A POST PROJECT ANALYSIS: AN ASSESSMENT OF AN URBAN RIPARIAN ECOSYSTEM RESTORATION IN CENTRAL OHIO

BY

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SPECIAL PROJECT

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ABSTRACT

Due to the continuously increasing levels of anthropogenic disturbances over the last

half-century, numerous central Ohio ecosystems have become significantly more susceptible to

invasion by a variety of non-native species. While invasive non-native species have infiltrated

many of the region's ecosystems, few have been as successful as Amur honeysuckle (*Lonicera*

maackii (Rupr.) Herder). Native to Asia and first introduced to North America in 1896, *L.*

maackii is one of the most intrusive invasive species found within central Ohio and the adjacent

region. Even though *L. maackii* has established itself within most habitats, many of the region's

riparian ecosystems have been extremely susceptible to invasion. This has prompted local

universities and state agencies, in collaboration with advocacy groups, to create and implement

restoration projects for riparian ecosystems impacted by *L. maackii*.

In 2001, a three-year restoration process began on a 5.26 ha bottomland hardwood forest

riparian ecosystem. The restoration site was concentrated within the Wilma H. Schiermeier

Olentangy River Wetland Research Park (ORWRP) in Columbus, Ohio situated on the western

bank of the lower Olentangy River. The goals of the restoration project were to remove *L.*

maackii and restore hydrological processes. Thus, this research project examined the

effectiveness of *L. maackii* removal.

To examine the removal of *L. maackii*, three study areas, an upstream non-restored site, a

downstream non-restored site and the original 5.26 ha ORWRP restoration site, were established

along the Olentangy River. The upstream non-restored site was located within the 58.9 ha

Whetstone-Northmoor Parks, while the downstream non-restored site was located within 17.8 ha

Tuttle Park. In each study area, four 4 m x 50 m macroplots were constructed and further divided into 1 m x 4 m quadrats allowing for 13, 4 m² quadrats per macroplot. It was anticipated that the original restoration site would have lower density levels of *L. maackii* and higher species diversity in comparison to both the upstream and downstream non-restored sites. It was also anticipated that, due to their proximity to water, quadrats <5 m from the Olentangy River would have lower levels of *L. maackii* within the ORWRP when compared to the Whetstone-Northmoor and Tuttle Park study areas.

There were significant differences in *L. maackii* density and frequency within the ORWRP compared to Whetstone-Northmoor Parks (p=0.03 for both density and frequency) and Tuttle Park (p=0.01 and p=0.03 respectively). There were also significant differences between the ORWRP study area and both non-restored sites for woody species basal area and Shannon-Wiener Diversity Index Values (p<0.05 for both non-restored sites). There was a significant difference in *L. maackii* frequency between the ORWRP and Tuttle Park (p<0.05) in quadrats <5 m from the Olentangy River. Lastly, there were significant differences in *L. maackii* frequency and density between the ORWRP when compared to the Whetstone-Northmoor Parks (p=0.03) and Tuttle Park (p=0.02) for quadrats >5 m from the Olentangy River.

Dedicated in loving memory of my father Arthur.

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

At the time of this report, Franklin County's population is estimated at 1,118,107, nearly

4% larger than in 2000, making Franklin County the second largest county in Ohio and the 34th

most populated county in the United States (U.S. Census Bureau 2007). Franklin County's

population increase can be attributed to its county seat, the City of Columbus. The estimated

population for Columbus is 747,755 (U.S. Census Bureau 2007), which is ~5% increase since

2000. This increase in population makes Columbus the 15th largest city and 34th largest

metropolitan area in the United States. Additionally, Columbus accounts for ~70% of the

population for Franklin County (U.S. Census Bureau 2007), due to the fact that Columbus has

annexed the majority of available land within Franklin County.

Urbanization within central Ohio has been and continues to be a major contributor to the

continuously increasing levels of disturbance upon the region's natural ecosystems over the last

half century. Some of the major disturbances influenced by urbanization include deforestation

and wetland drainage (Miltner et al. 2004). Furthermore, manipulation of lotic systems (i.e.

rivers and streams) has become a normal practice. Developers generally utilize channelization,

dredging, ditching and dam construction to control lotic systems, with most disturbances having

a negative impact (Miltner et al. 2004) and making the region's natural ecosystems more prone

to invasion by non-native species, which, in turn, have a detrimental impact on native flora

(Deering and Vankat 1999).

Invasive non-native species are characterized by spreading into habitats previously

unoccupied by the species, disruptive to the natural processes of the invaded habitat and

displacing and out-competing native species for essential resources (Schwartz 1997). Threats

from invasive non-native species are a major concern both from an ecological and economic

perspective. Invasive species contribute to the degradation of roughly 1,200,000 ha of habitat

within the United States annually (Czarapata 2005) and cost more than $34 billion annually to

control (Pimentel et al. 2000; Miller and Gorchov 2004; Czarapata 2005). By degrading and

altering the invaded habitat, invasive non-native species pose severe threats to both restored

habitats and endangered and threatened species (Czarapata 2005).

Long-term monitoring is a viable option to determine whether selected control methods

have been effective or whether the spread of invasive species has persisted. Long-term

monitoring allows researchers to either maintain current control methods or recommend

alternative measures to the site manager. Thus, monitoring is a powerful tool at a researchers'

disposal for identifying many problems that may arise throughout the control and management

process of invasive non-native species (Elzinga et al. 2001).

Many non-native species have permeated into central Ohio's disturbed ecosystems;

however, Amur honeysuckle (*Lonicera maackii* (Rupr.) Herder) is especially invasive and is one

of the most intrusive non-native species found throughout Ohio and adjacent states (Luken and

Goessling 1995; Hutchinson and Vankat 1997 1998; Luken et al. 1997; Collier et al 2002).

Lonicera maackii is a multi-stemmed, deciduous shrub native to Asia, which was introduced to

the United States in the late 1800's (Luken and Thieret 1995). At first *L. maackii* was lauded by

many in the United States for its perceived ability to stabilize soil and improve wildlife habitats

(Luken and Thieret 1995). Some of the first reports of *L. maackii's* tendency to proliferate

beyond its initial range were recorded in the 1920's at the Morton Arboretum outside of Chicago,

Illinois (Luken and Thieret 1997). Despite these warnings, many state and federal agencies

continued to tout *L. maackii* as an excellent plant, with many useful benefits (Luken and Thieret 1997). The inability to recognize *L. maackii's* invasive tendencies allowed *L. maackii* to escape from cultivation and establish throughout many disturbed habitats within the Midwest (Luken and Thieret 1997).

Although *L. maackii* is present throughout most of central Ohio's disturbed habitats, the region's riparian ecosystems have become overwhelmed by *L. maackii*; its over-abundance has prompted community groups to collaborate with universities and state agencies to design and implement restoration projects for riparian ecosystems affected by *L. maackii* in central Ohio. This research project examines the effectiveness of efforts to remove *L. maackii* from an urban riparian ecosystem located on the Lower Olentangy River, within Columbus, Ohio.

Lotic systems are considered major conduits for the transportation of material and energy, with the surrounding terrestrial communities characteristically containing more biodiversity in comparison to ecosystems further removed from lotic communities (Gregory et al. 1991). The interface between these two distinct ecosystems is the riparian ecosystem, which is generally a small narrow transitional zone (Richardson et al. 2007). Riparian ecosystems are impacted by many variables, such as the fluvial processes of flooding and deposition of alluvial soil, and typically support a distinctive flora, different from surrounding terrestrial communities (Richardson et al. 2007). As a connector between two distinct ecosystems, riparian ecosystems are highly variable and provide pertinent information relating to both ecosystem and community health for surrounding habitats (Planty-Tabacchi et al. 1996). Lastly, riparian ecosystems act as valuable corridors, allowing for the movement of various biotic species between different ecosystems (Naiman and Decamps 1997; Richardson et al. 2007).

The main variables determining vegetation type within riparian ecosystems are regional climate, available species and the ecosystem's hydrological and geomorphological configuration (Naiman et al. 1993; Decamps et al. 1995; Shafroth et al. 2002; Cooper et al. 2003; Richardson et al. 2007). Depending on the configuration of the aforementioned variables, different types of riparian ecosystems are able to form, including woodland, grassland, bottomland forest and shrub land riparian ecosystems (Richardson et al. 2007).

No matter the composition of the vegetation makeup, native vegetation found within riparian ecosystems is important for the fulfillment of a variety of ecological functions for both terrestrial and aquatic habitats, including regulation of aquatic water temperatures from shading and evapotranspiration, contributing to both terrestrial and aquatic food webs, stream bank stabilization and regulating excessive nutrients and sediments (Barling and Moore 1994; Hood and Naiman 2000; Richardson et al. 2007). These important habitat functions influenced Ewel et al. (2001) to use the phrase 'critical transition zones' to describe ecosystems such as riparian zones, which act as critical transition zones between distinct ecosystems (Richardson et al. 2007).

The study area where removal of *L. maackii* occurred is located within the Wilma H. Schiermeier Olentangy River Wetland Research Park (ORWRP), in Columbus, Ohio. The restored site is a 5.26 ha bottomland hardwood forest riparian ecosystem, located on the western bank of the Olentangy River, a main tributary of the Scioto River watershed. Bottomland hardwood forests are the dominant riparian ecosystems found throughout the lower Olentangy River. The restoration was designed as a three-year restoration project, which began in 2001 and concluded in 2003. The goals of the restoration project were to restore hydrological processes within the riparian ecosystem and remove *L. maackii*. An ecosystem's composition and

productivity are greatly influenced by hydrological processes (Anderson and Mitsch 2008). Furthermore, manipulation of hydrological processes is believed to reduce *L. maackii's* abundance at lower elevations (Swab et al. 2003).

Removal of *L. maackii* occurred on multiple occasions during the spring and summer months throughout the three-year restoration. Workers from the Ohio Department of Transportation (ODOT) and City of Columbus, along with volunteers from local environmental groups, participated in the removal of *L. maackii* by cutting plants and applying herbicide treatments to remaining stumps. Comparison of the ORWRP site to two non-restored sites, one upstream and one downstream will be used to gauge the effectiveness of *L. maackii* removal.

The collection and analysis of repeated measurements Elzinga et al. (2001) were used to evaluate changes in condition and progress toward meeting the restoration project's specific objectives.

In addition to the field research, a literature review was conducted to better understand the impact of *L. maackii* on natural ecosystems, especially on riparian ecosystems, and efficacy of *L. maackii* removal efforts elsewhere.

Most literature focuses on fragmented forests and restoration processes immediately following *L. maackii* removal. Excluding reports based on the three-year ORWRP restoration process, little has been published about long-term monitoring of *L. maackii* removal projects conducted in central Ohio. Furthermore, there has been no comparative study of restoration sites to adjacent or nearby non-restored sites. Consequently a monitoring-based comparative study of restored and non-restored sites is likely to better inform *L. maackii* restoration efforts within riparian ecosystems.

Hypotheses:

To examine the processes and impacts of *L. maackii* removal from a bottomland hardwood forest riparian ecosystem situated along the lower Olentangy River, two hypotheses were formulated:

1. Woody plant species diversity will be higher, while *L. maackii* density and frequency will be lower within the ORWRP site in comparison to the Whetstone-Northmoor and Tuttle Park study areas.

2. *Lonicera maackii* frequency and density will be lower in quadrats <5 m and >5 m from the Olentangy River in the ORWRP study area in comparison to both the Whetstone/Northmoor Parks and Tuttle Park areas.

CHAPTER 2

LITERATURE REVIEW

Invasive Non-Native Species and *Lonicera maackii*:

Invasive non-native species are defined as fast growing, non-indigenous species that become established in native plant communities, while replacing native vegetation and whose introduction is likely to cause environmental and/or economic harm (Czarapata 2005; Invasive Species Advisory Committee 2006; The Ohio Department of Natural Resources 2010). Alpert et al. (2000) constructed a two-way classification system to distinguish between native species and non-native invasive species. According to their classification system, a species is an invasive non-native species if 1) the species in question spreads into a habitat it has not previously occupied and has negative effects on the habitat and species already present and 2) the species in question was initially transported into the region by humans.

Taken as a whole, the preceding definitions and identification procedures help to illustrate how and why invasive species are able to effectively overwhelm various habitats throughout North America and globally as well. The ecological and economic impacts of invasive non-native species vary across both landscape and temporal scales. Even with varying degrees of impact, non-native invasive species characteristically decrease species diversity; alter energy, nutrient and water flow; modify a habitat's soil nutrient level and have the ability to persist in disturbed habitats negatively impacting native vegetation's structure, composition and growth (Schwartz 1997). There are numerous reasons invasive non-native species successfully

infiltrate a habitat; such as lack or complete absence of predators and/or diseases, within the new

habitat (Czarapata 2005), the ability of non-native species to better adapt to changing

environmental conditions (Luken and Thieret 1997), ability to out-compete native species and

non-native species typically have longer growing seasons than native species (Collier et al.

2002).

All the previously mentioned criteria determining an invasive non-native species are met

by *L. maackii*. *Lonicera maackii* changes an ecosystem's structure and function (Bazzaz 1986;

Collier et al. 2002), distributes numerous seeds and grows rapidly (Luken 1988; Deering and

Vankat 1999) and has the ability to persist and thrive within disturbed ecosystems (Meiners

2007). Lastly, one of the most important descriptions for invasive non-native species is the

ability to document its introduction, establishment, and spread, through written historical

records. The subsequent section will illustrate *L. maackii's* origin and dispersal.

Lonicera maackii Distribution:

Lonicera maackii's historical home range is located within the Amur and Ussuri River

valleys of central and northeastern China (Luken and Thieret 1997). Although Robert Fortune

was the first western explorer to collect specimens of *L. maackii*, an accurate description didn't

occur until 1855, when naturalist Richard Maack, *L. maackii's* name sake, collected an *L.

maackii* specimen from the Bureja Range north of the Amur River valley (Luken and Thieret

1995). In 1883, E. Regel, a German horticulturist, became the first European to successfully

cultivate *L. maackii* outside of its home range, in the Imperial Botanical Gardens in St.

Petersburg, Russia (Luken and Thieret 1997). After successful cultivation of *L. maackii*, the St.

Petersburg Botanical Garden made *L. maackii* seeds available for purchase across most of the

European continent; thus in a few decades many European countries were successfully cultivating *L. maackii* throughout a variety of gardens and landscapes (Luken and Thieret 1995).

The first successful cultivation of *L. maackii* within North America was in 1896, at the Dominion Arboretum in Ottawa, Canada (Luken and Thieret 1995). The first introduction of *L. maackii* into the United States came about by American explorations of the European and Asian continents (Luken and Thieret 1995). In 1897, the United States Department of Agriculture's (USDA) Section of Foreign Seed and Plant (SPI), designed for the procurement of new and valuable plants and seeds, sent Niels E. Hanson, an agricultural explorer, to Russia in order to find suitable exotic plant species seeds from the European and Asian continents suitable for culture in the United States (Hanson1909; Taylor 1941; Luken and Thieret 1995). In 1898, *L. maackii* seeds, believed to be from Russia, were among one of the first shipments sent back to the SPI by Hanson (Luken and Thieret 1995).

After *L. maackii's* initial introduction into the United States, Hanson continued to send a variety of plant seeds, including *L. maackii* seeds, from other parts of Europe and Asia back to the United States; this allowed the USDA to release different strands of *L. maackii* seeds into the United States within a relatively short period of time (Luken and Thieret 1995). Apparently, the methodology of multiple introductions for *L. maackii* was successful; by 1931 at least eight commercial nurseries cultivated and sold *L. maackii* within the United States (Farrington 1931; Luken and Thieret 1995).

Throughout the early and middle 1900s, *L. maackii* was very popular within many sectors of the United States, including farmers and gardeners, as well as many state and federal agencies, such as the USDA. This popularity was the determining factor for numerous state and federal programs designed to promote the cultivation of *L. maackii* throughout a variety of habitats

across the United States. For example, starting in the 1960s and concluding in 1984, the

USDA's Soil Conservation Service (SCS), the precursor to the Natural Resources Conservation

Service (NRCS), implemented a program to expand the traditional cultivation of *L. maackii* in

hopes of improving soil stabilization and increasing wildlife habitat (Lorenz et al. 1989; Luken

and Thieret 1995). While many land proprietors were expanding *L. maackii's* range across the

United States, ecological researchers were expanding their research on the invasiveness of *L.

maackii*, first described by the Morton Arboretum in 1924 (Ingold and Craycraft 1983; Luken

1988; Williams et al. 1992; Luken and Goessling 1995; Luken and Thieret 1995).   Intensive

ecological research did not fully begin until the 1980s, long after *L. maackii* had established

itself as one of the most invasive non-native species in the United States (Luken and Thieret

1997).

Additionally, *L. maackii's* widespread distribution pattern can also be attributed to seed

dispersal from numerous avian species (Borgmann and Rodewald 2005; Czarapata 2005) and

certain terrestrial wildlife species, particularly *Odocoileus virginianus* (Runkle et al. 2007).

Some avian species, particularly *Cardinalis cardinalis* and *Turdus migratorius,* were found to

forage upon many seed-bearing plants, including *L. maackii*, throughout multiple sites across

Ohio (Borgmann and Rodewald 2005). Runkle et al. (2007) also indicated that *L. maackii* fruits

were eaten on multiple occasions by *Odocoileus virginianus*. Thus, once *L. maackii* has been

successfully introduced into a particular region, many avian and terrestrial wildlife species would

help increase *L. maackii* dispersal. Evidence suggests avian species primarily disperse *L.

maackii* seeds in comparison to their terrestrial counterparts (Ingold and Craycraft 1983;

Williams et al. 1992; Deering and Vankat 1999).

Due in large part to its historical distribution and seed dispersal through numerous avian and terrestrial species, *L. maackii* has become firmly established throughout myriad regions of North America. *Lonicera maackii* has currently spread across 26 states, the District of Columbia and the Province of Ontario, Canada (Natural Resources Conservation Service 2010). States west of the Mississippi River only account for seven of the 26 states impacted by *L. maackii* and of them; three states border the Mississippi River. Thus, *L. maackii* distribution within the United States is primarily concentrated in states east of the Mississippi River (Natural Resources Conservation Service 2010).

Lonicera maackii's origin in Ohio is unknown; the first reported case was in Hamilton County (Braun 1961; Collier et al. 2002) and *L. maackii* was apparently first introduced into Oxford, Ohio in 1960 (Deering and Vankat 1999). Today *L. maackii* is found within 21 of Ohio's 88 counties, with the largest concentration of *L. maackii* located in the southwestern and central counties of the state (Natural Resources Conservation Service 2010).

Even with *L. maackii's* widespread dispersal across much of eastern North America, edge habitats, fence rows (Borgmann and Rodewald 2005) and disturbed forests with an open canopy (Deering and Vankat 1999) appear to be *L. maackii's* primary habitats. High light availability is believed to be the reason for *L. maackii* preferring these particular habitats (Borgmann and Rodewald 2005). *Lonicera maackii's* reproductive capacity and growth rate decline considerably in understory ecosystems with low light penetration (Bartuszevige et al. 2006), signifying that *L. maackii* appears to be shade intolerant. Bartuszevige et al. (2006) study demonstrated higher cover within urban forest ecosystems in comparison to rural forest ecosystems. These results are attributed to the higher amounts of forest fragmentation within

urban areas (Bartuszevige et al. 2006) and further suggest that *L. maackii* flourishes in disturbed ecosystems.

Physiognomy and Physiology of *Lonicera maackii*:

Lonicera maackii is an upright, multi-stemmed, deciduous shrub (Czarapata 2005) capable of growing to 4-5 meters in height (Dirr 1990; Collier et al. 2002). The leaves of *L. maackii* are generally 3.8 - 8.9 cm in length, simple, have an opposite stem configuration, elliptically shaped with light hair cover and taper to a long narrow point (Czarapata 2005). *Lonicera maackii* flowers are predominantly white, with traces of pink or yellow on older plants (Czarapata 2005). *Lonicera maackii* produces abundant red fruit, which ripen in early summer (Czarapata 2005), though the fruit is low in nutritional value (Runkle et al. 2007). Reproduction usually begins at five years of age (Deering and Vankat 1999).

Lonicera maackii is generally the first deciduous woody plant species in Ohio to flush its leaves during spring, and is one of the last to experience leaf senescence during fall (Collier et al. 2002). *Lonicera maackii's* ability to retain its leaves for a longer period of time helps to ensure longer periods of photosynthesis (Czarapata 2005). Once established, *L. maackii* is generally able to grow at a faster rate than many native species. This competitive advantage allows *L. maackii* to capture more sunlight, while reducing available sunlight for native species (Deering and Vankat 1999). *Lonicera maackii's* root system is extensive and typically shallow, allowing for more efficient consumption of both water and nutrients; the shallow roots reduce available resources for native woody species, which typically have deeper root systems (Trisel 1997; Collier et al. 2002). *Lonicera maackii* also exhibits a high level of plasticity, due to the fact that biomass allocations and stem structure are often habitat-specific (Luken 1988). These

characteristics provide *L. maackii* the potential to maintain a long-term presence within a variety of habitats.

Even with its multitude of adaptive features, the presence or absence of certain ecological variables may stymie *L. maackii's* distribution, for example high light availability is especially important during its seedling period (Luken 1988; Luken and Thieret 1997; Deering and Vankat 1999). Swab et al. (2003) examined why *L. maackii* was abundant in certain habitats and less intrusive in others across a relatively small landscape. Their study concluded that *L. maackii* was less prevalent in areas of lower elevation and where water was present; leading to the conclusion that 1) hydrology is a major variable in determining the distribution of *L. maackii* and 2) *L. maackii* establishes more readily in drier soils (Swab et al. 2003). Furthermore, habitats in the Bartuszevige et al. (2006) study, which contained more native woody species, exhibited lower density levels of *L. maackii* when compared to habitats with lower proportions of native woody species.

Removal Methods for *Lonicera maackii*:

Methods for removal of *L. maackii* may be chemical, manual and/or a combination of both (Czarapata 2005). Biological control methods have apparently not been investigated. For effective control, methods are typically repeated every 3-5 years in order to deplete the seed bank (Czarapata 2005). Currently, there is no comprehensive method pertaining to the overall treatment and removal of *L. maackii*, although certain herbicide treatments (i.e. glyphosate and triclopyr) coupled with the planting of native species may result in successfully removing *L. maackii* from a particular site (Hartman and McCarthy 2004).

Manual methods typically involve repeated cutting, hand pulling and digging of *L. maackii* from a site. *Lonicera maackii* will resprout vigorously if the stump portion is not chemically treated (Czarapata 2005). After *L. maackii* has been removed, site managers will typically replant an appropriate native species with the expectation it will inhibit and/or suppress further *L. maackii* invasions by utilizing available resources to quickly establish a canopy to shade-out *L. maackii* seedlings, making reestablishment more difficult (Hartman and McCarthy 2004). Seed bank regeneration is also effective at suppressing *L. maackii* after restoration. Regenerating a site through the seed bank allows native species to repopulate the site and reduce future growth of *L. maackii* seedlings (Czarapata 2005).

Current chemical control methods include cut-stump, basal bark and foliar spray applications (Czarapata 2005). Cut-stump treatments require first cutting *L. maackii* as near to the ground as possible and then applying either a 20% a.i. glyphosate or a 12.5% a.i. triclopyr formula in combination with penetrating oil immediately after *L. maackii* has been cut to get rid of the left-over stump (Czarapata 2005). The cut-stump removal method is time-consuming, but fewer non-target species are adversely impacted by this removal method. Both the cut-stump and basal bark methods can be administered between early July and December.

Basal bark treatment is another chemical control method for *L. maackii*; clipping before applying the herbicide is not required. The basal bark control method utilizes a 12.5% a.i. triclopyr formula, coupled with penetrating oil to effectively remove *L. maackii* (Czarapata 2005). The oil penetrates through the bark and distributes the herbicide to *L. maackii's* cambium, which is then distributed to its root system. Basal bark treatment is typically faster than the cut-stump method, due to the lack of required cutting. Similar to the cut-stump method,

the basal bark method is a highly selective chemical control method that reduces collateral damage to surrounding vegetation (Czarapata 2005).

Unlike the cut-stump and basal methods, herbicide administered through the foliar spray application process is not a highly selective method. The foliar spray method distributes herbicide across a larger portion of the site. Therefore, native species are also susceptible to herbicide during application if precautions are not taken, such as applying low concentrations of herbicide, making anti-drift formulas and adding surfactants to the herbicide (Czarapata 2005). It is recommended that the foliar spray treatment be used primarily during early spring, before most native species begin to flush their leaves (Czarapata 2005). Even though the foliar method makes native species more susceptible to herbicide, this method allows fewer workers to cover more area within less time.

Hartman and McCarthy (2004) conducted a study to examine how successful two different chemical applications of glyphosate were at removing *L. maackii*. Their experiment was performed at the Fernald Environmental Management Project site (FEMP), located in northwest Cincinnati, Ohio. The first method involved a glyphosate application after cutting and the second method was an injection of glyphosate into the stem. While both methods were found to be at least 94% effective in eradicating *L. maackii*, the glyphosate injection was both more efficient to apply and more effective on large *L. maackii*.

Lonicera maackii After Restoration:

Restoration includes removing invasive non-native species and trying to prevent their re-occurrence. One of the most difficult invasive non-native species to keep out of restored habitats is *L. maackii* (Hartman and McCarthy 2004) because of its ability to resprout after multiple

cuttings (Czarapata 2005), possible allelopathic impacts on native species (Trisel 1997; Hartman and McCarthy 2004) and physiological plasticity (Luken 1988).

Runkle et al. (2007) examined the current vegetative cover on a restored site eight years after removal of *L. maackii* had occurred. The purpose of the study was to gain an understanding of the immediate and long-term effects of restoration processes for both *L. maackii* and the habitat's native ground layer species. At the beginning of the study, the authors established ten pairs of plots; each pair contained a treatment plot and an untreated plot. *Lonicera maackii* within treatment plots was removed using the cut-stump method and applying glyphosate. All sampling of vegetation occurred after removal of *L. maackii*. After eight years, samples were collected from the same experimental plots and lower frequencies of *L. maackii* were found in most plots. The removal process was effective in reducing *L. maackii's* overall frequency and height. The study also demonstrates how habitats may respond to treatments and removal of *L. maackii* on a long-term basis.

CHAPTER 3

STUDY AREA

Historically, Ohio was predominantly forested and is still part of the great Deciduous

Forest of eastern North America, with four major forest regions expanding into the state (Braun

1961). The four major regions include the Mixed Mesophytic Forest, the Western Mesophytic

Forest, the Hemlock-White Pine-Northern Hardwood Forest and the Beech-Maple Forest (Braun

1950; Braun 1961). However, more than half of Ohio, including all three study areas, is

contained within the Beech-Maple Forest region. The Beech-Maple forests are primarily

dominated by American beech (*Fagus grandifolia* Ehrh.) and sugar maple (*Acer saccharum*

Marsh.), with smaller densities of black ash (*Fraxinus nigra* Marsh.), white ash (*Fraxinus*

Americana L.) and red maple (*Acer rubrum* L.) located in depressions and flats (Braun 1961).

Ohio's forests have been and still continue to be replaced by expanding agricultural lands and

more recently the spread of urbanization, particularly within central Ohio.

Multiple glaciations have had a tremendous effect on the geographic topography within

the region (Braun 1961). Central Ohio is characterized by calcareous glaciated till plains (Braun

1961) that contain moraines and kames (Miltner et al. 2004). The bedrock for the region consists

primarily of Upper Silurian Dolomite, coupled with Devonian Columbus Limestone in particular

sections of the region (King 1978). Generally, Franklin County has little to no relief; if present

the relief will be no more than 15.24 m (Miltner et al. 2004). This geographical characteristic is

reminiscent of most of central Ohio as well.

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Soils within central Ohio are comprised of two main soil types: Kokomo and Crosby. Both types are silty clay loams with poor drainage (King 1978). In adjacent areas, the soil composition begins to change over to Celina silt loam, Lewisburg silt loam and Miamian silt loam (King 1978). The surface layer of these soils is generally brown and less productive than Crosby soil (King 1978).

Central Ohio experiences four distinct seasons with growing seasons typically occurring between May and October, allowing for roughly 130 frost-free days annually (Braun 1961). Weather patterns within the region are primarily influenced by air masses originating from central and southwestern Canada, with air masses from the Gulf of Mexico contributing to climatic patterns mainly in the region's summer months (Gale 2006). Generally, the region experiences a temperate climate, with an average January temperature of -2.05 °C and an average July temperature of 23.94 °C (Gale 2006). In addition, central Ohio receives an annual rainfall amount of 96.1cm, and an annual snowfall total of 70.4 cm (Gale 2006).

The ORWRP study area and both the corresponding upstream and downstream non-restored sites are located along the lower Olentangy River (Anderson and Mitsch 2008), in northeast Columbus, Ohio. The Whetstone-Northmoor Parks upstream non-restored study area is roughly 2400 m from the ORWRP, while the downstream non-restored study area, located in Tuttle Park is roughly 640 m from the ORWRP. The Olentangy River's headwaters begin in the northern portion of the state, in Crawford County and its confluence point with the Scioto River is located in Franklin County. The Olentangy River primarily flows on a north to south gradient, with portions of the river designated as a scenic river by the State of Ohio.

The Wilma H. Schiermeier Olentangy River Wetland Research Park:

The restoration site is a 5.26 ha bottomland riparian hardwood forest ecosystem, located within the ORWRP, in northeast Columbus, Ohio, situated along the western bank of the Olentangy River (40°01.105'N, 83°00.961'W; FIGURE 1); site slope average was between 11-16%. The restoration site width varies between 25 m and 90 m and is 730 m in length (Anderson and Mitsch 2008). The ORWRP is situated on property owned and operated by the Ohio State University and is surrounded by urban infrastructure and residential neighborhoods on all sides, with U.S highway 315 just west of the restoration site. Additionally, the restoration site is adjacent to the 20.52 km Olentangy River Greenway multi-use trail that connects multiple parks located along the Olentangy River. The dominant tree species in the restoration site include boxelder (*Acer negundo* L.), Ohio buckeye (*Aesculus glabra* Willd.), paw paw (*Asimina triloba* L.), hackberry (*Celtis occidentalis* Willd.) and eastern cottonwood (*Populus deltoides* Bartr. Ex.) (Anderson and Mitsch 2008).

Whetstone-Northmoor Parks:

The upstream non-restored study area is located within both the Whetstone and Northmoor Parks, in northeast Columbus, Ohio (40°02.381'N, 83°01.770'W; FIGURE 2); site slope average was between 15-17%. Both parks are owned and operated by the City of Columbus. The Whetstone and Northmoor Parks are situated along the eastern bank of the Olentangy River and are designated as multi-use parks. Whetstone Park is the bigger of the two park systems and is comprised of 55.15 ha, with varying widths along the Olentangy River. Northmoor Park is connected to the south section of Whetstone Park and has a total land area of 3.76 ha with varying widths as well. The dominant tree species for both parks are similar to the

trees found within the ORWRP. The Olentangy River to the west borders both parks, with residential neighborhoods encompassing the remaining boundaries for each park.

Tuttle Park:

The downstream non-restored study area is located within Tuttle Park in northeast Columbus, Ohio (40°00.754'N, 83°01.021'W; FIGURE 3); site slope average was between 11-13%. Tuttle Park is also owned and operated by the City of Columbus and has a land area of 17.76 ha. Tuttle Park is adjacent to the northern section of the Ohio State University and is a few blocks north of Lane Avenue, a main thruway for the university. The communities surrounding Tuttle Park are a mixture of residential neighborhoods and student housing. Similar to the upstream non-restored location, Tuttle Park is also situated along the eastern bank of the Olentangy River and has a similar woody species composition as both the ORWRP and Whetstone and Northmoor parks.

CHAPTER 4

METHODS

Data Collection:

Sample plots were established within three study areas along the lower Olentangy River

to address the hypotheses. Both the upstream and downstream non-restored sites were located at

least 100 m from the ORWRP restoration site. Four 200 m² (4 m x 50 m) macroplots were

established within the 5.26 ha restoration site located in the ORWRP, the non-restored upstream

study area located within Whetstone and Northmoor Parks and the downstream study area

located in Tuttle Park.

A numbers table was used to generate starting coordinates for the first 4 m x 50 m

macroplot within each study area; the remaining three 4 m x 50 m macroplots were then arranged

with a10 m separation between the remaining macroplots within each study area. Macroplot

long sections were perpendicular to the Olentangy River to better account for the expected higher

density levels of *L. maackii* in areas further from the river. Each macroplot was additionally

divided into 1 m x 4 m quadrats distributed every 3 m along the 50 m portion of the macroplot

allowing for 13 sample quadrats per macroplot and 52 quadrats per study area. All study areas

were sampled during the spring of 2010.

Density and frequency for *L. maackii* were measured and recorded within all 12

macroplots. Density for all woody plant species within all macroplots were recorded as well. To

ensure data were collected accurately, if any fraction of a species was located within a quadrat, its information was documented accordingly.

In addition, basal area was recorded for all woody species within four randomly selected quadrats per macroplot, allowing for 16 randomly selected quadrats per site and 48 quadrats overall. In order to calculate basal area, diameter at breast height (DBH), 1.37 m above ground level, was recorded for all stems within each randomly selected quadrat. Once DBH was recorded, basal area was derived for each individual sampled. Furthermore, the number of *L. maackii* stems was recorded to determine density per macroplot and study area. *Lonicera maackii* density and frequency values are expected to be lower in the ORWRP site in comparison to both non-restored sites.

All plant identification methods used during this research were derived from Mohlenbrock (2002) and Braun (1961). Additionally, all Global Positioning System (GPS) spatial coordinates were derived through the use of a Garmin nuvi 265T Handheld GPS system. Maps depicting each study site were created through Environmental Systems Research Institute (ESRI) ArcMap version 9.3.1.

Data Analyses:

The inability to assign treatments randomly to sample plots violates the necessary assumptions needed to utilize typical parametric statistical analyses such as the t-test and Analysis of Variance (ANOVA). To overcome the lack of independent samples, non-parametric randomization tests were incorporated. Randomization methods are not as concerned with population parameters, instead testing relies on the mechanisms that led to the distribution of the data. More specifically, randomization tests randomly reorder the data, calculate the appropriate

statistic for each randomization and compare the calculated test statistic to results obtained after the data has been put through randomization testing (Manly 2007).

The randomization procedure I utilized was the comparison of two groups as implemented by the Resampling software package (David C. Howell, University of Vermont), that examined *L. maackii* density and frequency and woody species density within the ORWRP in comparison to both the upstream and downstream non-restored study areas.

Lonicera maackii density and frequency were compared between pairs of study areas. Specifically, randomization testing was used to determine if density and frequency differed between macroplots of: (1) the ORWRP site and the Whetstone/Northmoor Parks, (2) the ORWRP site and Tuttle Park, and (3) the Whetstone/Northmoor Parks and Tuttle Park. The procedures were repeated to determine whether density and frequency differed overall and for quadrats <5 m from the river or for quadrats >5 m from the river.

Data were entered into an Excel spreadsheet to calculate woody species Shannon-Wiener Diversity Index at the macroplot level. Once calculated, randomization testing was used to examine whether a significant difference exists between the ORWRP, Whetstone-Northmoor and Tuttle Park sites. The Shannon-Wiener Index is an index to measure the likelihood that the next individual will be the same species as before and is one of the most widely used species diversity indices for examining the overall community characteristics within a given habitat.

By using the natural logarithm (ln) to calculate the Shannon-Wiener Diversity Index, values will be between 0-7, a value near 0 indicates that every species will be similar and a value near 7 indicates species diversity is more evenly distributed. The Shannon-Wiener Diversity Index is expected to be lower in both the non-restored upstream and downstream sites in comparison to the restoration site.

The Shannon-Wiener Diversity Index was calculated by using the following formula:

$$H = -\sum_{i=1}^{s} p_i(ln(p_i))$$

Where *H* represents the Shannon-Wiener Index, the proportion of each species within the sample

is represented as p_i.

CHAPTER 5

RESULTS

Lonicera maackii **Density Comparisons:**

Overall ORWRP vs. WS-NM and Tuttle Parks

Lonicera maackii density was significantly (α=0.05) lower at the restored site (ORWRP)

than either the upstream (Whetstone-Northmoor Parks; p=0.03) or downstream (Tuttle Park;

p=0.01) non-restored sites (Figure 4; Table 5). There was no significant difference (p=0.76) in

L. maackii density between the Whetstone-Northmoor Parks and Tuttle Park (Figure 4; Table 5).

Fifteen percent of all *L. maackii* individuals sampled were located at the ORWRP (57

individuals), compared with 39% sampled at the Whetstone-Northmoor Parks (149 individuals)

and 46% found at Tuttle Park (174 individuals) (Figure 4 & 5).

The ORWRP study area had the lowest density of *L. maackii* at 0.13 stems/m² and the

downstream study area located in Tuttle Park had the highest density at 0.63 stems/m² (Table 2).

Lonicera maackii density sampled at the upstream study area located in the Whetstone-

Northmoor Parks was 0.60 stems/m² (Table 2). The ORWRP study area also had the lowest

average density of *L. maackii* with 27 stems sampled overall (800 m²) (Table 2). Both the

upstream and downstream non-restored sites showed exceptionally higher *L. maackii* averages in

comparison to the restored ORWRP site. The Whetstone-Northmoor Parks average (800 m²)

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number of *L. maackii* stems was 121, while the Tuttle Park study area (800 m²) had an average number of *L. maackii* stems of 126 (Table 2).

Lonicera maackii was fairly evenly split between mature individuals and saplings, with 49% of the individuals sampled being mature shrubs and 51% saplings (i.e. young trees and/or shrubs), within the ORWRP. The percent of mature *L. maackii* individuals sampled within the Whetstone-Northmoor Parks was 61%, while the number of saplings surveyed was 39%. The Tuttle Park study area also had an even distribution of *L. maackii*, with 50% mature and 50% saplings sampled throughout all four macroplots.

Less than 5 m ORWRP vs. WS-NM and Tuttle Parks:

There were no significant differences in *L. maackii* density in quadrats <5 m from the river between the ORWRP, restored site, and either the Whetstone-Northmoor (p=0.08) or Tuttle Parks (p=0.06) study areas (Table 5). Randomization testing between the Whetstone-Northmoor Parks and Tuttle Park (p=0.73) also resulted in no significant differences (Table 5). Ten percent of all *L. maackii* stems (109) sampled were found in quadrats <5 m (Table 6). Thirteen percent of all *L. maackii* stems (14) sampled in quadrats <5 m were found at the ORWRP study area, while 42% and 45% were found in the Whetstone-Northmoor (46) and Tuttle Parks (49), respectively (Table 1 & 6). These results may also be due to the fact that fewer quadrats were established in areas <5 m from the river.

More than 5 m ORWRP vs. WS-NM and Tuttle Parks:

Lonicera maackii density was markedly greater in quadrats >5 m from the river for both Whetstone-Northmoor (p=0.03) and Tuttle Parks (p=0.02), compared to the ORWRP (Table 5).

Conversely, *L. maackii* density between the Whetstone-Northmoor Parks and Tuttle Park (p=0.79) had no significant differences in macroplots >5 m from the Olentangy River (Table 5). Ninety percent of all *L. maackii stems* (989) were located in quadrats >5 m (Table 1 & 4). Ten percent of all *L. maackii* stems (94) sampled in quadrats >5 m were found in the ORWRP, while 44% and 46% were found in the Whetstone-Northmoor (438) and Tuttle Parks (457), respectively (Table 1 & 4). These results may also be due to the fact that more quadrats were established in areas >5 m from the river.

Lonicera maackii Frequency Comparison:

Overall ORWRP vs. WS-NM and Tuttle Parks:

Lonicera maackii frequency at the restored study area (ORWRP) was significantly lower than at either the upstream (p=0.03) or downstream (p=0.03) non-restored study areas (Whetstone-Northmoor and Tuttle Parks) (Table 5). There was no significant difference (p=0.63) between the upstream and downstream non-restored study areas of Whetstone-Northmoor and Tuttle Parks (Table 5). Each study area contained 13 quadrats per macroplot, for a total of 52 quadrats sampled per site. *Lonicera maackii* was present in 50% of all quadrats sampled in the ORWRP study area. Both the Whetstone-Northmoor and Tuttle Park quadrats had an 85% sample frequency rate overall.

Less than 5 m ORWRP vs. WS-NM and Tuttle Parks:

Each study area contained eight quadrats situated < 5 m from the Olentangy River. There was no significant difference (p=0.28) in *L. maackii* frequency between the ORWRP study area

and the upstream non-restored site located in the Whetstone-Northmoor Parks study area; nor was there a significant difference (p=0.14) between the Whetstone-Northmoor and Tuttle Park study areas (Table 5). There was a significant difference (p=0.03) in *L. maackii* frequency between the ORWRP and Tuttle Park study areas (Table 5). Only 25% of the ORWRP quadrats sampled contained *L. maackii,* while 63% of quadrats in the Whetstone-Northmoor Parks contained *L. maackii* and 100% of the quadrats sampled in Tuttle Park contained *L. maackii.*

More than 5 m ORWRP vs. WS-NM and Tuttle Parks:

Each study area contained 44 quadrats that were located > 5 m from the Olentangy River. *Lonicera maackii* frequency at the ORWRP restored study areas was significantly lower than at either the Whetstone-Northmoor Parks (p=0.03) upstream site or Tuttle Park (p=0.03) downstream site (Table 5). There was no significant difference (p=0.37) in *L. maackii* frequency between the Whetstone-Northmoor Parks upstream site and the downstream site in Tuttle Park (Table 5). *Lonicera maackii* frequency in quadrats located in the ORWRP was 55%, compared to 89% and 82% *L. maackii* frequency for the Whetstone-Northmoor Parks and Tuttle Park, respectively.

Shannon-Wiener Diversity Index:

There were significant differences, at the macroplot level, for the Shannon-Wiener Diversity Index between both the Whetstone-Northmoor Parks (p=0.03) and Tuttle Park (p=0.03) in comparison to the ORWRP restored study area (Table 5). There was no significant difference in the Shannon-Wiener Diversity Index (p=0.77) between the Whetstone-Northmoor and Tuttle Parks (Table 5). The ORWRP study area had the highest Shannon-Wiener Value calculated at

2.25, while Tuttle Park had the lowest value at 1.67 (Figure 6; Table 3). The Shannon-Wiener Value for Whetstone-Northmoor Parks was 1.71 (Figure 6; Table 3).

Twenty different species, totaling 1111 individuals, were sampled and identified throughout the three study areas (Table 4). Seventy-five percent of the total species were found in the upstream site located in Whetstone-Northmoor Parks, while only 70% were found in the downstream site located in Tuttle Park. One hundred percent of all species sampled were found at the ORWRP study area. The ORWRP had the highest number of individuals sampled at 396, while Whetstone-Northmoor Parks had the lowest number at 341 and Tuttle Park had a total of 374 individuals sampled within the study area (Table 4).

Basal Area:

There were significant differences in basal area between both the Whetstone-Northmoor Parks (p=0.04) and Tuttle Park (p=0.04) in comparison to the ORWRP study area (Table 5). There was no significant difference in basal area (p=0.07) between Whetstone-Northmoor and Tuttle Parks (Table 5). Twenty-eight individuals were randomly sampled in the ORWRP study area for basal area, with an average basal area of 0.20 m²/ha. Both non-restored study areas had drastically lower basal area averages, with 0.03 m²/ha and 0.02 m²/ha for the Whetstone-Northmoor Parks and Tuttle Parks, respectively.

CHAPTER 6

DISCUSSION

In general, restoration efforts for the ORWRP's bottomland hardwood forest appear to be effective. The overall number of *L. maackii* individuals is lower in the ORWRP study area, when compared to both the Whetstone-Northmoor and Tuttle Park non-restored study areas. Furthermore, *L. maackii's* overall density and frequency values were found to be lower in the ORWRP study area in comparison to both non-restored sites; therefore, the first hypothesis is supported. *Lonicera maackii* density and frequency rates were also significantly lower in quadrats >5 m from the river in the ORWRP when compared to both non-restored study areas. Lastly, woody species overall basal area in the ORWRP was substantially greater when compared to both non-restored sites.

Only one randomization test revealed any statistical differences between the ORWRP compared to both Whetstone-Northmoor and Tuttle Parks when examining *L. maackii* frequency and density values in quadrats <5 m from the river. Therefore, factors other than past restoration are believed to be responsible for the low abundance of *L. maackii* recorded in quadrats close to the Olentangy River. One hypothesis is that water adversely impacts the distribution of *L. maackii*; however, this was not within the scope of my research, thus, no tests were conducted to examine this hypothesis. Although only one test produced a statistically significant difference for quadrats <5 m from the river, results were not drastically higher than alpha (0.05); thus, further analyses may yield different results. Overall, it appears that restoration efforts have helped to reduce the number of *L. maackii* at the ORWRP site.

Hypothesis 1:

I hypothesized that woody plant species diversity would be higher, while *L. maackii* density and frequency would be lower within the ORWRP site in comparison to the Whetstone-Northmoor and Tuttle Park study areas. Support for this hypothesis was strong due to the fact that woody plant species diversity was higher and *L. maackii* density and frequency were both lower in the ORWRP, when compared to both non-restored sites. Multiple randomization tests revealed pronounced differences in *L. maackii* density and frequency, along with significantly different results for woody species diversity, providing compelling evidence to support the contention that the marked differences between the ORWRP and non-restored sites have developed from restoration efforts.

Twenty separate species were sampled throughout all study areas; the ORWRP was the only study area to have every species represented. The ORWRP study area also contained the highest number of individuals at 396, with the lowest number of *L. maackii* at 57. Even though Tuttle Park contained the second highest number of individual at 374, *L. maackii* comprised 47% of the total number of individuals sampled. The Whetstone-Northmoor Parks had the lowest number of individuals at 341, with *L. maackii* representing 44% of total individuals sampled. The average density for *L. maackii* stems in the ORWRP was also substantially lower, with 27 stems per macroplot compared to 121 stems per macroplot in the upstream site and 127 stems per macroplot in the downstream site.

As anticipated, the upstream and downstream non-restored sites in Whetstone-Northmoor and Tuttle Parks were very similar in almost all respects. Both sites had low species diversity, with a majority of their macroplots and quadrats comprised mainly of *L. maackii*, with 149

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individuals sampled in Whetstone-Northmoor Parks study area and 174 individuals sampled at Tuttle Park. Randomization tests between the Whetstone-Northmoor Parks study area and Tuttle Park study area resulted in no significant differences in every category (i.e. *L. maackii* density, frequency, Shannon-Wiener Diversity Index and <5 m >5 m).

Hypothesis 2:

Secondly, I hypothesized that *L. maackii* frequency and density would be lower in quadrats <5 m and >5 m from the Olentangy River in the ORWRP study area in comparison to both the Whetstone-Northmoor and Tuttle Park areas.

The second hypothesis was partially supported by statistically significant test results; however *L. maackii* density and frequency rates in quadrats <5 m from the Olentangy River were fairly similar across each study area. Although overall *L. maackii* density and frequency rates in both non-restored sites were markedly higher when compared to the ORWRP, the only density or frequency test (<5 m) that produced a statistically significant difference was the ORWRP vs. Tuttle Park frequency test ($p=0.03$).

Many of the tests were only slightly higher than alpha (0.05). Since current data resulted in slightly higher p-values compared to the selected alpha (0.05), further data analyses and testing could result in statistically significant differences among the ORWRP restored site and non-restored sites. To demonstrate differences, additional research should determine what variables are impeding *L. maackii's* ability to effectively establish in areas adjacent to the Olentangy River. However, given that randomization tests only produced statistically significant results for *L. maackii* density and frequency in quadrats >5 m, the null hypothesis should not be rejected.

Furthermore, *L. maackii* was only present in 50% of the macroplots sampled at the ORWRP, while *L. maackii* was present in 100% of all macroplots sampled in both non-restored sites. The two ORWRP macroplots that contained *L. maackii* were the two northern macroplots and were adjacent to areas where removal of *L. maackii* had occurred during the earliest stages of the three-year restoration project. This continued encroachment supports the belief that once an area has experienced disturbances, long term monitoring and management is needed to support restoration goals.

Density and frequency for *L. maackii* sampled in quadrats >5 m from the river resulted in pronounced differences between the ORWRP study area and both non-restored sites. Ten percent of the total number of *L. maackii* stems were sampled in quadrats >5 m at the ORWRP, while 44% and 46% of the total number of *L. maackii* stems were sampled in the Whetstone-Northmoor and Tuttle Parks, respectively. The significant increase in *L. maackii* sampled beyond 5 m supports the findings of Swab et al. (2003) that hydrology is an important variable in *L. maackii* distribution and *L. maackii* establishes more readily in drier soils. However, the increase in *L. maackii* stems, found in quadrats >5 m from the river, could be due to the fact that there were more quadrats found beyond >5 m as well. Nonetheless, future research needs to be conducted to further examine the natural processes that hamper the spread of *L. maackii* in ecosystems containing water.

CHAPTER 7

CONCLUSIONS

The ORWRP's bottomland hardwood forest ecosystem is a vital riparian ecosystem and provides numerous essential services to surrounding habitats, such as filtering excessive nutrients from runoff, groundwater recharge and critical habitat for native flora and fauna. Thus, in 2001, a three-year plan was put into place to oversee the restoration process. The main components of the restoration project included removal of *L. maackii* and restoration of the ORWRP's hydrological processes. Each spring and summer, workers from ODOT, the City of Columbus, and volunteers from various local environmental groups participated in *L. maackii* removal by cutting shrubs and applying herbicide treatments to remaining stumps.

At the time of this report, almost seven years have passed since restoration efforts have been completed. Many restoration projects don't have the budget for or simply fail to include long-term monitoring to examine the effectiveness of the project. This reality brought about my decision to examine and compare current conditions at the ORWRP restoration site to areas along the Olentangy River that had never undergone any type of restoration process. The non-restored sites were in parks owned by the City of Columbus, with the upstream site located in Whetstone-Northmoor Parks and the downstream site located in Tuttle Park. The intent of this project was to compare the three sites, thus affording an opportunity to make cogent inferences about the long-term effectiveness of the removal of *L. maackii*.

In general, *L. maackii* frequency and density were substantially lower within each ORWRP macroplot, when compared to macroplots in both non-restored sites, although all

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density and two frequency (<5 m) randomization tests had no statistically significant differences. Nevertheless, *L. maackii* was still less abundant in lower quadrats at the ORWRP, but quadrats where *L. maackii* was sampled typically had multiple individuals present.

The effects of restoration are evident when examining quadrats further away from the Olentangy River. Higher species diversity and greater numbers of native saplings are present throughout each macroplot in the ORWRP when compared to both non-restored sites. Beyond the first few meters from the river many macroplots, in the non-restored sites were engulfed with *L. maackii.* Most of the non-restored macroplots contained larger mature *L. maackii* with most of the mature individual's crowns growing together to effectively reduce most visible sunlight. The number of species sampled in these quadrats was significantly reduced when compared to the ORWRP.

Lonicera maackii's ability to rapidly reproduce and reach maturation has also contributed to native species reductions. Rapid growth and the ability to drastically reduce available sunlight have probably hampered the growth and spread of native species within both non-restored sites. As such, after a certain point, most quadrats in the non-restored sites only contained multiple individuals of *L. maackii*. However, even at significantly lower levels, *L. maackii* was present in many of the ORWRP quadrats, especially in quadrats located in the northern portions of the ORWRP, probably due to the fact that the northern area is exposed to adjacent non-restored areas, making that portion more susceptible to continued re-invasion.

As stated above, one of the major issues with most restoration projects is that they're not situated in a vacuum; many restoration projects are in areas where adjacent ecosystems are likely to be just as dilapidated, if not more so. The ORWRP is no different. Although the ORWRP is fairly large, at 5.26 ha, the site is still bordered by non-restored ecosystems that more than likely

share similar attributes to both the Whetstone-Northmoor and Tuttle Park study areas. Thus, even though restoration methods maybe sound, over time, without long-term monitoring, continuous reinvasions from *L. maackii* would be highly plausible.

Future research should examine how *L. maackii* in adjacent non-restored sites interacts and reinvades restored sites, especially on a landscape level. Additional research should be conducted on *L. maackii* and the apparent adverse effects water has on its ability to establish in adjacent areas. In addition, future studies should be conducted within these same macroplots to evaluate whether native species persisted or if *L.maackii* became the dominant understory species once again.

Lastly, one of the main goals for the ORWRP restoration project was to remove and/or reduce *L. maackii*, with the reduced individual number of *L. maackii* in the ORWRP; it appears the restoration project was successful. Most previous research was conducted within sites, while few studies compared restored sites and non-restored sites. Due to the lack of such research, much more examination is needed between restoration sites and non-restored sites in future studies.

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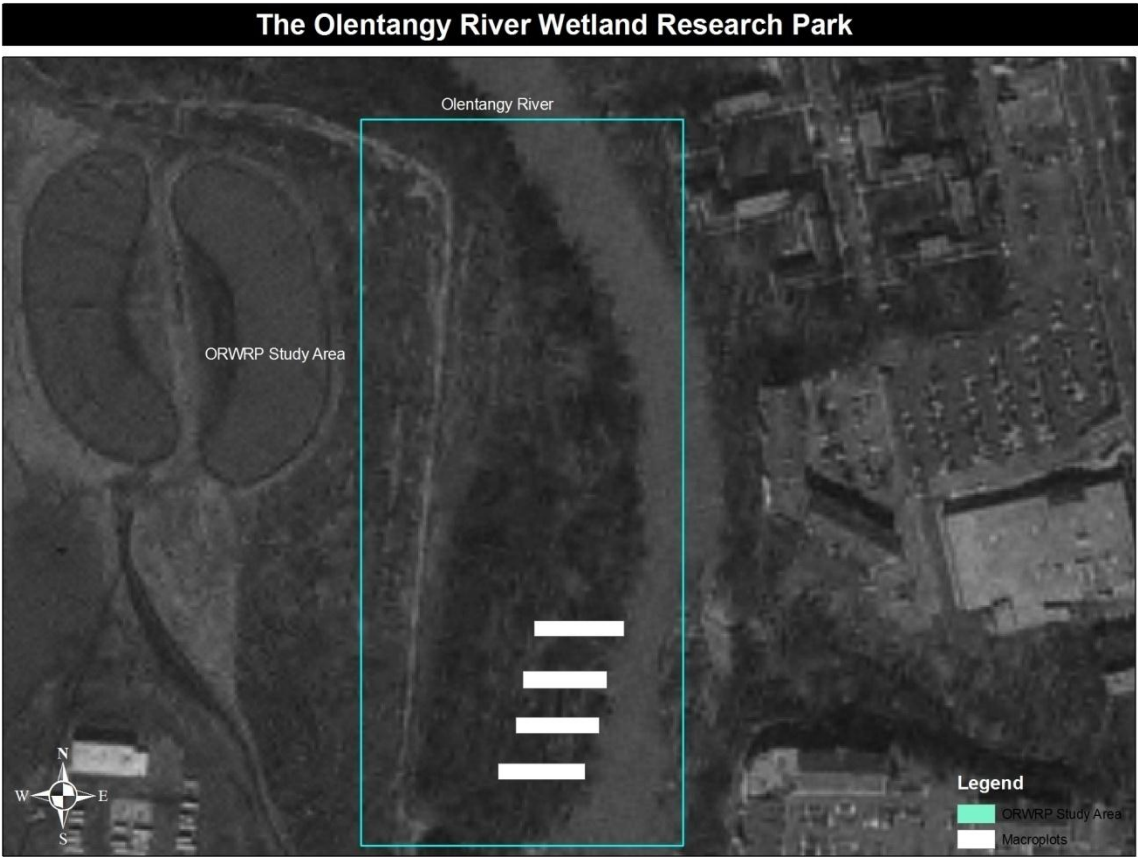
APPENDIX A

Figures and Tables

Figure 1. The Olentangy River Wetland Research Park restoration site in Columbus, Ohio. The four 4 m x 50 m macroplots are shown as the white rectangular boxes within the outlined box.
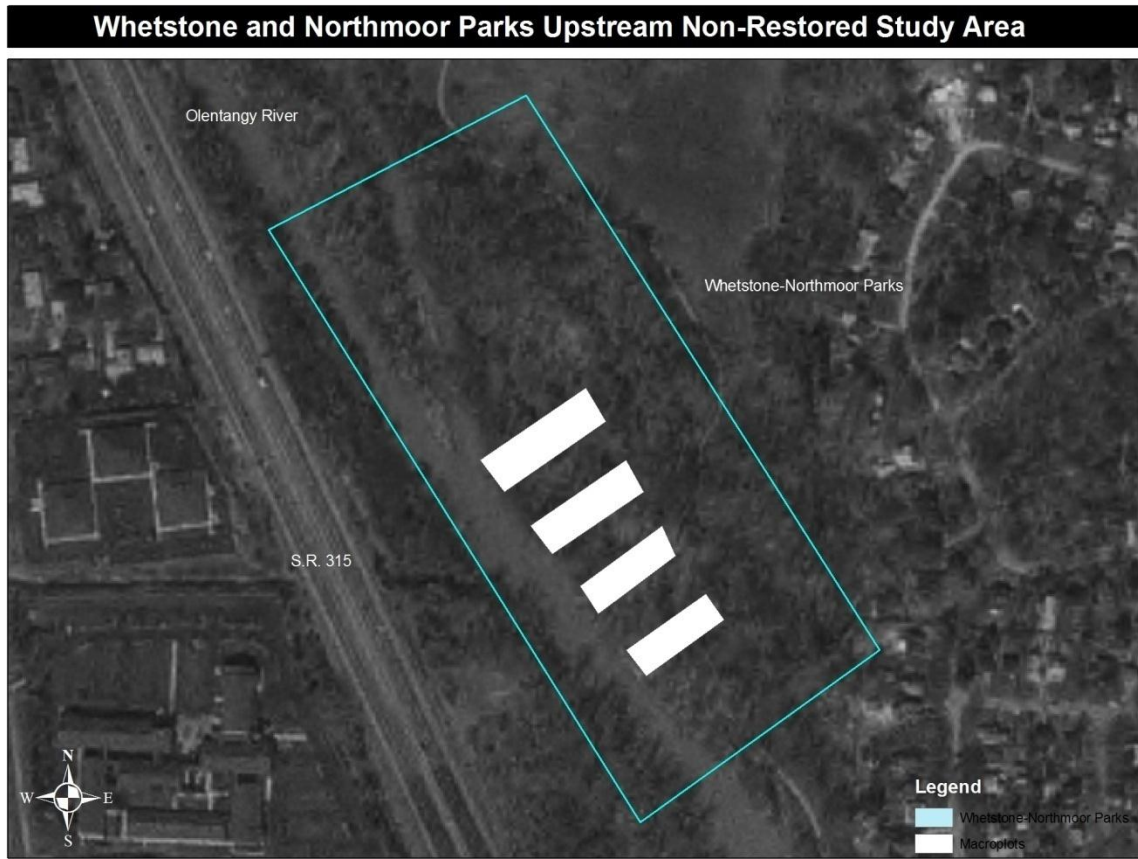
Figure 2. The upstream non-restored site within the Whetstone and Northmoor Parks in central Ohio, north of Columbus, Ohio. The four 4 m x 50 m macroplots are shown by the white rectangular boxes located in the outlined box.

Figure 3. The downstream non-restored site within Tuttle Park, directly north of Columbus, Ohio. The four 4 m x 50 m macroplots are shown by the white rectangular boxes located within the outlined box.
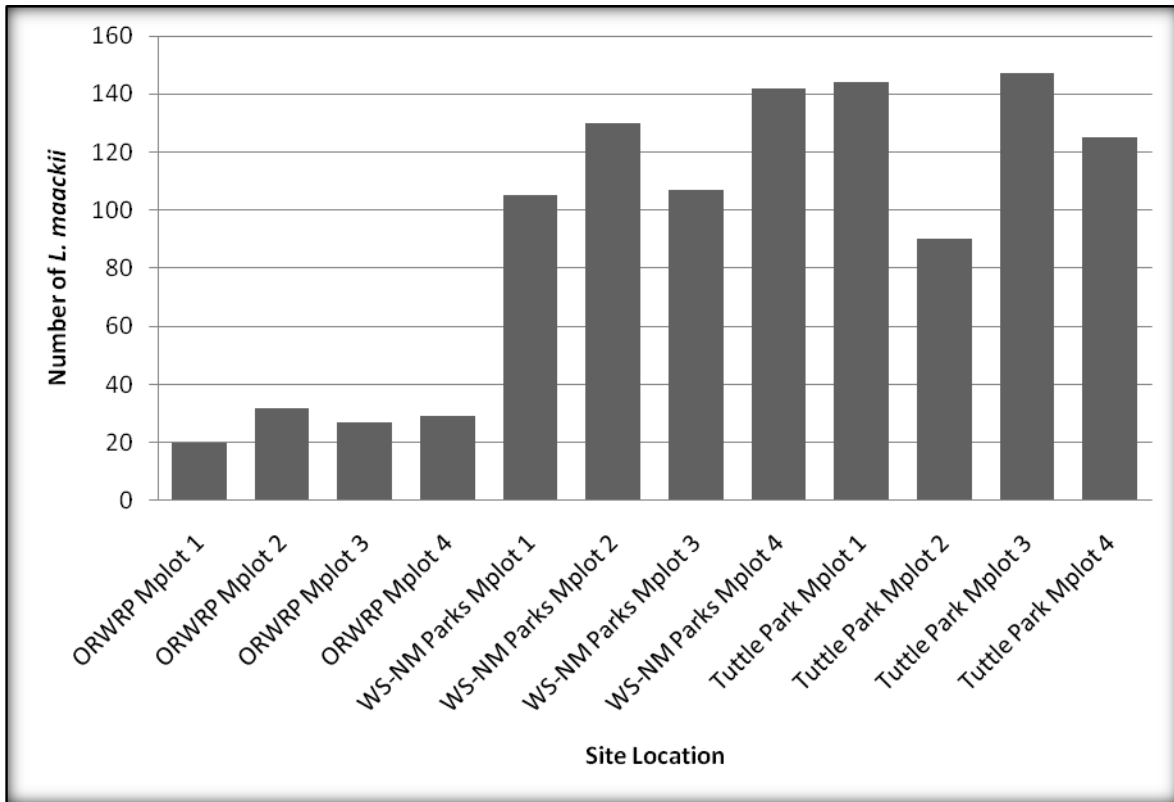
Figure 4. Total number of *L. maackii* stems sampled within each macroplot distributed across each study area. Both the WS-NM Parks and Tuttle Park had considerably more *L. maackii* stems in comparison to the ORWRP site (p=0.05).
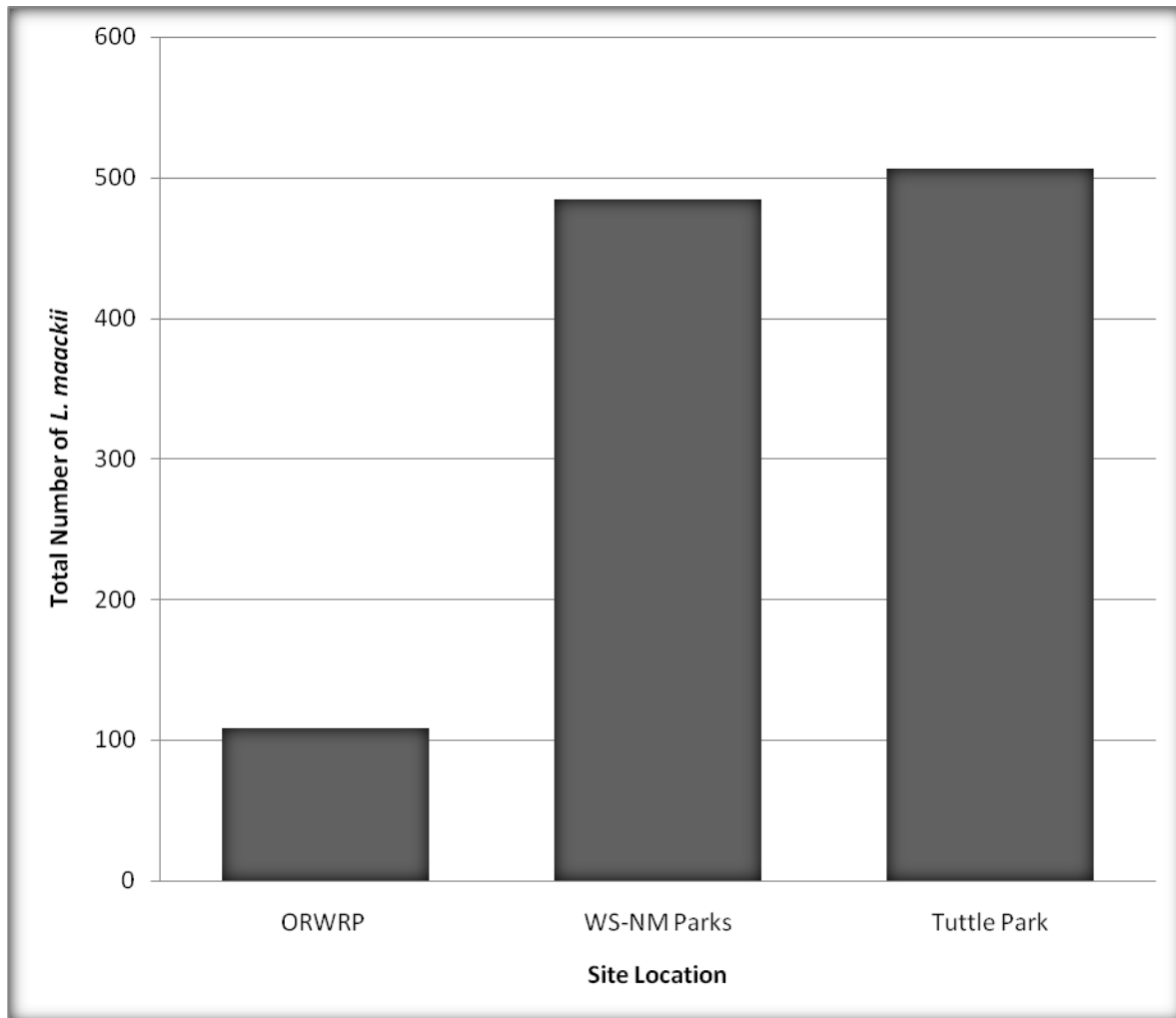
Figure 5. Total number of *L. maackii* stems sampled across all three study areas. Both the Whetstone-Northmoor and Tuttle Parks had considerably higher levels of *L. maackii* than the ORWRP site.
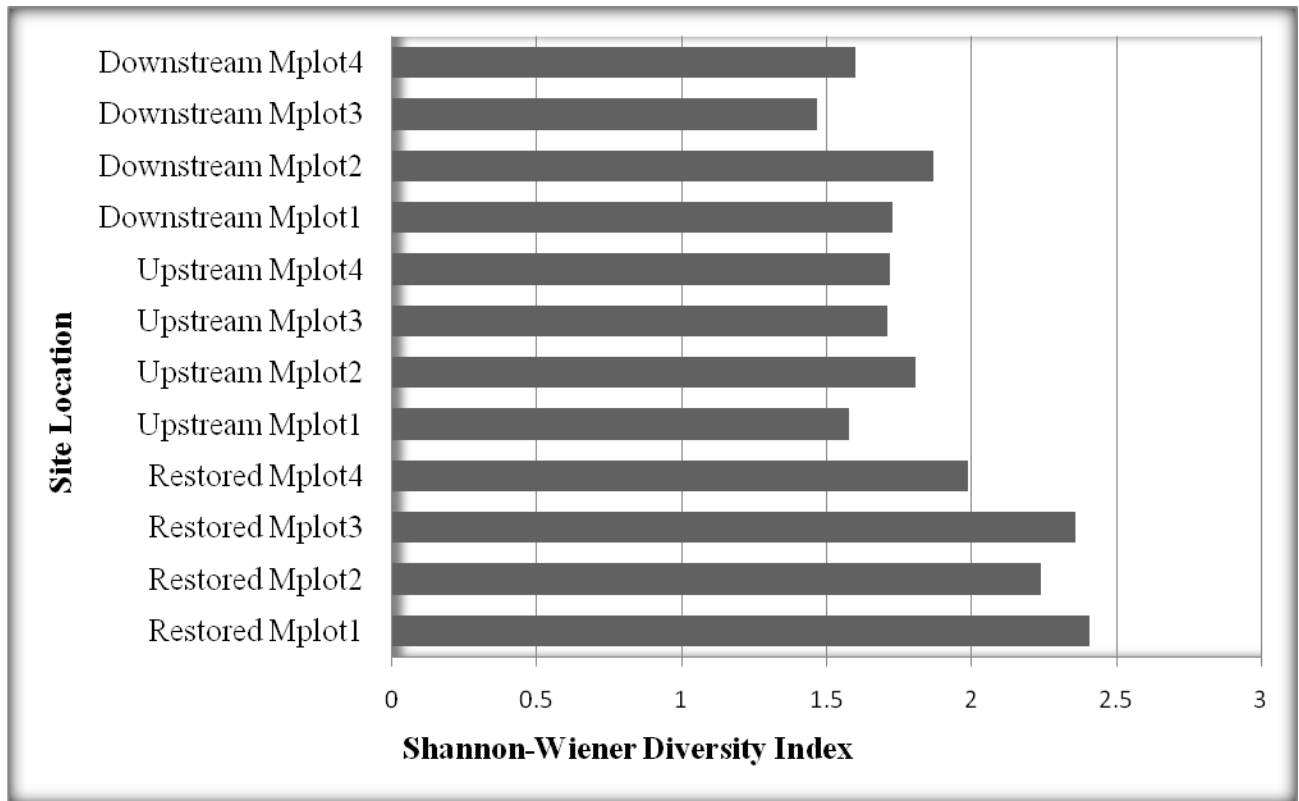
Figure 6. Shannon-Wiener Diversity Index values calculated within macroplots located in each study area. The restored site represents ORWRP, the WS-NM parks are represented by upstream and Tuttle Park is represented by as the downstream site. Tuttle Park generally had the lowest Shannon-Wiener Diversity Index values.

Figure 7. Mean number of *L. maackii* stems sampled, from all macroplots, within each study area. Both the WS-NM and Tuttle Parks mean number of *L. maackii* stems was significantly greater in comparison to the ORWRP site (p=0.05).

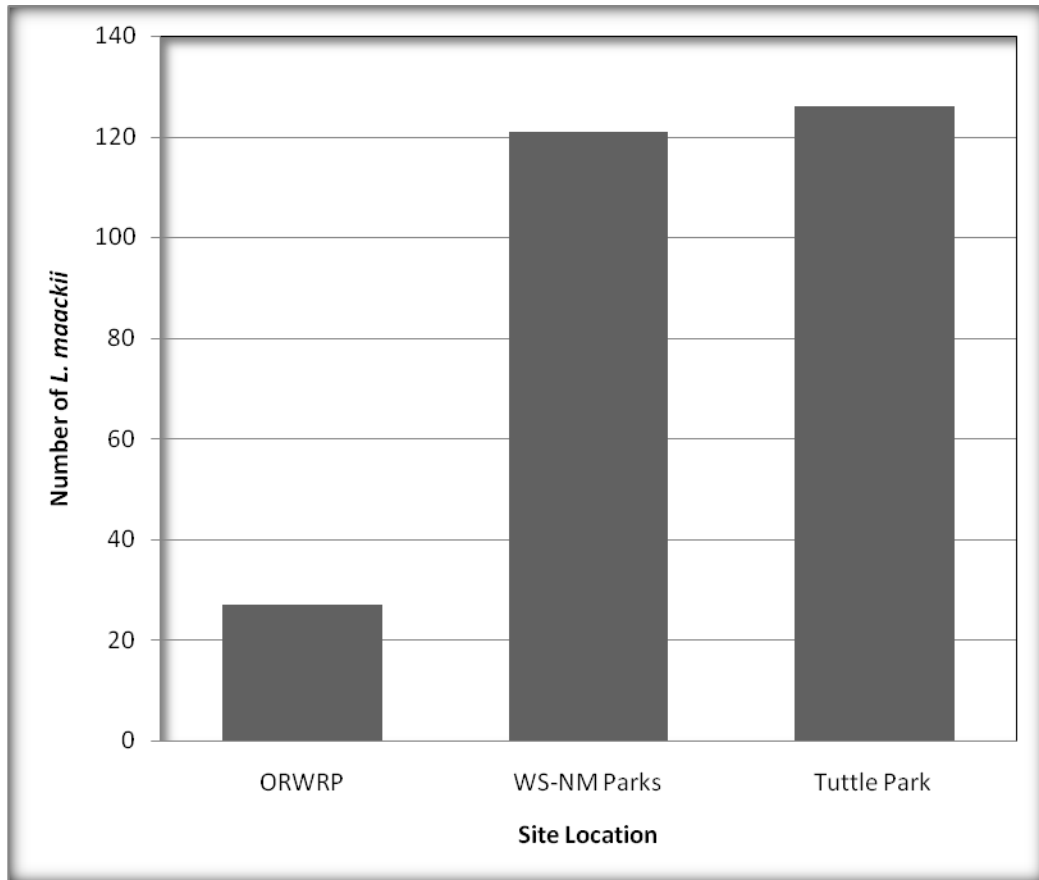| Site Location	<5 m quadrats Density (No./m²)	>5 m quadrats Density (No./m²)
ORWRP Mplot 1	0	0.11
ORWRP Mplot 2	0	0.18
ORWRP Mplot 3	0.45	0.1
ORWRP Mplot 4	0.25	0.13
WS-NM Parks Mplot 1	0.45	0.53
WS-NM Parks Mplot 2	0.45	0.67
WS-NM Parks Mplot 3	0.7	0.52
WS-NM Parks Mplot 4	0.7	0.71
Tuttle Park Mplot 1	0.45	0.75
Tuttle Park Mplot 2	0.55	0.44
Tuttle Park Mplot 3	0.8	0.73
Tuttle Park Mplot 4	0.65	0.62

Table 1. *Lonicera maackii* density per macroplot (Mplot) in each study area and total density per square meter (i.e. 200m² per macroplot; 800m² per study area). The ORWRP represents the restored site, WS-NM Parks represents the upstream non-restored site and Tuttle Park represents the downstream non-restored site.

Site Location	Density (No./m²)	Mean (Avg. No./Total # Mplot)
ORWRP	0.135	27
WS-NM Parks	0.605	121
Tuttle Park	0.633	126

Table 2. Density and mean number of *L. maackii* for the three study areas. Density was calculated by the total number of *L. maackii* stems sampled, per site, divided by the study area size (800 m²). The mean number of *L. maackii* stems sampled within the three study areas, was calculated as the total number of stems divided by the number of macroplots per site (4).

Site Location	S-W Diversity Index
ORWRP Mplot 1	2.41
ORWRP Mplot 2	2.24
ORWRP Mplot 3	2.36
ORWRP Mplot 4	1.99
WS/NM Mplot 1	1.58
WS/NM Mplot 2	1.81
WS/NM Mplot 3	1.71
WS/NM Mplot 4	1.72
Tuttle Park Mplot 1	1.73
Tuttle Park Mplot 2	1.87
Tuttle Park Mplot 3	1.47
Tuttle Park Mplot 4	1.60

Table 3. Shannon-Wiener Diversity Index Values for each macroplot within each study area. ORWRP represents the restored site, WS/NM represents the upstream non-restored site and Tuttle Park represents the downstream non-restored site. The ORWRP has the highest overall S-W index values, while Tuttle Park has the overall lowest index values for the three study areas. There were significant differences between the ORWRP and both non-restored sites.

Species	ORWRP	WS/NM Parks	Tuttle Park
Fraxinus pennsylvanica	8	1	11
Populus deltoides	20	2	8
Acer saccharinum	20	24	29
Acer negundo	95	71	80
Acer saccharum	8	2	5
Staphylea trifolia	10	0	7
Ulmus rubra	10	13	0
Aesculus glabra	23	10	17
Viola canadensis	45	0	0
Platanus occidentalis	5	1	0
Celtis occidentalis	1	26	9
Lonicera maackii	57	149	174
Fagus grandifolia	21	6	22
Unknown Tree	15	10	5
Unknown Shrub	18	2	2
Myosotis scorpioides	20	22	0
Asimina triloba	5	2	0
Solidago canadensis	7	0	0
Liriodendron tulipifera	3	0	3
Tilia americana	5	0	2
Total #:	396	341	374

Table 4. Total number of individuals for all species recorded within each study area.

Site Comparison	t-calculate	p-value
Overall Density		
ORWRP/WS-NM Parks	10.04	0.03*
ORWRP/Tuttle Park	7.453	0.01*
WS-NM Parks/Tuttle Park	0.346	0.77
Density <5 m		
ORWRP/WS-NM Parks	3.06	0.09
ORWRP/Tuttle Park	3.312	0.06
WS-NM Parks/Tuttle Park	0.361	0.73
Density >5 m		
ORWRP/WS-NM Parks	9.265	0.03*
ORWRP/Tuttle Park	6.899	0.03*
WS-NM Parks/Tuttle Park	0.32	0.79
Overall Frequency		
ORWRP/WS-NM Parks	6.971	0.03*
ORWRP/Tuttle Park	6.971	0.03*
WS-NM Parks/Tuttle Park	0	0.63
Frequency <5 m		
ORWRP/WS-NM Parks	1.964	0.28
ORWRP/Tuttle Park	5.196	0.03*
WS-NM Parks/Tuttle Park	3	0.14
Frequency >5 m		
ORWRP/WS-NM Parks	7.833	0.03*
ORWRP/Tuttle Park	5.196	0.03*
WS-NM Parks/Tuttle Park	1.567	0.37
S-W Diversity Index		
ORWRP/WS-NM Parks	5.19	0.03*
ORWRP/Tuttle Park	4.583	0.03*
WS-NM Parks/Tuttle Park	0.382	0.77
Density-Basal Area		
ORWRP/WS-NM Parks	1.752	0.04*
ORWRP/Tuttle Park	1.779	0.04*
WS-NM Parks/Tuttle Park	1.927	0.07

Table 5. Randomization tests for *L. maackii* density, frequency, Shannon-Wiener Index Values and basal area between the ORWRP, Whetstone-Northmoor and Tuttle Parks. Randomization tests were conducted with $\alpha=0.05$ and 5000 repetitions. Sample sizes were individual macroplots for each study area, except for density-basal area; samples for this test were based on combined macroplot totals for each study area. *$p< 0.05$.

Site Location	# L. maackii <5 m	% L. maackii <5 m	# L. maackii >5 m	% L. maackii >5 m
ORWRP	14	13%	94	10%
WS-NM Parks	46	42%	438	44%
Tuttle Park	49	45%	457	46%
Total:	**109**	**100%**	**989**	**100%**

Table 6. *Lonicera maackii* overall stem totals and percentage rates for each study area in quadrats <5 m and >5 m. ORWRP represents the restored site, WS-NM Parks represents the upstream non-restored site and Tuttle Park represents the downstream non-restored site. Each study area was composed of 8 quadrats <5 m and 44 quadrats >5 m.