Suitability Evaluation and Neighborhood Design for Pollinator Habitat, City of Madison, Wisconsin

A Plan for Healthy and Pollinator-Friendly Urban Community

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Executive Summary

The City of Madison is the capital of Wisconsin, a state whose pollinator-dependent crops account for over $55 million in annual production and honey and beeswax account for $3.5 million annually. However, the state lost about 60% of its honey bee colonies from springs 2014-2015. And this is only one part of a dramatic bee and bee habitat loss across the whole country since 2006. These pollinator declines have been associated with "Colony Collapse Disorder" (CCD), whose causes are considered to be a combination of factors including construction of roads, restrictive land regulations, overuse of agricultural pesticide, virus, etc. These factors together, constituted a potential threat to maintain the productions of many crops, which are central to Wisconsin's economy and food culture, such as apples and cranberries.

In consideration of these issues, the project conducted a GIS-based bee habitat suitability research, which aims at strengthening people's and local government's awareness on pollinator habitat protection through the provision of a spatial evaluation for Madison's regional potential to develop pollinator habitats and the causes that determine the corresponding spatial pattern. In order to construct the relevant GIS model, 6 spatial variables were integrated into the analysis processes. They are soil drainability, aspects, vegetation cover, environmental corridor, water proximity, and pesticide use.

Based on the analysis results, the study discovered that the overall habitat suitability scores could vary considerably from central urban areas to suburbs, determined by land use types, population, vegetation cover, etc. Relatively suitable areas for pollinator habitat development include Lakshore Path, Picnic Point, UW-Arboretum, Warner Park, Farewell Point, Olbrich Gardens, etc. While relatively unsuitable areas include the isthmus areas, West Towne Mall, municipal airport, etc. On these bases, pertinent policy and planning suggestions combined with conceptual space design were given to four specific sites within the city. They are Lakeshore Path-Picnic Point Cluster, Warner Park-Mendota Hills Cluster, E. Washington Ave-Blair-Baladwin St Cluster, and Target-Hilldale Shopping Center-Sundance Cinemas Cluster.

Acknowledgements

I want to show my sincere gratitude to my core advisor Asligul Gocmen, who provided my numerous guidance on finding available resources and feasible approaches to conduct the study. In addition, I would also like to give special thanks to Professor Claudio Gratton, who provided me specific suggestions on GIS analysis and available entomology professionals I can reach out to. Also, the project may not be completed without the helps of Hannah Gaines Day and Jeremy Hemberger in Gratton Lab, Katherine Cornwell, Linda Horvath, Milena Bernardinello in City of Madison planning department.

Key words: GIS, LiDAR, community development, urban design, food system, environmental planning, urban agriculture, conservation biology

Definitions of Terms

Pollinator: is the biotic agent (e.g. bees, butterflies, etc.) that moves the pollens from the male anthers of a flower to the female stigma of a flower to accomplish fertilization of the female gametes in the ovule of the flower by the male gametes from the pollen grain (Wikipedia).

Pollination: is the act of transferring pollen grains from the male anther of a flower to the female stigma (USDA). In this project, pollination only refers to cross-pollination, which means the relevant plant species cannot transfer their pollens to another flower of the same species without the assistance of pollinators.

Pollinator Habitat: Pollinator habitats are areas of permanent vegetationlocated in an agricultural landscape: field edges, field middles, odd corners, or virtually any location that is suited for pollinators. Vegetation consists of acceptable herbaceous and/or woody plants (NRCS).

GIS: refers to either geographic information system or geographic information science. In the project, GIS refers to geographic information system since it is mainly used as a specific tool for geospational information analysis. Among the many defintions of GIS, I choose:

> *A GIS is a computer-based system to aid in the collection, maintenance, storage, analysis, output, and distribution of spatial data and information* (Bolstad 2012, 1).

LiDAR: "Light Detection and Ranging", is a remote sensing method that uses pulsed laser to measure ranges to the Earth. These light pulses—combined with other data recorded by the airborne system— generate precise, 3D information about the Earth surface features (NOAA).

CCD: is the abbreviation of Colony Collapse Disorder. It is a seemingly new phenomenon began to occur based on reports of an "alarming" number of bee colony losses and die-off along the East Coast since the last three months in 2006 (Johnson 2010, 4). By the end of 2006, this phenomenon broadly spreaded to other states.

Aspect: as a terminology in the field of physical geography, refers to the compass direction that a slope faces. The direction that a slope faces can influence the physical and biotic features of the slope due to different temperature, precipitation, etc. Most native bees prefer south facing slopes to slopes of other aspects (Greer, 1999).

Soil Drainability: refers to the soil's natural ability to allow water to pass through it. Dense soil will hold water, while loose soil will allow water to pass through quickly. Soil drainage may determine which types of plants grow well in it. Besides these, soil drainage can also be related with pollinators such as bees since species richness of wild bees was more abundant on dry soils than moist soils (Dauber et al., 2003).

Environmental Corridor: are areas in the landscape that contain and connect natural areas, open space, and scenic or other resources. They often lie along streams, rivers, or other natural features.

Green Roof: is a vegetated landscape built up from a series of layers that are installed on a roof surface as 'loose-laid' or modular (that is, installed layer by layer on the roof or as pre-prepared layers in trays). ("Green Roof Definition" Growing Green Guide par 1).

Rain Garden: is a specially-designed garden that collect and infiltrate stormwater from impervious areas such as roofs, driveways, and heavily-compacted lawns ("Rain Gardens" City of Madison par 1).

Community Garden: is neighborhood space designed, developed, or managed by local residents on vacant land, possibly including viewing gardens, play areas, and community gardens (Lee and Francis 1).


Figure 1. The major types of pollinators. Source: United States Department of Agriculture, Forest Service.


Figure 2. Prairies near water ponds in Owen Park, western Madison. This is a classic example of ideal pollinator habitat. Source: City of Madison.

1. Introduction and Problem Statement

1.1 Pollinator, Pollination, and their Significance

Pollinator, as indicated by the name, generally refers to any types of agents or vectors that can transfer the angiospermous pollens from the male anthers of a flower to the female stigma to accomplish the fertilization of the plant species. In details, pollinators can include animals such as bees, butterflies, flies, humming birds, bats and even natural elements such as wind (see Figure 1). Naturally, pollination, defined by the United States Department of Agriculture (hereafter USDA), refers to the "act/process of transferring pollen grains from the male anther of a flower to the female stigma". This process is the unintended consequence of an animal's activity on a flower. Typical pollinator habitats are mainly consisted of diverse flowering vegetation communities and may include shrubs, dead woods, ponds, etc (see Figure 2).

In this project, in order to provide pertinent suggestions for pollinator habitat planning, the concept "pollinator" largely refers to bee pollinators. The type of pollination only refers to cross-pollination.

According to the study by Nicholas Calderone from Cornell University, the estimated economic value of honey bee pollination alone to the U.S. agriculture was roughly at $17 billion in 2009. In general, "the monetary value of honey bees as commercial pollinators in the United States is estimated at about $15 billion annually" (Johnson 1). This is mainly because lots of agricultural products such as alfalfa, apples, almonds, etc. are actually pollinator-dependent crops, which means the relevant plants cannot bear fruits or seeds without the assistance of insect pollinators to accomplish their fertilization. Consequently, a diminution of in managed or wild pollinator populations may seriously threaten the continued production of insect pollinated crops (e.g. cranberry yield in Wisconsin) and crops grown from seeds resulting from insect pollination.

1.2 Barriers, Benefits for Pollinator Protection

Even though pollinators play a very significant role in pushing the United States' agricultural economy forward by increasing the yields of the products, there are also an array of barriers that inhibit the development/execution of pollinator habitat planning or sometimes, even threaten the subsistence of pollinator population. Below, a brief summary of the major barriers and benefits for pollinator protection is given:

Barriers

• The American Ideal of the Lawn: nice house and beautiful lawn in the front yard are two very classic elements that constitute an ideal living style in American Dream. In addition, lawns are relatively much easier to clean and maintain than flowering shrubs or gardens.

• Fears of Bees and Wasps: some people are allergic to insects including bees, wasps or allergic to their venom. Adults' perceptions of bees and wasps as annoying insects due to their buzz nosies and yellow-black warning color, and as dangerous creatures for children.

• City Code or Land Covenants: certain cities have special land/road regulations restricting boulevard plantings or the height of the plantings in yards or gardens. Some land covenants do not allow owners to construct gardens or do any landscapings.

• The Use of Agricultural Pesticide: long history of applying pesticide to eliminate "injurious" insects over large amounts of lands.

• Roads: roads may act as barriers to pollinator movement (Valtonen and Saarinen 2005). Also, roads can contribute to habitat loss and fragmentation (Forman et al. 2003).

Benefits:

The overall benefits that people can gain from scientific pollinator habitat planning are substantial. These potential benefits include the economic values earned from the sales and exports of agricultural products whose pollination and fruiting processes are pollinator-dependent, the trades of bee pollinators' sideline products such as honey, beeswax, medicine-used venom, royal jelly, etc (see Figure 3).

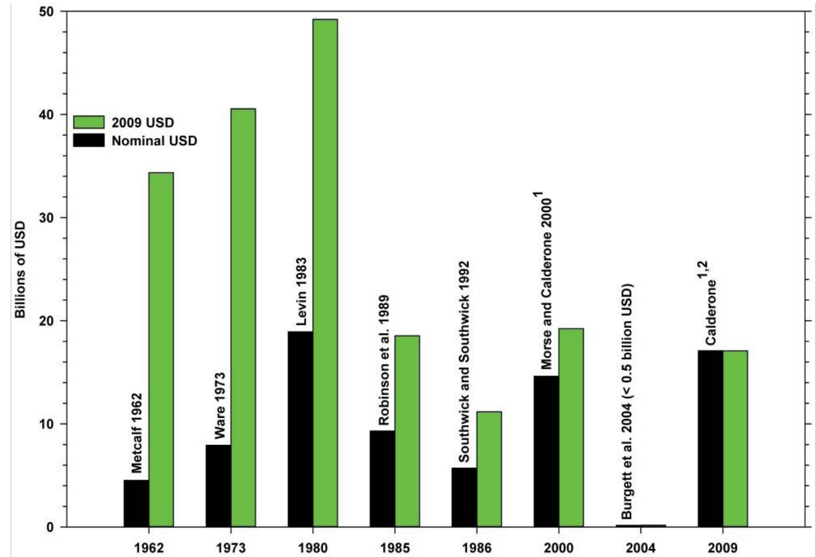


Figure 3. Historical estimates of the value of honey bees to US agriculture. Source: Nicholas W. Calderone, "Insect Pollinated Crops", 2012.

Table 1. Estimated Value of the Honey Bee to U.S. Crop Production, 2000 Estimates

Crop Category (ranked by share of honey bee pollinator value)	Dependence on Insect Pollination	Proportion of Pollinators That Are Honey Bees	Value Attributed to Honey Bees[a] ($ millions)	Major Producing States[b]
Alfalfa, hay & seed	100%	60%	4,654.2	CA, SD, ID, WI
Apples	100%	90%	1,352.3	WA, NY, MI, PA
Almonds	100%	100%	959.2	CA
Citrus	20%-80%	10%-90%	834.1	CA, FL, AZ, TX
Cotton (lint & seed)	20%	80%	857.7	TX, AR, GA, MS
Soybeans	10%	50%	824.5	IA, IL, MN, IN
Onions	100%	90%	661.7	TX, GA, CA, AZ
Broccoli	100%	90%	435.4	CA
Carrots	100%	90%	420.7	CA, TX
Sunflower	100%	90%	409.9	ND, SD
Cantaloupe/honeydew	80%	90%	350.9	CA, WI, MN, WA
Other fruits & nuts[c]	10%-90%	10%-90%	1,633.4	—
Other vegetables/melons[d]	70%-100%	10%-90%	1,099.2	—
Other field crops[e]	10%-100%	20%-90%	70.4	—
Total	—	—	**14,564**	—

Source: Renée Johnson, Honey Bee Colony Collapse Disorder, Congressional Research Service, January 7, 2010.

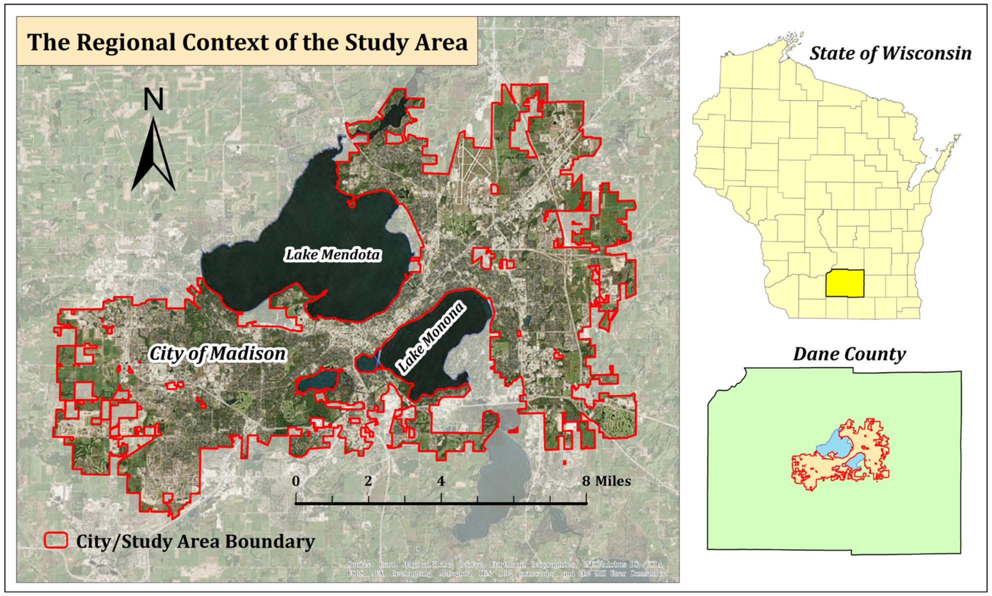


Figure 4. The regional context and geographic extent of the study area. Source: Created by author.

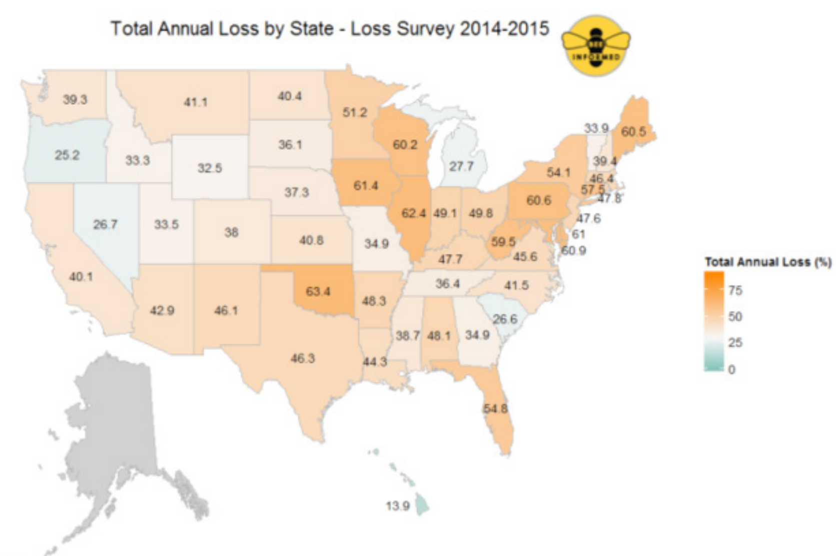


Figure 5. Total annual honeybee colony loss (%) 2014-2015 by state. Source: Steinhauer et al. 2015.

1.3 Regional Context and Issues

In Wisconsin, "pollinator-dependent crops account for over $55 million in annual production (6% over total agricultural production) while honey and beeswax account for $3.5 million annually"(Locke et al. 2). However, according to 2015 "Pollinator Protection Task Force Report" prepared for the City of Madison, "the state (Wisconsin) lost about 60.2% of its honey bee colonies from springs 2014-2015" (4) (Figure 5). And this is only one part of a dramatic bee and bee habitat loss across the whole country since 2006. These pollinator declines have been associated with "Colony Collapse Disorder" (CCD), whose causes are considered to be a combination of factors including construction of roads, restrictive land regulations, overuse of agricultural pesticide, virus, etc. These factors together, constituted a potential threat to maintain the productions of many crops, which are central to Wisconsin's economy and food culture, such as apples and cranberries.

Being the state's leading center for studying pollinators and urban agriculture, the University of Wisconsin-Madison has organized a series of researches on bee pollinator specieses and bee habitat protection. The City of Madison, on the other hand, "has published a city-level 'Pollinator Protection Task Force Report' as a response to the national movement in this field", said by Linda Horvath, a senior neighborhood planner in Madison.

Nevertheless, the city and the university so far have not established a cooperative relationship in terms of pollinator protection, education, and research.The lack of coordinations may largely limit the potential of each other to develop common awareness and comprehensive plan for city-wide pollinator habitats and food system. In addition, the public in general, lack a clear understanding about how significant the pollinators are to the healthiness of food system, economy, and their own. On these bases, this project constructs a GIS-based model to evaluate the overall suitability of pollinator habitats within the City. And based on the geospatial analysis results, two "development sites" with high suitability and two "improvement sites" with low suitability will be identified to initiate pollinator-related planning (e.g. beekeeping industries, pollinator pathway, educational center, etc) and to improve habitat conditions respectively. It is expected that the model, along with the policy strategies, neighborhood designs given later can not only enhance the awareness of the city as a whole to improve pollinator-friendly environments , but also to forge a city paragon leading urban communities and ecology towards a healthier and greener future.

2. Habitat Suitability Evaluation

2.1 Research Species

According to “Wisconsin Spring Bee Guide” prepared by the University of Wisconsin Madison, there are about 9 major spring bee species in Wisconsin. They are honey bee, bumble bee, green sweet bee, small carpenter bee, mason bee, small sweat bee, dark striped bee, large mining bee, and medium mining bee. While almost all the bees’ foraging habitats are either overalpped or the same with each other (places where flowering plants are abundant), the types of nesting habitats vary from species to species. In consideration of the difference in nesting habitats, the project divided these research bee species into two categories: above-ground nesting bees and undergound nesting bees. Classic bee species examples for each category are listed in the following tables.

Table 2. Characteristic Comparison for Certain Bee Species' Habitats

Bee Species	Images	Nesting Habitat Types	Nesting Details	Foraging Habitat Types	Flight Period
Honey Bee		Above-Ground	Human-constructed hives	Generalists	Long. Spring - fall
Mason Bee		Above-Ground	Hollow twigs, logs, beetle burrows and manmade holes	Generalists	Spring through early summer
Dark Striped Bee		Underground	Below-ground cavities	Generalists and Specialists	Variable. Long and short-lived species
Large Mining Bee		Underground	Long, underground tunnels	Generalists and Specialists	Spring

Source: Created by author. Information from “Wisconsin Spring Bee Guide”.

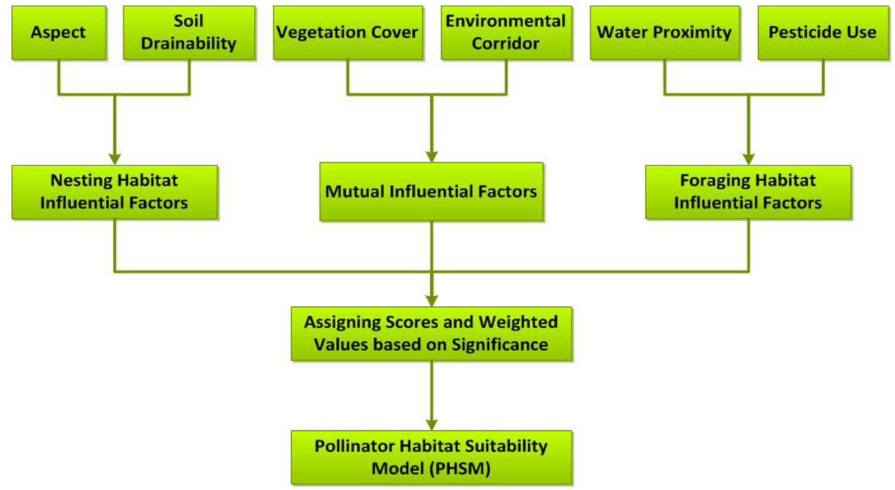


Figure 7. Evaluation factors for habitat suitability model and their relationships.

In order to construct a relatively comprehensive GIS model for evaluating pollinator habitat suitability, 6 factors were identified. They are soil drainability, aspect, environmental corridor, vegetation cover, water proximity, and pesticide use (Figure 7). The general relationship between each factor and pollinator habitat suitability were given below:

- Soil Drainability: most ground/soil-dwelling bees nest in bare or partially vegetated, well-drained soil (NRCS 2013).
- Aspect: most native bees thrive in sun and dry soils, preferring south facing slopes to slopes of other aspects (Greer 1999).
- Environmental Corridor: are usually landscapes with better natural preservation and less human interventions, which are suited for native pollinators.
- Vegetation Cover: a diversity of plants with different flower colors, sizes, and shapes, varying plant heights... can benefit the greatest numbers and diversity of pollinators (“West Virginia” 26).
- Water Proximity: water is needed not only to maintain cellular balance in adult bees, but to feed brood and maintain the hive temperature on hot days (Page et al., 1995).
- Pesticide Use: are derimental to a healthy community of native pollinators (“West Virginia” 19).

Soil Drainability Classification

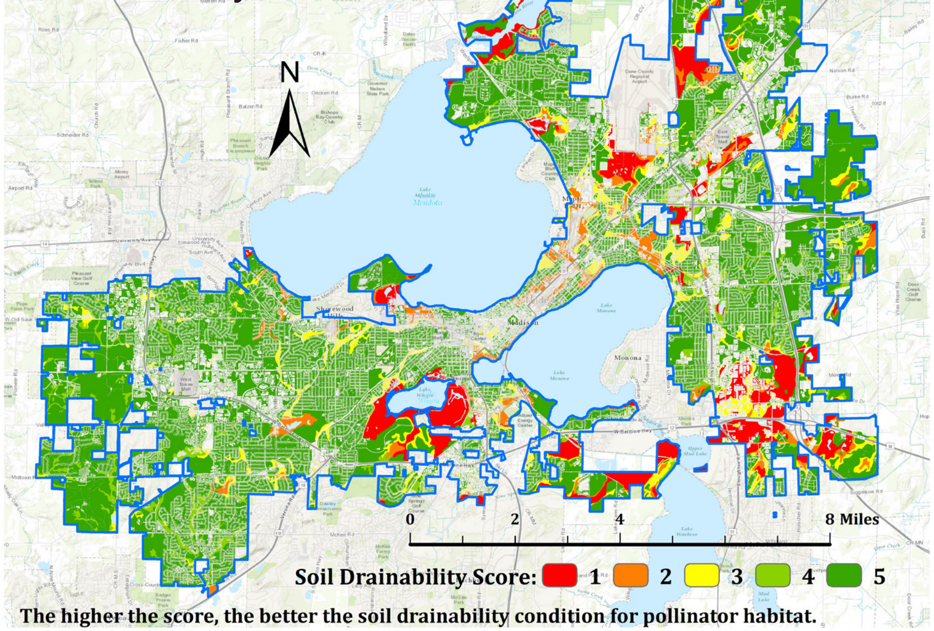


Figure 8. Source: Created by author.

Impervious Area Categories

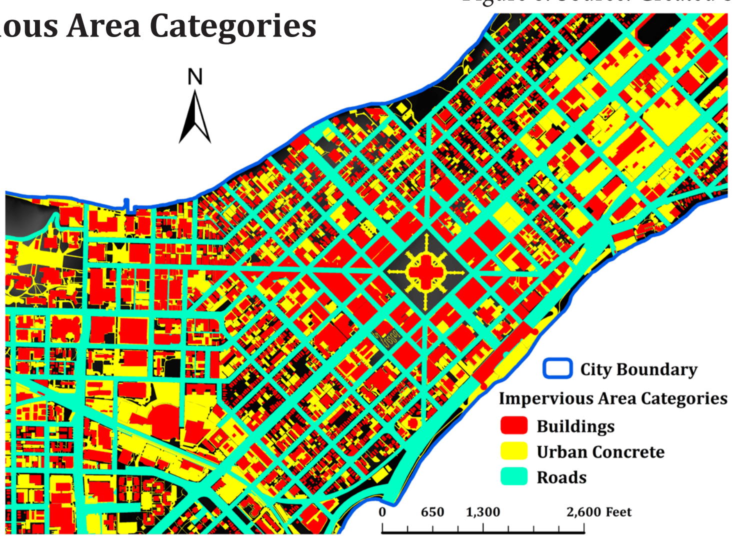


Figure 9. Source: Created by author.

2.2 Soil Drainability & Impervious Area

While other evaluatin factors may have impacts on both nesting and foraging habitats of bee pollinators, soil drainability is considered to be solely related with the nesting habitat of underground nesting species (e.g. sweat bee, mining bee). In general, a moderately well drained soil environment cannot only provide underground nesting bees relatively good air circulation condition, but also mitigate the possibility for the nest to be flooded by the runoff retained in soils after rainfall. The classification scores were given based on the soil drainability classes defined by USDA Natural Resources Conservation Service:

Table 3. Soil Drainability Classes and Scores

Soil Drainability Class	Score
Well Drained	5
Moderately Well Drained	4
Somewhat Excessively Drained	3
Excessively Drained	3
Somewhat Poorly Drained	3
Poorly Drained	2
Very Poorly Drained	1

Source: Created by author.

• *Somewhat excessively to excessively drained*: Water movement through these soils is rapid to very rapid and do not retain adequate water for plant growth.
• *Well drained*: Water movement is good in these soils, but it is not rapid.
• *Moderately well drained*: Water movement is slow during some parts of the year. Soils may have subsoils that slow infiltration.
• *Somewhat poorly drained*: Water movement is moderately slow through theses soils. Plant growth is restricted.
• P*oorly to very poorly drained*: Water movement is very slow through these soils and artificial drainage is required to grow most plants.

For completing soil drainability classification map (see Figure 8), impervious areas were firstly deducted from the originally continuous soil polygon layer by using “Erase” tool in ArcGIS. Then, corresponding suitability scores were assigned to soil polygons based on their drainability levels. Importantly, the City’s lands except imperious areas (pervious areas) were actually applied to all the following evaluation analyses since it is impossible for impervious areas to develop pollinator habitats (see Figure 9).

2.3 Aspect & Sun Exposure

According to Greer (1999), most native bees which thrive in sun and dry soils prefer south facing slopes to slopes of other aspects. Further, based on the theory of Dauber et al. (2003), this aspect preference was attributed to an increase in floral diversity and food resources (e.g. pollen and nectar) in areas with more sunlight. Combined with Madison's geographical location (43.0667° N, 89.4000° W), slopes facing south/east can usually receive more sunlight than slopes facing north/west. At the same time, in regardless of north or south hemispheres, flat areas are considered to be the areas receiving least sunlight.

Table 4. Aspect Suitability Classes and Scores

Aspect Suitability Class	Score
SE (90°- 180°)	5
SW (180°- 270°)	4
NE (0°- 90°)	3
NW (270°- 360°)	2
Flat (-1°)	1

Source: Created by author. Classification references: Michener et al., 1958; Wuellner, 1999.

In order to complete the reclassification for aspect suitability on the basis of the default aspect classification generated by ArcGIS (see Figure 11), a vector layer "Madison Pervious Total" was firstly generated by deducting the total impervious areas layer from the vector polygon of the City of Madison using the "Erase" tool. Then, the "Extract by Mask" tool in "Spatial Analyst" module was used to extract the DEM (Digital Elevation Model) layer covered only by the layer "Madison Pervious Total" from the DEM of City of Madison. Finally, "Reclassify" tool was used to generate the reclassified result by using the extracted DEM as the input layer (see Figure 10).

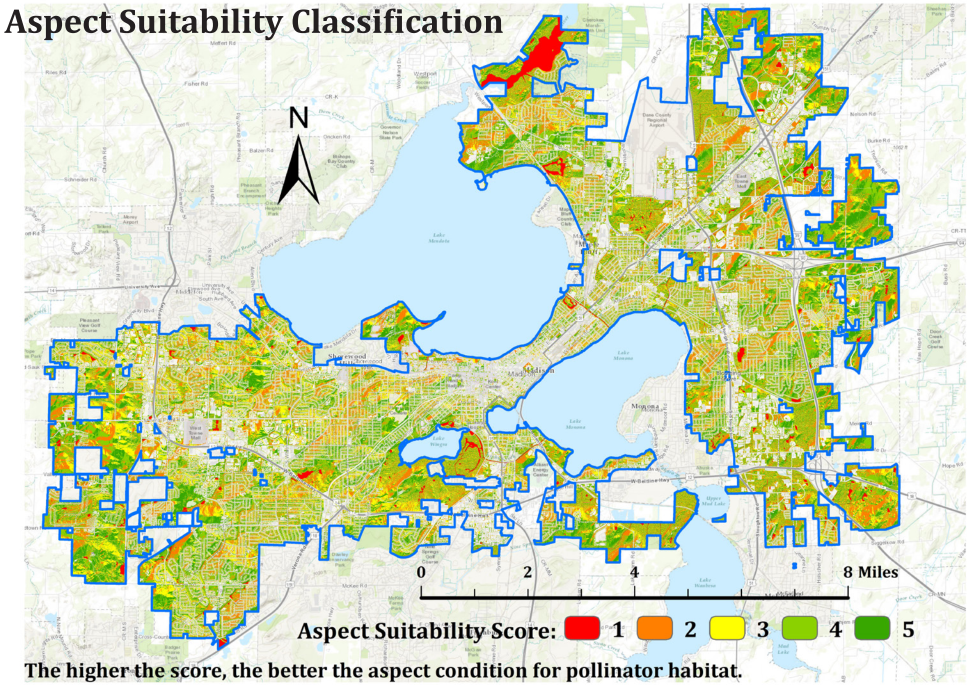


Figure 10. Source: Created by author.

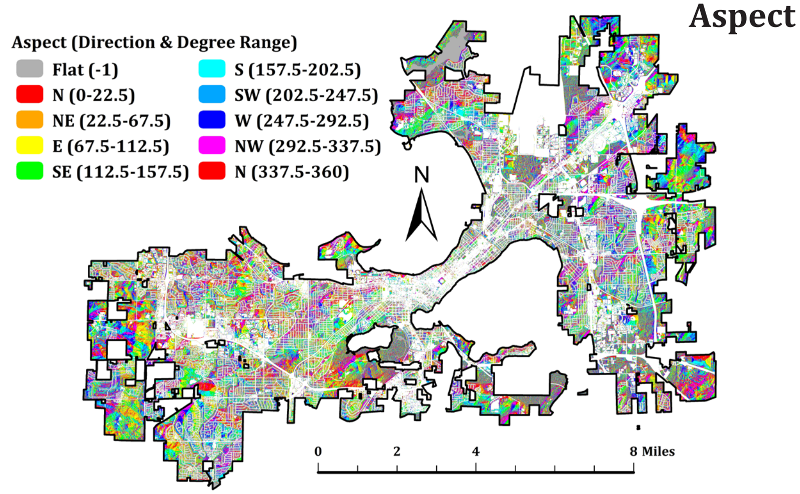


Figure 11. Source: Created by author.

Vegetation Cover Classification

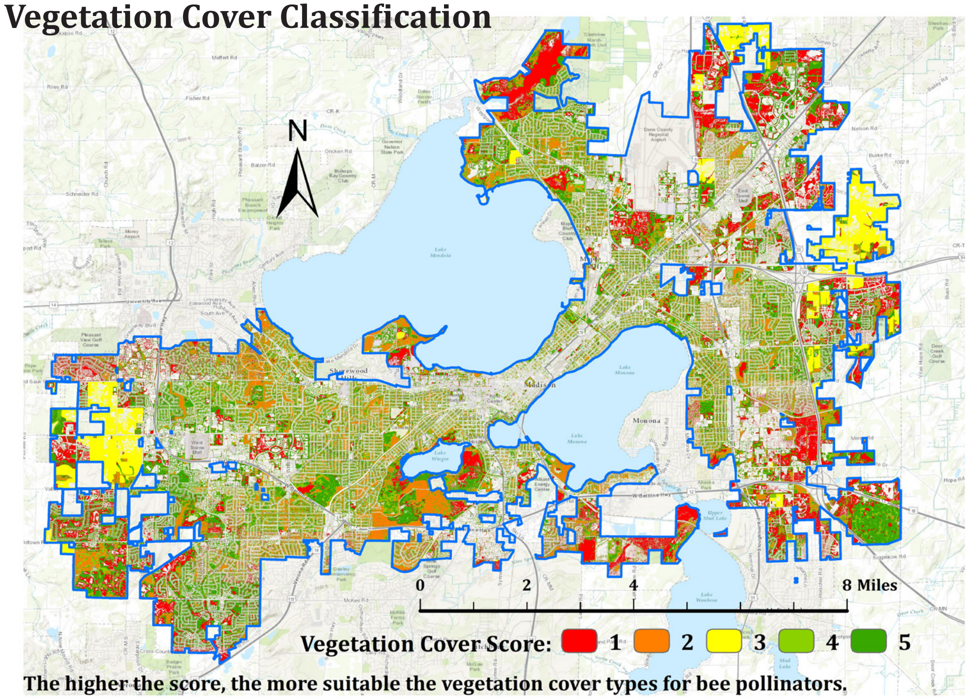


Figure 12. Source: Created by author.

Figure 13. The flowers of American basswood/linden (left) and silver maple (right) are two ideal food resources for Madison's bee pollinators. Source: Science for all: http://science-all.com/linden; Wikipedia: html https://en.wikipedia.org/wiki/Maple.

2.4 Vegetation Cover

Floral diversity is extremely important in terms of providing diverse and continuous succession of food resources for bee pollinators throughout the year, ensuring the persistence of bee populations (Caron 1999). Moreover, "a diversity of plants with different flower colors, sizes, and shapes, varying plant height and growth habitats can encourage and benefits the greatest numbers and diversity of pollinators " ("West Virginia" 26). Therefore, landscapes such as marginal ecotones around forests, prairies, or plant communities with mixed shrubs and woody plants can be considered as ideal natural habitats for bees to thrive.

Without considering pesticide use, farmlands are also relatively suitable sites for bees during blooming seasons. However, while crops may be attractive for specific crop pollinators, it may fail to attract pollinators as diverse as ecotones and prairies due to the simplex vegetation species. For dense forested areas or lawns and marsh, they are considered as unsuitable areas for bees due to lack of flowering species caused by lack of solar radiation, poorly drained soils, etc.

Table 5. Vegetation Cover Scores

Vegetation Cover Suitability Class	Score
Marginal Ecotones/Prairies/Wetlands (5-25ft)	5
Shrubs and Woody Plants Mixed (25-45ft)	4
Farmlands (assume no pesticide applied) (vary from 0-10ft)	3
Woody Plants Dominated (45-150ft)	2
Lawns/Grassland/Marsh/Water (0-5ft)	1

Source: Created by author.

The author here, used 2009 Dane County LiDAR data to generate the raw vegetation cover raster layer within the city. Then, the vegetation cover raster was briefly classified into the categories above based on the height ranges of different types of vegetation habitats (see Figure 12). Note that "Farmlands" and "Prairies" were classified independently based on the Dane County land use data. Finally, a landcover supervised classification based on 2011 Madison Landsat imagery was generated for comparing the similarities with the LiDAR height-based classification. The overall accuracy of the classification is 92.51%, gained from confusion matrix.

2.5 Environmental Corridor

In general, environmental corridors refer to "interconnected green spaces consisted of natural areas and features, public lands, and other open spaces" (Bay-Lake Regional Planning Commission). Within the City of Madison, such sort of naturally preserved areas include Lake Shore Natural Preserve, UW-Arboretum, Cherokee Marsh, etc. These areas are usually consisted of diverse, mixed plant communities and well-drained, fertile soils. Better, some corridors are adjacent to water bodies (will discuss more in "2.6 Water Proximity"). These conditions together constitute relatively ideal pollinator habitats in terms of floral diversity, nesting environment, air temperature, humidity, etc (see Figure 15a).

Table 6. Environemental Corridor Classes and Scores

Environmental Corridor Class	Score
Yes	5
No	1

Source: Created by author.

In the classification model for environmental corridor, lands within the City were simply classified into two categories: "Yes" which refers to lands that are environmental corridors, and "No" which refers to the remaining lands (see Figure 15b). Then the two types of lands were converted to a raster layer and finally assigned score 5 and 1 respectively in the image reclassification stage in GIS (see Figure 14).

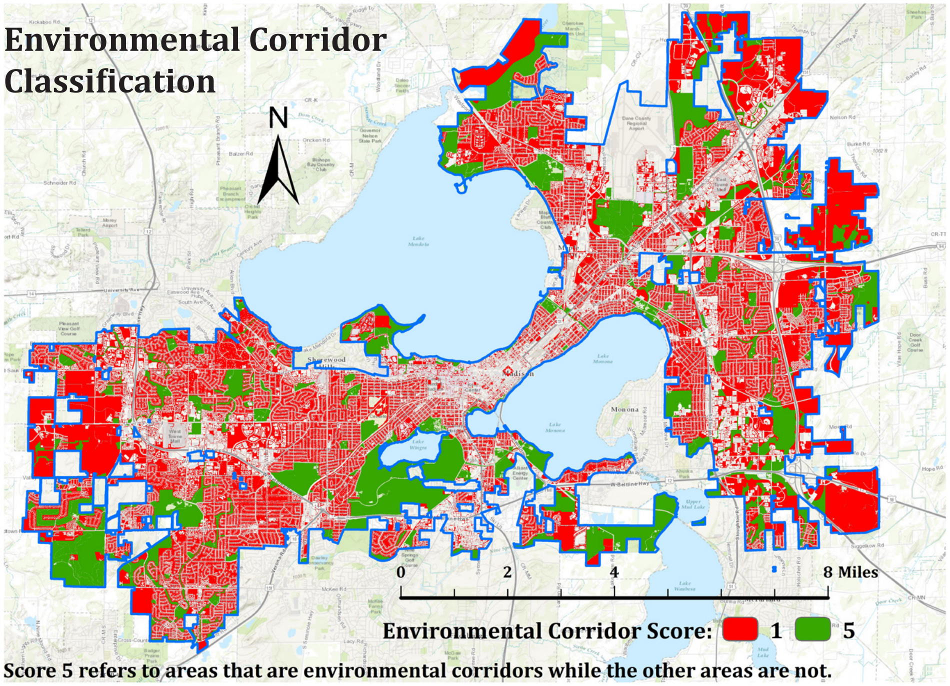


Figure 14. Source: Created by author.

Figure 15a. Environmental corridor. Source: WingraSprings.

Diverse marsh plant communities decorated by purple loosestrife during late spring at Lake Wingra Watershed. These constituted ideal conditions for pollinators' foraging and nesting habitats.

Figure 15b. No environmental corridors. Source: Google Map.

Broad lawns near South Rosa Road constituted a simple ecosystem with few plant species. It is hard for the system to attract pollinators due to the hot temperature, lack of flowering plants, etc.

Water Proximity Classification

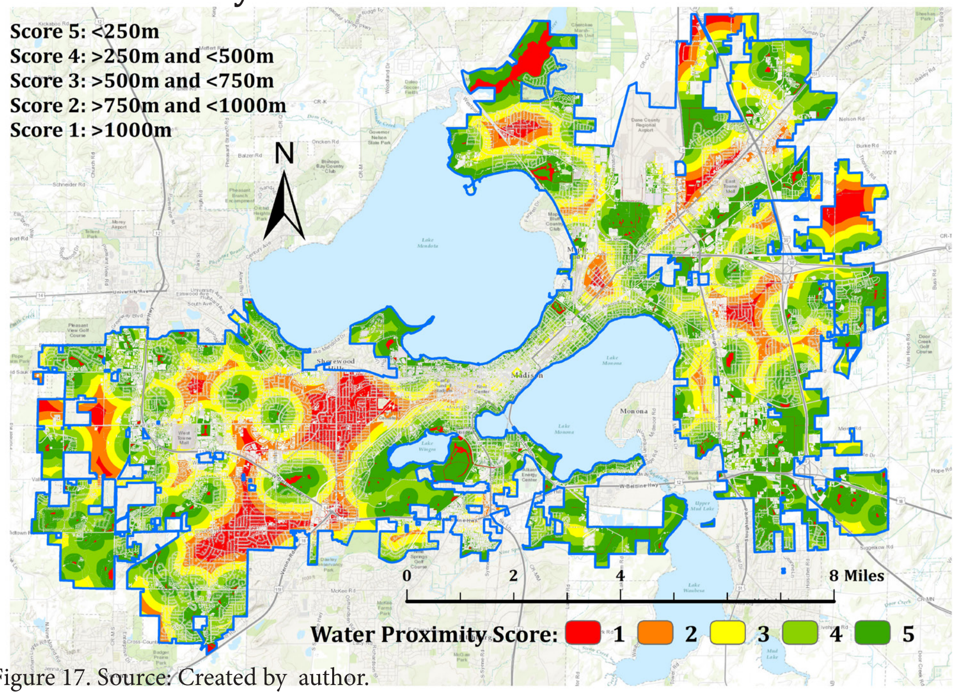


Figure 17. Source: Created by author.

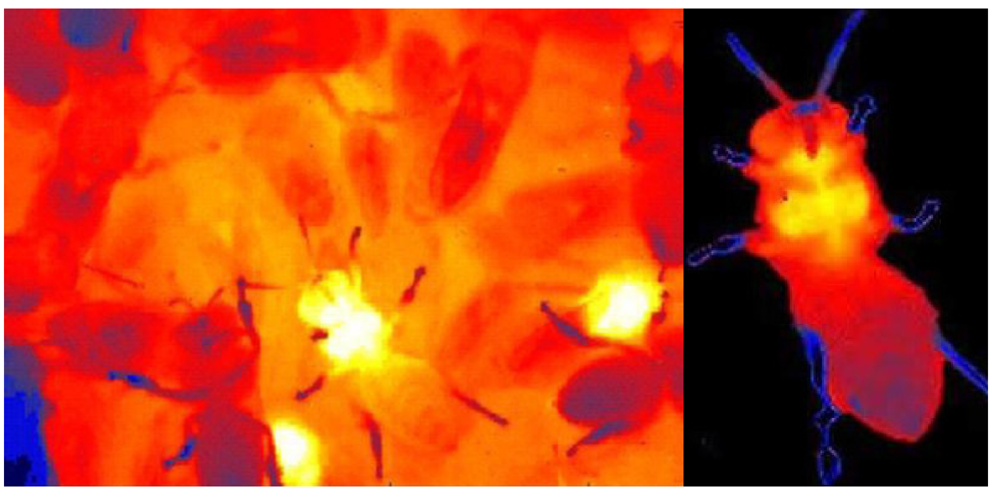


Figure 18. Thermal images that indicate the temperature variation in bee hive and of “heater” honey bees. Source: BeeHolder Library.

2.6 Water Proximity

Water is needed not only to maintain cellular balance and body temperature of adult bees, but to feed brood and maintain the hive temperature on hot days (Page et al., 1995). Generally, bees’ and bee hives’ (e.g. honey bee) need of water can be met by the collection of nectar. However, in some cases, bees have to “intentionally collect water from nearby lakes, ponds, or streams when nectar supply is deficient or during hot and dry weather” (Hartel and Dewenter, 2014)(Caron, 1999)(Okroukh and Plickert, 2015). Therefore, it is theoretically easier for bees to condition their body temperature when flying and to enhance their adaptability to climate changes if they nest or forage closer to water bodies (see Figure 18).

Table 7. Water Proximity Classes and Scores

Water Proximity Class	Score
<250m	5
>250m and <500m	4
>500m and <750m	3
>750m and <1000m	2
>1000m	1

Source: Created by author.

Furthermore, according to the studies about scale dependent effects of landscape context on pollinators by Steffan Dewenter et al. (2002), the strongest correlation between landscape metrics and bee abundance is at 250m (820ft), with correlations existing up to 1000m (3281ft) for native bees. On this basis, this project evenly categorized water proximity (area distances to nearby water bodies) into 5 suitability classes by assuming that the closer the landscape environments to water bodies, the more ideal the relevant habitats to bee pollinators (see Figure 17).

2.7 Pesticide Use

According to the “National Pollinator Health Task Force” published in May 2015, exposure to pesticide is one of the major stressors that impact pollinator health (1). More specifically, “Neonicotinoid (NNI hereafter) pesticides have gained attention as... one of the primary forces behind honeybee and native pollinator declines” (“Madison Pollinator Task Force” 4). In addition, “(NNIs) do not break down in soil, and residues may be transported through runoff from fields to water bodies, as well pesticide dust settling on flowers used by bees” (Thompson, 2010). Currently, Madison has developed recommendations to “adopt City ordinance banning the use of NNIs on all City-owned lands and property” (“Madison Pollinator Task Force” 25). However, the amounts of NNIs or other pesticides applied and where they are applied within the city are very difficult to predict.

Table 8. Pesticide Use Scores

Pesticide Use Class	Score
Polyculture(CSA)/Woodlands/Open Lands/Natural Preservation/Water	5
Farmland Margin (12-meter buffer inward farmlands)	4
Pervious Lands excluding all the other categories	3
Golf Courses (both public and private)	2
Conventional Farmlands (e.g. corn/soybean farming)	1

Therefore, excepts the two CSA farmlands in Madison (Eagle Heights Community Garden and Troy Community Garden) are actual pesticide-free zones, several assumptions were made on the probability of pesticide use for the other lands in the city:

•Woodlands, open lands, naturally preserved areas, water bodies have the least probabilities to be applied pesticides;

•Farmland margins around crop fields are out of the pesticie-applied ranges and are suitable for bees during crops’ blooming periods. However, it may be influenced by the pesticide drifts (Figure 20).

•All the human-activity lands have the possibilty to be applied pesticides for home needs or for operations. The amounts applied vary.

•The pesticide uses of Golf courses are usually under strict and scientific control of city governments or private firms.

•Private farmlands are applied large amounts of pesticides and are usually out of the surveillance of governments.

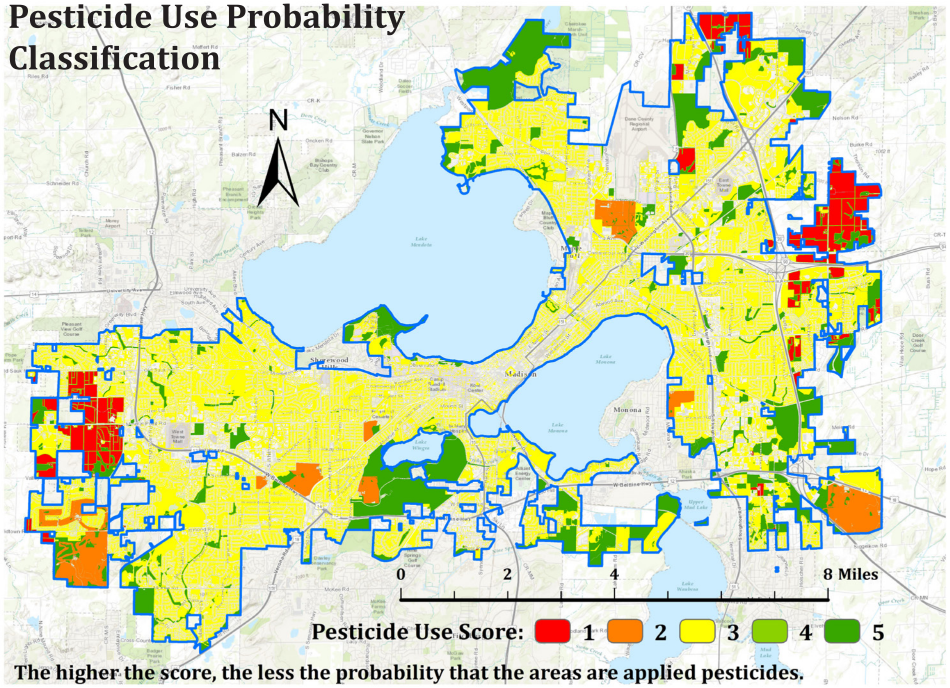
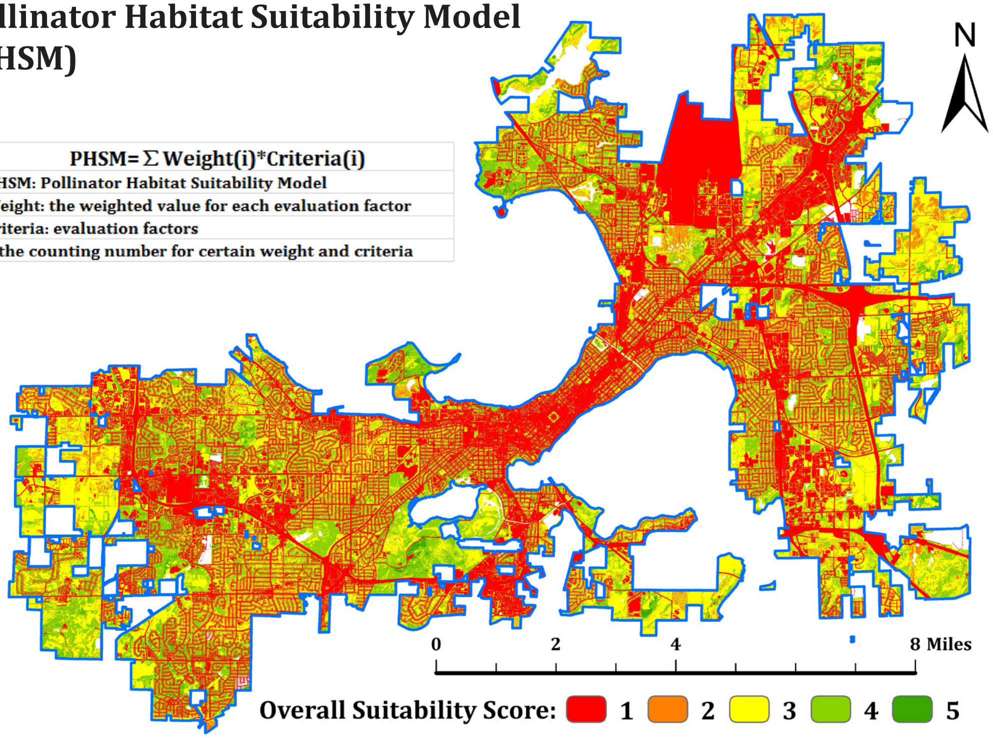


Figure 19. Source: Created by author.

Figure 20. The field margins (bright green strips) around a farmland on the west side of Madison, near Mineral Point Road. Usually the margins are about 12-meter (39 feet) width and are not applied pesticides. However, it may be influenced by the pesticide drifts from adjacent farmlands. Source: Google Map.

Pollinator Habitat Suitability Model (PHSM)

PHSM= Σ Weight(i)*Criteria(i)
PHSM: Pollinator Habitat Suitability Model
Weight: the weighted value for each evaluation factor
Criteria: evaluation factors
i: the counting number for certain weight and criteria



The higher the score, the more suitable the areas for pollinator habitats.

Figure 21. Source: Created by author.

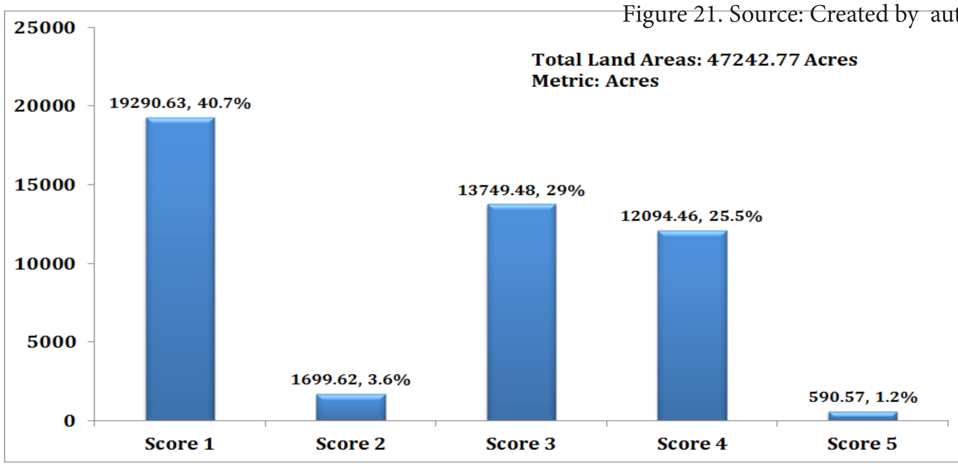


Figure 22. Area statistics for lands with different levels of suitability. Source: Created by author.

2.8 Overall Evaluation and Assumptions

By combining the 6 evaluation factors above, the pollinator habitat suitability model (PHSM hereafter) was constrcuted (see Figure 21). Note that PHSM aims at measuring the regional potential to develop pollinator habitats and pollinator-realted activities, rather than estimating the spatial distribution of bee populations or evaluating the quality of pollinator services. In addition, originally excluded impervious areas has been integrated into the model's score 1 category.

For determining the level of significance (weight) for each evaluation factor, several arguments were made based on previous articles and author's experiences: 1) vegetation cover (30%) is the most important factor since it determines the physical constitution of pollinator habitats; 2) aspect and pesticide use are equally important (20%) since the former is the primary factor for bees to constrcut nests while the latter determines the bee health or may cause immediate dealth for bees; 3) soil drainability comes after (15%) since it is the second primary factor for bee nesting; 4) water proximity (10%) and environmental corridor (5%) are less important since they are supplemenrtary instead of determining factors.

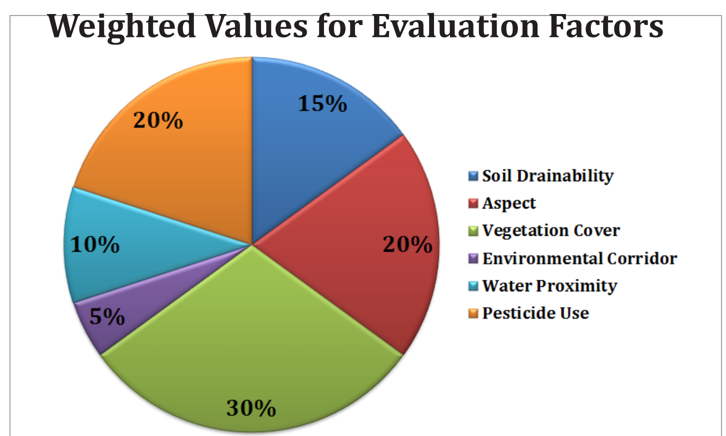


Figure 23. Source: Created by author.

3. Site Selection and Neighborhood Design

Suitable Site Identification

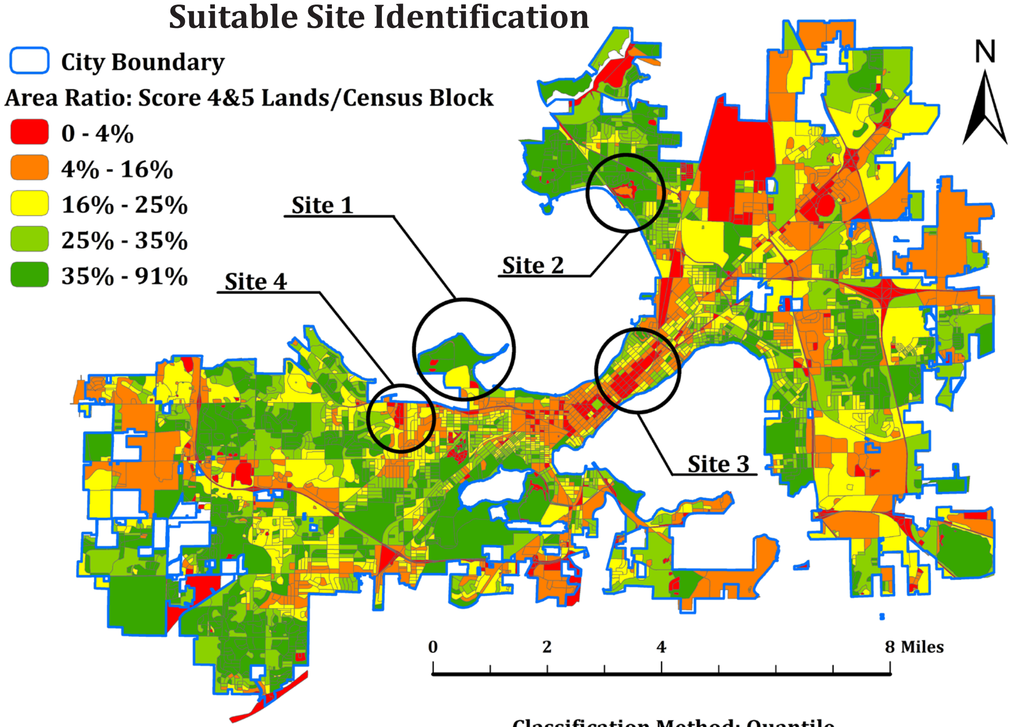


Figure 24. Source: Created by author.

3.1 Planning Site Identification

As for the evaluation model, although it can generally identify the suitable and unsuitable locations combined with census block data, "there were some limitations... as it was difficult to determine the accurate weighting of factors with 100% certainty" (Okroukh and Plickert 2015).

As the map indicates, areas such as Picnic Point, Curtis Prairie in UW-Arboretum, Warner Park and Farewell Point in northern Madison are very suitable places to develop pollinator habitats. On the other hand, places including the isthmus area, airport and West Towne Mall are not suitable for pollinators.

In addition, please also note that even though certain areas including Odana Hills Golf Course, University Ridge Golf Course were identified as suitable (dark green) areas in the census block map, they are not feasible areas to develop pollinator habitats in consideration of their land use types and ownerships.

Based on the analysis result, 4 sites were selected for providing design and planning suggestions (see Figure 24). 2 of these sites (1 & 2) with high suitability index were chosen for developing pollinator habitats. The other 2 sites (3 & 4) with low suitability index were chosen for improving their current conditions.

- ***Site 1: Lakeshore Path-Picnic Point Cluster***
High soil drainability; most areas' aspects are facing south; shrubs, medium high trees are the major vegetation covers along Lakeshore Path; large areas are naturally preserved and pesticide-free; most areas are within 500m from water bodies; where Eagle Heights prairie locates.

- ***Site 2: Warner Park-Mendota Hills Cluster***
Medium soil drainability overall; most of the areas' aspects are NE- or SW-facing; shrubs, prairies, medium high trees are the major covers; most areas are preserved ecological park and are within 500m from water bodies; medium pesticide-use intensity.

- ***Site 3: E.Washington Ave-Blair-Baladwin St Cluster***
Most areas are covered by highly urbanized, impervious areas; most lands are occupied by commercial or industrial buildings; very sparse trees or no trees distributed along both sides of the roads.

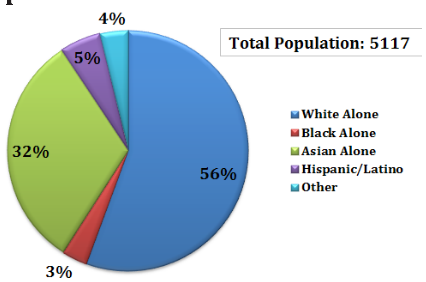
- ***Site 4: Target-Hilldale Shopping Center-Sundance Cinemas Cluster***
Typical supermall cluster; most areas are covered by commercial buildings and parking lots; very sparse trees along the edges of the land parcels.

3.2 Conceptual Design

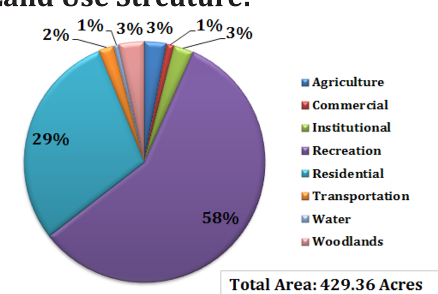
3.2.1 Development Site 1:

Location:
Lakeshore Path-Picnic Point Cluster

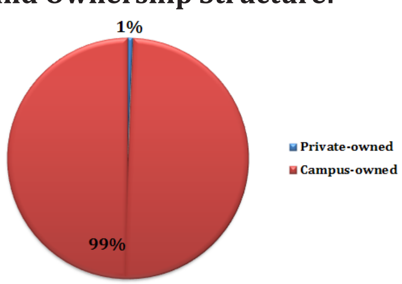
Population Strcuture:

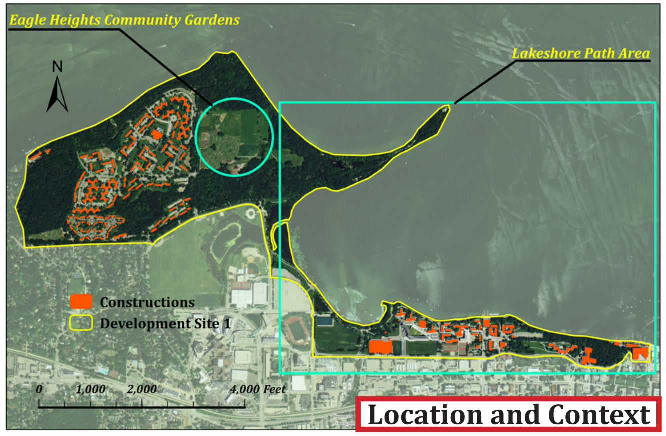


Land Use Strcuture:



Land Ownership Structure:





Location and Context

Concept 1: Mendota Pollinator Pathway

Concept 2: Mendota Pollinator Pathway

Concept 3: Eagle Heights Beekeeping

§ Planning and Design Suggestions:

- Construct a pollinator pathway along Lakeshore Path. Width can vary from 1 to 5 feet depending on the original landscape. UW-Madison and local governments may search cooperations on specific planning processes.
- Select native flowering species as priortized planting options. Enhance management on water utility.
- Develop small-medium-scale beekeeping industry at Eagle Heights Community Garden.
- Integrate beekeeping industry into education and researches on organic farming, pollinator protection, etc.

§ Involved Organizations:

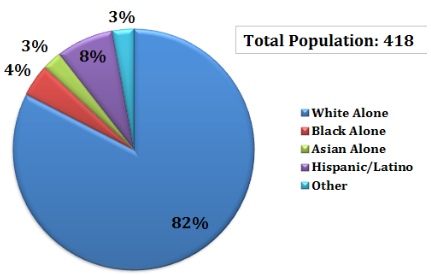
Eagle Heights Community Garden, Campus Planning and Landscape Architecture, City of Madison Department of Planning, Community, and Economic Development (DPCED hereafter), Engineering Division, etc.

Figure 25. Source: Created by author.

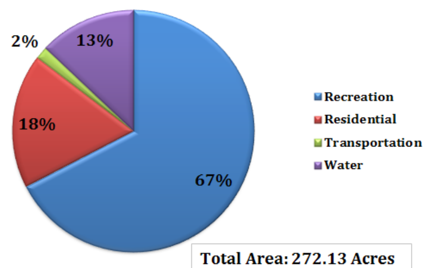
3.2.2 Development Site 2:

Location:
Warner Park-Mendota Hills Cluster

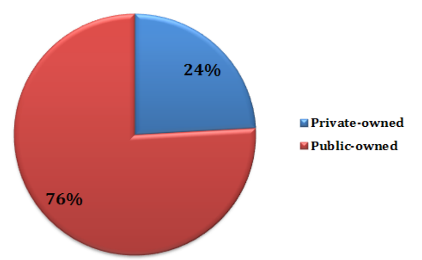
Population Strcuture:



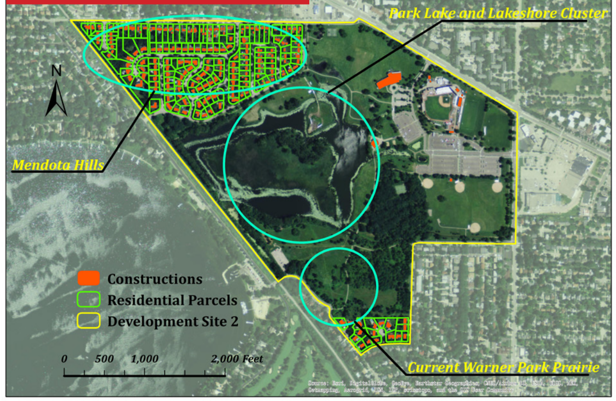
Land Use Strcuture:



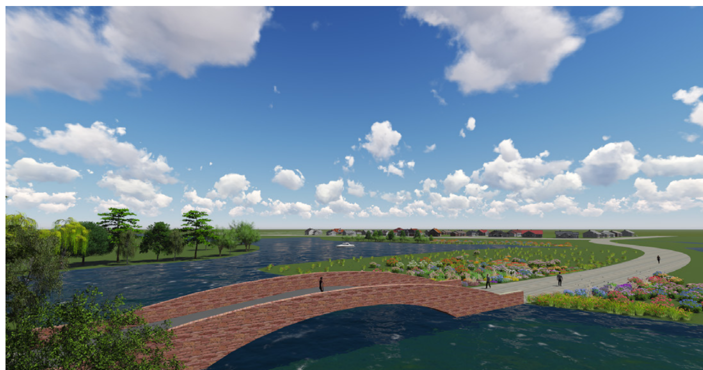
Land Ownership Structure:



Location and Context



Concept 1: Warner Park Recreation



Concept 2: Warner Park Recreation

Concept 3: Warner Park Recreation

§ Planning and Design Suggestions:

- Encourage qualified residents to develop small-scale beekeeping industry. The total number of man-made hives per lot should be no more than 6 ("Obtain a City of Madison Beekeeping License").
- Develop small-medium-scale beekeeping industry at Troy Community Gardens.
- Expand current prairies to the lakeshore area. Enhance manegement on prairies and water utility.
- Consider to extend the footpath from Mendota Hills Community to the central island of the lake for enhancing the interactivity between residents and environment.

§ Involved Organizations:

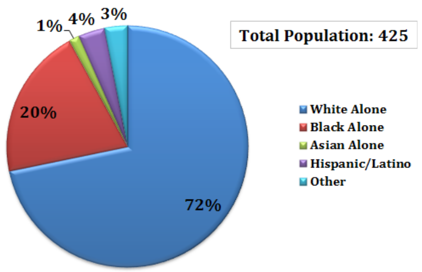
Mendota Hills Community, Troy Community Gardens, Brentwood Village, City of Madison Park Division, DPCED, Engineering Division, etc.

Figure 26. Source: Created by author.

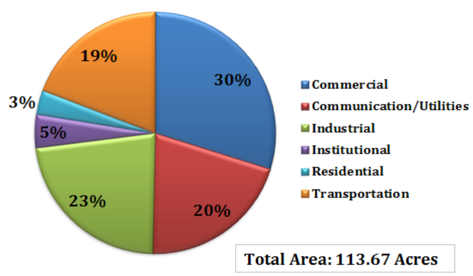
3.2.3 Improvement Site 1:

Location:
E. Washington Ave-Blair-Baladwin St Cluster

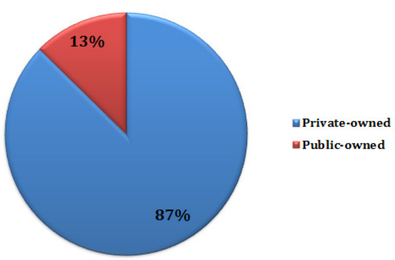
Population Strcuture:



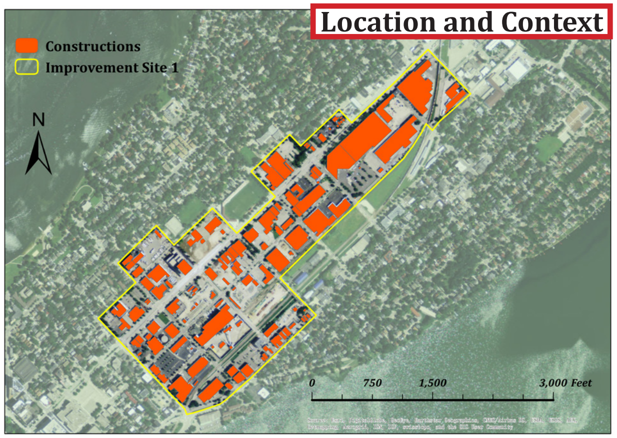
Land Use Strcuture:



Land Ownership Structure:



Location and Context



Concept 1: Street Landscaping

Concept 2: Street Landscaping

Concept 3: Green Roof

§ Planning and Design Suggestions:

- Communicate with and educate local land owners, residents about the significance of bee pollinators.
- Encourage private land owners to properly increase flowering vegetation coverage within their parcels.
- Provide government grants for neighborhood green project constructions, including green roof, rain garden.
- Enhance regulations by Building Inspection Division on minimum plantings and lawn maintenance.
- Improve current street landscape by planting flowering vegetation on both sides or central median of roads.
- Adopt city ordinances that standardize the types and amounts of pesticides permited to use in private lands.

§ Involved Organizations:

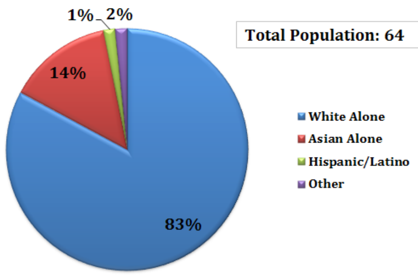
Private land owners, City of Madison Building Inspection Division, DPCED, Engineering Division, etc.

Figure 27. Source: Created by author.

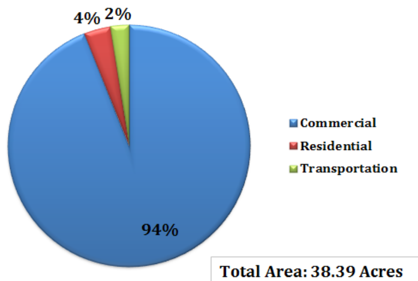
3.2.4 Improvement Site 2:

Location:
Target-Hilldale Shopping Center-Sundance Cinemas Cluster

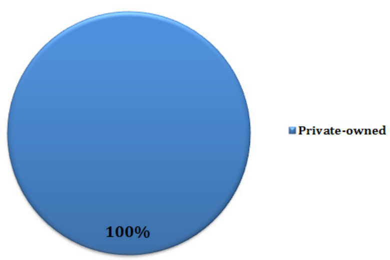
Population Strcuture:



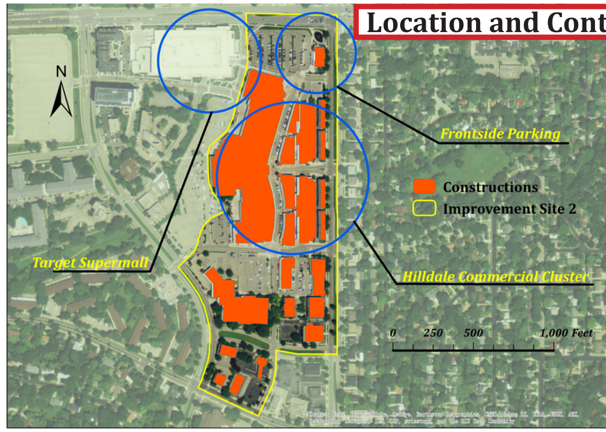
Land Use Strcuture:



Land Ownership Structure:



Location and Context



Concept 1: Parking Lot Landscaping

Concept 2: Parking Lot Landscaping

Concept 3: Hilldale Rain Garden

§ Planning and Design Suggestions:

- Communicate with and educate local land owners (e.g. Hilldale Inc.) on the significance of bee pollinators.
- Encourage private land owners to properly increase flowering vegetation coverage within their parcels.
- Encourage private land owners to increase and improve rain gardens within parking lots by planting more flowering vegetation and by increasing surface permeability.
- Adocate private land owners to improve parking facilities by applying pervious construction materials.
- Adopt city ordinances that standardize the types and amounts of pesticides permited to use in private lands.

§ Involved Organizations:

Hilldale Shopping Center, Target Corporation, DPCED, etc.

Figure 28. Source: Created by author.

4. Conclusion

Bee pollinators are not just regular insects. They are facilitating and maintaining the production of food through their pollination activities. Protecting bee pollinators is not only economically beneficial but also environmentally sustainable for urban development.

By identifying and analyzing multiple spatial variables imporatnt to bee habitats, a comprehensive GIS model was constructed to evaluate the overall environmental suitability and regional potential to develop pollinator habitats within the City of Madison. This, on the one hand, well demonstrated the value and comprehensibility of GIS modeling in researching specis habitat and complex, continuous landscape systems. On the other hand, besides soils, aspects, and vegetation cover such natural characteristics, urbanites' perceptions and knwoledge on insects, governments' attitude towards farmland presevation and urban growth mode, can also largely determine the health or death of bees.

It is expected that the model, designs, and suggestions provided by this study can facilitate the city's decision making on pollinator habitat planning within the near future. By establishing a benign relationship between bees and humans, it is hoped that the city and its people can step onto a more harmonious road of development with other animals and mother nature.

Appendix I. Literature Review for Pollinator Habitat Evaluation Models

This is a brief literature review about the the role of GIS in habitat suitability assessment and major pollinator-related evaluation modelling done by other scholars. The purpose of this review is to compare the differences and similarities, advantages and disadvantages between the PHSM constructed in this article and other previous GIS-based models for pollinator studies.

For evaluating pollinator habitat suitability or analyzing pollinator-related activities, they require researchers to consider multiple factors in terms of both foraging and nesting environments for bees (Foy, 2007). GIS-based multi-criteria evaluation (MCE), on the other hand, has been examined as a very powerful tool in conservation biology and habitat suitability analysis (HSI) by combining multiple simplified variables at a time (Pietsch, 2012). Therefore, during recent years, MCE model and principle have been frequently used, modified by entomology scholars for analyzing the spatial patterns of bee population, pollinator services, or bee habitat suitability. Below, I listed four representative GIS-based pollinator evaluation models done by the previous scholars.

• Andrew Scott Foy (2007), county-scale model, "A GIS-Based Landscape Scale Model for Native Bee Habitat":

Foy's model perhaps is the most similar model with PHSM in terms of its function among the four since both of the models are designed to generate a landscape scale bee habitat suitability index. Specifically, Foy's model involves land cover, aspects, and soil drainability three evaluation factors and assigned 0.5, 0.3, and 0.2 weighted values to each of them accordingly. Also, Foy argues that bees prefer south-facing slopes to other slopes and the stronger the soil drainability the more suitable the soils for bees to nest, which have been validated by NRCS.

However, in terms of the use of land cover data, Foy's model completely ignored prairies this land cover type, which is considered ideal for bees (Koh, 2015). In addition, the land cover categories include water, which ignored the simple facts that bees cannot live in water.

• Eric Lonsdorf et al. (2009), county-scale model, "Modelling Pollination Services across Agricultural Landscapes":

Instead of generating a comprehensive model that includes all the evaluation factors, Lonsdorf generated four models for predicting the nest suitability, floral suitability, pollinator abundance, and pollinator services respectively in Yolo County, California. And all the four models were generated from land cover data. In all, Lonsdorf's models are highly statistical-based and are not as detailed as the other models.

• Chiara Polce et al. (2012), national-scale model, "Species Distribution Models for Crop Pollination: A Modelling Framework Applied to Great Britain":

Polce's model focues on analyzing the spatial patterns of population distribution and pollinator services for a subspecies of bumblebee, "*Bombus pascuorum*". Although the overall accuracy of Polce's model tends to be higher than the other three since its predictions are based on the species' actual occurrance records rather than suitability scores, the national scale of the model may make it fail to perform precise assessment for pollinator services within urban settings.

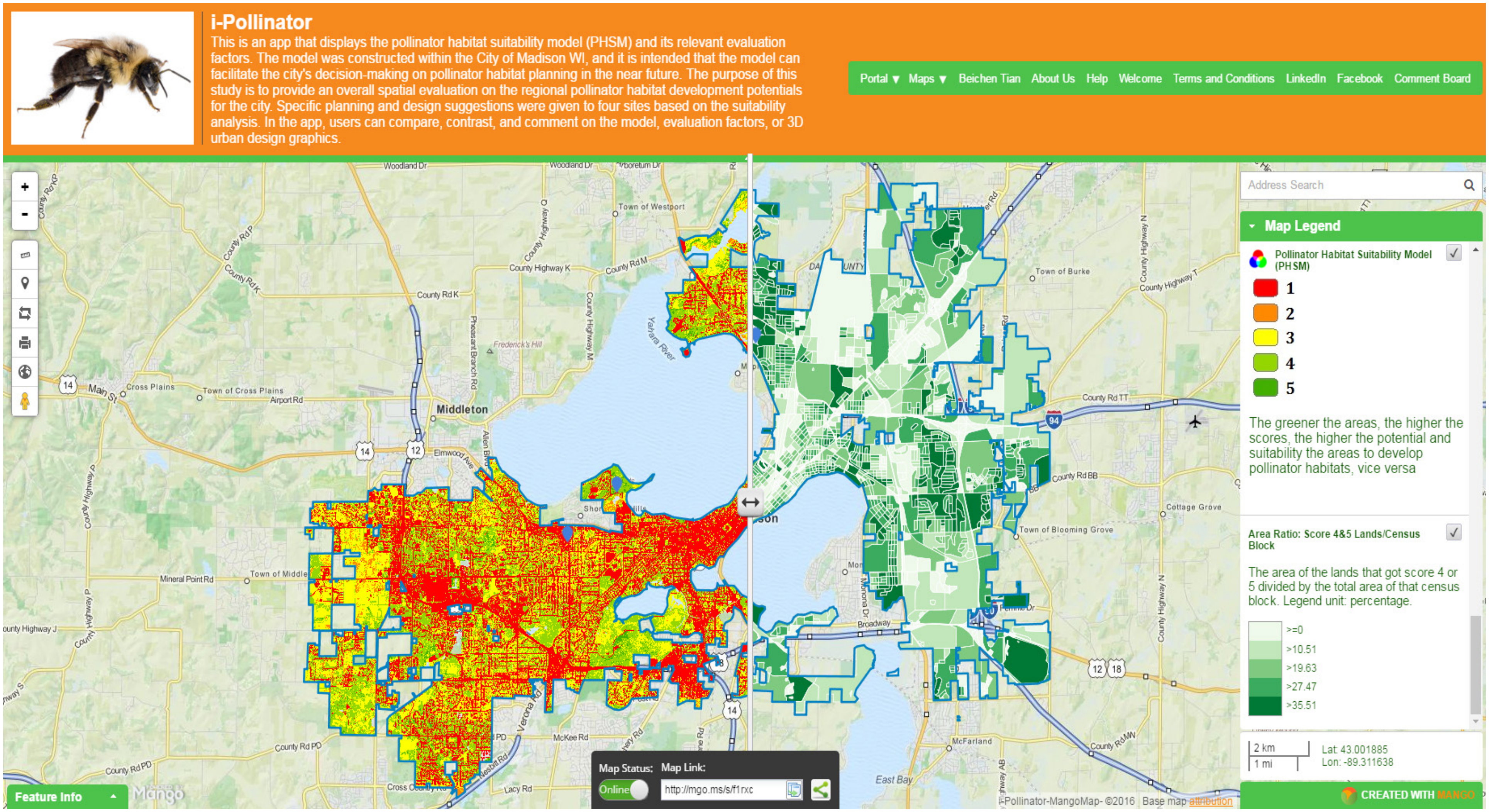
• Ivanna Okroukh and Rebecca Plickert (2015), city-scale model, "Using GIS to Determine Suitable Bee Habitat within the City of Toronto, Ontario":

Okroukh&Plickert's model is designed to identify the specific suitable sites to develop apiaries within Toronto whereas PHSM is designed to evaluate the overall suitability and regional potential to develop pollinator habitats for Madison.

One main drawback of the model is that, however, it perceived agriculture land use as a completely restrictive areas for bees while assuming that all the other lands in the city are completely pesticide-free. In other words, the model, on the one hand, excluded the effect of field margins on bees (Carvell et al., 2007). On the other hand, it ignored the pesticide uses in urban golf courses and single-family residential lands.

Appendix II. Web-GIS Application: i-Pollinator

An interactive tool to communicate the importance of pollinators for our urban living...



Login Link: http://mgo.ms/s/f1rxc

Appendix III. Interview Questions for Entomologists at UW-Madison and for City Planners

1. Interview with Entomologists at UW-Madison
- ***Interviewees:*** Jeremy Hemberger, Hannah Gaines Day
- ***Interview Date:*** Wednesday, 02/03/2016, 3:30pm-5:00pm

2. Interview with Planners from the City Government
- ***Interviewees:*** Linda Horvath, Milena Bernardinello
- ***Interview Date:*** Thursday, 02/11/2016, 10:00am-11:30am

1. Has Madison's (or Dane County's) urban agricultural economy ever experienced dramatic fluctuations ?

2. What is the city government's attitude towards pollinator habitat protection, support, discourage, or neutral? What has the city done for pollinator protection?

3. Do you know if Madison's bee pollinator population experienced dramatic fluctuations? If so, do you know if there have been any effects on the local urban agricultural economy?

4. What are the barriers/obstacles that Madison has come across during the process of pollinator protection?

5. Are you aware of factors that influence on Madison's bee species' spatial distribution? Are there any factors that can extremely reduce bee population within a relatively short period of time (e.g. 3 months, 6 months, 1 year, etc.)?

6. What factors can be used to evaluate the overall suitability of pollinator habitat for the City of Madison?

7. Can the different land areas be measurable in terms of the types of pesticides used ? Generally, which types of pesticides are harmful to pollinators while which else are not?

8. Do you know if commercial honey bees and native bees create different local economic impacts? If so, is one more important than the other?

9. Do honey bees' foraging habitats highly overlap with the native bees' foraging habitats? Will this impose negative influences on native bees' subsistence? Or vice versa?

10. What are the suggestions/actions the city/the university can provide/do for its citizens in terms of pollinator habitat protection?

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