanna, redcedar, and redcedar rocky-openings made up of *Juniperus virginiana, Pinus echinate, Liquidambar styraciflua, Andropogon spp.* and *Schizachyrium scoparium.* All these habitat types are on stony open landforms and their plant types tend to be grasses and hardy trees (Baskin, Baskin, & Lawless 2007). The species in these calcareous environments usually display wide physiological tolerance to soil chemistry or ecotypic adaptation which are associated with broad substrate distributions. Not every species from every calcareous habitat type can survive and reproduce in every one of these environments; it is a special ability to be so flexible to such a wide range of soil types that only a few plants have (Ware, 1990). Tolerance, like many of the qualities I have described, is not universal.

The Baskins are prominent researchers in glade ecology; they have a great deal of passion about the naming of glade habitat types, and thus provided a great deal of detail on the composition of each of these communities. Their outline of the successional sequence on bare rock from open cedar glades moves from bare rock pavement invaded by lichens, mosses, and cyanobacteria, then invasion of herbs and trees into soil-filled cracks, to oak hickory forest climax communities (Baskin, Baskin, & Lawless 2007). Given that oak-hickory forest is not the type of the surrounding forest (though the forest does contain both these tree species), it is unlikely that this will be the climax community of our quarry; however, there are other types of glades which the current state of the quarry floor approximates.

The quarry floor is rather more like a glade seep than a cedar glade. Glade seeps are dominated by *Juniperus virginiana* with thin soil in limited areas which supports herbaceous plant growth (Taylor & Estes 2012). The quarry floor hosts many *Juniperus virginiana* trees as well. In glade seeps, impermeable bedrock at the surface combined with seasonal precipitation leads to saturated conditions in the winter through early spring. Then in the summer it dries up and creates drought-like conditions (Taylor & Estes 2012). This is a pattern that is evident in the quarry which not only varies seasonally but is inconsistent over the years. The variable hydrology is demonstrated by the pictures below taken by Dr. Dana Dudle one year apart from the same place with extremely different levels of saturation. The picture on the left was taken in

2007 and depicts a dry spring. The picture on the right was taken one year later in 2008 and shows a flooded spring.

Figure 6.

Figure 6: Photos taken by Dr. Dana Dudle approximately 1 year apart of the quarry floor.

Within the temporary ponds, which the Taylor and Estes article refers to as "seeps," the communities are different from the dry areas (Taylor & Estes 2012). As long as they are saturated for long enough, these areas are expected to support hydrophytic vegetation. *Phragmites australis* is a facultative wetland species and *Typha angustifolia* is an obligate wetland species which means they are both considered hydrophytic plants. Further analysis in the quarry floor is needed to understand whether the outward appearance that these two plants grow in the most saturated regions is supported by data. The glade seeps described in Taylor and Estes' article describing glade seeps are in Tennessee and Kentucky, and the type of limestone present is different, but the description of this landform is still quite similar to what we see in some areas of the quarry floor (Taylor & Estes 2012). An important note is that though these descriptions very much approximate what we see in the quarry, one major difference is that the quarry is a highly disturbed environment and therefore is likely to support invasive species (Baskin & Baskin, 1975).

The quarry floor consists of micro-habitats such as dry flat areas, talus slopes, areas with seasonal flooding, and spoil heaps that appear to contain different distributions and abundances of plant species, though more research is needed to understand the composition of these apparently distinct areas. Some areas in the quarry, notably the areas where *Phragmites australis* and *Typha angustifolia* grow, are like glade seeps. Glade seeps in the Taylor and Estes research contained 20 taxa that were not found in the surrounding dry glade (Taylor & Estes 2012). Many were grasses or grass-like species and either facultative or obligate wetland plants like *Phragmites australis* and *Typha angustifolia* (Taylor & Estes 2012).

Understanding the species composition and changes undergone in similar ecosystems can help us evaluate the processes that the quarry floor is experiencing and assess the risk factors of the invasive species present. In similar environments there are plant “indicators” which grow in progressively deepening soils which may become more relevant as we monitor the progression of the quarry floor through successional stages (Baskin, Baskin, & Lawless 2007). There are “natural” plant communities on limestone substrates with poor thin soils, that are not disturbed habitats. Our quarry has natural “cognates” or “targets” that are not the same as the surrounding forested areas, that is why the changes that are occurring in the community composition of the quarry floor may not be moving toward woodland, but rather these natural cognates (Baskin, Baskin, & Lawless 2007). Limestone glades, barrens, and seeps are among these. Even though our quarry floor has some plants in common, our site is a long way from these targets. For example, it does not have many prairie grasses and there are more invasive species at our site (Baskin, Baskin, & Lawless 2007). Yet another landform to which the quarry floor may be similar is an alvar. Alvars are rare landforms that can support high biodiversity (Ohlsson, 2020). It may be worthwhile to study similarities between the quarry floor and alvars to continue the process of increasing our understanding of landforms that are like the quarry floor. Given that alvars and wetland areas are highly valued for the biodiversity which they can support, identifying areas of the quarry floor that could potentially develop into these landforms may aid in finding continued support for the quarry's management. Overall, it will be necessary to understand the long-term goal for the quarry floor to know what obstacles may be present. Those long-term goals are dependent upon which type of landform we would like to see the quarry floor end up looking like. What exactly might *Phragmites australis* and *Typha angustifolia* be preventing from becoming established if anything?

Field Data Collection, Analysis, and Interpretation

Introduction to the Mapping Project

The mapping project for which I collected data in the fall of 2020 has been taking place for fifteen years as students learned to use handheld GIS units and collect location and attribute data on *Phragmites australis* and occasionally *Typha angustifolia*. Now there is a large collection of data regarding cover, spread, density, phrenology (timing of life history events), and more to be examined. Up to this point, this paper has worked to establish the importance of understanding a plant's growth habits and the potential hazards they pose to other organisms in context, and this field project does just that. Tracking the growth of these two species and working to understand the modes of dispersal and spread is part of the larger work of accessing the risks posed by these plants in the context of the DePauw Nature Park quarry.

Looking at the data for this year alone, I was able to support the assumption that *Phragmites australis* covers a larger area than *Typha angustifolia*. *P. australis* may therefore need to be prioritized for determining management solutions. The maps also allowed me to examine the proportion of the quarry floor which is currently covered by *Phragmites australis* and *Typha angustifolia* which will be important for determining management priorities and timeline. I looked for patterns of resource partitioning between *Phragmites australis* and *Typha angustifolia* which I predicted would look like it does between two types of *Typha sp*ecies which arrange themselves along hydrologic lines. There is evidence that where *Typha angustifolia* and *Typha latifolia* compete *Typha latifolia* is more successful at shallow depths where *Typha angustifolia* thrives in deeper areas (Shih & Finkelstein, 2008). To investigate this hypothesis, I examined where each of these species are established relative to topography. I would expect *Typha angustifolia* to be at lower elevations and *Phragmites australis* at higher because *Typha angustifolia* is an obligate wetland species and *Phragmites australis* is a facultative wetland species. The maps also allowed me to analyze patterns in densities associated with patch movement. These and other analyses are described in this section, and they present some of the research which will be needed to understand the impacts of these two species in an abandoned limestone quarry such as this study site.

Methods

To begin the fall 2020 field collection, I conducted a walking survey through the quarry and identified areas with large patches of tall wetland grasses that upon a cursory assessment appeared to be either *Phragmites australis* or *Typha angustifolia*. During the survey I drew up a rudimentary map of areas where the two plants could be found. I then began by mapping *Phragmites australis* patches I positively identified. The data that comprises the fall 2020 maps of the populations of *Phragmites australis* and *Typha angustifolia* was collected using a hand-held Garmin GPS unit with an approximate three-meter accuracy, a 0.25 m^2 quadrat, a tally counter, and a tape measure. For collection of *Phragmites australis* data the information in the following table was taken down on a datasheet:

GPS unit number	Date	Waypoint	Latitude	Longitude	Patch ID number	Patch size	Patch diameter	Density of growing shoots	Flowering yes / no

The waypoint number corresponds to the order in which points were taken on the GPS unit. Recording this number allows for cross-referencing of coordinate data written on the data sheet with the numbers recorded on the unit. Latitudinal and longitudinal coordinates were recorded to five decimal places using a handheld Garmin GPS unit. The patch identification number was assigned to the patch in order of collection. The patch type refers to the size of the patch including point, small, medium, and large. The patch diameter was collected for point patches or patches that were less than three meters wide. The density of growing shoots collected for *Phragmites australis* populations and was accessed by placing a 0.25 m^2 quadrat over the plants at the edges of the patch where GPS points were taken, and this number was later extrapolated to yield density per square meter. Where plants were of too great a height to reach over their tops with the quadrat, a section of the PVC pipe making up the quadrat was removed, and the quadrat was then placed at the edge horizontally. The number of growing shoots within the quadrat area was counted with the use of a tally counter when their number was especially high. Flowering status was also assessed within the area of the 0.25 m^2 quadrat and was identified as yes (1) if any of the shoots within the sample quadrat had inflorescences or no (0) if they did not.

For each patch, I established an idea of the perimeter and assessed whether the patch was small, medium, large, or a point patch before beginning my data collection. Concurrently I identified points along the perimeter that would sufficiently capture the area of the patch. For small, medium, and large patches, points were collected approximately 10 meters apart along the outside perimeter of the patch due to the approximate 3-meter accuracy of the GPS unit. Patches smaller than 3 meters in diameter were defined as point patches and were captured with a single point taken at the center of the patch, and a diameter measurement for the point patches was collected using the measuring tape. Patches that were narrower than, but also longer than, 3 meters were treated as hybrid between point patches and larger patches and were collected as a line of points with given measurements for diameter at each point along the line. Collecting the data in this way prevented crossing-over fallacies for the shape of the patches, which can occur due to a mismatch between the grain of detail of the GPS unit and the complexity and width of the patches in nature.

For collection of *Typha angustifolia*, the same information was collected except the density of the growing shoots within the 0.25 m^2 quadrat. This information was not collected due to the limited time remaining in the season for collection at the start of data collection for *Typha angustifolia* (which began in October after all the *Phragmites australis* data was collected), the difficulty in discerning growing shoots as the plants became drier later in the season (and thus the likely error that would accompany that data), and the lack of past density data available for comparison for *Typha angustifolia*.

The data on spatial distribution, identification information, and flowering status of *Phragmites australis* and *Typha angustifolia* collected in the field was then transcribed into a Google Sheet shared with Dr. Dana Dudle and Beth Wilkerson of the ArcGIS lab at DePauw. Beth Wilkerson also received the GPS devices with the primary coordinate information which she cross-checked with the latitude and longitude numbers as they were copied down in the datasheet. Beth used the data to generate preliminary maps that made ground-truthing possible. When there were errors, such as crossing over within a patch or overlap between patches, Beth sent these points to me to be retaken or for ground-truthing. Beth prepared the data collected in fall 2020 as well as in past years for comparison in ArcGIS Pro. She also generated the layer patches for every year of collection since collection began in 2006 that designated the perimeter and area of each patch from joined points. The 2018 imagery and topographical data were also provided by and maintained by Beth Wilkerson.

All data was collected by Diana Borse who was occasionally accompanied and assisted by advisor Dr. Dana Dudle, and students Jacob Frech ’21 and Sophia Atkinson ’22.

Results/Discussion

To begin the data analysis, I generated a map containing all the patches and points collected in the field in fall 2020 for both species. This simple map gave a preliminary look into the relative distribution and area covered by the two species this year. It is clear from the maps that *Phragmites australis* covers a larger area of the quarry floor than does *Typha angustifolia*. This visual indication was confirmed by the areas of cover for both species as *Phragmites australis* covers an area of 9,183 +/- 349 m^2 and *Typha angustifolia* covers 6,314 +/- 137 m^2. The area was calculated in ArcGIS Pro using shapes generated by connecting the waypoints belonging to the same patch ID from the handheld GPS unit. The largest patches of *P. australis* were larger than the largest patches of *T. angustifolia* with values of 2,921 m^2 and 1,005 m^2, respectively. Thus, the maps confirmed the original observation that *P. australis* has a greater area cover in the quarry floor than *T. angustifolia*. Out of the entire quarry floor, which is approximately 179,481 m^2, *Phragmites australis* and *Typha angustifolia* together cover approximately 8.6%.

Next, I compared both species' distributions on the quarry floor to elevation. The trend shows no significant difference in elevation. This may be an area to delve into deeper in future research with more precise elevation measures or a look at the hydrology of the quarry floor which is what we are trying to examine with elevation data. This data is not precise enough to conclude that there is no difference in the elevations at which the two species are found.

Figure 7.

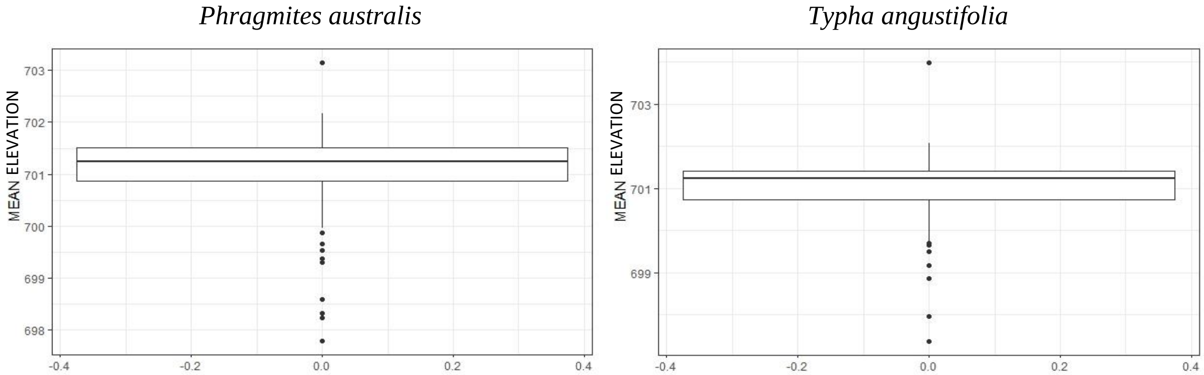


Figure 7: The boxplot on the left shows the distributions of the elevations contained within *P. australis* patches and the boxplot to the right shows the distribution of elevations in *T. angustifolia* patches. They are shown as averages calculated from the elevations within the patches so that each patch that contains elevation data is given an average measure for the elevation. The overall average elevation for each species is represented by the dark black bar in the center of the boxes. Both distributions were centered about a mean of approximately 701 meters in elevation. It is evident from these graphs that the data does not indicate a difference in the elevations contained within *Phragmites australis* and *Typha angustifolia* patches.

After looking at the data for 2020 alone, I proceeded to compare the 2020 data to past fall data collections to track the possible growth, shrinking, and movement of *Phragmites australis* populations over the years during which collections have taken place.

The total area increased over the years. The graph below shows the trendline for the total area over time measured in years with an R^2 of 0.795. R^2 represents the proportion of the variation in total patch area that can be explained by the explanatory variable which in this case is the year in which the area was calculated. An R^2 of 0.795 indicates that about 79.5% of the variation in the total area of cover for the *Phragmites australis* in the quarry can be attributed to the year. Using Rstudio to calculate a linear regression for this data the same R^2 was given but with an adjusted R^2 of 0.754 and a p-value of 0.007. The p-value indicates the likelihood that the variation observed is due to random chance, in this case there is about a .7% chance that the variation in the total *Phragmites australis* area is due to random chance. Taken together, this data indicates that the total area of *Phragmites australis* cover is increasing significantly as years pass. From 2009 to 2020, the area covered by *Phragmites australis* has increased by about 64%, or on average 5.8% yearly. What is missing is the data from when there was little to no *Phragmites australis* in the quarry. If we started from zero *P. australis* cover, it is likely that this line would be more curved than linear. The difference becomes important when we try to make predictions about the likely spread of *Phragmites australis* in the coming years. If it is linear as it appears and the growth continues at its current rate (9,183 x 1.058[ii] x 18.5 ≈ 179,481), then the entire quarry would be filled with *Phragmites australis* in 18.5 years. Of course, this is unlikely given that many regions of the quarry would not support *Phragmites australis* because they are too dry, are bare rock, or are already covered by another plant that would preclude *Phragmites australis* from establishing for example. Still, the rate of increase and current percent cover of *Phragmites australis* in the quarry floor are both high for a single plant species.

[ii] This value is derived from the 5.8% yearly increase in the area of Phragmites australis populations over the last 11 years.

Figure 8.

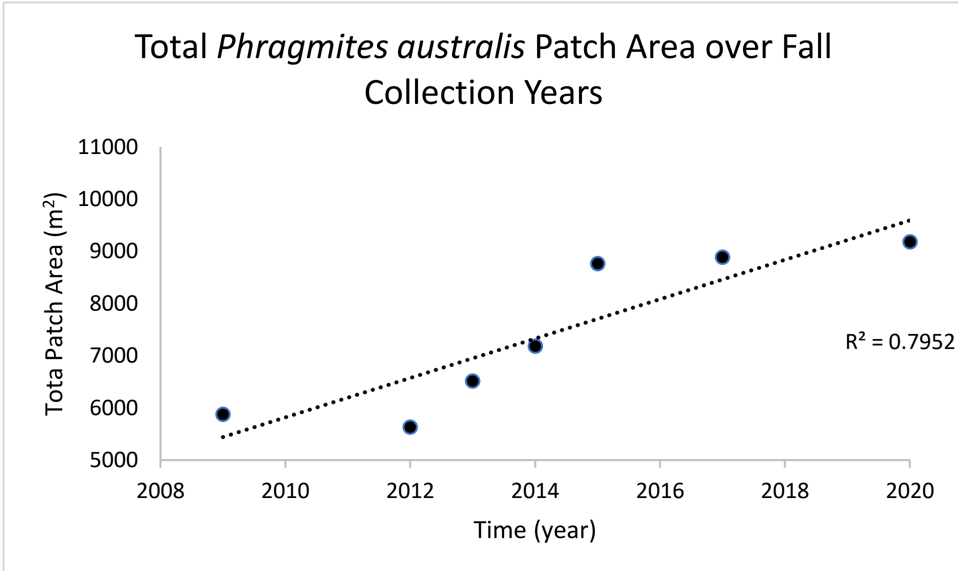
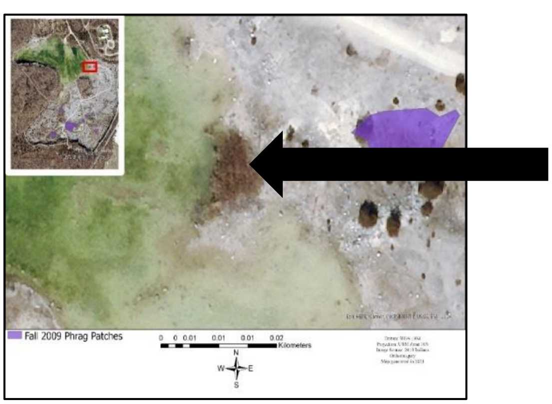


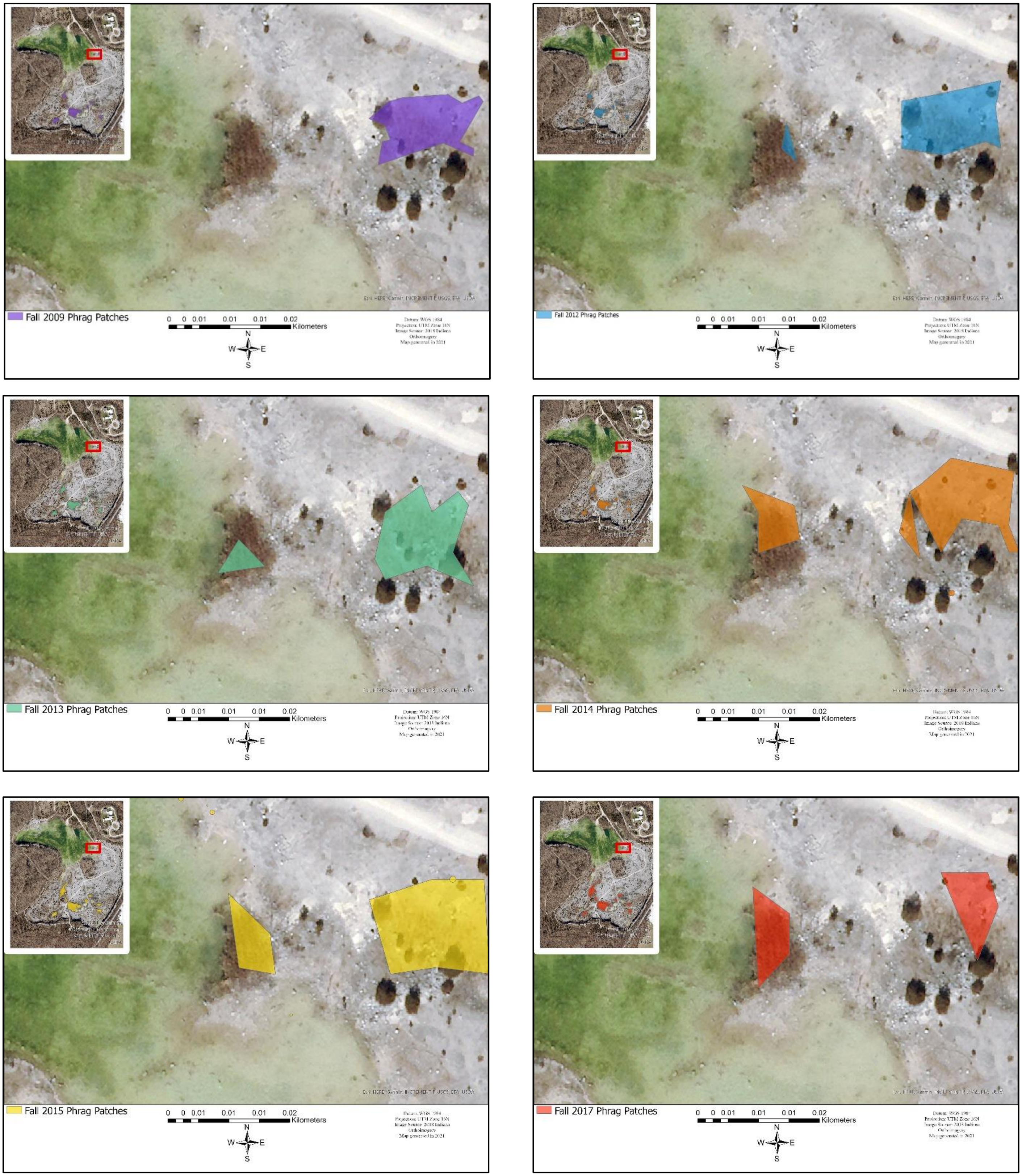
Figure 8: The graph contains the total area comparison for *Phragmites australis* patch area cover for 2009, 2012, 2013, 2014, 2015, 2017, and 2020. This chart shows a general upward trend for the total area of *P. australis* patches over time.

The next figure (Figure 10) looks at one patch in particular that appeared in 2012 and grew every year from that time. The underlying imagery which shows the green water in the quarry pond, the grey of the limestone, the green brown of Eastern Redcedar trees, and the brown of the *Phragmites australis* and *Typha angustifolia* patches was taken in a 2018 survey. The black arrow in the explanatory map on this page points to the Phragmites australis patch on which the proceeding set of maps focus. It is important to note that the imagery is from 2018, so



though the brown shape is present in all the maps, it is a static image, and the color-coded shapes represent the patch area for each year, not the brown picture of the patch. The years represented in the figure from left to right and top to bottom are 2009, 2012, 2013, 2014, 2015, 2017, 2020.

Figure 9.


Fall 2009 Phrag Patches
0 0 0.01 0.01 0.01 0.02
Kilometers
N
W
E
S
Fall 2012 Phrag Patches
0 0 0.01 0.01 0.01 0.02
Kilometers
N
W
E
S
Fall 2013 Phrag Patches
0 0 0.01 0.01 0.01 0.02
Kilometers
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Fall 2014 Phrag Patches
0 0 0.01 0.01 0.01 0.02
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Fall 2015 Phrag Patches
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Fall 2017 Phrag Patches
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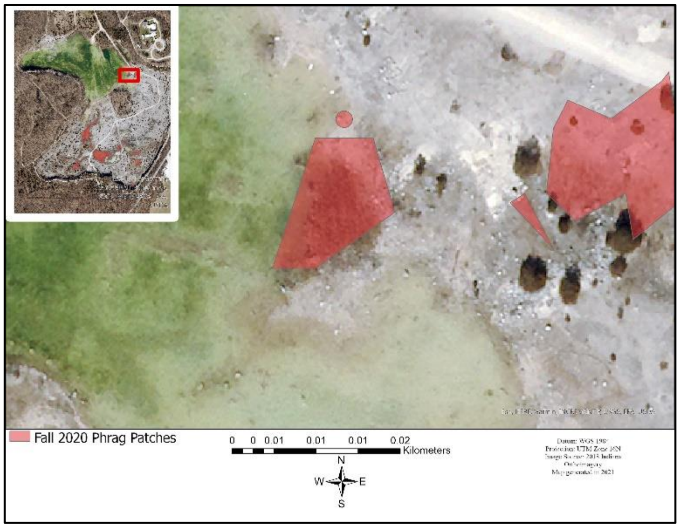

Figure 9: This series of maps shows the growth of the easternmost patch in the map with ID #3(that being the identification number assigned to this patch in the 2020 data collection). The data for 2009, 2012, 2013, 2015, and 2017 was collected by Dr. Dana Dudle's BIO 345 (Conservation Biology) class. The data from 2014 was collected by that year's HONR 291 class, and the 2020 data was collected by Diana Borse. As one can see from the map made of the data collected in the Fall of 2009, this patch did not exist at that time or it was sufficiently small that it was missed by the students who collected the data. By 2020, this patch had reached a size to constitute a "medium" patch size. The specific numbers for the size of this patch at each year are listed in the table below.

The growth that is observable in this data could be described using different metaphors depending on one's perspective and what a scientist wants the data to say. It could either be framed in terms of a species spreading and surviving to establish against the odds in a desolate environment or an invasive species planting itself and taking over a region. The same growth pattern is happening in either case; it is the scientists' perspectives that differ. In my study of *Phragmites australis* in the quarry, this series of maps shows a model for the way that the plant spreads and patches grow over the years. The table below shows the patch area for this patch in each year that the quarry was mapped. There has been a consistent increase in the patch area for each year. A linear regression of this data gave an R^2 value of 0.8895, an adjusted R^2-value of 0.8674, and a p-value of 0.001 which indicates that the variation in the area for this patch over the years is significant.

Table 1.

Year	2009	2012	2013	2014	2015	2017	2020
Area in m^2	0	6.67	19.53	54.7662	55.72	65.24321	143.821654

Table 1: This table contains the area values for the patch with fall 2020 ID #3 for the years that were sampled between 2009 and 2020.

One model for the expansion of *Phragmites australis* is that it disperses to new areas with sexual reproduction in the form of seeds and once established, they grow stands predominately through vegetative reproduction. In this way, they are said to exploit the benefits of clonal and sexual reproduction. Sexual reproduction allows for recombination, widespread dispersal, and greater movement into new areas. Asexual reproduction increases the stability of the stand as established clones tend to be very well suited to their environment (Kettenring et al., 2016). Sexual reproduction leads to more efficient establishment or movement following disturbance than asexual reproduction, but seedlings are poorly provisioned compared to propagules (Kettenring et al., 2016). Expansion and establishment of invasive plants more generally is usually initiated episodically through disturbance and the presence of seeds and are sustained through vegetative expansion of rhizomes and stolons (Kettenring et al., 2016).

The following figure (Figure 10) goes a bit deeper in analyzing this pattern of spread by looking at the density of green shoots at the waypoints and the expansion of the patch in the subsequent year. The two maps provided are from the same patch (fall 2020 ID #3) and are from 2013 and 2014.

Figure 10.

Figure 10: This pair of maps shows the growth of patch ID #3 - the patch to the east (that being the identification number assigned to this patch in the 2020 data collection). The data for 2013 was collected by Dr. Dana Dudle's BIO 345 (Conservation Biology) class. The data from 2014 was collected by that year's HONR 291 class. I selected years with densities and movements that might exemplify a potential predictive pattern. In addition to the information present in the previous figure, these maps contain the density of growing shoots at each point of data. The densities are represented by tear-drop shapes which have a darkened color as the density increases. The color darkens on a spectrum from yellow to red with light yellow being the least dense and dark red being the densest.

In the 2013 map, the northern most point on the map (to which the black arrow points) is red which indicates that this point is dense with growing shoots, it is notably the densest of the three points in the patch for 2013. Looking at the map from next year's data, the patch area has expanded to the north. This is a preliminary pattern that indicates that expansion of the total patch area may tend to occur where the densities of growing shoots are highest. Such predictability may prove useful for management strategies to target the areas of greatest expansion, but bore quantitative research is required to support this pattern of predictability.

Figure 11.

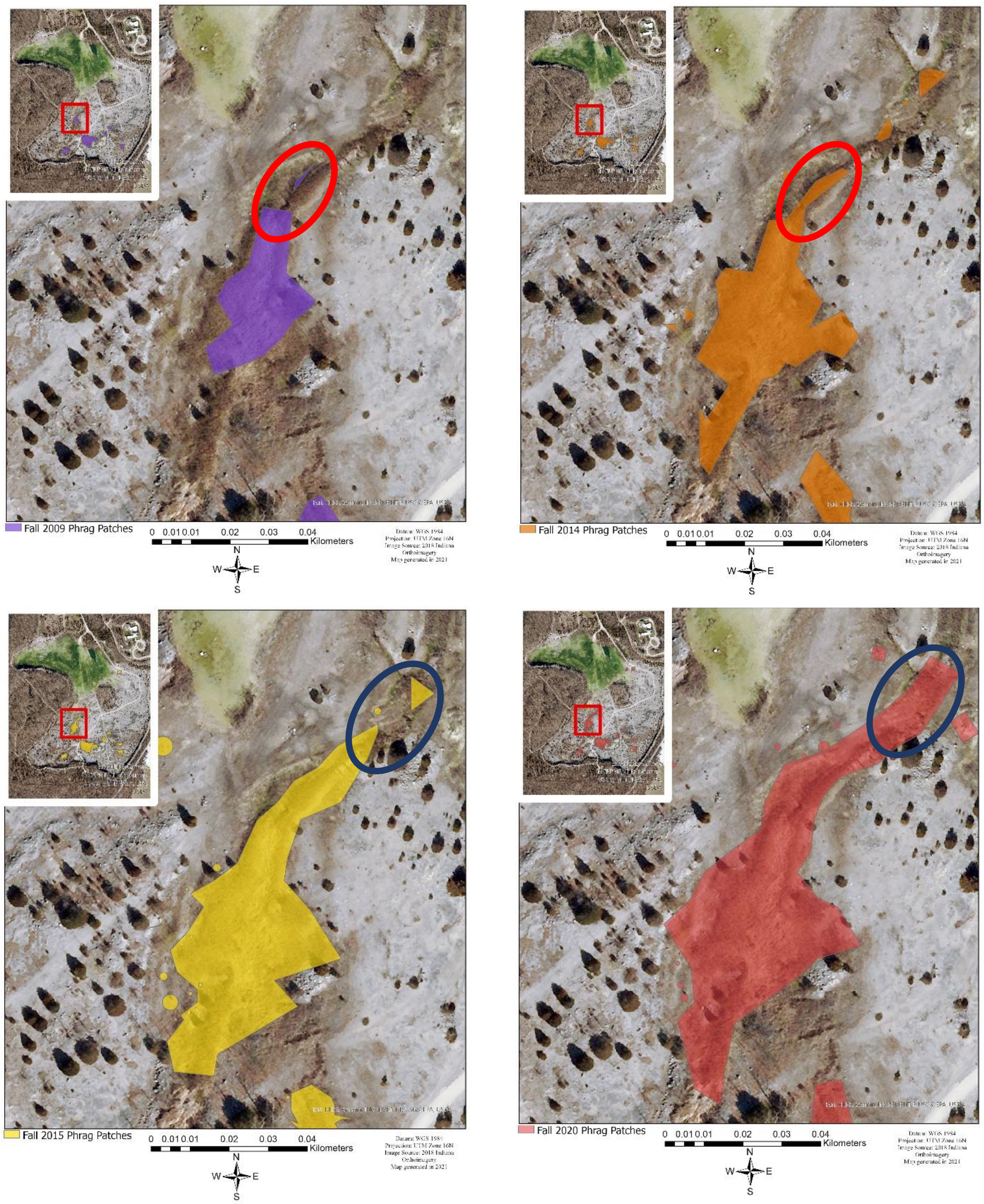

Figure 12: These maps show a large patch of *Phragmites australis* with 2020 ID number 16 which we referred to in the field as "the beast". From the top left to the bottom right the years of data collection shown in these maps are 2009, 2014, 2015, and 2020. The data for 2009 and 2015 was collected by Dr. Dana Dudle's BIO 345 (Conservation

Biology) class. The data from 2014 was collected by that year's HONR 291 class, and the 2020 data was collected by Diana Borse. The red ovals in the 2009 and 2014 maps show an area where in 2009 there were two patches and by 2014 the patches merged. This occurs again between 2015 and 2020 where in the area encircled by the dark blue ovals smaller individual patches become a part of the larger patch.

The pattern of larger patches absorbing smaller patches which is being shown by the maps in figure 11 is one that I observed in multiple patches throughout the quarry. This indicates that there may be a mixture of sexual and vegetative reproduction that cause the growth in patch area that we observe. This type of spread through connections may facilitate the speed with which we are seeing *Phragmites australis* area increasing.

Conclusions from this Data

There is significant growth in the area covered by *Phragmites australis* that has occurred over the past 15 years for which data has been collected. There was not evidence to support the hypothesis that *Phragmites australis* and *Typha angustifolia* are distributed in the quarry according to topography, but the topographical data is not precise enough to rule out the possible influence of topography on the distributions of these plants. Future research into the limitations imposed upon the distributions of *Phragmites australis* and *Typha angustifolia* by topography and hydrology would increase our understanding of their dynamics in the quarry floor. The maps provide evidence of both vegetative spread and sexual reproduction, but genetic testing is needed to prove which type of reproduction is occurring and has occurred in different areas throughout the quarry.

Conclusion

The quarry floor in the DePauw Nature Park is a distinct anthropomorphic landform surrounded by better preserved natural areas. The DePauw Nature Park got its start from the donation of the quarry without which the entire park would most likely not exist at all. Maybe this razed quarry floor serves as a message representing what humans leave behind when we extract what we want from the land and leave it untended. A nature park usually serves to celebrate the ideal natural world and quarrying in this area left it anything but natural, still it was donated to become a place where reverence is paid to nature. Since its abandonment, the quarry has come to serve as a home for many plant species and may now approximate a natural glade landform. Now there are plants and animals that have made their homes in the quarry that may help reconcile this anthropogenic landscape to some greater value as a host for species that would not find homes in the surrounding hardwood forest.

It was in that abandoned limestone quarry, however much it may belong in a nature park, that I conducted research on invasive species. As I planned a study that would be conducted in the quarry, based upon the research that I did in the summer of 2020, not only was there a pandemic underway, but another civil rights movement. That sociopolitical context made me consider what responsibilities that I have as a scientist. As I studied invasive species and read articles that sounded incredibly violent and xenophobic, I understood that I have a responsibility to consider the language I use and how it is impacted by and can contribute to the human rights issues of my time. That consideration grew to become this thesis. Though I do not plan to write a new thesis every time I undertake a new project, I will conduct similar investigations to understand where the ecology research I plan to conduct addresses and interacts with modern issues such as racism, sexism, homophobia, xenophobia, etc. and this is something I think every scientist should do.

I learned that invasive species research uses more militaristic language than other disciplines in biology. Invasive species studies also tend to anthropomorphize organisms and this anthropomorphism can be misleading. Anthropomorphism is especially harmful when it muddies up driver-passenger models and displaces the human responsibility for invasive species introductions onto organisms. These organisms, be they plants or animals, cannot form malintent. It is nonsensical to vilify plants. It would better represent the issue to focus instead on the underlying mechanisms that drive plant introductions such as overconsumption, disruption of the land, and irresponsible global trade. Militaristic language, anthropomorphism, and spillovers from invasion biology into politics combine and create a problematic synchronicity between non-human and human migration rhetoric. When we use the same words to describe plants and people, it is irresponsible to use violent language. Based on the literature related to language use in invasion biology that I reviewed, I recommend that the use of militaristic metaphors and anthropomorphism that places non-human organisms as the drivers of introductions be discontinued.

With such strong metaphors being employed, one would expect that invasive species are a well-defined and extensively studied group which is distinct from other groups of species. I found that this was not the case. Not only is native status challenging to ascertain, but also the rules set out for its determination are arbitrary and inconsistent. As for the negative environmental and economic effects of the presence of these plants, these effects can be true of other groups of plants as well. The physiological traits that invasive species tend to have which cause these issues are also not specific to only invasive species. Early successional species share many of the traits that are related to tolerance and dispersal ability. Invasive species cannot be identified therefore, by either native status or a series of traits.

Invasive species can have positive effects on the economy and ecosystem. *Typha angustifolia* can act as a water filter. *Phragmites australis* can be a vegetative filter for wastewater treatment, it can prevent erosion, and provide habitat for small mammals and reptiles (Mamolos, 2011). *Phragmites australis* can also be used for compost and green manure in agriculture. Identifying invasive species as only detrimental cuts off an entire line of research into their potential benefits.

As we consider the future management of the quarry, it is vital that we frame our decisions in terms of long-term goals. As it stands, the quarry has little in common with the hardwood forests that surround it. It has much more in common with various types of limestone glades that are found throughout the Midwest. The specific wetter areas in which *Phragmites australis* and *Typha angustifolia* grow are like glade seeps. These are wetland landforms that can host a variety of hydrophytic species and may be interesting for DePauw students and faculty to study. The climax communities in the quarry could then approximate glades and glade seeps rather than woodland. If this is the case, then management strategies will differ from what they would be if they aimed at restoring the quarry to a woodland. It is important to decide what we want the climax community to be to dictate what types of management steps need to be taken. This will affect the future of *Phragmites australis* and *Typha angustifolia* on the quarry floor. Hardwood trees would eventually shade out these plants, but wetland establishment would likely require removal of these species for a more biodiverse community to be able to establish itself.

The mapping project showed that *Phragmites australis* cover has significantly increased in the past eleven years. *Phragmites australis* and *Typha angustifolia* cover a combined area of approximately 15,500 square meters. There is a large portion of the quarry floor covered by monospecific stands of these two species. This current coverage may only be a step in the successional process, or in the future these plants might prevent the establishment of later successional species entirely. If it is the goal to have the quarry remain a glade, albeit one with greater biodiversity, the expansion of the coverage of these two species will need to be addressed. From the analysis that I performed on data that I collected this year and that other students collected in previous years, it is clear that *Phragmites australis* is on a trajectory of continually expanding coverage. More data is needed to track the changes in *Typha angustifolia* coverage dynamics. Management steps would likely need to be undertaken to change the growth we are seeing in *Phragmites australis* area if a glade is the preferred climax community.

Understanding what species are present and how they interact will be an important step to move forward with the management of the quarry floor. Due to the lack of clarity surrounding the term “invasive species,” I recommend that we study the population dynamics of the quarry floor to decide how best to aid reclamation efforts rather than using this category to determine a species’ value in the quarry floor. Given that the quarry floor is a landform that is undergoing succession, high numbers of non-native species are expected in these early stages of the process. What we need to concern ourselves with are the impacts of individual species on this environment, not what impacts they may have had in different environment types. Invasive *Phragmites australis*, unlike native *Phragmites species*, have been known to displace other wetland plants and form monoculture stands (Ward & Jacono, 2009). There were no other species present in the quarry floor before the arrival of *Phragmites australis*, and therefore no native species to be displaced. However, we have observed *Phragmites australis* having increasingly large cover in the form of monospecific stands, which is a concern for efforts to establish a biodiverse wetland area. *Phragmites australis* can become the only climax species in an area (Mamolos, 2011). Research which determines whether these two species are spreading from the quarry floor to surrounding wetland areas is needed. In an environment like the quarry, where nothing but bare rock is native, there is no other plant that *Phragmites australis and Typha angustifolia* could replace. This is not the case in the surrounding ecosystems and there may be displacement occurring that is seeded by the populations on the quarry floor. This must be proven or disproven to further contextualize the management need of the quarry floor. If these species are shown to be spreading from the quarry floor or if a wetland is the preferred climax community for the quarry floor, a reduction in the population sizes of *P. australis* and *T. angustifolia* is warranted. Then the next steps following this study would be to focus on how removal can proceed and how to establish more biodiverse populations that do not form monospecific stands in their place. There is no need to militarize or anthropomorphize this process. Rather, there should be future studies and plans to manage the long-term communities in the quarry floor.

Potential Future Projects

The aforementioned researchers Boscutti, Bozzato, and Casolo working in abandoned quarries in Italy recommend introducing native perennials to promote biodiversity and control invasive plants (Boscutti, Bozzato, & Casolo, 2017). They call for the newly established communities to be "coherent" with the surrounding ecosystem (Boscutti, Bozzato, & Casolo, 2017). I would question whether this coherence is called for in the DePauw Nature Park quarry or if we should pursue instead a glade type community. The value of a glade is that there can be glade seeps which may offer habitat for diverse and protected wetland species. A glade may also continue to provide an interesting area for DePauw students and faculty to conduct research.

More irreversible changes to the environment (like quarrying) are making old conservation and restoration norms less applicable (Verbrugge, Leuven, & Zwart, 2016). The newness of this kind of restoration effort means that there is still a great deal to be learned about the reclamation process and plenty of space still available for creative solutions. The quarry floor may be an area where members of the DePauw community can be at the forefront of those creative solutions.

It will be important that researchers remain open-minded about the potential of different species, even those that have had many negative impacts in other environments. For example, *Typha* can remediate contaminated water and soil and have been applied in restorative work for this purpose (Shih & Finkelstein, 2008). Even invasive *Typha* species may have something to add to restoration efforts. Invasive species are not evil and can still have potential positive effects depending on their context. Given risks invasive species can have in some environments it is necessary to take care that they not spread beyond the target environment. I am not calling for researchers to ignore negative potentials of the introductions of species. I am calling for researchers to stop ignoring the positive potential of species despite their categorization, especially when that category is as ill-defined as invasive species.

Beyond quarry restoration, future research is needed to define what invasive species are. Political boundaries are not the most rational lines to draw for native ranges and should be replaced by defining native status based upon ecological niches. Related to this boundary distinction is a consideration of invasiveness in the context of climate change and shifting ecological niches. Researchers will need to be flexible as ranges shift based on changing climatic conditions. Once native range is thus more logically defined, risk assessments that determine the likelihood that an organism will cause negative economic, environmental, and human health effects need to be more quantitatively defined than they currently are. For the term "invasive species" to have the meaning it currently has, both native status and potential hazards need to be absolute categories about which there can be a consensus.

Final Word

Are invasive species problematic in an environment like the quarry which is largely devoid of life? If writing this thesis has taught me anything it is that thinking in these kinds of universals is seldom advisable. One answer to all questions is a tempting solution, but to fit all situations such an answer must be so vague that it loses all meaning. A better question for this project is whether the *Phragmites australis* and *Typha angustifolia* populations present in the DePauw Nature Park quarry floor present obstacles for the restoration of this quarry. This question still does not lead to one great universal answer, but it does lead to better questions. What is the end goal? What plants are they keeping away? What threats might they pose to the surrounding area? What value do or can they add? What uses do these plants have?

One universal statement that I will make is that demilitarization of invasive species biology is warranted not only because it is ill suited to the phenomena it is meant to describe, but because the language scientists use in militaristic metaphors is harmful. The word invasion itself is militaristic, and therefore the term "invasive species" is itself militarized. Replacing the use of this term with "introduced species" not only serves to demilitarize the terminology but replaces the impetus on the drivers of the introductions as well. We scientists are taught to question everything, and that should include the terminology and metaphors that we choose to use. We need to question our assumptions that something is mostly harmful just because it has caused harm in one area. An introduced species is not an identity but an event.

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