THE INFLUENCE OF URBANIZATION ON INSECT POLLINATORS ACROSS LOCAL AND REGIONAL SCALES

A proposal for research submitted
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by

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1. Project Summary

Given the rapid spread of urbanization, understanding how it impacts ecological communities is integral to predicting and mitigating its effects. Insect pollinators — which transfer pollen in or between flowers — are critical to ecosystem health and resilience (Abrol, 2012, Chapter 16; Katumo et al., 2022). Studying insect pollinators provides an understanding of the broader ecological impacts of urbanization, as their diversity, abundance, and interactions with plants are key indicators of ecosystem health. Pollinator phenology and community interactions offer valuable insight into how urbanization may alter pollinator seasonality and interactions with angiosperms. Owing to logistic constraints however, urban pollinator research is lacking in breadth and nuance: pollinator phenology studies in urban areas are often constrained to narrow geographic and taxonomic scales, and the mechanisms driving plant-pollinator interactions are poorly understood. My thesis research will investigate how urbanization influences pollinator phenology and interactions. I will test how urbanization changes pollinator phenology by assessing species-specific changes in the timing of life history stages across an urbanization gradient. I will also determine which characteristics of urban green spaces in South Florida are predictors of unique plant-pollinator interaction diversity. This thesis will provide new insight into urbanization's effect on pollinators by using large data sets to widen the geographic/taxonomic scales that are assessed, and by quantifying a unique measure of diversity: interaction diversity (i.e., the total number of unique plant-pollinator interactions within an urban greenspace). I will leverage ideas from community ecology, urban ecology, urban landscape planning, and phenology to assess the pollinator-urbanization relationship at both local and regional spatial scales, providing results that are both nuanced and expansive in scope.

2. Specific Aims

My thesis is structured by two research objectives, each intended to be stand-alone chapters and papers, but which both contribute to the overall research goal of understanding how pollinators respond to urbanization.

Research Objective 1: To assess pollinator phenology as a function of urbanization across spatial and taxonomic scales.
Hypothesis 1: I expect that urbanization will be a significant predictor of pollinator phenology, and that the pollinator phenological response to urbanization will vary by taxonomic group, functional group, and along latitudinal/longitudinal gradients.
Research Objective 2: To examine unique plant-pollinator interaction diversity in urban green spaces.

Hypothesis 2: I expect that historic habitat, presence/abundance of non-native plant species, annual human visitation, proportion of non-permeable surfaces, proximity to other urban areas/presence of buffer zones, management intensity, and distribution/abundance of vegetation will significantly predict the diversity of unique plant-pollinator interactions.

3. Background and Significance

3.1 The Role of Insect Pollinators

Insect pollinators serve various roles in the ecosystem, making them integral to ecosystem health (Abrol, 2012, Chapter 16). One such role is co-evolutionary force. Many plants co-evolve with pollinators, modifying traits to match certain pollinator species that can best aid in their reproductive success (Mitchell et al., 2009). These relationships have existed for millions of years, with plant-pollinator relationships in at least 15 insect families being traced back to the Upper Jurassic (Peña-Kairath et al., 2023). Today, insects pollinate approximately 80% of angiosperms globally (Nath et al., 2020). Pollinators also serve as decomposers, aiding in the breakdown of organic material while – often inadvertently – pollinating plants (Vermaa et al., 2023). One example of such pollinators is the dung beetles of the genus *Onthophagus*, which pollinate plants of the family Lowiaceae during the process of breaking down dung containing undigested plant materials (Sakai and Inoue, 1999). Pollinators also influence the soil they live in – tilling and aerating it during burrowing/nest building activities. Soil aeration and turnover aids in enhanced nutrient recycling, water infiltration, and reduced soil erosion. These activities modify the chemical and physical composition of the soil (Vermaa et al., 2023). Lastly, insect pollinators are an abundant food source. There are more than approximately 1,000,000 insect pollinator species globally. They are present in every terrestrial ecosystem except for Antarctica (Wojcik, 2021, Chapter 2). The sheer biomass and the relatively low positions of pollinators in trophic webs makes them significant prey for many species of wildlife (Vermaa et al., 2023).

Insect pollinators also contribute to human health and well-being. Due to their pollination of cultivated crops, pollinators are embedded in the global food system (Murphy et al., 2022). Approximately two-thirds of global food crops are pollinated by insects, with a third of this production being carried out by bees alone (Khalifa et al., 2021; FAO, 2004). These crops are of heightened quantity and nutritious quality (Khalifa et al., 2021). An economic evaluation of the United States in 2012 valued these pollination services at $34 billion USD (Jordan et al., 2021). Ornamental flowers – which are largely insect-pollinated, have also been shown to produce better human mental health outcomes, resulting in an increased state of relaxation and comfort (Xie et al., 2021; Lin et al., 2021).

Despite their critical role in human and environmental health, much is left to be understood about how and why insect pollinators will respond to current and future changes in their environments. With the ~20-40% decline in insect pollinator populations, this is important now more than ever (Nath et al., 2020). Key to understanding pollinator ecology– and thus the health of ecosystems in urban areas – is an investigation of not only **how** they pollinate, but also **when** they pollinate.

3.2 Biodiversity in Urban Areas

Urbanization is projected to encompass larger areas and involve denser populations over time. By 2050, more than two-thirds of the world's population is expected to live in cities (Welford & Yarbrough, 2021, Chapter 8; Gerten et al., 2019). The reality that an increasing proportion of natural habitat will become urbanized has placed urbanization at the forefront of many ecological studies: namely, studies of biodiversity in urban areas. These studies indicate that changes in the biodiversity within cities vary by taxon. For example, the abundance of certain animal taxa (e.g., birds) tends to increase in cities despite the overall decrease of richness of animal species, while plant richness is generally higher in cities due to the human-facilitated influx of non-native plants (Faeth et al., 2011). Although these studies have made strides to identify broad patterns of urban biodiversity, they contain knowledge gaps and biases that reduce their scope of inference. One issue with these studies is their use of differing methodologies and focus taxa, making it difficult to compare their findings. They are also biased toward temperate rather than tropical cities, and are mostly conducted in Nearctic and Palearctic regions, with little research being conducted in the Global South (Faeth et al., 2011, Rega-Brodsky et al., 2022). Many studies fail to account for the ways in which scale will influence the ecological processes that determine biodiversity and are limited in spatial and temporal scope (Uchida et al., 2021; Rega-Brodsky et al., 2022). Lastly, most studies of urban biodiversity lack an investigation of the relationship between biodiversity and ecosystem functions and services (Rega-Brodsky et al., 2022).

Urbanization has varied effects on insect pollinator biodiversity, with variation by taxonomic and functional group. While the richness and abundance of Hymenopterans and generalist pollinators increases in cities, the opposite is true for Dipterans, Lepidopterans, and specialist pollinators (Theodorou et al., 2020; Silva et al., 2023). Although the mechanisms of these differences are not totally understood, there is a growing body of literature showing that the mechanism of impact can drive this variation in pollinator response. For example, urbanization can result in the increase of non-local plants, which reduces the negative impacts of fragmentation on the abundance and richness of generalist pollinators and extends the pollinator season (Wraye & Elle, 2015). Additionally, the characteristics of urban areas themselves can impact pollinator biodiversity (Schueller et al., 2023). According to Zeng et al. (2023), the flowering abundance of nectar plants, vertical and horizontal vegetation structure, herb richness, shrub coverage rate, and management intensity all influence pollinator diversity in urban green spaces. Connectivity to other green spaces is also positively related to pollinator richness and abundance (Graffigna et al., 2024). The biases and gaps found in urban biodiversity studies are prevalent in current urban pollinator biodiversity research. If urban pollinator biodiversity is to be well understood, further research must be conducted to address these biases and gaps in knowledge.

3.3 Phenology as a function of urbanization

Phenology is the timing of cyclical life history events in an organism's life such as breeding, flowering, and emergence. Shifts in phenology serve as a measure of the impacts of climate change

(Inouye, 2022; Chmura et al., 2018). Urbanization can be linked to plant and pollinator phenological shifts in cities and urban centers (Neil et al., 2006; Li et al., 2023). In some cities, for example, plants flower earlier than in surrounding non-urban areas. This tends to occur most prominently in spring and summer. These shifts can be caused by the urban heat island effect, in which urban areas are warmer than surrounding areas due to their high density of impermeable areas which absorb and retain more heat than surrounding areas (Jochner & Menzel, 2015; Sun et al., 2022; Deilami et al., 2018). Sexton et al. (2023), for example, found that plants in urban areas of Louisville, Kentucky, which is an urban heat island, flowered 1-2 weeks earlier than plants in rural areas within the same city. The study also found evidence that summer-flowering plant species in urban areas can shift into the temporal niche of spring and fall-flowering species.

Phenology studies are most often conducted on plants and – to a lesser extent – insects, with an emphasis on pollinators (Jochner & Menzel, 2015). There are many mechanisms by which urbanization could change plant and pollinator phenology. Harrison and Winfree (2015) identified four primary mechanisms that influence pollination in urban areas: habitat loss and fragmentation, non-native species introductions, urban warming, and environmental contaminants such as nitrogen deposition/pollution. They found several ways in which these altered resources influence pollinator activity. For example, non-native plants in urban areas may retain their native blooming season and therefore provide resources to pollinators during months where their native resources are generally lower. In some cases, pollinators have adjusted their phenology to match that of the non-native plants. Similarly to how plants are impacted by the urban heat island effect, increased heat in urban centers can lead to altered pollinator phenology (Freimuth et al., 2022). In this way, urban centers serve as a method of examining and predicting the impacts of climate change on a system. Investigating the phenology of species inhabiting urban areas is therefore critical not only to our understanding of the impact of urban areas on ecosystem health, but also to climate change research.

3.4 Pollinator Interactions in Urban Green Spaces

Key to the study of insect pollinators is their interactions with plants (Rafferty & Cosma, 2024). While the effects of urbanization on pollinator or plant diversity have gained considerable interest, there exists another type of diversity that has not yet been explored: the diversity of unique plant-pollinator interactions. It is important to note that "pollination" is an interaction between two species. Therefore, these interactions can be quantified as their own measure of diversity. For example, in one ecosystem, pollinator species A and B may forage on and pollinate plant species C, D, and E, but in another ecosystem those interactions may be absent. The unique plant-pollinator interaction diversity would be lower in this second ecosystem. Whether a given interaction is present in an ecosystem can depend on many factors, including size matching of morphology between plants and pollinators, competitive exclusion between co-occurring pollinators, and facilitation of interactions by other species (Naghiloo et al., 2021; Sargent and Ackerly, 2008). Biotic and abiotic factors influence plant-pollinator interactions both **directly** and **indirectly** (Sargent and Ackerly, 2008). For example, habitat filtering occurs when environmental conditions of a site select for species with higher fitness, often resulting in communities with phenotypic clustering. Although habitat filters are often abiotic (e.g., soil type), this is not always the case. Pollinator communities themselves can serve as habitat filters. They can **directly** influence plant-pollinator interactions by determining which plant communities can grow locally. They do this by simply being locally present or absent – if a plant species cannot persist without a species of pollinator that is locally extinct, then this plant species will not grow locally. Abiotic filters, on the other hand, **indirectly** influence plant-pollinator interactions by influencing the plants and pollinators directly, which in turn have altered interspecific interactions (Sargent and Ackerly, 2008). Although studies have identified certain biotic and abiotic factors as influential to plant-pollinator interactions, they have not yet measured their effect on the diversity of plant-pollinator interactions. For example, there may be a site with a high alpha diversity of host plant species for three pollinator species. However, if the pollinators do not utilize these plants, then the unique plant-pollinator interaction diversity would be low. Although a high alpha diversity of host plants can be associated with more plant-pollinator interactions, this may not always be the case, especially when combined with the impact of other biotic and abiotic factors. Due to the different ways that urban green spaces are managed, there is a large variation within the abiotic and biotic factors that could impact the diversity of unique plant-pollinator interactions. For example, some urban green spaces, designated as natural areas, are managed to preserve their original state as closely as possible. Other urban green spaces focus more on sports recreation and therefore are managed to have a higher impact on the abiotic and biotic resources found within them. Seven parks in the same area could all be managed differently and therefore have a wide range of native angiosperms present per park. This makes urban green spaces a useful tool to examine the impact of these factors on the diversity of unique plant-pollinator interactions.

Urban green spaces are defined by Taylor and Hochuli (2017) as vegetated areas that exist within an urban landscape and that are designed and maintained by humans. Examples of urban green spaces include parks, urban forests, and community gardens. Although there are other definitions of urban green spaces, this is the definition that will be used in this thesis. Urban green spaces can help achieve conservation goals by reducing the urban heat island effect, improving air quality, and increasing the biodiversity of pollinator communities (Das et al., 2022; Diener & Mudu, 2021; Baldock et al, 2019). However, not all urban green spaces are alike in ecological value. The characteristics of the urban green spaces themselves, many of which are shaped by their design and management, largely determine the extent to which they alter plant-pollinator interactions. Some influential urban green space characteristics include: the distribution of floral resources, landscape composition, connectivity to each other and to other land use types, level of air pollution, heat island effect, pesticide use, human social factors, and local flora and fauna. Patchy floral resource distribution, for example, can cause pollinators to spend more time at each plant to maximize energy rather than spending less time pollinating more plants (Silva et al., 2021). The design and management intensity of an urban green space – which plants are prioritized, how much detritus is allowed to remain, etcetera – has been shown to alter pollinator abundance and richness (Zeng et al., 2023; Schueller et al., 2023). This could have important implications for plant-pollinator interactions. Although research has highlighted the importance of urban green space characteristics and management on pollinator diversity and abundance, less is known about their influence on plant-pollinator interactions.

3.5 Linking regional and local scales of analysis

Multiple scales of analysis are necessary to accurately understand how urbanization influences pollinators and their interactions. Larger scales of analysis reveal overarching broad-scale patterns. However, what they gain in large-scale patterns they lose in fine details. Large-scale analyses often fail to identify local variations in patterns, which reveal the mechanistic underpinnings of a relationship. For example, phenology has been shown to vary by spatial scale (Park et al., 2021). Studies of vegetation at different resolutions show that different phenological estimates from the same dataset can be produced by simply altering the spatial resolution (Liu et al., 2019; Zhang et al., 2017). Phenology also varies along latitudinal, longitudinal, and elevational gradients (Williams, 1971; Gao et al., 2020). Knowing how phenology varies by spatial scales offers valuable insights into the global impacts of climate change. However, there are other scales yet to be explored: taxonomic groups and data size. Many studies of phenology are limited by taxonomic scale and limited data due to logistic constraints (Jochner & Menzel, 2015). As a result, there are many taxonomic groups with little to no existing phenological studies. Without this knowledge, we can gain insight into how and where climate change is impacting certain species and groups, but it is difficult to determine which taxonomic/functional groups will be the most strongly impacted in the future and why. Plant-pollinator interactions in urban green spaces are another prime example of this. Large-scale analyses of urban-green spaces reveal that urbanization generally causes pollinators to alter foraging routes, reduce the duration and frequency of floral visits, and alter floral resource selection. However, the increased size and number of floral displays and increased pollen and nectar production in cities compensate for the reduced visitation rate, resulting in increased floral visitation by bees (Silva et al., 2021). This site-level variation is only possible to detect at smaller scales. It is therefore important to not only evaluate these topics and patterns at multiple scales, but to evaluate them at scales not typically explored. Because of this, my work will focus on two related scales: (1) the state of Florida for research objective 1 and (2) local urban areas within Broward County, Florida for research objective 2.

4. Research Design and Preliminary Data

4.1 Research Objective 1: To assess pollinator phenology as a function of urbanization across spatial and taxonomic scales.

The objective of this research is to (a) determine whether urbanization is a significant predictor of pollinator phenology, and (b) ascertain whether pollinator phenological responses to urbanization vary longitudinally/latitudinally or by taxonomic group. To ask these questions I will use research grade iNaturalist occurrence observations to quantify phenology using a gridded map of Florida and the R package ‘phenesse’ (Belitz et al., 2020). I will use linear models to assess the relationship between phenology and urbanization.

4.1.1 Research Design

The study design is a predictive analysis of insect pollinator observations in Florida. The **scope of my data** will include all iNaturalist pollinator observations located in Florida from 2008 to 2024. There are approximately 450,000 observations available on iNaturalist during this time frame. Florida, with its subtropical **and** tropical climates, serves as a region with a significant longitudinal climate gradient as well as a large array of insect pollinator taxa to sample from. I will obtain the pollinator observations from the Pollinators of Florida iNaturalist project, which compiles observations of **insect** pollinators found in Florida. I will collate observations into 5 x 5 km grid cells across the state. In each grid cell I will quantify urbanization using two Google Earth Engine data sets: the Global Human Modification Index (GHMI) and Dynamic World.

The GHMI dataset uses 13 individual data sets to estimate the proportion of a given area of land that is human modified. It ranges from 0-1, with 1 being very urbanized. It has a resolution of 1 square kilometer, thus there are multiple pixels with GHMI values within one 5 x 5 grid cell. I will calculate the mean GHMI value of all pixels that fall within each 5 x 5 grid cell in my data set. Similarly, Dynamic World is a land cover dataset that calculates values for 9 land cover variables at a 10-meter resolution. The 8 variables that I will be using include bare land, built land, crops, flooded vegetation, grass, shrub and scrub, trees, and water. The snow and ice variable has been excluded due to Florida’s climate. These variables are not centered on human modification but can be utilized to measure urbanization as they include vegetation variables and account for bare ground. For each grid cell, I will calculate the total number of pixels of each of the 8 Dynamic World variables. Each pixel is 10 x 10 meters. I will then calculate the proportion of area that each variable represents relative to the total area of each grid cell. The strength of using urbanization variables from both data sets lies in predictive ability for a true measure of “urbanization” rather than overfitting to a single, imperfect, index.

Then, in each grid cell I will use observations to estimate the onset, median, offset, and total duration of seasonal activity for each pollinator species. I will test how pollinator phenology differs with urbanization using linear models, in which the mean GHMI, Dynamic World variables, taxonomic groups (genus and family), functional groups (generalist and specialist), and latitude and longitude are **predictors** of phenological estimates. The expansive data set provides a large scale of phenological estimates (Y values), providing <u>predictive power</u> to the design. This will shed insight into whether urbanization **predicts** pollinator phenology.

4.1.2 Proposed Methods

Data Collection/Species

For this study, pollinators are defined as insects that engage in pollination activities (e.g., collect pollen/nectar, and contact plants reproductive parts). Observational data will be obtained from the iNaturalist Pollinators of Florida project, (https://www.inaturalist.org/projects/pollinators-of-florida). This project only includes insect pollinators that are found in Florida and that are from the following taxa: Superfamily Apoidae, Family Bombyliidae, Subfamily Cetoniinae, Order Lepidoptera, and Subfamily Lepturinae. These are the target taxa of this study. I will filter through all observations to include only photographic observations of pollinators located in Florida from 2008 to 2024. To increase identification certainty, I will only include Research Grade observations. The Research Grade designation is given to observations that (a) meet iNaturalist data standards of a verifiable observation, and (b) have acquired more than two-thirds agreement by the iNaturalist community on the taxonomic identification. Furthermore, only grid cells with at least 10 observations and 3 different species will be included for analysis.

Study Site

Florida is a southern state in the United States that contains three climatic zones - North, Central, and South. Seasonality varies by climate zone, resulting in the subtropical classification of north-central sections of Florida and tropical classification of the southern section of Florida. (Black, 1993). Any grids that meet the above criterion in the entire state of Florida will be utilized as study sites.

Flight Period

Flight period will be utilized as the phenological measure of pollinator activity, which can be seasonal or year-round. It will be quantified by the iNaturalist observations in Florida. Only grids that contain 10 or more unique species observations of at least 3 species will be considered suitable for analysis. For each grid cell, I will calculate the mean GHMI value as well as the total pixels of each Dynamic World land cover variable. Flight period will be further broken down into three categories: Onset (10^{th} earliest percentile of observations, i.e. beginning of season), Median, Offset (90^{th} percentile of observations, i.e. end of season), and Total Duration (number of days in the season). These estimates will be calculated using a Weibull probability distribution, found in the ‘phenesse’ package.

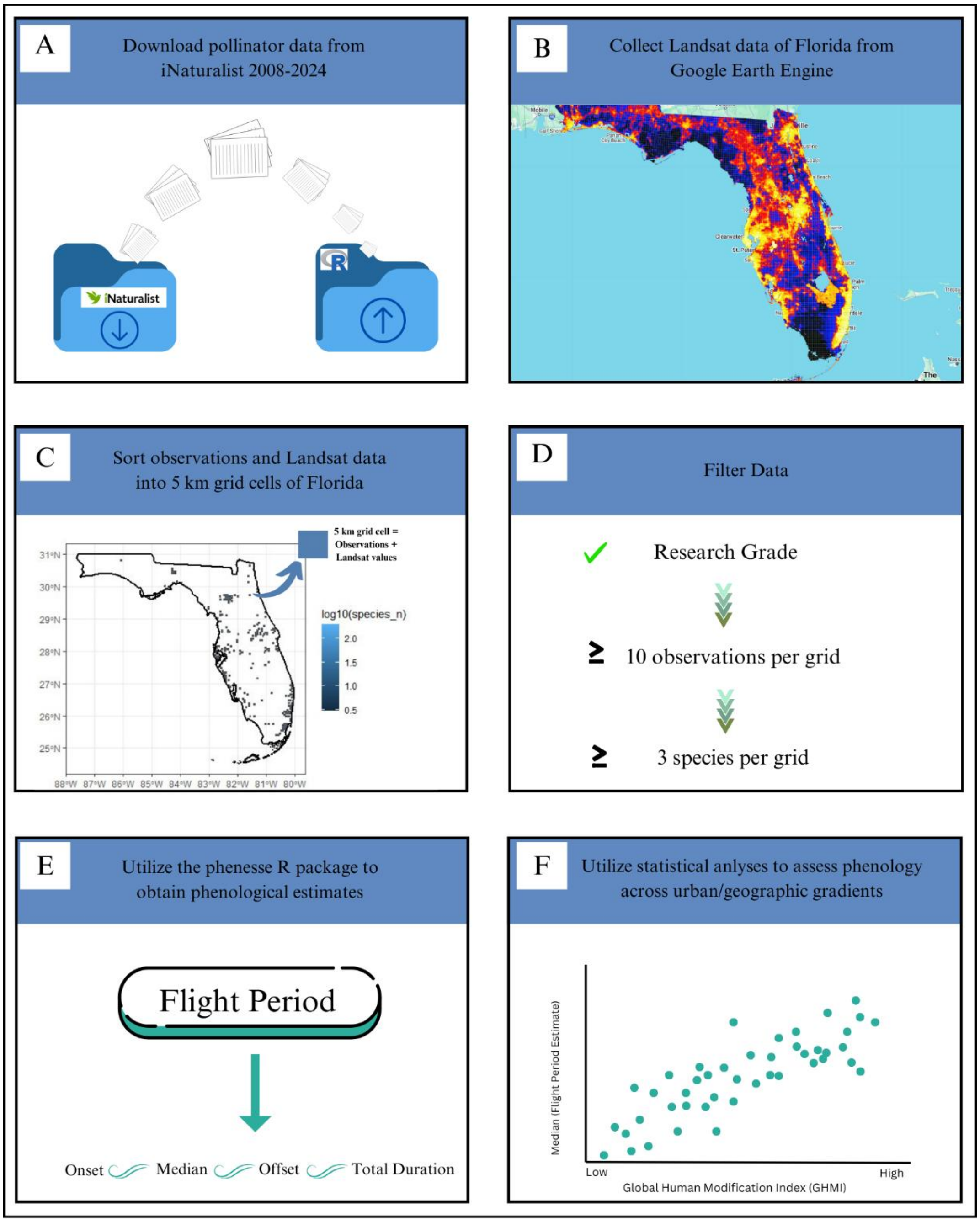

Figure 1: To accomplish Research Objective One, I will (A) download photographic insect pollinator observations from the iNaturalist Pollinators of Florida Project during the years of 2008 to 2024, (B) obtain the Dynamic World and Global Human Modification Index land cover data for Florida from Google Earth Engine, (C) create a gridded map of Florida and place both observations and land cover data into the appropriate grids based on location data of each observation, (D) filter the data so that Research Grade observations are placed into each grid, which has at least 10 observations, 3 species, and no observations that are recorded at the same time and day, (E) use the phenesse package in R (R version 2024.09.1) to calculate estimates of the beginning, middle, end, and total duration of

flight period of each species in each grid, and (F) use linear models to test the significance of urbanization as a predictor of the phenological estimates estimated in Step E.

Data Analysis

Linear mixed effects models will be used to determine whether urbanization is a significant predictor of insect pollinator phenology. Phenological estimates (Total Duration, Onset, Middle, and Offset) will be used as the response variable. The mean GHMI, Dynamic World variable values, latitude, and longitude will be used as predictor variables, with grid ID, species and a random slope as random intercepts. To assess the model results, the models will be run a second time with a subsample of the grids so that they all contain the same number of observations.

4.1.3 Preliminary Data

After all the iNaturalist observations from the Pollinators of Florida Project (2008-2024) were filtered, there were 68,370 observations remaining for analysis. From this data set, 417 pollinator species are represented. The observations include four taxonomic orders: Hymenoptera, Lepidoptera, Diptera, and Coleoptera. Of these orders, 44 families are present. Of the 6,550 five-kilometer grid cells spanning Florida, 4,915 were matched to pollinator observations. 313 (6.37%) of these grids met the filtering criteria, with an average of approximately 10 species per grid cell. *Dione vanillae* is the most abundant species represented in this data set.

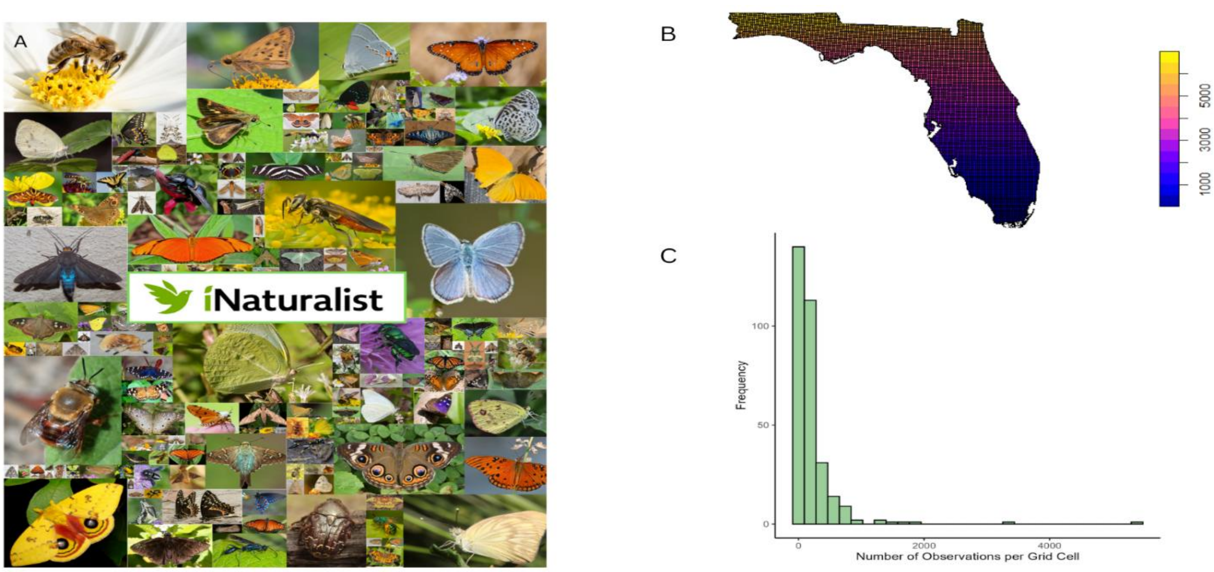

Figure 2: (A) A selection of some species present in the data set obtained from the 'Pollinators of Florida' iNaturalist project. (B) 5-kilometer grid cells across the state of Florida (C) Distribution of the number of observations found per grid cell.

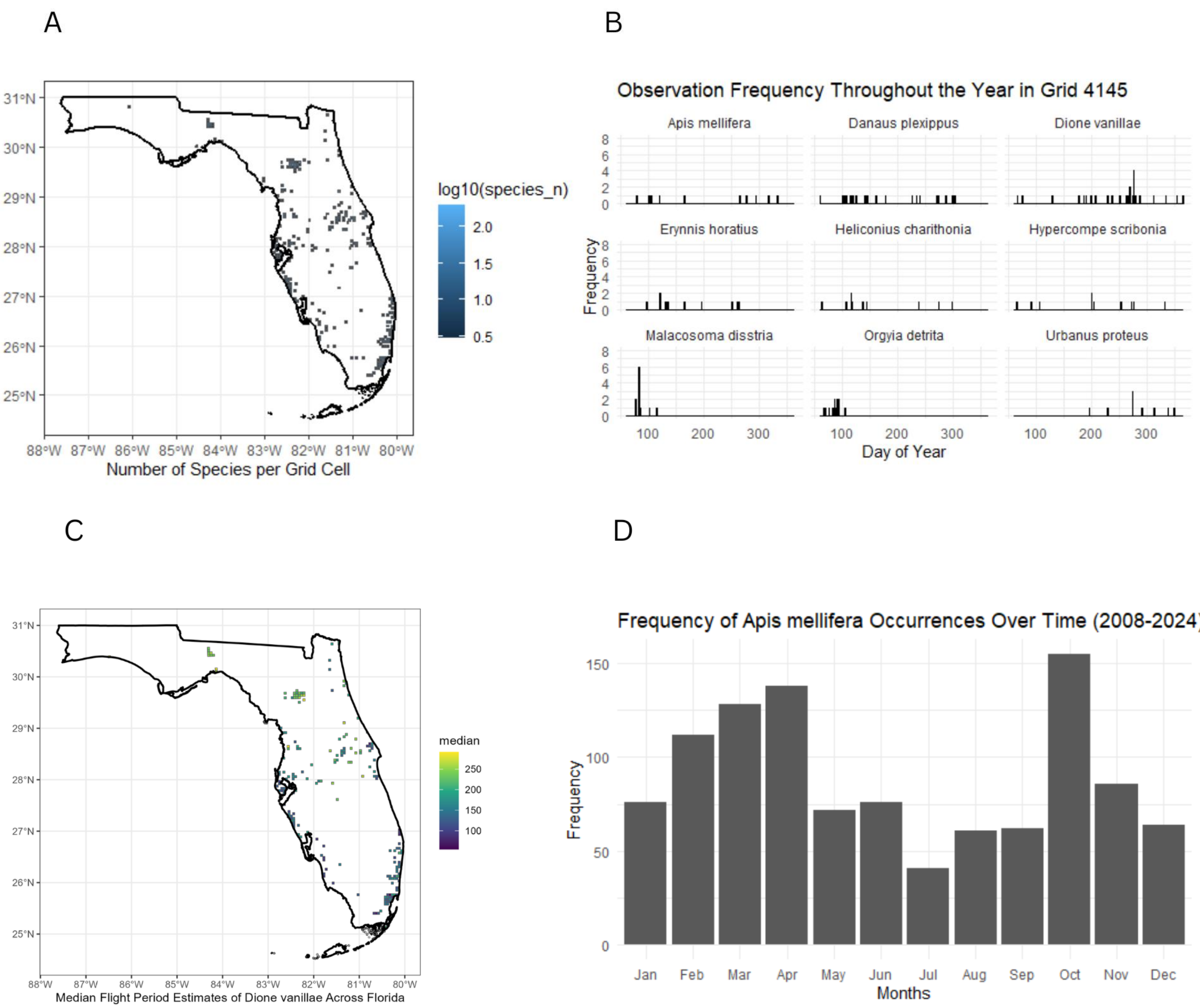

Figure 3: (A) The log of the number of species from the data that are represented in each grid cell across Florida. (B) Temporal frequency of observations of each species found in sample grid cell 4145. (C) Median day of year (middle of flight period season) of Dione vanillae across all grid cells of Florida. (D) Temporal frequency of observations of sample species Apis mellifera.

4.2 Research Objective 2: To examine unique plant-pollinator interaction diversity in urban green spaces.

The objective of this research is to ascertain which characteristics of urban green spaces significantly predict the diversity of unique plant-pollinator interactions.

4.2.1 Research Design

The study design is a **predictive investigation** of which urban green space characteristics significantly predict the diversity of unique plant-pollinator interactions and also a **comparative** investigation of citizen science. The **scope of inference** is urban green spaces in Florida. The main **data of interest** is plant-pollinator observational data. I chose South Florida as a study area due to its large spread of urbanization as well as its tropical climate, which allows for year-round observation of many insect species and expands upon previous urban pollinator diversity studies, which are biased toward non-tropical cities (Silva et al., 2023). I selected insect pollinators as the study taxon due to their utility as indicators of ecosystem health. I will sample 8 urban green spaces in South Florida which vary in the characteristics being assessed. I plan to minimize bias by using **random proportional stratification** to select sampling areas within sites and by only sampling on days with clear skies.

4.2.2 Proposed Methods

Study sites

The study sites will consist of 8 urban green spaces in South Florida. Urban green spaces are defined by Miguez et al. (2024) as open-space areas located within cities that were created to serve as parks/recreational areas. This is the definition that I will be using in this study. I will select urban green spaces that vary by historic habitat, proportion of non-permeable surfaces, proximity to other urban green spaces/presence of buffer zones, management intensity, and distribution/abundance of vegetation. Landsat variables and historic habitat data will be used to quantify the above traits in urban green spaces and guide site selection. I will obtain Landsat data from the Dynamic World data set provided by Google Earth Engine, and I will extract the historic habitat data from the John Henry Davis 1943 Vegetation Map. Using the Dynamic World dataset, we can obtain the percentage of land cover for each of the following variables in each grid cell: water, trees, grass, flooded vegetation, crops, shrub and scrub, built, bare, and snow and ice. The snow and ice variable will be taken out of all analyses as it is not relevant to tropical South Florida.

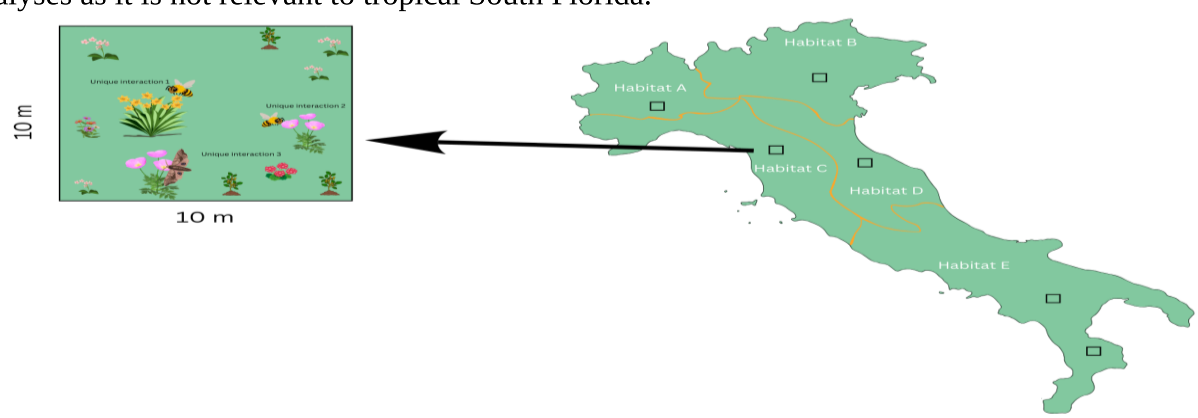

Figure 4: Sample plot layout at an urban green space

Data Collection

I will conduct an exhaustive documentation of all unique plant-pollinator interactions in urban green spaces in South Florida. Field observations will be collected bi-weekly from eight urban green spaces during the months of February 2025-2026. During each sampling day, three sites will be randomly selected for visitation. The sampling location in each site will be determined using proportional random stratification, with 10 x 10-meter plots placed in each habitat type present at each site. The plot locations will be selected via a random coordinate generator run in Rstudio, and located with a GPS. I will only use random coordinates that are suitable for sampling. For example, if I arrive at a randomly selected site and it is in a body of water, I will select another randomly generated site to sample from instead. For each plot in each habitat type, I will record all unique plant-pollinator interactions. A plant-pollinator interaction is defined as an observation of a pollinator that is found on a plant. Every new plant-pollinator species combination that is seen will be recorded as a unique interaction. Pictures will be taken of each observation to later confirm the identification of all species recorded. After ten minutes of no new unique observations, the sampling period concludes. I will also measure the flower density and native/non-native plant density in each habitat type at each site. All plant sampling will be conducted in the same plots used for plant-pollinator interaction observations. To measure flower density, I will count the number of flowers (found at any stage of development) found on each plant. I will also note the developmental stage of each flower to account for flowers that are present but perhaps not able to be utilized by pollinators. To measure native and non-native plant density, I will utilize the angle-order method. This is a plotless method of sampling plant density in which a point is placed in the center of a quadrat (a plot, in this case), and the plot is visually divided into four smaller quadrats. In each quadrat, the third-closest individual of each species to the center of the quadrat is measured. After measuring the flower and plant density at a particular plot, the sampling session concludes. This is repeated for all plots in each park. All sampling sessions will be recorded on days that are not overcast/raining to control for variation in weather.

Annual human visitation rates at each site will be obtained from park managers. I will utilize iNaturalist observation data to calculate the presence/abundance of native and non-native plant species in each site, as well as the site-level proportion of non-permeable surfaces, proximity to other urban areas/presence of buffer zones, and distribution/abundance of vegetation.

Data Analysis

Data will be analyzed using R (R version 2024.09.1). Using linear mixed effects models, I will test for significance of each habitat characteristic as a predictor of unique plant-pollinator interaction diversity, the response variable.

5. Synthesis and Significance

Insect pollinators are a testament to the phrase, *small but mighty*. In 2005 the annual pollination services provided by insect pollinators to the United States was valued at $215 billion, or 9.5% of the global food production (Vangergen, 2013). Additionally, 75% of global crop species are yielded or enhanced by insect pollinators. Pollinators are also widely appreciated for the aesthetic value that they add to human-inhabited environments. Not only are they vital to human food security, but they also provide critical ecosystem services such as soil aeration, nutrient cycling, and as resources to other wildlife (Vangergen, 2013; Vermaa et al., 2023). In recent years, studies have shown that many pollinator species are on the decline (Lebuhn et al., 2012). Many of these studies focus on bee species, so the actual number of pollinator species that are declining may be higher. Some of the threats to pollinators are linked to anthropogenic change (Vangergen, 2013).

A significant threat to pollinators is habitat degradation, alteration, and fragmentation (Harrison and Winfree, 2015; Vangergen, 2013; Siviter et al, 2023). Measurements of the spread of urbanization as well as their patterns show that not only is urbanization rapidly increasing but will also continue to increase in upcoming years (Gerten et al., 2019). Accompanying this spread will be increased habitat alteration. Although not all habitat changes are shown to negatively impact pollinator species (Ayers et al., 2021), not enough is known about why this is the case. To accurately prepare for how pollinator species will fare in an increasingly human-populated world, we must first understand their relationship with urbanization. This will not only heighten our understanding of pollinator behavior in urban areas, it will also allow us to assess the impacts of urbanization on ecosystem health. Additionally, the utilization of a novel measure of diversity in the under-studied urban tropics expands upon existing methods of measuring ecosystem health.

6. Works Cited

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