Relationship of Habitat Variables and Observation Data to Muskrat Occupancy in an Urban Green Space Waterway: A Case Study from Forest Park, St Louis, USA

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The undersigned, appointed by the dean of the Graduate School, have examined the

dissertation entitled

Relationship of Habitat Variables and Observation Data

to Muskrat Occupancy in an Urban Green Space Waterway: A Case Study from Forest Park, St Louis, USA

Presented by Matthew D McCloud

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and hereby certify that, in their opinion, it is worthy of acceptance.

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Abstract

Urban green spaces (UGS) are high value areas that strive to serve both ecological and social goals. Quality stewardship of these areas require that all components affecting the ultimate site goals be addressed in not only the planning and development of an UGS but also in the day to day management of the area. My research was prompted by park stewards looking for a non-lethal method in which to manage an ever-growing muskrat population. To address this topic, my research established twenty study sites located throughout the Linear Connected Waterway System (LCWS) in Forest Park located in St. Louis, MO. Research began by monitoring how these sites changed over time and the site variables that made them more similar/dissimilar to each other and how this change affected the suitability of the sites to support muskrat occupancy using the established muskrat Habitat Suitability Index (HSI). The HSI quantifies habitat variables crucial to the support of muskrat occupancy. A Similarity/Dissimilarity analysis of sites was conducted through Bray-Curtis ordination and showed two main clusters of sites. Group one (Axis one) identified that vegetation stand density and bank slope were correlated for the site cluster whereas Group two (Axis two) identified proximity to disturbance and percent aquatic vegetation being responsible for the clustering of the remaining study sites. The next goal was to generate HSI scores for each of the twenty sample sites and analyze changes observed in the terrestrial and aquatic vegetation over time that affected the sites suitability for muskrat occupancy. Data showed that seasonal and yearly fluctuations of these two variables showed a corresponding change in the sites' habitat suitability score being most pronounced by the availability of aquatic vegetation. Next, muskrat absence/presence data was collected and analyzed to determine if any of the site classification variables could be used to

predict muskrat occupancy. Analysis was conducted using three generalized linear models which identified that a site's density of aquatic vegetation and proximity to disturbance were most supportive in predicting a sites muskrat occupancy. The last question this research addressed was whether specific water quality components, phosphorus and nitrogen, could be used to predict the potential level of aquatic vegetation support. Monthly water samples showed that during the regional growing season nitrogen was generally found to be at a level of low enrichment whereas phosphorus was recorded consistently at highly enriched levels. These levels both supported the assumption that the capacity for higher densities of aquatic vegetation was possible thus the capacity to support higher muskrat occupancy. All of the data generated during this research reinforced the importance of proper UGS planning and monitoring and the perils, both financially and ecologically, managers may face if plans don't fully consider all potential flora and fauna occupancy.

Renovation and establishment of urban green spaces presents the potential for undesirable effects brought about by unchecked, historically native wildlife species. Habitats that are not ecologically balanced can result in unanticipated problems, such as species overpopulation, that can result in habitat damage or the overall destruction of the habitat type. An ecologically balanced UGS is one in which proper biological checks and balances are in place allowing the habitat to develop through natural processes while supporting sustainable populations of naturally occurring organisms. This process can only occur if organisms do not exceed the habitat's carrying capacity. Without naturally occurring mechanisms such as predators and habitat fluctuations, species population levels can become unsustainable when they reach carry capacity thus depleting an areas abiotic and biotic resources potentially negatively affecting not only the target species but other species that occupy the space. Addressing this habitat degradation can lead to additional cost to UGS managers in maintaining these highly valued urban green spaces through constant remediation efforts. However, through careful monitoring and habitat design many of these habitats can be sustained with minimal cost and disruption. Current research has shown that properly designed habitats allow for natural succession to occur while facilitating the control of varying species populations. These strategies address problems that urban resource managers throughout the world face when managing designed habitats in which natural processes have been manipulated. Investing limited time and money into reestablishing urban ecosystems without appreciating these potential pitfalls could lead to the eventually loss of the valued resource and the societal benefits they provide.

Chapter 1: Introduction

Urban Green Spaces (UGS)

Parks in America have evolved since the first urban park was established in Boston in 1634. Boston Commons, as well as many other urban parks that were created over the last 250 years, were primarily established as pastoral landscapes that provided city residents with a slice of nature, without the “wild” component. However, with the advent of the industrial revolution in the late ninetieth century, increased immigration to urban centers and the resulting deterioration of living conditions led to Progressive Era of social reforms in the early twentieth century (Birch 2009). A common theme in many of these reforms was a focus by urban planners on improving the physical fabric of cities through the expansion and creation of urban parks (Eisenman 2013). Frederick Law Olmsted, a pioneering landscape architect who was responsible for designing many of the United States’ first city parks, was the first to design urban parks with a focus on fully utilizing naturally occurring features in a landscape, while also integrating elements that facilitated the needs and desires of different park users (Kalfus 1991). The shift by Olmstead in designing urban green space design from open fields with supporting man-made structures to areas in which an effort was made to bring “nature” to the urban dweller was the birth of linking a constituent’s well-being to ecosystem services (Eisenman 2013). Ecosystem services are defined as the variety of well-being benefits provided to humans by a natural and healthy environment. Linking ecosystem processes to ecosystem services requires UGS designers to fully appreciate the connection between an ecosystems design and ecological processes to its capacity for ecological services (Fu et al. 2013).

Olmstead's focus on bringing nature to the city was quickly adopted by other landscape architects and parks were established throughout the U.S. to provide urban residents an escape from the "concrete jungle" they inhabited. These initial green spaces were designed to maximize the amount of "nature" that could be provided through the reduction of impervious surfaces and the greening up of all available space. During this build-up of urban green spaces, little regard was given to the ecosystem/habitat functions, with all focus directed towards maximizing the park user's experience through pleasing aesthetics (Gobster 2001).

As the newly established green spaces began to take on a more natural setting, wildlife began utilizing these areas. The types of flora and fauna found in these early parks were limited by the habitat needs of particular species as well as the ability of the species to immigrate into the park. Some species of local and regional birds quickly colonized these green spaces due to their mobility and adaptability. Terrestrial species were slower to establish resident populations due to the difficulty of many species to navigate the urban terrain (surface streets, highways and fragmented habitat patches) surrounding the parks. As more parks developed, immigration barriers eased for many species due to the green corridors that emerged or were established. These vegetation corridors were responsible for not only linking urban green areas to each other but in certain instances linking urban green spaces to more rural areas on the fringes of cities. Studies showed that these corridors were integral in enhancing biodiversity in urban parks by providing an effective way for wildlife to travel densely populated urban areas and a population source for many different species (Flink & Searns 1993; Clergeau, 1998). As more wildlife moved into urban green spaces, unanticipated problems began to appear in the form of negative human/wildlife interactions, habitat degradation, species overpopulation and the introduction of invasive species. These issues arose at a time in which many urban parks were experiencing funding issues in the mid 1970's that prevented park managers from implementing strategies to address the aforementioned problems (Harding 1999).

Forest Park

Forest Park occupies an area of 526 ha within the city of Saint Louis, Missouri and is considered an "active participant and catalyst in the Saint Louis community" (Forest Park - City of St. Louis, 2022). Forest Park is one of the largest urban green spaces (UGS) in the United States and attracts over 13 million visitors per year (Visit Forest Park 2022). Forest Park offers a variety of habitat types ranging from native old growth forest, savannas, tall grass prairies, wetlands and over two miles of a reconstructed river system (Hazelrigg 2004, Witt et al. 2020). Park managers have recorded over 45,000 trees, 219 species of animals and over 750 species of vascular plants (Fox 2019) in what many residents refer to as an urban oasis. Forest Park is located within a densely populated residential and commercial central corridor of St. Louis, bounded in the west by Skinker Boulevard, the east by South Kingshighway, the north by Lindell Boulevard and on the south by US Highway 64/40. In accordance with the master plan that was created in 1995, the St. Louis City Parks Department in collaboration with the private, not-for-profit organization Forest Park Forever, began a restoration of the park to return it to its former status as an urban oasis for both people and wildlife (Hazelrigg 2004). One of the specific goals of the master plan was to return a continuous stream/wetland system to the park. Construction started in 1997, to re-connect all the lakes and lagoons from Jefferson Lake in the southeast corner of the park, to the Cascades located on the western border. (Figure 1). This system is referred to as the Linear Connected Water System (LCWS) and stretches approximately 2.5 miles across almost the entirety of the park. This restoration involved not only creating a new stream channel but the establishment of a riparian buffer, storm water drainage and recirculation pumps to reduce water usage (Hazelrigg 2004, Visit Forest Park 2022).

The stream system is fed by multiple municipal water hydrants that keep the water at a stable level year-round eliminating seasonal variability. This course of action is employed to address potential negative impacts such as unpleasant odors and increased mosquito habitat a naturally fluctuating stream can present. Furthermore, the manipulation of the waterways seasonal variability affects not only the ability of some flora and fauna to colonize the stream year-round but also the composition of both aquatic and riparian flora due to their need for water permanence or variability.

In addition to natural succession, habitat changes brought on by human modifications, in pursuit of realizing Forest Park Forever's master restoration plan, has also contributed to significant changes in the parks landscape (Witt et al. 2020). Removal of invasive species, turf management and native flora reintroductions by park stewards have impacted the waterways through reduced/increased erosion, changes in aquatic and riparian zone's species composition, elimination and establishment of riparian buffers and changes in naturally occurring water chemistry and watershed inputs.   Furthermore, these changes also possess the potential to change not only the type of species that can exist in the habitat but also affect the life histories traits of those species occupying the area.

In the process of recreating these bygone natural areas, changes in both biotic and abiotic features of the LCWS have affected some animal populations allowing them to increase to nuisance levels due to the dearth of natural predators and supportive habitat parameters. One specific species that has responded well to implemented wetland manipulations and the improved habitat quality is the muskrat (*Ondatra zibethicus*). The abundance of muskrats found in the park is supported by the several years of trapping data, increased sightings, many observed burrows and lodges and confirmed damage attributed to muskrats (Steve Buback FPF, Personal Correspondence 2009). This evidence has led FPF management and park stewards to conclude that high muskrat populations have the potential to negatively impact the wetland areas throughout the park and ultimately affect park user satisfaction through reduced park aesthetics.

Wetland Systems

Hydrology is defined by the EPA as the science that "encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle" (USGS 2011). There are numerous characteristics that define a wetland and make it unique. Characteristics can be structural such as the water profile, substrate type or plant and animal composition or they can be functional such as the systems rate of nutrient cycling or organic production. These differences illustrate not only how wetlands differ from other habitats but can also be used to differentiate wetland habitats amongst themselves (Cowardin et al. 1979, Friess et al. 2011). One component of a wetland is its shoreline/banks. The shoreline/banks in a wetland system provide areas in which wetland species can feed, nurse young, evade predators and provide refuge from the elements. This feature of a wetland can differ in part by its composition, gradient, and availability. Nearly as important as water in identifying an area as a wetland would be the flora that it supports. The specific flora species found in wetlands is the result of the wetlands ability to provide sufficient moisture. Plant species thus are normally made up of those that either require persistent water or those that can tolerate prolonged periods of soil saturation (Brooks et al. 2003). Additionally, the composition of vegetative species found in a specific wetland can be dictated by its geographical location, proximity to colonizing species, the pressure put on it by its inhabitants as well as other factors. Furthermore, physical and environmental factors such as the amount of disturbance that an area receives and the microclimate that can exist can lead to radically different manifestations of wetlands within the same region. Finally, the characteristics of the water found in a wetland can vary immensely. Water characteristics such as the average depth of the water, chemistry and hydrology are just a small number of the differences that can exist.

Like urban green spaces, wetlands in urban areas occur along a gradient ranging from natural areas to highly modified systems (Bucci 2009). The LCWS was designed primarily to remove/redirect storm water runoff to alleviate public safety hazards, eliminate unpleasant odors and improve year-round aesthetic appreciation (STLCDC 1995, Hazelrigg 2004, Steve Buback FPF, Personal Correspondence 2009). Additionally, these modifications to the water system at Forest Park improved the desirability of the urban ecosystem for species that utilized the waterways such as waterfowl, muskrats, fish and mink. Changes to the LCWS included the connection of the surface waterways, re-introduction of native riparian and aquatic flora and the elimination of seasonal water fluctuations which increased the colonization of the ecosystem by numerous wetland species (Hazelrig 2004). This type of wetland is found in many urban green spaces including those where muskrat populations have been studied (Ganoe et al. 2021).

Wetland systems are found throughout the United States and vary greatly in both size and characteristics; they are species rich ecosystems that provide ideal habitat for many different types of flora and fauna. This wetland variation challenges ecologists to fully appreciate the role that both terrestrial and aquatic variables have on the ability of the habit to support a targeted species. To this point, a recent article published in Marine Ecology suggests that wetland ecology is difficult to place in either terrestrial or aquatic ecology because it rests somewhere between the two disciplines, and both are strongly linked (Guenet et al. 2010). However, one common factor found in all wetland areas is the persistence of water. This persistence defines not only the nature of soil development, but also the types of plant and animal communities living in the soil and on its surface (Cowardin et al. 1979). The pseudo-wetland areas located in Forest Park are particularly unique in that they are located within an urban landscape, thus providing opportunities for the establishment of species not commonly found in an urban greenspace that lack a persistence of water and habitat features normally associated with a wetland environment. As stated earlier, the wetland areas/habitat within Forest Park can be found throughout the park and are the result of modifications made to the park in the last two decades.

Muskrats

Muskrats are a medium sized rodent species characterized by a broad head, stocky body and a sparsely haired, flattened tail (Schwartz et al. 2016). Muskrats range from the Carolinas, north Texas to Oregon, northward to all of Quebec and all of Alaska (Niering 1985). Habitat suitability indices (HSI) have shown that good muskrat habitat is characterized by permanent, slow-moving water, emergent vegetation, and suitable bank den sites (Brooks & Prosser 1994).

An ideal water depth for muskrats is deep enough to prevent complete freezing in the winter, yet shallow enough to support aquatic vegetation (Aleksiuk 1987). Muskrats are primarily nocturnal, but during the peak breeding season (spring to early summer) they become quite active throughout the day (Schwartz et al. 2016). Muskrats rely on both stream/pond bank burrows and open water lodges for den sites and refuge. Bank den sites are established at or just below the water levels whereas, open water lodges consist of wetland vegetation that is primarily gathered late summer and early fall (Kadlec et al. 2007). Bank dens and open water lodges serve three main purposes: they provide protection from inclement weather and seasonal temperature swings; lodges give the muskrat a safe area in which to rest and feed and they provide a safe refuge for the muskrat to bear young (Kadlec et al. 2007). Home range sizes average approximately 60 m in diameter in marshes, and up to 305 m of shoreline in stream environments (Brooks & Proffer 1994). Though muskrats are known to be aggressive to each other when defending scarce resources, this aggression quickly diminishes as resources become abundant (Schwartz et al. 2016). Limited resources and the subsequent fighting that occurs is known to drive submissive individuals out of the area, leading to the colonization of other wetland areas.

Muskrat breeding occurs from late winter to late summer with three main peaks, which occur in the spring and early summer months (Schwartz et al. 2016). Muskrats possess a high fecundity rate and have been documented to produce from 1 to 5 litters annually, with an average of four to seven individuals birthed each time they breed (Schwartz et al. 2016). With this high rate of reproduction, a corresponding high juvenile mortality occurs with an estimated 66% of all newly born individuals not reaching their first winter (Schwartz et al. 2016). Of the remaining individuals born each year, life spans will range between one to three years (Schwartz et al. 2016).

Muskrats are an important component of the marsh ecosystem, serving as a food source for many predators such as raptor species, coyotes (*Canis latrans*), and their primary predator American mink (*Mustela vison*) (Wilson 1968; Niering 1985; Kadlec et al. 2007; Ahlers et al. 2021). Consequently, in areas in which there is low predation, unchecked populations can potentially have a major impact on wetland vegetation (O'Neil 1949; Errington 1961; Errington 1963; Weller & Spatcher 1965). Muskrats are primarily herbivores, although animal matter is also consumed (Errington 1963). Muskrats use the most available plant species; therefore, commonly consumed foods will vary with the type of habitat (Wilner et al. 1980). The basal portions of aquatic vegetation are eaten most often, followed by the rhizomes and leaves (Neal 1968). Cattails (*Typha spp*.), the predominant species in many wetlands, has frequently been identified as a highly preferred food of the species and can support approximately seven times as many muskrats as other types of wetland plants (Allen & Hoffman 1984; Errington 1963).

Muskrats, like all species, however, possess the potential to increase their populations to whatever the carrying capacity of their habitat can sustain. Resource abundance, in the form of not only food but den site availability, reduced intraspecific competition and the absence of predation can lead to large populations that shape their habitat. Furthermore, over time muskrat overgrazing can change wetlands from being densely vegetated to a patchwork of open and emergent areas, and in some cases completely denude the wetland (Berg & Kangas 1989).

Utilization of Forest Park's Linear Connected Water System (LCWS) by Muskrats

An ecosystem is defined as an "interdependent, functioning system of plants, animals and microorganisms" (National Ecosystem Services Classification System Plus 2022). All species that occupy and function within a particular habitat or ecosystem play an integral role in shaping and defining the system and thus can have a disproportionately large influence on other aspects of the system if their impact is not balanced. Predator and prey relationships, the amount of food and shelter that is available, and the amount of space available for utilization shape ecosystem function. These relationships are dynamic, and changes in species abundance may lead to changes in the whole system may result. Ultimately, imbalances can lead to irrevocable changes to the system, manifesting in changes to the species, habitats and the physical components of the ecosystem.

All species affect their environment in a variety of ways, with some species having a greater impact on their habitat than others. The effect can be through modifications of the physical environment or manipulations of available resources. Regardless, fragile ecosystems can quickly become altered if particular species populations are left unchecked. Animal species that possess this ability to significantly modify their habitat have been termed ecological engineers or more specifically, allogenic engineers (Jones et al. 1994). One such species that has shown an ability to impart significant change within their aquatic habitat is the muskrat. Past research has shown that the presence and relative abundance of muskrats found in wetland ecosystems have the potential to significantly impact the physical attributes of their wetland habitat including but not limited to its water chemistry, stream morphology and aquatic species diversity (Bomske & Ahlers 2020; Brooks 1997). Additionally, the overall abundance of muskrats within an ecosystem also has the potential to affect the overall perceived health of the system through the manipulation of indicators such as plant species abundance and species richness that human users deem aesthetically pleasing (Nadeau et al. 1995).

Kadlec et al. (2007) has described the role of muskrats as ecosystem engineers in managed wetlands noting potential impacts on wetland water quality and hydrology. Addressing the relationship between muskrat occupancy and their effect on water quality, the issue has been considered in previous studies, but no in-depth research has been conducted to date. In fact, a 2007 paper published in Ecological Engineering supports the need for additional research to quantify the potential effects that a muskrat density that exceeds the habitats natural carrying capacity can have on wetland water quality (Kadlec et al. 2007). Nonetheless, even in the absence of published research, basic limnology suggests that a denudation or significant reduction in vegetation caused by an over abundant muskrat population, can affect water chemistry components, including but not limited to, nitrogen and phosphorus.

As for the effect that higher muskrat densities have on the integrity/sustainability of the wetland, a population that exceeds its habitats carrying capacity should also theoretically result in a negative effect to the system. For example, muskrats will readily feed on the most abundant plant species available (Schwartz 1986, Skyrienė & Paulauskas 2013). It therefore stands to reason that the removal of mass quantities of a particular vegetative species, along with the vegetation unique characteristics, can have a cascading effect on other system components, including the wetland's nutrient uptake capability, the wetland's ability to serve as a cover/nursery for other species an d the impact to water hydrology and stream channel morphology (Brooks et al. 2003). Cattails, waterlily (*Nymphaea* spp.) and bulrush (*Scirpus* spp.) are preferred vegetation of muskrats due to their high value as food as well as their use as a versatile building material (Errington 1963, Skyrienė & Paulauskas 2013). Wetland ecology research has shown that each of these aquatic species have ideal growing parameters as it relates to the concentrations of nitrogen and phosphorus availability in their aquatic environment and stabilized water levels (Boers & Zedler 2008; Tanner 2001). Furthermore, research has correlated stand densities to the availability of phosphorus and nitrogen for growth uptake and its corresponding effect on free nitrogen and phosphorus availability/concentration in the aquatic growing environment (Barry et al. 2014). Seasonal fluctuations in these concentrations occur as vegetation matures and site concentrations respectively change (Reddy & Portier 1987; Barry et al. 2014; Abbasi & Abbasi 2010).

Drawing a correlation between the availability of limiting nutrients in an aquatic environment and the uptake rates of a muskrat's preferred vegetation can inform site managers of an areas potential for aquatic vegetation occupancy and the carry capacity of the habitat. Past research has examined miscellaneous habitat variables including bank structure and composition, burrow and house abundance, soils, hydrology, etc. in an attempt to estimate quantitatively muskrat densities for large watersheds (Brooks & Dodge 1986). Estimating a sites overall habitat quality is essential for biologist to predict possible muskrat abundance at the site and adding an additional habitat variable has the potential to not only improve efficiency of data collection but also improve the accuracy of an estimation.

Evidence collected by Forest Park personnel indicates that the muskrat population is increasing in the Forest Park's LCWS (Steve Buback FPF, Personal Correspondence 2009). This assumption corresponds with the Muskrat Habitat Suitability Index (HSI) generated by the U.S. Department of Interior (Allen & Hoffman 1984). A HSI is an assessment tool that identifies different habitat components that are most conducive to supporting a species' population. When assessing the suitability of the LCWS in Forest Park to support muskrats, the HSI indicates that several of the habitat components are ideal for an unsustainable increase in the muskrat population, including the permanence and stability of water, the abundance of herbaceous vegetation and the suitability of the shoreline to facilitate den sites. These components, combined with the minimal pressure placed on muskrats by their primary predators, humans and American mink, make conditions perfect for the continual growth of muskrat populations within the park (Schwartz et al. 2016; Niering 1985; Steve Buback FPF, Personal Correspondence 2009). As such, an unrestrained muskrat population has the potential to extensively transform the LCWS wetland habitat, due to their capacity as ecosystem engineers, to adversely affect the availability of resources to sustain them.

Determining a species distribution within an ecosystem is necessary for managers attempting to make meaningful management decisions proportional to the population size of a target species. Additionally, accurate estimations of species distribution levels aide managers in predicting the impact that a population can have on the study system allowing managers to anticipate and plan for potential disruptions (Lee 1992; Gormley et al. 2010; Elith et al. 2006). Detection models are useful when researching evasive species that challenge normal census methodology due to cost, time or spatial and detection biases (Gu & Swihart 2004). Using biophysical habitat variables identified as being crucial for muskrat occupancy gives managers an effective tool to get more accurate estimations of a population based on the inclusion of such covariate variables when building your model. Furthermore, establishing a relationship between absence/presence data with recorded habitat variables allows mangers to focus their efforts on detection and eventually management of areas known to have higher habitat suitability thus propensity for target species occupation (Thompson 2013).

An effective way to determine a species occupancy and distribution within an ecosystem is the collection of absence and presence data. The collection of such data is often employed in studies in which the targeted species are elusive, difficult to trap, capture is cost or time restrictive or the target is nocturnal in activity. Researchers conduct surveys of study areas to look for signs that the targeted species occupies said area. Signs can include scat, feeding debris, burrows, tracks, etc. Researchers then use collected absence presence data to estimate species populations. (Ramsey et al. 2015; Stahl et al. 2020).

HSI models were developed to aid researchers in predicting a specific species occupancy based on habitat variables known to be vital to a species' existence. The accuracy of the models is important for managers making decisions on how to manage these individual populations (Hirzel et al. 2006; Hirzel & Metral 2001). A common caveat of all established HSI models is that due to the many habitat variables that are included in an HSI they may generate erroneous estimation due to unique site characteristics (Hirzel & Metral 2001).

This research is important because habitat managers are tasked with the goal of maintaining wildlife habitat in the most cost-effective way. Understanding components of a specific site that can lead to elevated muskrat populations, wildlife managers would be able to target manipulations of the habitat in ways that could more effectively mitigate muskrat population growth and/or occupancy (Miller 2018).

In conclusion, established HSI models indicate that abundant aquatic and riparian vegetation used as both food, cover and building material is integral to high muskrat densities. (Errington 1963). Limits or abundance in vegetation availability has the potential to quickly pressure muskrat population numbers and can lead to exponential growth or intra-species competition resulting in reductions in muskrat population due to emigration (Danell 1977). This research will attempt to further biologists' and UGS stewards' understanding of the sensitivity of the established HSI to reflect the suitability of habitat for muskrat occupancy based on fluctuations in aquatic and riparian vegetation as well as other habitat characteristics.

Research Impetus/Goals/Questions

The value of urban green spaces (UGSs) in providing meaningful ecosystem services to a vast array of stakeholders cannot be overstated (Gómez-Baggethun et al. 2013). UGSs exist in many shapes and sizes and range from those that are remnant forest patches to heavily built and managed spaces. Large urban parks represent a unique group of urban greenspaces (Aronson et al. 2017, Beninde et al. 2015). Research has shown that the differences in UGS structure, size, geographic location make them novel environments with unique characteristics directly affecting the biodiversity they support (Aronson et al. 2017, Ives et al. 2016). The challenge for many UGS managers is balancing the desires of mixed stakeholders with the goal of maximizing biodiversity. Currently, there has been little research exploring the how UGS biodiversity is affected by not only by individual novel design but by the associated ecosystem processes, and the role specific flora and fauna species play in a UGS's species composition (Aronson et al. 2017, Sandifer et al. 2015, Ziter 2016).

The setting for this research was the UGS of Forest Park. Forest Park possesses many elements that make it unique as a UGS and provides a novel environment in which to study muskrats. On the UGS continuum between a remnant patch and a heavily managed space it sits somewhere in the middle. Forest Parks' unique biological and physical components make it difficult to compare or contrast it to other UGS's because each of these components has the potential to affect the way the system functions as a whole. Though Forest Park space is heavily managed to the benefit of varied stakeholders, recent restoration efforts to restore more "natural" ecological systems has led to increased biodiversity in both plant and animal species as measured by the Academy of Science of St. Louis in their annual Bioblitz which inventories species composition throughout the park (Academy of Science of St. Louis 2023*).* Muskrats occupy the LCWS that runs throughout the park and questions have arisen from park management about their potential to impact their habitat, acting as ecosystem engineers, and what effect their occupancy can have on the biodiversity of flora and fauna found within the park's waterways (Steve Buback FPF, Personal Correspondence 2009). A recent article authored by muskrat researchers (Bomske & Ahlers 2020) highlights the fact that there has been minimal scientific literature published that specifically explores. After an extensive scientific literature review, Bomske and Ahlers (2020) were able to identify 363 publications concerning muskrats but only 6% (n=13) explicitly focused on muskrats operating as ecosystem engineers or keystone species. Appreciating the potential impact that a specific species can have on its habitat and its resulting effect on biodiversity could be another valuable tool in an UGS manager's management repertoire regardless of the UGS habitat heterogeneity or target species.

Research Goals

The goals of this study are twofold:

- To determine how habitat changes over time, through both human manipulation and natural succession, can affect suitability of said habitat to support muskrat occupancy and changes to the habitat's carrying capacity.
- To provide a case study for other UGS researchers and managers to utilize when studying or managing their novel UGS's.

This research is based in Forest Park, located in the central corridor of St. Louis Missouri. Management of the park is carried out by the private nonprofit conservancy Forest Park Forever (FPF) in collaboration with the Saint Louis City Parks Department. The study was initiated by FPF in response to excessive muskrat habitat damage documented by FPF staff. Initial remediation efforts employed by FPF were outpaced by documented muskrat damage leading to an intense trapping effort. After several years of trapping effort, FPF's concern with the potential for public backlash and reoccurring cost led to FPF staff looking for a more sustainable way to reduce the park's muskrat population (Steve Buback FPF, Personal Correspondence 2009). My involvement in this research began in Spring of 2009 with the goal of documenting the changes in Forest Park habitat, specifically the Linear Connected Water System (LCWS), and to explore what habitat features were driving the muskrat population growth with a goal of reducing muskrat populations through habitat manipulation and eliminating the need to annually trap the muskrats.

Early in this research, it was determined that FPF management of the LCWS and its riparian buffer were contributing to the large muskrat populations the park system supported.

The conflicting goals in managing both the muskrat population and the LCWS, namely water level manipulation, made reducing muskrat populations unattainable given the ideal habitat parameters and therefore the capacity the LCWS to support additional muskrats.

Physical habitat variables of the LCWS were collected over the next eight years through site visits and assembly of twelve years of FPF water quality data. This data was then analyzed to document any changes and identify if observable changes had an effect on the suitability of the habitat to support muskrat occupancy based on HSI score fluctuations. Additionally, an attempt was made to determine if a correlation existed between water chemistry variables and fluctuations of aquatic and riparian vegetation stem density in HSI scoring.

A major benefit of this study is the length of time that LCWS site characteristics have been documented. Physical components deemed crucial in determining the suitability of habitat for muskrat occupancy have been documented since 2014, and water chemistry variables have been recorded since 2007. Both data sets were collected throughout the calendar year to account for seasonal variability.

Research Questions

Question 1

How are the study sites similar/dissimilar, and what habitat variable(s) drive this grouping? How have the identified study sites changed over time and what potential effect do the changes have on the suitability of the habitat to support muskrat populations as measured by its habitat site index score?

Question 2

Does muskrat absence/presence observations and site HSI scores confirm the suitability of sites for muskrat occupancy. Does the strength of these relationships move in step with changes reflected over time in HSI variable fluctuation, specifically aquatic and terrestrial vegetation data?

Question 3

Can specific water chemistry variables be used to predict the capacity of a waterway to support stands of aquatic vegetation and its corresponding effect on habit suitability for muskrat occupancy?

Chapter 2: Research Methods

Study Site Selection

Forest Park located in St. Louis, Missouri is the crown jewel of the city's 110 urban green spaces managed by St. Louis city's Department of Parks, Recreation and Forestry. At almost twice the size of New York's Central Park it encompasses numerous habitat types and cultural institutions (Forest Park - City of St. Louis, 2022). In 2013, twenty sites were established over the entirety of Forest Park's LCWS to capture the variability of habitat settings that naturally occurred (Figure 1). To ensure unbiased selection, sites were spaced 100m apart. Due to the fragmented nature of the LCWS, new "starting points" had to be established when surface water was absent in the next interval or concrete bank walls made muskrat occupancy unfeasible. Each of these sites were selected based on the study goals, comparing and contrasting habitat suitability for muskrats. More specifically, criteria for selecting the sites were based on waterbody size, water permanency and site diversity regarding disturbances, vegetation proximity and stream class. For this research, waterbody size refers to the physical size of the waterway at each site with a goal of identifying sites within the park representing streamways as well as standalone ponds. Water permanency pertains to the ability of the selected site to permanently hold water, thus supporting muskrats, year-round. Disturbances are defined by the site's proximity to human interaction in the form of trails, roadways and preferred fishing areas. Vegetation proximity is defined as the presence of vegetation along the riparian bank of each selected site. The last characteristic in selecting the study sites was stream class within 30 meters of the identified site. The three stream classes that were considered were whether the waterway could be identified as being a rapid/riffle, run or pool/backwater.

Site Classification

All 20 study sites were classified according to five components assessing the respective sites morphological, aquatic and spatial characteristics: vegetation stand density, percent of aquatic vegetation, waterbody width, bank slope and site proximity to disturbance. Each of these features were chosen based on their inclusion in established muskrat habitat suitability index models and their relevance to muskrat persistence within wetland habitats (Allan & Hoffman 1984). All the components were qualitatively identified and rated on a scale between 1 – 5 to generate a quantitative data set for statistical analysis (Table 1). Site classification observations were conducted a total of 10 times from Spring of 2014 through Summer of 2022. Observations were conducted during different seasons of the year to fully evaluate seasonal changes as well as year to year changes to the habitat. Each observation period consisted of visiting each of the 20 study sites, assessing the habitat for the indicated components and documenting the observation with digital photographs.

Vegetation Stand Density (VSD) refers to the stem density of all terrestrial plants within one meter of the water and land interface. Estimations were based on visual observations and quantified on a scale between one and five. A score of one represented no ground cover whereas five represented a stem density of 75% or greater (Table 1).

Percent aquatic vegetation was based on the percentage of the water surface that was covered by floating or rooted aquatic vegetation within two meters on the water and land interface. Percentages were converted to numerical values ranging from one to five. A score of one represented the absence of any aquatic vegetation whereas a score of five was assigned to a site if aquatic vegetation exceeded 75% of the observed site (Table 1).

Waterbody width referred to the width of the waterbody at each respective study site. Observations were measured from the study sites center point (GPS tagged), at the land/water interface, perpendicular to the bank. Observations were further quantified by assigning a number based on a one to five scale with one representing a waterbody width of less than 10 meters and a five indicating a water body width in excess of 41 meters (Table 1).

Bank slope was measured at the land/water interface to determine slope steepness from horizontal. Observations were measured from the study sites center point (GPS tagged), at the land/water interface. Slope was calculated as a percentage by converting the rise and run to the same units and then dividing the rise by the run. This number was then multiplied by 100 to generate the slope percentage. Percentages were then converted to a five-point system based on their respective slope. One was assigned to a bank slope of zero whereas a slope greater than 46% was assigned a value of five (Table 1).

The last category measured for site classification was proximity to disturbance. The winding nature of the waterways throughout the park at times put study sites near disturbances. For the scope of this study, disturbances were identified as any non-natural structure(s) (roads, trails, bike paths, docks, viewing platforms, fountains, benches, and picnic areas) that occurred within the immediate proximity of the study site. Observations were measured from the study sites center point (GPS tagged) and recorded based on a one to five scale. One was assigned to a site in which identified disturbances were present at the site center or within 10 meters of the study sites center; whereas a value of five was assigned to a site in which any disturbances were greater than 41 meters from the site center (Table 1).

Polar (Bray-Curtis) Ordination

The 10 sampling periods at the 20 sites resulted in 200 samples that were used to analyze changes in habitat structure over time. We used Bray-Curtis Ordination (PCORD 7, Wild Blueberry Media LLC), using Bray-Curtis distance to study the patterns of dissimilarity among the 200 samples. Bray-Curtis ordination was selected because of its effectiveness in comparing ecological differences between samples. Ordination arranged the two hundred samples in a space defined by the similarity of the samples in scores for the five site classification variables. The samples were then plotted on a graph in which similar sample sites are plotted close together, and dissimilar sites are placed further apart in respect to their location along the two axes. Correlations ($r > \pm 0.500$) between site classification variable scores and the sample site axes scores were used to identify variables that might explain differences among the sites (PC Ord 7. Wild Blueberry Media LLC).

Muskrat HSI

Habitat Suitability Index (HSI) values are generated by evaluating key habitat components as they relate to the fundamental needs (life requisites) of a selected species (Entz 2005). These components incorporate water, food, cover, etc. and are unique to each species. Thus, the goal of an HSI model is twofold: it predicts the suitability of a habitat to sustain a viable population of a targeted species; and it can identify individual habitat components in which managers can manipulate to affect carrying capacity of a target species. Index values range from 1.0, indicating optimum suitability of a particular habitat variable, to 0.0 which indicates the respective variable is not suitable for supporting the targeted species. Reproductive habitat requirements correlate with the HSI values in that if HSI values are met then no environmental impediment exists to species propagation.

HSI models for freshwater muskrat have identified two categories of life requisites, food and cover. Within these two categories, freshwater muskrat HSI models are divided into two different cover types, herbaceous wetland and riverine based on a sites specific characteristic according to terminology established by the U.S. Fish and Wildlife Service (USFWS 1981). The herbaceous wetland model was the most appropriate HSI model to use for generating Forest Parks site index (SI) despite the lack of seasonal fluctuations in water levels due to constant inflow of water into the LCWS resulting in a near negligible year-round change in water levels across the system. This choice was made not only for the stable water level that was maintained but also due to the minimal gradient observed affecting flow, present in all riverine habitat, and the herbaceous vegetation that dominates the riparian area for much of the system.

Three variables were used to calculate SI values: percent canopy cover of emergent herbaceous vegetation (stand density, V_1), percent of year with surface water present (waterbody width, V_2) and percent of emergent aquatic herbaceous vegetation, primarily bulrush, duckweed and cattails, (percent aquatic vegetation, V_8). These three variables were used to determine cover suitability using the equation $(V_1 \times V_2)^{1/2}$, and food suitability using the equation $(V_1 \times V_8)^{1/2}$. Optimal SI values for V_1 ranged from 50% to 75% (Figure 2), V_2 ranged from 75% to 100% (Figure 3) and V_8 ranged from 25% to 100% (Figure 4). The overall HSI value computed for each sample site was determined by assuming a limiting factor mechanism. Thus, the HSI value equaled the lowest life requisite value calculated for either food or cover.

HSI scores were compared by determining the mean food SI and cover SI for each site and averaged them among three sampling dates: 6/2014, 7/2017 and 7/2022. These three sampling sessions were chosen for two reasons, to give consistency to the time period in which the data was collected (Summer) thus minimizing seasonal bias from samples taken at different times of the year and, to ensure that samples covered the entire duration of the study. Yearly averages for all three sampling dates across all 20 sites were analyzed using ANOVA (PCORD 7, Wild Blueberry Media LLC) to determine if the difference in means for each category (Food & Cover) were statistically significant ($\alpha=0.05$).

Muskrat Absence/Presence

Confirmed muskrat sightings and/or verifiable muskrat signs such as tracks or den sites (Wardrop et al. 2004) was used to determine the absence or presence of muskrats within the twenty observed water body sample sites located throughout Forest Park's waterways. Muskrat presence in any waterway is highly dependent on the waterbody morphology, water quality, food availability, social pressures and condition (Perry 1982). Additionally, proximity to site disturbances such as human interactions and primary predators such as the American mink can greatly affect the presence within the selected waterbody (Kadlec et al. 2007). Muskrats prefer waterways that generally have an abundance of retreat areas (water or bank based), water of sufficient depth to prevent full freezing and a riparian area of dense herbaceous vegetation (Errington 1974).

Searches for muskrat presence were conducted at each site during each of the 10 site classification visits between 2013 and 2022. Observations were made within approximately

50m upstream or downstream of the center point of each study site. Muskrat presence was defined as signs of muskrat activity (chutes and runs, feeding mounds, pull out spots), verifiable foot tracks, burrows, scat or the actual sighting of a muskrat (Appendix 1, Nadeau et al. 1995). Each site was visited two times during the crepuscular times of day as well as during the different quarters of the year to increase the probability of sighting individual muskrats. Additional searches for muskrat presence on the sites were made during separate 90-minute observation sessions where sites were monitored with binoculars. To account for limited sightlines and ensure full coverage of the site I would reposition myself within the study area every 15mins. Information on bank condition were collected noting steepness/slope, location of cattails and bullrush stands and the composition of the waterway/ bank interface (riprap, concrete, or soil) medium to determine its conduciveness to muskrat use and burrowing as prescribed in the Muskrat HSI. All observations were recorded, indicating the respective study site, date, time of day, and temperature and weather conditions. Observations where muskrats were present, or muskrat sign was visible were defined as samples with muskrats present. Observations without muskrat sightings and no muskrat signs were defined as samples with muskrats absent.

The ability of the five site classification variables to predict muskrat presence /absence was analyzed using backwards stepwise generalized linear regression. Muskrat presence / absence data for the 200 samples where both muskrat observations and site classification observations were made were analyzed. Presence/absence was treated as a binomial variable (presence = 1, absence =0). The analysis was conducted using the R Core Team GLM Package (2022). Evaluation of how well each of the three models fit the data was accomplished by reviewing the Akaike Information Criteria (AIC) scores to identify the best supported models. The lower the AIC score the better the model fits the data.

Trapping Data

Data on trapped and euthanized muskrats were used to provide information on muskrat presence along the LCWS in the years before the start of this study, when muskrat populations were thought to be at a peak. Trapping contractor AB Wildlife trapped and euthanized muskrats within the park for four seasons beginning in winter/fall 2005 and ending in 2008 (Forest Park Forever, personal communication). A combination of lethal and non-lethal colony traps was employed throughout the park with the maximum effort employed in Post-Dispatch Lake and the waterways feeding and draining this section of the LCWS. Trapping occurred in waterways associated with 19 of the 20 study sites in 2005, one study site in 2006, four study sites in 2007, and 8 sites in 2008 (Table 2).

Water Chemistry

Water samples were collected monthly, from 2007 to 2019 by Forest Park Forever personnel from four sites located throughout the Forest Park LCWS (Figure 5): Probstein Golf course (Golf) associated with sites 17 and 18,; Deer Lake Riffles (WetIN) associated with sites 14 and 15; Prairie near Steinberg Arena (Stein) associated with sites 4, 5, 6, and 7; and Post-Dispatch Lake (PDL) associated with site 16 (Table 3). Samples were collected in sterile water sampling bottles and processed by the Saint Louis City Water Department in accordance with protocol published in the Standard Methods for the Examination of Water & Wastewater (Eaton et al. 2005). Three water quality variables were measured; dissolved oxygen (DO) reported in mg/l; Nitrogen (N), including NO^2/NO^3 present, reported in mg/l; and Total Phosphorus (P) reported in mg/l and µ/l.

Phosphorus (P) and nitrogen (N) standards from the Nutrient Criteria Technical Guidance Manual: Wetlands (2008) were used to determine productivity of aquatic vegetation. P and N levels recorded during the sampling regime were grouped into three levels of nutrient enrichment and their corresponding potential for aquatic vegetation productivity. Phosphorus standards were 10 µg/l (ambient), 80 µg/l (moderately enriched) and 500 µg/l (highly enriched) (Li et al., 2010). Nitrogen standards were < 1 mg/l (low enriched), 5 mg/l (moderately enriched) and 10 mg/l (highly enriched) (Nutrient Criteria Technical Guidance Manual Wetlands, 2008). Monitoring data for phosphorus and nitrogen were collected during the months of April to September (St. Louis's growing season) for six years starting in 2014 and concluding in 2019. Nutrient levels recorded for each of the target months were then averaged to generate an overall site value for each year. For P and N average concentration levels for each waterway (Golf, PDL, STEIN and WETIN) an average concentration level for all six years was generated to compare individual years at the site to the overall site average.

Chapter 3: Results

Site Polar Ordination/Clustering Over Time and Effect to HSI Scores

Twenty study sites were visited ten times over eight years to provide ample time for documentation of any discernable changes, primarily terrestrial and aquatic vegetation, brought on by muskrat. Of the five site characteristics measured, vegetation stand density, percent of aquatic vegetation, waterbody width, bank slope and site proximity to disturbance, only two, percent aquatic vegetation and vegetation stand density showed consistent change from survey to survey. Changes were documented seasonally and year over year. One site, Site 20, was surveyed for the full study but drainage through site management prevented the site from holding water after the summer of 2016 thus rendering it incapable of supporting muskrat occupancy.

Three groups of samples were identified in the polar ordination plot (Figure 6). Group one was composed of 21% of the samples (sites 1,2,3, and 9), Group 2, representing the largest group, encompassed 58% of the 20 samples (sites 4,5,7,8,10,13,14,16,17,18, and 19) and Group 3 consisted of the remaining four sites (6,11,12, and 15). The groups of samples remained consistent over the course of the study with any changes detected among the samples occurring in a specific sites Stand Density or Percent Aquatic Vegetation. These changes resulted from site manipulation (mowing) in the case of Stand Density and significant increases/decreases in aquatic vegetation.

The first ordination axis was positively correlated with bank slope (r = 0.653) and negatively correlated with stand density (r = -0.530), indicating a separation of samples with steep bank slopes from those with low vegetation stand density. The second ordination axis was negatively correlated with percent aquatic vegetation (r =-0.482) and negatively correlated with proximity to disturbance (r = -0.646), indicating a separation of samples with less aquatic vegetation and close to roads or sidewalks from other samples. (Table 4).

Data collected over all 10 sampling sessions (2014-2022) reported a Stand Density average of 4.03 on the 1-5 scale, 51% -75% coverage, with 81.5% of all sites falling within one standard deviation (SD=1.43). Percent Aquatic vegetation had an average of 2.28 on the 1-5 scale, 1% -30%, with 79% of sites falling within one standard deviation (SD=1.45). Classification variable three, Proximity to Disturbance, had an average of 2.15 on the 1-5 scale, 11% - 23%, with 79.5% of all sites falling within one standard deviation (SD=1.18). Variable four, Water Body Width, had an average of 2.74 on the 1-5 scale, 11m -26.5m, with 70% of all sites falling within one standard deviation (SD=1.34). The last classification variable, Bank Slope had an average of 3.21, 10% - 24.75%, with 50% of all sites falling within one standard (SD=1.6; Table 5).

HSI Scoring

There was no statistically significant difference between the three sampling sessions (6/2014, 7/2017 and 7/2022) for HSI Food and Cover values as determined by one-way ANOVA (F=.5421, P-value = .5949) (Table 6). Data collected during session 6/2014 had a mean of .39 for Cover and .23 for Food (Table 7). Sampling session 7/2017 recorded SI means of .41 for Cover and .21 Food and Sampling session 7/2022 recorded SI means of .38 for Cover and .15 for Food (Table 8; Table 9). Average scores for all twenty sites across all three years were .20 with the highest averages occurring in Sites 3 through 13 which had a recorded average of .28 (Table 7, Table 8, Table 9).

Variable V1, percent canopy cover, was recorded as zero in 15% of the sites sampled in 2014 (Sites 1,13,14), 25% of the sites sampled in 2017 (Sites 1,12,14,17,18) and 35% of the sites in 2022 (1,2,12,15,17,19,22). Zero values for V1 generated a suitability index (SI) value zero when calculated in the HSI equation due to the inclusion of V1 in both the Cover and Food equations. Percent canopy cover averaged 23% in 6/2014, 25% in 7/2017 and 25% in 7/2022 (Table 7, Table 8, Table 9).

HSI Variable V2, percent of year surface water present, was calculated to be 100% in all but one site (Site 20). Landscape management in 2016 near Site 20 led to the site drying out post 2016 thus rendering it uninhabitable for muskrats (Table 7, Table 8, Table 9).

The last variable used in calculating the SI scores was V8, percent aquatic vegetation. Seasonal fluctuations in emergent and floating aquatic vegetation were noted each year as changes in the weather suppressed growth. No aquatic vegetation was recorded five times (25%) during 6/2014 with Sites 11, 17,18,19 and 20 having no observable aquatic vegetation. Observations of no aquatic vegetation increased to seven (35%) in the sampling session conducted 7/2017 with no observable aquatic vegetation being observed in Sites 3,7,10,17,18,19 and 20. The last sampling session analyzed, 07/2022, had the highest observed absence of any year with eleven sites (55%) recording zero percent aquatic vegetation at Sites 2,3,7,8,9,10,16,17,18,19 and 20).

Water Chemistry

Three water chemistry variables; nitrates, total phosphorus and dissolved oxygen were collected from Forest Park Forever (FPF) personnel since 2007 but were only analyzed over the time period in which classification data was collected during this research. Known concentrations of nutrients could be used to determine the potential for aquatic vegetation production based on nutrient availability and the known nutrient requirements of the targeted vegetation species.

Site averages for Nitrogen (N=6) were recorded at .351mg/l for Golf, .204mg/l for Stein, .263mg/l for PDL and .405mg/l for WETIN (Table 10). These values indicate low nitrogen enrichment indicating that across all sites measured it was a limiting factor in aquatic vegetation growth (Nutrient Criteria Technical Guidance Manual Wetlands 2008)

Phosphorus was measured in µg/l over six years (2014-2019) at four different sampling collection points and correlated with study sites based on proximity (Golf/Sites 17 & 18; Stein/Sites 4,5,6 & 7; PDL/Sites 16 and WETIN/Sites 14 & 15). The highest overall average for phosphorus was recorded at 294.58 µg/l at Golf, followed by 174.195 µg/l at PDL, 169.938 µg/l at WETIN and 127.12 µg/l at STEIN (Table 10). These averages indicated a moderately enriched environment for Phosphorus (> 80 µg/l) increasing the potential for excessive growth of aquatic plants and algae leading to possible eutrophication (Schindler et al. 2016).

The last water chemistry variable measured, dissolved oxygen (DO), was measured in mg/l and had a calculated average of 8.9mg/l for Golf, 8.6mg/l for WETIN, 7.1mg/l for STEIN and 8.5mg/l for PDL. Mode calculated for each of the sites was calculated at 12.5mg/l for Golf, 7.5mg/l for WETIN, 5.1mg/l for Stein and 7.2mg/l for PDL. Levels exceeding 6.5mg/l would support all but the smallest of fish and indicate a robust amount of aquatic vegetation (Horne & Goldman 1994). Levels of this magnitude present the potential for large seasonal swings in oxygen due to increased oxygen consumption outside aquatic growth periods in which plants dying back would consume more oxygen during decomposition (Wang et al. 2003).

Absence/Presence Data

Absence/Presence data was collected from Summer 2006 until Summer of 2022. Data was compiled from trapping data, observations conducted during site classification surveys and FPF personnel and lastly through dedicated observation session. Data collected from FPF trapping occurred during the summer of 2005-2008 (Table 2) and consisted of 173 trapped individuals. Individuals were trapped throughout the waterways except for Study Sites 9, 12 and 20.

Aggregated absence/presence surveys recorded 264 observations with positive sightings (1) occurring in 67 of the sessions and absence being recorded for the remaining 197 sessions. GLM analysis focused on the 200 observations with accompanying classification data and resulted in nine positive observations (Appendix 1A). Observations collected during dedicated observation sessions 2009-2019 resulted in 19 positive observations (Appendix 1B). Observational data collected by FPF personnel resulted in 39 positive observations in May 2006 (Appendix 1C).

The stepwise generalized linear model relating muskrat presence/absence data to the five site classification data resulted in three models (Table 11). Models 1 (the full model) and

Model 2 were the best supported models. T2 were the best supported models and distinct from the null model. Two classification variables, proximity to disturbance and percent aquatic vegetation were significant ($\alpha < 0.05$) in both models.

Muskrat Trapping

From 2005 through 2008 173 muskrats were trapped throughout the LCWS with efforts focused from Steinberg arena to Pagoda circle (Table 2). 2005 had the highest capture rate at 104 individuals followed by 2008 with 33 individuals, 21 individuals in 2006 and 15 individuals in 2007. Data provided by FPF broadly identified capture sites, which only allowed generalized association with established study sites by geographic location.

Chapter 4: Discussion

The novel characteristics of Forest Park make it a unique setting in which to study the effects that natural and management induced changes can bring to a particular habitat type. The diversity of UGS throughout the world precludes a “one size fits all” approach. Taking into consideration all a UGS’s biotic and abiotic factors as well as its geographic location, the species or community focus, and level of management can lead to different outcomes no matter how similar a UGS might be to another site. Cicero (1989) describes how managing a series of ponds in San Francisco’s Golden Gate Park for a diverse avian community may require a manger to focus on the pond size, shape and perimeter to increase biodiversity. Bucci (2009) describes muskrat ecology and management in a variety of urban wetland habitats in central Illinois noting that water availability, stream size, and site and landscape variables influence habitat size and occupancy.

The setting for this research, Forest Park, presented many unique characteristics that factored into the biodiversity of the site and the occupancy by muskrats. Forest park’s location within its surrounding urban environment, its size, management goals of varied habitats and the manipulation of the LCWS make Forest Park a unique setting for naturally occurring flora and fauna to occupy. These features at times led to management goals conflicting with each other and potentially having a positive effect on biodiversity of one habitat at the expense of another habitat type. Looking at muskrats specifically, recent articles by both Kua et al. (2020) and Smirnov & Tretyakov (1998) have shown how seemingly comparable sites can have different outcomes based on specific site characteristics known or unknown to site managers. In the article by Kua et al. (2020) reported that overall plant diversity increased following muskrat induced disturbances in wetlands located along the upper St Lawrence riverway, whereas a similar study conducted in Russia had a negative effect on plant diversity (Smirnov & Tretyakov 1998). These conflicting outcomes highlight the uniqueness of individual sites and the importance of conducting more experimental research for mangers to better understand the effects that UGS management and specific site characteristics can have not only biodiversity but habitat quality.

This dissertation addressed three questions concerning muskrats and muskrat habitat in Forest Park:

1. Site Change Over Time

Of the six measured variables, vegetation stand density, percent of aquatic vegetation, waterbody width, bank slope, site proximity to disturbance and percent canopy cover, only three; percent aquatic vegetation, vegetation stand density and percent canopy cover showed measurable fluctuations over time. The remaining two variables, proximity to disturbance and bank slope were fixed and did not deviate from their initial classification scoring due to minimal natural or park management implemented site manipulation.

Ordination analysis of the 200 sample sites showed that sites differed primarily in density of riparian vegetation (stand density) and in percent aquatic vegetation. Differences among the three groups can be explained by seasonal fluctuations in vegetation growth, and by site management practices implemented by Forest Park Forever such as mowing, invasive plant removal and the planting of native aquatic and terrestrial plants.

The study sites identified in the ordination in Group One, apart from Site 9, were clustered in the southeast of the park around Jefferson Lake (Figure 1). These three sites had relatively high scores in Proximity to Disturbance, 3 or higher, based on the vehicle road that runs parallel to Jefferson Lake. Though a score of three or higher would normally be conducive to muskrat occupancy the high fishing pressure on Jefferson Lake experienced year-round negated any location benefit. Additionally, Bank Slope was found to score low (low gradient) which also negatively affected the site's desirability for muskrat occupancy (Clark 2000).

Group Two composed the largest group of study sites and showed considerable change over time specifically in the recorded percent of aquatic vegetation and stand density. Much of this change was based on observed seasonal fluctuations in duckweed (*Lemna* spp.) and cattail between sampling sessions during and outside the growing season. Both species are preferred browse species for muskrats (Brooks & Prosser 1994).

The linear regression trendlines for both aquatic vegetation and stand density showed that roughly 92% of the sites in Group 2 showed either no change or an increase in the amount of aquatic vegetation whereas 60% showed no change or an increase in stand densities (Figure 7). As noted above many of these sites showed seasonal change in both stand density and percent aquatic vegetation but Group 2 sites were the most pronounced in terms of increases over time.

Of all the sites in Group Two, 77% (10/13) were geographically located in the northeast quadrant (Figure 1) of Forest Park and possessed very similar scores in the remaining three variable measured, Proximity to Disturbance, Waterbody width and Bank Slope. The matrix that surrounded these sites were consistent in that the sites were removed from the higher pedestrian traffic areas and received minimal manipulation by landscaping personnel. Turf grass was mowed but large riparian vegetation buffers were present at many of the sites.

Most pronounced in the thirteen sites that comprised Group Two was the high scoring (steeper) of bank slopes. Per HSI literature steep bank slopes are highly valued by muskrats for den construction (Allen & Hoffmann 1984). Of the thirteen study sites that comprised Group Two, 75% of the sites scored greater than three (10-19%) when assessed with 50% of the sites having bank slopes scoring at the highest level (5) indicating they possessed slopes with a 1:2 gradient and favorable soil substrate for burrow construction (Errington 1963; Earhart 1969). This data supports the need by muskrats to have suitable banks to construct burrows when sufficient emergent vegetation is not available for aquatic lodge construction (Messier & Virgl 1992). Absence/Presence data as well as FPF observations confirmed the extensive use of bank burrows by muskrats with forty plus burrows confirmed between study sites 4 through 14 (Appendix 1C).

Group Three recorded high scores for proximity to disturbance (least distance), a low percentage of canopy cover, high stand density and non-existent aquatic vegetation. All sites were located next to high traffic trails and/or roads with Site 15 being adjacent to a busy vehicle intersection and commercial boathouse restaurant and equipment rental facility. These sites showed minimal change over time due to the intense turf management that was implemented by golf course and recreation field personnel. (Figure 7).

In response to minimal year to year variation shown in the measured HSI variables and to compare data collected during similar times of the year the HSI data was analyzed over three different summer sampling sessions (6/2014, 7/2017 and 7/2022). Standardizing this data eliminated any seasonal bias (vegetation growth, water chemistry properties) that existed when comparing site data at different times of the year and its corresponding effect to HSI scoring over time (Table 7, Table 8, Table 9).

Canopy cover (V1) averaged 23-25% across all sites for each sampling session and varied only in cases of site tree removals and natural growth. Percent Aquatic vegetation (V8) experienced large fluctuations from year to year across varied sites with the highest recorded levels being year over year at Sites 5 through 14. Percent Aquatic vegetation showed the lowest average across all sites in 2022 with an average of 24% compared to 41% in 2014 and 45% in 2017. These results could not be correlated with measured water chemistry data fluctuations in total phosphorus, nitrate or dissolved oxygen (Table 10).

Oscillations in water chemistry, and its effect on the presence/absence of aquatic vegetation, is believed to be due to the constant feed of treated water into the LCWS (Li et al. 2010; Reddy & Portier 1987). Municipal hydrants feeding the LCWS showed high levels of chlorine treatment during summer months as well as elevated temperature that negatively impacts the growth of cattails (Reddy & Portier 1987).

The last variable to calculate site index scores (HSI) is that of site water permanence (percent of the year service water present, V2). Suitable muskrat habitat is defined by slow velocity water resulting from a low stream gradient (Brooks & Dodge 1981). The LCWS in Forest Park has minimal elevation change along the LCWS corridor averaging 141m along the entire waterway resulting in minimal areas in which discharge flows exceeded 0.1m^3/sec (Allen & Hoffmann 1984; Figure 8). Ideal discharge flow combined with water depths that rarely exceeded two meters made the LCWS highly suitable for muskrat occupancy (Errington 1963; Danell 1978).

Due to the consistent presence of non-fluctuating, ideal water depth, and low discharge flow favorable HSI scores were supported through all years (Table 7, Table 8, Table 9). Any future attempts to control muskrat populations would have to address this ideal parameter of muskrat occupancy. The lack of fluctuations in the water levels throughout the LCWS suppresses competition between muskrats for burrow establishment thus allowing unlimited population growth until burrow carrying capacity within the LCWS is met. In systems without a constant influx of water maintaining artificial water levels, thus consistent bank burrow access, seasonal water fluctuations would encourage naturally occurring intra-species territoriality. This competition would force submissive/immature individuals to disperse leading to their increased susceptibility to predation during the exiled individual's migration to available suitable habitat (McDonald 2006).

Of the two variables (V1 & V8) generating habitat SI scores, emergent aquatic vegetation (V8) was responsible for limiting the life requisite score for Food. Food, as calculated as a function of percent canopy cover and percent emergent aquatic vegetation, was consistently lowered by the availability of aquatic vegetation thus lowering the overall sites suitability for muskrat occupancy.

2.Correlation of Legacy Trapping, Absence/Presence Detection and HSI Scores

Before engaging in this research, Forest Park managers contracted trappers to remove muskrats from the park's LCWS. Over the next three years, 173 muskrats were trapped throughout the LCWS with efforts focused from Steinberg arena to Pagoda circle (Table 2). This region encompassed ten of the twenty study sites that were established for the purpose of the research. In addition to this data Absence/Presence observations conducted by this research and FPF personnel resulted in 263 unique observations in which generated 67 confirmed observations of muskrat presence (Appendix 1A, Appendix 1B, Appendix 1C). This data suggests that there was a strong association between the trapping data and observation data with confirmed muskrat (signs and/or individuals sighted) observations occurring in all sites in which muskrats were previously trapped (Table 2, Appendix 1A, Appendix 1B, Appendix 1C).

A similar association was seen between trapping data and HSI scores. With the exception of study site 7 and 11, sites that generated the highest SI scores (combined life requisites scores of food and cover) showed weak association with confirmed presence data (Table 7, Table 8, Table 9). Site 7 and 11 recorded high values for both food and cover as well as generating high SI scores. Both sites were located in a low traffic area of the LCWS and were situated in areas that comprised narrow water body widths of less than 20m, high riparian stand densities and numerous coves, islands and areas of low water velocity favored by muskrats (Allen & Hoffmann 1984; Figure 7). This association supports the current HSI employed for determining site suitability for muskrat occupation and provides a model for high value muskrat habitat.

The difficulty in associating high value muskrat habitat and confirmed muskrat occupancy is limited by the ability to detect muskrat presence though signs or active sightings (Gu & Swihart 2004). The elusive nature of the muskrat and its aversion to human presence/interaction makes collecting this data extremely time consuming and labor intensive (Westworth 1974; Schwartz et al. 2016). Current use of absence/presence data to estimate muskrat occupancy is only effective if intense effort was made to thoroughly evaluate the habitat for known muskrat signs and/or mark-recapture efforts. Proximity to disturbance percent aquatic vegetation were significant in both supported GLM models. These variables were identified through ordination as driving the dissimilarity/similarity of the study sites and were the most effective at detecting muskrat occupancy at a specific site. Knowing the elusive nature of the muskrat and the increased potential for human disturbance presented in a high traffic urban green spaces a tendency for muskrats to retreat to areas in the park that are more isolated (Boutin & Birkenholz 1987; Nowak 1991). Regarding the variable percent aquatic vegetation, the prominence of cattails and bulrush, a preferred muskrat browse and building material, also supports these findings. Furthermore, of all the absence/presence data collected approximately 41% of all recorded presence occurred within six study sites. These sites (4 through 9) were identified by dense aquatic vegetation, low foot traffic areas, furthest from park roadways and along waterways that received minimal fishing pressure (Figure 1; Appendix 1A, Appendix 1B, Appendix 1C).

In conclusion, HSI models are effective, but value could be brought to their prediction of occupancy if additional variables were added when calculating the suitability of said habitats. Some sites identified in this research scored relatively low SI scores but absence and presence data and/or trapping data contradicted their favorability for muskrat occupancy. As noted earlier, water permeance is most crucial in determining year-round site occupation by muskrats but further investigation should be made to either include more variables such as proximity to disturbance (site isolation) bank slope, waterbody width etc. inclusion into the HSI model. Including additional variables would not only increase the model's ability to determine habitat suitability but could possibly better estimate the carrying capacity of the habitat to attract and support muskrat higher muskrat occupancy. Knowing this information would allow managers to address and possibly mitigate potential impacts on targeted habitats before habitat degradation can occur.

3.Water Chemistry and Aquatic Vegetation

The initial goal of this question was to determine if specific water chemistry components could be used to predict the capacity of a target waterway to support stands of aquatic vegetation and what effect if any the influx of treated water into the LCWS has on the waterway system.

Research has shown that the most growth-limiting nutrients for aquatic plants growth are nitrogen and phosphorus. Many plants require nitrogen at about ten times the concentration of phosphorus to support fast growing and diverse aquatic vegetation (Peters & Clarkson 2010). In oligotrophic systems, waterways low in plant nutrients but high in oxygen concentration, that derive all their influx of water through rain, phosphorus tends to be the vegetation growth limiting nutrient (Peters & Clarkson 2010; Güsewell & Koerselman 2002). Phosphorus levels exceeded an ambient level (>10 µg/l) in all but two sites (PDL & WETIN, 2015) and showed highly enriched levels in years 2018 (Golf, PDL & WETIN). Nitrogen conversely was recorded at low enrichment levels (<1mgl) during all samples analyzed. These levels suggest that the capacity for preferred browse such as *Typha* as well as other aquatic vegetation to grow was unlimited in regard to key nutrient supply and stabilized water levels (Boers & Zedler 2008). Past research has shown that elevated levels of these two nutrients could result in species, such as *Typha,* having increased success in inundating the LCWS with aquatic vegetation (Elgersma et al. 2017; Estime et al. 2003; Reddy & Portier 1987; Li et al. 2010). Let unchecked this could raise the effective carrying capacity of muskrats in the system based on the known effect that Typha can have on muskrat fecundity (Allen & Hoffman 1984; Errington 1963).

As Table 10 highlights, concentrations of these targeted nutrients varied by sites in which samples were collected and according to their proximity to municipal hydrant discharge (CH2MHill 2003; Figure 5). During this research, it was determined that the three city hydrants input 1165 million gallons of water into the LCWS every year (CH2MHill 2003). The sheer volume and sitewide distribution of treated water being fed into the waterway and the varying levels of chlorine that it contained made the potential negative impact that it posed to the LCWS biotic system difficult to ignore.

Chlorine, acting as disinfectant, provides potable water for human consumption but when introduced to a waterway such as Forest Park's LCWS the potential for it to harm biotic life is an often-overlooked effect (Eaton et al. 2005). Absent in the list of tested nutrients and minerals concentration that were compiled by the SLPD was any measurement of chlorine levels. Chlorine has been used to sanitize water for human consumption for roughly the last 100 years but only recently have researchers began to ask what effect an oxidizer such as chlorine has on biological systems as whole outside its intended disease microbes' targets (Fairweather 1990). Over the last 25 years researchers have begun to look at the unintended side effects of treating potable water with chlorine and the resulting chloroforms and other toxic compounds that result for chlorine breaking down organic compounds (Rook 1974; Bellar et al. 1974). These byproduct compounds have been shown to be carcinogenic and detrimental to all organisms (Richardson et al. 2007). Chlorine's effect on breaking down nitrates (N) into nitrites and phosphorus (P) into orthophosphates makes any attempt to utilize measured amounts of N and P in the LCWS compromised (Han et al. 2021). Additionally, the presence of chlorinated water in natural water systems can lead to the creation of trihalomethanes (THMs) which are formed when chlorine reacts with organic material affecting the sequestering of nitrogen and phosphorus by wetland flora and the breakdown in dissolved oxygen making it extremely difficult to accurately measure the potential DO available for use in Forest Park's LCWS (O'Connor et al. 1975; Ehbair 2017). Elevated THMs are known to be carcinogenic to humans and animals but the overall long-term effect on flora has yet to be determined (Division of Public Health 2015; Pal et al. 2014).

Forest Park's LCWS is a unique setting but to determine the feasibility of using of N, P and DO in determining the potential availability for components uptake and production of aquatic flora would require a setting in which naturally occurring concentrations of these variables are not compromised by chlorine introduction. Additionally, as the current muskrat HSI differentiates between three different habitat types (riverine, herbaceous wetland and estuarine models) when calculating the suitability of a particular habitat type for muskrat occupancy the goal of using nutrient and DO concentration to predict effects on aquatic flora may be suitable for only a specific habitat type. Water sampling, as utilized in this research, is snapshot in time and parameters would need to be established to ensure that the concentration levels of any targeted water chemistry variables represent the most accurate measurement to give park stewards the most accurate nutrient levels so tailormade adjustments can be made to reduce high concentrations and allow better management of aquatic vegetation density.

The use of water chemistry to predict potential aquatic flora densities in a waterway would be an invaluable tool to assess large areas suitability for muskrat occupancy thus reducing the time, hence money, current HSI models utilize. Further research into this proposal question is warranted and has the potential to be effective if only in select habitat types.

Chapter 5: Conclusion

Urban Green Spaces Design Recommendations

Current research supports the theory that urban green spaces (UGS) enhance the lives of urban residents. Through ecosystem services, UGS provides a long list of benefits in high density urban areas throughout the world including supporting biodiversity (Aronson et al. 2017; Niemela et al. 2010;). These services have been shown to increase the well-being of urban residents that utilize these varied spaces, as well as to play a crucial role in increasing the capacity of the UGS to offset some of the detriment brought on by climate change (Gómez-Baggethun et al. 2013; Elmquist et al. 2015). These benefits, coupled with the ever-increasing population of urban residents, highlight the need to continually provide these in demand areas. Pressures placed on creating, maintaining, and renovating UGS continue to grow as urban areas become more densely populated and available urban land becomes more coveted. With these pressures, opportunities to improve the ecological functioning of UGS are of upmost importance and is being driven worldwide by parties to the Convention on Biological Diversity (Elmqvist et al. 2015, CBD 2011). Unfortunately, limited budgets and competing land uses require that funds used to design, renovate, and maintain these areas be spent in the most judicious manner to ensure the best return on investment. Estimates to restore/redesign UGS have been estimated to range anywhere between $26,000 to $49,000 per hectare, depending on the type of habitat being restored and the scope of the restoration (Gómez-Baggethun & Barton 2013). As large as these restoration costs can be, benefits provided by UGS range between $3,212 and $17,772 ha/yr, when quantifying the positive health effects and social welfare benefits that they offer (Pataki et al. 2011). Basic math and cost/benefit analysis show that investing in UGS pays dividends for perpetuity if UGS are well planned and implemented.

The crucial requirement is that UGS planners “do it right the first time,” and to accomplish this they must recruit appropriate habitat specialists in the initial planning process to mitigate potential future issues. Forest Park in St. Louis Missouri is an example of the problems that can occur if these guidelines are not followed when renovating/maintaining/restoring an UGS.

When the city of St. Louis began the planning process for renovating Forest Park, project leaders made a conscious effort to include professionals from a variety of disciplines to ensure a detailed plan that addressed all stakeholders and ecosystem functions. Hired professionals included “architects, urban designers, landscape architects, a traffic engineer, community liaison specialist, golf consultants, an ecologist/naturalist, soil and water consultants, a civil engineer/hydrologist and numerous facilitators” (STLCDC 1995). This list of professionals is the crux of the policy procedure that I am recommending. Even as extensive as the list of professionals was, conspicuously absent were more habitat specialists for the different types of both preexisting and newly implemented habitats. An ecologist/naturalist, though well-educated and trained in the field of ecology, does not possess the expertise to predict all the potential pitfalls that could arise in the variety of habitat types within Forest Park. The myriad of habitats that exist within the park dictates that specialists in each habitat type be employed to ensure that suggested designs do not fail to recognize potential conflicts that may arise in the future. Specialists such as arborists, horticulturists, wetland biologists, etc. are better equipped to analyze/prepare the plans for their respective habitat specialties. This theory is reinforced by many of the issues that arose with the park’s resident muskrat population. Large populations of muskrats in the park resulted from designs that though esthetically pleasing and functional, failed to appreciate how this known resident species (muskrats) would react to the suggested changes. The budget for Forest Park’s Master Plan was in excess of $100 million dollars, thus resources existed to recruit the right specialists for the varied habitat types (STLCDC 1995). A valid argument could be made that if a wetland specialist was consulted in the planning phase of Forest Park's Master Plan, that the issue of muskrat over-abundance could have been minimized if not eliminated. This assumption is made based on the abundance of muskrat literature that outlines their life history traits. Competency in wetland ecology would have identified many of the issues that led to the over-abundance of muskrats in the park. Two aforementioned issues that stand out were the aquatic vegetation stands and the slope of the waterway banks. Over the years that I have studied the muskrat problem at Forest Park, countless journal articles and wetland specialists have educated me on what resources and exclusions can lead to rampant growth of muskrat populations. Knowing that water levels were going to be kept constant year-round, cattails stands were going to be established, and the channeling of waterways was going to leave the banks at a slope of 1:1 (1ft of rise for every foot of run) or higher, the outcome of non-limiting growth in muskrat populations was a foregone conclusion. Specialists would have known about the case studies that have shown that non-fluctuating water levels eliminate the need for muskrats to leave the water thus opening them up to predation, cattails are the preferred browse of muskrats resulting in higher fecundity, and that steep waterway banks provide ample den spaces. All of these variables combine to make the wetland areas of Forest Park an oasis for muskrats. As specific as this information is, it is easy to conceive how these types of errors could manifest in other habitat types in which specialists are not consulted before plans are implemented.

Regardless of the habitat type or the species involved, the issue of overabundant muskrats highlights the need for UGS managers to be vigilant with consulting the right specialists to make the most informed decisions regarding UGS creation/renovation. Putting renovation plans in place that have not been vetted by the appropriate habitat specialist will likely lead to future system issues that undoubtedly could have been avoided. A classic adage sums up the biggest selling point for this suggested policy, pay me now or pay me more later: the right choice is obvious.

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Tables

Table 1: *Site Classification key and notes for 20 study sites.*

Vegetation Stand Density – Percent Herbaceous Vegetation within 1m of bank.

1 = 0%
2 = 1 – 25%
3 = 26 – 50%
4 = 51 – 75%
5 = 75%+

Percent Aquatic Vegetation – Floating or rooted vegetation within 2m of bank.

1 = 0%
2 = 1 – 25%
3 = 26 – 50%
4 = 51 – 75%
5 = 75%+

Waterbody Width – Width of waterbody at site.

1 = 0 -10m
2 = 11 – 20m
3 = 21 – 30m
4 = 31 – 40m
5 = 40m+

Bank Slope – Slope of bank at water/land interface.

1 = 0%
2 = 1 – 9%
3 = 10 – 19%
4 = 20 – 45%
5 = 46%+

Proximity to disturbance – Distance from roadways, trails, docks, viewing platforms, etc.

1 = 0 -10m
2 = 11 – 20m
3 = 21 – 30m
4 = 31 – 40m
5 = 41m+

Table 2: *Muskrat trapping data by site and year with corresponding study sites.*

Year	Trapping Site(s)	Muskrats Trapped	Associated Study Sites
2005	Throughout Park Waterways	104	1,2,3,4,5,6,7,8,10, 11,13,14,15,16,18, 19
2006	Deer Lake to Post Dispatch Lake (PDL)	21	16
2007	PDL, Probstein Golf Course (PGC), Waterway from PGC to Pagoda Circle (PC)	15	16,17,18,19
2008	Waterways from PC to Steinberg Arena (SA), SA to Columbus, PC to Columbus	33	4,5,6,7,8,10,11,13, 14,15

Table 3: *Water Sampling Sites with collection site description and associated study sites.*

Water Sampling Site	Sampling Site Description	Associated Study Sites
Probstein Golf Course (Golf)	Off the wood golf cart bridge	17,18
Post Dispatch Lake (PDL)	Off the suspension bridge	16
Deer Lake Riffles (WETIN)	In waterway just before water may enter the gravity feed into Deer Lake Savanna Wetlands	14,15
Steinberg Lagoon (STEIN)	In the waterway just before the water enters the drop structure	4,5,6,7

Table 4: *Pearson and Kendall Correlation with ordination axis for 10 sampling sessions from 2014-2022 (N=200). R levels of significance (r > ± .500) are bolded.*

Axis		**1**			**2**			**3**	
	r	**r-sq**	**tau**	**r**	**r-sq**	**tau**	**r**	**r-sq**	**Tau**
Stand Density	**-0.530**	0.281	-0.339	-0.281	0.079	-0.183	0.434	0.188	0.416
% Aquatic Vegetation	0.320	0.103	0.324	-0.482	0.233	-0.417	-0.114	0.013	-0.171
Proximity to Disturbance	-0.052	0.003	-0.095	**-0.646**	0.417	-0.530	**-0.590**	0.348	-0.427
Waterbody Width	0.236	0.056	0.050	-0.315	0.099	-0.237	**-0.756**	0.571	-0.457
Bank Slope	**0.653**	0.427	0.493	-0.203	0.041	-0.155	**0.629**	0.396	0.508

Table 5: *Site Classification scores – All Sites/All Years (2014-2022).*

Site	Stand Density	% Aquatic Vegetation	Proximity to Disturbance	Waterbody Width	Bank Slope
1Y314	3	2	4	5	2
2Y314	2	3	4	5	1
3Y314	2	2	3	5	2
4Y314	1	1	1	2	2
5Y314	4	1	1	3	2
6Y314	2	1	2	2	3
7Y314	1	1	1	2	2
8Y314	5	1	3	2	4
9Y314	2	2	3	5	1
10Y314	5	2	2	3	3
11Y314	2	2	1	1	5
12Y314	3	3	1	3	5
13Y314	2	2	3	2	5
14Y314	4	1	3	2	5
15Y314	3	2	2	2	5
16Y314	3	2	2	2	3
17Y314	4	1	2	3	5
18Y314	5	2	1	2	4
19Y314	5	1	1	3	5
20Y314	5	1	2	0	0
1Y614	3	3	4	5	2
2Y614	2	3	4	5	1
3Y614	2	2	3	5	2
4Y614	1	5	1	2	2
5Y614	5	5	1	3	2
6Y614	2	5	2	2	3
7Y614	5	5	1	2	2
8Y614	5	3	3	2	4
9Y614	5	3	3	5	1
10Y614	5	5	2	3	3
11Y614	5	2	1	1	5
12Y614	1	2	1	3	5
13Y614	5	5	3	2	5
14Y614	5	5	3	2	5
15Y614	3	2	2	2	5
16Y614	5	2	2	2	3
17Y614	5	1	2	3	5
18Y614	5	1	1	2	4

19Y614	5	1	1	3	5
20Y614	5	1	2	0	0
1Y1114	5	1	4	5	2
2Y1114	5	3	4	5	1
3Y1114	3	2	3	5	2
4Y1114	4	1	1	2	2
5Y1114	4	1	1	3	2
6Y1114	5	1	2	2	3
7Y1114	5	2	1	2	2
8Y1114	5	1	3	2	4
9Y1114	4	1	3	5	1
10Y1114	3	1	2	3	3
11Y1114	5	1	1	1	5
12Y1114	1	1	1	3	5
13Y1114	5	2	3	2	5
14Y1114	5	3	3	2	5
15Y1114	1	1	2	2	5
16Y1114	4	1	2	2	3
17Y1114	5	1	2	3	5
18Y1114	5	1	1	2	4
19Y1114	5	1	1	3	5
20Y1114	5	1	2	0	0
1Y1115	4	2	4	5	2
2Y1115	5	1	4	5	1
3Y1115	4	4	3	5	2
4Y1115	5	1	1	2	2
5Y1115	5	1	1	3	2
6Y1115	1	1	2	2	3
7Y1115	5	1	1	2	2
8Y1115	4	2	3	2	4
9Y1115	5	4	3	5	1
10Y1115	4	1	2	3	3
11Y1115	3	2	1	1	5
12Y1115	1	3	1	3	5
13Y1115	5	3	3	2	5
14Y1115	5	3	3	2	5
15Y1115	1	1	2	2	5
16Y1115	3	1	2	2	3
17Y1115	5	1	2	3	5
18Y1115	5	1	1	2	4
19Y1115	5	1	1	3	5
20Y1115	5	1	2	0	0

1Y516	3	4	4	5	2
2Y516	3	2	4	5	1
3Y516	4	3	3	5	2
4Y516	4	2	1	2	2
5Y516	5	1	1	3	2
6Y516	1	2	2	2	3
7Y516	5	1	1	2	2
8Y516	4	5	3	2	4
9Y516	4	2	3	5	1
10Y516	5	5	2	3	3
11Y516	5	2	1	1	5
12Y516	1	1	1	3	5
13Y516	5	5	3	2	5
14Y516	5	4	3	2	5
15Y516	1	2	2	2	5
16Y516	5	1	2	2	3
17Y516	5	2	2	3	5
18Y516	5	1	1	2	4
19Y516	5	5	1	3	5
20Y516	5	1	2	0	0
1Y1016	4	3	4	5	2
2Y1016	4	2	4	5	1
3Y1016	5	3	3	5	2
4Y1016	5	2	1	2	2
5Y1016	5	2	1	3	2
6Y1016	1	2	2	2	3
7Y1016	5	2	1	2	2
8Y1016	5	2	3	2	4
9Y1016	4	3	3	5	1
10Y1016	5	2	2	3	3
11Y1016	5	5	1	1	5
12Y1016	3	3	1	3	5
13Y1016	5	5	3	2	5
14Y1016	5	4	3	2	5
15Y1016	1	3	2	2	5
16Y1016	4	1	2	2	3
17Y1016	5	1	2	3	5
18Y1016	5	1	1	2	4
19Y1016	5	1	1	3	5
20Y1016	5	1	2	0	0
1Y717	4	5	4	5	2
2Y717	2	3	4	5	1

3Y717	1	1	3	5	2
4Y717	5	5	1	2	2
5Y717	5	5	1	3	2
6Y717	3	4	2	3	3
7Y717	5	1	1	2	2
8Y717	5	5	3	2	4
9Y717	5	5	3	5	1
10Y717	5	1	2	3	3
11Y717	5	5	1	5	5
12Y717	2	3	1	3	5
13Y717	5	5	2	3	5
14Y717	5	4	3	2	5
15Y717	5	5	2	2	5
16Y717	4	2	2	2	3
17Y717	5	1	2	3	5
18Y717	5	1	1	2	4
19Y717	5	1	1	3	5
20Y717	4	1	2	0	0
1Y819	4	2	4	5	2
2Y819	5	1	4	5	1
3Y819	3	1	3	5	2
4Y819	5	5	1	2	2
5Y819	5	5	1	3	2
6Y819	1	2	2	2	3
7Y819	5	2	1	2	2
8Y819	5	3	3	2	4
9Y819	5	4	3	5	1
10Y819	5	2	2	3	3
11Y819	5	5	1	1	5
12Y819	1	2	1	3	5
13Y819	5	5	3	2	5
14Y819	5	3	3	2	5
15Y819	1	1	2	2	5
16Y819	5	1	2	2	3
17Y819	5	2	2	3	5
18Y819	5	1	1	2	4
19Y819	5	1	1	3	5
20Y819	5	1	2	0	0
1Y620	5	2	4	5	2
2Y620	4	1	4	5	1
3Y620	3	2	3	5	2
4Y620	3	2	1	2	2

5Y620	**5**	**3**	**1**	**3**	**2**
6Y620	**1**	**2**	**2**	**2**	**3**
7Y620	**5**	**2**	**1**	**2**	**2**
8Y620	**5**	**2**	**3**	**2**	**4**
9Y620	**5**	**5**	**3**	**5**	**1**
10Y620	**5**	**2**	**2**	**3**	**3**
11Y620	**5**	**5**	**1**	**1**	**5**
12Y620	**1**	**2**	**1**	**3**	**5**
13Y620	**5**	**3**	**3**	**2**	**5**
14Y620	**5**	**5**	**3**	**2**	**5**
15Y620	**1**	**1**	**2**	**2**	**5**
16Y620	**5**	**1**	**2**	**2**	**3**
17Y620	**5**	**2**	**2**	**3**	**5**
18Y620	**5**	**1**	**1**	**2**	**4**
19Y620	**5**	**1**	**1**	**3**	**5**
20Y620	**5**	**1**	**2**	**0**	**0**
1Y722	**1**	**4**	**4**	**5**	**2**
2Y722	**3**	**1**	**4**	**5**	**1**
3Y722	**2**	**1**	**3**	**5**	**2**
4Y722	**5**	**5**	**1**	**2**	**2**
5Y722	**5**	**5**	**1**	**3**	**2**
6Y722	**1**	**3**	**2**	**2**	**3**
7Y722	**5**	**1**	**1**	**2**	**2**
8Y722	**5**	**1**	**3**	**2**	**4**
9Y722	**5**	**1**	**3**	**5**	**1**
10Y722	**5**	**1**	**2**	**3**	**3**
11Y722	**5**	**1**	**1**	**1**	**5**
12Y722	**1**	**2**	**1**	**3**	**5**
13Y722	**2**	**5**	**3**	**2**	**5**
14Y722	**5**	**2**	**3**	**2**	**5**
15Y722	**5**	**1**	**2**	**2**	**5**
16Y722	**5**	**5**	**2**	**2**	**3**
17Y722	**5**	**1**	**2**	**3**	**5**
18Y722	**5**	**1**	**1**	**2**	**4**
19Y722	**5**	**1**	**1**	**3**	**5**
20Y722	**5**	**1**	**2**	**1**	**1**
	Stand Density	**% Aquatic Vegetation**	**Proximity to Disturbance**	**Waterbody Width**	**Bank Slope**
Mean	4.03	2.28	2.15	2.74	3.21
Standard Deviation	1.43	1.45	1.18	1.34	1.60

Table 6: *One-Way ANOVA for HSI: Food & Cover values between sites over three sampling sessions, 2014,2017,2022. Significance level P ≤ 0.05.*

Food:

Source	DF	Sum of Squares	Mean Square	F Statistic	P-value
Groups (between groups)	2	0.06729	0.03365	0.5241	0.5949
Error (within groups)	57	3.6594	0.0642		
Total	59	3.7267	0.06316		

Cover:

Source	DF	Sum of Squares	Mean Square	F Statistic	P-value
Groups (between groups)	2	0.007503	0.003752	0.03895	0.9618
Error (within groups)	57	5.4903	0.09632		
Total	59	5.4978	0.09318		

Table 7: *2014 Habitat Suitability Index (HSI) values indicating the limiting life requisite of Cover or Food for all 20 study sites. Table includes variables to calculate Cover and Food indices; Cover =* $(V_1 \times V_2)^{1/2}$ *Food =* $(V_1 \times V_8)^{1/2}$

Site/Year	**% Canopy Cover (V1)**	**% of Year with Surface Water Present (V2)**	**% Aquatic Vegetation (V8)**	**Cover SI**	**Food SI**	**HSI Score (Lowest Life Requisite)**
1Y614	0	100	38	0.00	0.00	Cover/Food - 0.00
2Y614	10	100	38	0.32	0.19	Food – 0.19
3Y614	40	100	13	0.63	0.23	Food – 0.23
4Y614	20	100	87	0.45	0.42	Food – 0.42
5Y614	20	100	87	0.45	0.42	Food – 0.42
6Y614	10	100	87	0.32	0.29	Food – 0.29
7Y614	90	100	87	0.95	0.88	Food – 0.88
8Y614	30	100	38	0.55	0.34	Food – 0.34
9Y614	10	100	38	0.32	0.19	Food – 0.19
10Y614	80	100	87	0.89	0.83	Food – 0.83
11Y614	10	100	0	0.32	0.00	Food – 0.00
12Y614	5	100	13	0.22	0.08	Food – 0.08
13Y614	0	100	87	0.00	0.00	Food – 0.00
14Y614	5	100	87	0.22	0.21	Food – 0.21
15Y614	10	100	13	0.32	0.11	Food – 0.11
16Y614	80	100	13	0.89	0.32	Food – 0.32
17Y614	0	100	0	0.00	0.00	Cover/Food - 0.00
18Y614	5	100	0	0.22	0.00	Food – 0.00
19Y614	30	100	0	0.55	0.00	Food – 0.00
20Y614	5	50	0	0.16	0.00	Food – 0.00
Mode	10	100	87	0.32	0.00	
Mean	25	97.50	40.65	0.39	0.23	

Table 8: *2017 Habitat Suitability Index (HSI) values indicating the limiting life requisite of Cover or Food for all 20 study sites. Table includes variables to calculate Cover and Food indices; Cover =* $(V_1 \times V_2)^{1/2}$ *Food =* $(V_1 \times V_8)^{1/2}$

Site/Year	% Canopy Cover (V1)	% of Year with Surface Water Present (V2)	% Aquatic Vegetation (V8)	Cover SI	Food SI	HSI Score (Lowest Life Requisite)
1Y717	0	100	87	0.00	0.00	Cover/Food – 0.00
2Y717	10	100	38	0.32	0.19	Food – 0.19
3Y717	40	100	0	0.63	0.00	Food – 0.00
4Y717	20	100	87	0.45	0.42	Food – 0.42
5Y717	30	100	87	0.55	0.51	Food – 0.51
6Y717	20	100	63	0.45	0.35	Food – 0.35
7Y717	90	100	0	0.95	0.00	Food – 0.00
8Y717	40	100	87	0.63	0.59	Food – 0.59
9Y717	20	100	87	0.45	0.42	Food – 0.42
10Y717	80	100	0	0.89	0.00	Food – 0.00
11Y717	20	100	87	0.45	0.42	Food – 0.42
12Y717	0	100	38	0.00	0.00	Cover/Food – 0.00
13Y717	40	100	87	0.63	0.59	Food – 0.59
14Y717	0	100	63	0.00	0.00	Cover/Food – 0.00
15Y717	30	100	87	0.55	0.51	Food – 0.51
16Y717	40	100	13	0.63	0.23	Food – 0.23
17Y717	0	100	0	0.00	0.00	Cover/Food – 0.00
18Y717	0	100	0	0.00	0.00	Cover/Food – 0.00
19Y717	30	100	0	0.55	0.00	Food – 0.00
20Y717	5	0	0	0.00	0.00	Cover/Food – 0.00
Mode	0	100	87	0.00	0.00	
Mean	25.75	95	45.55	0.41	0.21	

Table 9: *2022 Habitat Suitability Index (HSI) values indicating the limiting life requisite of Cover or Food for all 20 study sites. Table includes variables to calculate Cover and Food indices; Cover =* $(V_1 \times V_2)^{1/2}$ *Food =* $(V_1 \times V_8)^{1/2}$

Site/Year	% Canopy Cover (V1)	% of Year with Surface Water Present (V2)	% Aquatic Vegetation (V8)	Cover SI	Food SI	HSI Score (Lowest Life Requisite)
1Y722	0	100	63	0.00	0.00	Cover/Food – 0.00
2Y722	0	100	0	0.00	0.00	Cover/Food – 0.00
3Y722	30	100	0	0.55	0.00	Food – 0.00
4Y722	20	100	87	0.45	0.42	Food – 0.42
5Y722	30	100	87	0.55	0.51	Food – 0.51
6Y722	20	100	38	0.45	0.28	Food – 0.28
7Y722	90	100	0	0.95	0.00	Food – 0.00
8Y722	30	100	0	0.55	0.00	Food – 0.00
9Y722	20	100	0	0.45	0.00	Food – 0.00
10Y722	80	100	0	0.89	0.00	Food – 0.00
11Y722	20	100	6	0.45	0.11	Food – 0.11
12Y722	0	100	13	0.00	0.00	Cover/Food – 0.00
13Y722	90	100	87	0.95	0.88	Food – 0.88
14Y722	10	100	13	0.32	0.11	Food – 0.11
15Y722	0	100	0	0.00	0.00	Cover/Food – 0.00
16Y722	50	100	87	0.71	0.55	Food – 0.55
17Y722	0	100	0	0.00	0.00	Cover/Food – 0.00
18Y722	10	100	0	0.32	0.00	Food – 0.00
19Y722	0	100	0	0.00	0.00	Cover/Food – 0.00
20Y722	0	0	0	0.00	0.00	Cover/Food – 0.00
Mode	0	100	0	0.00	0.00	
Mean	25	95	24.05	0.38	0.15	

Table 10: *Average levels of Phosphorus (P, µg/l), Nitrogen (N, mg/l) and Dissolved Oxygen (DO, mg/l) by year and location for sampling sites Probstein Golf Course (GOLF), Steinberg (STEIN), Post Dispatch Lake (PDL) and Deer Lake (WETIN)***.**

Location	Year	DO	P	N		Location	Year	DO	P	N
GOLF	2014	15.26	15.50	0.572		STEIN	2014	13.79	36.33	0.263
GOLF	2015	9.59	71.66	0.522		STEIN	2015	7.50	31.00	0.241
GOLF	2016	9.43	42.66	0.258		STEIN	2016	10.54	29.83	0.282
GOLF	2017	6.43	276.66	0.046		STEIN	2017	4.89	365.33	0.170
GOLF	2018	8.75	1073.00	0.515		STEIN	2018	5.58	238.83	0.070
GOLF	2019	8.72	288.00	0.194		STEIN	2019	6.47	61.40	0.196
	AVE	9.70	294.58	0.351			**AVE**	8.13	127.12	0.204

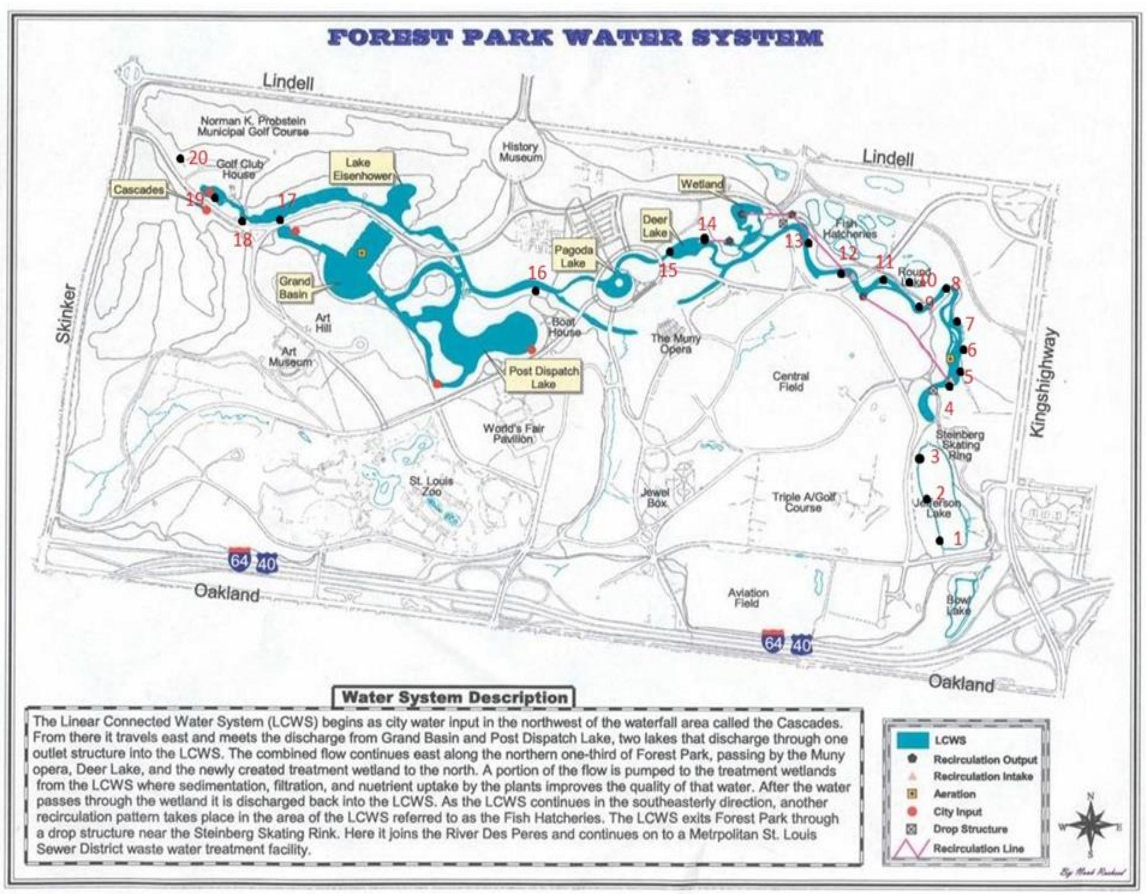
Location	Year	DO	P	N		Location	Year	DO	P	N
PDL	2014	14.56	20.50	0.350		WETIN	2014	13.43	29.00	0.435
PDL	2015	8.71	0.00	0.304		WETIN	2015	8.52	10.00	0.423
PDL	2016	7.65	1.24	0.563		WETIN	2016	5.98	13.30	0.509
PDL	2017	6.78	59.50	0.123		WETIN	2017	8.00	95.50	0.173
PDL	2018	7.60	921.33	0.240		WETIN	2018	8.41	832.83	0.216
PDL	2019	8.09	42.60	0.000		WETIN	2019	9.50	39.00	0.674
	AVE	8.90	174.20	0.263			**AVE**	8.97	169.94	0.405

Table 11 – *Generalized Linear Model outputs for muskrat detection using aggregate absence/presence data (n = 264). Lowest Akaike's Information Criterion (AIC) value indicated in bold.*

Model	AIC Score	Coefficients – Pr (> l z l)	
GLM 1 – All 5 classification variables	72.692	Bank Slope Waterbody Width Proximity to Disturbance Aquatic Vegetation Stand Density	0.3178 0.2285 0.0277* 0.0536 0.1247
GLM 2 – Classification variables - Proximity to Disturbance & Percent Aquatic Vegetation	**72.244**	Proximity to Disturbance Percent Aquatic Vegetation	0.0476* 0.1119
GLM 3 – Null model	75.408	Intercept	<2e-16 ***

Figures

Figure 1: *Forest Park – Linear Connected Water System (LCWS) with numbered study sites.*



Map: Forest Park Forever

Figure 2: *Suitability Index graph for habitat variable (V_1) – Percent canopy cover of emergent herbaceous vegetation*.

Cover type	Variable	
HW, EI	V_1	Percent canopy cover of emergent herbaceous vegetation.

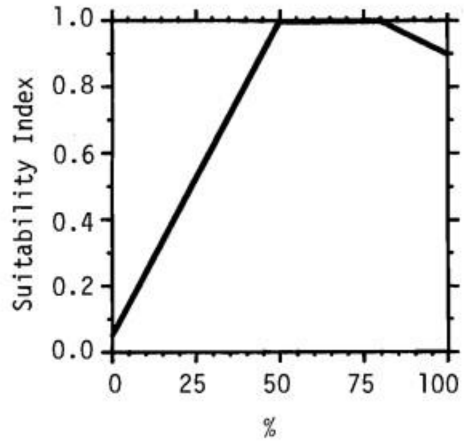


Figure 3: *Suitability Index Graph for habitat variable (V_2) – Percent of year with surface water present.*

HW	V_2	Percent of year with surface water present.

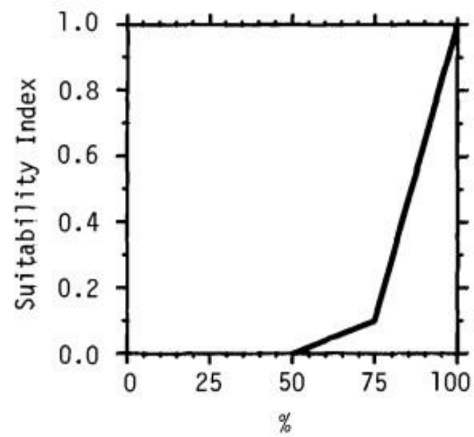


Figure 4: *Suitability Index graph for habitat variable (V_8) –Percent of emergent herbaceous vegetation consisting of Olney bulrush, Common Three-Square bulrush or Cattail.*

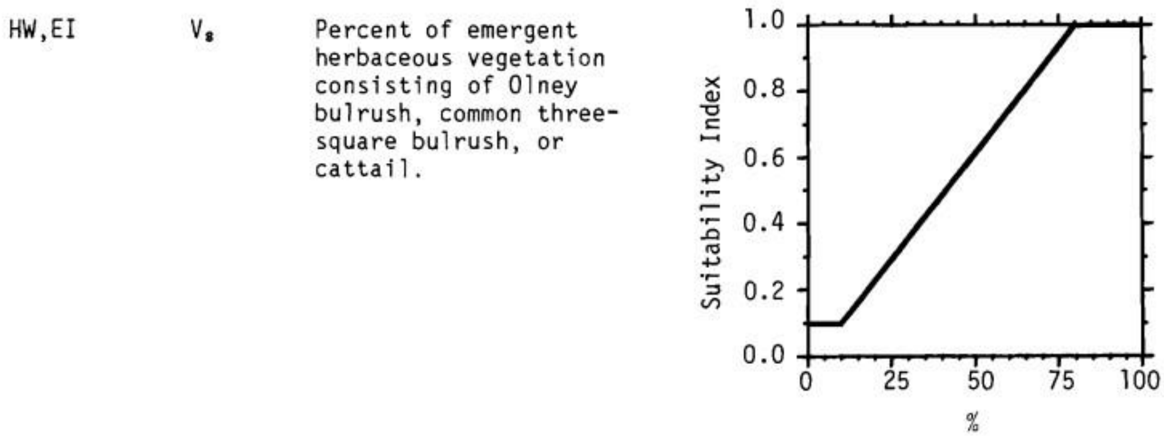


Figure 5: *Four water sampling locations (yellow points) GOLF, PDL WETIN and WETOUT located on Forest Parks LCWS with numbered (1-20) research sample sites.*

Map: Forest Park Forever

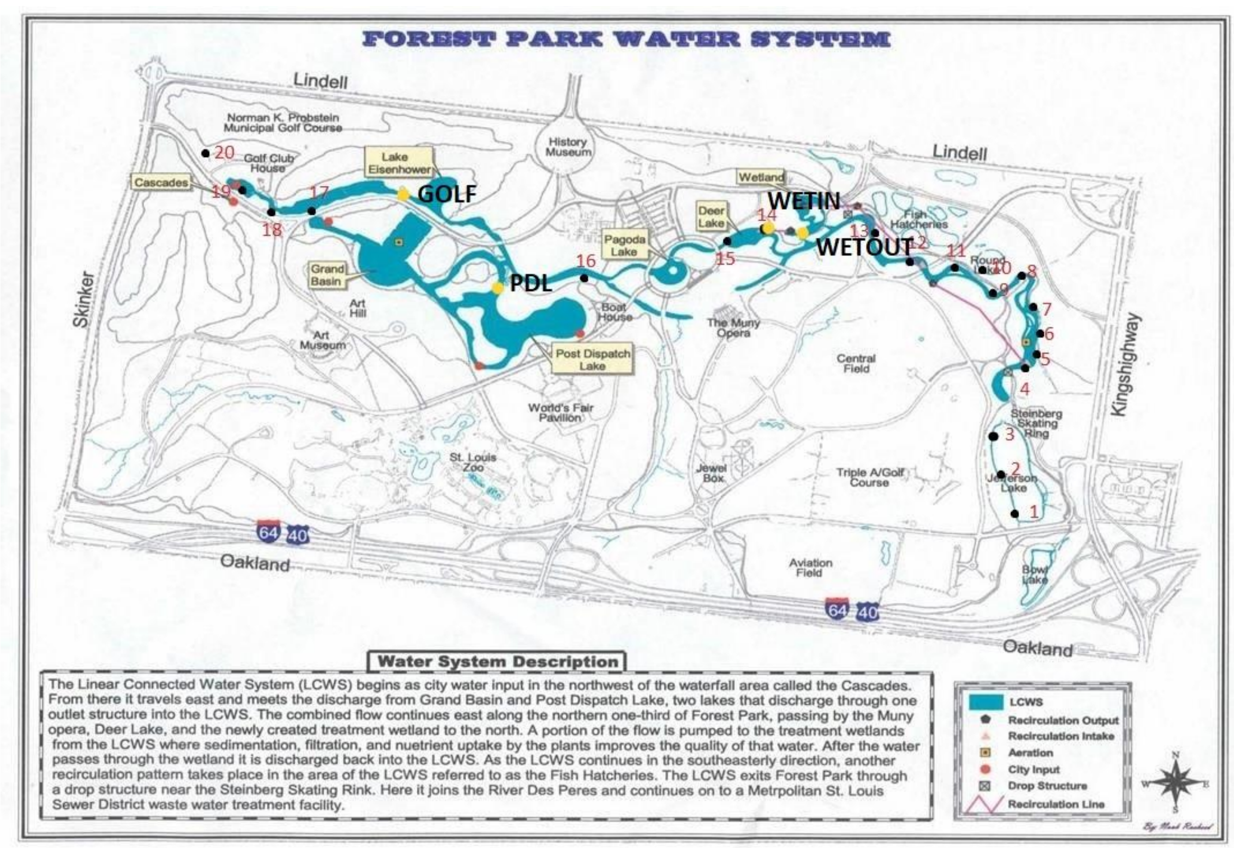


Figure 6: Bray Curtis polar *Ordination of 20 sample sites for 10 sampling sessions from 2014-2022. Three distinct groups: Group 1-blue circle, Group 2-Yellow circle and Group 3-Red circle. Sample sites are separated by five classification variables: Bank Slope, Vegetation Stand Density, Percent Aquatic Vegetation, Waterbody Width and Proximity to Disturbance. Site Identification: Study Site /Month/Year (XX/Y/XX/XX)*

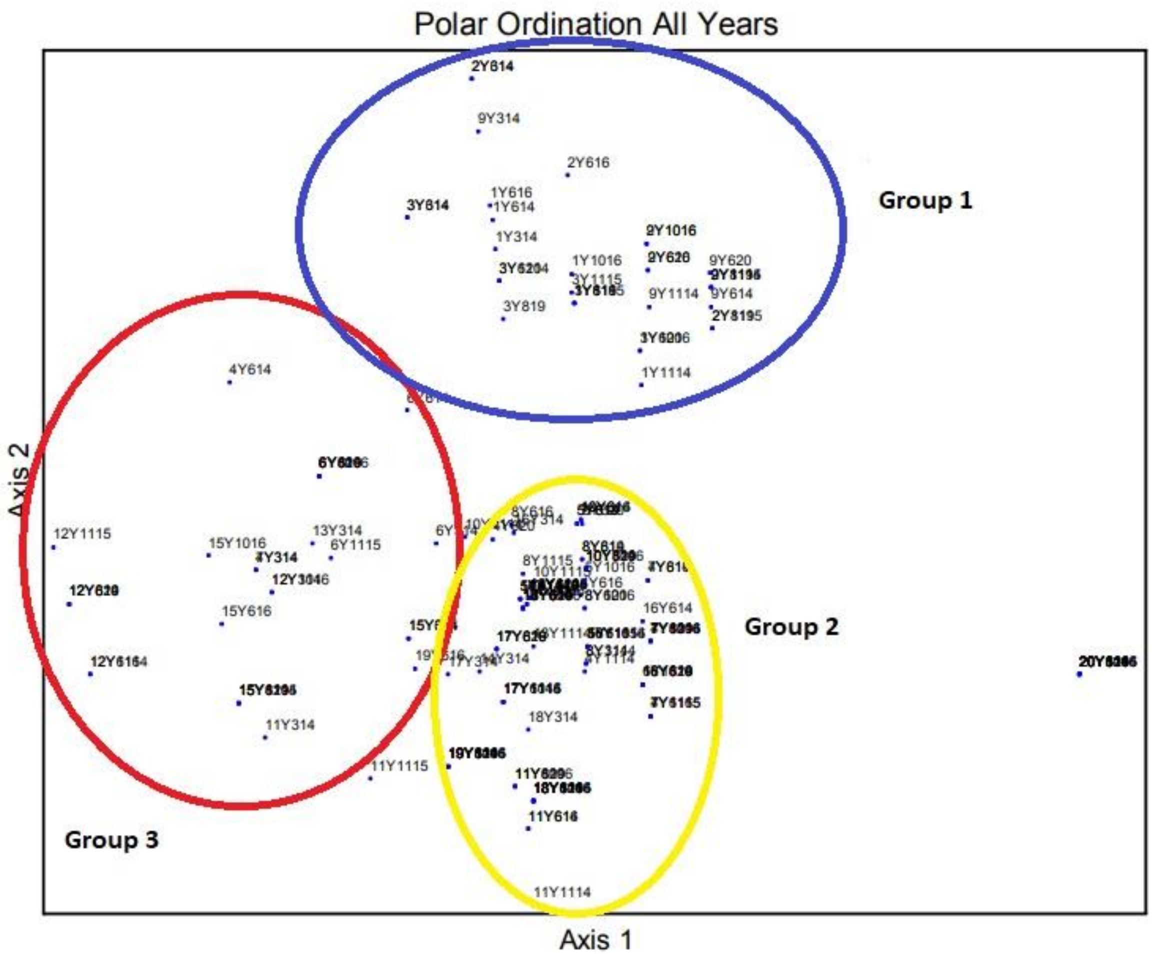
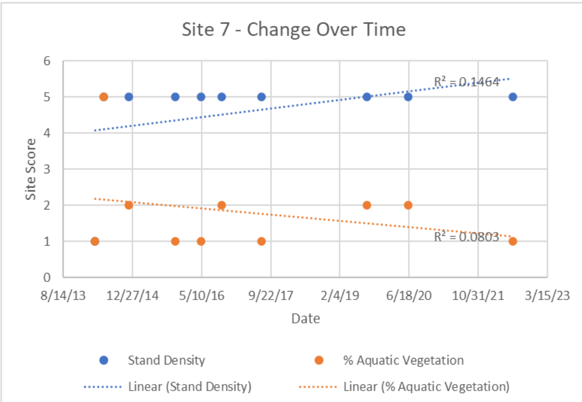
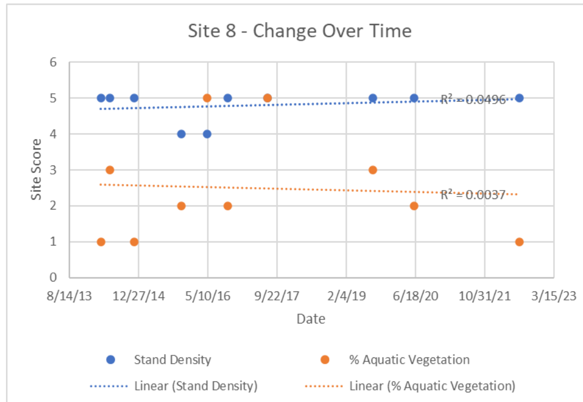
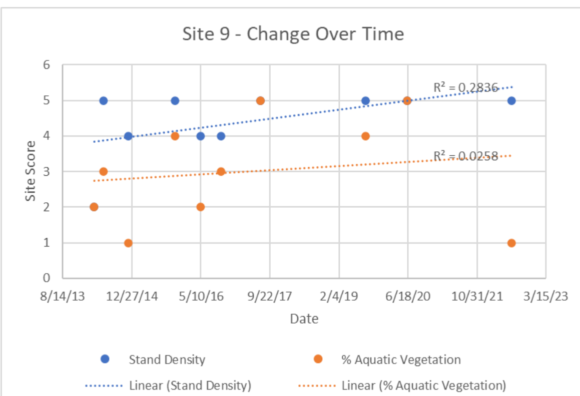


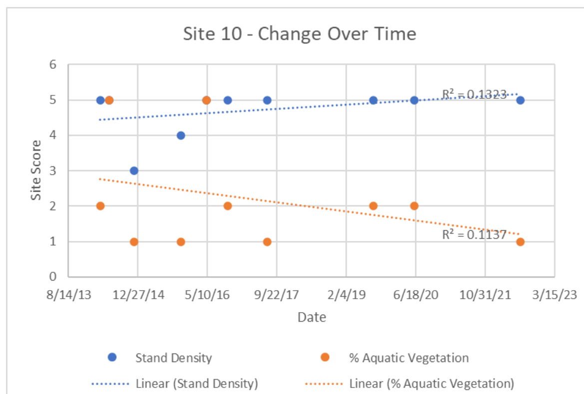
Figure 7: *Changes in Stand Density and Percent Aquatic vegetation over time with trendlines and R^2values.*

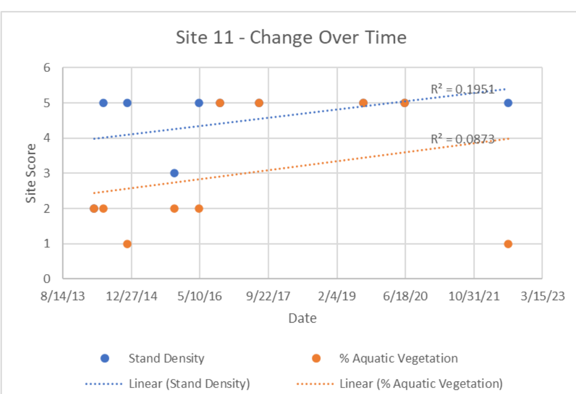
Figure 7: *Changes in Stand Density and Percent Aquatic vegetation over time with trendlines and R^2values.*











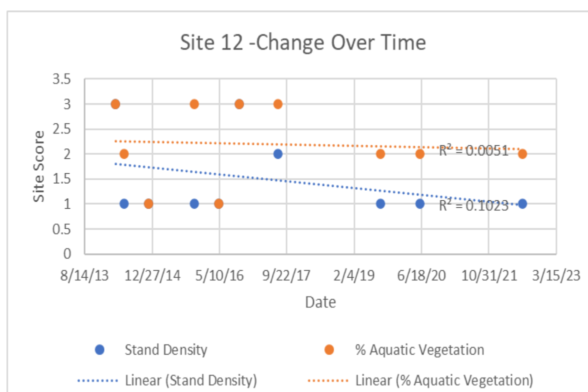


Figure 7: *Changes in Stand Density and Percent Aquatic vegetation over time with trendlines and R^2values.*

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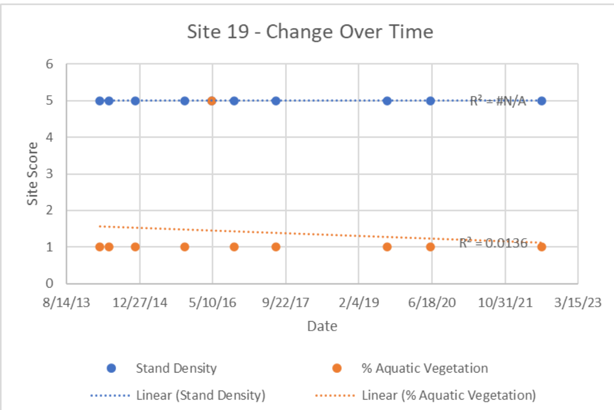

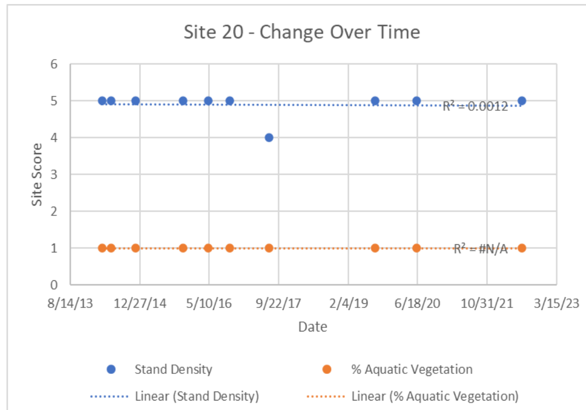

Figure 8: *Forest Park Topographical Map and related stream gradient.*

Appendices

Appendix 1A: *Binary response of muskrat Absence (0) and Presence (1) conducted during classification sampling 2014-2022.*

Date	Site	Absence/Presence
3/30/2014	1	0
3/30/2014	2	0
3/30/2014	3	0
3/30/2014	4	0
3/30/2014	5	0
3/30/2014	6	0
3/30/2014	7	0
3/30/2014	8	0
3/30/2014	9	0
3/30/2014	10	0
3/30/2014	11	0
3/30/2014	12	1
3/30/2014	13	0
3/30/2014	14	0

3/30/2014	15	1
3/30/2014	16	0
3/30/2014	17	0
3/30/2014	18	0
3/30/2014	19	0
3/30/2014	20	0
6/3/2014	1	0
6/3/2014	2	0
6/3/2014	3	0
6/3/2014	4	0
6/3/2014	5	1
6/3/2014	6	0
6/3/2014	7	1
6/3/2014	8	0
6/3/2014	9	0
6/3/2014	10	0
6/3/2014	11	0
6/3/2014	12	0
6/3/2014	13	0

6/3/2014	14	0
6/3/2014	15	0
6/3/2014	16	0
6/3/2014	17	0
6/3/2014	18	0
6/3/2014	19	0
6/3/2014	20	0
11/29/2014	1	0
11/29/2014	2	0
11/29/2014	3	0
11/29/2014	4	0
11/29/2014	5	0
11/29/2014	6	0
11/29/2014	7	0
11/29/2014	8	0
11/29/2014	9	0
11/29/2014	10	0
11/29/2014	11	0
11/29/2014	12	0

11/29/2014	13	0
11/29/2014	14	0
11/29/2014	15	0
11/29/2014	16	0
11/29/2014	17	0
11/29/2014	18	0
11/29/2014	19	0
11/29/2014	20	0
11/3/2015	1	0
11/3/2015	2	0
11/3/2015	3	0
11/3/2015	4	0
11/3/2015	5	0
11/3/2015	6	0
11/3/2015	7	0
11/3/2015	8	0
11/3/2015	9	0
11/3/2015	10	0
11/3/2015	11	0

11/3/2015	12	0
11/3/2015	13	0
11/3/2015	14	0
11/3/2015	15	0
11/3/2015	16	0
11/3/2015	17	0
11/3/2015	18	0
11/3/2015	19	0
11/3/2015	20	0
5/5/2016	1	0
5/5/2016	2	0
5/5/2016	3	0
5/5/2016	4	0
5/5/2016	5	0
5/5/2016	6	0
5/5/2016	7	0
5/5/2016	8	0
5/5/2016	9	0
5/5/2016	10	0

5/5/2016	11	0
5/5/2016	12	1
5/5/2016	13	0
5/5/2016	14	0
5/5/2016	15	1
5/5/2016	16	0
5/5/2016	17	0
5/5/2016	18	0
5/5/2016	19	0
5/5/2016	20	0
10/2/2016	1	0
10/2/2016	2	0
10/2/2016	3	0
10/2/2016	4	0
10/2/2016	5	0
10/2/2016	6	0
10/2/2016	7	0
10/2/2016	8	0
10/2/2016	9	0

10/2/2016	10	0
10/2/2016	11	1
10/2/2016	12	0
10/2/2016	13	0
10/2/2016	14	0
10/2/2016	15	0
10/2/2016	16	0
10/2/2016	17	0
10/2/2016	18	0
10/2/2016	19	0
10/2/2016	20	0
7/15/2017	1	0
7/15/2017	2	0
7/15/2017	3	0
7/15/2017	4	0
7/15/2017	5	0
7/15/2017	6	0
7/15/2017	7	0
7/15/2017	8	0

7/15/2017	9	0
7/15/2017	10	0
7/15/2017	11	0
7/15/2017	12	0
7/15/2017	13	0
7/15/2017	14	0
7/15/2017	15	0
7/15/2017	16	0
7/15/2017	17	0
7/15/2017	18	0
7/15/2017	19	0
7/15/2017	20	0
8/16/2019	1	0
8/16/2019	2	0
8/16/2019	3	0
8/16/2019	4	0
8/16/2019	5	0
8/16/2019	6	0
8/16/2019	7	0

8/16/2019	8	0
8/16/2019	9	0
8/16/2019	10	0
8/16/2019	11	0
8/16/2019	12	0
8/16/2019	13	0
8/16/2019	14	0
8/16/2019	15	0
8/16/2019	16	0
8/16/2019	17	0
8/16/2019	18	0
8/16/2019	19	0
8/16/2019	20	0
6/9/2020	1	0
6/9/2020	2	0
6/9/2020	3	0
6/9/2020	4	0
6/9/2020	5	0
6/9/2020	6	0

6/9/2020	7	0
6/9/2020	8	0
6/9/2020	9	0
6/9/2020	10	0
6/9/2020	11	0
6/9/2020	12	1
6/9/2020	13	0
6/9/2020	14	0
6/9/2020	15	0
6/9/2020	16	0
6/9/2020	17	0
6/9/2020	18	0
6/9/2020	19	0
6/9/2020	20	0
8/7/2022	1	0
8/7/2022	2	0
8/7/2022	3	0
8/7/2022	4	0
8/7/2022	5	0

8/7/2022	6	0
8/7/2022	7	0
8/7/2022	8	0
8/7/2022	9	1
8/7/2022	10	0
8/7/2022	11	0
8/7/2022	12	0
8/7/2022	13	0
8/7/2022	14	0
8/7/2022	15	0
8/7/2022	16	0
8/7/2022	17	0
8/7/2022	18	0
8/7/2022	19	0
8/7/2022	20	0

Appendix 1B*: Binary response of muskrat Absence (0) and Presence (1) conducted during dedicated observation sampling sessions 2009-2019.*

Date	Site	Absence/Presence
4/24/2009	4	1
5/7/2009	1	1
5/18/2009	*10*	*1*
5/30/2013	17	1
5/30/2013	18	1
6/3/2013	16	1
6/24/2013	3	1
6/26/2013	5	1
6/26/2013	7	1
6/26/2013	15	1
5/30/2016	4	1
8/2/2016	13	1
8/3/2016	12	1
8/8/2017	1	1
8/8/2017	2	1
8/8/2017	3	1

8/8/2017	8	1
8/9/2017	7	1
8/9/2017	8	1
8/2/2019	1	0
8/2/2019	2	0
8/2/2019	3	0
8/2/2019	4	0
8/2/2019	5	0
8/2/2019	6	0

Appendix 1C*: Binary response of muskrat Absence (0) and Presence (1) collected by Forest Park Forever personnel 2006.*

Date	Site	Absence/Presence
5/30/2006	4	1
5/30/2006	5	1
5/30/2006	5	1
5/30/2006	5	1
5/30/2006	6	1
5/30/2006	6	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	7	1
5/30/2006	8	1
5/30/2006	8	1

5/30/2006	9	1
5/30/2006	11	1
5/30/2006	11	1
5/30/2006	11	1
5/30/2006	11	1
5/30/2006	11	1
5/30/2006	11	1
5/30/2006	11	1
5/30/2006	11	1
5/30/2006	12	1
5/30/2006	12	1
5/30/2006	13	1
5/30/2006	13	1
5/30/2006	13	1
5/30/2006	13	1
5/30/2006	13	1
5/30/2006	13	1
5/30/2006	14	1
5/30/2006	14	1

5/30/2006	14	1
5/30/2006	15	1
5/30/2006	15	1

Vita

Matthew D. McCloud was born in Centerville, Illinois and attended school throughout the St. Louis Metro East region, graduating from Granite City Community High School in May 1990. In May 1996, he received a Bachelor of Science in Fisheries and Wildlife Management from the school of Natural Resources at the University of Missouri-Columbia. From the Fall of 1996 until 1999 he was a Crew Leader on a large-scale Urban White-tailed Deer (*Odocoileus virginianus*) Telemetry Project located in St. Louis Missouri for the Missouri Department of Conservation. At the completion of this project in 1999 he was hired as a Zookeeper at The Saint Louis Zoological Park. In August of 2000 he began working on his master's in business management at Webster University located in St. Louis Missouri, graduating with honors in May 2002. Three years after joining the Saint Louis Zoological Park he was hired to oversee all Aquatic Life Support Systems located throughout the Zoo. In 2013 he ended his employment with the Zoo and started his doctoral work examining muskrat (*Ondatra zibethicus*) habitat use within the urban greenspace of Forest Park located in St. Louis Missouri. While finishing his doctorate he started employment as an adjunct instructor at several universities in the St. Louis Metropolitan Area teaching a variety of biology courses. In July of 2023, he received his Ph.D. in Fisheries and Wildlife from the University of Missouri-Columbia.