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Ecosystem Enriching and Efficient Solar Energy: Exploring the Effects of Pollinator-Friendly Solar Facilities on Ecosystem Function and Solar Panel Efficiency

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Ecosystem Enriching and Efficient Solar Energy: Exploring the Effects of Pollinator-Friendly Solar Facilities on Ecosystem Function and Solar Panel Efficiency

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ABSTRACT

As the solar energy industry grows, many hundreds of thousands of acres of land will be transformed into solar panel facilities. With this large change in land use, there is the opportunity to promote biodiversity and support pollinators by using pollinator-friendly management practices at the solar facilities. This paper explores the ecological and economic effects of a pollinator-friendly solar facility compared to a turfgrass solar facility.

I hypothesized that a pollinator-friendly solar facility would be functionally equivalent in pollinator support and overall insect diversity to a pollinator-friendly non-solar field and that both sites would have far greater pollinator support and insect diversity than a turfgrass solar field. To test this hypothesis, vegetation and insect sampling were conducted and the resulting data were analyzed for differences in vegetative and insect diversity and pollinator abundance at a pollinator-friendly solar facility, a turfgrass solar facility, and a reference non-solar pollinator-friendly field. The diversity analysis revealed that the pollinator-friendly solar site was overall functionally equivalent to the non-solar pollinator-friendly site and the turfgrass solar site had low insect and vegetative diversity, but high insect abundance.

Photovoltaic solar panel energy production is negatively affected by high temperatures. Therefore, to maximize energy production and promote biodiversity native forbs may be incorporated into a solar facility landscape to cool the solar panels by the cooling effect of transpiration and produce more energy than a traditional turfgrass landscaped solar facility throughout the growing season. This study tested that hypothesis by analyzing environmental and vegetation data from two solar facilities, one with a turfgrass landscape and one with a pollinator-friendly forb-dominated landscape. Irradiance, ambient temperature, panel temperature, and percent forb ground cover were recorded for a section of solar panels at each site throughout the 2021 growing season. This data was used to create generalized linear models (GLMs) for predicting panel temperature and humidity based on irradiance, ambient temperature, site, and the interactions between each of them. The predictions made by the panel temperature predicting model supported the hypothesis that the pollinator-friendly landscape had a greater cooling effect than the turfgrass landscape under high and medium irradiance conditions. But this cooling effect was not seen under low irradiance conditions. This suggests that the negative effect of high temperatures on energy output is only significant under high irradiance conditions. Overall, this study supports the idea that pollinator-friendly landscapes could be more economically viable, as pertaining to energy output, and more ecologically beneficial compared to turfgrass. More research is necessary to further investigate and test the patterns seen at only these two solar sites, but these results are encouraging for the future widespread implementation of pollinator-friendly management practices in solar facilities across the Mid-Atlantic.

TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

1.1 Background

Two of the biggest challenges the Earth is facing today are climate change and decreasing biodiversity, the former being caused primarily by the burning of fossil fuels for energy, and the latter by changes in land use such as deforestation for agriculture (Pimm et al. 1995). The technological advancements needed to support sustainable alternatives to a fossil fuel-based energy economy have been in development for many years, but only recently have these advancements been implemented on a widespread scale. For example, one of the most practical renewable energy sources in the U.S. is solar power. The U.S. has committed to increasing solar energy generation through aggressive energy portfolios that anticipate carbon-neutral energy production by 2050 (Blinken 2021, Horowitz 2021). As the solar energy industry grows to address climate change by reducing our carbon footprint, the “ecological footprint” of solar energy generation has been called into question, particularly concerning biodiversity losses incurred by the construction and management of solar energy facilities (McDonald et al. 2009, Lovich and Ennen 2011, Hernandez et al. 2019, Weselek et al. 2019). The solar energy industry is now seeking development, operation, and maintenance strategies with the potential to address problems on both fronts (climate and biodiversity).

The solar energy industry includes thermal, fuel, and electrical energy (Tsao et al. 2006). This study is focused on the production of photovoltaic (PV) electrical energy in the Mid-Atlantic. Solar energy generation sufficient for regional distribution (i.e., utility-scale solar energy; USSE) generally requires the construction of solar panels covering large tracks of land over hundreds of acres in size (Moore-O’Leary et al. 2017, DeBerry et al. 2019). In the eastern U.S., these facilities are most commonly sited in post-agricultural landscapes, which are preferred because they require minimal grading for site construction and no tree clearing (Macknick et al., 2013). To stabilize the soil at these sites, turfgrass is commonly planted under and around the solar panels, creating a monoculture that requires regular mowing, reduces biodiversity, and limits the amount of available habitat for native flora and fauna (Tiller 2013). However, alternative landscaping strategies have the potential to turn solar facilities into habitats for wildlife such as pollinators, while also performing other ecosystem services like erosion prevention, flood abatement, and carbon sequestration (Blaydes et al., 2021; Hernandez et al., 2014, 2019; Moore-O'Leary et al., 2017; Tsoutsos et al., 2005). Solar energy facilities can be designed to accomplish these goals by using pollinator-friendly plants rather than turfgrass or gravel (Macknick et al. 2013, Montag et al. 2016, Walston et al. 2018).

1.1.1 Virginia Pollinator-Smart Program

Recognizing the potential for solar facilities to provide habitat for wildlife and increase biodiversity, the Virginia Department of Environmental Quality (DEQ) partnered with the Virginia Department of Conservation and Recreation (DCR) to create the "Virginia Pollinator-Smart Solar Industry". This program was designed to equip solar energy companies with strategies and incentives for converting solar facilities into pollinator-friendly landscapes (DeBerry et al. 2019). Pollinator-friendly landscapes are dominated by beneficial plants that provide food through nectar for native pollinators, as well as habitat to support diverse insect communities (Seitz et al. 2020). In the Virginia program, a "Pollinator-Smart" landscape achieves these objectives by planting and maintaining a diverse vegetative community of beneficial flowering forbs, in and around a solar installation in lieu of traditional turfgrass. Many other states across the US are in the process of or have already created their own pollinator-friendly solar facility programs (Terry et al. 2020).

1.1.2 Ecosystem services of pollinator-friendly solar facilities

Pollinator-friendly solar facilities, like those in Virginia's Pollinator-Smart Program as well as those of other states, are expected to increase ecosystem services as compared to turfgrass solar facilities. Ecosystems services can be defined as properties of ecosystems that generally benefit humans (Oliver et al., 2015). The pollinator-friendly landscape should provide the following ecosystem services (Beatty et al. 2017):

- Prevent erosion
- Sequester carbon
- Prevent flooding
- Support pollinators for crop pollination
- Support natural insect enemies of crop pests

In addition to the ecosystem services of pollination and crop pest suppression, the insect community of a pollinator-friendly landscaped solar facility may also increase the overall ecosystem function and biodiversity of that area. Ecosystems functions are the physical, chemical, and biological attributes that contribute to the self-maintenance of an ecosystem over time (Oliver et al. 2015), so functions can be thought of as the ecological underpinning of services. Chapter 2 of this study is focused on answering the question: Is a Pollinator-Smart landscape functionally equivalent to a natural landscape counterpart with respect to pollinator support and insect diversity, and how does a turfgrass landscape compare? To examine how a pollinator-friendly landscape affects the ecosystem function of a solar facility, I measured the vegetative community diversity and insect community taxonomic and functional diversity of the study sites described below.

1.1.3 Economics of pollinator-friendly solar facilities

The widespread implementation of pollinator-friendly management plans on USSE facilities across the Mid-Atlantic depends on those regimes being economically viable compared to turfgrass management. There are many factors in the assessment of economic viability of a pollinator-friendly solar site compared to a turfgrass solar site (in order of implementation):

1. Preparation of land for planting (soil amendments, fertilizer, erosion and sediment control cover crops, and grading)
2. Seeding costs
3. Maintenance costs (mowing and herbicide application)
4. Vegetation shading of solar panels, decreasing energy production
5. Vegetation's effect on solar panel temperature and therefore energy production (thermal buffering effect of transpiration)

The first three factors depend partially on the circumstances of each solar facility, such as its former land use. But for most solar sites the estimated cost reductions in land preparation and maintenance could outweigh the higher cost of pollinator-friendly seed mixes compared to turfgrass seed mixes (Beatty et al., 2017; Hopwood et al., 2015; Kuzovkina et al., 2016; Robin Ernst, Monarch Vegetation Services, pers. comm.). The cost reduction in land preparation and maintenance of the pollinator-friendly landscape is partially due to the hardy native plants not requiring the costly soil amendments otherwise needed to promote turfgrass growth. Soil amendments also have the potential to introduce foreign seeds and potentially promote invasive species growth (Hodkinson and Thompson 1997). Native plants are known to outcompete non-native invasives better than turfgrass and thus reduce the need for herbicide application (Alpert et al. 2000). Pollinator-friendly landscapes also require significantly less mowing than turfgrass landscapes. Less frequent mowing saves money, and that cost reduction has been found to outweigh the higher cost of pollinator-friendly seed mixes, compared to turfgrass seed mixes, in as little as three years after planting (Tiller 2013).

The last two factors, panel shading and thermal buffering, have not been studied to see which landscape (turfgrass or pollinator-friendly) is more cost-effective. The panel shading factor can be mitigated by only planting vegetation with a maximum height less than that of the panels in the panel area and/or by raising panel height (DeBerry et al. 2019). The effect of each landscape type on the thermal buffering of solar panels is the focus of Chapter 3, which investigates the question: Does a pollinator-friendly solar facility have higher energy production efficiency and a greater thermal buffering capacity than a turfgrass solar facility?

1.2 Study Design

To investigate the question of thermal buffering, solar panel microclimate research was conducted at a pollinator-friendly landscaped photovoltaic solar facility (Cople Solar Site) and a turfgrass landscaped solar facility (Middlesex Solar Site), both owned and operated by Sun Tribe Solar, a prominent and fast-growing clean energy company in the Mid-Atlantic region. To investigate the ecosystem function and services question, insect

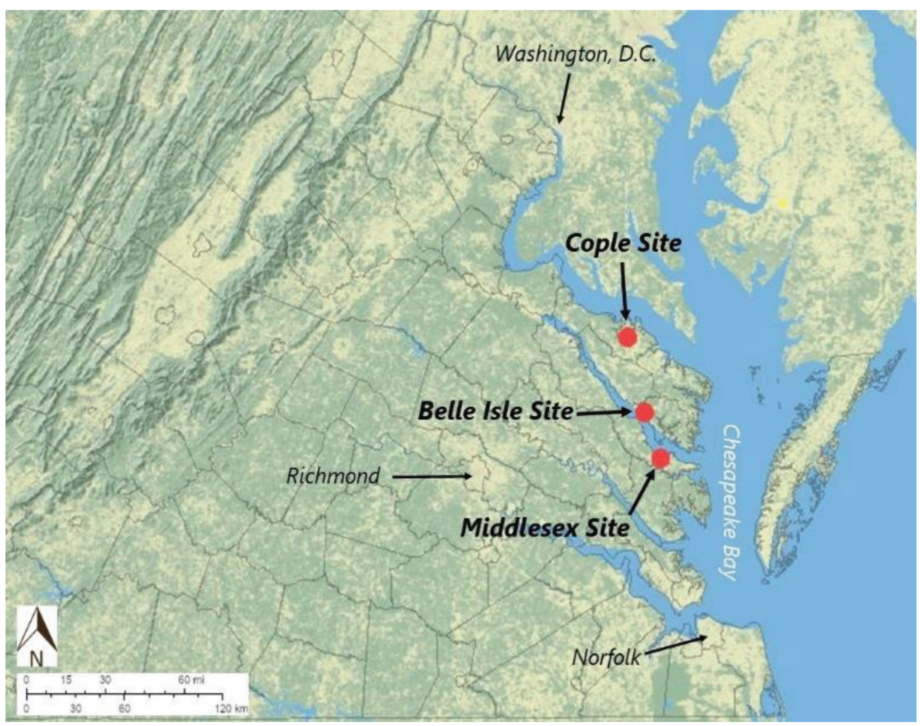

Figure 1.1 Location map of study sites.

and vegetation surveys were conducted at Cople, Middlesex, and at a non-solar native pollinator meadow created for conservation and recreation at Belle Isle State Park. All three sites are approximately five acres in size and are located in the northeastern region of Virginia (Figure 1.1), and each has a similar landscape setting with the surrounding area comprised of agricultural fields and forests with minimal development.

1.3 Site Descriptions

1.3.1 Cople Solar Site

The Cople Site, which is next to Cople Elementary School in Westmoreland County, Virginia, was built in 2019 and was the first solar facility in Virginia to be Gold Certified Pollinator-Smart, the highest certification rank for the program. The Cople Site is made up of two different management areas, the Cople open area (CO), 2.02 acres, and the Cople panel zone (CP), 2.04 acres (Figure 1.2). Although these two areas are co-located at the Cople Site, they are treated as separate sites in the diversity analyses in order to analyze the effects of the different planting plans and management strategies. Cople Site's solar infrastructure is made up of 13 ground-mounted, fixed-tilt PV solar panel rows spaced 14 ft apart and uses the Seraphin SEG-6MA-365WW

Figure 1.2 Cople Site showing sampling transect layout (see Methods, Chapter 2). CP means "Cople Panel" and CO means "Cople Open". Numbers T1-T4 correspond to individual transects.

module and Canadian Solar CSI-66KTL-GS 2017-08 inverters (Taylor Brown, Sun Tribe solar, pers. comm.).

Cople Management: CP and CO were each planted with a different seed mix to accommodate the height of the panels in CP, while also incorporating taller native vegetation into the solar facility in CO (VHB 2019). CP and CO are mown once in the early winter and once in the spring each year. CP was also mown in August of 2021 to prevent the vegetation from shading the panels. Herbicide spot treatment was also applied following Integrated Vegetation Management (IVM) techniques at CP and CO in August of 2020 and July of 2021, although herbicide management was more focused on CP (Taylor Brown, Sun Tribe solar, pers. comm.).

1.3.2 Middlesex Solar Site

Figure 1.3 Middlesex Site (MS). See Figure 1.2 for an explanation of figure references.

The Middlesex Site (MS) is a solar facility in Middlesex County, Virginia that supplies power for Middlesex Elementary School and St. Clare Walker Middle School. The Middlesex Site was built in 2018 and prior to installation was a turfgrass field used by the school. The Middlesex facility is made up of two different enclosed solar panel areas. This study was conducted on the enclosed solar panel area which was the most similar in size and shape to the Cople Site (Figure 1.3). Vegetation and insect surveys were only conducted in the panel zone of Middlesex due to the observed vegetative homogeneity of the panel zone and open area. Middlesex's solar infrastructure is made up of 14 ground-mounted, fixed-tilt PV solar panel rows spaced 15 ft apart and uses the Mission Solar MSE340O6 module and Solectria (Yaskawa Solectria Solar) PVI 60TL 2-21-2017 inverters (Taylor Brown, Sun Tribe solar, pers. comm.).

Middlesex Management: After installation, disturbed areas at the site were treated with German millet (*Setaria italica*) to help reestablish the turfgrass vegetation in 2018. Otherwise, the site was overseeded with a tall fescue cultivar (*Schedonorus arundinaceus*) typical of post-construction site stabilization practices in the region. Since installation, the site has been mown approximately every two weeks.

1.3.3 Belle Isle Native Meadow

The Belle Isle Site (BI) is a pollinator-friendly meadow next to the Belle Isle State Park Visitor's Center and is maintained by the Virginia Department of Conservation and Recreation (DCR). This site was used for agriculture, mainly corn and soybeans, before DCR purchased it in 1993.

The area of Belle Isle State Park surrounding the study site is made up of primarily active agriculture fields and hardwood forests. The Belle Isle Site is also near the Rappahannock River, but our transects were chosen to be an adequate distance from the shore to avoid shoreline vegetation and river borne insects (Figure 1.4).

Figure 1.4 Belle Isle Native Meadow (BI). See Figure 1.2 for an explanation of figure references.

Belle Isle Management: As Belle Isle State Park was being constructed prior to 2008, the study site was taken out of active agriculture and converted to a warm-season grassland. The Belle Isle site was planted first with grass-heavy seed mixes and then pollinator-friendly seed mixes in the following years. The site's continual resource management efforts since 2008 include herbicide application to control invasive species, as well as the use of prescribed fire on a three-year cycle (Katie Shepard, Belle Isle State Park Manager, pers. comm.). Because of its longevity as a native meadow and the active management over the past 13 years undertaken to maintain it, BI was chosen to serve as a reference site for the pollinator-friendly conditions at CP and CO.

Chapter 2: Comparing Insect and Vegetation Diversity Across Landscapes

2.1 Introduction

One negative environmental impact of particular importance for ground-mounted solar facilities is the loss of biodiversity (Abbasi and Abbasi 2000, Tsoutsos et al. 2005, Hernandez et al. 2014, Montag et al. 2016, Grodsky and Hernandez 2020). There have been studies conducted on how solar facilities affect plant, bee, bird, and mammal diversity across different landscape types showing both positive and negative results depending on the vegetative community of the solar field (Montag et al. 2016, Peschel et al. 2019, Grodsky and Hernandez 2020). The biodiversity of an area can be altered by bottom-up changes in the landscape (Scherber et al. 2010). The negative impact of solar development on local biodiversity may be mitigated or even reversed depending on the former landscape's land use by incorporating beneficial vegetation into the solar facility landscape.

The effects of the beneficial vegetation on biodiversity would be greatest at the lower trophic levels, such as with terrestrial invertebrates (Scherber et al. 2010). In the current biodiversity crisis, the abundance and species diversity of terrestrial invertebrates are declining at a faster rate than that of vertebrate species (Dirzo et al. 2014). The declines seen in terrestrial invertebrates are thought to be mostly due to changes in land use, with greater declines seen in grassland landscapes surrounded by agricultural land (Seibold et al. 2019). Because USSE (utility-scale solar energy) is expected to develop large tracts of land in agricultural areas, there is a significant opportunity for those areas to be made pollinator-friendly and thus boost insect biodiversity. This boost to insect diversity will also benefit agricultural interests through increased pollinator abundance and insect species diversity.

Insect species fill many different unique niches, therefore insect biodiversity is vital in supporting ecosystem function and providing ecosystem services (Kim 1993, Anderson et al. 2000, Foottit and Adler 2009). Because terrestrial insects fill so many unique niches and support ecosystem functions, they are a good measure of biodiversity for an entire ecosystem (Wilson 1987, Duelli et al. 1999, Bellamy et al. 2018). One way to analyze insect biodiversity in a community, with regard to its effects on the ecosystem function and ecosystem services, is by the relative abundance of different functional groups (Bellamy et al. 2018). For example, a high relative abundance of sanguivores (blood-sucking insects) indicates disturbance and environmental stress in the ecosystem (Foottit and Adler 2009), while a high proportion of detritivores indicates high ecosystem functioning in bottom-up interactions and increased nutrient cycling, which is an important ecosystem function (Seastedt and Crossley, 1984, Armstrong et al. 2021). The intensity of another ecosystem service, crop pollination, can be estimated through the relative abundance of the pollinators in an insect community (Aizen et al. 2009, Woodcock et al. 2019).

Pollinator-friendly landscapes provide habitat and food for pollinators that have plant species-specific life stages, like butterflies that only lay their eggs on milkweeds (Zaya et al. 2017). The native plants likewise rely on pollinators to spread their pollen so they can reproduce and maintain genetic diversity within plant populations (Kearns and Inouye 1997). Wild pollinators are important not only for the pollination of native plants but also for the pollination of the many crops on which our food system relies (Kearns and Inouye 1997, Aizen et al. 2009, Burkle et al. 2013, Woodcock et al. 2019).

Crop reliance on insect pollination is estimated to equal $14.6 billion in agriculture production each year (Bauer and Wing 2010). Of the 100 crop species that make up 90 percent of the food supply for 164 countries in the United Nations, 71 of those crop species rely on pollination mainly from wild bees, and many more species rely on other pollinators like flies, beetles, and other insects (Williams 1996). For agricultural areas, the visitation rates of pollinators, species richness of flower-visitors, and overall pollination services have been shown to decrease with distance to natural areas (Ricketts et al. 2008, Carvalheiro et al. 2010, Garibaldi et al. 2011, Geslin et al. 2016). Crops also depend on diverse insect communities to supply natural arthropod enemies of crop pests to protect the crops from the damaging effects of insect pests (McCravy 2018). These observations underscore the importance of supporting native pollinators and diverse insect communities not only to increase plant biodiversity but also to maintain agricultural systems and ensure reliable food supplies. The pollinator habitat provided by pollinator-friendly solar facilities is expected to have positive impacts on agriculture in America, but the size of those effects depends on the effectiveness of pollinator-friendly management strategies in supporting diverse insect communities and pollinator abundance (Walston et al. 2018, 2021).

There have been few studies on how incorporating non-turfgrass vegetation into solar energy infrastructure will affect terrestrial insect communities (Montag et al. 2016, Jeal et al. 2019, Armstrong et al. 2021). The most recent research on solar-ecosystem impacts has focused on mitigating the negative effects of solar facilities on aquatic insects. Solar fields are seen as an ecological trap for aquatic insects because the aquatic insects can be attracted to solar panels instead of water bodies to lay their eggs due to the polarized light pollution from solar panels, which mimics the reflection of light off water bodies at night (Horváth et al. 2010, Száz et al. 2016, Black and Robertson 2020). Although solar panels without proper light pollution mitigation features may act as ecological traps for aquatic invertebrates, they do not function as ecological traps for terrestrial insects and can even be designed to support diverse insect communities.

To investigate how different pollinator-friendly and turfgrass landscape management regimes affect terrestrial insect communities, I analyzed the relationship between pollinator abundance, insect diversity, and floristic conditions established at the four differently managed sites described in Chapter 1 (CP, CO, BI, MS). I hypothesized that the pollinator-friendly solar facility (CP, CO) would support taxonomic and functional insect diversity and overall proportion of pollinators similar to that of the reference site (BI), and that these community properties would be greatly diminished on the turfgrass site (MS). This is based on the rationale that the pollinator-friendly facilities would provide food and habitat to support a diverse insect community, mimicking that of a natural meadow. I hypothesized that a pollinator-friendly landscape would be less invaded by non-native plants than a turfgrass landscape and have a higher overall floristic quality because of the combination of planting diversity and management strategy designed to outcompete non-native invasive plants. I anticipated that this expected increase in floristic quality would be correlated with the increased insect functional diversity.

2.2 Methods

2.2.1 Research Design and Data Collection

For each landscape site (Belle Isle (BI), Cople Panel (CP), Cople Open (CO), and Middlesex (MS)) vegetation and insect sampling was conducted 3 times throughout the 2021 growing season (late May, late July, and early October). For brevity, these sampling times will be summarized as spring, summer, and fall. At each landscape area, four 50 meter transects were chosen to best represent the entire landscape. For the CP and MS areas, transects were restricted to the rows between solar panels due to the restrictions of the insect sampling technique (described below). Also, the differences in the insect communities under different shade regimes of solar panels have been studied and the flower visitation rates of pollinators did not differ between shade treatments (Graham et al. 2021) (Figures 1.2 and 1.3). The insect sampling and vegetation surveys were conducted on the four transects at each site during all three sampling periods.

2.2.2 Insect Sampling

Insect sampling was conducted between 9 am and 4 pm on dry days with less than 50% cloud cover, temperature greater than 15.5 degrees Celsius, and wind speed less than 30km/h to get to best representative samples of the insect communities (Bates et al. 2011, O'Connor et al. 2019). The insect sampling was conducted using a sweep net while walking at a steady pace down the 50m transects (1 sweep per step)(Spafford and Lortie 2013, Canola Council of Canada 2017). The sweep net method was chosen because it has been shown to reflect the insects using the meadow better than other insect collection methods, such as bee bowl traps (Roulston et al. 2007, Meyer et al. 2017).

The sweep net containing the insects was then placed in a kill jar made of plaster of Paris soaked with ethyl acetate for 2-3 minutes (Droege et al. 2016). The euthanized insects were then transferred to Ziploc bags and placed in a cooler. After being stored in a cooler for the field day, the specimens were taken back to the lab and placed in a zero-degree Celsius freezer to prevent decay. The mature specimens of Class Insecta were then separated from the debris and sorted by order. From there, the insect specimens of each sweep net sample were identified to family or lowest possible taxonomic level for certain groups (Diptera, which was categorized as Syrphidae or "other", Microlepidoptera which could not be identified further due to the loss of scales from the violent sweep netting, and chalcid wasps which could not be identified further than the Superfamily of Chalcidoidea)(Borror et al. 1998, Marshall 2006). Thysanoptera (thrips) were not included in this study due to their small size and lack of relevance to our research question.

All specimens were then sorted into morphospecies from their family/lowest taxonomic level, as morphospecies has been shown to be an adequate representation of diversity when the expertise needed to identify specimens to genus or species is not available (Oliver and Beattie 1996, Derraik et al. 2002, 2010, Obrist and Duelli 2010). A “type” specimen of each morphospecies was collected and kept frozen for future reference (Bellamy et al. 2018). The families and lowest taxonomic levels of each specimen were assigned to one of seven functional groups: predator, pollinator, parasitoid, herbivore, detritivore, sanguivore, and ant (Borror et al. 1998, Zumbado 2000, Bellamy et al. 2018, Armstrong et al. 2021).

2.2.3 Vegetation Sampling

Plot-based vegetation sampling was conducted using randomly placed 1-meter square sampling frames along the insect sweep net transects. For all sites, the transects were subdivided into four equal segments of 12 meters each (48 meters total, leaving 1 meter unsampled at both ends), and a random number between 1 and 12 was selected for each segment using a random numbers generator to indicate the linear distance along the segment where the plot would be sampled. An additional second random number between -2 and +2 was selected specifically for the panel zone transects (CP and MS) to indicate a perpendicular offset distance in either the south (-2, -1) or north (+1, +2) direction, or centered on the transect (0). For example, if the first random number drawn for a panel transect segment was “7” and the second was “0”, the plot was placed directly on the transect centerline at 7 meters from the start of the segment. If instead the second number was “-2”, the plot was offset from the centerline 2 meters in the direction of the panel to the south, and so on. The rationale for this adjustment in the panel zones was to get a representative sample across the variable light environment created by shading from the adjacent panels. For all transects, the above sampling approaches yielded four plots per transect per sampling event or 16 plots per site per event.

Within the 1-meter square vegetation plots, all plants were identified to species level and assigned a cover class using a modified Daubenmire cover class scale with midpoints recorded for analysis (Mueller-Dombois and Ellenberg 1974). The cover classes, with midpoints in parentheses (rounded to the nearest whole integer), included: 0-1% (1%); 1-5% (3%); 5-25% (15%); 25-50% (38%); 50-75% (63%); 75-95% (85%); and, 95-100% (98%). Three additional attributes were recorded for each species in each plot: 1) presence or absence of flowering at the time of the sample (forbs only); 2) Coefficient of Conservatism (*C*-value); 3) native, non-native, or invasive status. Plant nomenclature follows Weakley et al. (2020), native/non-native status was based on Virginia Botanical Associates (2021) and Weakley et al. (2020), invasive species were determined from Heffernan et al. (2014), and *C*-values were derived from DeBerry et al. (2021).

2.2.4 Data Analysis

Data analysis was conducted using R version 4.1.1 (R Core Team 2021) and the BiodiversityR package (Kindt and Coe 2005) with the vegan package (Oksanen et al. 2020). The insect and vegetative data were first summarized descriptively to give an overview of the insect and plant communities at each of the sites throughout the growing season. The proportion of each order and the overall abundance of insects were displayed in bar graphs for each site and across the three sampling periods. Properties of the insect communities of each of the sites were evaluated using family level accumulation curves (family richness), family level and morphospecies level Renyi profiles (species diversity), and an analysis of similarity (ANOSIM) (Kindt and Coe 2005). For the vegetation data, summary statistics included the following intrinsic floristic quality parameters (DeBerry and Perry, 2015): species richness (S), native species richness (N), relative percent native abundance (%N), relative percent invasive abundance (%Inv), Floristic Quality Index (FQI), and percent flowering (%Fl).

The insect functional group data were summed for each site individually by sampling period and then collectively across all three sampling events. The proportions of each functional group's abundances were represented graphically for each site over the entire growing season and by sampling period. The monotypic relationships in the insect communities of each site were evaluated using Spearman rank-order correlation tests on the insect diversity, insect functional groups, and intrinsic floristic quality parameters (Kindt and Coe 2005). The Spearman rank-order correlation test was chosen due to its ability to handle deviations from normality and examine non-linear relationships. The differences in the insect communities of each site and their relationship with the vegetative community variables, percent flowering, FQI, and plant species richness, were modeled using non-metric multidimensional scaling (NMDS)(Kindt and Coe 2005, Armstrong et al. 2021). The final NMDS was chosen based on the number of dimensions (k value) with the least stress according to the "stressplot" function in the vegan package.

2.3 Results

2.3.1 Insect Descriptive Diversity Metrics

Season	BI	CP	CO	MS	Total
Spring	723	192	151	341	**1407**
Summer	1183	1049	643	1099	**3974**
Fall	2221	751	716	1674	**5362**
Total	**4127**	**1992**	**1510**	**3114**	**10743**

Table 2.1 Insect abundance summaries by season and overall.

From the sweep net samples, a total of 10,743 insect specimens were collected in the 2021 growing season. These insects represented 8 orders, 56 families/lowest taxonomic level (see Table A.1, Appendix), and 226 morphospecies. At all sites except CP, the overall number of insects collected increased across the growing season with the fall samples from all sites totaling almost four times that of the spring samples. BI had the greatest overall insect abundance across the growing season, followed by MS and then, CP, and CO (Table 2.1). The insect communities of the sites were sufficiently sampled according to the family accumulation graph, which is seen to be approaching an asymptote for every site (Figure 2.1). Although MS had the second greatest overall insect abundance, it had low evenness at the order level (Figure 2.2). The unevenness of MS is most likely due to the high proportion of Diptera in MS across all seasons compared to the other sites (see Table A.1, Appendix).

The trends seen at the order level analysis are similar to those seen at the family level Renyi profile. BI, CP, and CO have similar high richness, Shannon Diversity Index, Simpson Diversity Index, and species evenness values compared to MS, which has much lower scores for every diversity metric (Figure 2.3). The Renyi profiles for each site conducted at the morphospecies level showed a similar pattern to the family level Renyi profiles (Figure 2.3). The insects collected at each site grouped both at the family level (ANOSIM: R=0.437, p=0.001) and morphospecies level (R=0.356, p=0.001) were significantly different (Figure 2.4).

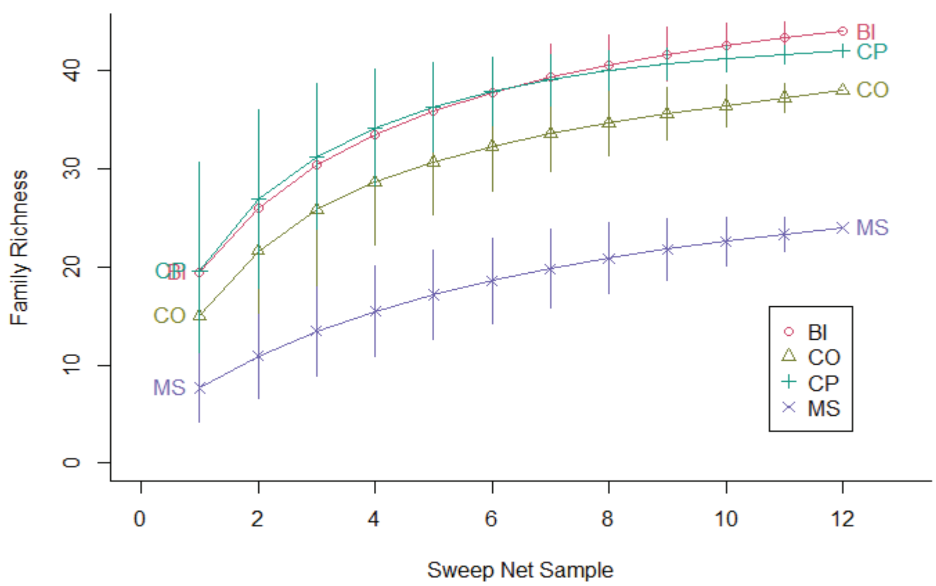

Figure 2.1 Family accumulation curves

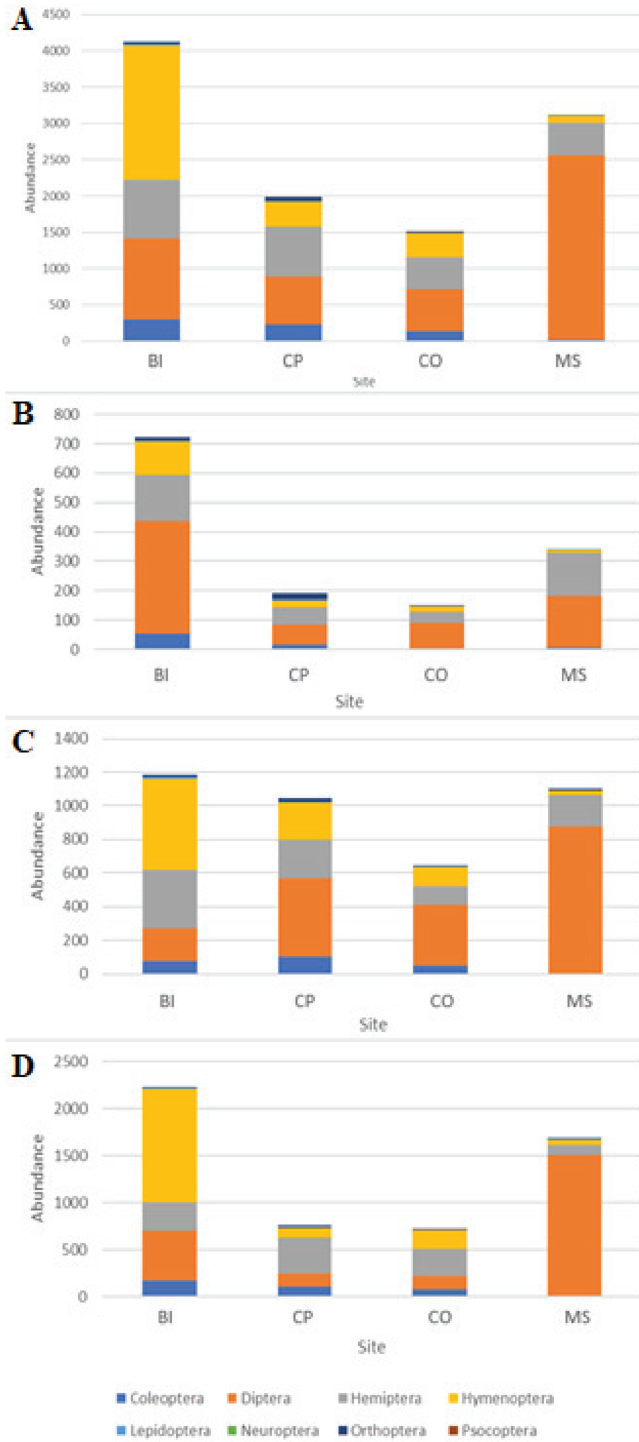

Figure 2.2 Insect abundance for each site by order: (A) overall, (B) spring, (C) summer, and (D) fall.

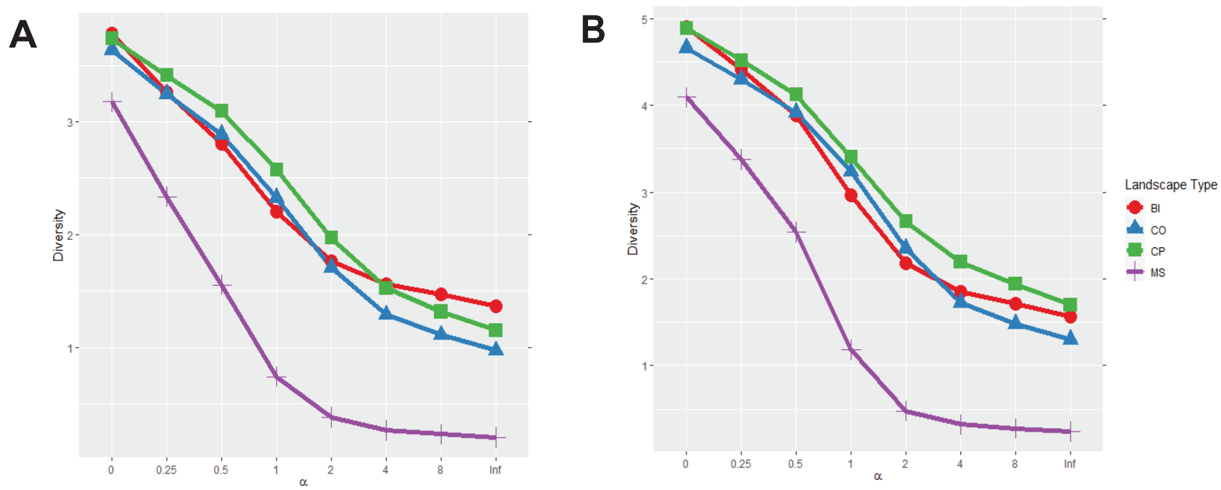

Figure 2.3 The x-axis on the insect Rényi profiles ((A) family level and (B) morphospecies level) is a unitless diversity ordering scale referred to as alpha (α). It represents species richness (α=0, left-hand side), Shannon diversity index (α=1, center), Simpson diversity index (α=2, center), and species evenness (α=inf., right-hand side), all of which represent transformed values of those original metrics to make them proportional and thus representable on one graph.

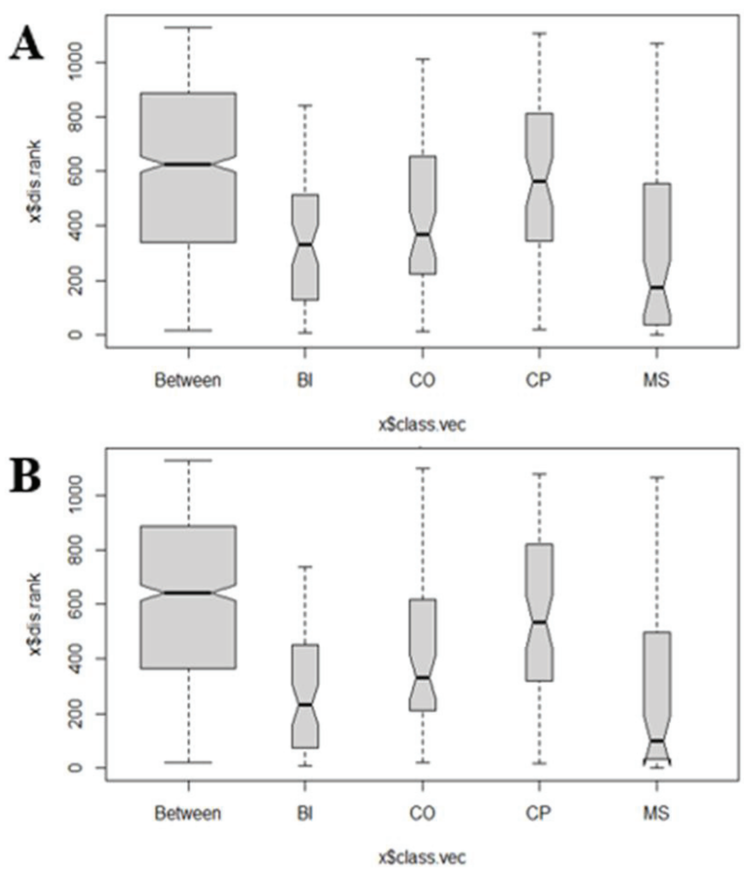

Figure 2.4 ANOSIM box-and-whiskers plot for insects at (A) family level and (B) morphospecies level.

2.3.2 Insect Functional Diversity Metrics

Insects from all seven functional groups were found at every site throughout the entire growing season; however, the proportion of each functional group's abundance differed between sites. Notably, MS was dominated by sanguivores and herbivores, while the other sites had a more even representation of all the functional groups. The relative evenness of the functional groups differed across the growing season for BI and

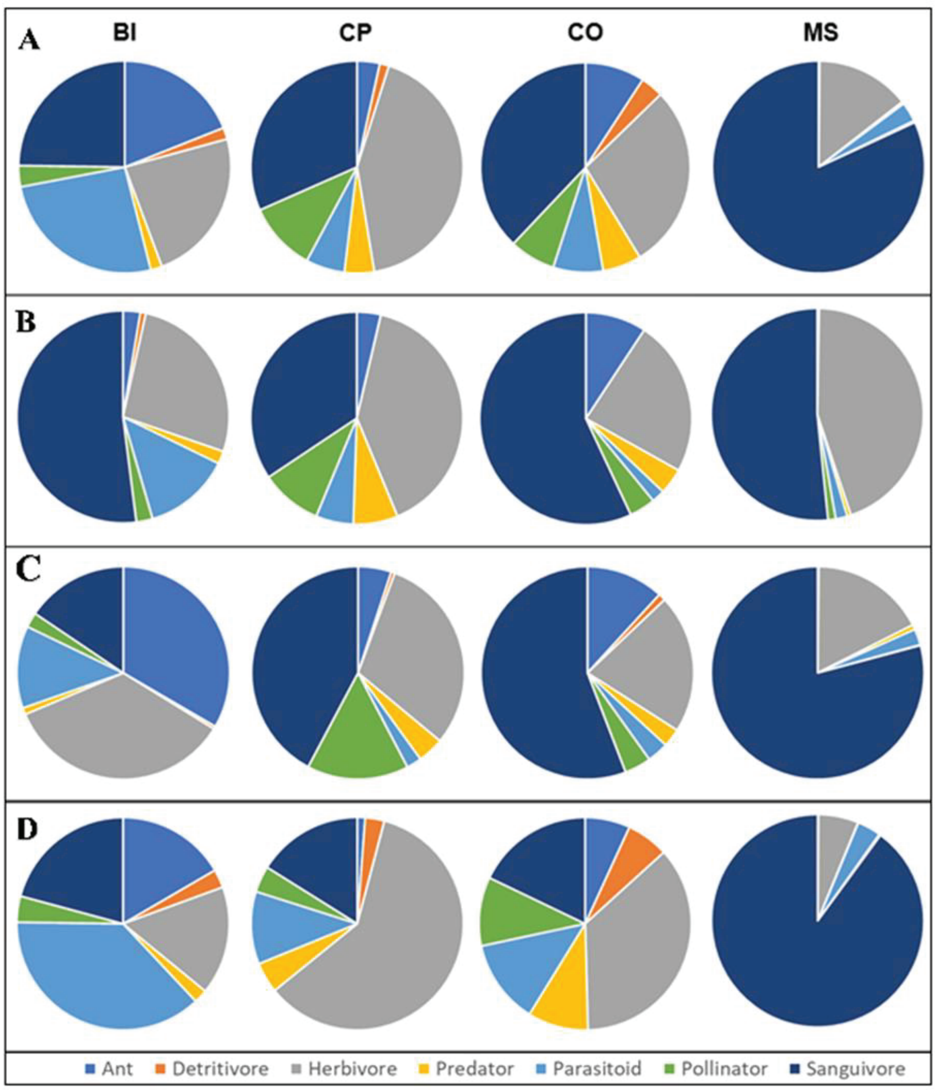

Figure 2.5 Functional group distribution for (A) overall, (B) spring, (C) summer, (D) fall.

MS, while CP and CO's functional group evenness remained relatively stable over the growing period (Figure 2.5).

2.3.3 Vegetation Diversity Metrics

One hundred thirty-five (135) plant species were documented in the overall study across the 4 sites (CP, CO, BI, MS), with the full spring, summer, and fall sampling effort including 48 transects and 192 plots sampled. Seasonal abundance matrices are provided in the Appendix (Tables A.2 through A.13).

Throughout the growing season, dominant species included *Rudbeckia hirta* (black-eyed Susan), *Chamaecrista fasciculata* var. *fasciculata* (partridge pea), and *Symphyotrichum pilosum* var. *pringlei* (frost aster) at CP, *Coreopsis lanceolata* (long-stalk coreopsis), *Helianthus angustifolius* (narrow-leaf sunflower), and *C. fasciculata* var. *fasciculata* at CO, *Solidago altissima* ssp. *altissima* (tall goldenrod), *Andropogon gerardii* (big bluestem), and *Eragrostis spectabilis* (purple lovegrass) at BI, and a cultivar of *Schedonorus arundinaceus* (tall fescue) at MS. The above species had been included in the seed mixes for the sites when they were developed, and all but the latter three (i.e., all but the grasses) were the most prolific flowering forbs on the respective sample sites. Additional volunteer species included *Setaria parviflora* (knotroot bristlegrass) at CP, *Kummerowia stipulacea* (Korean clover) at CP and CO, *Bromus japonicus* (Japanese brome) at BI, and *Trifolium repens* (white clover) and *Digitaria sanguinalis* (northern crabgrass) at MS. Although non-native invasive species were uncommon on all sites, *Lespedeza cuneata* (sericea lespedeza) had a scattered distribution on CP, CO, and BI, *Sorghum halepense* (Johnson grass) was noted in several plots on BI, and *Stellaria media* (common chickweed) had a scattered distribution on MS.

The intrinsic floristic quality parameters for each site are summarized by season and for the overall datasets in Table 2.2. Of note, CP had the highest overall values for S (82), N (69), and %FI (26.1%), as well as the highest single-season S (51 species, summer sample). CO had the highest overall FQI (22.7), lowest overall %Inv (0.3%), and the highest single-season %FI (42.5%, fall sample, owing mostly to the late-flowering dominant *H. angustifolius*). BI had the highest overall %N value (85.7%) and was overwhelmingly dominated by native species in the latter half of the growing season (%N = 90.0% and 97.3% in summer and fall, respectively). As might be expected, the turfgrass condition at MS was lowest for most floristic quality parameters, with the exception of a surprisingly high %FI measure in spring (22.7%) due mostly to the predominance of early-flowering *T. repens*.

Site	S-Spring	S-Summer	S-Fall	**S-Overall**	N-Spring	N-Summer	N-Fall	**N-Overall**	%N-Spring	%N-Summer	%N-Fall	**%N-Overall**	%Inv-Spring	%Inv-Summer	%Inv-Fall	**%Inv-Overall**	FQI-Spring	FQI-Summer	FQI-Fall	**FQI-Overall**	%FI-Spring	%FI-Summer	%FI-Fall	**%FI-Overall**
CP	46	51	41	**82**	40	44	36	**69**	64.0%	71.8%	78.1%	**72.4%**	4.2%	8.8%	3.2%	**5.7%**	18.4	15.4	13.3	**21.0**	6.7%	42.1%	19.5%	**26.1%**
CO	34	40	38	**65**	30	37	34	**58**	74.3%	66.6%	64.8%	**73.9%**	0.3%	0.5%	0.2%	**0.3%**	16.1	18.6	16.8	**22.7**	28.3%	29.1%	42.5%	**25.5%**
BI	29	28	15	**42**	20	21	12	**31**	71.1%	90.0%	97.3%	**85.7%**	3.9%	7.1%	1.9%	**4.3%**	9.8	10.8	8.3	**12.9**	4.4%	5.2%	39.6%	**15.8%**
MS	15	12	12	**20**	0	1	1	**2**	0%	0.1%	0.2%	**0.07%**	2.8%	0.9%	1.1%	**1.6%**	-1.8	-0.6	-0.6	**-1.3**	22.7%	12.6%	0%	**12.1%**

Table 2.2 Floristic quality metrics by season and overall.

2.3.4 Correlation Analysis

Site-Insect Correlations: The overall Spearman correlation tests averaged across the three sampling events (spring, summer, fall) showed that CP was positively correlated with pollinator abundance (p=0.012), while MS was negatively correlated with pollinator abundance (p=0.005) (see Table A.14, Appendix). Overall CP, CO, and BI were either positively correlated with the insect functional groups or showed no significant relationship, except for a negative correlation between CO and herbivore abundance (p=0.03). MS, unlike the others, was negatively correlated with insect morphospecies diversity and most insect functional groups ($p<0.001$). Two exceptions included a positive correlation between MS and sanguivore abundance ($p<0.001$) and no significant relationship with parasitoid abundance ($P=0.139$). Finally, insect morphospecies diversity was positively correlated with CP ($p=0.004$) and negatively correlated with MS ($p<0.001$).

Site-Floristic Quality Correlations: Although CP and CO are adjacent sites, the different management strategies used on each were reflected in their unique relationships to floristic quality. For example, CO showed a positive relationship with plant species richness ($p=0.005$), FQI ($p<0.001$), and percent flowering ($p=0.005$), and a negative relationship with %invasive species ($p=0.001$). By contrast, CP showed only one significant positive correlation, which was with plant species richness ($p<0.001$), and one significant negative correlation with %invasive species ($p = 0.001$). The reference site at BI was significantly positively related to %native species ($p<0.001$). Finally, as expected, the turfgrass condition at MS was negatively correlated with nearly all floristic quality metrics, including species richness ($p<0.001$), %native species ($p<0.001$), FQI ($p<0.001$), and %flowering ($p=0.023$).

Floristic Quality-Insect Correlations: Based on the overall dataset, pollinators were positively correlated with plant species richness ($p=0.014$), %native species ($p=0.002$), and %flowering ($p<0.001$), but there was no significant relationship between pollinators and FQI ($p=0.0565$). For sanguivores, the overall correlation analysis showed significant negative relationships with most floristic quality metrics (plant species richness, %native species, and FQI; $p<0.01$). Finally, morphospecies diversity was positively correlated with plant species richness, %native species, %invasive species, FQI, and %flowering ($p<0.01$).

Seasonal Correlation Trends: Pollinator abundance was not significantly correlated with any site throughout all three seasons (see Tables A.15-A.17, Appendix). Although pollinator abundance was positively correlated with CP overall, it was only seasonally correlated with CP in summer ($p<0.001$). In the fall pollinator abundance was positively correlated with BI ($p=0.022$) and negatively correlated with MS ($p<0.01$). Insect morphospecies diversity was negatively correlated with MS throughout all three seasons and was only positively correlated to CP in the spring ($p=0.026$). Pollinator abundance was positively correlated with different floristic quality measure throughout the seasons.

Although both CP and CO were planted with a beneficial seed mix, they were found to not be equally resistant to invasive species. CP had a positive relationship with %invasive species, while CO had a significant negative relationship with %invasive species in both spring and summer. But both CP ($p=0.078$) and CO ($p=0.172$) were not significantly correlated with %invasive species in the fall. CP and CO were also positively significantly correlated with %flowering during different seasons; CO in the spring (($p<0.01$), CP in the summer ($p<0.01$), and neither in the fall. Unlike CO and CP, BI was negatively correlated with %flowering in the summer ($p=0.025$) and spring ($p=0.011$).

2.3.5 Insect Community Modeling

The relationship between floristic quality and insect communities shown in the overall NMDS model is similar to the results from the correlation analysis (Figure 2.6). In the NMDS, CP and CO data points are seen to be closely aligned with and overlapping with some of the BI data points. This pattern is also seen in the separate Summer (Figure A.2) and Fall (Figure A.3) NMDS plots, but not the Spring (Figure A.1) NMDS plot. The MS points, however, remain separate from the other groups in the lower right corner and are clearly negatively correlated with floristic quality and insect diversity, which show positive relationships with CP, CO, and BI based on the vector trajectories in the NMDS biplot.

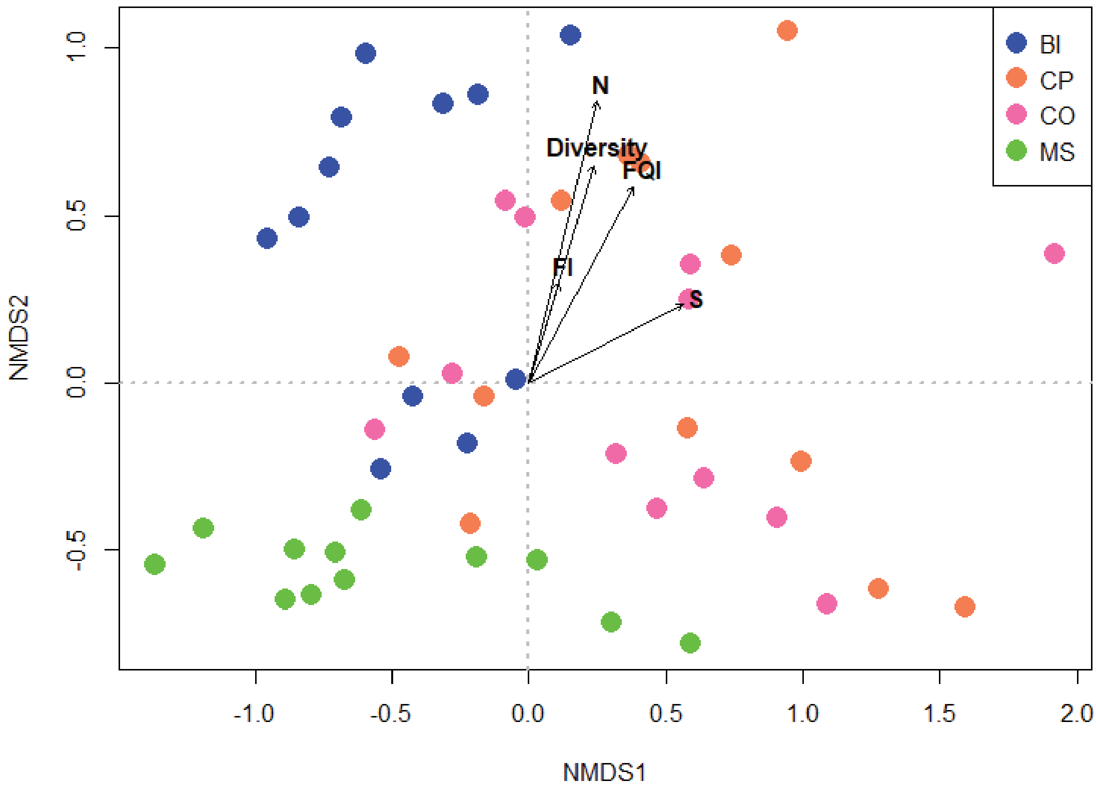

Figure 2.6 NMDS of Insect Morphospecies Abundance. K = 2. Environmental variables shown in relation to insect samples are percent native species cover (N), floristic quality index (FQI), percent flowering (Fl), plant species richness (S), and insect morphospecies Shannon Diversity (Diversity). The length of each environmental variable's arrow corresponds to the strength of the relationship.

<u>2.4 Discussion</u>

2.4.1 Findings

Although the Pollinator-Smart sites, CP and CO, were found to have fewer total insects than the pollinator-friendly meadow and the turfgrass site, they had more taxonomically and functionally diverse insect communities (Figure 2.3 and Figure 2.5).

The Pollinator-Smart sites also had the highest proportion of pollinators across all seasons (Figure 2.5). The turfgrass site was found to be overwhelmingly dominated by sanguivores and, to a lesser extent, parasitoids, with few insects from other functional groups and low insect diversity values compared to the other sites (Figure 2.3 and Figure 2.5). The Pollinator-Smart sites showed floristic quality measures similar to the native pollinator reference meadow at BI (Table 2.2). This suggests that the Pollinator-Smart landscapes at Cople overall succeeded in having a beneficial vegetation community, mimicking a pollinator-friendly meadow, supporting pollinators, and producing a functionally and taxonomically diverse insect community throughout the growing season.

Although the Cople sites as a whole achieve the goals of pollinator support and floristic diversity, there were differences in how CO and CP related to the floristic quality measures and insect functional groups across the seasons. This suggests that the different management strategies used inside (CP) and outside (CO) of the panel zone can create different vegetative and insect communities that provide the most support for pollinators at different times during the growing season. CP and CO also differed in their relationship to invasive species cover with CP being significantly positively correlated with %invasive species cover and CO being significantly negatively correlated with % invasive species cover. This indicates that the vegetative community planted at CP was less resistant to invasion from invasive plant species than the vegetative community planted at CO. This difference in invasive species cover could also be related to the greater disturbance seen in CP than in CO during solar panel construction, as the panel zone would naturally incur more disturbance during panel installation than the surrounding area (Alpert et al. 2000). This suggests that the panel zone of pollinator-friendly solar facilities may require more management strategies than the open zone to combat invasive species, at least in the first few years after installation until the panel zone vegetation can fully recover from the initial disturbance. Both CO and CP, however, had overall low percentages of invasive species cover, 5.7% and 0.3% (Table 2.2)

The insect diversity seen at MS adds to the findings of other researchers that a vegetated solar facility, even if dominated by turfgrass, supports more insects than a facility lacking vegetation (Armstrong et al. 2021). This study's results further suggest that although a turfgrass landscape can increase overall insect abundance, increases in functional and taxonomic diversity require landscapes with a more diverse vegetative community including more beneficial plants. The high taxonomic and functional insect diversity seen at CO, CP, and BI indicate that these landscapes support greater ecological functioning at the regional level (Bond and Chase 2002). Increased ecological functioning provides greater control over crop pests through natural enemies, and thus can increase crop yields (Collins and Qualset 1998). Higher functional diversity has been shown to increase the robustness of ecosystem food webs (Dunne et al. 2002, Foottit and Adler 2009). The positive effects of the functionally diverse insect community seen at the Pollinator-Smart site should extend to the other parts of the food web, and thus support greater bird, mammal, and reptile diversity in the area (Foottit and Adler 2009, Scherber et al. 2010).

2.4.2 Limitations

This study provides the first look into the effects of pollinator-friendly solar facilities on insect and plant diversity in the Mid-Atlantic, but replication is needed to support the conclusions drawn here. The "pilot study" nature of this project was necessitated by the lack of available pollinator-friendly solar sites in the region, the Cople Solar Site being the only certified facility in the Virginia Pollinator-Smart program at the time this study was initiated. However, there are likely to be more pollinator-focused sites developed in the future given the increasing popularity and interest in these types of sustainable practices on solar facilities.

The results seen here should encourage further research into the ecological effects of pollinator-friendly management at solar facilities across the Mid-Atlantic, as many states are following suit with their own pollinator-friendly solar programs. More studies should focus on the effects of solar development practices on biodiversity of higher trophic levels, such as birds and mammals. Other methods of insect community data collection, such as bee bowls, vacuum collection, and point observation of vegetation, could also be implemented to look more closely at specific insect taxonomic groups, such as Lepidoptera, which are underrepresented in this study due to their fast reaction times in avoidance of sweep nets.

The functional and taxonomic insect diversity metrics were also limited by categorizing the Diptera families as Sryphidae and “other”. This “other” category, which was assigned the sanguivore functional group, most likely underestimates the functional and taxonomic diversity of Diptera. These negative effects on Diptera diversity in the family and functional group analyses may be mitigated by the morphospecies analyses of Diptera, which included a vast number of morphospecies in the “other” category.

2.4.3 Conclusions

From the results of this study, I concluded that, at a minimum, a proactively managed pollinator-friendly solar facility can support an insect community that is functionally equivalent to a reference ecosystem and, by some standards, more diverse for certain beneficial taxa. By implementing pollinator-friendly landscape practices like those described in Virginia’s Pollinator-Smart Program rather than turfgrass landscapes, USSE facilities in the Mid-Atlantic can increase the ecosystem services of pollination and pest control through natural enemies for nearby agricultural lands and increase overall ecosystem functioning and biodiversity. However, pollinator-friendly landscapes are not a “one size fits all” solution to solar facility development, as they may not always be the most beneficial land use for that area or not well-suited for a particular environment. There are many other beneficial land uses for solar facilities currently being explored, such as agrivoltaics and grazing (Dupraz et al. 2011). There is even the opportunity for sheep grazing to co-exist with pollinator-friendly solar facilities at low densities (Montag et al. 2016). The future looks bright for pollinator-friendly solar facilities, but more studies need to be conducted across different areas and environments to better understand the effects of a pollinator-friendly landscape on ecological services and function.

Chapter 3: Microclimate Effects of the Pollinator-Smart Landscape Compared to the Traditional (Turfgrass) Landscape in Mid-Atlantic Solar Facilities

3.1 Introduction

In addition to the ecosystem benefits described in Chapter 2, there may be economic advantages to a solar-pollinator co-location approach that derive from the higher transpiration rates of forbs when compared to grasses and grass-like plants (i.e., graminoids) resulting in a cooler microclimate (Lambers and Oliveira 2019). Transpiration is an endothermic process in which water evaporates from plant leaves through the stomata and causes the canopy leaves to be a cooler temperature than the surrounding air (Mahan and Upchurch 1988).

The mechanism of transpiration is found in all plants, but the rate of transpiration can vary between species due to differences in stomatal density and water use. Decreases in leaf temperature due to transpiration are called latent heat loss. Latent heat loss refers to cooling as water changes from one state to another (Rupp and Gruber 2019). Physical leaf traits, in addition to transpiration, affect a plant's thermal tolerance. These physical traits include many leaf characteristics like color, size, shape, surface area, and surface texture, which differ between graminoids and forbs. The cooling effects of physical leaf traits are called "sensible heat loss" because no state change is involved in the cooling; only convective cooling through heat exchange is present (Rupp and Gruber 2019). However, sensible heat loss from physical leaf traits can affect transpiration rates and thus have indirect effects on latent heat loss (Monteiro et al. 2016, Lin et al. 2017, Rupp and Gruber 2019). The differing transpiration rates between graminoids and forbs could have significant cooling effects on PV solar panels.

PV solar panels produce less energy at higher temperatures and this energy production deficit is significant at temperatures greater than 25 ℃ (Kaldellis et al. 2014). Native broad-leaved plants have been shown to cause a cooling effect on solar panels, which is believed to be due to the plants' transpiration causing sensible and latent heat loss from the surrounding microclimate (Hernandez et al. 2019, Barron-Gafford et al. 2019). This cooling effect then has the potential to promote more efficient solar energy production at higher temperatures (Macknick et al. 2013, Kaldellis et al. 2014, Hernandez et al. 2019). The economic benefits of this phenomenon have been assessed using agricultural crops under solar panels, an emerging field referred to as "agrivoltaics". One study in Arizona cited an 8.9 degree Celsius decrease in agrivoltaic panel daytime temperatures throughout the growing season, with an estimated 3% increase in energy production compared to bare-ground panels (Barron-Gafford et al. 2019). While these benefits should theoretically translate to pollinator-friendly approaches, these concepts have yet to be tested in the Mid-Atlantic Region or on sites comparing pollinator-friendly and turfgrass landscapes.

The purpose of this study was to evaluate the potential for increased energy generation efficiency using a pollinator-friendly landscaping strategy in comparison with a traditional turfgrass approach on solar installations in the Mid-Atlantic Region. This was done by measuring panel temperature, ambient temperature, panel humidity, and under-panel plant species cover differences between two solar facilities – one certified Pollinator-Smart and one traditional turfgrass – that were approximately the same size and age, with the same panel technology and energy generating capacity, located in close proximity to one another in eastern Virginia (see site descriptions, Chapter 1). I hypothesized that: 1) the transpiration-mediated cooling effect from the forb-dominated Pollinator-Smart facility would result in significantly more humid and cooler under-panel conditions in comparison with the turfgrass facility; 2) this would translate into a measurable increase in energy production; and, 3) this relationship would be most apparent on hotter days (> 25 ℃) at high irradiance conditions (i.e., higher sunlight intensity).

3.2 Methods

3.2.1 Study Sites

Descriptions of the Cople and Middlesex Sites are provided in Chapter 1.

3.2.2 Data Collection

Over the course of the 2021 growing season, under-panel temperature, under-panel humidity, ambient temperature, irradiance, and energy output were measured at each site. Wiring diagrams were acquired from the solar developer (Sun Tribe Solar) and a single row of panels (12 total) was selected for instrumentation at each site such that the measured environmental variables could be tied directly to energy output at a single inverter. At each site, 6 iButton Hygrochron continuous recording temperature/humidity sensors were placed under the selected panel section and monitored from June 10 to November 10 (153 days), during which time sensors recorded the temperature (℃) and percent relative humidity every 30 minutes. Ambient temperature (℃) and solar irradiance (watts/m^2) were also tracked on the same time interval using continuously recording weather stations, the Meter Group ATMOS41 for ambient temperature and the Hukseflux SR05 pyranometer for irradiance, installed by the solar developer at each site.

The vegetation under the iButton sensors at each site was surveyed in mid-July, mid-August, and early October to characterize the under-panel plant community throughout the monitoring period. Vegetation surveys were completed using 2m x 2m plots placed directly under each iButton. Within plots, all plants were identified to species level and cover class and habit (i.e., graminoid or forb) were recorded for each species

3.2.3 Data Synthesis

Any timepoints missing observations for one or more of the environmental variables were excluded from the datasets. These few missing environmental data observations at each of the sites were due to blackouts in the energy output recording and missing iButton data from the times the iButtons were offline during data downloads. All rows with irradiance values equal to zero were deleted from the datasets because the research question only pertained to energy and temperature effects under non-zero irradiance conditions (i.e., values recorded during night hours or under heavy cloud cover were removed from the datasets). A few outliers such as aberrantly high or negative energy values were thought to be due to data transcription errors or potentially anomalous factors related to the solar panel circuit and were therefore also removed from the datasets.

To examine the relationship between forb cover and panel temperature, the difference between under-panel temperature (iButtons) and ambient temperature (weather stations) recorded within +/- two weeks of each vegetation sampling event were paired with the percent forb values recorded for each sample. These temperature difference and percent forb data points were then filtered to include only data points where ambient temperature was greater than or equal to 25 degrees Celsius and irradiance was equal to 500. These filters were used because the temperature difference has been shown to only have detectable effect on energy production at temperatures greater than or equal to 25 degrees Celsius (Kaldellis et al. 2014). Further, PV energy production is expected to be maximized under sunny conditions as is photosynthesis, which is linked to the thermal buffering effect.

3.2.4 Statistical Modeling

The data were analyzed using generalized linear models (GLM) to predict under-panel temperature and relative humidity. The predictor variables used in each model were ambient temperature, irradiance, and site, as well as their interactions. Only variables that were significant predictors of the response variable, as determined by the GLM statistical confidence tests, were included in the final models. Model fits were assessed by using McFadden's pseudo-R-squared. All statistical models were evaluated in R version 4.1.1 (R Core Team 2021).

A GLM was selected for the under-panel temperature model ("temperature model") over other possible model types (e.g., linear regression, generalized additive model, or ANOVA) due to its ability to handle multiple predictor variables and because the relationships of the predictor variables with the response variable were expected to be linear (Campbell and Norman 2000, Zuur et al. 2009). A Gaussian distribution was used for the temperature model because the variables were continuous and normally distributed. The under-panel humidity model ("humidity model") used the Poisson distribution because relative humidity is a percentage and therefore discrete, not continuous like the Gaussian distribution requires (Zuur et al. 2009). The residuals for both models were checked and found to be consistent with the implicit assumptions of a GLM (Zuur et al. 2009). The final models were then used to predict response variables for each of the sites given a 0-30 ℃ range of ambient temperatures held constant at high (800 watts/m^2), medium (500 watts/m^2), and low (200 watts/m^2) irradiance values.

A Pearson correlation test was conducted on the percent forb and temperature difference filtered dataset (Zuur et al. 2007). The average temperature difference for each vegetation sample was calculated and graphed with percent forb cover. A linear model was used to make a line of best fit for the relationship between percent forb cover and the difference in ambient and panel temperature.

The System Advisory Model (SAM) created by the National Renewable Energy Lab (NREL) was used to quantify normal power generation in a standard 200kW DC system for both a traditional and Pollinator-Smart PV system based on the under-panel temperature difference found between both sites in the temperature GLM. The SAM simulations were parameterized for the 2021 weather file from the National Solar Radiation Database representing the geographic midpoint between the two sites (37°48'36.0"N, 76°34'48.0"W). These simulations used the standard defaults of SAM, a PV array of Sunpower-X21-335 (mono-crystalline silicon) modules with a nominal efficiency of 20.5521% (Blair et al. 2013, Barron-Gafford et al. 2019, NREL 2020). The only variable that differed between the Pollinator-Smart landscape simulation and the traditional ground-mounted simulation was PV panel temperature. To best estimate the possible difference in standard power generation for these two landscape types, we used the temperature difference found between the two sites under high irradiance conditions and applied that difference to the panel temperature used in SAM for the Pollinator-Smart simulation between June and October.

3.3 Results

3.3.1 Under-Panel Temperature and Humidity GLMs

Predictor variables (ambient temperature, irradiance, site, and the interaction terms between site and irradiance, site and ambient temperature, and irradiance and ambient temperature) in the GLM were all determined to be significant predictors of average under-panel temperature and humidity (for all under-panel temperature variables, $p < 0.001$; for all under-panel humidity variables, $p < 0.001$, with the exception of site ($p =$

0.04 ,temperature model; p = 0.00124, humidity model) so all variables were retained in the final models. The temperature GLM accounted for most of the variation in under-panel temperature (pseudo-R-squared = 0.83); however, the humidity GLM did not (pseudo-R-squared = 0.23).

The predictions of the temperature GLM in the high and medium irradiance conditions showed that the turfgrass site was 1-2 ℃ hotter than the Pollinator-Smart site across all the ambient temperatures tested. Predicted under-panel temperatures for both sites were hotter than ambient temperature, but the Pollinator-Smart site stayed cooler than ambient temperature up to 29 ℃, while the turfgrass panels were hotter at lower ambient temperature (24 ℃) under high irradiance conditions (Figure 3.1). This same pattern was seen to a lesser extent under medium irradiance conditions (Figure 3.2). Under low irradiance conditions, however, the GLM predicted similar under-panel temperatures for each of the sites under the same ambient temperatures (Figure 3.3).

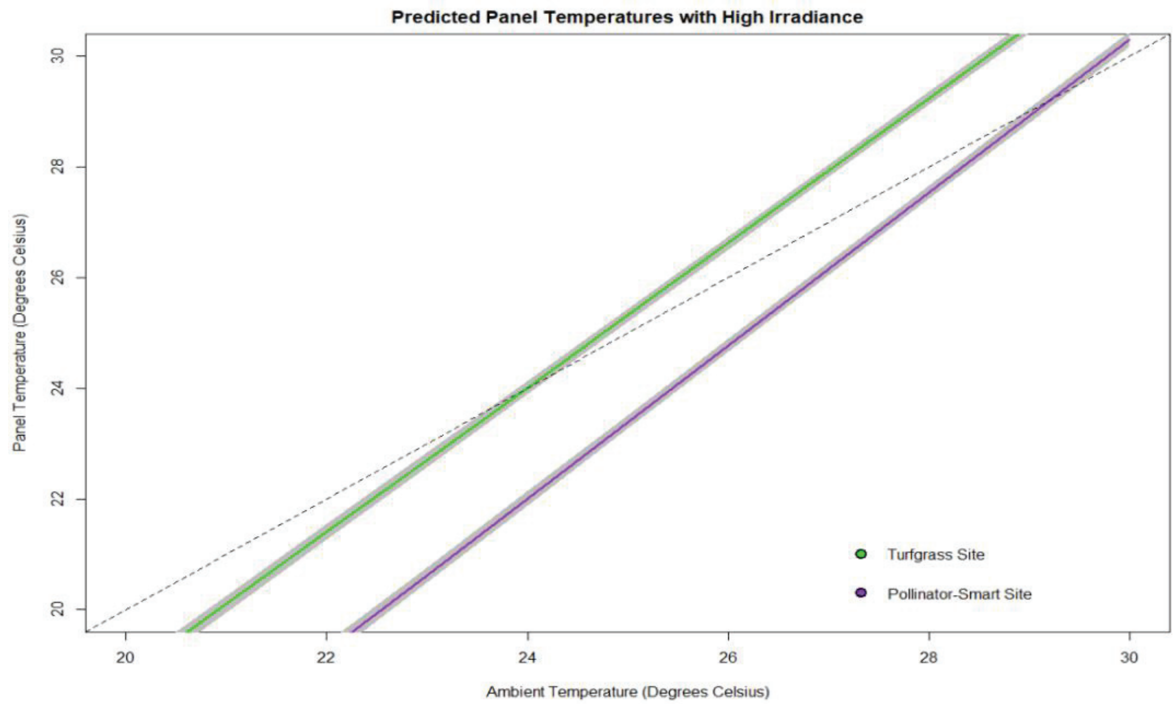

Figure 3.1 Predicted Panel Temperature with High Irradiance. This figure was made using the panel temperature predicting GLM with irradiance equal to 800 watts per meter squared and was formatted to best show the intersections of each line with the 1:1 relationship shown by the dotted line. 95% confidence intervals are shown in gray around each of the lines.

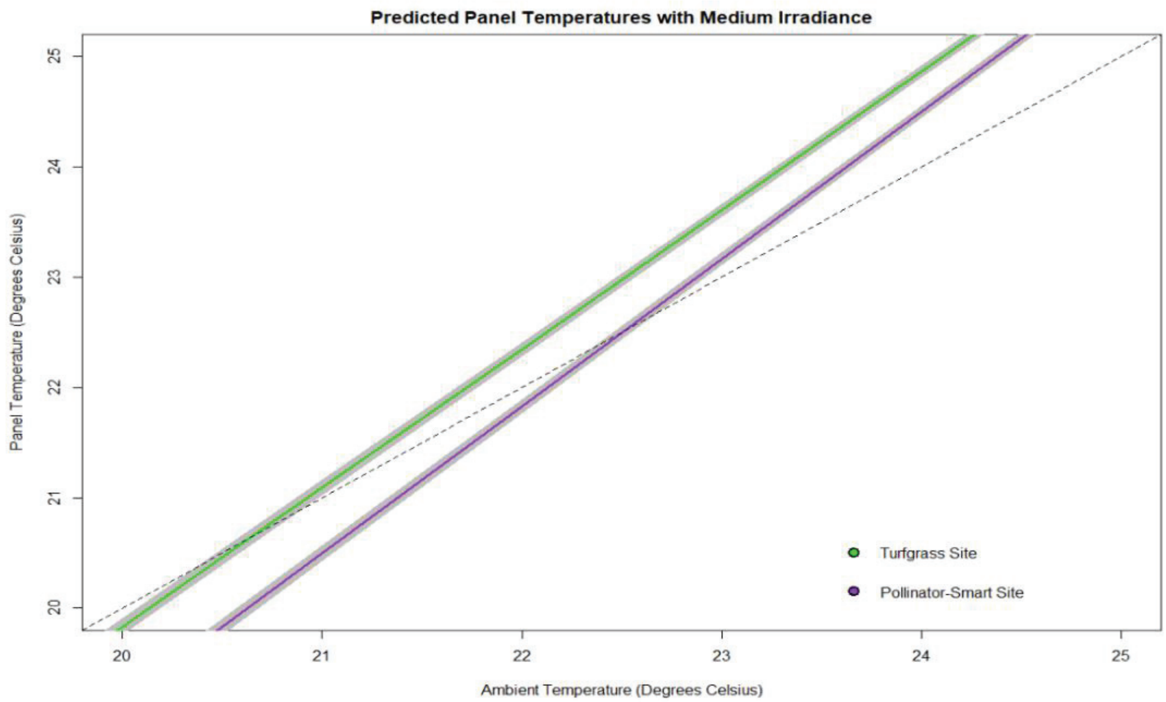

Figure 3.2 Predicted Panel Temperature with Medium Irradiance. This figure was made using the panel temperature predicting GLM with irradiance equal to 500 watts per meter squared and was formatted to best show the intersections of each line with the 1:1 relationship shown by the dotted line. 95% confidence intervals are shown in gray around each of the lines.

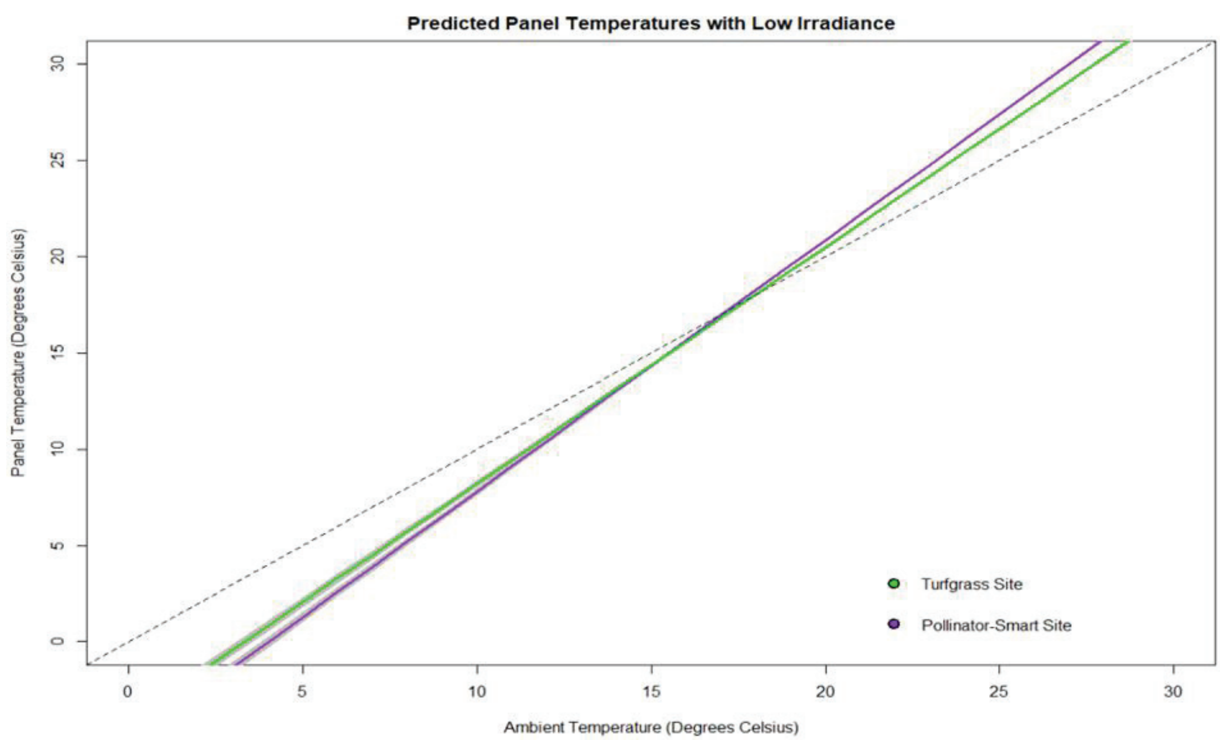

Figure 3.3 Predicted Panel Temperature with Low Irradiance. This figure was made using the panel temperature predicting GLM with irradiance equal to 200 watts per meter squared and was formatted to see the overall trends of each line across all the given temperatures. A 1:1 relationship is shown by the dotted line. 95% confidence intervals are shown in gray around each of the lines.

Under high irradiance conditions, the humidity GLM predicted higher under-panel relative humidity at the Pollinator-Smart site versus the turfgrass site in all tested ambient temperatures (Figure 3.4). Under medium irradiance conditions, under-panel relative humidity was higher for the Pollinator-Smart site at lower ambient temperatures, but this trend reversed at higher temperatures (Figure 3.5). Under low irradiance conditions, the under-panel humidity was higher for the turfgrass panels across all modeled temperatures (Figure 3.6).

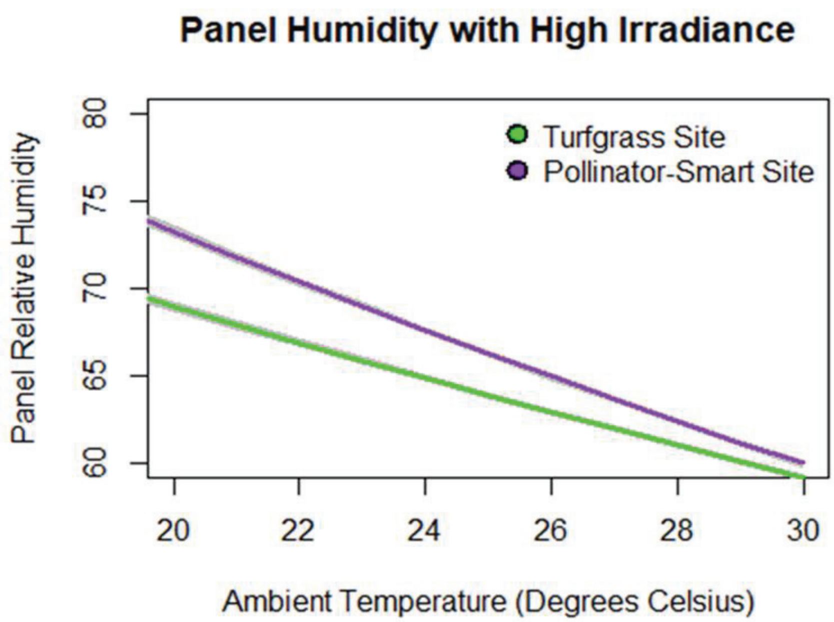

Figure 3.4 Predicted Panel Humidity with High Irradiance. This figure was made using the panel humidity predicting GLM with irradiance equal to 800 watts per meter squared and was formatted to see the overall trends of each line across all the given temperatures. 95% confidence intervals are shown in gray around each of the lines.

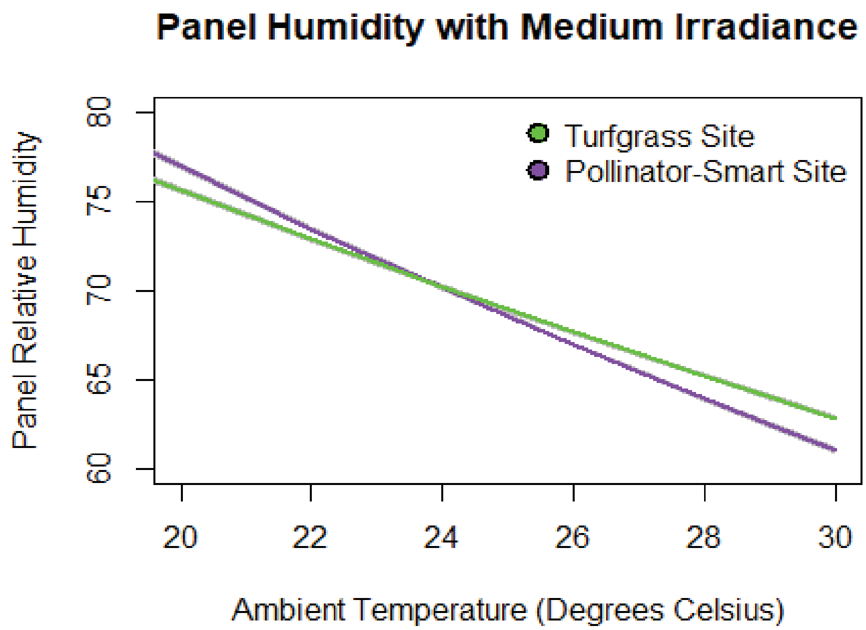

Figure 3.5 Predicted Panel Humidity with Medium Irradiance. This figure was made using the panel humidity predicting GLM with irradiance equal to 500 watts per meter squared and was formatted to see the overall trends of each line across all the given temperatures. 95% confidence intervals are shown in gray around each of the lines.

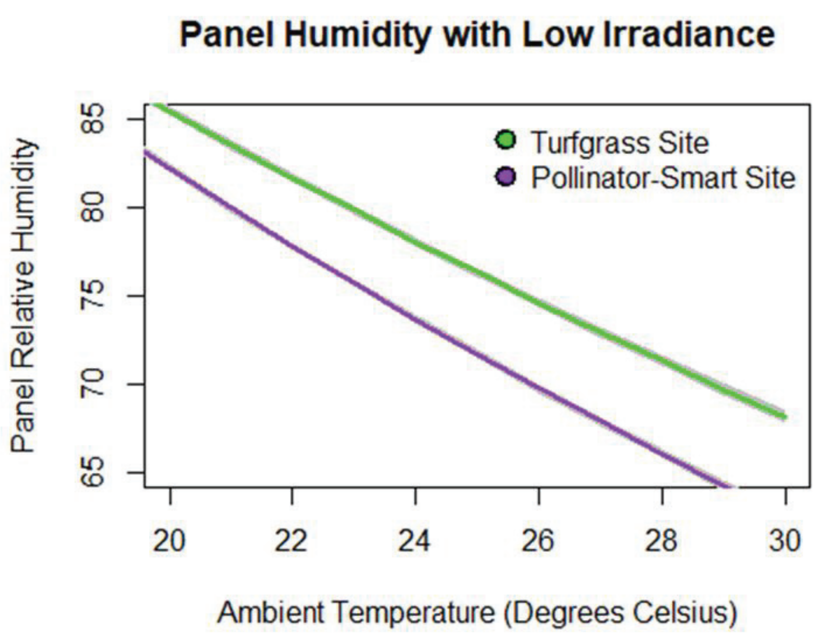

Figure 3.6 Predicted Panel Humidity with Low Irradiance. This figure was made using the panel humidity predicting GLM with irradiance equal to 800 watts per meter squared and was formatted to see the overall trends of each line across all the given temperatures. 95% confidence intervals are shown in gray around each of the lines.

3.3.2 Percent Forb vs. Humidity Model

The Pearson correlation test showed a significant negative relationship between percent forb cover and the difference between solar panel temperature and ambient temperature ($p<0.001$) (i.e., greater forb density was correlated with lower under-panel temperature). This relationship is seen in the line of best fit plotted over the average temperature difference for each percent forb cover sample (figure 3.7). The variance in the averages also shows that, although the relationship was significant, other factors, such as wind and rainfall, which were not accounted for, likely contribute to the difference in panel temperature and ambient temperature.

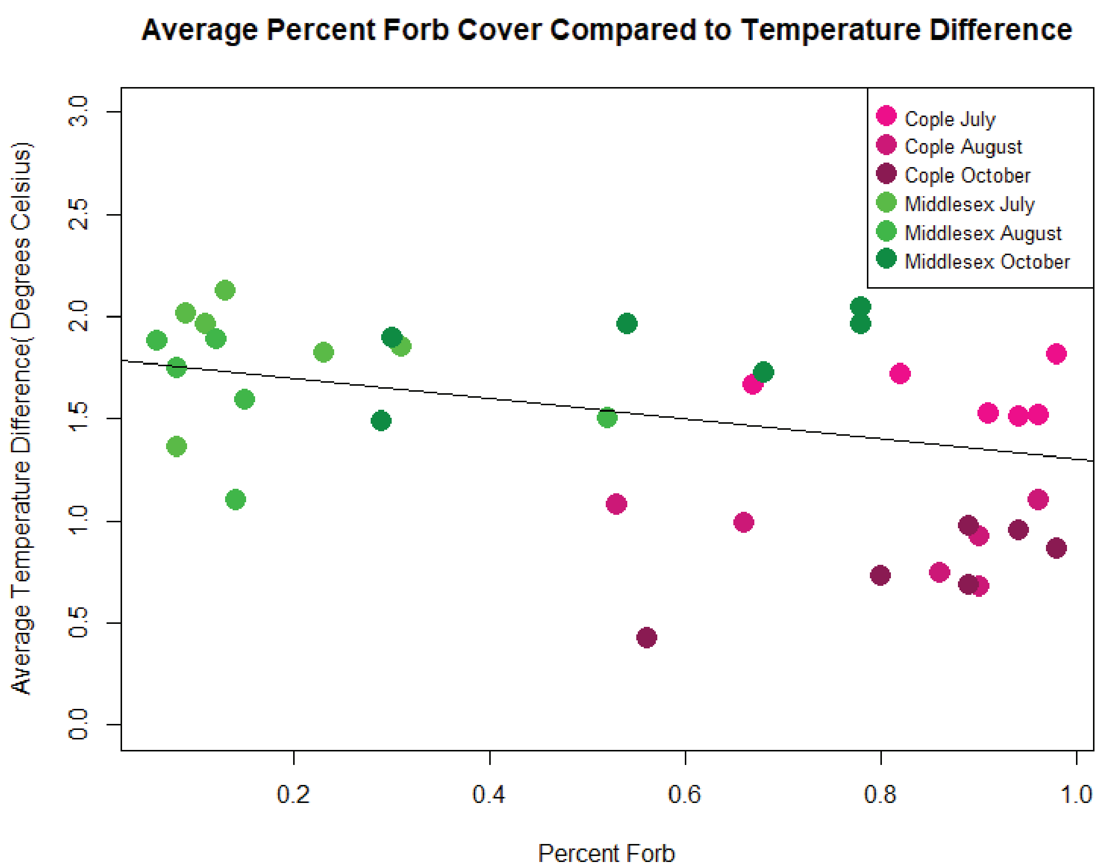

Figure 3.7 Average Percent Forb Cover Compared to Temperature Difference. The line of best fit for the whole data set is shown in black. The points represent each under-panel vegetation sampling point and the average temperature difference for the two weeks before and after that sampling date.

3.3.3 SAM Energy Estimates

The turfgrass simulation produced 8,668 kWh per year (16.4% capacity factor), while the Pollinator-Smart simulation, with reduced PV panel temperatures, produced 8,709 kWh per year (16.5% capacity factor). This energy difference equates to the Pollinator-Smart landscape producing approximately 0.5% more energy per year than the turfgrass landscape. The Pollinator-Smart landscape simulation produced approximately 1% more energy than the traditional simulation during June-October, the time period in which the under-panel temperature differed between the simulations.

3.4 Discussion

The panel temperature part of my hypothesis was supported since the Pollinator-Smart site did show cooler under-panel temperatures across the range of normal ambient conditions under high irradiance. This cooling effect weakened under mean irradiance conditions and was not present under low irradiance conditions, which suggests the cooling effect from transpiration of forbs is somewhat dependent on irradiance, particularly in high ambient temperatures. The panel temperature differences between the sites seen in the predictions are smaller than the differences seen in the Arizona study (Barron-Gafford et al. 2019), but that is likely due to the traditional landscape in this study being turfgrass instead of bare-groundClick or tap here to enter text..

Although the turfgrass site had a greater overall mean relative humidity than the Pollinator-Smart site, the humidity GLM, which took into account the effects of site and irradiance, predicted that the Pollinator-Smart site would have greater under-panel humidity. The overall average relative humidity could differ between sites due to a difference in ambient humidity and soil at each of the sites, not due to microclimate caused by the vegetation. Based on site observations, the soils at the turfgrass site were more loamy in texture compared to the sandier soils at the Pollinator-Smart site, in which case the turfgrass soils would likely have a higher water-holding capacity which could perhaps contribute to the differences in overall humidity measured. More studies should be done looking at the effect of the different plant communities on microclimate humidity in controlled settings. Ambient humidity could not be controlled for in this study due to the lack of site-level ambient humidity data throughout the growing season.

The humidity GLM, which accounted for significant site differences in ambient irradiance and ambient temperature, supported my hypothesis that the Pollinator-Smart site would have a greater relative humidity in high irradiance and high ambient temperature conditions. The humidity GLM also showed that under medium irradiance conditions the sites did not differ in relative humidity and that the turfgrass site had a greater relative humidity in low irradiance conditions. This supports the notion that the cooling effect from transpiration of the forb-dominated Pollinator-Smart landscape is most effective during high irradiance conditions. This is likely due to plants having greater photosynthetic activity under high irradiance, which would lead to a greater rate of transpiration in the plants (Lambers and Oliveira 2019). Under these conditions, the difference in transpiration rates between forbs and graminoids and their relative cooling effects would be most apparent. These conditions are often present in the afternoons of the summer months when energy demand is highest due to air conditioner usage (Taylor Brown, Sun Tribe solar, pers. comm.). The Pearson correlation test showed that percent forb cover did have a significant negative effect on the difference in panel temperature and ambient temperature. This supports my hypothesis that greater forb cover increases the cooling effect on the panels from transpiration of vegetation.

The results of the SAM simulations show that the cooling effect of the Pollinator-Smart landscape under high irradiation would have a positive effect on overall energy output. These results support the idea that, in terms of energy production, Pollinator-Smart solar facilities could be economically favorable in the Mid-Atlantic region, particularly when energy production efficiency is averaged across the 25-30 year lifespan of a typical solar installation. The results of the temperature model can be used along with the SAM simulations to make inferences about how the different landscape types could affect energy production during the growing season in the Mid-Atlantic region.

These inferences could then be used to inform landscaping decisions for solar companies, as well as the government agencies regulating the solar industry, to promote management practices on these sites that also promote biodiversity. With an anticipated nationwide increase in USSE in the coming years as many states work towards 100% carbon free electricity generation (Blinken 2021, Horowitz 2021), there is potential for hundreds of thousands of acres of USSE facilities to be filled with native plants, thus promoting pollinator communities and increasing biodiversity. With a measurable difference in thermal buffering and an estimated significant difference in energy production between pollinator-friendly and turfgrass solar sites during the growing season, the rationale for solar developers to “make the switch” to a pollinator-friendly approach is even more compelling.

Appendix

Insect Family Abundance			May				July				October			
Order	**Family/LTL**	**Functional Group**	**BI**	**CP**	**CO**	**MS**	**BI**	**CP**	**CO**	**MS**	**BI**	**CP**	**CO**	**MS**
Coleoptera	Cantharidae	PL	1	2	2						6		5	
	Carabidae	PR	1	1			5	5	1			1		
	Cerambycidae	D	6					1	1					
	Chrysomlidae	H	12	1		2	38	11	7	4	1	2	15	
	Coccinellidae	PR	1	6	1		1	2	2			4	3	
	Curculionidae	H	26	2		2	2	1	6		14	66	7	
	Elateridae	PR	1			1		1				1		
	Lampyridae	PR							1					
	Lathridiidae	D					5	3	6		62	22	45	2
	Melyridae	PL										1	3	
	Mordellidae	PL	4	3	1	1	2							
	Phalacridae	H							6		78	4	4	
	Scarabeidae	H	1				6	71	17	1		1		
Diptera	Syrphidae	PL	8	4	2		11	21	3		7	9	6	3
	Other	S	376	66	86	176	184	443	359	87	462	121	128	15 5
Hemiptera	Alydidae	H	2				3	2	1		3	15	1	
	Anthocoridae	PR	1	7	4	1	1	3	13	1	41	4	6	1
	Aphididae	H	14	4		36	143	15	1	11	31	214	3	3
	Berytidae	H		1				1				4		
	Cercopidae	H					2					6	24	5
	Cicadelliddae	H	58	25	13	112	52	5	41	149	6	55	75	74
	Corimelaenidae	H					5	4					1	
	Derbidae	D						2		1				
	Issidae	H					9							
	Lygaeidae	H					1		1					
	Membracidae	H	1				1	2	2		17	1	3	
	Miridae	H	8	14	18		7	1	35	26	148	67	98	19
	Pentatomidae	PR	5		1		4	3	2		2	17		
	Psyllidae	H	64	7	2		113	21	4		1			
	Reduviidae	PR	2				1					7	2	
	Tingidae	H					6							
Hymenoptera	Apidae	PL						6			2		45	
	Braconidae	PA	3	1				1	1	5	1	6	4	2
	Chalcidoidea	PA	91	1	3	6	147	12	18	22	813	76	86	52
	Colletidae	PA				1					1			
	Formicidae	A	19	7	14	1	395	53	76	1	369	9	49	
	Halictidae	PL		6	1			126	18	1	3	9	13	
	Ichneumonidae	PA							2		3		2	3
	Pompilidae	PA	2					5						3
	Scoliidae	PA						6				1		
	Sphecidae	PR						5						
	Tiphiidae	PA					1				1			
	Vespidae	H						8	1		1	3		
Lepidoptera	Lycaenidae	PL									1			
	Microlepidoptera	PL	4			2	9	4	4		5	1	3	1
	Pieridae	PL		2										
Neuroptera	Chrysopidae	PR					1							
Orthoptera	Acrididae	H	6	1	3		1	6	2		2	9		
	Gryllacrididae	H	1											
	Gryllidae	PR								7		2		
	Mantidae	PR	4				4	1			3		1	
	Tetrigidae	H												1
	Tettigonildae	H	1	13			5	18	3		2	4	2	
Psocoptera	Psocidae	D								1				

Table A.1 Insect family abundance summary.

CP SPRING - Cople Panel Zone (CP): Spring Plant Cover Data[1]

Date: June 1, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Acalypha rhomboidea	Common Three-seeded Mercury	Euphorbiaceae											1	1					
Ambrosia artemisiifolia	Common Ragweed	Asteraceae				3						3				3			15
Andropogon virginicus var. *virginicus*	Broomsedge	Poaceae			3	3		3	1							3		3	
Aquilegia canadensis	Wild Columbine	Ranunculaceae									**3**								
Campsis radicans	Trumpet-creeper	Bignoniaceae		3	15				15			3					1		15
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae		3	3			63				15	15	15	1	3		15	
Chenopodium album	Lamb's-quarters	Amaranthaceae						1											
Conyza canadensis var. *canadensis*	Horseweed	Asteraceae						3										1	
Danthonia spicata	Poverty Oatgrass	Poaceae					3							3		1			
Dichanthelium clandestinum	Deer-Tongue Grass	Poaceae				3	1	15			3								
Dichanthelium meridionale	Matting Panic Grass	Poaceae				3	3												3
Dichanthelium scoparium	Velvet Panic Grass	Poaceae								15				3					15
Digitaria ciliaris	Southern Crabgrass	Poaceae															1		
Diodia virginiana	Virginia Buttonweed	Rubiaceae									15								
Eragrostis curvula	Weeping Lovegrass	Poaceae	*				3			3	3	3	3	3	3			15	
Erigeron annuus	Annual Fleabane	Asteraceae									**3**								
Eupatorium capillifolium	Dog-fennel	Asteraceae																1	
Eupatorium rotundifolium	Roundleaf Thoroughwor	Asteraceae					1								1				
Gamochaeta purpurea	Purple Cudweed	Asteraceae		1										3					
Geranium carolinianum	Carolina Geranium	Geraniaceae		3															
Helianthus angustifolius	Narrow-leaved Sunflower	Asteraceae				15													
Houstonia purpurea var. *purpurea*	Summer Bluets	Rubiaceae												**1**					
Hypericum gentianoides	Pineweed	Hypericaceae												15				3	3
Hypericum punctatum	Spotted St. John's-wort	Hypericaceae				1	1												
Juncus tenuis	Path Rush	Juncaceae				3													
Kummerowia stipulacea	Korean-clover	Fabaceae	*	63	15		15			63		38		1		63	85	15	3
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*		15	3			3	1	15	3		1	3	3	3		3
Lespedeza violacea	Wand Lespedeza	Fabaceae				1				1							3		
Liquidambar styraciflua	Sweetgum	Altingiaceae								1									
Liriodendron tulipifera	Tulip-tree	Magnoliaceae					1												
Lobelia nuttallii	Nuttall's Lobelia	Campanulaceae											**1**	**1**				**3**	
Monarda fistulosa var. *fistulosa*	Wild Bergamot	Lamiaceae						3											
Oxalis dillenii	Southern Yellow Wood-sorrel	Oxalidaceae		**1**	**1**	**15**		**15**	**3**		**1**	**1**	**3**	**15**				**3**	
Oxalis violacea	Violet Wood-sorrel	Oxalidaceae													**3**				
Penstemon australis	Southern Beard-tongue	Plantaginaceae					**3**												
Plantago lanceolata	English Plantain	Plantaginaceae	*	3															
Potentilla canadensis var. *canadensis*	Dwarf Cinquefoil	Rosaceae					1			3		15				38			3
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae								3									
Rudbeckia hirta	Black-eyed Susan	Asteraceae		15	38	63	38		63		38	3		3			3	3	
Senecio vulgaris	Common Groundsel	Asteraceae	*		1														
Sisyrinchium mucronatum	Needle-tip Blue-eyed-grass	Iridaceae												**3**					
Solanum carolinense var. *carolinense*	Horse-nettle	Solanaceae					3	3											
Taraxacum officinale	Common Dandelion	Asteraceae	*		1														
Tradescantia ohiensis	Ohio Spiderwort	Commelinaceae		3															
Triodanis perfoliata	Small Venus' Looking-glass	Campanulaceae		**3**	**1**							**1**							
Viola sagittata var. *sagittata*	Arrow-leaved Violet	Violaceae																	1

[1] Pecent cover classes in 1m^2 sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.2 Vegetation abundance matrix, CP, spring sample.

CO SPRING - Cople Open Area (CO): Spring Plant Cover Data[1]

Date: June 1, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Achillea millefolium	Common Yarrow	Asteraceae															3		
Ambrosia artemisiifolia	Common Ragweed	Asteraceae											3	3					
Andropogon virginicus var. *virginicus*	Broomsedge	Poaceae		1		3							3						
Bidens bipinnata	Spanish Needles	Asteraceae						3											
Carya glabra	Pignut Hickory	Juglandaceae															15		
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae		3		3	1	3									3	15	3
Coreopsis lanceolata	Long-stalk Coreopsis	Asteraceae	Uncertain	**38**	**63**	**3**	**15**	**38**	**3**	**3**	**38**	**15**	**3**	**63**	**63**	**15**		**38**	**63**
Danthonia spicata	Poverty Oatgrass	Poaceae							3	15		3				3			
Dichanthelium meridionale	Matting Panic Grass	Poaceae		15	3					15	3							3	
Digitaria sanguinalis	Northern Crabgrass	Poaceae	*		1			3							1				
Eragrostis curvula	Weeping Lovegrass	Poaceae	*				3							3					
Gamochaeta purpurea	Purple Cudweed	Asteraceae											1						1
Helianthus angustifolius	Narrow-leaved Sunflower	Asteraceae		3	3	38	38	38	38	15	15	15	38	38	38	3	15	15	38
Houstonia purpurea var. *purpurea*	Summer Bluets	Rubiaceae		**1**		**3**		**1**		**3**									
Hypericum punctatum	Spotted St. John's-wort	Hypericaceae												3					
Kummerowia stipulacea	Korean-clover	Fabaceae	*	15	15	38	85	3	3		63	38	38	38	15	63	15	3	3
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*		1	1					3								
Lespedeza virginica	Slender Lespedeza	Fabaceae							1								1	3	
Liquidambar styraciflua	Sweetgum	Altingiaceae									1								
Liriodendron tulipifera	Tulip-tree	Magnoliaceae																1	
Lobelia nuttallii	Nuttall's Lobelia	Campanulaceae					**3**												
Monarda fistulosa var. *fistulosa*	Wild Bergamot	Lamiaceae									1	15	15	3			3	1	15
Oxalis dillenii	Southern Yellow Wood-sorrel	Oxalidaceae		1	1						3						1		
Paspalum laeve	Field Paspalum	Poaceae									3	1							
Pinus virginiana	Virginia Pine	Pinaceae				1				3									
Potentilla canadensis var. *canadensis*	Dwarf Cinquefoil	Rosaceae		3	15	3				38		3				1			
Rhus copallinum var. *copallinum*	Winged Sumac	Anacardiaceae			3														
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae															3		
Rudbeckia hirta	Black-eyed Susan	Asteraceae		3	**3**	15						38				**3**	38	**3**	**15**
Setaria parviflora	Knotroot Bristlegrass	Poaceae						3	3			3	3		3	15	3	3	
Solidago nemoralis var. *nemoralis*	Gray Goldenrod	Asteraceae												3	3				
Symphyotrichum novae-angliae	New England Aster	Asteraceae										1	3						
Triodanis perfoliata	Small Venus' Looking-glass	Campanulaceae		1															
Verbesina occidentalis	Yellow Crownbeard	Asteraceae										3							

[1] Pecent cover classes in $1m^2$ sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.3 Vegetation abundance matrix, CO, spring sample.

BI SPRING - Belle Isle (BI): Spring Plant Cover Data[1]

Date: June 1, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Andropogon gerardii	Big Bluestem	Poaceae							3	63	85					63	38	15	63
Andropogon virginicus var. *virginicus*	Broomsedge	Poaceae					15	15				15		63					
Bromus japonicus	Japanese Brome Grass	Poaceae	*	15		38	1	38	38	3	3	15	38	15	3	3	38	15	3
Campsis radicans	Trumpet-creeper	Bignoniaceae						15	3	3	3	15			15			38	
Carex albolutescens	Greenish-white Sedge	Cyperaceae												3	3				
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae		3															
Cynodon dactylon var. *dactylon*	Bermuda Grass	Poaceae	*											15	3				
Diospyros virginiana	Common Persimmon	Ebenaceae				15													
Erigeron annuus	Annual Fleabane	Asteraceae			**3**	**3**					**3**		**15**			**3**	**3**	**15**	**15**
Eupatorium capillifolium	Dog-fennel	Asteraceae																3	
Galium aparine	Cleavers	Rubiaceae		1				1							3				
Gamochaeta purpurea	Purple Cudweed	Asteraceae							**1**									**3**	
Geranium carolinianum	Carolina Geranium	Geraniaceae		1					1		1	1	1			3	1		
Juncus tenuis	Path Rush	Juncaceae													3				
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*			3	3	3		3		3	38						
Monarda fistulosa var. *fistulosa*	Wild Bergamot	Lamiaceae				3												15	
Oxalis stricta	Common Yellow Wood-sorrel	Oxalidaceae										3		1			1		
Parthenocissus quinquefolia	Virginia-creeper	Vitaceae																	
Ranunculus hispidus	Bristly Buttercup	Ranunculaceae															1		
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae			**15**	3													
Rudbeckia hirta	Black-eyed Susan	Asteraceae				15	3		3		**3**								
Rudbeckia laciniata var. *laciniata*	Cut-leaf Coneflower	Asteraceae						15											
Rumex crispus ssp. *crispus*	Curly Dock	Polygonaceae	*					**3**	**3**										
Schedonorus arundinaceus	Tall Fescue	Poaceae	*	63	15	15	85						15						15
Solidago altissima ssp. *altissima*	Tall Goldenrod	Asteraceae		63	85	38	15	38	85	15	15	63	63	38	85	38	38	63	3
Sorghum halepense	Johnson Grass	Poaceae	*			3	15						3						
Trifolium campestre	Low Hop Clover	Fabaceae	*										1				3		
Valerianella locusta	European Corn-salad	Caprifoliaceae	*											3					
Vicia sativa ssp. *sativa*	Common Vetch	Fabaceae	*				3		1			1		1		**3**	3	3	

[1] Pecent cover classes in 1m[2] sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.4 Vegetation abundance matrix, BI, spring sample.

MS SPRING - Middlesex (MS): Spring Plant Cover Data[1]

Date: June 1, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cynodon dactylon var. *dactylon*	Bermuda Grass	Poaceae	*							3			1				15		
Digitaria sanguinalis	Northern Crabgrass	Poaceae	*									15							
Galium sherardia	Field Madder, Blue Field Madder	Rubiaceae	*	**1**	**3**	**15**	**3**	**3**			**3**			**3**		**3**	**15**	**1**	**15**
Geranium molle	Dove's-foot Geranium	Geraniaceae	*					3		1	**3**							3	
Hypochaeris radicata	Spotted Cat's-ear	Asteraceae	*										3						
Paspalum dilatatum	Dallis Grass	Poaceae	*	3					3					15		3			
Plantago lanceolata	English Plantain, Rib-grass	Plantaginaceae	*									3				3			
Potentilla indica	Indian-strawberry	Rosaceae	*					15							**38**				3
Ranunculus sardous	Hairy Buttercup	Ranunculaceae	*					3			3								
Rumex crispus ssp. crispus	Curly Dock	Polygonaceae	*					3	1	3	15			3			3	3	
Schedonorus arundinaceus	Tall Fescue, Alta Fescue	Poaceae	*	63	63	63	85	63	85	63	85	85	63	85	85	98	63	85	85
Stellaria media	Common Chickweed	Caryophyllaceae	*								1				3				15
Taraxacum officinale	Common Dandelion	Asteraceae	*	3	3	15	3	3		3			3				3	3	
Trifolium repens	White Clover, Dutch Clover	Fabaceae	*	**38**	**38**	**15**	**15**	**38**	**15**	**38**	**3**	**3**	**38**	15	**15**	1	**38**	**3**	**15**
Veronica hederifolia	Ivy-leaf Speedwell	Plantaginaceae	*										**1**				1		

[1] Pecent cover classes in 1m[2] sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.5 Vegetation abundance matrix, MS, spring sample.

CP SUMMER - Cople Panel Zone (CP): Summer Plant Cover Data[1]

Date: July 31, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Acalypha rhomboidea	Common Three-seeded Mercury	Euphorbiaceae			1				15				1						
Acalypha virginica	Virginia Three-seeded Mercury	Euphorbiaceae													**3**			**3**	**15**
Achillea millefolium	Common Yarrow	Asteraceae										**15**						15	
Ambrosia artemisiifolia	Common Ragweed	Asteraceae						15				15				3			
Andropogon virginicus var. *virginicus*	Broomsedge	Poaceae			3		3	38											
Asclepias tuberosa var. *tuberosa*	Butterfly-weed	Apocynaceae																	**3**
Campsis radicans	Trumpet-creeper	Bignoniaceae				3			3					3	3		1		
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae		**85**	**63**	**85**	**15**	**85**	**63**	**15**	**3**	**15**	**85**	**15**	**63**	**15**	**15**	**15**	**15**
Conyza canadensis var. *canadensis*	Horseweed	Asteraceae		3		3		15				3	3						
Cynosurus echinatus	Rough Dogtail Grass	Poaceae	*																1
Cyperus esculentus var. *leptostachyus*	Yellow Nutsedge	Cyperaceae							3										
Dichanthelium clandestinum	Deer-Tongue Grass	Poaceae				15				3	1							3	
Dichanthelium meridionale	Matting Panic Grass	Poaceae					3							3					3
Dichanthelium scoparium	Velvet Panic Grass	Poaceae																	3
Digitaria ciliaris	Southern Crabgrass	Poaceae		3		3								3					
Diodia teres	Common Buttonweed	Rubiaceae			**3**		**3**				**63**					**1**			
Eragrostis spectabilis	Purple Lovegrass	Poaceae								15	15			15					38
Erechtites hieraciifolius	Fireweed	Asteraceae				15				15	3	15		15				3	38
Erigeron annuus	Annual Fleabane	Asteraceae									**15**								
Eupatorium capillifolium	Dog-fennel	Asteraceae										1							
Eupatorium rotundifolium	Roundleaf Thoroughwort	Asteraceae									**3**			**3**	**15**	1	**3**	**15**	
Euphorbia maculata	Spotted Spurge	Euphorbiaceae																	**3**
Hypericum gentianoides	Pineweed	Hypericaceae					**1**			**15**		**3**		**15**	**3**	**15**	**3**	**3**	**1**
Hypericum mutilum var. *mutilum*	Dwarf St. John's-wort	Hypericaceae			**3**									**3**					**1**
Hypericum punctatum	Spotted St. John's-wort	Hypericaceae									3								
Ipomoea hederacea	Ivy-leaf Morning Glory	Convolvulaceae							3	3	3								3
Ipomoea purpurea	Common Morning Glory	Convolvulaceae	*												3				
Kummerowia stipulacea	Korean-clover	Fabaceae	*				85		15	38	3	38			63	85	63	63	
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*	3	3		1	3	15	38	3	63		3		38	38	3	
Lespedeza violacea	Wand Lespedeza	Fabaceae														1			
Lobelia inflata	Indian Tobacco	Campanulaceae					**3**					**3**						**1**	
Nuttallanthus canadensis	Blue Toadflax	Plantaginaceae																1	
Oxalis stricta	Common Yellow Wood-sorrel	Oxalidaceae			15			15				15	3	1	1				3
Parthenocissus quinquefolia	Virginia-creeper	Vitaceae														3			
Paspalum dilatatum	Dallis Grass	Poaceae	*			1													
Paspalum laeve	Field Paspalum	Poaceae												3	3				3
Perilla frutescens	Beefsteak Plant	Lamiaceae	*			3													
Persicaria pensylvanica	Pennsylvania Smartweed	Polygonaceae		**1**		**1**			**1**			**1**			**3**				
Phytolacca americana var. *americana*	Common Pokeweed	Phytolaccaceae						3											
Polypremum procumbens	Juniper-leaf	Tetrachondraceae								**38**				**1**	**1**				**3**
Potentilla canadensis var. *canadensis*	Dwarf Cinquefoil	Rosaceae																	3
Rhus copallinum var. *copallinum*	Winged Sumac	Anacardiaceae										3							
Rudbeckia hirta	Black-eyed Susan	Asteraceae		**15**	**3**	**15**	**3**		**15**		**3**			**15**	**3**	**3**	**3**		**3**
Ruellia caroliniensis	Carolina Wild-petunia	Acanthaceae													**3**				
Setaria faberi	Nodding Bristlegrass	Poaceae	*											15					
Setaria parviflora	Knotroot Bristlegrass	Poaceae						3	38				38		38	15	15	3	
Solanum carolinense var. *carolinense*	Horse-nettle	Solanaceae									3								
Symphyotrichum pilosum var. *pringlei*	Pringle's Aster	Asteraceae					3												
Tridens flavus	Purpletop	Poaceae				15					15	3							38
Triticum aestivum	Wheat	Poaceae	*		1														
Viola sagittata var. *sagittata*	Arrow-leaved Violet	Violaceae														3		15	

[1] Pecent cover classes in 1m^2 sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.6 Vegetation abundance matrix, CP, summer sample.

CO SUMMER - Cople Open Area (CO): Summer Plant Cover Data[1]

Date: July 31, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Achillea millefolium	Common Yarrow	Asteraceae												**3**			**3**		
Ambrosia artemisiifolia	Common Ragweed	Asteraceae					1					15		3	38				
Ampelopsis brevipedunculata	Porcelain-berry	Vitaceae	*											1					
Asclepias incarnata var. *incarnata*	Swamp Milkweed	Apocynaceae										3							
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae		**3**	**15**	**3**	**3**	**15**	**15**	**15**	**38**	**15**	**15**	**38**		**3**	**15**	**85**	**15**
Coleataenia anceps ssp. *anceps*	Beaked Panic Grass	Poaceae		15															
Conyza canadensis var. *canadensis*	Horseweed	Asteraceae										**38**						3	
Coreopsis lanceolata	Long-stalk Coreopsis	Asteraceae	Uncertain	3	3	**38**	1	3		3	**15**		15	**38**	**3**		**38**		**15**
Danthonia spicata	Poverty Oatgrass	Poaceae							3										
Dichanthelium meridionale	Matting Panic Grass	Poaceae		15	3		3												
Diodia teres	Common Buttonweed	Rubiaceae			1		1								**15**				**38**
Diospyros virginiana	Common Persimmon	Ebenaceae							1										
Eragrostis spectabilis	Purple Lovegrass	Poaceae								3				15		15	3		3
Erechtites hieraciifolius	Fireweed	Asteraceae									3								
Eupatorium capillifolium	Dog-fennel	Asteraceae									1		1						
Eupatorium rotundifolium	Roundleaf Thoroughwort	Asteraceae												**3**					
Eupatorium serotinum	Late Thoroughwort	Asteraceae													**15**				
Helianthus angustifolius	Narrow-leaved Sunflower	Asteraceae		15	63	38	63	63	38	38	15		63	38	63	38	63	3	38
Heliopsis helianthoides var. *helianthoides*	Oxeye	Asteraceae										**3**							
Hypericum stragulum	Low St. Andrew's Cross	Hypericaceae		**15**	**3**					**3**	**3**								
Kummerowia stipulacea	Korean-clover	Fabaceae	*	38	63	63	38	63	63	85	63	15	63	63	85	63	63	38	
Lespedeza capitata	Round-headed Lespedeza	Fabaceae							3						3		3		**3**
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*				3				3		3		3				
Lespedeza violacea	Wand Lespedeza	Fabaceae								1									
Lespedeza virginica	Slender Lespedeza	Fabaceae		3				1											
Liatris spicata var. *spicata*	Dense Blazing Star	Asteraceae		**3**			**3**		**15**	**3**	**15**	**15**						**15**	
Liquidambar styraciflua	Sweetgum	Altingiaceae					1				1								
Lobelia inflata	Indian Tobacco	Campanulaceae									**3**		**3**						
Monarda fistulosa var. *fistulosa*	Wild Bergamot	Lamiaceae		1								3		3	3		3		3
Oxalis stricta	Common Yellow Wood-sorrel	Oxalidaceae									**1**	3						1	
Parthenocissus quinquefolia	Virginia-creeper	Vitaceae			1														
Paspalum laeve	Field Paspalum	Poaceae				15		3											15
Pinus taeda	Loblolly Pine	Pinaceae								3	1								
Potentilla canadensis var. *canadensis*	Dwarf Cinquefoil	Rosaceae					3			3									
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae									3								
Rudbeckia hirta	Black-eyed Susan	Asteraceae			**3**			**15**				**15**	3		15	**15**		**38**	
Schizachyrium scoparium var. *scoparium*	Little Bluestem	Poaceae			3	3		3	15				3						
Setaria parviflora	Knotroot Bristlegrass	Poaceae		1						3									
Solidago nemoralis var. *nemoralis*	Gray Goldenrod	Asteraceae			15							3				**3**	**15**		
Symphyotrichum pilosum var. *pringlei*	Pringle's Aster	Asteraceae													15				3

[1] Pecent cover classes in 1m^2 sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.7 Vegetation abundance matrix, CO, summer sample.

BI SUMMER - Belle Isle (BI): Summer Plant Cover Data[1]

Date: August 2, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Achillea millefolium	Common Yarrow	Asteraceae																	3
Andropogon gerardii	Big Bluestem	Poaceae			3		63		63	15	15	63	38	38		15	38	85	63
Andropogon virginicus var. *virginicus*	Broomsedge	Poaceae												15	15				
Campsis radicans	Trumpet-creeper	Bignoniaceae			3			15	15	3	15	3		3				1	
Carex albolutescens	Greenish-white Sedge	Cyperaceae													1				
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae			**1**	**3**		**3**						**3**			**15**		
Cynodon dactylon var. *dactylon*	Bermuda Grass	Poaceae	*										15		3				
Cyperus strigosus	Straw-colored Flatsedge	Cyperaceae												3					
Daucus carota	Queen-Anne's Lace	Apiaceae	*							**3**									
Diospyros virginiana	Common Persimmon	Ebenaceae								3									
Elymus virginicus	Virginia Wild Rye	Poaceae			15														
Erigeron annuus	Annual Fleabane	Asteraceae			**3**				**3**		**3**								
Gamochaeta purpurea	Purple Cudweed	Asteraceae				1													
Lactuca canadensis	Wild Lettuce	Asteraceae		**3**															
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*			15	2	2			2		2		2		2		
Lespedeza virginica	Slender Lespedeza	Fabaceae																	3
Lonicera japonica	Japanese Honeysuckle	Caprifoliaceae	*														38		
Monarda fistulosa var. *fistulosa*	Wild Bergamot	Lamiaceae				3	15			38	1	3		3	3	15		3	3
Panicum virgatum var. *virgatum*	Switchgrass	Poaceae							38		38			3					38
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae			38											15			
Rudbeckia hirta	Black-eyed Susan	Asteraceae		**3**	**3**	**3**	**3**	**15**	**3**	**3**	**15**								
Rudbeckia laciniata var. *laciniata*	Cut-leaf Coneflower	Asteraceae				**15**													
Rumex crispus ssp. *crispus*	Curly Dock	Polygonaceae	*												1				
Schedonorus arundinaceus	Tall Fescue	Poaceae	*		38														
Schizachyrium scoparium var. *scoparium*	Little Bluestem	Poaceae				15				3						3			
Solanum carolinense var. *carolinense*	Horse-nettle	Solanaceae							3										
Solidago altissima ssp. *altissima*	Tall Goldenrod	Asteraceae		63	63	38	38	38	38	63	85	15	63	63	63	85	63	15	3
Sorghum halepense	Johnson Grass	Poaceae	*	15	3	15	3	15			3		3	15		3			

[1] Pecent cover classes in 1m^2 sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.8 Vegetation abundance matrix, BI, summer sample.

MS SUMMER - Middlesex (MS): Summer Plant Cover Data[1]

Date: August 2, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Digitaria sanguinalis	Northern Crabgrass	Poaceae	*	15	15	3	63	63	63	63		85	3	63	85	15	15	3	38
Euphorbia maculata	Spotted Spurge	Euphorbiaceae					1												
Galium sherardia	Field Madder	Rubiaceae	*												**1**				
Medicago sativa	Alfalfa	Fabaceae	*							3									
Paspalum dilatatum	Dallis Grass	Poaceae	*	15	3		15	38	3		3	15	38	15	15		15	15	15
Plantago lanceolata	English Plantain	Plantaginaceae	*									3							
Potentilla indica	Indian-strawberry	Rosaceae	*				**38**												
Rumex crispus ssp. *crispus*	Curly Dock	Polygonaceae	*			3		1			3		3				3	3	
Schedonorus arundinaceus	Tall Fescue	Poaceae	*	63	85	85	38	15	38	15	85	3	63	63	15	85	63	85	63
Stellaria media	Common Chickweed	Caryophyllaceae	*													1			
Taraxacum officinale	Common Dandelion	Asteraceae	*			1													
Trifolium repens	White Clover	Fabaceae	*	**38**	**3**	**3**			**38**	**15**	**15**		**15**	**15**	**3**	**3**	**38**	**3**	**15**

[1] Pecent cover classes in 1m[2] sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.9 Vegetation abundance matrix, MS, summer sample.

CP FALL - Cople Panel Zone (CP): Fall Plant Cover Data[1]

Date: October 1, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Acalypha rhomboidea	Common Three-seeded Mercury	Euphorbiaceae			3			3	15				3						
Acalypha virginica	Virginia Three-seeded Mercury	Euphorbiaceae														1			3
Ambrosia artemisiifolia	Common Ragweed	Asteraceae					15					38				15			38
Andropogon virginicus var. *virginicus*	Broomsedge	Poaceae																	3
Campsis radicans	Trumpet-creeper	Bignoniaceae			3	3			3			1	1	15					
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae			38	**3**					**3**	**3**		3		1		3	15
Chamaecrista nictitans var. *nictitans*	Wild Sensitive Plant	Fabaceae					3		38			15							
Conyza canadensis var. *canadensis*	Horseweed	Asteraceae																3	
Coreopsis lanceolata	Long-stalk Coreopsis	Asteraceae	Uncertain								3								
Cuscuta compacta	Compact Dodder	Convolvulaceae										**1**							
Dichanthelium clandestinum	Deer-Tongue Grass	Poaceae												15					
Dichanthelium meridionale	Matting Panic Grass	Poaceae					3												15
Digitaria ciliaris	Southern Crabgrass	Poaceae		1							3						3	15	
Diodia teres	Common Buttonweed	Rubiaceae					1									38			
Eragrostis spectabilis	Purple Lovegrass	Poaceae				15					15	3		3	38	3			63
Erechtites hieraciifolius	Fireweed	Asteraceae							15					3				15	
Eupatorium capillifolium	Dog-fennel	Asteraceae							3										
Eupatorium rotundifolium	Roundleaf Thoroughwort	Asteraceae												**3**	**15**				15
Helianthus angustifolius	Narrow-leaved Sunflower	Asteraceae			**3**		**15**									**15**	**15**		
Hypericum gentianoides	Pineweed	Hypericaceae					3				3	3			3				
Ipomoea hederacea	Ivy-leaf Morning Glory	Convolvulaceae						3							3				
Ipomoea purpurea	Common Morning Glory	Convolvulaceae	*		3														
Kummerowia stipulacea	Korean-clover	Fabaceae	*	38			85			1	63	85		38		38	63		
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*	15				38	3			3			3	3			3
Liquidambar styraciflua	Sweetgum	Altingiaceae								1									
Lobelia inflata	Indian Tobacco	Campanulaceae										**1**		15					
Oxalis stricta	Common Yellow Wood-sorrel	Oxalidaceae		**38**	1	3													
Panicum dichotomiflorum var. *dichotomiflorum*	Spreading Panic Grass	Poaceae			3			15	15				38					3	
Paspalum dilatatum	Dallis Grass	Poaceae	*																1
Paspalum laeve	Field Paspalum	Poaceae					1	3										3	15
Persicaria longiseta	Long-bristled Smartweed	Polygonaceae	*					**1**										**1**	
Persicaria pensylvanica	Pennsylvania Smartweed	Polygonaceae		**15**									**63**						
Pinus taeda	Loblolly Pine	Pinaceae															3		
Plantago virginica	Virginia Plantain	Plantaginaceae					3										1		
Potentilla canadensis var. *canadensis*	Dwarf Cinquefoil	Rosaceae										1					3		1
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae								3									
Rudbeckia hirta	Black-eyed Susan	Asteraceae		**3**				**15**											
Setaria parviflora	Knotroot Bristlegrass	Poaceae		38	63	63		38	38	63	3		63	1	3	38	3	63	
Solanum carolinense var. *carolinense*	Horse-nettle	Solanaceae									3								
Symphyotrichum pilosum var. *pringlei*	Pringle's Aster	Asteraceae		**15**		**38**				**63**	**38**		**3**	**3**	**38**	**3**	**3**		**15**
Tridens flavus	Purpletop	Poaceae								15	63				15				3

[1] Pecent cover classes in 1m[2] sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.10 Vegetation abundance matrix, CP, fall sample.

CO FALL - Cople Open Area (CO): Fall Plant Cover Data[1]

Date: October 1, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Agrostis stolonifera	Creeping Bentgrass	Poaceae	*				1												
Ambrosia artemisiifolia	Common Ragweed	Asteraceae				15						15							
Andropogon virginicus var. virginicus	Broomsedge	Poaceae		3							15								
Chamaecrista fasciculata var. fasciculata	Common Partridge-pea	Fabaceae				3	1	3	3		15			3	1	**3**		3	3
Chamaecrista nictitans var. nictitans	Wild Sensitive Plant	Fabaceae		1								1							
Conyza canadensis var. canadensis	Horseweed	Asteraceae				**3**													
Coreopsis lanceolata	Long-stalk Coreopsis	Asteraceae	Uncertain		3				15	38			3	15	3	3	3	15	3
Dichanthelium clandestinum	Deer-Tongue Grass	Poaceae									3								
Dichanthelium meridionale	Matting Panic Grass	Poaceae														1			
Digitaria ciliaris	Southern Crabgrass	Poaceae						3											
Diodia teres	Common Buttonweed	Rubiaceae														3			3
Eragrostis spectabilis	Purple Lovegrass	Poaceae													3	3	15		
Eupatorium capillifolium	Dog-fennel	Asteraceae				**15**	**3**										**15**		
Eupatorium hyssopifolium	Hyssop-leaf Thoroughwort	Asteraceae					**15**												
Helianthus angustifolius	Narrow-leaved Sunflower	Asteraceae		**63**	**63**	**63**	**38**	**38**	**38**	**63**	**38**	**38**	**63**	**63**	**63**	**38**	**63**	**38**	**63**
Hypericum stragulum	Low St. Andrew's Cross	Hypericaceae		3															
Kummerowia stipulacea	Korean-clover	Fabaceae	*	15	85	63	85	15	63	63	38	38	15	63	38	63	38	85	63
Lespedeza capitata	Round-headed Lespedeza	Fabaceae						3							3	3			3
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*							3									
Liatris spicata var. spicata	Dense Blazing Star	Asteraceae									15	3						3	
Monarda fistulosa var. fistulosa	Wild Bergamot	Lamiaceae										3	3	15			1		
Oxalis stricta	Common Yellow Wood-sorrel	Oxalidaceae				**3**													
Paspalum laeve	Field Paspalum	Poaceae													3				
Perilla frutescens	Beefsteak Plant	Lamiaceae	*									1							
Pinus taeda	Loblolly Pine	Pinaceae		3					3										3
Polypremum procumbens	Juniper-leaf	Tetrachondraceae		1															
Potentilla canadensis var. canadensis	Dwarf Cinquefoil	Rosaceae		1	3				1										
Rhus copallinum var. copallinum	Winged Sumac	Anacardiaceae						15											
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae															3		
Rudbeckia hirta	Black-eyed Susan	Asteraceae							1		3	3	1	**3**					1
Schizachyrium scoparium var. scoparium	Little Bluestem	Poaceae		15	3	15	3	15	3	15	15	3	15	3		15	3	3	15
Setaria parviflora	Knotroot Bristlegrass	Poaceae				3												1	
Solidago nemoralis var. nemoralis	Gray Goldenrod	Asteraceae							3		15		**3**						
Symphyotrichum novae-angliae	New England Aster	Asteraceae										**3**					3		
Symphyotrichum pilosum var. pringlei	Pringle's Aster	Asteraceae										**15**	**38**		**15**		**38**	**3**	
Tridens flavus	Purpletop	Poaceae												3	15		15	3	
Verbesina occidentalis	Yellow Crownbeard	Asteraceae													1				
Viola sagittata var. sagittata	Arrow-leaved Violet	Violaceae		1															

[1] Pecent cover classes in 1m^2 sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.11 Vegetation abundance matrix, CO, fall sample.

BI FALL - Belle Isle (BI): Fall Plant Cover Data[1]

Date: October 6, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Andropogon gerardii	Big Bluestem	Poaceae								63	63	85	3		63	85	63	85	85
Campsis radicans	Trumpet-creeper	Bignoniaceae		1				3			15	3							3
Chamaecrista fasciculata var. *fasciculata*	Common Partridge-pea	Fabaceae								1	3								
Cynodon dactylon var. *dactylon*	Bermuda Grass	Poaceae	*												15				
Eragrostis spectabilis	Purple Lovegrass	Poaceae					38	15	63		15		85	63			15		
Eupatorium capillifolium	Dog-fennel	Asteraceae			15												3		
Lespedeza cuneata	Sericea Lespedeza	Fabaceae	*		3			15					1						
Monarda fistulosa var. *fistulosa*	Wild Bergamot	Lamiaceae					15									3		3	
Rubus pensilvanicus	Pennsylvania Blackberry	Rosaceae			3														
Schizachyrium scoparium var. *scoparium*	Little Bluestem	Poaceae				15												3	
Solanum carolinense var. *carolinense*	Horse-nettle	Solanaceae														15			
Solidago altissima ssp. *altissima*	Tall Goldenrod	Asteraceae		**85**	**63**	**38**	**38**	**63**	**63**	**38**	**63**	**15**	**15**	**15**	**63**	**15**	**63**	**3**	**3**
Sorghastrum nutans	Indian Grass	Poaceae				38		15		3				3	3	1	1	3	15
Sorghum halepense	Johnson Grass	Poaceae	*				3		3	3	3	3		1					
Symphyotrichum pilosum var. *pilosum*	Frost Aster	Asteraceae		**3**	**15**	**15**	**15**	**38**					**3**	**3**			**3**		

[1] Pecent cover classes in $1m^2$ sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.12 Vegetation abundance matrix, BI, fall sample.

MS FALL - Middlesex (MS): Fall Plant Cover Data[1]

Date: October 1, 2021

(Note: **bold red typeface** indicates that a species was in flower in that plot during the sampling event)

Scientific Name	Common Name	Family	Introduced[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cynodon dactylon var. *dactylon*	Bermuda Grass	Poaceae	*						3				3	3		3	3	1	
Digitaria sanguinalis	Northern Crabgrass	Poaceae	*	63	85	85	63	38	63	85	63	85	85	38	85	63	85	63	85
Kummerowia striata	Japanese-clover	Fabaceae	*			3													
Kyllinga gracillima	Pasture Spikesedge	Cyperaceae	*								15								
Oxalis dillenii	Southern Yellow Wood-sorrel	Oxalidaceae						3											
Paspalum dilatatum	Dallis Grass	Poaceae	*	3	3	3	15		3							15			3
Potentilla indica	Indian-strawberry	Rosaceae	*					63							1				
Rumex crispus ssp. *crispus*	Curly Dock	Polygonaceae	*													1			
Schedonorus arundinaceus	Tall Fescue	Poaceae	*	38	3	15	3	15	38	15	38	15	15	38	15	3	15	38	15
Stellaria media	Common Chickweed	Caryophyllaceae	*	1								1		15					
Taraxacum officinale	Common Dandelion	Asteraceae	*				3			1		1			3				
Trifolium repens	White Clover	Fabaceae	*	3			15		3	1	1	1	1	15	3	3	3	3	3

[1] Pecent cover classes in $1m^2$ sampling frame (with midpoints rounded to nearest whole integer shown in parentheses) include: 0-1% (1%), 1-5% (3%), 5-25% (15%), 25-50% (38%), 50-75% (63%), 75-95% (85%), 95-100% (98%).

[2] Introduced: Species annotated with * are non-native (introduced) in Virginia per Weakley et al. (2012)

Table A.13 Vegetation abundance matrix, MS, fall sample.

Spearman Correlation Values Overall

Rho-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%FI	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	**-0.333**															
CO	**-0.333**	**-0.333**														
MS	**-0.333**	**-0.333**	**-0.333**													
S	-0.278	**0.541**	**0.397**	**-0.660**												
%N	**0.496**	0.242	0.207	**-0.945**	**0.470**											
%Inv	0.221	**0.456**	**-0.447**	-0.230	**0.316**	0.225										
FQI	0.050	0.107	**0.677**	**-0.834**	**0.671**	**0.751**	-0.089									
%FI	-0.161	0.092	**0.396**	**-0.327**	**0.293**	**0.338**	-0.119	**0.372**								
Predator	0.044	0.169	0.169	**-0.382**	0.282	**0.359**	0.003	**0.386**	**0.606**							
Herbivore	**0.386**	0.223	**-0.313**	**-0.296**	0.040	**0.404**	0.258	0.104	0.227	**0.448**						
Pollinator	0.069	**0.360**	-0.029	**-0.400**	**0.352**	**0.427**	0.199	0.269	**0.688**	**0.640**	**0.420**					
Parasitoid	**0.610**	-0.196	-0.197	-0.217	**-0.322**	**0.405**	-0.051	0.133	0.198	0.244	**0.325**	0.254				
Detritivore	**0.304**	-0.101	0.124	**-0.327**	-0.099	**0.416**	-0.182	**0.309**	**0.528**	**0.573**	**0.461**	**0.371**	**0.670**			
Sanguivore	-0.072	-0.236	-0.260	**0.568**	**-0.449**	**-0.511**	-0.227	**-0.473**	-0.252	-0.133	-0.084	-0.077	0.033	-0.093		
Ant	**0.640**	-0.214	-0.131	**-0.295**	-0.220	**0.465**	0.156	0.217	0.129	0.205	**0.537**	0.252	**0.571**	**0.408**	-0.049	
Diversity	0.217	**0.407**	0.205	**-0.829**	**0.614**	**0.780**	**0.374**	**0.655**	**0.459**	**0.518**	**0.416**	**0.522**	0.167	**0.417**	**-0.679**	0.245

P-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%FI	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	**0.021**															
CO	**0.021**	**0.021**														
MS	**0.021**	**0.021**	**0.021**													
S	0.056	**0.000**	**0.005**	**0.000**												
%N	**0.000**	0.097	0.158	**0.000**	**0.001**											
%Inv	0.132	**0.001**	**0.001**	0.116	**0.029**	0.124										
FQI	0.733	0.470	**0.000**	**0.000**	**0.000**	**0.000**	0.549									
%FI	0.273	0.532	**0.005**	**0.023**	**0.044**	**0.019**	0.422	**0.009**								
Predator	0.768	0.250	0.250	**0.007**	0.052	**0.012**	0.985	**0.007**	**0.000**							
Herbivore	**0.007**	0.127	**0.030**	**0.041**	0.789	**0.004**	0.076	0.483	0.121	**0.001**						
Pollinator	0.641	**0.012**	0.843	**0.005**	**0.014**	**0.002**	0.176	0.065	**0.000**	**0.000**	**0.003**					
Parasitoid	**0.000**	0.183	0.179	0.139	**0.026**	**0.004**	0.729	0.369	0.178	0.095	**0.024**	0.081				
Detritivore	**0.036**	0.493	0.402	**0.024**	0.504	**0.003**	0.215	**0.033**	**0.000**	**0.000**	**0.001**	**0.009**	**0.000**			
Sanguivore	0.627	0.106	0.074	**0.000**	**0.001**	**0.000**	0.121	**0.001**	0.084	0.369	0.570	0.602	0.825	0.530		
Ant	**0.000**	0.143	0.376	**0.042**	0.133	**0.001**	0.290	0.139	0.382	0.162	**0.000**	0.083	**0.000**	**0.004**	0.739	
Diversity	0.138	**0.004**	0.162	**0.000**	**0.000**	**0.000**	**0.009**	**0.000**	**0.001**	**0.000**	**0.003**	**0.000**	0.255	**0.003**	**0.000**	0.093

Table A.14 Spearman correlation rho and p-values overall. The rho values with significant p-values are bolded green for positive correlations and red for negative correlations. Significant p-values are in red bold type. A p-value of 0.000 means < 0.001. (S = plant species richness, %N = percent native plant cover, %Inv = percent invasive plant cover, FQI = Floristic Quality Index, Diversity = Shannon diversity of the insects at the morphospecies level).

Spring Spearman Correlation Tables

Rho-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%FI	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	-0.333															
CO	-0.333	-0.333														
MS	-0.333	-0.333	-0.333													
S	-0.040	0.436	0.391	**-0.787**												
%N	0.350	0.200	0.407	**-0.957**	**0.733**											
%Inv	0.102	**0.536**	**-0.588**	-0.049	0.134	-0.034										
FQI	-0.054	0.156	**0.719**	**-0.821**	**0.789**	**0.859**	-0.350									
%FI	**-0.615**	-0.389	**0.646**	0.358	-0.132	-0.268	**-0.504**	0.131								
Predator	0.403	0.327	-0.211	**-0.519**	0.465	**0.549**	0.470	0.253	-0.458							
Herbivore	**0.640**	-0.305	**-0.636**	0.301	-0.419	-0.265	0.459	**-0.645**	-0.479	0.333						
Pollinator	0.396	0.396	-0.335	-0.457	0.424	0.415	**0.574**	0.081	**-0.628**	**0.722**	0.424					
Parasitoid	**0.923**	-0.248	-0.358	-0.317	0.011	0.384	0.165	-0.034	**-0.622**	**0.557**	**0.666**	0.480				
Detritivore	**0.758**	-0.253	-0.253	-0.253	-0.082	0.195	-0.053	-0.033	-0.423	0.112	0.403	0.239	**0.498**			
Sanguivore	**0.808**	-0.444	-0.363	0.000	-0.202	0.046	0.147	-0.297	-0.421	0.205	**0.681**	0.216	**0.750**	0.488		
Ant	0.496	-0.184	0.212	**-0.524**	0.365	**0.507**	-0.109	0.399	-0.145	**0.605**	0.109	0.260	0.430	0.418	0.151	
Diversity	0.246	**0.554**	-0.298	**-0.502**	0.351	0.466	**0.521**	0.208	**-0.559**	**0.685**	0.178	**0.677**	0.301	0.255	-0.162	0.358

P-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%FI	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	0.207															
CO	0.207	0.207														
MS	0.207	0.207	0.207													
S	0.884	0.091	0.134	**0.000**												
%N	0.184	0.459	0.117	**0.000**	**0.001**											
%Inv	0.707	**0.032**	**0.017**	0.856	0.620	0.902										
FQI	0.843	0.563	**0.002**	**0.000**	**0.000**	**0.000**	0.184									
%FI	**0.011**	0.137	**0.007**	0.174	0.625	0.315	**0.047**	0.629								
Predator	0.121	0.217	0.432	**0.040**	0.070	**0.027**	0.066	0.344	0.074							
Herbivore	**0.008**	0.251	**0.008**	0.258	0.106	0.322	0.073	**0.007**	0.060	0.207						
Pollinator	0.129	0.129	0.204	0.075	0.102	0.110	**0.020**	0.767	**0.009**	**0.002**	0.102					
Parasitoid	**0.000**	0.355	0.173	0.232	0.966	0.142	0.541	0.900	**0.010**	**0.025**	**0.005**	0.060				
Detritivore	**0.001**	0.345	0.345	0.345	0.764	0.470	0.846	0.904	0.102	0.681	0.121	0.373	**0.050**			
Sanguivore	**0.000**	0.085	0.167	1.000	0.453	0.864	0.586	0.265	0.104	0.447	**0.004**	0.423	**0.001**	0.055		
Ant	0.051	0.495	0.430	**0.037**	0.165	**0.045**	0.688	0.126	0.593	**0.013**	0.687	0.331	0.096	0.107	0.577	
Diversity	0.358	**0.026**	0.262	**0.048**	0.183	0.069	**0.038**	0.440	**0.024**	**0.003**	0.510	**0.004**	0.258	0.340	0.550	0.174

Table A.15 Spearman correlation rho and p-values for spring dataset. See Table A.14 for interpretation.

Summer Spearman Correlation Tables

Rho-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%FI	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	-0.333															
CO	-0.333	-0.333														
MS	-0.333	-0.333	-0.333													
S	-0.271	**0.657**	0.343	**-0.729**												
%N	**0.537**	0.256	0.155	**-0.948**	**0.523**											
%Inv	0.436	**0.505**	**-0.502**	-0.439	0.401	0.451										
FQI	0.065	0.095	**0.685**	**-0.846**	**0.720**	**0.689**	0.122									
%FI	**-0.556**	**0.696**	0.210	-0.350	**0.574**	0.265	-0.036	0.239								
Predator	-0.245	**0.673**	-0.061	-0.367	**0.540**	0.286	0.261	0.248	**0.704**							
Herbivore	**0.661**	0.244	**-0.576**	-0.329	-0.063	0.475	**0.546**	-0.009	-0.186	0.144						
Pollinator	-0.220	**0.879**	-0.228	-0.432	**0.547**	0.422	0.299	0.136	**0.818**	**0.787**	0.278					
Parasitoid	**0.714**	-0.238	-0.261	-0.215	-0.161	0.383	0.268	0.060	-0.324	-0.175	0.243	-0.145				
Detritivore	0.026	0.131	0.235	-0.392	0.311	0.392	0.068	0.390	0.232	-0.096	0.015	0.075	0.267			
Sanguivore	**-0.573**	-0.043	-0.215	**0.831**	-0.442	**-0.867**	-0.478	**-0.610**	-0.024	0.054	-0.254	-0.111	-0.408	-0.342		
Ant	**0.722**	-0.214	-0.151	-0.357	-0.187	**0.504**	0.237	0.263	-0.356	-0.127	**0.665**	-0.071	**0.539**	0.099	-0.354	
Diversity	0.237	0.479	0.247	**-0.963**	**0.789**	**0.902**	**0.550**	**0.755**	0.450	0.416	0.312	**0.518**	0.124	0.425	**-0.817**	0.213

P-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%FI	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	0.207															
CO	0.207	0.207														
MS	0.207	0.207	0.207													
S	0.309	**0.006**	0.193	**0.001**												
%N	**0.032**	0.339	0.565	**0.000**	**0.037**											
%Inv	0.092	**0.046**	**0.047**	0.089	0.123	0.080										
FQI	0.810	0.726	**0.003**	**0.000**	**0.002**	**0.003**	0.653									
%FI	**0.025**	**0.003**	0.436	0.184	**0.020**	0.321	0.894	0.373								
Predator	0.361	**0.004**	0.822	0.162	**0.031**	0.283	0.330	0.354	**0.002**							
Herbivore	**0.005**	0.362	**0.020**	0.213	0.815	0.063	**0.029**	0.972	0.490	0.594						
Pollinator	0.413	**0.000**	0.396	0.095	**0.028**	0.104	0.261	0.615	**0.000**	**0.000**	0.296					
Parasitoid	**0.002**	0.375	0.329	0.424	0.552	0.143	0.315	0.825	0.220	0.516	0.365	0.591				
Detritivore	0.923	0.629	0.380	0.133	0.241	0.133	0.804	0.136	0.388	0.723	0.956	0.781	0.318			
Sanguivore	**0.020**	0.874	0.424	**0.000**	0.087	**0.000**	0.061	**0.012**	0.931	0.843	0.343	0.681	0.116	0.195		
Ant	**0.002**	0.425	0.576	0.175	0.488	**0.047**	0.378	0.325	0.176	0.640	**0.005**	0.793	**0.031**	0.714	0.179	
Diversity	0.376	0.060	0.357	**0.000**	**0.000**	**0.000**	**0.027**	**0.001**	0.080	0.109	0.239	**0.040**	0.647	0.101	**0.000**	0.429

Table A.16 Spearman correlation rho and p-values for summer dataset. See Table A.14 for interpretation.

Fall Spearman Correlation Tables

Rho-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%Fl	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	-0.333															
CO	-0.333	-0.333														
MS	-0.333	-0.333	-0.333													
S	**-0.516**	**0.559**	**0.542**	**-0.585**												
%N	**0.591**	0.270	0.082	**-0.944**	0.331											
%Inv	0.039	0.453	-0.359	-0.133	0.035	0.208										
FQI	0.136	0.073	**0.639**	**-0.848**	**0.660**	**0.717**	-0.218									
%Fl	0.392	-0.178	0.490	**-0.704**	0.259	**0.669**	-0.020	**0.600**								
Predator	0.136	-0.030	0.438	**-0.543**	0.416	0.442	-0.080	**0.575**	**0.683**							
Herbivore	0.257	**0.556**	-0.125	**-0.688**	0.459	**0.696**	0.112	0.414	0.483	0.413						
Pollinator	**0.566**	-0.281	0.376	**-0.661**	0.132	**0.664**	-0.104	**0.622**	**0.772**	**0.728**	0.372					
Parasitoid	**0.958**	-0.311	-0.296	-0.350	-0.437	**0.595**	0.071	0.192	0.298	0.089	0.203	0.479				
Detritivore	**0.621**	-0.236	0.278	**-0.664**	0.044	**0.741**	-0.051	**0.543**	**0.811**	**0.533**	0.446	**0.728**	**0.559**			
Sanguivore	-0.079	-0.370	-0.364	**0.813**	**-0.645**	**-0.706**	-0.263	**-0.708**	**-0.522**	-0.414	-0.485	-0.456	-0.106	-0.416		
Ant	**0.959**	-0.357	-0.211	-0.390	-0.419	**0.619**	0.026	0.186	**0.580**	0.325	0.347	**0.685**	**0.881**	**0.743**	-0.123	
Diversity	0.205	0.310	0.445	**-0.960**	**0.634**	**0.862**	0.186	**0.828**	**0.723**	**0.616**	**0.587**	**0.690**	0.196	**0.650**	**-0.859**	0.296

P-Values

	BI	CP	CO	MS	S	%N	%Inv	FQI	%Fl	Predator	Herbivore	Pollinator	Parasitoid	Detritivore	Sanguivore	Ant
CP	0.207															
CO	0.207	0.207														
MS	0.207	0.207	0.207													
S	**0.041**	**0.024**	**0.030**	**0.017**												
%N	**0.016**	0.311	0.762	**0.000**	0.211											
%Inv	0.886	0.078	0.172	0.623	0.899	0.440										
FQI	0.617	0.788	**0.008**	**0.000**	**0.005**	**0.002**	0.417									
%Fl	0.133	0.510	0.054	**0.002**	0.333	**0.005**	0.942	**0.014**								
Predator	0.616	0.912	0.090	**0.030**	0.109	0.086	0.768	**0.020**	**0.004**							
Herbivore	0.337	**0.025**	0.645	**0.003**	0.074	**0.003**	0.679	0.111	0.058	0.112						
Pollinator	**0.022**	0.291	0.151	**0.005**	0.627	**0.005**	0.703	**0.010**	**0.000**	**0.001**	0.156					
Parasitoid	**0.000**	0.241	0.266	0.183	0.091	**0.015**	0.793	0.477	0.262	0.743	0.451	0.060				
Detritivore	**0.010**	0.380	0.297	**0.005**	0.872	**0.001**	0.853	**0.030**	**0.000**	**0.033**	0.083	**0.001**	**0.024**			
Sanguivore	0.772	0.158	0.166	**0.000**	**0.007**	**0.002**	0.324	**0.002**	**0.038**	0.111	0.057	0.076	0.697	0.109		
Ant	**0.000**	0.174	0.432	0.135	0.106	**0.011**	0.923	0.490	**0.019**	0.220	0.187	**0.003**	**0.000**	**0.001**	0.649	
Diversity	0.446	0.243	0.084	**0.000**	**0.008**	**0.000**	0.491	**0.000**	**0.002**	**0.011**	**0.017**	**0.003**	0.466	**0.006**	**0.000**	0.265

Table A.17 Spearman correlation rho and p-values for fall dataset. See Table A.14 for interpretation.

Spring NMDS

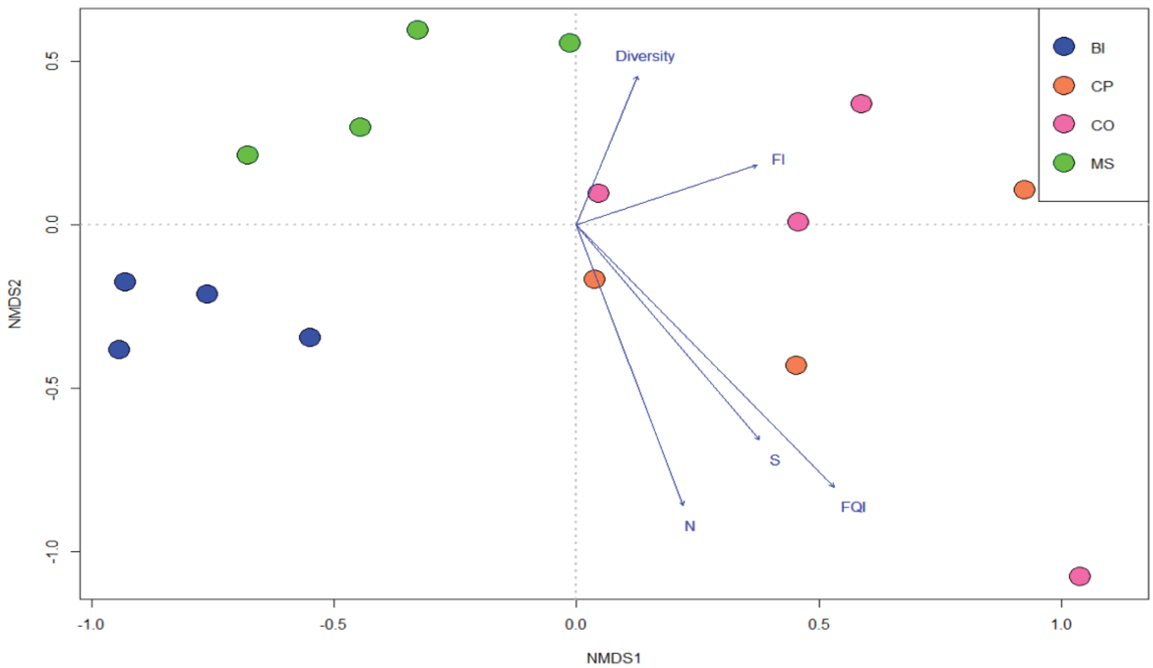

Figure A.1 Spring NMDS of Insect Morphospecies Abundance. K = 2. Environmental variables shown in relation to insect samples are percent native species cover (N), floristic quality index (FQI), percent flowering (Fl), plant species richness (S), and insect morphospecies Shannon Diversity (Diversity). The length of each environmental variable's arrow corresponds to the strength of the relationship.

Summer NMDS

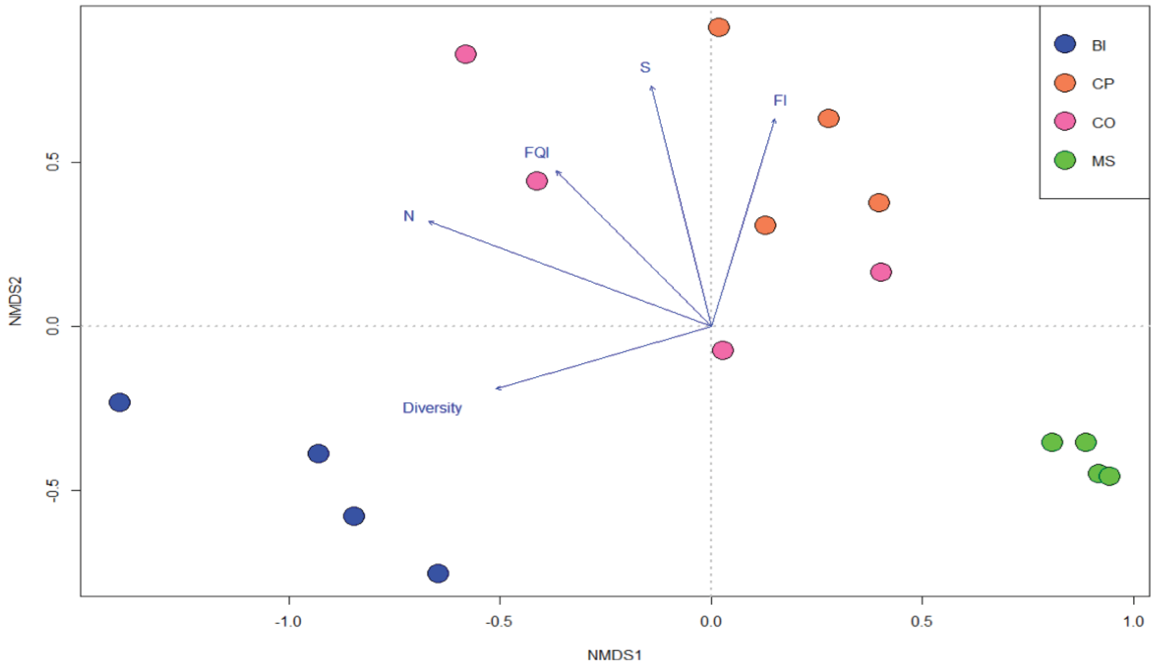

Figure A.2 Summer NMDS of Insect Morphospecies Abundance. K = 2. Environmental variables shown in relation to insect samples are percent native species cover (N), floristic quality index (FQI), percent flowering (Fl), plant species richness (S), and insect morphospecies Shannon Diversity (Diversity). The length of each environmental variable's arrow corresponds to the strength of the relationship.

Fall NMDS

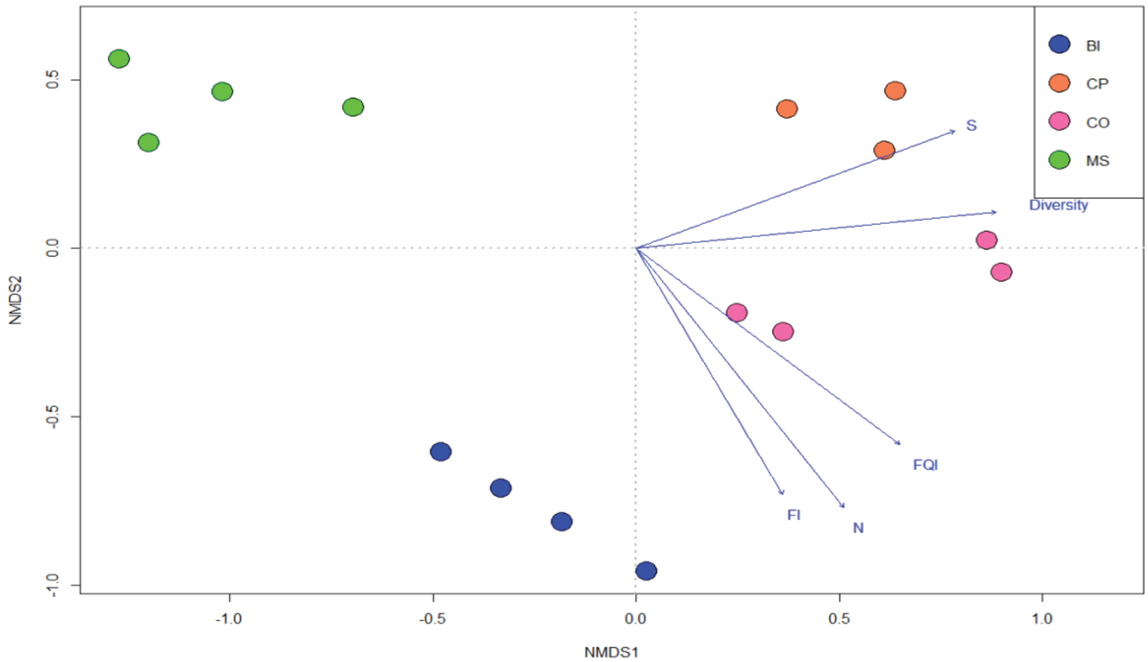

Figure A.3 Fall NMDS of Insect Morphospecies Abundance. K = 2. Environmental variables shown in relation to insect samples are percent native species cover (N), floristic quality index (FQI), percent flowering (Fl), plant species richness (S), and insect morphospecies Shannon Diversity (Diversity). The length of each environmental variable's arrow corresponds to the strength of the relationship.

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