LAND COVER AND IMPERVIOUSNESS IMPACTS

ON INSECT POLLINATOR VISITATION IN LATE SUMMER

by

ANDIE CULBERTSON

(Under the Direction of Jon Calabria)

ABSTRACT

With climate change and urbanization leading to the decline of insect pollinators, there is a need to provide resources for them in urbanized areas. I hypothesize that the higher the level of urbanization, the lower the abundance and diversity of pollinators. This study evaluates imperviousness and land cover impacts on pollinator foraging behavior during late summer. Sites varying in vegetation, imperviousness, and surrounding land cover are observed in this study. The insect data is analyzed to determine if these environmental factors impacted foraging preference. Surrounding landcover effected pollinator abundance, however local imperviousness did not impact overall pollinator metrics. Studies suggest creating habitat patches within urbanized areas may be the most effective method to support insect pollinators within developed areas. Further research should include implementation of the suggested guidelines to validate findings and trends.

INDEX WORDS: Connect to Protect, Corridors, Habitat Fragmentation, Insect Pollinators, Pollinator Decline, Pollinator Gardens, Urbanization

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DEDICATION

I would like to dedicate my thesis to my parents who have worked hard to allow me to experience so many opportunities. I would also like to dedicate my thesis to Austin and Donut, who have been my biggest supporters through my time in graduate school.

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CHAPTER 1

INTRODUCTION

Insect pollinators are an important part of natural ecosystems and agricultural production (Holm 2014; Klein et al. 2007; National Research Council (U.S.) [USNRC] Committee on the Status of Pollinators in North America 2007; Potts et al. 2010). Pollination is an important ecosystem service that supports vegetation critical to human and wildlife survival. Over the past few years, environmental changes have led to a decline in insect pollinators (National Research Council (U.S.) Committee on the Status of Pollinators in North America 2007). This includes the introduction of parasites, pathogens, and invasive, non-native species (Kearns, Inouye, and Waser 1998; USNRC Committee on the Status of Pollinators in North America 2007; Vanbergen et al. 2013). Despite all these environmental changes, the primary contributor to the decline of insect pollinators is the loss of habitat as a result of urbanization (Potts et al. 2010; Vanbergen et al. 2013).

This study evaluates the impacts that differing levels of urbanization and land cover have on the abundance and diversity of insect pollinators. Research questions included in this study, are insect pollinators more abundant and diverse in less developed areas? Which vegetation type attracts insect pollinators? Also, does imperviousness on a local-scale impact pollinator populations? The results of this study contribute to a framework for creating pollinator gardens that are attractive to insect pollinators and promote conservation through creating habitat stepping-stones (Heller and Zavaleta 2009; Hilty et al. 2019).

The Importance of Pollinators

Plant-pollinator interactions lay the foundation for both natural communities and many anthropogenic activities (Holm 2014; Klein et al. 2007; USNRC Committee on the Status of Pollinators in North America 2007; Potts et al. 2010). Because both humans and wildlife rely heavily on the ecosystem services they provide, a significant decrease of pollinators would lead to a loss of various ecosystems and a sharp decline in agricultural outputs. Hand and wind pollination are alternative options, but neither of these methods is as efficient or as widespread as animal-facilitated pollination. Because it has been estimated that about 75% of the vegetation in temperate areas relies on some type of animal-aided pollination, it is important to support pollinators and their habitats to ensure the continued survival of our ecosystems and agricultural practices (Ollerton, Winfree, and Tarrant 2011).

Pollination increases an ecosystem's resiliency by enhancing vegetation reproduction. Although pollination only directly benefits vegetation, enhanced plant reproduction benefits all wildlife living in a community. An increased level of plant material can provide additional food and nesting resources to both vertebrates and invertebrates. This includes resources such as fruits, nuts, seeds, leaves, and woody plant material. If the pollinator population were to decrease significantly, almost all ecosystems would suffer significantly. Because the relationship between wildlife, vegetation, and pollinators is mutually beneficial and co-dependent, the loss of plant-pollinator interactions would lead to a cyclical decline of organisms.

Although not all plants require pollinators to reproduce, self-pollination and wind pollination may cause genetic homogeneity within a plant community. This increases the chances of genetic drift, inbreeding depression, and in more extreme situations, extinction (Hilty et al. 2019; Kearns, Inouye, and Waser 1998). Plant-pollinator interactions enhance genetic

diversity in plant communities. When foraging for floral resources, pollinators transfer pollen from one plant to another. This improves genetic variation, decreasing the chances of a species' extinction when exposed to potentially deadly stressors such as disease, fungi, and harmful insects. Although hand pollination can contribute to genetic diversity in small, controlled settings, wildlife carries pollen much faster and farther in natural communities.

Pollinators are not only important for the survival of natural communities, but also for agricultural activities. Like some vegetation in natural assemblages, not all crop-yielding plants require animal-facilitated pollination to create fruits and reproduce, however it has been studied that insect pollinators enhance the production of thirty-nine of the leading fifty-seven single crops (Klein et al. 2007). The decline of insect pollinators would lead to a drop in the production of crops that rely on animal-facilitated pollination. Furthermore, the quantity of other goods derived from vegetation like fibers used in textiles, raw materials, and food needed for livestock would also be reduced. Although vegetation in agricultural settings would not be affected the same way vegetation in natural setting would, the decrease of crop yields would also have economic consequences due to the decline of outputs.

A drastic loss of insect pollinators would greatly impact the world as we know it today. Even though plant-pollinator interactions only directly affect vegetation, losing those interactions has much greater consequences. As a building block of natural communities and the base of many human activities, the loss of vegetation as a result of pollinator decline would change the world as we know it today. The loss of pollinators has not yet had a major impact on our environment. However, if we continue to ignore pollinator decline without intervening, we will not only suffer the consequences, but the pollinator population would likely struggle to recover.

Urbanization, Habitat Fragmentation, and Insect Pollinators

As the desire to live closer to urban centers increases, more infrastructure is continually being built to accommodate a growing urban and suburban population (Parker et al. 2018; United Nations 2018). The increase of impervious surfaces and infill has fragmented landscapes that were once areas of continuous habitat, into small patchy spaces. Altering large areas of habitat, also known as habitat fragmentation, decreases the amount of livable space and resources available for insect pollinators and makes foraging more difficult (Hilty et al. 2019; Kearns, Inouye, and Waser 1998; Xiao et al. 2016). The effects that habitat fragmentation and urbanization have on insect pollinators vary from species to species depending on how well they adapt to urbanization (Frankie et al. 2005; Kearns, Inouye, and Waser 1998; McKinney 2002; 2006). Although the loss of high-quality habitat has been suspected to be a main contributor to non-managed pollinator decline, more recent studies suggest otherwise indicating the need to continue studying pollinator populations (Crossley et al. 2020; Hall et al. 2017; McKinney 2002; Kearns and Inouye 1997; Kearns, Inouye, and Waser 1998; Harrison and Winfree 2015; Lewis-Beck, Bryman, and Futing Liao 2012).

When habitat is altered to create new infrastructure, it is usually replaced with buildings, impervious surfaces, lawns, or managed vegetation (McKinney 2002). This leaves small patches of habitat scattered throughout urbanized areas and increases the chances of an insect pollinator dying prematurely because of increased exposure to human activities. Urbanized areas typically have an increased amount of chemical inputs and using them improperly may harm not only pollinators, but a wide range of biological systems. Even when formulated to target specific plant or insect species, some of these chemistries (i.e. neonicotinoids) have been shown to be harmful to pollinators (Goulson et al. 2015; McKinney 2002; Potts et al. 2010; Vanbergen et al.

2013; “What Is a Neonicotinoid?” n.d.). In addition to chemicals, roadways pose a challenge and can inhibit movement from one habitat space to another (Goulson et al. 2015; Hopwood 2013). The level of risk a roadway poses depends on the number of lanes, vehicle speed, and activity level. The wider and busier a roadway is, the greater chance an insect pollinator has of being hit by a moving vehicle. Although smaller roads pose less of a risk than multilane roads, they are still hazardous due to the unavoidability of moving vehicles.

Access to floral resources is another challenge that insect pollinators face in urbanized areas and fragmented habitats. This is not necessarily because of a lack of floral resources, but rather the distance and obstacles between them (Harrison and Winfree 2015; Potts et al. 2010). Areas of high floral density sometimes exist within urban landscapes because of organized flower beds and gardens, however, the distribution of floral resources is more uneven in comparison to natural landscapes (Harrison and Winfree 2015). A higher floral density may be more efficient for insect pollinators when they are foraging, but long stretches of landscapes without floral resources increase the chances of a pollinator becoming stranded. If an insect pollinator runs out of energy, it has little to no chance of surviving. The inability to fly makes it nearly impossible for an insect pollinator to gather any more floral resources (Goulson 2013). This not only means that the insect will be unable to return to its nest to feed its brood, but also has a much higher chance of being eaten by a predator.

The disconnect between fragmented habitats poses many challenges that insect pollinators must overcome. Being isolated in a small habitat patch limits the number of floral resources and nesting spaces (Hilty et al. 2019; Kearns, Inouye, and Waser 1998). Furthermore, smaller habitat spaces place pollinators at a higher risk of extinction compared to large habitats because small population sizes and the lack of inputs increases the risk of inbreeding and genetic

drift (Hilty et al. 2019). Because urban centers are continuing to grow, creating spaces that act as stepping stone corridors allows for insect pollinators to move within urbanized landscapes and can increase connectivity between larger habitats. This may prove to be the most effective method for conservation because it makes access to a wider range of resources and other habitats much easier (Heller and Zavaleta 2009; Hilty et al. 2019).

Pollinator Support in Urbanized Areas

It has been largely agreed upon that habitat loss as a result of urbanization is the largest contributor to insect pollinator decline (Goulson et al. 2015; Potts et al. 2010; Vanbergen et al. 2013; Winfree, Bartomeus, and Cariveau 2011) . However, this does not mean that developed areas are void of resources. Some pollinator species are considered urban adapters or urban utilizers and can live in areas with moderate levels of development, but most are unable to live in areas with heavy development (Fischer et al. 2015; Fortel et al. 2014; McKinney 2002). Urban adapters have acclimated to challenges present in developed areas and may suffer lower extinction rates in comparison to other species. For example, cavity-nesting insect pollinators like Carpenter bees (*Xylocopa* spp.) may take advantage of intentional plantings or holes on built infrastructure and can use these spaces as nesting sites. This not only saves energy and time by using a pre-existing space but will allow for easier nest access and foraging within an urban center. On the other hand, ground-nesting bees like sweat bees (*Halictus* spp.) would have a much harder time finding bare soil to create their nests, due to increased amount of impervious surfaces.

Another benefit urban areas may offer is the availability of floral resources. Managed vegetation and flower beds can provide higher floral density and diversity and may also have

longer bloom periods than vegetation in natural landscapes. In the wake of climate change, insect pollinator emergence and bloom periods are at risk of becoming unsynchronized (Robbirt et al. 2014). Incorporating non-native vegetation into the landscape can extend the time at which floral resources are available when native species may not be blooming.

Significance and Goals

The purpose of this study is to examine environmental variables such as imperviousness, vegetation type, and land cover and their impacts on the abundance and diversity of insect pollinators using nondestructive sampling methods. By studying how urbanization affects the behavior of insect pollinators, the design and placement of future pollinator gardens can serve a greater number and diverse population of insect pollinators.

The analysis segment of this experiment requires some knowledge using geographic information systems (GIS) and statistical software. At the same time, however, the data collection method of this experiment is simple and follows similar guidelines already used to easily engage a public audience. With the assistance of professionals, students and educators can perform similar studies as completed in this thesis. To educate the public and extend conservation efforts, the methods used in the study present opportunities to incorporate a community science (also referred to as citizen science) and educational component for future studies.

Limitations and Vulnerabilities

Data availability was the most significant limitation of this study. GIS land cover data from the Multi-Resolution Land Characteristics Consortium (MRLC) was available, but the data

has a limited resolution of 30-meter by 30-meter grid cells and was last updated in 2016. Athens-Clarke County (ACC) Unified Government has GIS data of all impervious surfaces in the county which was mapped in 2018. Although this data has a much higher resolution and was more recently created, it does not include roads or large portions of sidewalks. Because of these discrepancies and the time it would have taken to make the ACC data more precise, the National Land Cover Data (NLCD) from the MRLC was selected for this study to examine imperviousness.

During data collection, site access became an unexpected limitation. Due to heavy rain jeopardizing infrastructure, the North Oconee River Park site was inaccessible from September 1, 2020 through September 3, 2020. Because of this, data collection only occurred three times at this location rather than six. In addition to site access, the data collection times are less varied due to its isolated location between the other study sites.

The intention of this study is to contribute to insect pollinator conservation. Although creating spaces that provide floral resources and nesting spots should in theory be beneficial, they are vulnerable to becoming ecological traps. When an animal suffers a negative outcome because it selects a habitat to occupy due to favorable conditions, it becomes an ecological trap (Robertson and Hutto 2006). Habitat alterations that can create ecological traps must either increase a habitat's attractiveness, decrease its suitability, or do both at the same time (Robertson and Hutto 2006). By making spaces that provide floral resources and nesting spots, a location that was once an unfavorable habitat will begin to attract more insect pollinators. This can lead to them being stranded within an urban core and increase their risk of being exposed to potentially dangerous environmental changes. Additionally, an increased number of insect pollinators consistently visiting the same location may also attract a higher number of predators to the same

area. The likelihood of these negative outcomes occurring varies depending on the location. However, considering these vulnerabilities are important when designing and implementing new pollinator spaces.

Delimitations

The first delimitation for this study was the data collection period and data set size. Unlike many other insect pollinator studies, data was only collected for a portion of one season. The limited data collection period limits the insect and vegetation species examined in this study. The suggestions and designs in this study may not be beneficial for insects that are either no longer foraging in the late summer or are nocturnal. This eliminates most moth species and some spring foraging pollinators such as mason and mining bees (Sculueter 2020). The collection of insect visitation data is also limited in this study. An increase in data collection sessions could lead to a more accurate analysis of pollinator visitation. Further research is required to understand how spring and early summer flowering plant species and nocturnal insect pollinators respond to environmental factors along an urban gradient.

As the seasons change, floral resource composition also changes. Although unintentional, the data collected for this study only assessed perennial vegetation. Preferred sampling includes observing insect pollinators over spring, summer, and fall to best understand their response to annual vegetation versus perennial vegetation. Many lists of pollinator-attractive plants already exist. However, with more research, a more detailed plant list that attracts insect pollinators based on seasonality and species could maximize the potential of pollinator gardens and could serve specific guilds.

Another delimitation set for this research was the proximity of the study sites. The locations selected to collect data were chosen for convenient sampling. Some of the study sites are located near each other to ensure the completion of data collection in one day. To understand how imperviousness and land cover alter the abundance and diversity of insect pollinators in more detail, more locations with a smaller gradation of imperviousness and land cover could be selected and studied by multiple researchers.

The final delimitation set was the identification of insects. The method of insect identification varies from study to study ranging from the use of destructive sampling, capture and releasing, or pan trapping. Data collection methods that are non-destructive are used in this study because it focuses on land use composition and its influence rather than on specific insect species. Using observational methods to collect insect data limits identification, therefore families are used to measure diversity. The total pollinator abundance and diversity in this study do not include beetles or true bugs although they may still contribute to pollination. This is based both on literature and my lack of knowledge of these morphogroups. Further research should focus on insect composition to further the design of pollinator gardens aimed at serving specific species.

CHAPTER 2

LITERATURE REVIEW

This study seeks to increase insect pollinator connectivity in urbanizing areas. Although research suggests exposure to chemicals, pathogens, parasites, and exotic species contributes to the decline of pollinators, urbanization is arguably the largest contributor to habitat loss and pollinator decline (Kearns and Inouye 1997; Kearns, Inouye, and Waser 1998; McKinney 2002; 2006; 2008; Potts et al. 2010; Vanbergen et al. 2013). Increasing levels of urbanization fragments large habitat spaces. To better accommodate pollinators, planning prior to development needs to occur. Studies have shown that mitigating threats and planning for climate change are effective methods of increasing biodiversity, however, increasing connectivity between habitats was the most effective conservation method and was frequently suggested by researchers (Heller and Zavaleta 2009). Because there is a lack of habitat in urbanized areas, providing stepping stones of floral resources and nesting spaces may be the most useful method of contributing to pollinator conservation in developing areas (Hilty et al. 2019).

Although development and urbanization are linked with insect pollinator decline, there is still a need to study the relationship between landscape context and pollinator behavior (Geslin et al. 2016; Harrison and Winfree 2015; Kearns and Inouye 1997; Kearns, Inouye, and Waser 1998; McKinney 2002; 2006; 2008; Potts et al. 2010; Vanbergen et al. 2013). Researchers examining pollinators over various scales have found both local and landscape-scales impact pollinator populations. Competing results imply that regional context plays a role in how development and land cover affect pollinator abundance and diversity but is not well understood. Flower

abundance and nesting location availability have also been attributed to impacting pollinator foraging behavior and edge effects suggesting that future research may be applicable to areas with similar environmental characteristics (Kohler et al. 2008). To more accurately understand how urbanization impacts pollinator populations, studies should examine the regional context and local environmental qualities.

Urbanization and Classification

Urbanized centers have higher percentages of impervious cover because of the increased number of buildings, roads, and hardscapes. When measuring urbanization for ecological studies, imperviousness is a surrogate for development intensity because higher levels of impervious surfaces may indicate less habitat (Mcintyre and Hostetler 2001). At the same time, however, pervious surfaces such as lawns do not meaningfully contribute to insect pollinator habitat. Researchers examining insect pollinators frequently look at land cover types to account for environmental characteristics that imperviousness data does not capture (Lewis et al. 2019; Pardee and Philpott 2014; Plascencia and Philpott 2017; Quistberg, Bichier, and Philpott 2016). This allows for the examination of variables, such as tree cover and land use, when studying the impacts of urbanization on pollinators.

The MRLC utilizes regression tree models derived from land cover and land-use data to determine imperviousness (Yang et al. 2003). Each grid cell has an estimated margin of error ranging from approximately 9% to 11% (Yang et al. 2003). Although the calculated imperviousness percentage may not be exact, urbanity is frequently classified into levels of urban intensity based on a range of percentages. (McKinney 2002; 2008; "National Land Cover Database 2016 Legend" 2016) The NLCD classifies developed areas as < 20% imperviousness

open space, 20% ≥ 49% imperviousness as low intensity development, 50% ≥ 79% imperviousness as moderate intensity development, and < 80% imperviousness as high intensity development ("National Land Cover Database 2016 Legend" 2016). The non-developed land cover types have the assumption of < 20% imperviousness and environmental characteristics determine their classification ("National Land Cover Database 2016 Legend" 2016). Another imperviousness percentage range used in research suggests that < 20% imperviousness is a low level of urbanization, 20% ≥ 49% imperviousness is a moderate level of urbanization, and < 50% imperviousness is a high level of urbanization (McKinney 2002; 2008). When examining conservation, urbanization, and biodiversity, these ranges represent various levels of urbanity (McKinney 2002; 2008). Because pervious surfaces provide space and vegetation for habitat, this smaller range of imperviousness percentages may more accurately capture the needs of wildlife.

Researchers offer differing opinions of local and landscape-scales. While some considered anything under a 750-meter radius local, others consider this same distance a landscape-scale (Pardee and Philpott 2014). A 500-meter radius was most commonly used when examining land cover effects on insect pollinators, however, radii ranged from 200 meters to 3,000 meters (Geslin et al. 2016; Hegland and Boeke 2006; Matteson and Langellotto 2010; Sivakoff, Prajzner, and Gardiner 2018; Steffan-Dewenter et al. 2002). Studies show examining landscape-scales between 250- and 750-meter radii yielded similar results when predicting pollinator guild distribution (Steffan-Dewenter et al. 2002). Capturing a land cover radius of at least 250 meters could implicate insect pollinator guild populations and impacts on a larger scale, but this should be further studied.

Data Collection Conditions and Methods

Insect data is best collected on sunny days with little to no wind (Ahrné, Bengtsson, and Elmqvist 2009; Bates et al. 2011; Fortel et al. 2014). However, in previous studies, light wind and scattered cloud coverage were also acceptable conditions (Ahrné, Bengtsson, and Elmqvist 2009; Bates et al. 2011; Fortel et al. 2014). When cloud coverage was heavy or wind speeds exceed greater than fifteen kilometers per hour (9.32 miles per hour) researchers no longer considered weather conditions "good" (Ahrné, Bengtsson, and Elmqvist 2009; Bates et al. 2011; Fortel et al. 2014). Researchers observing insects suggested various times at which data collection should occur. Some collected data based off sunrise and sunset, while others indicated specific times (Ahrné, Bengtsson, and Elmqvist 2009; Fishbein and Venable 1996; Kark et al. 2007; Kohler et al. 2008; Pardee and Philpott 2014). Gathering data based on sunrise is important when considering ambient temperature requirements. 65°F (18°C) is the minimum suggested ambient temperature when collecting insect data during the summer (Fortel et al. 2014; Frankie et al. 2005; Kohler et al. 2008; Wojcik et al. 2008). The earliest specified times researchers suggested to collect insect data was at 9:00 A.M. (Ahrné, Bengtsson, and Elmqvist 2009). Because of the time and temperature constraints, the earliest time data collection could occur was at 8:00 A.M., which was always at least one and a half hours after sunrise and at least 65°F (18°C) (Fishbein and Venable 1996).

The simplest non-destructive method of collecting insect data is counting all insect pollinators that land on a single plant during a specified observation period ("The Great Georgia Pollinator Census" 2020). This method is currently used by individuals participating in The Great Georgia Pollinator Census. However, studying a single plant could skew the results of the overall diversity if specific insect species were particularly attracted to the observed plant

species. To better capture pollinator composition and vegetation, study plots would need to be established. Plots between one square meter and three square meters were the most common size when studying insect pollinators (Ahrné, Bengtsson, and Elmqvist 2009; Hegland and Boeke 2006; Matteson, Ascher, and Langellotto 2008; Utelli and Roy 2000; Vrdoljak, Samways, and Simaika 2016; Wróblewska, Stawiarz, and Masierowska 2016). However, studies with a lower number of observers utilized smaller study plots to allow for easier examination of insects and vegetation.

Another easy and commonly used method to collect insect data is pan trapping. It involves putting water and soap in a brightly colored tray or bowl to attract and trap insects. Although this hands-off method may be the easiest way to collect insect data, it does not accurately represent insect populations (Cane, Minckley, and Kervin 2000; Popic, Davila, and Wardle 2013). Pan trapping collects invertebrates that fly into a study area, but this data collection method does not indicate any plant visitation because the color of the bowls may influence insect behavior (Cane, Minckley, and Kervin 2000). Because this study examines the attractiveness of a specific location and the available floral resources, utilizing this method could have greatly skewed the data by not accurately capturing plant visitations.

Sweep netting is another method used to collect insect visitation data. Although this technique may lead to more accurate results in comparison to pan trapping, it may still have bias towards insects that land on the top portion of vegetation (Buffington and Redak 1998; Cane, Minckley, and Kervin 2000; Doxon, Davis, and Fuhlendorf 2011). Furthermore, sweep netting may break vegetation which would impact future insect data collection and go against the wishes of property owners (Buffington and Redak 1998; Doxon, Davis, and Fuhlendorf 2011). Although

sweep netting may not have been destructive towards insects, the potential breakage of plant material and habitat destruction made this method unfavorable.

Data Exploration and Analysis Methods

Data exploration, also referred to as exploratory data analysis (EDA), is one of the first steps of analyzing data (Liu et al. 2020; "What Is Data Exploration?" n.d.). It does not answer specific questions about a data set but may indicate any correlations, trends, or errors that appear (Liu et al. 2020; Meyer 2015; "What Is Data Exploration?" n.d.). Exploration frequently includes a data visualization component in the form of charts or graphs. This allows an easier assessment of the data, rather than looking through complex tables and equations (Liu et al. 2020). A basic understanding of the data informs the decision-making process when selecting analysis methods (Liu et al. 2020).

Principal component analysis (PCA) is a data exploration method that simplifies multivariate data sets into individual linear components for easier visualization (Wold, Esbensen, and Geladi 1987; "JMP 15 Help" 2020). This method reduces data dimensions while minimizing data loss and accounts for variability (Jolliffe and Cadima 2016). By using matrix theory, PCAs create principal components from the variables and calculate percentages of variability they represent (Jaadi 2019; Jolliffe and Cadima 2016). Oftentimes the first two to three components capture most of the data's variability but this is not always the case (Jolliffe and Cadima 2016). Arrows in the PCA biplots represent variables, their relationships to each other, and the strength of their impacts (Jolliffe and Cadima 2016; Wold, Esbensen, and Geladi 1987). The relationships between the plotted responses on a PCA biplot and component arrows show the general correlation between the variables (Jolliffe and Cadima 2016). Examining the biplot created by a

PCA shows variable and response relationships which gives a reader a quick summary of data patterns and trends.

Hypothesis testing involves taking a sampled data set and analyzing it to deduct conclusions about a population (Conover 1999). This test occurs in steps starting with the formation of a hypothesis, formulation of a null hypothesis, testing the data, and deciding whether to accept or reject the null hypothesis depending on the results (Conover 1999). The distribution of the sampled data set is important when deciding which analysis method to use. Statistical tests require assumptions to be met to accurately calculate equations. Data sets with normal distributions generally have an increased number of data points near the median and decreases as it approaches the minimum and maximum values, also known as central tendency (Meyer 2015). Visually, datasets with normal distributions generally form a "bell curve" and are symmetrical. Unlike normal distributions, data with non-normal distributions do not have a bell-curved shape. However, they can still be symmetrical around the y axis.

There are two categories that statistical tests fall under, parametric and non-parametric tests (Dinov 2003; "What Is the Difference Between a Parametric and Nonparametric Test?" n.d.). Non-parametric tests do not rely on a normal distribution when applying them and can more frequently analyze data because they have less rigid assumptions (Zar 1999). The downside of using non-parametric methods is that they have less statistical power when analyzing data and are less likely to have a lower p-value in comparison to parametric tests. (Dinov 2003; "What Is the Difference Between a Parametric and Nonparametric Test?" n.d.). However, analyzing a data set with a non-normal distribution with a parametric test requiring a normal distribution would lead to inaccurate calculations and ultimately potentially erroneous conclusions.

Analysis of Variance (ANOVA) is a type of data analysis method that determines how a variable affects an outcome (Zar 1999). Researchers have been using this method to determine environmental impacts on wildlife, however, this method only allows for analysis of a single variable (Fukase and Simons 2016; Gomez and Zamora 1999). Multivariate Analysis of Variance (MANOVA) has grown in popularity because it analyzes more than one variable at a time and new software can easily calculate complex equations (Zar 1999). Although researchers frequently use ANOVA or MANOVA for data analysis, neither of these methods are appropriate for analyzing the data gathered in this study because the required assumptions are not met. (Vieira 2011; Zar 1999). In order for ANOVA/MANOVA to accurately calculate the significance of variables, the data being analyzed must have a normal distribution (Vieira 2011; Zar 1999).

The Wilcoxon Signed-Rank Test is a non-parametric test that can analyze multiple variables (Cuzick 1986). This method has been used by researchers when examining pollinator data with a non-normal distribution (Levé, Baudry, and Bessa-Gomes 2019; Wickramasinghe et al. 2004; Winfree et al. 2007). The Wilcoxon Signed-Rank Test is applicable whenever a paired sample t-test is, but the assumptions are not met (Zar 1999; "Wilcoxon Signed-Rank Test in R (Non-Parametric Equivalent to Paired t-Test)" n.d.). The paired sample t-test evaluates the differences between population means when observations are comparable between samples (Shier 2004). Although this test is not as rigid as ANOVA/MANOVA when it comes to the data having a normal distribution, outliers cause the analysis to become less accurate (Shier 2004).

Informing Design with Landscape Ecology

Landscape ecology is the understanding of landscape dynamics and composition and their effects on ecological processes and interactions (Diaz and Apostol 2000; Forman 1995; Nassauer and Opdam 2008; Turner 1989). It is difficult to change pre-developed spaces to serve ecological functions because of existing infrastructure. However, by starting the design process with ecologically oriented goals and inventory analysis, both human and natural processes can be better served by the landscape and planning practices (Lyle 1999; McHarg 1969).

Research using the fundamentals of landscape ecology starts with a similar basic understanding of the study area, these include characteristics like landscape composition, ecological processes, and resource movement (Diaz and Apostol 2000; Forman 1995; Lovell and Johnston 2009; Lyle 1999; McHarg 1969; Risser, Karr, and Forman 1983; Turner 1989). Some examples of these characteristics are forested areas, migrations, and water flow in and out of the site. However, the basic understandings and inventory gathered should include features outside of the study location. Ecological processes are open systems meaning interactions happening inside of a study location are not independent of interactions occurring outside of it (Diaz and Apostol 2000; Hilty et al. 2019). Effects from ecological processes occur at various levels (Diaz and Apostol 2000; Forman 1995; Lovell and Johnston 2009; Lyle 1999; Nassauer and Opdam 2008; Turner 1989). Some ecological processes occur on a "human scale" while others span over several ecosystems (Diaz and Apostol 2000; Forman 1995). Because ecological interactions occur on various levels, examining multiple scales when studying landscape ecology has become standard practice (Chittka and Raine 2006; Diaz and Apostol 2000; Lovell and Johnston 2009; Lyle 1999; Nassauer and Opdam 2008). Studying various scales was particularly important for

this study due to the foraging distances of insect pollinators and inconsistent results of local and landscape-scale effects on insect pollinators.

CHAPTER 3

METHODS

Gathering data for this study occurred in two phases. The first phase involved site analysis and the second was collecting insect pollinator counts. Landscape analysis included gaining an understanding of the local and landscape-scale environmental characteristics. This knowledge informed the site selection process and ensured that vegetation, imperviousness, and land cover would vary from site to site for a more thorough pollinator impact analysis.

Site Selection and Categorization

During the site selection process, the study locations with higher urban density were selected first because I was familiar with the more developed areas of Athens-Clark County (ACC). All data study sites with moderate to high urban density were located at The University of Georgia (UGA) main campus for convenient sampling. Prior knowledge of the campus was used to select six data collection sites (Figure 1). Each site was conveniently selected to ensure a variety of vegetation, imperviousness, and surrounding land cover located in an accessible area.

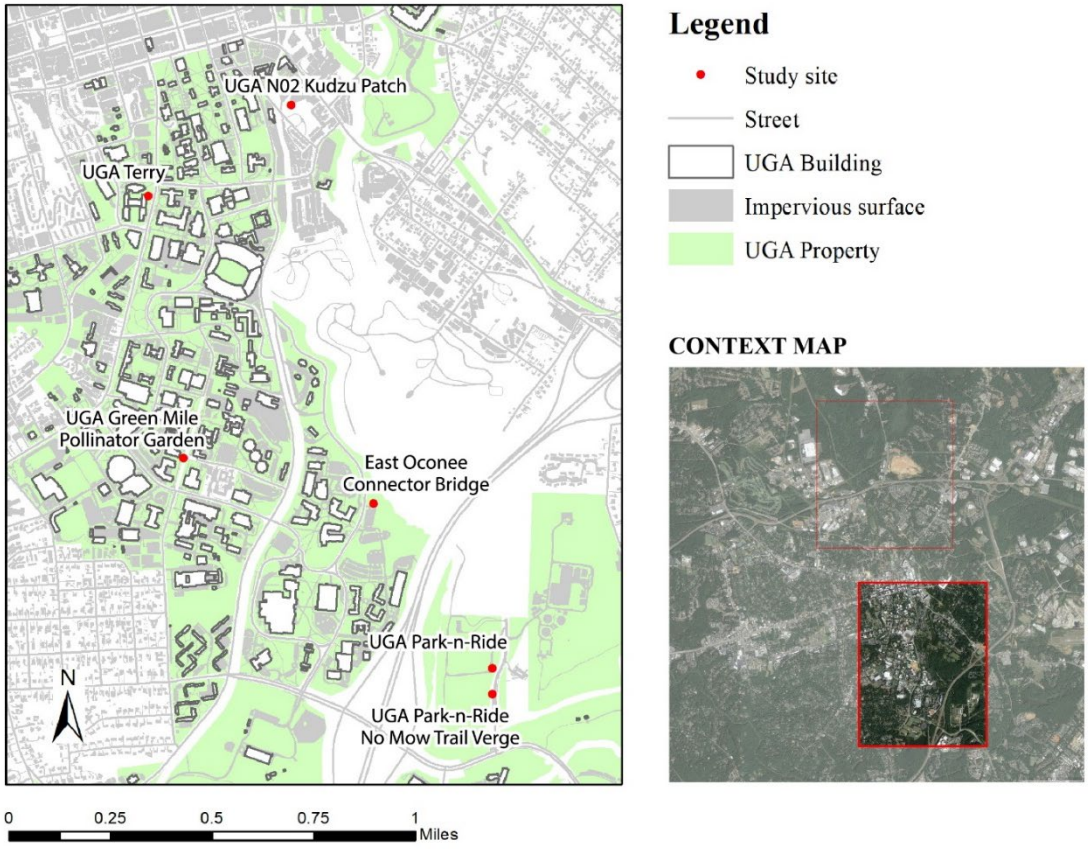

Figure 1: Map of study sites located on UGA property.

To find locations with lower levels of urban density, the ACC Sustainability Office assisted with selecting study locations and receiving a study permit. The Sandy Creek Nature Center (SCNC) and The North Oconee River Park located in Athens, Georgia could provide locations with lower levels of urban density and mixed environmental variables. I chose three locations on SCNC property and one location along The North Oconee River Park Greenway to gather insect visitation data (Figure 2).

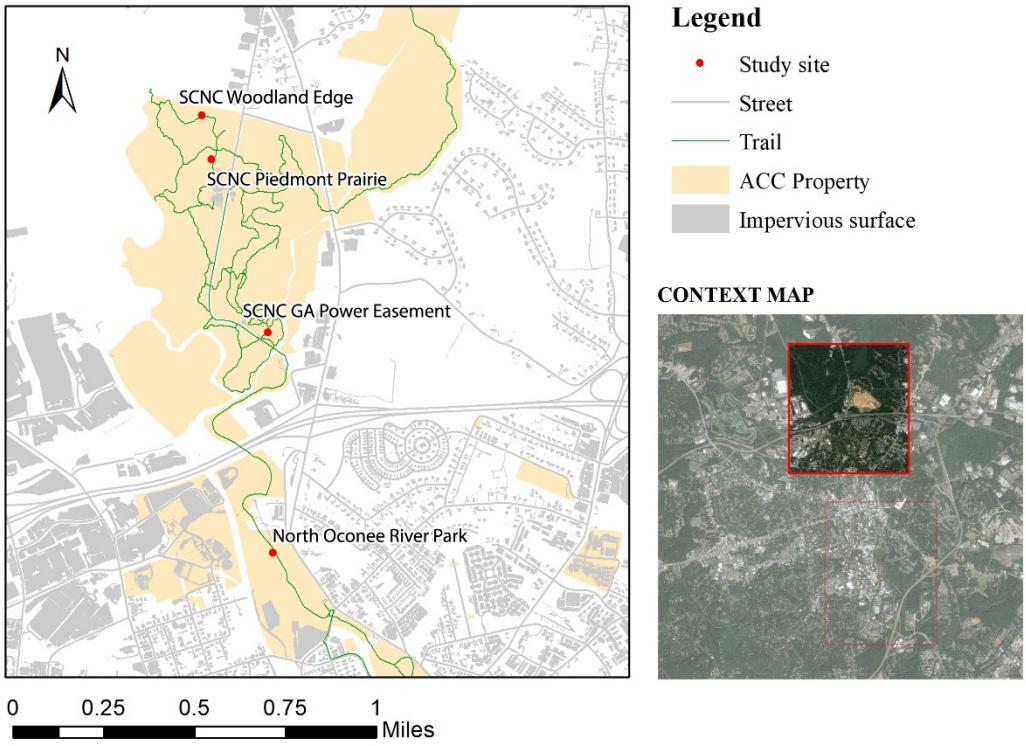

Figure 2: Study sites located on ACC property.

I visited the UGA campus, SCNC, and North Oconee River Park to select the exact areas where data collection would occur. I then selected locations in areas of high urban density and low urban density if they had similar vegetation, goals, or other shared environmental characteristics. All of the selected sites had to have sun exposure and I preferred areas that had blooming flowers. Bloom quantity and quality were not always equal from site to site. For example, the Kudzu (*Pueraria montana*) located that the North Oconee River Park were hardier in appearance and survived longer in comparison to the blooms located in the UGA N02 Kudzu patch. Finally, I measured a five-foot by two-foot square around the selected location to determine which plants would be studied. The same plants were observed during all data collection sessions. Review Appendix B for the list of observed plant species.

After I selected specific locations, I mapped each of them on ArcMap 10.7.1 using road centerlines, trail data provided on the Athens-Clarke County Open Data website, and a campus

footprint provided by the UGA Office of University Architects for Facilities Planning ("ArcMap 10.7.1" 2019). I also imported NLCD data that had I previously clipped to Athens-Clark County into the same data frame.

Due to limitations of site locations and time restrictions, studying a 500-meter radius would have led to the overlap of land cover analysis and study sites for all study sites at either Sandy Creek Nature Center or the UGA campus. Based on the literature, I chose to create a 300-meter buffer for each location and used these radii to clip the land cover data. This length maximized the land cover being examined while minimizing the overlap of study sites, though some overlap still occurred. I used the clipped imperviousness data to determine the land cover surrounding each site by using the calculate area function in the attributes table (Figure 3).

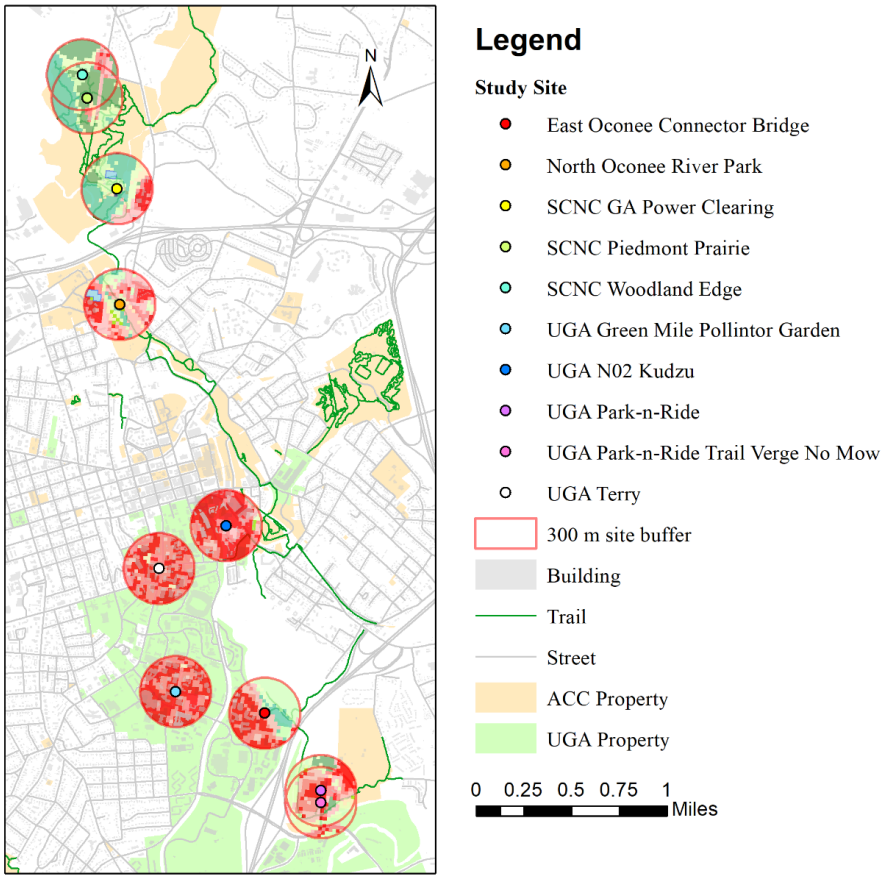

Figure 3: Map with all study locations and 300-meter radius land cover.

I determined local imperviousness using urban imperviousness data provided by the NLCD. The impervious percentage of the grid cell the study site was located in was used as the measurement for study site imperviousness. To determine adjacent imperviousness, the percentages of the grid cell each site was located in was averaged with the eight grid cells surrounding it (Figure 4). The exact values of imperviousness percentages were shown in the information box in ArcMap. When examining imperviousness on a local scale, none of the data collection sites exceed 80% imperviousness in this study. Because of this, the level of urbanization around the study locations was classified into ranges where < 20% imperviousness is considered low urbanization, 20% ≥ 49% imperviousness is considered moderate urbanization, and < 50% imperviousness is considered a high level of urbanization (McKinney 2002; 2008).

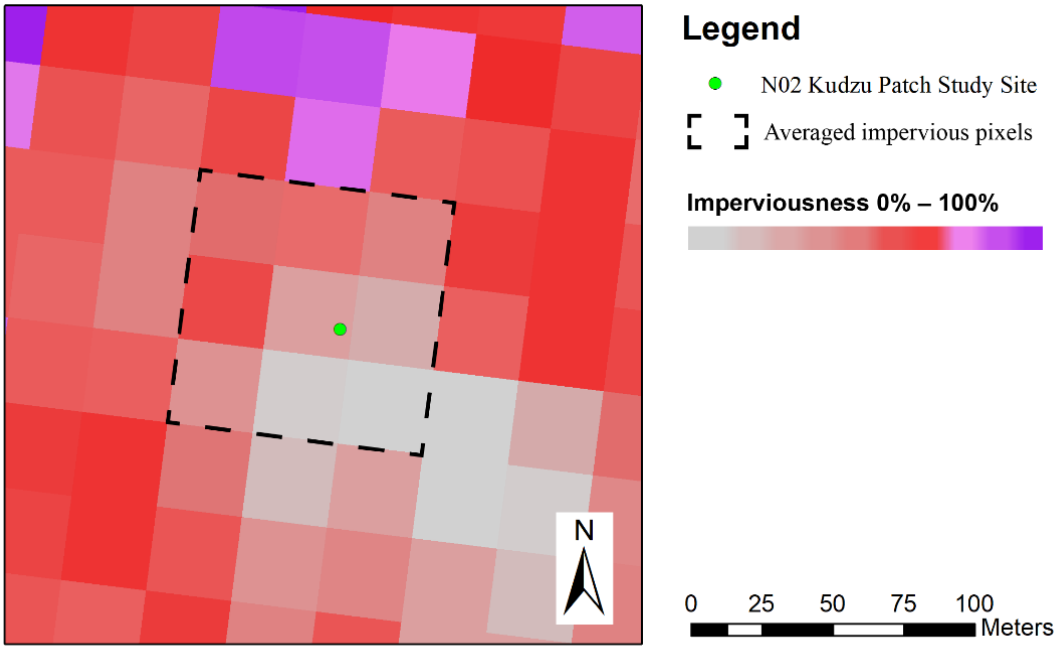

Figure 4: Example of grid cells averaged around the N02 kudzu patch. The exact percentage of imperviousness for each 30 m x 30 m grid cell was available as an attribute in ArcMap.

I also created five typologies to describe site characteristics that GIS data would not capture. The typologies were exotic assemblage, frostweed patch, herbaceous mix, organized bed, and wildflower mix. These were used to hint at whether or not the study locations were intentionally designed or created, naturally occurring, or capture more specific details about vegetation composition. Each typology had to have at least two sites under each category for analysis to be done correctly. Because of the nature of the site locations and surrounding characteristics, this led to some sites within the same typology sharing other site characteristics.

Pollinator Data Collection and Categorization

Data collection occurred on days that were either sunny or had light cloud coverage and had little to no wind. The time frame to collect data was set between 8:00 A.M. and 2:00 P.M. based on literature review and personal time restrictions. Because sun exposure and heat affect insect pollinator foraging behavior, the order of site visitation was rotated. For convenience purposes, sites within proximity to each other were visited in groupings. For this study, the locations were grouped as followed, group one: Sandy Creek Nature Center and North Oconee River Park locations, group two: UGA Terry College and UGA N02 parking lot, group three: UGA Green Mile Pollinator Garden and The East Oconee Connector Bridge, and group four: UGA Park-n-Ride and UGA Park-n-Ride No-Mow Trail Verge. Site visitation within each group was also rotated when collecting data in addition to the rotation of the groups based on proximity to capture insect behavior during various hours of the day for all the study plots.

Because this study is intended to inform educational and community science practices, sweep netting would have made this study much less accessible to a general audience. Collecting data by visual observation was the most suitable method for this study. This method was not only

non-destructive but also did not require the skilled use or purchasing of a sweep net. As an educational component, an observational study method also lowers the risk of getting stung by insects and makes it safer for young children to participate in a study similar to this one.

Upon the arrival of each study location, I recorded the time, temperature, and weather conditions. Next, I set a fifteen-minute timer and recorded and identified all insects that landed on the previously determined vegetation into families. I took photographs of as many insects as possible to confirm on-site identification after data collection was completed (Figure 5). Post-data collection, I recorded insect counts into a spreadsheet identifying insects by scientific name and common name when possible.

Figure 5: Photos taken during insect observation periods. Identification starting from top left moving clockwise: Hesperiidae on *Lobelia cardinalis*, Thynnidae on *Verbesina virginica*, Apidae on *Helenium autumnale*, and Megachilidae on *Gaillardia* sp.

(Culbertson, 2020)

To more accurately understand how the landscape affects insect pollinators, I categorized the gathered data into different groups for analysis. During data collection, I counted all insects regardless if it was a bee, butterfly, fly, or wasp. To begin data organization, I categorized pollinators categorized into their own group to determine the total abundance and diversity of each data collection session. Next, I categorized the pollinator data into groups based on commonly recognized morphological Refer to Appendix A for a summary of observed insect families and morphogroups.

Analysis

Site information, variables, and insect counts were entered into a database ("JMP Pro 15" 2019). Each row consisted of insect data organized by each data collection session. I ran a distribution analysis for both the total pollinator abundance and total pollinator diversity datasets to test if the data had a normal or non-normal distribution. I created normal quantile plots for each dataset examined them to determine what type of distribution the collected data had. The distribution analysis informed which type of statistical test I would need to use to properly analyze the pollinator data.

A "Fit Y by X" analysis was run in JMP Pro 15 to analyze the data ("JMP Pro 15" 2019)s. This method analyzes pairs of factor (X) and response (Y) data and automatically selects the model type depending on the type of data provided ("JMP 15 Help" 2020). Because I made all my environmental factors nominal, and response data was all numerical, the Fit Y by X function automatically applied a one-way analysis of the gathered data. The local imperviousness percentages categorized into groups, typologies, vegetation, and majority land cover within a 300-meter radius were all factors (X) and total pollinator abundance, diversity, and all the

subcategories created were responses (Y). After I completed the Fit Y by X analysis, I also applied a one-way Wilcoxon Signed-Rank Test on all pairings to determine significance. If any significance between the variable and response was found, I used the Steel-Dwass test to examine significant pairings.

After I performed a Wilcoxon Signed-Rank Test was performed on all factors and responses, I entered significant environmental factors with the highest mean rank score and corresponding responses were put into a matrix for further analysis of local characteristics (Refer to Appendix C for matrix). When the significance of a factor was $p<.01$, I highlighted the corresponding box dark green. When the significance was $0.01 < p < 0.05$, I highlighted the corresponding box light green. I then analyzed the environmental factors and pollinator outcomes placed into the matrix to determine any potential relationships between them. I used this matrix to inform the design process and understand how the environmental characteristics may have impacted pollinator behavior.

Site Selection and Site Design

Prior to site design or local analysis, I applied a similar framework used in this study to each selected design location. I examined the 300-meter radius land cover of each site in ArcMap and examined them using the attributes table to determine the land cover area. I compared each site's surrounding land cover to the results of the Wilcoxon Ranked Signed Test completed during data analysis. This comparison was used to create a hierarchy for the proposed sites from the predicted highest pollinator abundance to the lowest.

I performed a landscape analysis following methods proposed in the literature (Diaz and Apostol 2000; Lovell and Johnston 2009; Lyle 1999). The process began with an analysis of the

sites and potential insect pollinator movement in and out of the locations. First, I located the areas that posed risks such as fast-moving traffic. Next, I drew green arrows to show the safest pathways to areas with floral resources, nesting resources, or a large habitat space. I intentionally drew these pathways to be as short as possible while avoiding high levels of impervious surfaces, fast-moving vehicles, and densely built infrastructure, however avoiding areas that pose risk was not always possible. I utilized this context analysis along with the analysis of the surrounding land cover to determine whether a selected location posed too many risks or did not have enough linkages to other habitats. Site visits were conducted after context analysis to confirm landscape features and vegetation to assist the site design process.

I revisited the hierarchy created using land cover to ensure it accurately represented the suitability of each site. Maps were created for the locations that were determined to be good locations for placing a pollinator garden or habitat. Bubble diagrams for the desired garden location were created to determine where signage, pathways, and certain plantings should be located. I selected plant species from an approved Connect to Protect plant list based on desired beneficiaries, sun needs, moisture needs, and bloom periods to fulfill the established requirements. I also created plant mixes to create a more naturalistic aesthetic with a randomized plant distribution. Furthermore, plant species that were not included in a mix were chosen to be planted as masses for easier planting and maintenance. For design recommendations that did not involve a specific planting plan, observations I made during the data collection period were applied to the area rather than selecting specific plants from the provided Connect to Protect list. If a proposed site was deemed as a poor location for creating a pollinator garden, further explanation of site details, risks, and potential alternatives were proposed if applicable.

CHAPTER 4

RESULTS AND DISCUSSION

The results and discussion of this research should act as a guide to creating effective pollinator habitats and gardens in urbanized areas. The outcomes and suggestions are only applicable to Athens-Clarke County and species active during late August and early September. Although the methods in this study can be applied in other settings with similar conditions, they may not yield the same results.

Data exploration

Data exploration was completed using a PCA. Two analyses were run with all majority land cover percentages and average 90 square meter imperviousness as column (Y). However, the supplementary values (Z) for one analysis examined abundance metrics, and the other examined diversity metrics. The PCAs were analyzed and represented with biplots to allow for the summary plots to be read more easily (Figure 6).

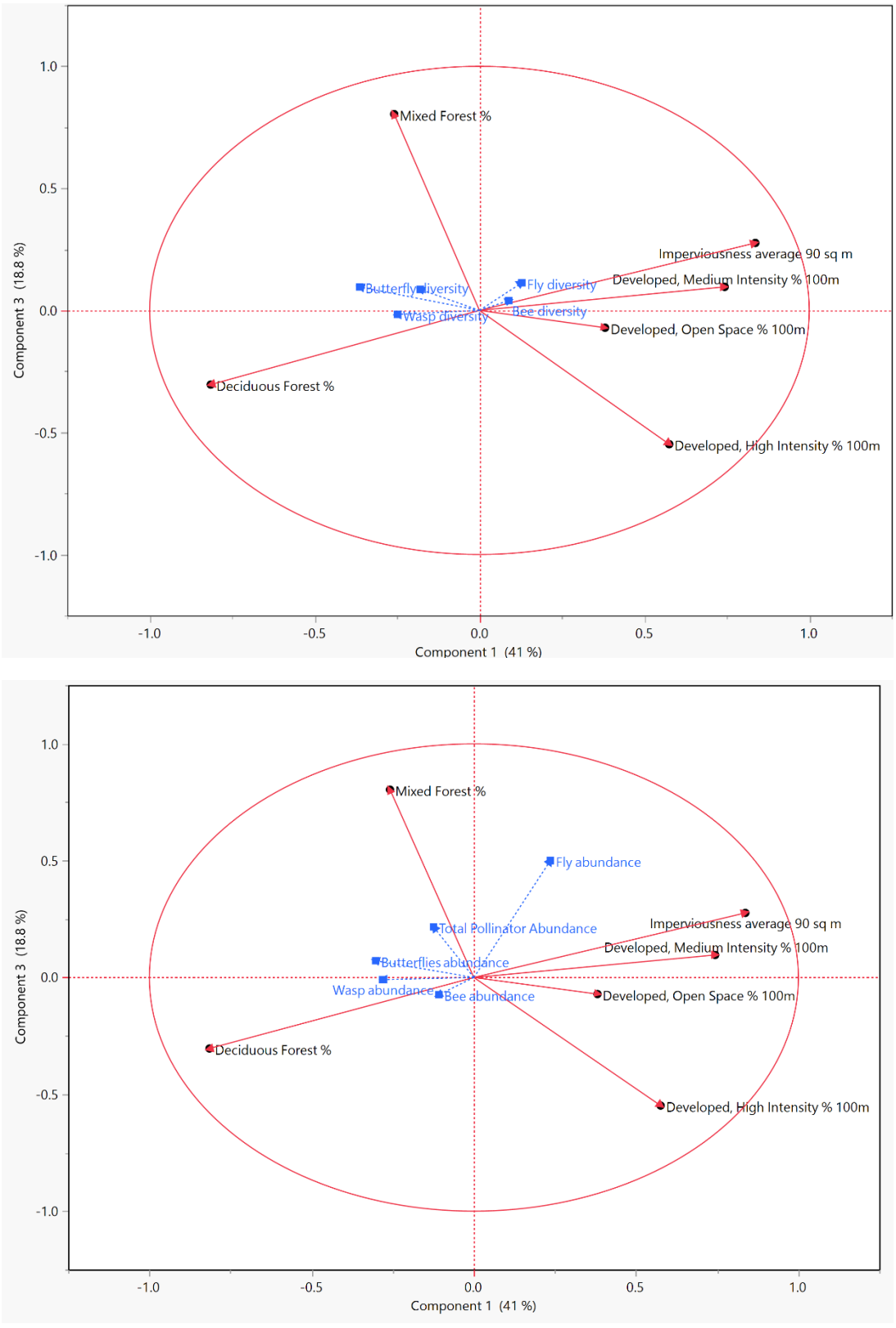

Figure 6: The top chart shows the PCA biplot for diversity and the bottom chart shows the PCA biplot for abundance.

Both PCAs were calculated using principal components one and three. Although components one and two captured about sixty-five percent of the data variance, a significant drop in the scree plot occurred after component three and had an eighty-four cumulative percent. Refer to Appendix E for summary plots, eigenvectors, eigenvalues, and scree plots.

Examining the abundance summary plot, most pollinator morphological groups negatively correlated with types of land cover with increased levels of impervious surfaces. Both fly diversity and abundance had a positive correlation to areas with higher levels of imperviousness. Although bee abundance still had a positive correlation to mixed forest land cover, it was less affected than butterflies and wasps. One detail that may guide future directions of plant species selection by location is the negative correlation between butterflies and wasps to medium and open intensity development. This could point to future pollinator garden siting being catered to wasps and butterflies being outside urbanized areas, whereas bees and flies could be guided through them.

Results

The Wilcoxon Signed-Rank Test indicated there was a significant difference between scores given for medium intensity development and deciduous forest compared to the other land covers within a 300-meter radius of each site and their impacts on total insect pollinator abundance, $\chi^2 = 12.6938$, $p < 0.0129$. The mean rank scores for medium intensity development and deciduous forest were much higher than other types of land cover. This suggests that locations surrounded mostly by medium intensity development or deciduous forest within a 300-meter radius will have a higher pollinator abundance than locations surrounded mostly by open space development, high intensity development, or mixed forest. An additional analysis

combining mixed forest and deciduous forest into a single forest group was conducted with similar significant results, $\chi^2 = 11.3166$, $p < 0.0101$. Although the surrounding majority land cover impacted total pollinator abundance, total pollinator diversity did not have any significant difference between surrounding land covers.

Total pollinator diversity showed a significant difference, $\chi^2 = 6.6331$, $p < 0.0363$, between immediate site imperviousness. A moderate level of site imperviousness was the only variable that had a negative standardized score. Low and high levels of site imperviousness scored closely, suggesting these two landcovers may preferred over moderate levels of urbanization. For further details of Wilcoxon Signed-Rank Tests, refer to Appendix D.

Upon further analysis, butterfly diversity and abundance and fly abundance were the only morphological groups that had a significant difference when analyzing the 300-meter radius land cover. When analyzing fly abundance using the Wilcoxon Signed-Rank Test, a significant difference, $\chi^2 = 17.7074$, $p < 0.0014$, was found between medium intensity development and other land cover types with deciduous forest scoring the second highest. Local-scale urban density also showed a significant impact, $\chi^2 = 6.0254$, $p < 0.0492$, on fly abundance with a high level of urbanization having the highest mean rank score. Surrounding medium intensity development and high levels of local imperviousness had increased fly counts. These two environmental factors can act as predictors of increased fly abundance when creating pollinator gardens in urbanized spaces.

Butterfly abundance and diversity had significant differences for the same environmental factors. The majority land cover, local imperviousness, and typology all had the greatest significant difference on butterfly metrics (Table 1, Table 2). Although butterflies are not ground-nesting insects, the environmental factors with low levels of imperviousness (deciduous

forest and low levels of local imperviousness) consistently scored higher than those with higher levels of imperviousness (high intensity development, medium intensity development and moderate and high levels of local imperviousness).

Table 1: Wilcoxon Oneway Test, ChiSquare Approximation for butterfly abundance.

Factor (variable)	ChiSquare	DF	Prob > ChiSq
300 meter radius majority land cover	13.8698	4	0.0077
90 square meter imperviousness	6.9387	2	0.0311
NLCD Site imperviousness	8.0254	2	0.0181
Typology	16.8699	4	0.0020

Table 2: Wilcoxon Oneway Test, ChiSquare Approximation for butterfly diversity.

Factor (variable)	ChiSquare	DF	Prob > ChiSq
300 meter radius majority land cover	14.0566	4	0.0071
90 square meter imperviousness	7.0635	2	0.0293
NLCD Site imperviousness	7.6553	2	0.0218
Typology	17.8616	4	0.0013

Bees were the only other morphogroup that showed any significant difference, using the Wilcoxon Signed-Rank Test. Unlike butterflies and flies, the 300-meter radius majority land cover did not have any significant difference. Instead, local imperviousness (NLCD Site Imperviousness Groups) had a significant difference, $\chi^2 = 6.4116$, $p < 0.0405$ with high levels of local urbanization scoring the highest, however, this data may be skewed due to the nature of the study areas.

Discussion

The number of flies observed was disproportionately higher than any other morphogroup when examining sites surrounded mostly by medium intensity development or had high local imperviousness. Furthermore, long-legged flies (*Dolichopodidae*) were the most frequent visitors. The increase in human activity may contribute to the increased abundance of flies. The presence of trash and food may attract flies to areas of higher imperviousness and development, despite the lack of decaying organic material or fecal matter which are also commonly associated with the presence of flies.

The sites with deciduous forest as the majority surrounding land cover are all far from areas with concentrated development. A butterfly's need for increased plant material for egg-laying could be a contributing factor to a decreased abundance and diversity in areas with higher levels of imperviousness. However, this is not confirmed and is just conjecture. Further research is required to understand butterflies' preference for areas of lower imperviousness.

The UGA Park-n-ride No-Mow Trail Verge and UGA Green Mile Pollinator Garden are the only two locations that have high levels of adjacent imperviousness, but both of these locations were intentionally created to attract pollinators. This result suggests that high levels of imperviousness do not deter bees from foraging in highly urbanized areas if floral resources are available. This was not an expected result and further studies are needed to confirm these findings.

When analyzing all environmental factors, the typologies created for this study most frequently had a significant difference with eight groups showing significant differences. For all the responses where typologies had a significant difference, the "Frostweed patch" typology always scored the highest (Table 3). Based on the shared characteristics of the Frostweed patch

study sites, I recommend densely planting Frostweed (*Verbesina virginica*) in areas with lower levels of imperviousness or nearby forested areas to attract late summer foraging pollinators. I also recommend minimizing mowing and allowing the vegetation to go through life cycles. Although this typology was shown to have a significant difference on total pollinator abundance, $\chi^2 = 19.8454$, $p < 0.0005$, and diversity, $\chi^2 = 22.7822$, $p < 0.0001$, this study only examines pollinators that forage during late August and early September.

Table 3: Table showing all the responses where typology (x) had a significant difference. The frostweed score is the only typology shown because it always scored the highest where typologies were significant.

Response	p-value	Frostweed standardized score
Total Pollinator Abundance	0.0005	3.967
Total Pollinator Diversity	.0001	4.241
Bee Abundance	0.0007	2.740
Bee Diversity	0.0076	1.688
Butterfly Abundance	0.0020	4.005
Butterfly Diversity	.0013	4.076
Wasp Abundance	<.0001	4.402
Wasp Diversity	<.0001	4.330

In this study, butterflies, wasps, and beetles had a greater negative correlation to developed areas than flies and bees. This could potentially change the way that pollinator gardens and stepping-stone corridors should be created. Although it may be more efficient for bees and flies to travel through urbanized areas, butterflies may be deterred from traveling along the same path due to higher levels of impervious surfaces. It could be more effective to create stepping stones for butterflies, wasps, and beetles in areas with more tree coverage and less imperviousness while creating bee and fly targeted spaces through the areas with higher urban density. Although the PCA test shows a correlation between pollinators, land cover, and imperviousness, additional studies are required to determine if pollinator gardens targeted

towards specific guilds would be beneficial. By creating pollinator spaces that maximize floral resources for the most abundant guild, habitat stepping stones may be created to not only provide floral resources, but also act as a guide through potentially dangerous spaces.

Additional observations

The additional observations in this section were not specifically studied for this thesis. All descriptions of floral density are anecdotal and based on observations made while collecting insect data. Moreover, any insects flying outside of the study areas were not examined closely or specifically identified. Statements made about using these additional observations should be considered in other studies, but are based on observations and not quantitative data.

Although floral density was not a factor included in this study, but previous research has shown a positive correlation between flower density and pollinator visitation (Elliott and Irwin 2009; Harrison and Winfree 2015; Hegland and Boeke 2006; Westphal, Steffan-Dewenter, and Tscharntke 2003). The floral densities for each of these sites are anecdotal and were not measured. The SCNC Piedmont Prairie, UGA Green Mile Pollinator Garden, and SCNC GA Power Easement all had high floral densities and on average had the highest average insect counts at 14.500, 13.667, and 12.667 respectively (Table 4). The SCNC Woodland Edge and UGA N02 Kudzu Patch had the lowest floral densities and had the two lowest average insect counts at 1.333 and 3.500. The remaining sites' averages insect counts did not have a positive correlation with increased flower density. The North Oconee River Park had a very low floral density and plant composition similar to the UGA N02 Kudzu Patch, however, it had the fourth-highest average pollinator count. On the other hand, the UGA East Oconee Connector Bridge

had similar floral density and plant composition to the UGA Park-n-ride No-Mow Trail Verge, but had the fourth-lowest pollinator count.

Table 4: Table showing each study location's observed floral density and average pollinator abundance.

Site	Floral density	Average pollinator abundance per visit
SCNC Piedmont Prairie	High	14.500
UGA Green Mile Pollinator Garden	High	13.667
SCNC GA Power Easement	High	12.667
North Oconee River Park	Low	11.000
UGA Park-n-ride No-Mow Trail Verge	High	6.833
UGA Park-n-Ride	Low	5.333
UGA East Oconee Connector Bridge	High	3.667
UGA Terry	High	3.667
UGA N02 Kudzu Patch	Low	3.500
SCNC Woodland Edge	Low	1.333

Another observation I made during this study, was the visibility of flowers and visitation by insects. The area adjacent to the UGA Park-n-Ride study plot consisted of the same vegetation being observed. However, pollinators were seen foraging on taller vegetation directly outside of the study area rather than those in the study boundary. I hypothesize the visibility of the flowers played a role in pollinator preference because the floral resources higher up were much easier to access and allowed for efficient foraging. This observation is provided in a qualitative context, and more studies are required to understand how height variances and floral clarity affect foraging preferences.

Analysis Application and Design

The UGA Connect to Protect Pollinator Garden program promotes the creation of pollinator gardens to educate the public about pollinators and contribute towards conservation efforts. Two locations on the UGA campus are currently being considered to create new Connect to Protect pollinator gardens. One location is directly adjacent to a path leading to the courtyard of the Biological Sciences building, and the other is near the pond in the Oconee Forest Park (OFP). This study also includes the Odum School of Ecology Connect to Protect garden as an alternative location to the Biological Sciences building (Figure 7).

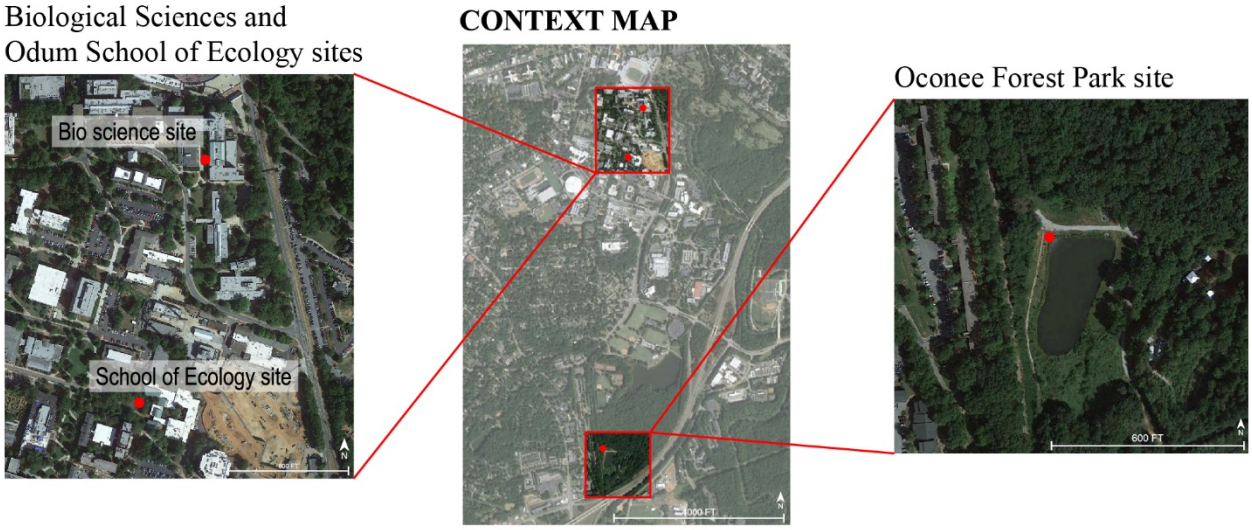

Figure 7: Context map for the proposed Connect to Protect pollinator gardens.

I applied a similar framework used in this study to the proposed design locations. I calculated the majority land cover for each site using ArcMap the calculate area function in the attributes table ("ArcMap 10.7.1" 2019). The majority land cover may be used as a tool to determine potential pollinator abundance and create a hierarchy for pollinator garden placement. To determine which pollinator morphological groups are likely to visit a specific location, an

additional analysis is required. Although these methods can be used to predict the behavior of some pollinators, expertise and design knowledge must be applied when creating pollinator gardens. Local conditions surrounding a proposed location will affect pollinator attractiveness and vegetation, and a site inventory and analysis needs to be part of the decision-making process when siting pollinator gardens.

Based solely on the majority land cover within a 300-meter radius, the proposed location in The Oconee Forest Park is the only location where a pollinator garden would effectively attract pollinators. Although medium intensity development is the majority land cover, the total area of both deciduous and mixed forest space is greater than medium intensity development. These land covers scored the highest in the Wilcoxon Signed-Rank test for one-way comparison of pollinator abundance. Based on the analysis of the collected data, this site should readily attract butterflies due to its high levels of forested area, but may also attract a high number of flies due to medium intensity development being the majority land cover. Bees should also be abundant at this site because they appeared to be attracted to locations aimed at serving pollinators regardless of imperviousness.

High intensity development is the majority land cover for both the Biological Sciences building and the Odum School of Ecology. As the second-lowest scoring land cover in the Wilcoxon Signed-Rank Test, it is predicted that these surrounding land covers contribute to low pollinator abundance. The second highest land covers for the School of Ecology and Biological Sciences building are medium intensity development and open space development, respectively. Upon further analysis using the Steel-Dwass method to compare factors as pairings showed a significant difference between these two land covers. Because medium intensity development ranked highly in the Wilcoxon Rank Signed test, the Odum School of Ecology has the potential

to attract a high number of pollinators despite its majority land cover being high intensity. On the other hand, I predict that the Biological Sciences building will attract few pollinators due to open space development ranking last.

Based on the surrounding land cover analysis, the hierarchy for creating new Connect to Protect pollinator gardens is as follows: Oconee Forest Park, Odum School of Ecology, then the Biological Sciences building (Table 5). I completed additional landscape context analyses of the sites to further support creating or avoiding these selected locations for the creation of pollinator gardens. See Appendix E for landscape context analysis.

Table 5: Table showing the selected Connect to Protect locations and their two highest majority land covers within a 300-meter radius.

Site	Majority land cover	2nd highest land cover
Oconee Forest Park	Developed, medium intensity	Mixed Forest
Odum School of Ecology	Developed, high intensity	Developed, medium intensity
Biological Sciences building	Developed, high intensity	Developed, open space

Connect to Protect requirements

Designing and creating a Connect to Protect pollinator garden has some requirements. One requirement is providing a variety of plant species that bloom throughout the year. There must be three plant species blooming during the summer, spring, and fall. In addition to bloom period requirements, three plant species must also be larval host plants. To make creating pollinator gardens more accessible to the public, the program provides a list of plants recognized by Connect to Protect program. This list includes information such as blooming periods, larval host, food web beneficiaries, light requirements, moisture preference, and ecoregions to assist in plant selection.

A few management restrictions are also established by the Connect to Protect program and are designed for low-input and labor. There must be a commitment to maintenance for the garden, which can be simple depending on the location. When maintaining the gardens, the use of broad-spectrum insecticides should be discouraged. Although the use of pesticides targeted at specific pests may not directly kill desired pollinator species, eliminating the use of chemicals on any of the gardens would also eliminate any risk of exposure. This may not be realistic for more formal spaces that are part of the program, however, I highly encourage greatly limiting chemical inputs, and if possible, eliminating the use of all pesticides.

The plants on the Connect to Protect plant list are all native species. Because the creation of a Connect to Protect garden requires the use of recognized plants, the selections below are limited to the vegetation species provided. The data did not show any significant difference between exotic, native, or mixed plant species in this study. I suggest planting non-invasive exotic species to extend bloom periods where native species may not be available.

Oconee Forest Park

The Oconee Forest Park proposed site is the best location for a new Connect to Protect pollinator garden. The land cover surrounding this site scored highly in this study and it is located directly inside of a large natural space. Pollinators can move freely in and out of this site in comparison to the other selected locations because of the undisturbed connection to the Oconee Forest Park and the residential areas surrounding Milledge Avenue. See Appendix E for the landscape context analysis diagram.

Forested areas provide both nesting and floral resources for pollinators, however, the conditions under a dense tree canopy limits the floral availability and diversity due to the lack of sunlight. Some flowering plants can thrive under shade, however pollinators favor areas that are open and sunny. The location selected to place a Connect to Protect pollinator garden in the Oconee Forest Park can combat these problems. Creating a garden on the northwestern bank of the pond allows it to be close enough to the forest edge so it is easily accessible for pollinators, but also receives sun exposure for most of the day.

The design I created for a new pollinator garden utilizes the plant list approved by the Connect to Protect Pollinator Garden program (Table 6). Although the focus of this study and design is to support insect pollinators, the location of this garden allows for the opportunity to serve a more diverse wildlife community. Many of the selected plant species serve a variety of insect pollinators as well as bats, birds, and small mammals. Most of the plantings have either been massed together or randomly mixed for easier planting, reseeding, and allows for vegetation to grow more freely with a naturalistic aesthetic that minimizes the need for pruning or mowing (Table 7). Some of the existing vegetation along the bank of the pond will need to be removed to add flood tolerant species. The existing Dogfennel (*Eupatorium capillifolium*) that

grows on the bank of the pond may provide habitat resources and deters deer and does not need to be completely removed from the entire bank of the pond, however this species is quite weedy and will need to be maintained to keep it from over taking intentional plantings ("Eupatorium Capillifolium," n.d.). I added an additional pathway through the garden to allow visitors to more easily examine insects and plants which allows for greater education opportunities (Figure 8). Optional signage can be added through the garden to increase the garden's educational value. See Appendix F for the full planting plan and plant schedule.

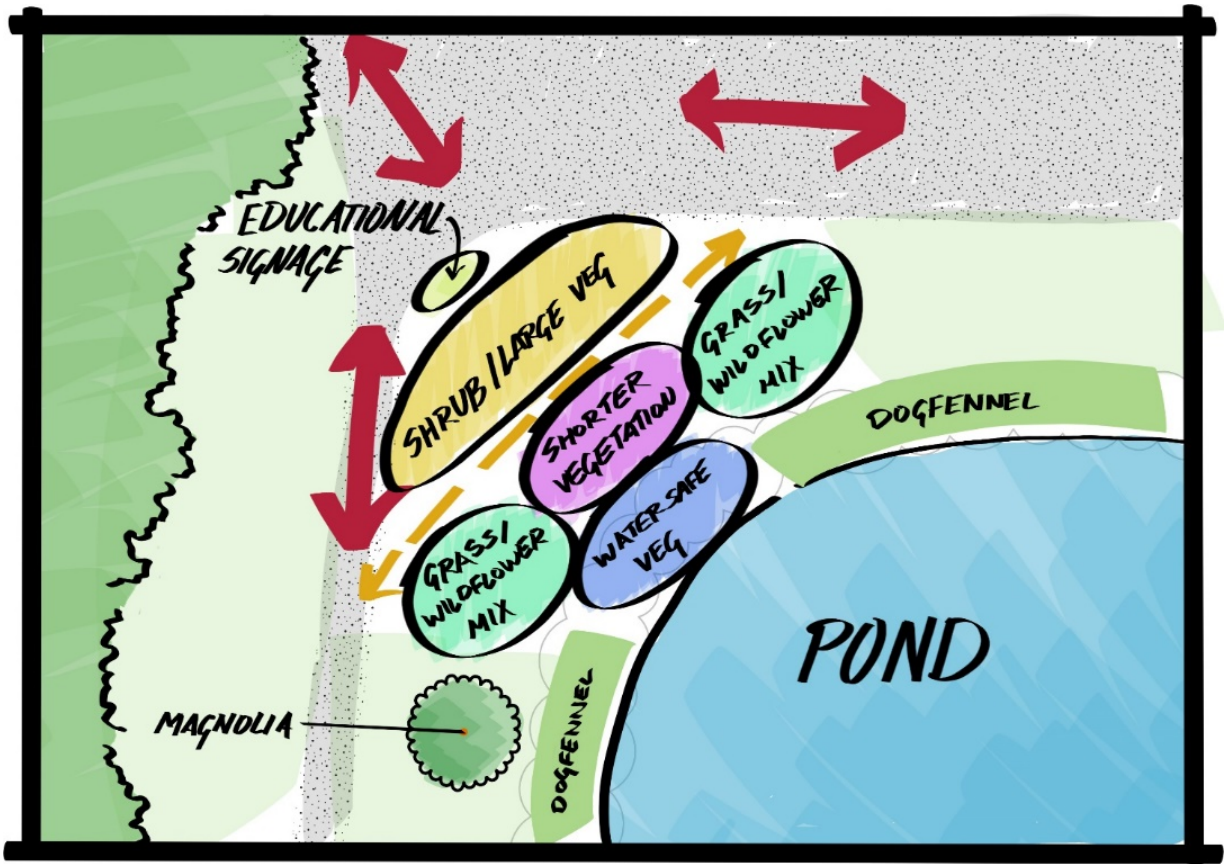

Figure 8: Bubble diagram of the design for a new Connect to Protect pollinator garden in the Oconee Forest Park

Table 6: Connect to Protect approved plant species selected to plant at the Oconee Forest Park. Of the selected plant species, Monarch butterflies (Danaus plexippus) are specialists that will only lay eggs on Butterfly Milkweed (Asclepias tuberosa).

Scientific name	**Common Name**	**Larval Host**	**Beneficiaries**	**Bloom period**
Asclepias tuberosa	Butterfly Milkweed	Butterflies, Monarch butterflies	Bees, butterflies, hummingbirds	Spring - Summer
Eupatorium hyssopifolium	Hyssop-leaf Thoroughwort	Moths	Bees, beetles, birds, butterflies	Summer - Fall
Iris virginica	Southern Blue Flag	Moths	Bees, beetles, birds, butterflies	Spring
Liatris spicata	Dense Blazing Star		Bees, birds, butterflies, hummingbirds	Summer
Muhlenbergia capillaris	Pink Muhly Grass	Moths	Bats, insects, moths, small mammals	Summer - Fall
Solidago odora	Anise-Scented Goldenrod	Moths	Bats, bees, beetles, birds, butterflies, moths	Fall

Table 7: Table of plant mixes created using Connect to Protect species.

Inner Vegetation Mix				
Scientific name	**Common Name**	**Larval Host**	**Beneficiaries**	**Bloom period**
Elephantopus tomentosus	Elephant's foot	Beetles	Bats, bees, birds, butterflies, moths	Summer - Fall
Eurybia divaricata	White Wood Aster	Butterflies, moth	Bats, bees, beetles, birds, butterflies, flies, moths, wasps	Summer - Fall
Monarda didyma	Scarlet Bee Balm	Moths	Bats, bees, birds, butterflies, hummingbirds	Summer
Scutellaria integrifolia	Helmet Skullcap	Moths	Bees, butterflies	Spring - Summer
Solidago odora	Anise-Scented Goldenrod	Moths	Bats, bees, beetles, birds, butterflies, moths	Fall
Grass/Wildflower Mix				
Scientific name	**Common Name**	**Larval Host**	**Beneficiaries**	**Bloom period**
Asclepias amplexicaulis	Clasping Milkweed	Butterflies, Monarch Butterflies	Bees, butterflies, hummingbirds	Spring - Summer
Eryngium yuccifolium	Rattlesnake Master	Moths	Bees, beetles, birds, butterflies, wasps	Summer
Eupatorium hyssopifolium	Hyssop-leaf Thoroughwort	Moths	Bees, beetles, birds, butterflies	Summer - Fall
Rudbeckia laciniata	Cut-leaf Coneflower	Butterflies, moths	Bats, bees, beetles, birds, butterflies, moths	Summer - Fall

Odum School of Ecology

Prior to this study, it was unclear whether the Biological Sciences building was a suitable location to place a new pollinator garden. Replanting flowering vegetation is an easy method to renovate this space and provide additional floral resources. Although this garden is located in an area with higher levels of development, its proximity to the UGA Green Mile Pollinator Garden, UGA Trail Gardens, and the naturalistic design make this space an ideal location within an urban landscape to provide habitat.

The majority land cover surrounding a 300-meter radius of this site is high intensity development followed by medium intensity development. Although high intensity development scored poorly for total pollinator abundance, medium intensity scored the highest. The UGA Green Mile Pollinator garden study site, located just southwest of this location, on average had the second-highest insect pollinator count and third-highest pollinator diversity in this study. Additionally, I have observed many bees in the UGA Trial Gardens nearby during the summer months. There is a high likelihood that insect pollinators will also travel to this space because these gardens are within proximity of this site and pollinators are seen frequently in this area.

The Odum School of Ecology has an existing Connect to Protect pollinator garden located in front of the building. Pollinator attractive plants such as Beggarticks (*Bidens* sp.), Cardinal Flowers (*Lobelia* spp.) and Downy Ragged Goldenrod (*Solidago petiolaris*) once grew in this space. However, a large portion of the plantings no longer exist due to the previous student caretakers no longer being at the University. The remaining vegetation in the garden is now located within the planting bed containing the Odum School of Ecology and Connect to

Protect signage (Figure 9). Although all the plants selected to be in the garden are pollinator attractive, about half of the remaining species are grasses.

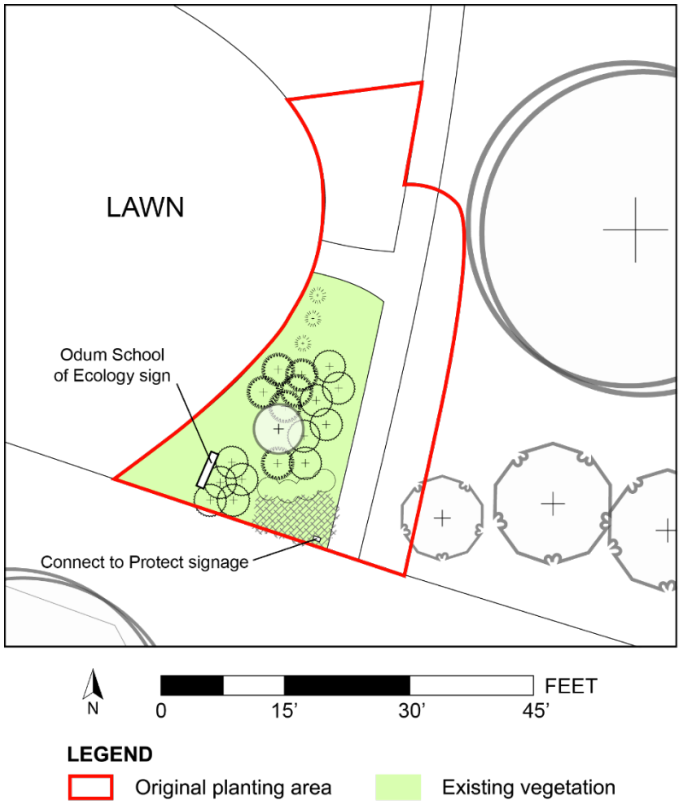

Figure 9: Diagram showing where vegetation was planted for the Connect to Protect pollinator garden in front of the Odum School of Ecology. Overtime, some of the vegetation has died leaving only one area with vegetation.

The large planting beds surrounding the turtle pond and plaza present an opportunity to extend pollinator habitat past the existing Connect to Protect garden (Figure 10). Birch trees (*Betula* sp.*)* shade this area and vegetation requiring full sun has been unable to grow. Inland Sea Oats (*Chasmanthium latifolium*) are currently growing in this area and although they are on the recognized Connect to Protect plant list, are not a preferred species to plant on UGA property due to such prolific growth. The existing vegetation in the shaded areas could be removed and replaced with shade-tolerant species that provide resources to a wider range of pollinators.

However, most of the shade-tolerant plant species that require medium to low moisture on the Connect to Protect list bloom during the spring. If this area were to be used as a part of the Connect to Protect program, it is suggested to plant an increased number of summer and fall-blooming vegetation in the area that is currently considered the Connect to Protect garden and

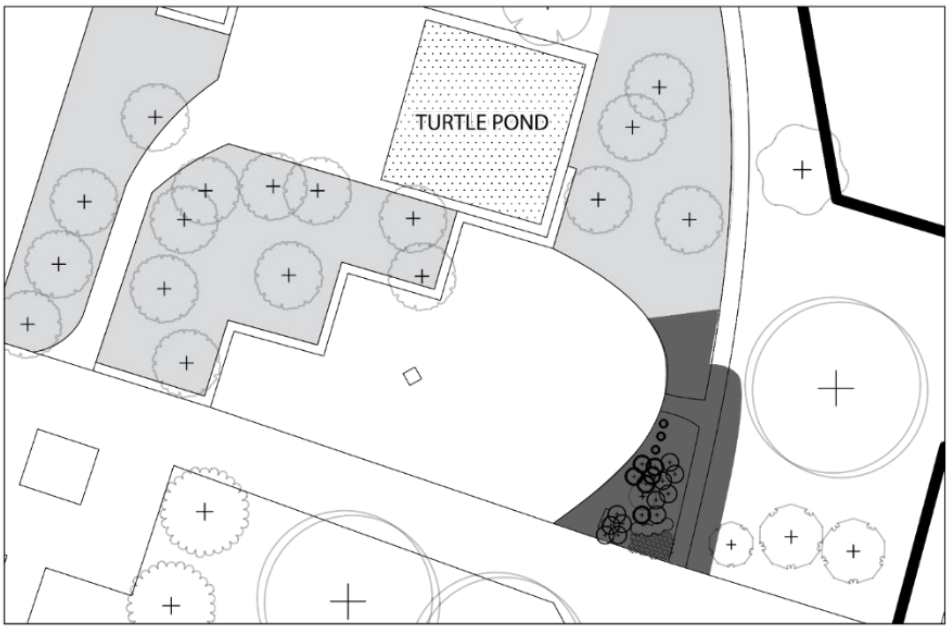

Figure 70: The dark grey area indicates the existing Connect to Protect garden boundary. The areas highlighted in light grey are the proposed areas for extending the Connect to Protect garden to create a larger habitat.

concentrate more spring-blooming vegetation in the shaded areas.

Because student caretakers constantly change, it is recommended to pick hardy plant species in case there are extended periods of little to no maintenance. Study locations consisting of Frostweed (*Verbesina virginica*) were shown to have high pollinator abundance and richness, and although they were only maintained every few years, they continue to grow abundantly. Although not on the Connect to Protect plant list, this species performed well in this study and I

suggest planting it in locations where maintenance may not always be consistent to increase resiliency.

Biological Sciences building

I do not recommend placing a pollinator garden by the Biological Sciences building pathway. The top two majority land covers of this location are high intensity development and open space development, respectively. These two land cover types scored much lower than any others in the Wilcoxon Signed-Rank Test. Study sites where either high intensity or open space development were the majority land cover on average, had the lowest insect counts. Although deciduous forest is the third most abundant land cover for the Biological Sciences building site, the high intensity and open developed space make over half of the surrounding land cover within a 300-meter radius. Even though I predict few pollinators will visit this location based on land cover, the local characteristics also make it an undesirable location to place a new pollinator garden.

The proposed location for a new pollinator garden exists along a pathway leading to an internal courtyard of the Biological Sciences building on the UGA campus (Figure 11). The limited visibility and access to this courtyard make it more difficult for insect pollinators to not only find this location but may also make it even more difficult for them to exit. The internal courtyard poses a risk to pollinators being unable to leave this space due to the building enclosing the area, however, this was not tested and is anecdotal. Furthermore, the flowering vegetation and largely forested habitat located near this site are difficult to access because it forces pollinators to cross either East Campus Road or Cedar Street, which have high vehicle traffic.

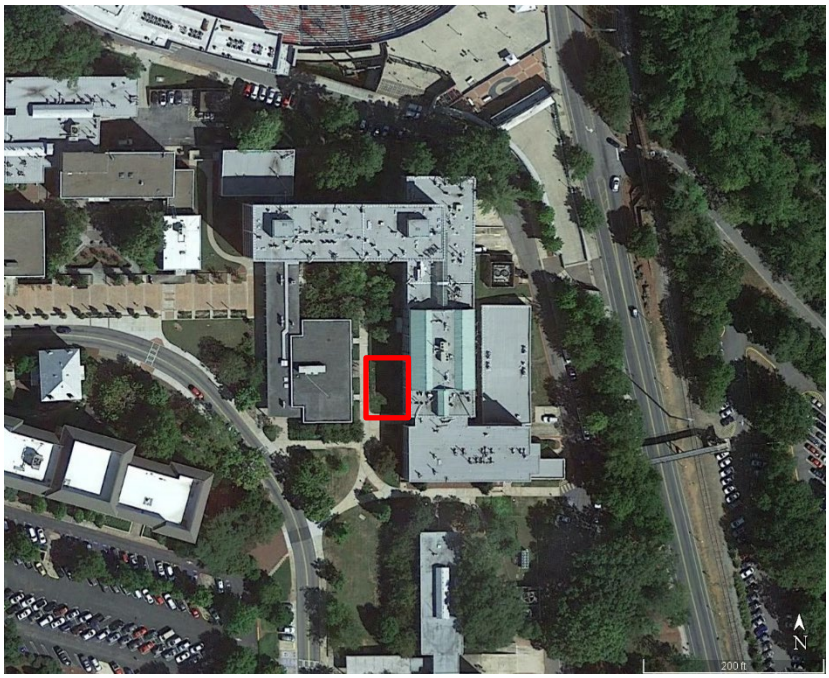

Figure 11: The proposed location for a Connect to Protect pollinator garden adjacent to a pathway leading to an internal courtyard of the UGA Biological Sciences building.

Another challenge that this location poses is sun exposure. Because this site is directly adjacent to the building, it receives limited sunlight during the day. Although shade-tolerant species are on the Connect to Protect plant list, many of them are large trees, shrubs, or require high levels of moisture. In addition to a limited plant palette, some research has indicated that bees may benefit from sun exposure while foraging (Rands and Whitney 2008; Whitney and Chittka 2007). This area may be exposed to the sun during certain hours of the day, but it is very limited and insects that get trapped in this area would be unable to absorb heat due to a lack of sunlight.

Finally, the existing conditions of this site would greatly increase the cost of this project. The removal of the existing Asiatic Jasmine (*Trachelospermum asiaticum*) would have to occur for the project to begin. Next, there would need to be an installation of an irrigation system to

water the newly planted vegetation during the establishment period. If the design implements a diverse plant palette that does not consist mostly of trees and shrubs, watering would need to occur more frequently due to many shade-tolerant plants needing high levels of moisture. The plants would be the final upfront cost for the new garden. Funds are always required to purchase plants and this would be a factor for all three locations. However, the removal of the existing vegetation and the potential need for long-term watering is where the cost of this project increases drastically in comparison to the other two proposed locations.

An alternative location to create a new Connect to Protect pollinator garden is in a triangle-shaped opening where the courtyard sidewalk and another sidewalk converge (Figure 12). This spot is not only visible but is also far enough from any buildings and will have sun exposure for most of the day. Although this spot solves some of the issues that the proposed location has, moving the pollinator garden over a few hundred feet does not change the issues surrounding the lack of connectivity and land cover preference.

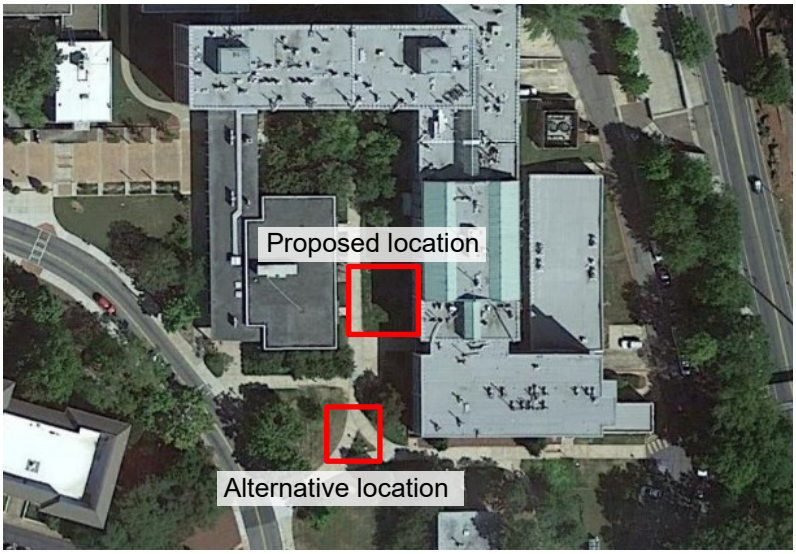

Figure 12: Map showing the proposed location for a new Connect to Protect pollinator garden and the proposed alternative location.

Because this location poses so many challenges financially and environmentally, I do not recommend placing a pollinator garden in this location. The time it would take to receive the money and approval for a project like this may span over years, creating more difficulties as the student body changes. I advise replanting and renovating the space in front of the Odum School of Ecology rather than creating a new pollinator garden by the Biological Sciences building. Not only would that location be more effective for providing resources for insect pollinators, but it would also have a much lower cost.

CHAPTER 5

CONCLUSION

The information shared in this study can inform the siting and creation of pollinator gardens and habitat connections in Athens, Georgia. Individual cities should conduct local studies due to previous researchers offering different opinions on pollinator behavior over local or landscape scales (Steffan-Dewenter et al. 2002; Williams and Winfree 2013). For insect pollinators observed in Athens, land cover and imperviousness on a landscape-scale had a significant impact on pollinator abundance, whereas local-scale did not. Because COVID-19 limited the data collection process, more data may point to a greater understanding of pollinator behavior during other parts of the year.

Sites surrounded by medium intensity land cover or forested areas within a 300-meter radius had a significant difference, $\chi^2 = 12.4362$, $p < 0.014$, on the abundance of total insect pollinators, but no significant effect on total pollinator diversity. However, sites surrounded mostly by medium intensity land cover on average had lower diversity due to a disproportionately higher number of fly visitations. The sites categorized as Frostweed Patches significantly affected the most pollinator responses and consistently scored the highest on all significant tests.

This study can further the understanding of land cover and imperviousness on insect pollinator behavior in urbanized areas. Continuing exploration is needed to examine specific species impact, seasonality, and vegetation to better serve specific guilds or families as needed. Results could inform the design of stepping-stones corridors between large areas of habitats, thus

increasing connectivity. By supporting pollinators in the most efficient areas, we may be able to address pollinator decline. However, like all studies surrounding ecological issues, this problem is complex and ever changing. This study may address some methods and issues surrounding insect pollinator decline, but there is an endless number of possibilities to contribute to conservation efforts.

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APPENDIX A

List of Observed Pollinator Families

Bees	**Flies**
Apidae	Anthomyiidae
Halictidae	Bombyliidae
Megachilidae	Calliphoridae
Butterflies	Dolichopodidae
Hesperiidae	Lauxaniidae
Lycaenidae	Lonchaeidae
Nymphalidae	Muscidae
Papilionidae	Syrphidae
Pieridae	Tachinidae
	Wasps
	Crabronidae
	Pompilidae
	Scoliidae
	Sphecidae
	Thynnidae
	Vespidae

APPENDIX B

Table of Observed Plants

North Oconee River Park		
Common Name	***Scientific name***	**Vegetation type**
Kudzu	*Pueraria montana*	Exotic
Hawksbeard	*Youngia* sp.	Exotic
SCNC GA Power Easement		
Common Name	***Scientific name***	**Vegetation type**
Frostweed	*Verbesina virginica*	Native
SCNC Piedmont Prairie		
Common Name	***Scientific name***	**Vegetation type**
Frostweed	*Verbesina virginica*	Native
Hawksbeard	*Youngia* sp.	Exotic
SCNC Woodland Edge		
Common Name	***Scientific name***	**Vegetation type**
Frostweed	*Verbesina virginica*	Native
Sicklepod	*Senna obtusiflora*	Native
UGA East Oconee Connector Bridge		
Common Name	***Scientific name***	**Vegetation type**
Bahia Grass	*Paspalum notatum*	Exotic
Brown-Eyed Susan	*Rudbeckia triloba*	Native
Firewheel	*Gaillardia* sp.	Native
UGA Green Mile Pollinator Garden		
Common Name	***Scientific name***	**Vegetation type**
Autumn Sneezeweed	*Helenium autumnale*	Native
Cardinal Flower	*Rudbeckia triloba*	Native
Great Blue Lobelia	*Gaillardia* sp.	Native
Shallow Sedge	*Carex lurida*	Native
UGA N02 Kudzu Patch		
Common Name	***Scientific name***	**Vegetation type**
Kudzu	*Pueraria montana*	Exotic
Paper-mulberry	*Broussonetia papyrifera*	Exotic
UGA Park-n-Ride		
Common Name	***Scientific name***	**Vegetation type**
Bahia Grass	*Paspalum notatum*	Exotic
Blue Vervain	*Verbena hastata*	Native
False Mallow	*Sida spinosa*	Native
Red Morning-glory	*Ipomoea coccinea*	Native

Smallflower Morning-glory	*Jacquemontia tamnifolia*	Native
Trailing Fuzzy Bean	*Strophostyles umbellata*	Native
UGA Park-n-Ride No Mow Trail Verge		
Common Name	***Scientific name***	**Vegetation type**
Bahia Grass	*Paspalum notatum*	Exotic
Firewheel	*Gaillardia* sp.	Native
Showy Patridge Pea	*Chamaecrista fasciculata*	Native
UGA Terry		
Common Name	***Scientific name***	**Vegetation type**
Rose Creek Glossy Abelia	*Abelia x grandiflora 'Rose Creek'*	Exotic
Short's Goldenrod	*Solidago shortii 'Solar Cascade'*	Native

APPENDIX C

Significant Difference Analysis Matrix

Landscape Element	Response			
	Total Abundance	Total Diversity	Bee Abundance	Bee Diversity
Typology				
Exotic assemblage				
Frostweed patch	Highest density of floral resources and is surrounded mostly by undisturbed landscape.	Same as total abundance.	Highest density of floral resources and is surrounded mostly by undisturbed landscape.	Same as bee abundance.
Organized bed				
Wildflower mix				
Vegetation				
Mixed			Mixed allows for greater mix of pollen and nectar nutrition.	
NLCD 300m Radius Majority Land Cover				
Deciduous Forest				
Developed, Open Space				
Developed, Medium Intensity	Medium intensity developed space had much higher fly counts than any other taxon. This could be due to an increase of trash and food.			
Mixed Forest				
NLCD Site Imperviousness groups				
Low urbanization				
High urbanization			Increased flower density. Bees are better able to cope with urban environment other butterflies. The locations in this category were designated pollinator spaces.	Same as abundance.
Urban density 09 sq m				
Low urbanization		Most of the sites with lower levels of site imperviousness also have lower levels of imperviousness on a larger scale, but is not applicable to all sites. many of these sites also have a minimally disturbed connection to large patches of natural habitat.		
High urbanization				

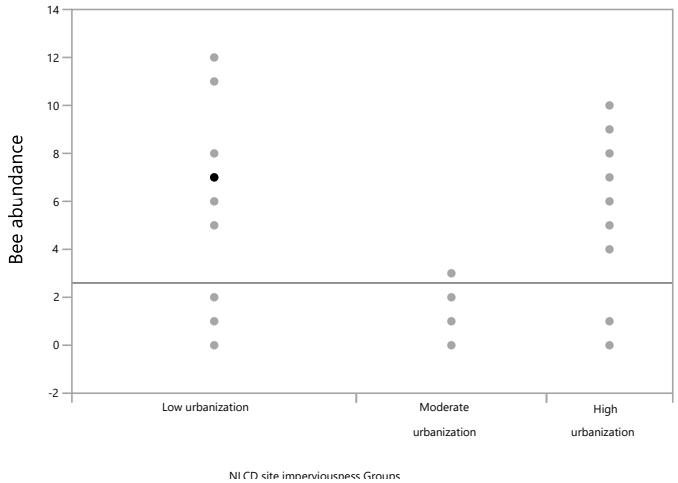
Landscape Element	Butterfly Abundance	Butterfly Diversity	Fly Abundance	Wasp Abundance	Wasp Diversity
Typology					
Exotic assemblage					
Frostweed patch	Highest density of floral resources and is surrounded mostly by undisturbed landscape.	Same as butterfly abundance.		No impervious surfaces nearby. Bees and wasps, which were observed foraging more frequently in these locations. There was a large conenction to natural spaces.	Same as wasp abundance.
Organized bed					
Wildflower mix					
Vegetation					
Mixed					
NLCD 300m Radius Majority Land Cover					
Deciduous Forest	More habitat opportunities in natural spaces than in urbanized spaces.	Same as butterfly abundance.			
Developed, Open Space					
Developed, Medium Intensity			Areas with development have increased level of food and trash but also still provide enough natural spaces for shelter.		
Mixed Forest					
NLCD Site Imperviousness groups					
Low urbanization	More habitat opportunities in natural spaces than in urbanized spaces.	Same as butterfly abundance.			
High urbanization				Sites with immediate high urbanization sites are both pollinator gardens/pollinator habitat. Pollinators will travel long distances and this is not indicative of nesting needs.	
Urban density 09 sq m					
Low urbanization	More habitat opportunities in natural spaces than in urbanized spaces.	Same as butterfly abundance.			
High urbanization			Areas with development have increased level of food and trash but also still provide enough natural spaces for shelter.		

APPENDIX D

Significant Wilcoxon Signed-Rank Tests

Fit Group

Oneway Analysis of Bee abundance By NLCD site imperviousness Groups



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

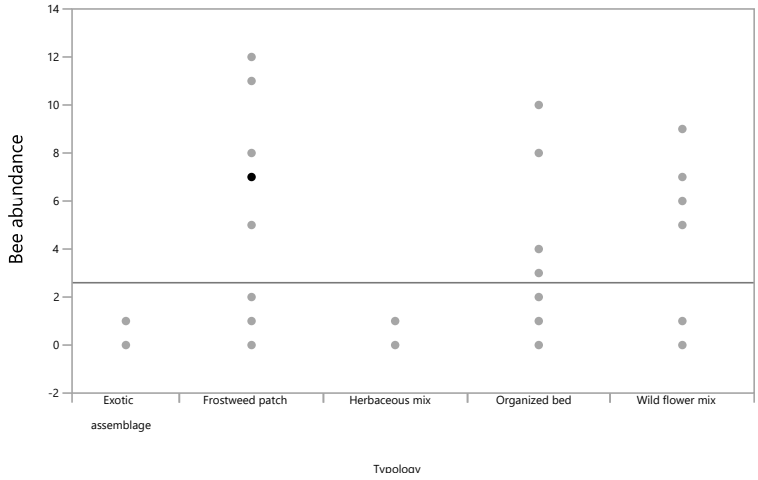
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	798.500	783.000	29.5741	0.249
Moderate urbanization	18	404.500	522.000	22.4722	-2.083
High urbanization	12	450.000	348.000	37.5000	2.060

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.4116	2	0.0405*

Missing Rows 17

Oneway Analysis of Bee abundance By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

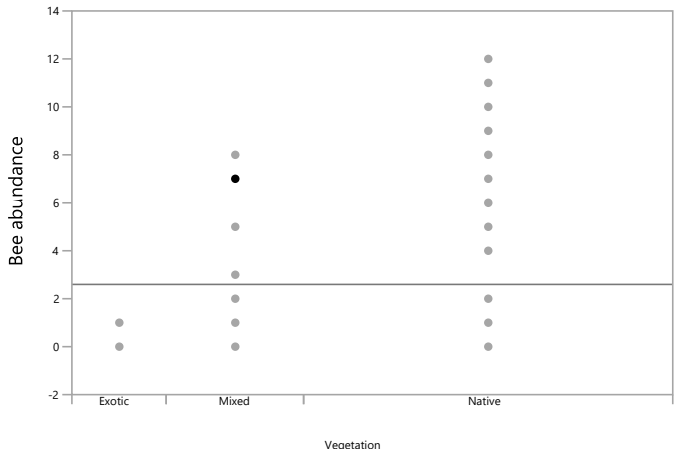
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	156.000	261.000	17.3333	-2.371
Frostweed patch	12	483.500	348.000	40.2917	2.740
Herbaceous mix	12	208.000	348.000	17.3333	-2.831
Organized bed	12	413.500	348.000	34.4583	1.319
Wild flower mix	12	392.000	348.000	32.6667	0.883

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
19.1507	4	0.0007*

Missing Rows 17

Oneway Analysis of Bee abundance By Vegetation



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

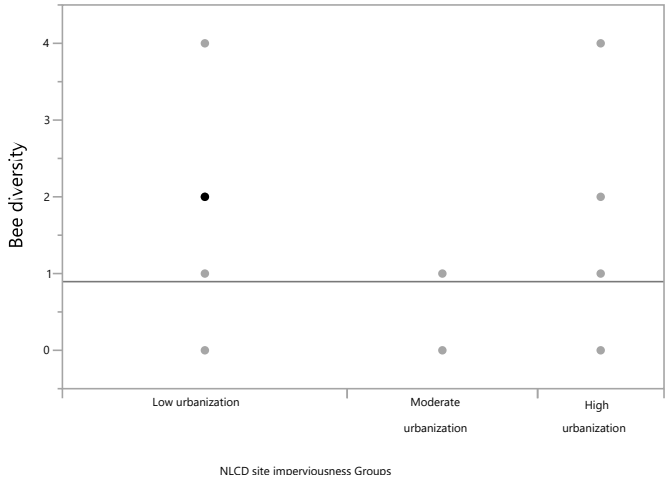
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic	9	156.000	261.000	17.3333	-2.371
Mixed	13	445.500	377.000	34.2692	1.341
Native	35	1051.50	1015.00	30.0429	0.612

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.3378	2	0.0420*

Missing Rows17

Oneway Analysis of Bee diversity By NLCD site imperviousness Groups



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

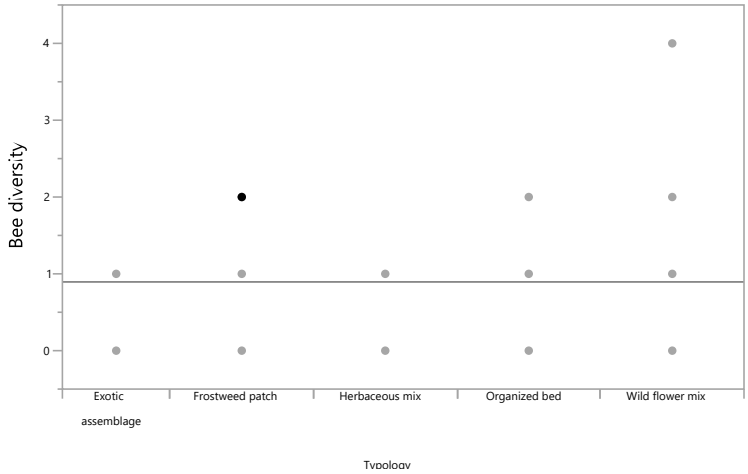
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	775.500	783.000	28.7222	-0.120
Moderate urbanization	18	409.500	522.000	22.7500	-2.059
High urbanization	12	468.000	348.000	39.0000	2.505

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.9339	2	0.0189*

Missing Rows17

Oneway Analysis of Bee diversity By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

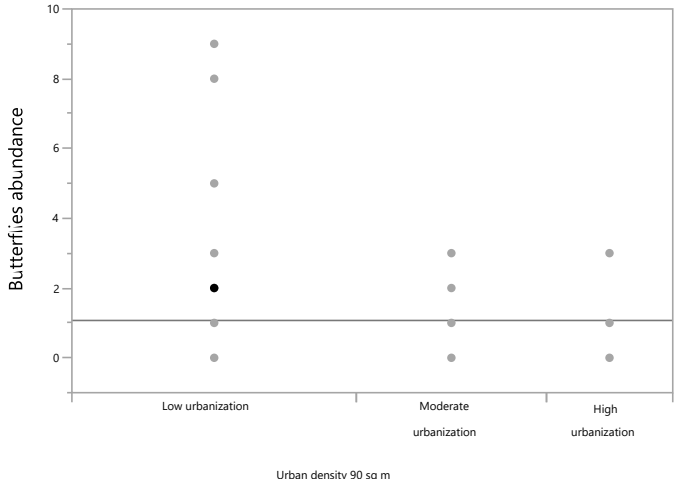
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	171.000	261.000	19.0000	-2.098
Frostweed patch	12	429.000	348.000	35.7500	1.688
Herbaceous mix	12	228.000	348.000	19.0000	-2.505
Organized bed	12	412.500	348.000	34.3750	1.342
Wild flower mix	12	412.500	348.000	34.3750	1.342

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.9094	4	0.0076*

Missing Rows17

Oneway Analysis of Butterflies abundance By Urban density 90 sq m



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

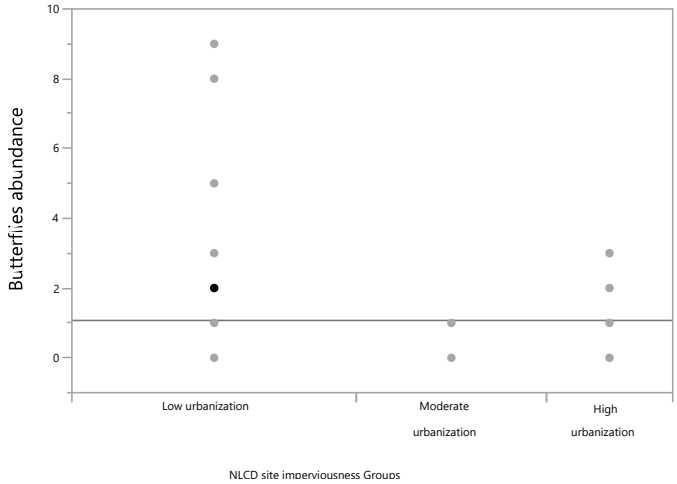
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	925.500	783.000	34.2778	2.517
Moderate urbanization	18	406.500	522.000	22.5833	-2.190
High urbanization	12	321.000	348.000	26.7500	-0.575

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.9387	2	0.0311*

Missing Rows17

Oneway Analysis of Butterflies abundance By NLCD site imperviousness Groups



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

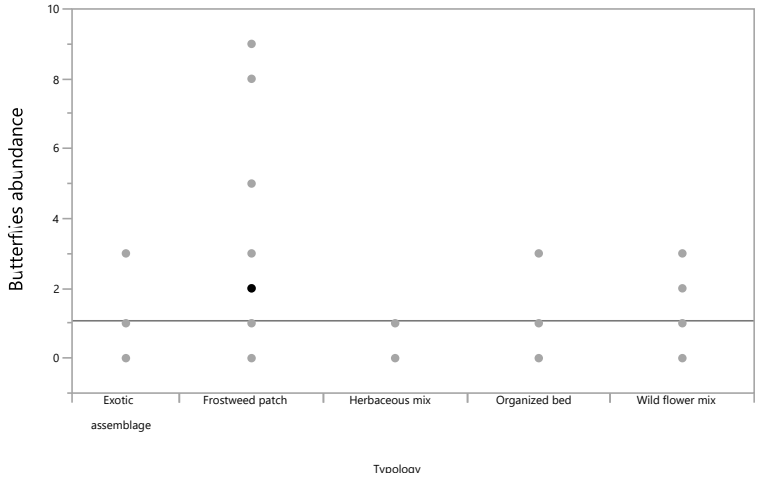
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	925.500	783.000	34.2778	2.517
Moderate urbanization	18	385.000	522.000	21.3889	-2.599
High urbanization	12	342.500	348.000	28.5417	-0.109

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.0254	2	0.0181*

Missing Rows17

Oneway Analysis of Butterflies abundance By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

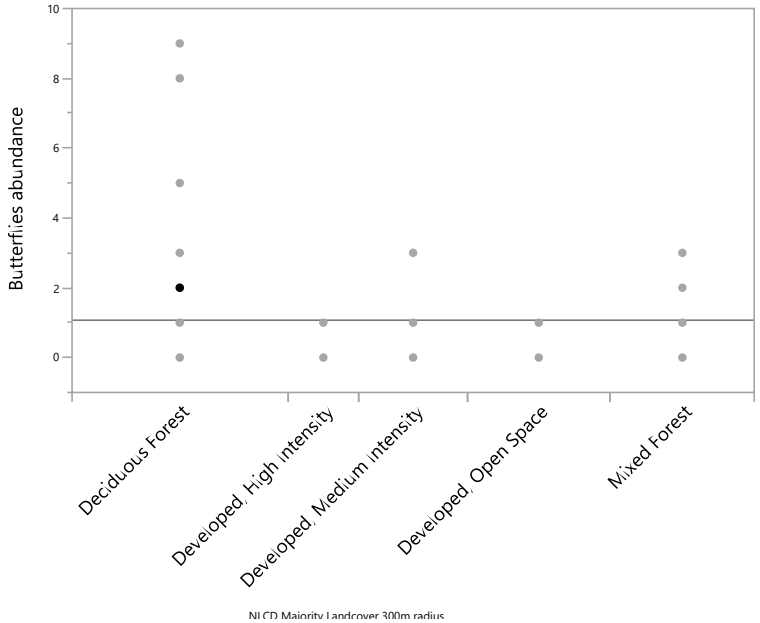
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	205.500	261.000	22.8333	-1.335
Frostweed patch	12	533.000	348.000	44.4167	4.005
Herbaceous mix	12	330.000	348.000	27.5000	-0.380
Organized bed	12	277.000	348.000	23.0833	-1.531
Wild flower mix	12	307.500	348.000	25.6250	-0.868

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
16.8699	4	0.0020*

Missing Rows 17

Oneway Analysis of Butterflies abundance By NLCD Majority Landcover 300m radius



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

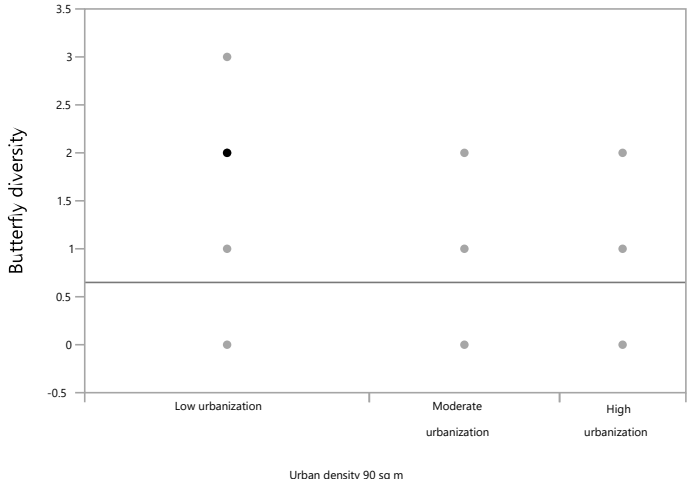
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Deciduous Forest	18	667.500	522.000	37.0833	2.761
Developed, High Intensity	6	121.000	174.000	20.1667	-1.514
Developed, Medium Intensity	9	262.500	261.000	29.1667	0.024
Developed, Open Space	12	220.000	348.000	18.3333	-2.768
Mixed Forest	12	382.000	348.000	31.8333	0.727

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.8698	4	0.0077*

Missing Rows 17

Oneway Analysis of Butterfly diversity By Urban density 90 sq m



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

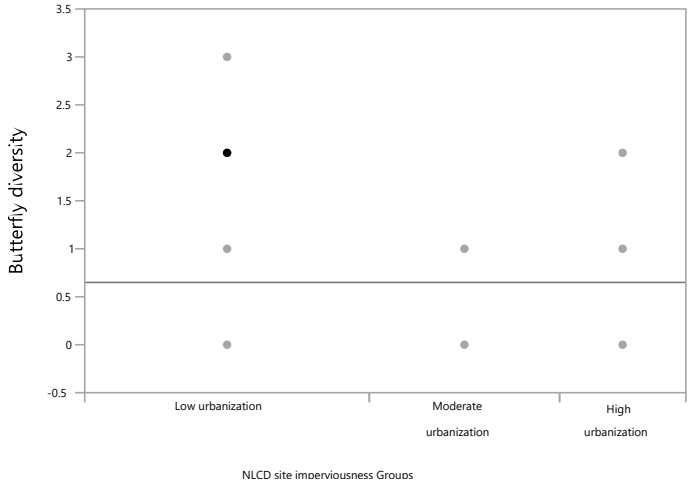
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	923.500	783.000	34.2037	2.498
Moderate urbanization	18	402.500	522.000	22.3611	-2.281
High urbanization	12	327.000	348.000	27.2500	-0.448

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.0635	2	0.0293*

Missing Rows 17

Oneway Analysis of Butterfly diversity By NLCD site imperviousness Groups



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

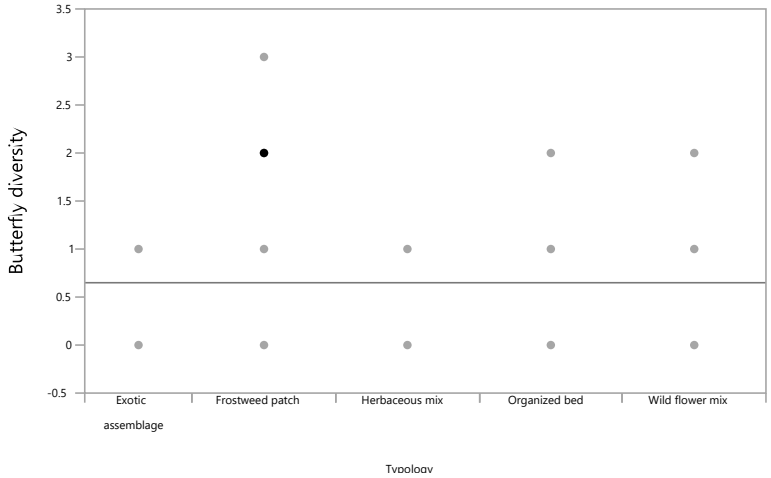
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	923.500	783.000	34.2037	2.498
Moderate urbanization	18	391.000	522.000	21.7222	-2.501
High urbanization	12	338.500	348.000	28.2083	-0.197

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.6553	2	0.0218*

Missing Rows 17

Oneway Analysis of Butterfly diversity By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

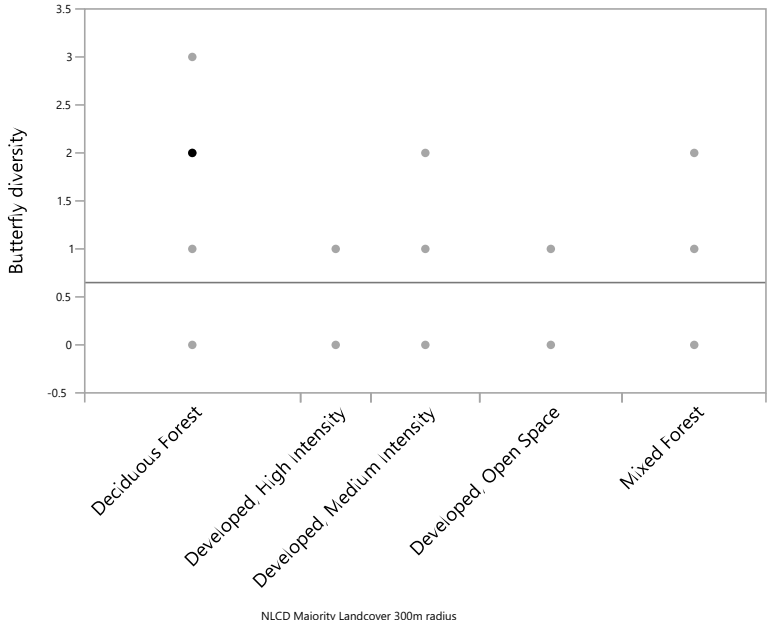
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	195.500	261.000	21.7222	-1.588
Frostweed patch	12	535.000	348.000	44.5833	4.076
Herbaceous mix	12	339.000	348.000	28.2500	-0.186
Organized bed	12	280.000	348.000	23.3333	-1.475
Wild flower mix	12	303.500	348.000	25.2917	-0.962

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
17.8616	4	0.0013*

Missing Rows 17

Oneway Analysis of Butterfly diversity By NLCD Majority Landcover 300m radius



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

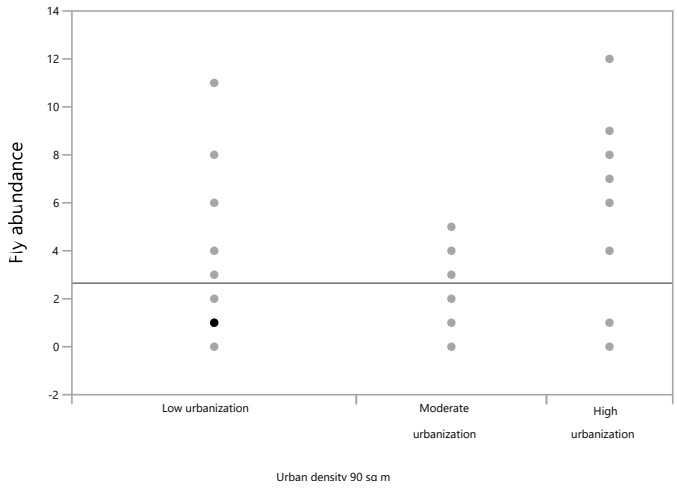
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Deciduous Forest	18	669.500	522.000	37.1944	2.817
Developed, High Intensity	6	122.500	174.000	20.4167	-1.481
Developed, Medium Intensity	9	254.000	261.000	28.2222	-0.159
Developed, Open Space	12	221.500	348.000	18.4583	-2.754
Mixed Forest	12	385.500	348.000	32.1250	0.809

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
14.0566	4	0.0071*

Missing Rows 17

Oneway Analysis of Fly abundance By Urban density 90 sq m



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

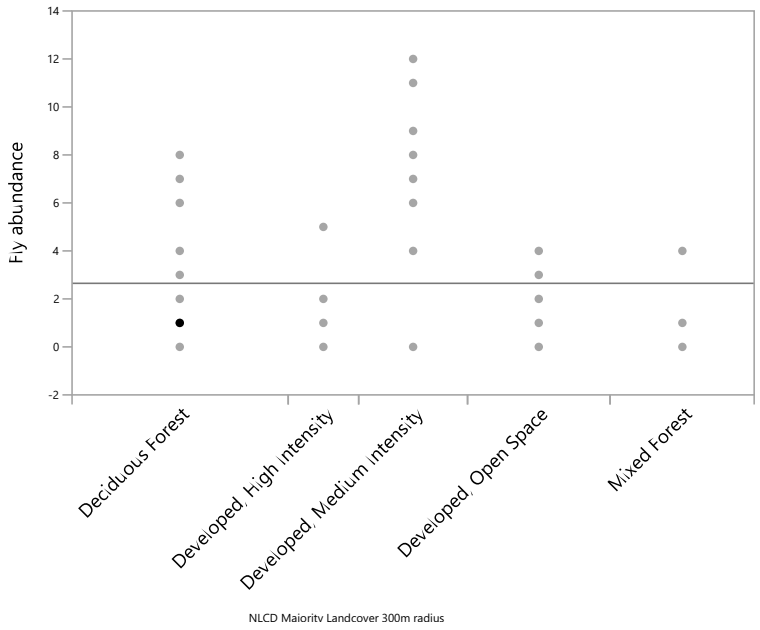
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	710.500	783.000	26.3148	-1.178
Moderate urbanization	18	472.000	522.000	26.2222	-0.870
High urbanization	12	470.500	348.000	39.2083	2.445

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.0254	2	0.0492*

Missing Rows 17

Oneway Analysis of Fly abundance By NLCD Majority Landcover 300m radius



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

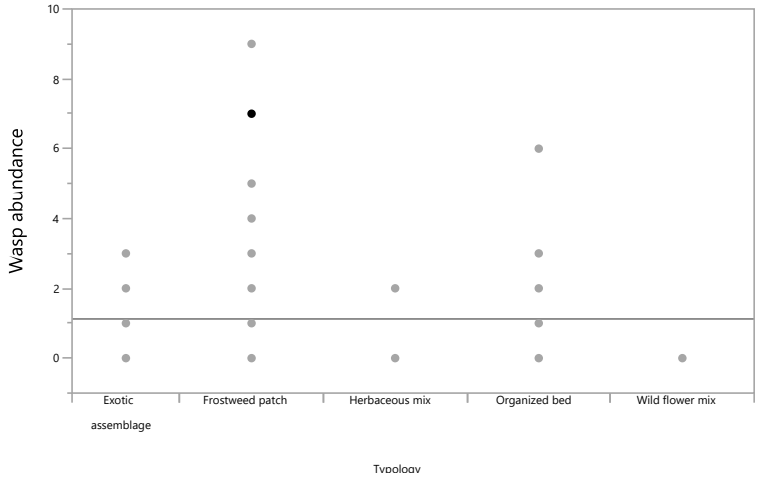
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Deciduous Forest	18	532.500	522.000	29.5833	0.176
Developed, High Intensity	6	140.500	174.000	23.4167	-0.878
Developed, Medium Intensity	9	424.000	261.000	47.1111	3.640
Developed, Open Space	12	342.500	348.000	28.5417	-0.100
Mixed Forest	12	213.500	348.000	17.7917	-2.685

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
17.7074	4	0.0014*

Missing Rows 17

Oneway Analysis of Wasp abundance By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

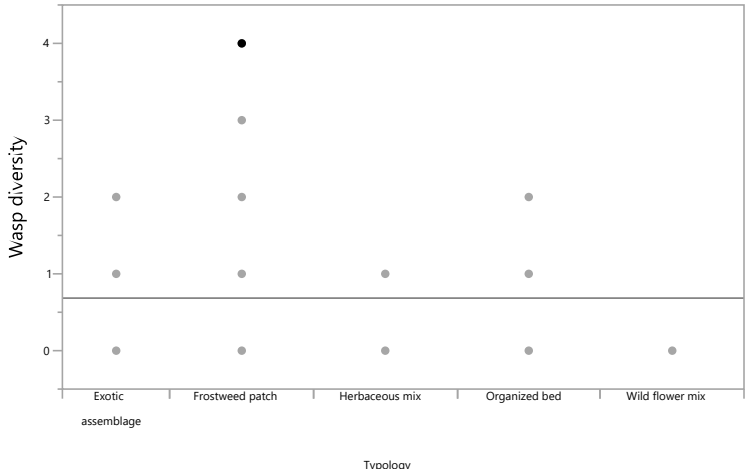
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	248.000	261.000	27.5556	-0.321
Frostweed patch	12	540.000	348.000	45.0000	4.402
Herbaceous mix	12	254.000	348.000	21.1667	-2.149
Organized bed	12	383.000	348.000	31.9167	0.793
Wild flower mix	12	228.000	348.000	19.0000	-2.747

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
25.6758	4	<.0001*

Missing Rows 17

Oneway Analysis of Wasp diversity By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

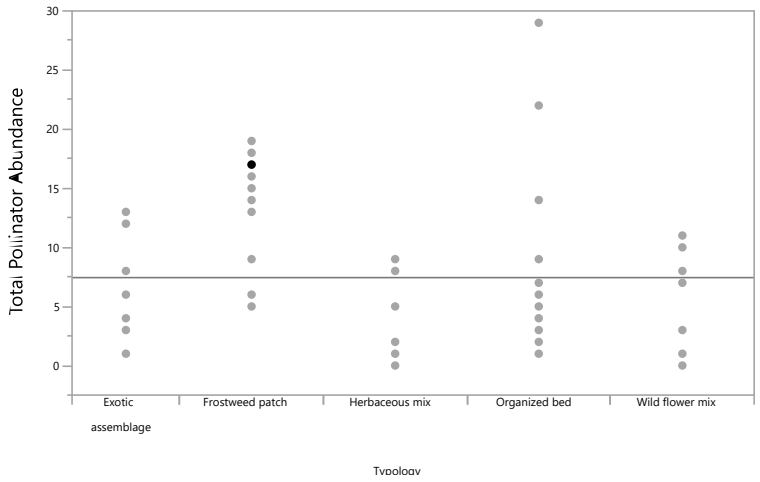
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	251.000	261.000	27.8889	-0.241
Frostweed patch	12	539.000	348.000	44.9167	4.330
Herbaceous mix	12	244.500	348.000	20.3750	-2.341
Organized bed	12	396.500	348.000	33.0417	1.091
Wild flower mix	12	222.000	348.000	18.5000	-2.853

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
26.7415	4	<.0001*

Missing Rows 17

Oneway Analysis of Total Pollinator Abundance By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

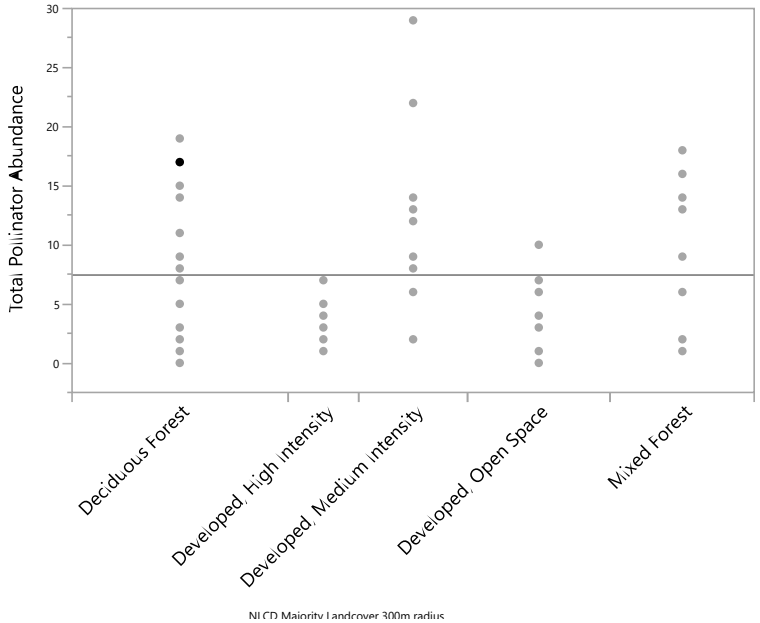
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	245.000	261.000	27.2222	-0.340
Frostweed patch	12	550.500	348.000	45.8750	3.967
Herbaceous mix	12	207.500	348.000	17.2917	-2.749
Organized bed	12	364.000	348.000	30.3333	0.304
Wild flower mix	12	286.000	348.000	23.8333	-1.208

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
19.8454	4	0.0005*

Missing Rows 17

Oneway Analysis of Total Pollinator Abundance By NLCD Majority Landcover 300m radius



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

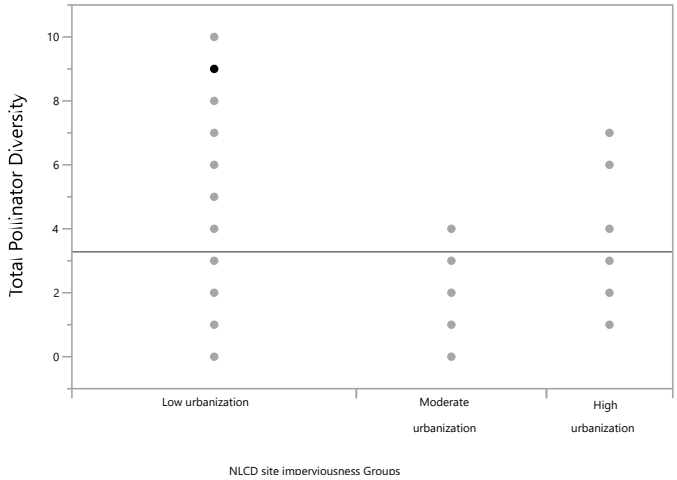
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Deciduous Forest	18	614.000	522.000	34.1111	1.576
Developed, High Intensity	6	121.000	174.000	20.1667	-1.370
Developed, Medium Intensity	9	368.000	261.000	40.8889	2.338
Developed, Open Space	12	227.500	348.000	18.9583	-2.356
Mixed Forest	12	322.500	348.000	26.8750	-0.491

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.6938	4	0.0129*

Missing Rows 17

Oneway Analysis of Total Pollinator Diversity By NLCD site imperviousness Groups



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

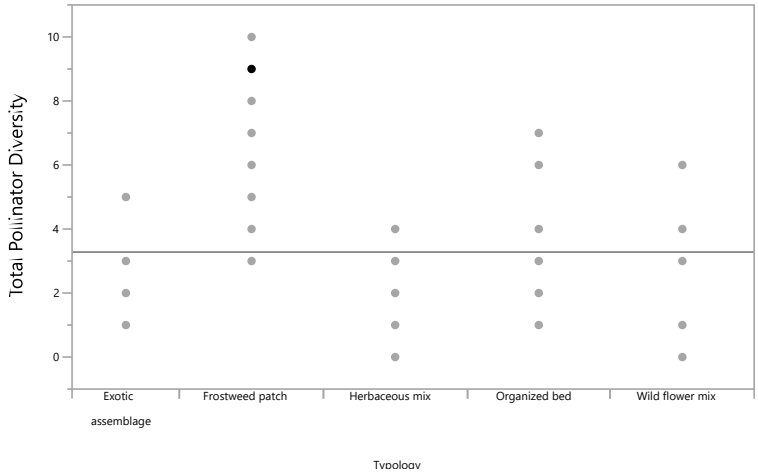
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Low urbanization	27	865.000	783.000	32.0370	1.322
Moderate urbanization	18	376.000	522.000	20.8889	-2.535
High urbanization	12	412.000	348.000	34.3333	1.261

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.6331	2	0.0363*

Missing Rows 17

Oneway Analysis of Total Pollinator Diversity By Typology



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Exotic assemblage	9	219.500	261.000	24.3889	-0.911
Frostweed patch	12	562.000	348.000	46.8333	4.241
Herbaceous mix	12	197.000	348.000	16.4167	-2.989
Organized bed	12	369.000	348.000	30.7500	0.407
Wild flower mix	12	305.500	348.000	25.4583	-0.834

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
22.7822	4	0.0001*

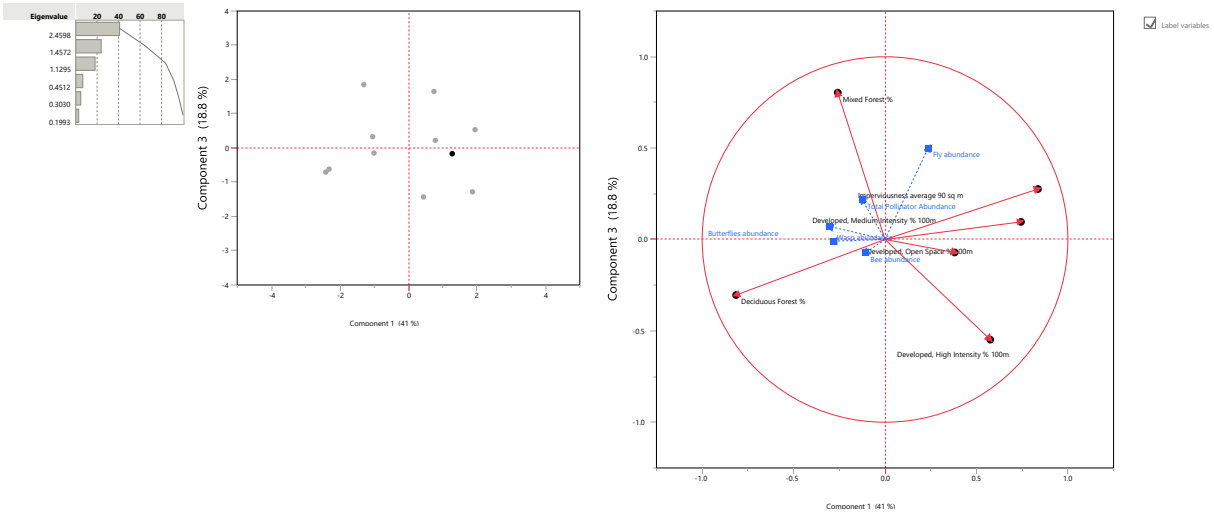
Missing Rows 17

APPENDIX E

Principle Component Analysis Summaries

Principal Components: on Correlations

Summary Plots



Select component Component 1 Component 3

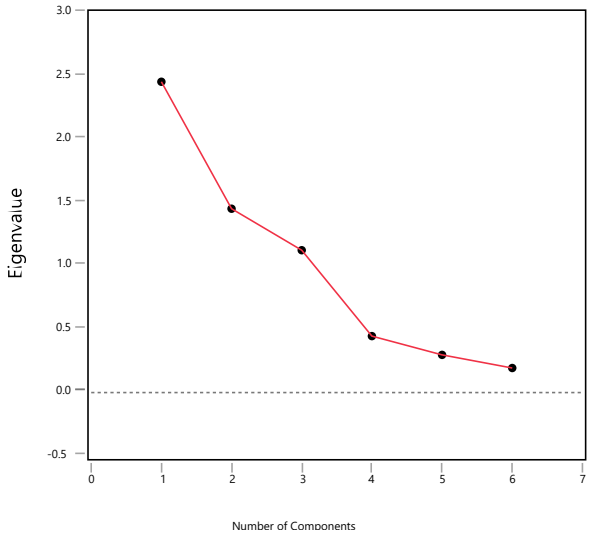
Eigenvectors

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6
Imperviousness average 90 sq m	0.53341	-0.20882	0.25990	0.39197	0.10497	-0.66306
Developed, High Intensity % 100m	0.36696	0.35324	-0.51570	0.60215	-0.07884	0.32530
Developed, Medium Intensity % 100m	0.47415	-0.44697	0.09061	-0.17258	0.50114	0.53504
Developed, Open Space % 100m	0.24287	0.68678	-0.06681	-0.42493	0.48501	-0.22152
Deciduous Forest %	-0.51946	-0.16716	-0.28594	0.34777	0.68774	-0.16286
Mixed Forest %	-0.16483	0.36362	0.75635	0.39048	0.15298	0.30441

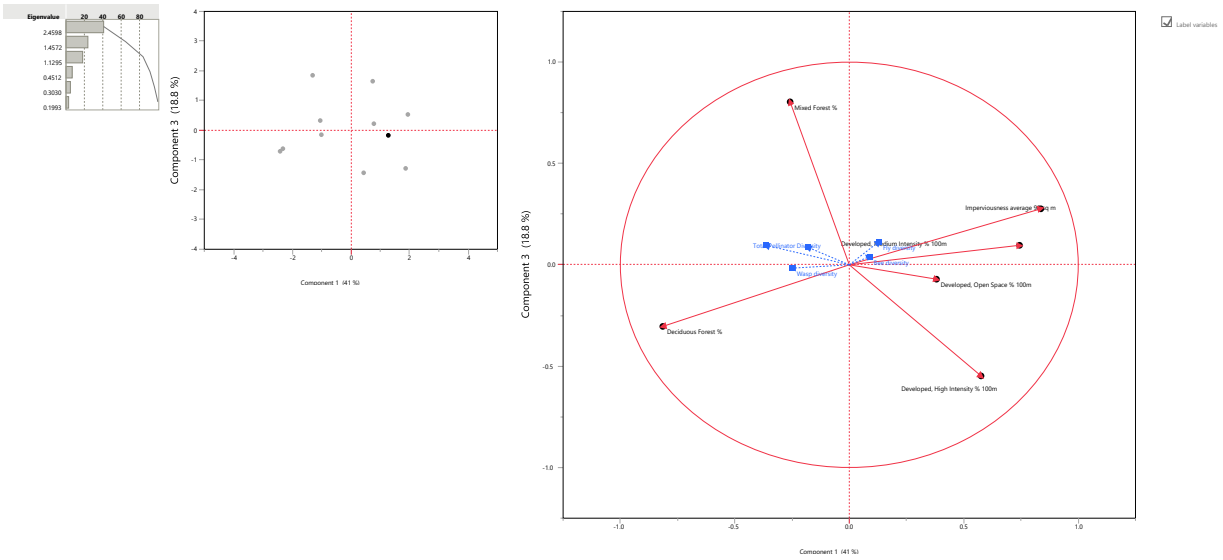
Eigenvalues

Number	Eigenvalue	Percent	Cum Percent	ChiSquare	DF	Prob>ChiSq
1	2.4598	40.997	40.997	126.026	15.280	<.0001*
2	1.4572	24.287	65.284	77.877	12.963	<.0001*
3	1.1295	18.825	84.109	48.639	9.436	<.0001*
4	0.4512	7.519	91.628	9.055	5.874	0.1616
5	0.3030	5.050	96.679	2.376	2.595	0.4211
6	0.1993	3.321	100.000	.	.	.

Scree Plot


Eigenvalue
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
1
2
3
4
5
6
7
Number of Components

Principal Components: on Correlations
Summary Plots



Select component Component 1 Component 3

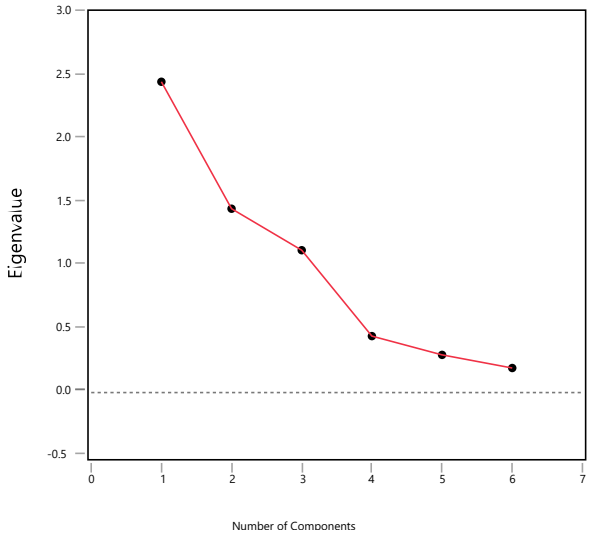
Eigenvalues

Number	Eigenvalue	Percent	Cum Percent	ChiSquare	DF	Prob>ChiSq
1	2.4598	40.997	40.997	126.026	15.280	<.0001*
2	1.4572	24.287	65.284	77.877	12.963	<.0001*
3	1.1295	18.825	84.109	48.639	9.436	<.0001*
4	0.4512	7.519	91.628	9.055	5.874	0.1616
5	0.3030	5.050	96.679	2.376	2.595	0.4211
6	0.1993	3.321	100.000	.	.	.

Eigenvectors

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6
Imperviousness average 90 sq m	0.53341	-0.20882	0.25990	0.39197	0.10497	-0.66306
Developed, High Intensity % 100m	0.36696	0.35324	-0.51570	0.60215	-0.07884	0.32530
Developed, Medium Intensity % 100m	0.47415	-0.44697	0.09061	-0.17258	0.50114	0.53504
Developed, Open Space % 100m	0.24287	0.68678	-0.06681	-0.42493	0.48501	-0.22152
Deciduous Forest %	-0.51946	-0.16716	-0.28594	0.34777	0.68774	-0.16286
Mixed Forest %	-0.16483	0.36362	0.75635	0.39048	0.15298	0.30441

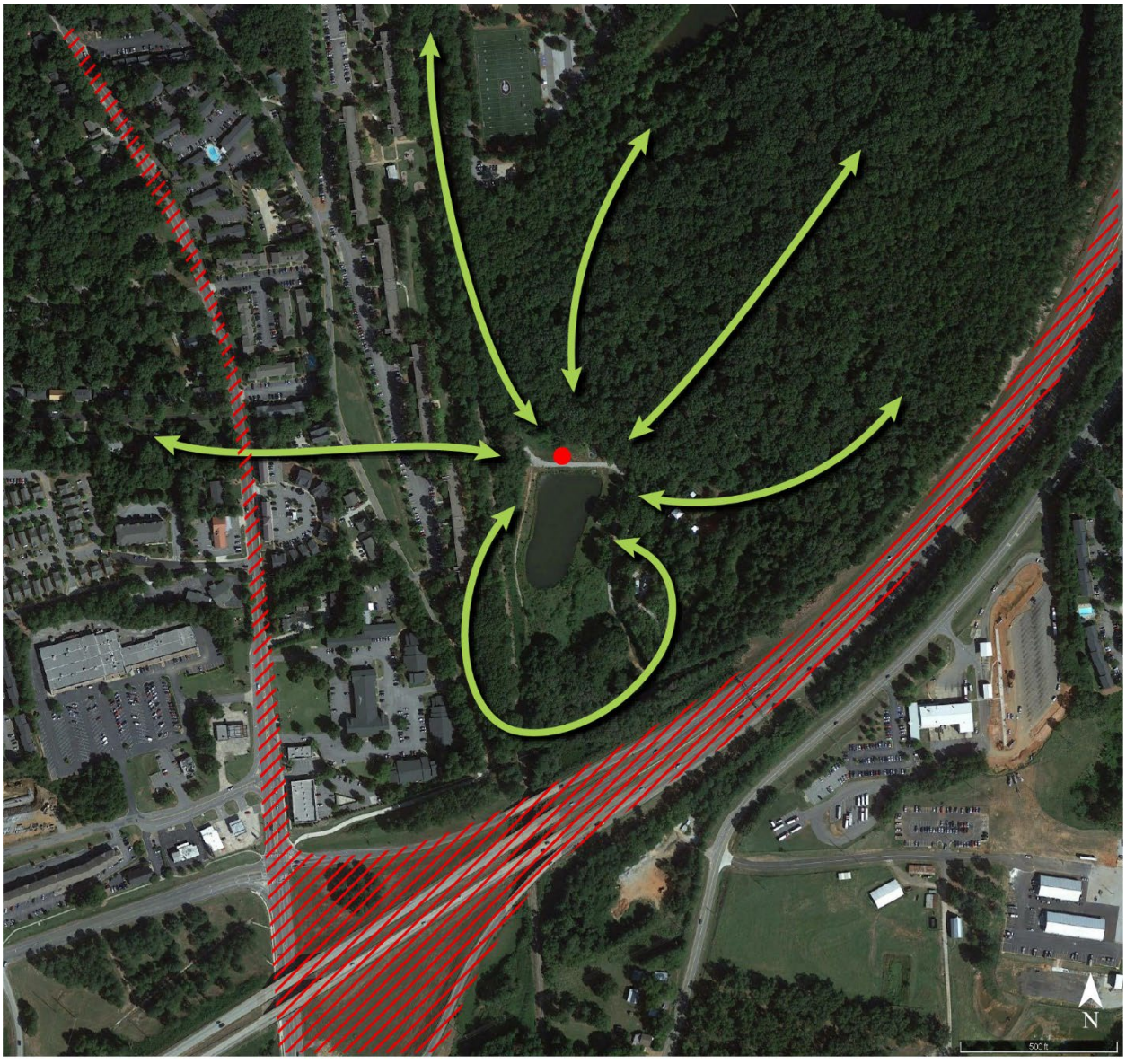
Scree Plot


Eigenvalue
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
1
2
3
4
5
6
7
Number of Components

APPENDIX F

Landscape Context Analysis

Proposed Connect to Protect pollinator garden location in the Oconee Forest Park



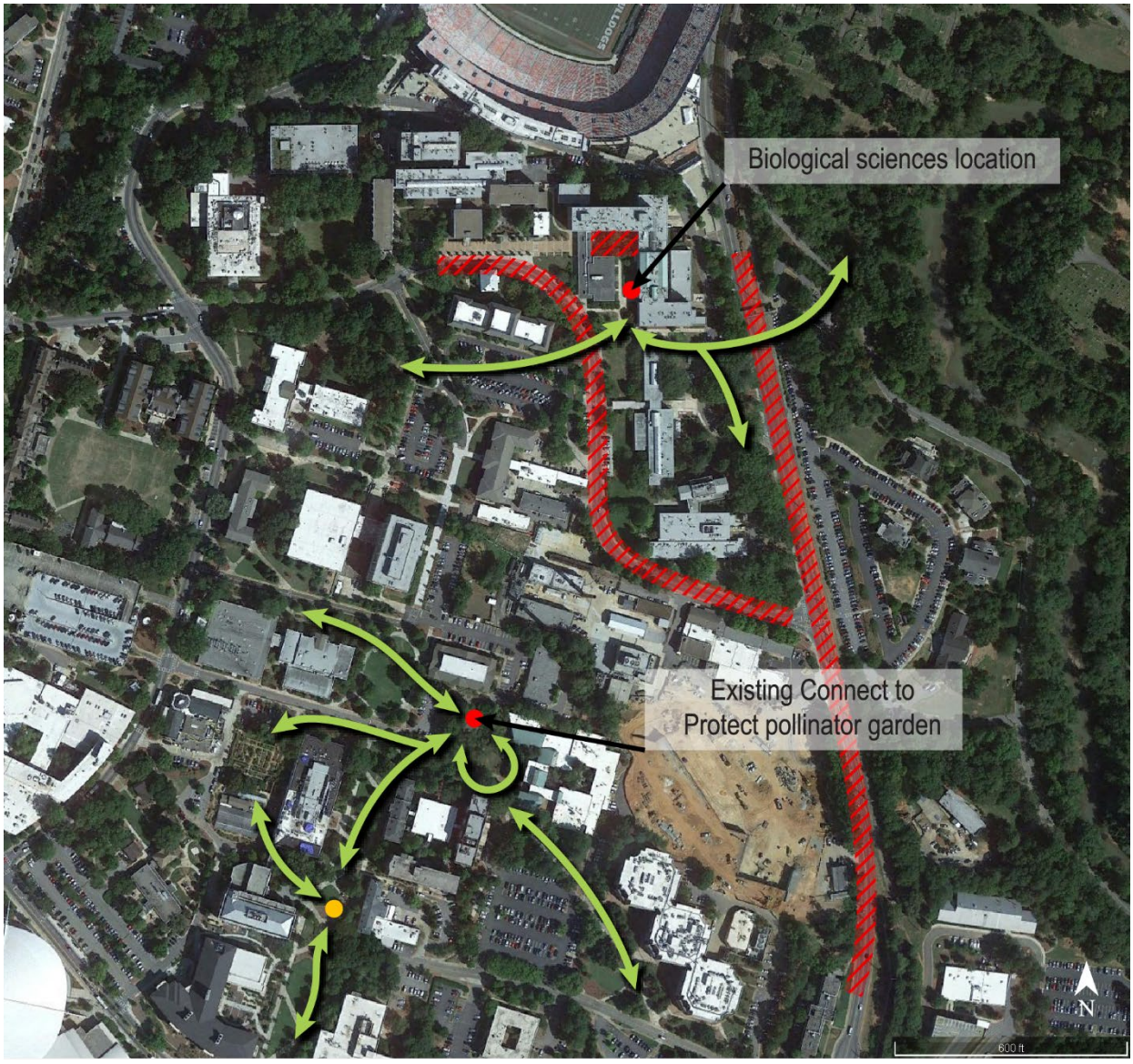
Legend

Site selected for pollinator garden

Potenital flow in/out of site

Area posing risk

Analysis of the Proposed Biological Sciences Pollinator Garden and the existing Connect to Protect pollinator garden at the Odum School of Ecology

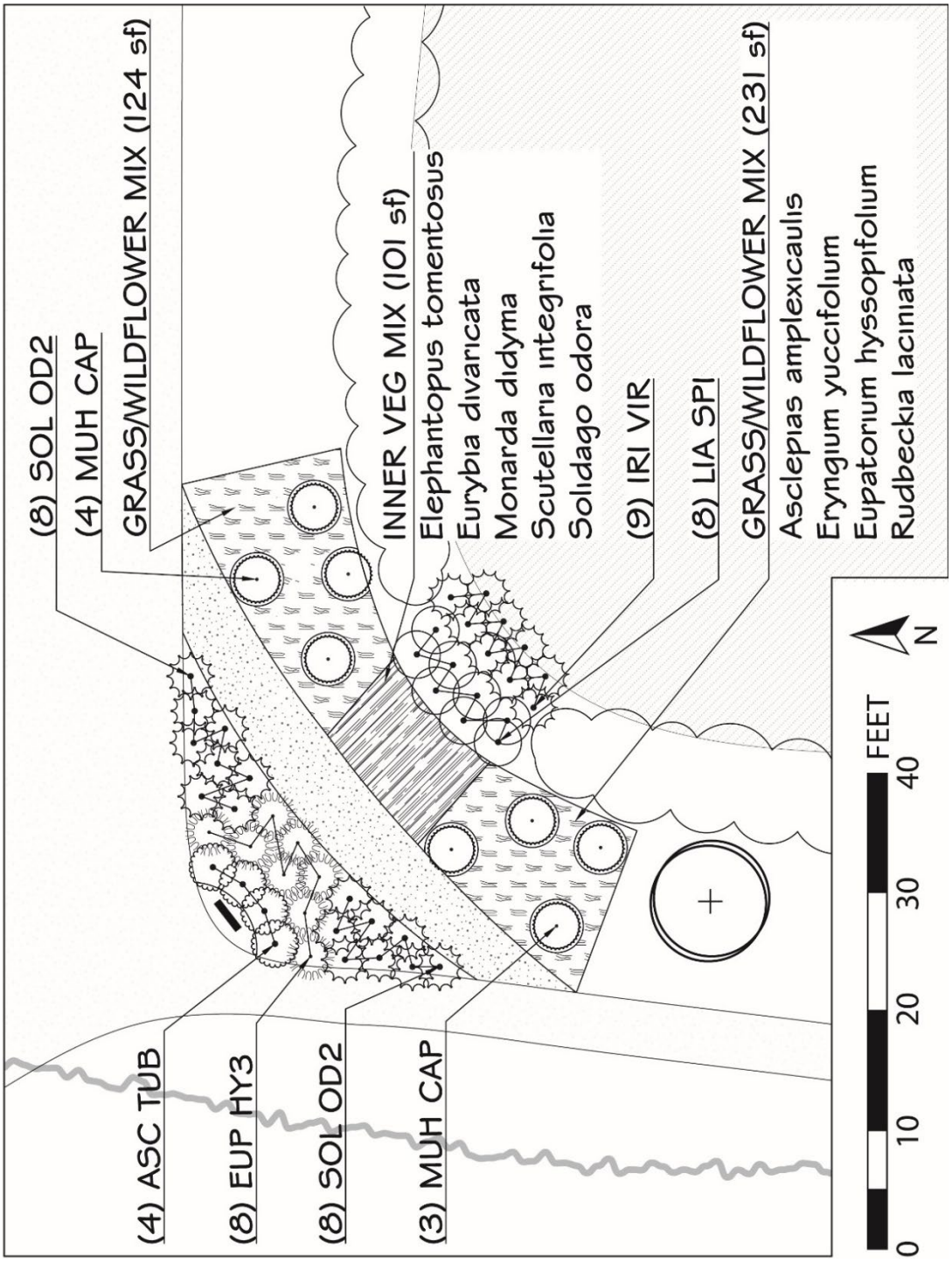


Legend

- Site selected for pollinator garden
- UGA Green Mile Polliantor Garden
- Potenital flow in/out of site
- Area posing risk

APPENDIX G

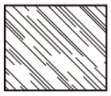
Proposed Planting Plan for Oconee Forest Park



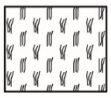
PLANT SCHEDULE

TREES	CODE	BOTANICAL NAME	COMMON NAME	SIZE	QTY
	MAG GRA	Magnolia grandiflora	Southern Magnolia	---	3
SHRUBS	**CODE**	**BOTANICAL NAME**	**COMMON NAME**	**SIZE**	**QTY**
	ASC TUB	Asclepias tuberosa	Butterfly Milkweed	2` Ht.	4
	EUP HY3	Eupatorium hyssopifolium	Thoroughwort	3` Ht.	8
	SOL OD2	Solidago odora	Sweet Goldenrod	3` Ht.	16
GRASSES	**CODE**	**BOTANICAL NAME**	**COMMON NAME**	**SIZE**	**QTY**
	MUH CAP	Muhlenbergia capillaris	Pink Muhly Grass	3` Ht.	8
PERENNIALS	**CODE**	**BOTANICAL NAME**	**COMMON NAME**	**SIZE**	**QTY**
	IRI VIR	Iris virginica	Blue Flag Iris	3` Ht.	9
	LIA SPI	Liatris spicata	Dense Blazing Star	4` Ht.	8

CONCEPT PLANT SCHEDULE



INNER VEG MIX — 101 sf
Elephantopus tomentosus / Elephant`s Foot
Eurybia divaricata / White Wood Aster
Monarda didyma / Bee Balm
Scutellaria integrifolia / Helmet Flower
Solidago odora / Sweet Goldenrod



GRASS/WILDFLOWER MIX — 354 sf
Asclepias amplexicaulis / Clasping Milkweed
Eryngium yuccifolium / Rattlesnake Master
Eupatorium hyssopifolium / Thoroughwort
Rudbeckia laciniata / Cutleaf Coneflower