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A HABITAT SUITABILITY ANALYSIS AND THEORETICAL MODEL OF HONEYBEES (*APIS MELLIFERA*) IN MARYLAND

By

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ABSTRACT

A HABITAT SUITABILITY ANALYSIS AND THEORETICAL MODEL OF HONEYBESS (*APIS MELLIFERA*) IN MARYLAND

Casey N. Bartoe

Honeybees are vital pollinators for a majority of agricultural produce. Unfortunately, their resilient populations are endangered with the threats of Colony Collapse Disorder. This plaguing ailment is spreading nationwide and dangerously diminishing insect populations of all species. This study analyzed and quantified the suitable habitat in Maryland using Geographic Information System analysis. A theoretical model was constructed to conduct the analysis which has the potential application in other states with additional pollinators in future studies. This model was used to investigate whether habitat degradation and electrical radiation can explain honeybee losses in this state or if another trigger dominates collapse. Productivity of numerous hives was compared to the suitable habitats to further validate these findings. It was found that the majority of Maryland contains suitable land for honeybees and the decline is likely unrelated to malnutrition, land use properties, or electrical towers. Additional factors including pesticide toxicity may therefore be the governing variable contributing to honeybee losses.

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THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Casey N. Bartoe entitled A Habitat Suitability Analysis and Theoretical Model of Honeybees (*Apis mellifera*) in Maryland has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Master of Science

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SECTION I: INTRODUCTION

Objectives of This Research

The challenge of this study entailed measuring a colony's productivity and other factors in order to identify habitats that are suitable for honeybee colonization, development, and proliferation. Habitat degradation is one of the strongest factors contributing to the global decline of the honeybee population. In order to identify the degree of degradation and compromised areas, the suitable habitat locations were identified and the amounts of such habitats were quantified in the state of Maryland. A model and framework was constructed that can be applied for future use for other species of endangered pollinators and in additional regions of the country. The objecting of this research was to conduct a Habitat Suitability Analysis and comprise a Composite Map and Theoretical Model of ecological conditions contributing to suitable habitats for the honeybee. Additionally, this research observed the influence of particular variables on the preferred, viable, or compromised habitats to attempt to slow the effects on the decline of honeybee populations. Areas identified that are not considered suitable that may need restoration, remediation, and conservation efforts. The results of this research can be used to help reverse the trend of lost colonies and declining populations of these vital insects. Identifying the locations of suitable habitats can also aid commercial beekeepers in pinpointing appropriate locations to keep bees or grow certain crops and for recreational beekeepers to obtain potential information of healthy practices and productive areas to establish their hives. This will assist the beekeeping and agricultural industry and have positive implications for the ecosystem.

Understanding the Importance and Decline of Apis mellifera

The declining health of honeybee populations is a current and escalating global environmental issue. Honeybees are responsible for the pollination of a wide range of vegetation and are the only insect that produces food for humans (Moisset & Buchmann, 2011). They also play a large role in the pharmaceutical industry and health care research (Son et al., 2007). Although there are other organisms that aid in the pollination of trees and plants however, bees are by far the largest contributor of fruit and vegetable pollination (around 80% of all production) for the agricultural industry (Moisset & Buchmann, 2011). According to the National Resources Defense Council (NRDC), $15 billion of U.S. crops are pollinated by bees annually (NRDC, 2016). The Department of Agriculture and thousands of private farmers transport bees around the country to pollinate a variety of crops. The movement depends on the season and the location of the particular type of crop. Needless to say, honeybees are vital in the agricultural industry in order for fruits and vegetables to be readily available throughout the year for public consumers. In the past year, an average of 61% of Maryland bee colonies have died and beekeepers have been reporting losses between 30-90% in some states according to the U.S. Department of Agriculture (USDA, 2015). However, according to the University of Maryland, 44% of bee colonies collapsed from April 2015 to April 2016, indicating the country is experiencing an ecological emergency that affects agriculture consumer markets and export industries (UMD, 2016).

There is an argument that honeybees are not native to the U.S., which is in fact true; however, the first honeybees were brought to the United States nearly 400 years ago and the society has adapted to their presence (Moisset & Buchmann, 2011). Honeybees are now responsible for the pollination of 1/3 of all the food nationally consumed and a loss of this magnitude is devastating to the economy and Americans' health. A few crops that are affected from a loss of bees include apples, peaches, plums, broccoli, squash, cucumber, melons, blueberries, almonds, sunflowers, coffee, and cotton (Morse et al., 2000). A variety of detrimental effects would ensue from the collapse of the honeybee population.

An Explanation of Honeybee Behaviors

Honeybees are social altruistic individuals in the group Hymenoptera that function as superorganisms in large colonies (Mortiz et al., 1992). A honeybee colony is formed by a hierarchical caste system which can mature into hundreds of thousands of individuals dependent on adequate space and resources. Each bee has a position and occupation within the colony. Forager bees collect pollen and nectar, which are required to pollinate other plants and make honey as well as feed their brood (larval bees). These workers are the older individuals within the group and avoid contact with other members of the colony to prevent disease and pathogen transfer. The hive usually stays in one place until the size of the colony is too large for their surroundings. The colony will then form a swarm and will move to a larger home, leaving behind the young members and a developing queen in their previous residence. The area in which they forage depends on the amount of food sources in a nearby radius. If there are no food sources nearby, then bees are able to fly further distances but gain weight and collect food less quickly and efficiently then bees that are able to stay close to their hive

(Traynor, 2002). It has been found that these insects will fly an average of 5 to 8 miles away from their home in search of food (Ratnieks, 2000) but will fly as far as 10 miles (16,093 meters) if necessary. Bees forage during the day and return to the hive before night. They will report the location and quality of the food to other foragers upon returning to the hive who will then return to that location and collect from those same sources. This repetitive behavior allows for efficient foraging amongst a colony.

These eusocial hymenoptera exhibit polyandry and the queen will mate once in her life with more than 17 males (drones). Once a queen has mated and returned to her hive, she will lay up to 2,000 eggs a day for the duration of her five year lifespan and only pausing egg production during the coldest winter months. Although relatedness between workers within a colony decreases as a result of multiple mating, this phenomenon attempts to ensure that long-lived queens do not run out of sperm, to increase genetic diversity promoting colony-level productivity as well as increasing the range of skills exhibited by the workforce. This polyandrous behavior has evolved to enhance disease or parasite resistance of the colony as a whole. A study on genetic diversity within honeybee colonies (Mattila & Seeley 2007) indicated that a colony with a multiply-mated queen will develop a larger area of comb and be more efficient in colony development versus a singly-mated queen colony which will remain smaller, collect less food, and make fewer combs. Having a more efficient and larger colony also helps to ensure the colony endures unpredictable weather and disease threats. A more efficient colony is able to regulate its nest at an optimal temperature of 35°C with a graded response base of varying temperature threshold and therefore maintain a stable nest temperature with less effort. A similar study from Seeley and Tarpy in 2007 stated that colonies headed by multiply mated queens are less susceptible to the bacterial pathogen (American foulbrood) and the fungal pathogen (Chalkbrood) than singly mated queens (Seeley & Tarpy, 2007). In order to achieve these benefits, the queen must have a suitable amount of drones to mate with and ultimately one or multiple neighboring colonies in close proximity. Although the queen is a poor flier, a swarming colony will choose a site that is further away from the initial colony to avoid competition with their relatives (University of Kentucky, 2015). Larger more efficient colonies that are able to endure environmental and biological threats require sufficient sources of nutrients and neighboring colonies to proliferate. Few floral resources or monoculture situations can lead to malnutrition within a hive.

A colony will rely heavily on the sun to not only warm their hive after colder night-time temperatures but also to allow the indication of the distance and direction of food. The bees also use the sun as their circadian clock to determine when it is time to go inside of their hive for the night in order to be protected from predators and the cold (Moore, 2001). If they are too far from their hive and will not make it back to the hive before nightfall, the bees will seek refuge for the night in a meadow flower or similar temporary shelter. Despite the benefits of a large efficient and productive colony, the honeybees require protection from the elements with a suitable “home”. They will engross and inhabit trees and cliffs in lightly forested areas. Bees prefer forested or riparian habitats and although they can survive in urbanized areas, they are much more efficient and able to combat other threats in more suitable habitats. Urbanization, which removes vital habitats and increases electrical infrastructure, has led to an increase in hives seen in highly populated areas (Naug, 2009). Bees are making their hives wherever they can: inside cars and air conditioning units, street lamps and parking garages, etc. instead of their natural habitat which is inside hollowed trees. The bees choose their ultimate landing place and permanent home based on a variety of factors. These insects do not typically carve out a tree without the presence of an entrance opening (Alcock, 2013). Although they can chew through the wood and enlarge their tree cavity, they will search for a relatively hollow tree or a tree with a substantial opening and potential hive chamber that is 30 to 60 liters in volume to get a new colony started. Windbreaks help to protect the colony from cold or strong winds and the threat of dysentery and depletion of food stores. The best suitable homes for the bees will have an entrance that is far enough off the ground to prevent possible flooding, was a strong and permanent structure to prevent destruction from falling over and other possible damage, was near a wind block from various types of structures (other trees, shed, etc.), and will face the sun when it rises and at the sun's highest peak during the day (Karaboga, 2005). This direction depends on where the bees are in the world. In Maryland the optimal direction for a bee hive is facing East for the sunrise and South for the meridian sun light. Most beekeepers set their hives in a Southeastern orientation to achieve optimal heating of the hive. Although trees are necessary for the basic needs of non-domesticated bees, a heavily forested area is much colder than an area with less sunlight. Domesticated hives are best located in a sunny area on the edge of a tree-line. This is also the area where wild bees inhabit most often. The best habitat for a vulnerable swarm looking to develop a home is a hollow tree with adequate sun, close to multiple food sources likely in meadows or fields with plentiful amounts of unmaintained vegetation where native species proliferate. Although bees are able to live in extremely cold areas, the colony is required to work extremely hard to maintain a microclimate within their hive allowing proper brood development and to keep the bees from freezing to death in the winter or overheating in the summer (Corbet et al., 1993 & Heinrich et al., 1994). The colony must consume around two pounds of honey a week throughout the winter (NOVA, 2000) and thus the colony must work efficiently and quickly during the nectar flow to store adequate amounts of food. The bees' behavior is also affected by temperature where foraging trips and in-hive work ceases below 57° F or above 100° F. All bees are unable to fly when outside temperatures are below 55° F (University of Kentucky, 2015). The foragers orient themselves using the sun and are most active in the early afternoon. They can fly in any direction but foragers must consider the energy consumed from a foraging flight especially when weighed down from collected pollen and nectar on their way back to the hive. Colonies compensate for temperatures that are suboptimal by establishing their hive in areas of direct sunlight, especially with full morning sun allowing the workers to warm up from colder temperatures at night and to prepare for day's work. Aspect ratio is an important variable to consider for the locations a colony may prefer to build a hive or thrive in an established location. Foragers will look for paths that are uphill on the way to a food source so that they can fly downhill when their corbiculae (pollen baskets) are full and heavy. Bees are sensitive to slope and aspect differences and consequently, elevation is an extremely important variable in assessing the quality of a habitat (Seeley et al., 1999). Typically, as elevation increases, slope increases, temperature and aspect decreases and thus bees may be more productive and efficient in areas with lower elevations.

Bees also need water to dilute honey and cool the hive in warmer seasons. They seek shelter that is close to a water source (Seeley, 2009). A wide river or open water body was believed to impede efficiency as the bees often drop into the water and drown if loaded with nectar and pollen from a foraging trip. Honey production and colony efficiency can increase if the water and plant sources (both winter and summer plant sources) are nearby and they can spend more time gathering food than collecting water, flying to far sources, are in areas with optimal temperatures, and have direct access to the sun. Examples of the most suitable and preferred habitats for bees are displayed in Figure 1 below.

Figure 1: Example of Most Suitable Habitat for Bees. Modified from FarMeadow.com.

Forager bees will convey information about the type, location, and quality of food through regurgitated transfer (trophallaxis). The location of the food is indicated by sound pulses and dancing motions that act as a map for the future forager. Although the foragers can obtain food from up to 16,000 m from their hive, they will visit a feeding source or site multiple times if it is within 2500 m from their hive. The further the distance the food source, the less visits from foragers and the more energy expended to obtain the nutritional value. If a forger encounters a danger upon landing on a food source, then it also warn other members of their hive to avoid these sources by marking the dangerous sources with an alarm pheromone that deters future visitors. Dangers include spiders and other predators, toxic or tainted sources, or diseased and low quality foods. Bees attempt to avoid plants with low quality food sources or predators but inadvertently contact these sources and bring back contaminants to the colony. In Maryland, the preferred food sources of honeybees are black locust trees, tulip popular trees, dandelion plants, and clover. Crops in Maryland that are pollinated directly by honeybees include potatoes, apples, melons, peaches, and beans which are also some of the largest cash crops in this State. Plants and crops that bees avoid include mountain laurel which is toxic to bees and corn, soybeans, and wheat which provide them with no nutritional benefit and are wind-pollinated. Evergreens also do not provide any nutritional benefits to the species however the trees do serve as hive sites for colonies to inhabit.

An envirogram, serving as a technical conservation assessment identifying system inputs that modify a system component and ultimately affects a species, is shown in Appendix 1 of this paper. This summary of the variables affecting the bees is a graphic representation of the pathways of a modifier to a target within a system and analyzes distal and proximate causes of changes and influences on an organism; there are four main modifiers in the centrum with specific outputs for each organism. Conservation efforts need to reflect on the mating and biological breeding habits, the predators and malentities that threaten the species, and the resources available that the bees are specialized to consume. Through human disturbance, natural disturbances, grazing, and seasonal variability, the honeybee community is in a desperate state of decline. This envirogram helps to organize the efforts to protect and understand a species as it is a tool that relates species' key life history attributes and their relationship to the environment. This analysis highlights the important ecological factors that affect the population of a species.

What Causes the Decline?

There is a long list of culprits involved in the declines of the honeybee populations. Factors involved in the decline include habitat loss from increased urbanization and development, pesticide and herbicide toxicity, radiation from cell phone and electrical towers (Favre, 2011), and invasive pest increases and decreased immunity caused specifically from the Varroa mite (Dively et al. 2015), Nosema parasites (Pettis et al. 2013), and fungal pathogens (Pettis et al. 2012) . A study published in *Apidologie* stated electrical infrastructure has been found to interfere with magnetite crystals within fat cells which impede the bees' communication and homing mechanisms shown by piping experiments. Any close contact with electrical infrastructure impairs the bees' magneto-reception system and the electromagnetic interference decreases the foraging ability (Favre, 2011).The combined effects of these pressures are believed to be the cause of a new phenomenon known as Colony Collapse Disorder (CCD) where large and seemingly healthy colonies die seemingly overnight leaving 50,000 dead honeybee carcasses scattered around the hives. This carnage is not only devastating for both backyard beekeepers and commercial farmers alike but the loss is disturbing as it serves as an example of other insect populations' health and their decline in the area and as indication of the health of cascading trophic levels. The effects on other trophic levels include the loss of birds from lack of insect food sources and the loss of vegetation and the organisms that consume this vegetation from the decrease in pollination. For these reasons, bees may be considered a keystone species as they are crucial for the health of an ecosystem. Losses to this extent further exacerbate stresses on commodity availability and markets as well as agricultural industries and natural environmental systems.

There is "ubiquitous exposure" of honeybees to pollen contaminated by pesticides (Smart et al., 2016) which greatly decreases the health of these organisms at the individual and colonial level (Gill et al., 2012). Repetitive foraging behavior during mid-afternoon threatens the health and productivity of a colony from continuous exposure to dangerous chemicals at the time most common for application. Pesticides are also found to pollute water sources frequented by honeybees and have sub lethal effects with contamination concentrations as low as seven ppb (Johnson, 2015). The chemicals are also found in soil and sediments, leaf litter, guttation water, systemically throughout most crops in the U.S., and in surface waters (Johnson, 2015). Pesticides are applied liberally to large areas of crops and can accumulate in the atmosphere for long periods of time. The chemicals can also drift for miles (Owens & Feldman, 2004) to unintended areas by factors including: spray solution characteristics, weather, application equipment, and applicator decisions (Fishel & Ferrell, 2015). This drift unintentionally covers pollen and nectar sources that bees pick up and take back to their colony and consume.

With overdevelopment and urban sprawl, a variety food of sources become depleted and monoculture increases as well as the increase of habitat destruction which are additional factors which may contribute to CCD. The radiation from cell phone and electrical towers may also contribute to CCD through radiative emissions and therefore honeybees may attempt to avoid these areas. A picture of a colony lost to CCD is exemplified in Figure 2 below.

Figure 2: A Colony Lost to Colony Collapse Disorder. Modified from Rosenberg, 2010.

There are many cascading effects of honeybee loss. First, the prices of food would rise and consumers would struggle to find produce they are accustomed to in America. Secondly, some plants, such as alfalfa, almost all types of clover, and beans, are pollinated by honeybees and are also used to feed large populations of livestock (University of Illinois, 2016). Without their availability and inflation of prices, farmers will struggle to effectively feed their livestock and populations would be difficult to sustain. With a decrease in livestock populations, meat industries could eventually suffer. Vegetation that requires pollination to grow and spread would deplete and herbivores may ultimately starve from lack of resources. Carnivore populations that consume the herbivores could waiver. Large-scale devastating cascades could plague the nation upon the loss of these vital insects. The exacerbation of human perturbations, habitat destruction, pollution, and chemical contamination are increasing and affect the health of the honeybee population within the natural habitat as well and the commercial and recreational industries in which domesticated bees reside.

As land development and zonation make a shift from rural to urban uses, erosion and pollution increase chemicals in the environment and decrease natural food sources and habitats for a variety of organisms (Smart, 2016). Through the increase of activities, pollutants in densely populated areas also increase. These factors include: industrial wastes, the rise of fracking or hydraulic fracturing, and domestic oil and gas drilling, residential and recreational development, and changes in the agricultural and farming industry. With the decrease in some farming efforts, erosion and pollution as well as the rise of impervious surfaces further the contaminants that may come in contact with wildlife. Other farming changes include the use of monoculture, genetically engineered seeds, and progressively toxic pesticides in the agricultural industry.

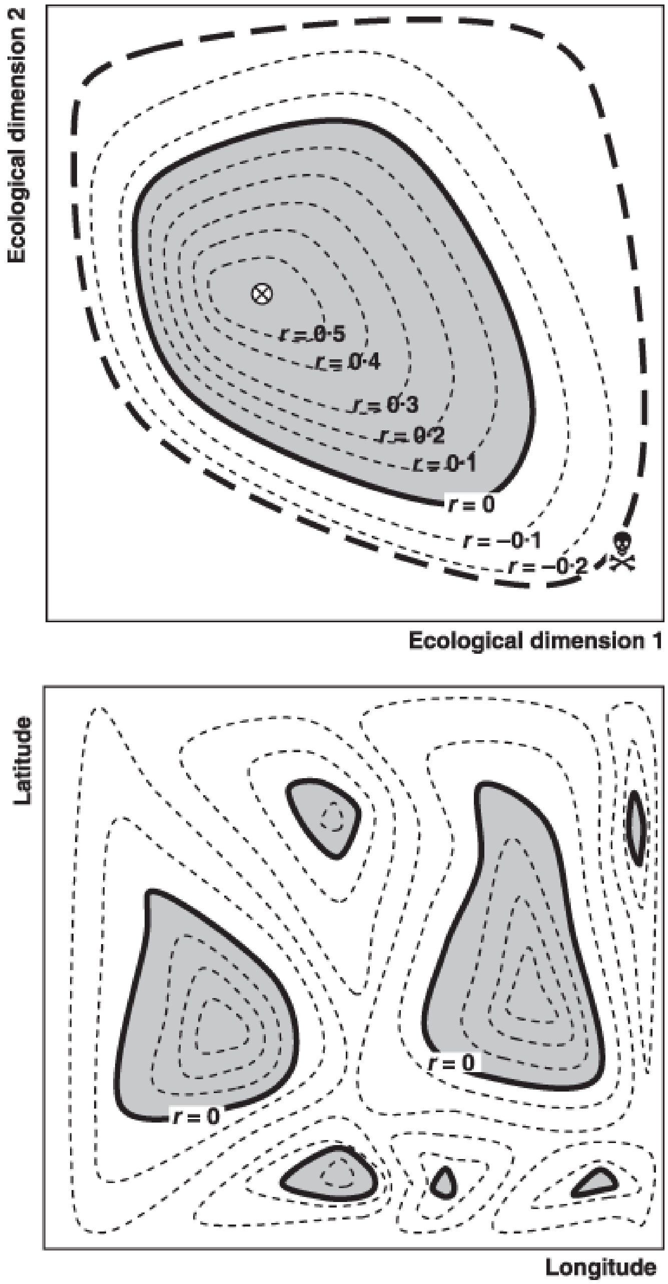
Although the exact cause of CCD is unknown, it is believed that pesticides play the largest role in killing vital pollinators. It has been found that this pesticide exposure severely impacts the health of honeybees both at the individual and colony level (Gill et al., 2013). An estimated 15 million acres are sprayed annually with neonicotinoids which are the most dangerous, poisonous, and widely used pesticide in the U.S. (NRDC). The European Food Safety Authority (EFSA) banned neonicotinoids in 2013 (McGrath, 2014) and the fight to ban these toxins in the United States is a significant topic in the environmental industry today (Alemanno, 2013). Pests are thought to also play a role in CCD including Varroa mites. Typically, infestations of Varroa mites and other infecting biological agents can be eradicated with the application of medications to the bees but the diseases associated with pesticide exposure cannot be currently prevented or directly treated. Although CCD was not directly investigated in this study, investigating the factors contributing to CCD (in this case habitat suitability and electrical infrastructure causing radiation) areas that are most significantly affected by these anthropogenic influences can be identified and quantified, recommendations for critical zones in need of conservation can be made, and the population decline can eventually be slowed.

Benefits of Research

Through this study, findings indicate the geographical areas that contain the necessary resources for a colony to thrive and be productive and therefore shed light on habitats that are suitable for the insects to colonize. Likewise, areas that are not included in these "suitable habitats" are an indication of areas requiring additional conservation or restoration efforts to increase honeybee productivity through resource availability in order to prevent their decline. The study helps to compile a theoretical model of habitat suitability indexes highlighting the environmental conditions that allow for healthy colonies. Known values of productivity compared to the areas of various degrees of suitability further validate the findings. Productivity, in this study, is defined by the average weight gain of a hive over time which is the result of water deposition or evaporation, pollen and nectar collection, honey production, bee reproduction, and colony growth. These findings were established by an investigation of colony productivity based on hive weight paralleled with land use and cover, water availability, elevation, sun orientation and aspect ratio, and distance from power and electrical infrastructure. The model identifies areas where habitats have been depleted by anthropogenic effects and urbanization, which dwindle natural resources and increase the bees' contact with harmful agents. An area with high concentrations of habitat degradation, densities of electrical and cell phone towers, and undesirable distances to water and food sources, displays values indicating less suitable habitat and potentially less productive hives. On the contrary, areas that are found to contain large amounts of suitable habitat based on a variety of specifications, the bee colonies are more productive and have a larger cumulative hive weight gain over time.

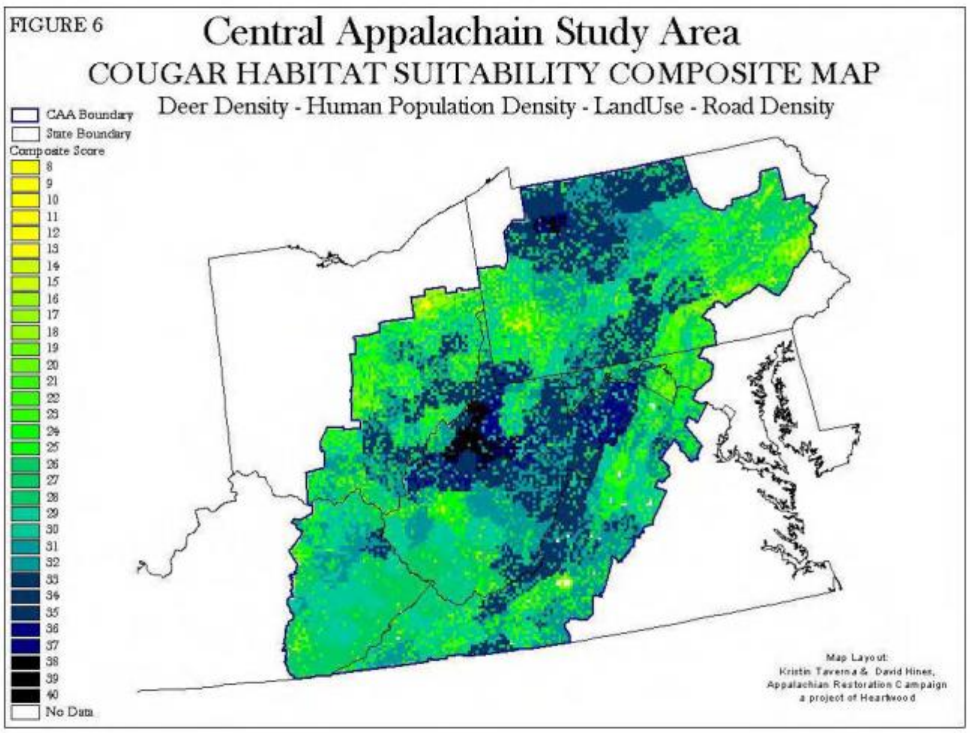
Suitable habitats can be considered a contributor to population health as exemplified by the 2008 study conducted by Alexandre Hirzel, *Habitat suitability modelling and niche theory.* He concluded habitat suitability modeling can help relate environmental variables to the fitness of a species while investigating an ecological niche of a species. In his analysis, he stated niche theory is developed for this field to determine the ecological dimensions that produce a suitable habitat and this analysis plays a large role in determining health related variables of a species' population. The following figure (Figure 3) shows that organisms outside the range of suitable habitat have an increased likelihood of mortality and a decreased fitness. This study yielded similar representations of the area around productive hives as well as most suitable habitats, although this research did not discuss expected mortality outside this range.

Figure 3: Representation of the ecological niche and its relationship to species' distribution in the geographical space. Modified from Hirzel, 2008.



Similar studies of habitat suitability analysis include the U.S. Geological Survey National Wetlands Research Center's Habitat Suitability Index Models and Species Conservation Assessments from the U.S. Department of Agriculture Forest Service Division. An example of another habitat suitability map similar to the composite map produced by this research was conducted by Krista Taverna and David Hines at the Appalachian Restoration Campaign for the Eastern Cougar displayed in Figure 4. This composite map has a complex scale of the degrees of suitability from yellow to blue which has a similar result at this study but a much larger scale which may have been inappropriate for this study.

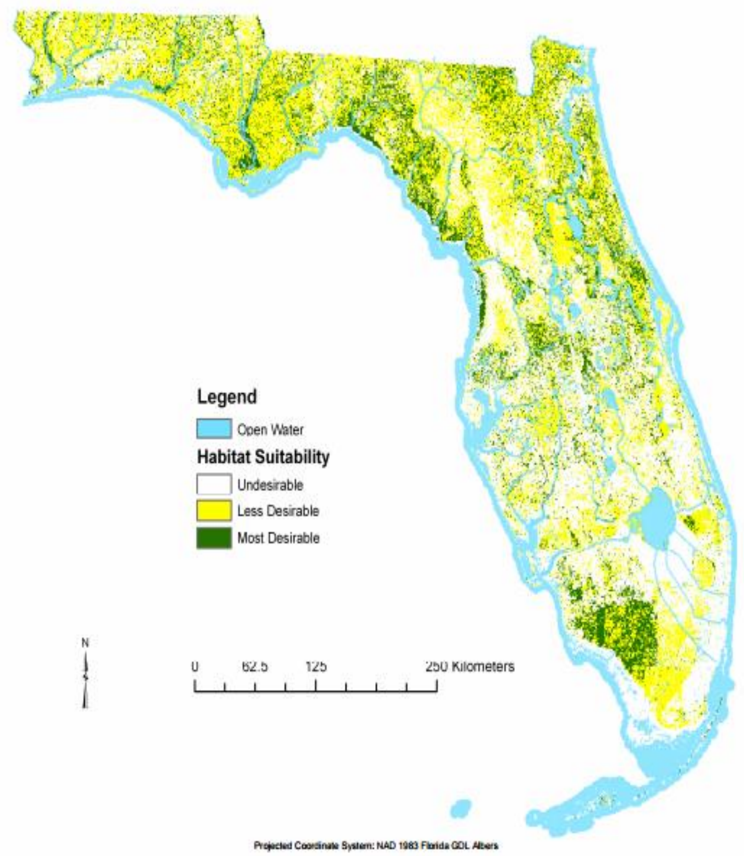
Figure 4: Habitat Suitability Map for the Eastern Cougar. Modified from Tavrna et al., 1999.



Another similar example of past research was the habitat suitability analysis conducted by Ian McCullough and Andrew Young at Colby College Department of Environmental Studies for the Florida Panther as displayed in Figure 5. This study used an extremely similar methodology as the Florida Panther habitat suitability analysis as the same coordinate projection system was used, simply substituting Maryland for

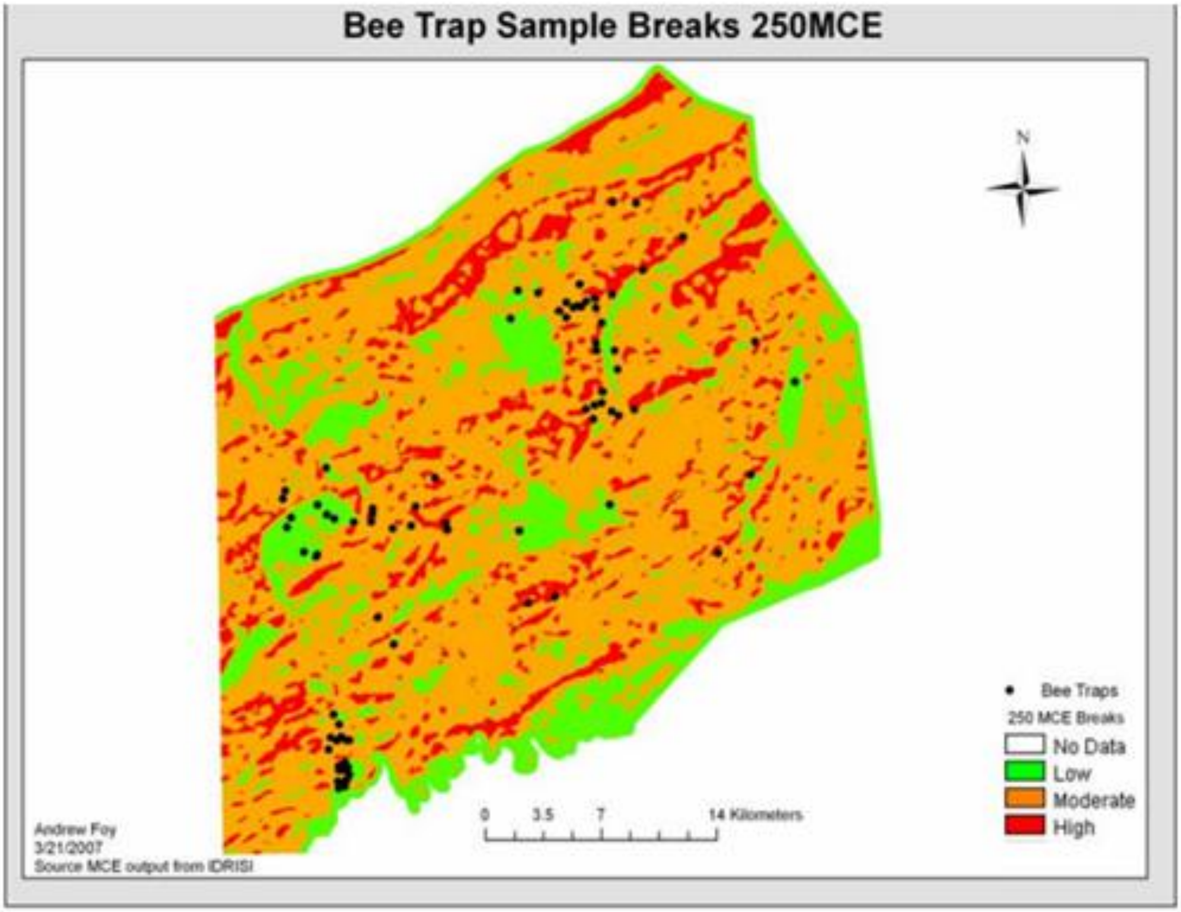
Florida, and the same scale of three degrees of suitability were categorized only differing by the definitions.

Figure 5: Habitat Suitability A for the Florida Panther. Modified from McCullough et al.,2008.



A final example of a similar analysis is shown in Figure 6. This study was conducted for wild honeybees in Virginia by Andrew Foy at Virginia Tech. He trapped native bees and determined their hive sites to study where and why bees choose a particular site and also if native bees can be targeted for specific pollination efforts.

Figure 6: Habitat Suitability Map for Native Bees in Virginia. Modified from Foy, 2007.



These studies are interesting; however, a habitat suitability analysis has not been analyzed for honeybees, especially domesticated honeybees in hives, or for the state of Maryland. Also, no mode has been previously constructed.

SECTION II: METHODS

Data Analysis

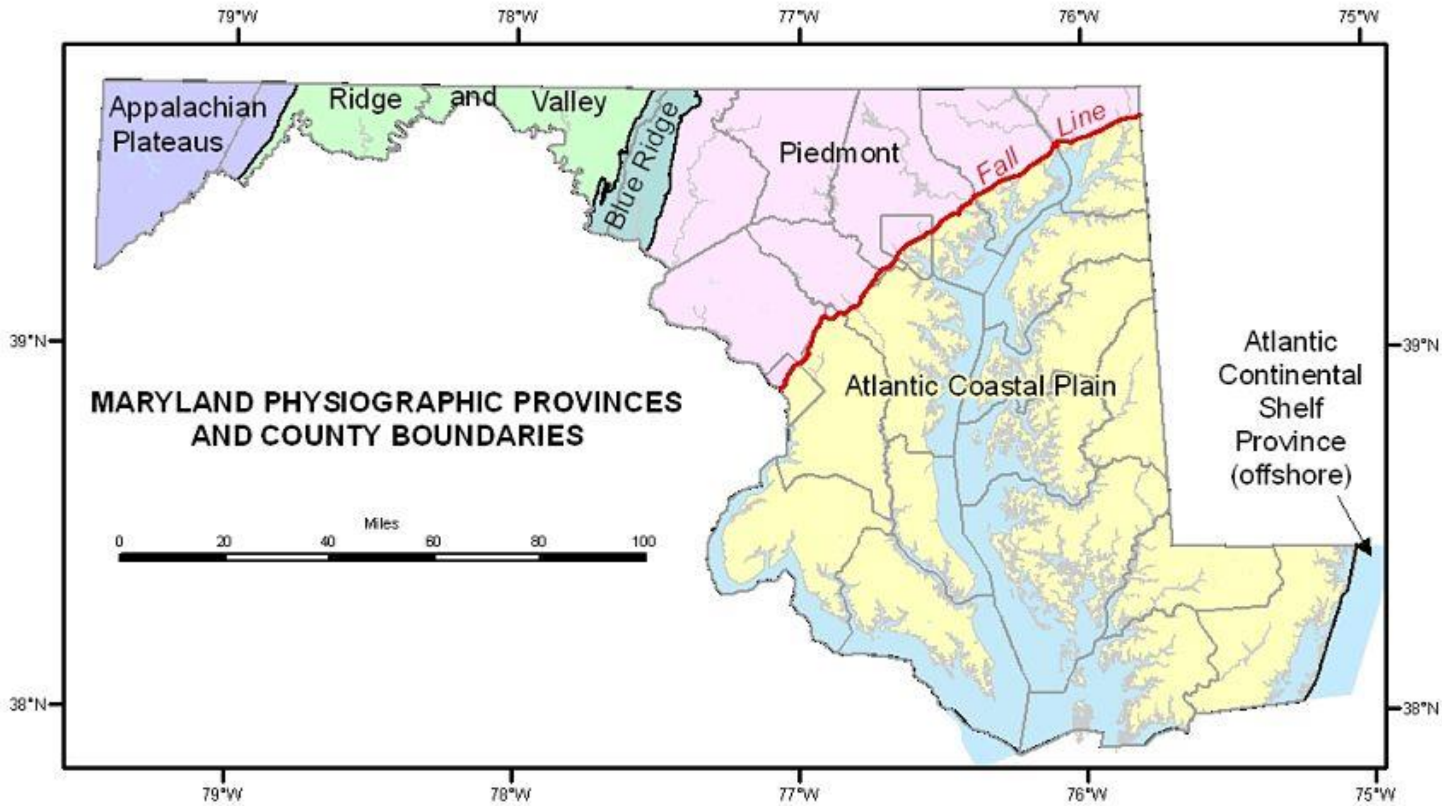
In order to identify the habitat suitability in Maryland that contributes to the productivity of *Apis mellifera* (Honeybees) this study investigated human perturbations of ecosystems and a variety of other factors. The habitat suitability analysis was based on six key variables: land cover and use, open water, inland waterways, slope, aspect, and electrical infrastructure. The land cover data was collected from the Multi-Resolution Land Characteristics Consortium and National Land Cover Database sponsored by the USGS. This organization collects data every five years so the 2011 data set was the most recent data available and was included in this study. These data included variables such as the percent of canopy cover, land use, elevation, and hydrography data sets derived from the United States Department of Agriculture Natural Resources Conservation Service website (NRCS, 2011). The open water data set was derived from the land cover data file. The inland waterways data was derived from the 2015 data provided by the State of Maryland iMAP portal. This portal also provided the data for the elevation which slope and aspect were derived from via the Digital Elevation Models (DEM). High quality data for distance to electrical towers from sample sites are difficult to gain access to due to security and disclosure purposes of electrical companies. Therefore, Open Source Street Maps (OSM, 2016) provided digitized and trace information from satellite imagery of the locations of the electrical infrastructure including poles, towers, transformers, stations, and substations merged into one variable. Known characteristics and values of hive productivity were compared with the final output and composite map of the suitable bee habitat in Maryland to determine if the suitable habitats contribute to productivity and less productive hives were found in less suitable areas. These data were collected from NASA's Honey Bee Scale Hive Project most recently in 2012. Lastly, the amount of registered beekeepers in the State of

Maryland in 2016 was obtained from the Maryland Department of Agriculture to determine if the density of hives is similar to the findings of the composite map and the land cover variables.

Other variables including the preferred land cover types, food sources, and plant/crop types are derived from the National Agricultural Statistics Service (NASS, 2011) as well as the published works of Mark Winston in *The Biology of the Honey Bee* (Winston, 1987) and Thomas Seeley including *Honeybee Ecology* (Seeley, 1985). Other behavioral traits were included based information regarding the behavioral capacities of complex altruistic social insect societies from John Alcock's (2013) text on Animal Behavior and TD Seeley's (1995, 2007) research studies.

An appropriate way to describe specific regions of Maryland that are the most suitable are to use the physiographic provinces of Maryland which are displayed in Figure 7 and include: 1) Atlantic Continental Shelf Province, 2) Coastal Plain Province, 3) Piedmont Plateau Province, 4) Blue Ridge Province, 5) Ridge and Valley Province, and 6) Appalachian Plateau Provinces. These areas are separated based on various factors including elevation, sediment composition and consolidation, geological factors and rock types, and other topographical features. Originally, the experiment was designed differentiating regions by county and differentiation by province proved more efficient for analysis.

Figure 7: Maryland Physiographic Provinces and County Boundaries. Modified from the Maryland Geological Survey et al., 2016.



GIS Processing

The data sets were downloaded and utilized in the program Arcgis.com. Areas where the bees are located was useful in observing the potential preferred elevation, distance from rivers, distance from national forests, and distance from urbanized areas by comparing the amount of productivity with factors measured with degrees of suitability. The model also accounted for habitat specific requirements of the insects including distance away from electrical towers and major geographical and topographical features in the State of Maryland including the Chesapeake Bay Watershed. The major geographical features of the State including the Chesapeake

Watershed was the result of the data from the category “Open Water”. Other water shapefiles helped to identify and display data on smaller bodies of water including rivers or streams that were also available from the State of Maryland’s 2005-2015 iMAP GIS Data Portal. The data for distances to commercial farming from sample sites are included in the “Cultivated Crops” category of the National Land Cover Database 2011 (NLCD) from the Multi-resolution Land Characteristics Consortium (MRLC). Cultivated crops could not be further differentiated into specific types of crops which would have been helpful as bees pollinate some crops but not others. Additionally, if the crops are using large amounts of pesticides, the crops could be extremely dangerous to a colony. Therefore, the land cover and use data were calculated using three different definitions on experimental basis: cultivated crops as most suitable, moderately suitable, and least suitable to determine if the crop category were in fact areas that contributed to suitability or lack thereof.

All files were first projected into the same coordinate system: NAD 1983 StatePlane Maryland FIPS 1900 in meters. In order to run analysis on the variables, the “environments” specifications, which are settings that allow multi-tasked processing, were set so that processes could run without being prompted after the initial process was outlined. The GIS analysis was conducted using raster analysis, vector analysis, and python scripting.

A raster dataset is a grid of cells, similar to pixels in a photograph. Typically, a dataset with smaller pixels will have a higher resolution. The values of interest from the Land Cover Dataset, which has a 30 meter resolution, was used by using Map Algebra to extract the cell values needed. Various tools in ArcGIS were used to calculate distance from specific features. For example, the Map Algebra used a formula similar to the following: (FileName == “Open Water”) and the ArcGIS used a formula similar to this example: (DistanceFromWater <= 1 Mile). Vector files are also referred to as “Shapefiles” and are comprised of Points, Lines, and Polygons. This information included the honeybee hive locations, Rivers/Streams, Roads, and other descriptive features of the topography.

The Raster Analysis helped to mask the data to only include what fell inside the Maryland State Outline and to outline the cell sizes to correspond with the same size as the inputs. The Processing Extent was defined as the Maryland State Outline. This tool is also helpful to outline the cells and allow the overlay of the variables to line up with one another for the raster calculator portion of this analysis. The tool “Parallel Processing” was used to increase the computer processing power that was used for parts of the raster analysis. This decreases the time it takes to run some of the tools that honor this environment setting such as raster calculator.

Python Scripting is a form of programming used in the ArcGIS program. For our purposes, this feature was used to automate processes in ArcGIS. The Map Algebra program also uses Python syntax in order to process values in a raster dataset. The methodology employed here was similar to one presentation by Joshua House at the University of Maryland. The habitat suitability analysis conducted by Mr. House provided a formula of Seasonal Habitat Suitability Analyses for Moose populations in Colorado and resulted in the following:

Winter Habitat= (winter_1c) + (winter_elev) + (winter_slope) + (moose_NF)

A similar equation was derived in the "Theoretical Model" of the Results section of this paper.

The data set for elevation was downloaded from the State of Maryland's iMAP portal website[1]. These LIDAR data are used to create Digital Elevation Models (DEM's). The tool "Reproject" was used to convert all the DEM files for each county into the same projection which is the NAD 1983 StatePlane Maryland FIPS 1900 (meters) coordinate system. "Resample" was used to convert all the DEM files to 30 m resolution. "Raster to New Mosaic" was used to group all the DEM files together to make one DEM of Maryland at 30 meter resolution. Lastly, "Extract by Mask" was helpful in clipping all the data that falls outside the Maryland State Outline so the sample only processes data within the state. "Slope" a tool used to determine the rise over run, quantities, and locations of specific slopes throughout the state. This tool calculated the slope between each 30 meter cell in the Maryland DEM raster file. "Aspect" determined the degree of angle for each cell within the MD Slope raster as well as determining the quantity and locations of specific aspect values. Both Slope and Aspect used the "Reclassify" tool to rate the values calculated by GIS into two categories of suitability (1 = preferred or 2= viable) as shown in Tables 1 and 2.

[1] http://imap.maryland.gov/Pages/lidar-dem-download-files.aspx

Slope values were considered optimal with lower values (0-30) and lower elevation as foragers are more efficient in areas with flatter flight paths. Aspect was considered based on the bee's requirements of full morning sun and exposure to median sun mid-afternoon with an optimal aspect ratio of 75-180°. This measure of the direction of a particular slope (North, South, East, and West) is measured with values between 0-360°. The slopes with an aspect value between 75 and 180 are a good indicator of the best habitat for a successful and productive colony. The analysis focused on the immediate area around specific hive points and considered the average, minimum, and maximum aspect values and provide a range of values indicating the "suitable" aspect values for the GIS analysis (Burrough and McDonell, 1998) (ArcMap, 2016).

The land cover data set was downloaded from the USGS website at the Multi-Resolution Land Characteristics Consortium[2]. Again, "Extract by Mask" was used to specify the land cover data that intersects with the MD State Outline file was to be processed and then the data used "Reclassify" to rate the types of land cover into three equally weighted categories of suitability displayed in Table 3.

Open Water was processed using "Raster Calculator" with the Maryland Land Cover Raster to extract the areas and amount of both variables in Maryland. The "Raster to Polygon" tool converted the Open Water raster cells to polygon feature. "Dissolve" changed the Open Water and Inland Waterways polygons to consist of one feature

[2] http://www.mrlc.gov/nlcd2011.php

instead of having an attribute record for each individual area of open water. This was done for all vector shapefiles (Points, Lines, Polygons) prior to running Euclidean distance. The "Euclidean Distance" tool then used the dissolved Open Water and Inland Waterways polygons to get proximity to open water in Maryland. The output cell size for all Euclidean distance tools was 30 m. "Reclassify" was then used to rank the Open Water and Inland Waterways Distance raster into three categories of suitability as shown in Table 4. The Inland Waterways data set was from the Maryland Waterbodies-Rivers and Streams file from the Maryland State website[3]. The file used "Reproject" to be converted to the same coordinate system and projection of the original DEM used for elevation.

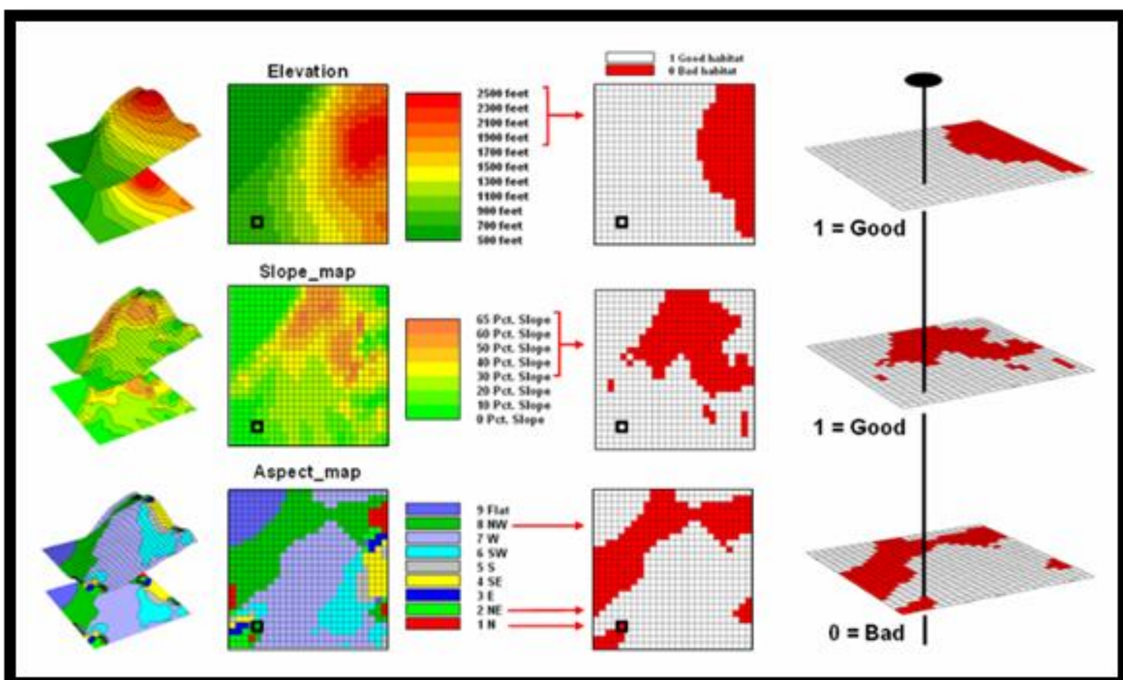
Power and Electrical Infrastructure, the final variables, were merged together to create one output distance raster because the distance rating was the same for both variables. This data was downloaded from Open Street Maps (OSM) which is open source collected data input by independents that have digitized the geographic data. The data has been reviewed to increase consistency and robustness[4]. The Quantum GIS plugin was used to convert the OSM data format into a shapefile format that can be easily processed using ArcGIS. A new shapefile was created by exporting the data from the OSM by using "Select by Attribute" where type = "Tower" or "Pole". Next, "Merge" was used to convert both files into one concise data set and "Dissolve" was used to simplify the amount of features of the merged file. The tool "Euclidean Distance" was

[3] http://imap.maryland.opendata.arcgis.com/datasets/9ba87d5942744b3bb61c78dd22c76564_0
[4] http://download.geofabrik.de/

used on the merged dissolved file to calculate the proximity to power infrastructure which was then ranked into three categories (Table 5) pertaining to suitability using "Reclassify".

The final tool used in the process of the GIS analysis was "Raster Calculator" which added all six reclassified, ranked raster files together. This tool helped to calculate the count of cells and their total area that qualified for the pre-defined ranked categories and quantified the area considered to be suitable habitat. The following image is an example of a separated representation of the variable layers and concept of values that are extracted in order to classify them based on rank.

Figure 8: Cartographic Modeling and Analysis Representation of Layered Data with Ranked Matrix Cells. Modified from Madden et al., 2009.



Variable Classification

The six variables included within the analysis were rated based on the predilection of the bees established by their necessity and natural habits. The rating of these variables as processed in the GIS analysis is displayed in Tables 1-5 below. In this study, slope is a function of elevation and can be considered as the changes in elevation throughout the state. Power stations and electrical infrastructure were grouped as one category to classify their rating.

Table 1: MRLC and NLCD Categories for Land Cover and Usage and Reclassified Ratings

LAND COVER TYPE CATEGORIES	SUITABILITY RATING
Open Water	3
Developed Open Space	2
Developed Low Intensity	2
Developed Medium Intensity	2
Developed High Intensity	2
Barren Land (Rock, Sand, Clay)	3
Deciduous Forest	1
Evergreen Forest	1
Mixed Forest	1
Shrub/Scrub	1
Grassland/Herbaceous	1
Pasture/Hay	2
Cultivated Crops	2
Woody Wetlands	1
Emergent Herbaceous Wetlands	1

* 1- Preferred/ Most Suitable
* 2 – Viable/Moderately Suitable
* 3- Compromised/ Least Suitable

Table 2: Rating for Open Water and Inland Waterways

DISTANCE TO OPEN WATER OR INLAND WATERWAYS	SUITABILITY RATING
≤1,609 meters (1 mile)	1 or Preferred/ Most Suitable
1,609-16,093 meters (1-10 miles)	2 or Viable/ Moderately Suitable
≥16,093 meters (10 miles)	3 or Compromised/ Least Suitable

Table 3: Reclassified Rating of Slope from Elevation Data

GIS CALCULATED SLOPE	SUITABILITY RATING
0-30	1 or Preferred/ Most Suitable
30+	2 or Viable/ Moderately Suitable

Table 4: Reclassified Rating of Aspect from Slope Data

GIS CALCULATED ASPECT	SUITABILITY RATING
0-59°	2 or Viable/ Moderately Suitable
60-185°	1 or Preferred/ Most Suitable
≥185°	2 or Viable/ Moderately Suitable

Table 5: Rating for Electrical Poles, Towers, Transformers, Power Stations, and Substations

DISTANCE TO ELECTRICAL INFRASTRUCTURE	SUITABILITY RATING
≤1,609 meters (1 mile)	3 or Compromised/ Least Suitable
1,609-16,093 meters (1-10 miles)	2 or Viable/ Moderately Suitable
≥16,093 meters (10 miles)	1 or Preferred/ Most Suitable

GIS Output Interpretation

A total of six components were processed in the GIS Analysis: Land Cover Type, Slope, Aspect, Distance to Inland Waterways, Distance to Open Water, and Distance to Electrical/Power Infrastructure and their outputs were entered into the Raster Calculator tool. The “Raster Calculator” provided a value for each matrix cell that indicated the number of variables that met each suitability rating criteria or value. The values were additive and would increase as suitability decreased. Therefore, in this case, the best possible score a matrix cell could achieve would have a value of 6 indicating this cell qualified for a suitability rating of 1 for each of the 6 variables. Cells with this value were the most suitable because they included the preferred land types, were the furthest from electrical infrastructure, were closest to small water bodies but were not constrained by open water systems, and fell within the preferable slope and aspect ratio. Given the ranking of each variable, the highest possible score for a cell would be 16. For example, a matrix cell with a value of 16 would qualify for the following suitability ratings: Aspect = 2, Slope = 2, Land Cover = 3, Distance to Open Water = 3, Distance to Inland Waterways = 3, Distance to Electrical Infrastructure = 3. The sum of these values is 16 and this cell is contains the least suitable habitat. The amount of cells with values of 15 and 16 were so few, they were excluded from the output of the raster. Therefore, the values provided by the output of the raster calculator include 6, 7, 8, 9, 10, 11, 12, 13, and 14.

Once the GIS processes were conducted, an output was generated of the number of cells (Count) within the Raster Matrix that consisted of suitable factors and unsuitable factors (Raster Value or Score). The total area that comprises these values was then calculated. First, the area of each Raster matrix cell was determined based on the 30 m resolution with which the data sets were processed (Area of Each Matrix Cell = 30 m x 30 m). Secondly, the area of land with a particular raster value or score was calculated and the formula for this process is posted below:

Area of Raster Score M^2 = Count of cells with this score x Area of matrix cell

Next, the percent of a degree of suitability was then calculated using the Area with a particular score:

Percent of Suitability = (Area of Raster Score / Total Area of Maryland) x 100

Lastly, raster values and scores were then reclassified into three degrees of Suitability: Preferred/ Most Suitable (value of 6, 7, or 8), Viable/ Moderately Suitable (value of 9 or 10), and Compromised/ Least Suitable (value of 11 and above).

The known productivities in terms of weight gain of 38 hive sites were compared with the final Habitat Suitability Composite Map to determine if the most suitable areas contributed to increased productivity. The data collected by the NASA Goddard Space Flight Center and their program “HoneyBeeNet” were used to determine hive site locations, hive weights, colony productivity, colony size, and food storage (NASA, 2015). The data were also analyzed for outliers and other data that are inaccurate for this study including sites outside of Maryland, past and older data, etc. and will only include data from the Mid-Atlantic Region. These data helped to discover the honey yield and degree of bee productivity in site specific areas of the State. These variables were compared with the decline or incline in site-specific honeybee productivity. The data were obtained from a) this previous study and recorded data, b) scales presently determining hive weight, c) survey, and d) physical observation. The map of hive sites that was used for this analysis as a result of the findings from the analysis from NASA can be viewed as Figure 9.

Originally, there was concern that various natural factors were affecting the hive's productivity by impeding their gathering abilities. Possible factors include extreme weather, branches or other debris that fell near or on the hive blocking the entrance, damage from predators, etc. Each hive was monitored by a beekeeper and was only given assistance to keep the hive alive and to prevent swarming throughout the study. Therefore, no hives were lost or replaced during the study time-frame and any immediate impeding factors were removed from the vicinity of the hive whilst allowing natural processes and fluctuations to occur. Drawn but empty comb may or may not have been provided to allow open storage space for the colony, however, weight measurements accounted for the increases in anthropogenic additions to the hive. Each hive was also viewed using the geobrowser "GoogleEarth" which allowed aerial and satellite viewing of the hives to observe any noticeable structures or features that would affect the weight gains. A Google Earth image of a hive site is shown in Figure 10 and a display of how the hives are set up on scales is displayed in Figure 11. An example of NASA's findings of hive weights is posted below in Figure 12. The productivity data are displayed in Map 10. The suitability degrees of each hive site location deterred by the raster score were determined and are posted in Appendix 4 and the percentage of hive sites that qualified for each of the three degrees of suitability were then calculated and the results of this analysis is displayed in Table 8 of the Results section. Additional hive site locations of the registered Maryland beekeepers (Map 11) were included on a secondary map and the data were provided by the Maryland Department of Agriculture. This information helped to identify areas where bees are currently being kept but did not consist of hive weights and is reflected in the discussion portion of this paper. Once the data supplied by NASA were organized in a fashion that could be used for GIS calculations, the variables under investigation contributing to productivity were analyzed and the percentage of the most, moderate, and least productive hives in each degree of suitability were determined using the following formula:

Percent of Types of Productive Hives in each degree of Suitability =

Number of Hives in one suitability degree / Total number of Hives x 100

Figure 9: NASA Study Scale Hive Sites . Modified from Esaias et al., 2015.

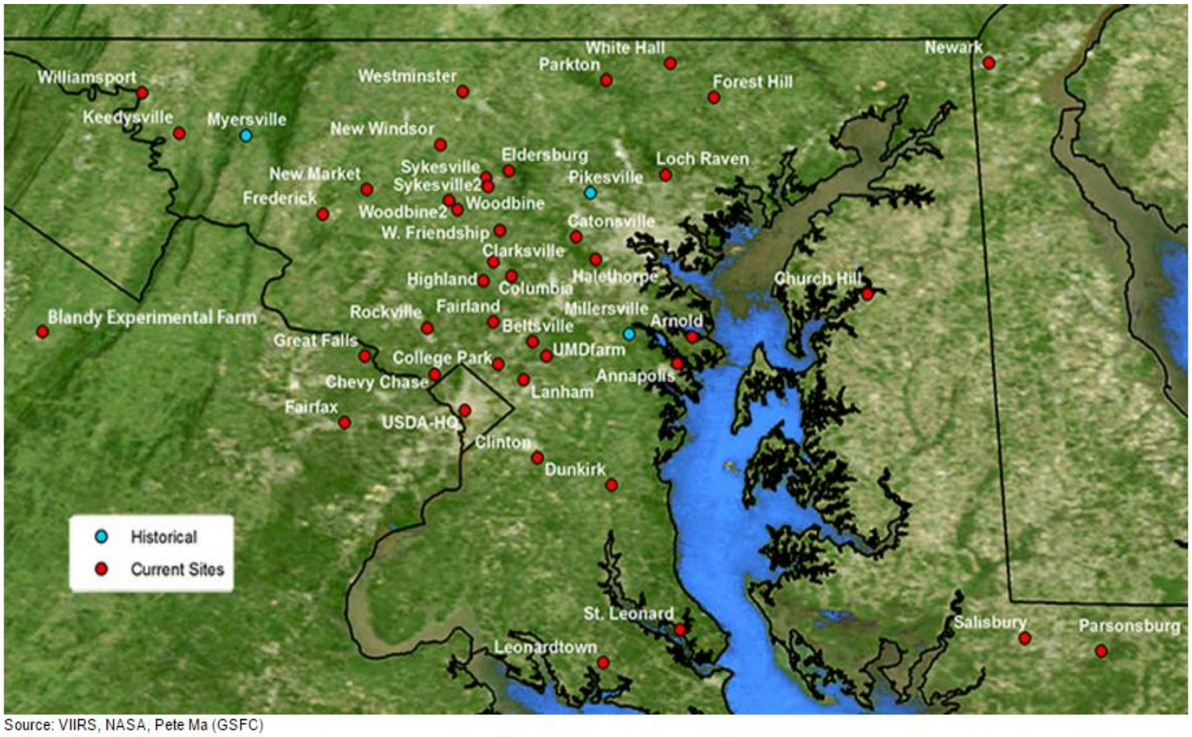


Figure 10: Google Earth Image of Harwood, MD Hive Site. Modified from Esaias et al., 2015.

Figure 11: Hive Details and Sample Set-Up of Hive from NASA. Modified from Esaias et al., 2015.

Beltsville, MD

Return to Regional/National map

County: Prince Georges	**State:** MD
Active Since: 2007	**Observer:** Smith
Lat/Long: 39, -76.9	**Landsat WRS Path/Row:** 15/33
MODIS Tile V/H: 5/12	**MODIS Line, Samp:** 114.45, 35.67

Site/Hive Description:

Hive is located is at the USDAâ€™s Beltsville Agricultural Research Center (BARC) Bee Research Laboratory, next to building 483 with a northern exposure. The BARC facility is extensive and is adjacent to the USFWS Patuxent Wildlife Refuge, thus the site is located among extensive mature mixed hardwood and conifers, as well as crop and pasture lands within foraging radius.

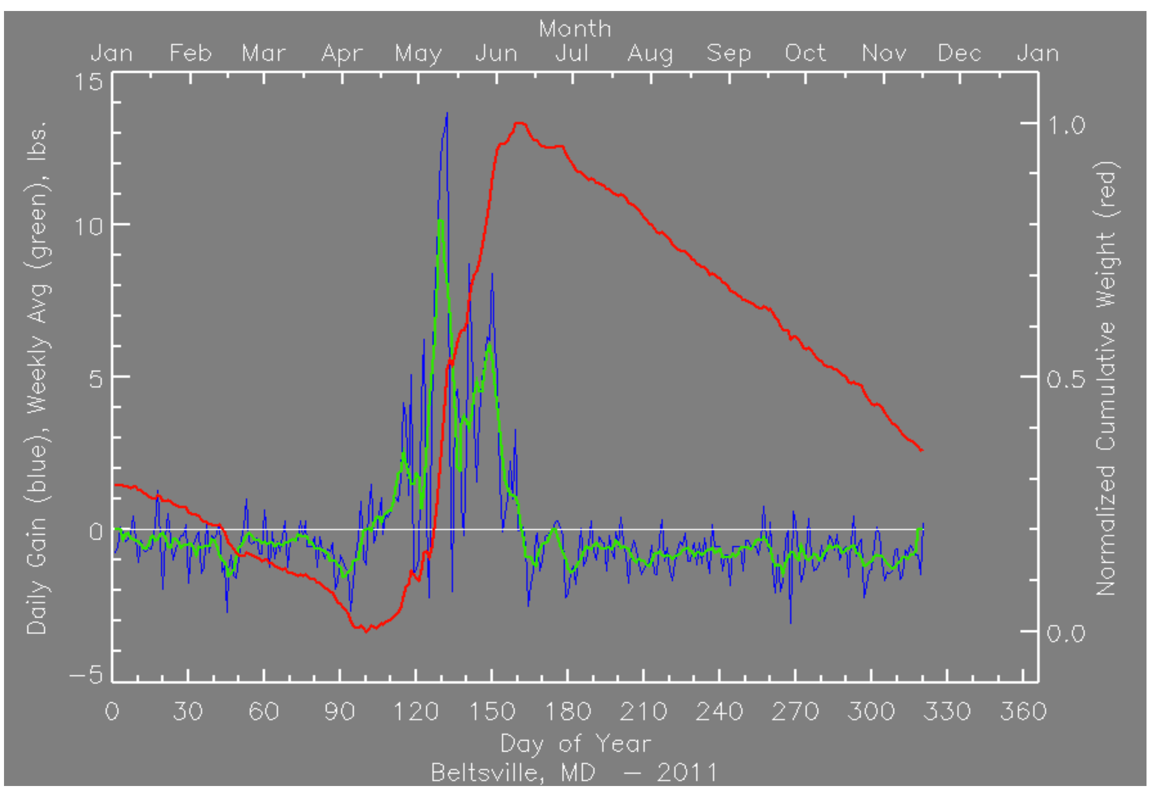
In the photo here, the red section indicates that there is mite medication on the colony. The box above that is a hive-top feeder for sugar syrup.

Colony:
2 deeps plus supers during the summer. Italian queen.

Scale:
Fairbanks Model 1124, 0.5 lb divisions, new in 2007. Weights maintained 2/07.

Forage:
May Black Locust, Tulip Poplar
Late Spring/Summer White Clover
October Aster

Figure 12: Graph of Hive Weight Increase for One Year from NASA. Modified from Esaias et al., 2015.



Following the production of the final composite map showing habitat suitability for honeybees in Maryland, another secondary variable was compared to the output of this analysis. Most Beekeepers in the State of Maryland register their hives annually with the Maryland Department of Agriculture. These beekeepers have currently productive hives and relatively established colonies, however the data points only account for beekeepers per address and not the number of hives. Each registered beekeeper may have one or many hives. The quantity of hives per registered beekeeper is not considered in the hive location markers. A map of the registered beekeepers was generated and the number and percentage of beekeepers in each suitability category was determined via the following formula:

Percent of Registered Beekeepers in each degree of Suitability = Number of Beekeepers in one suitability degree / Total number of beekeepers x 100

Most Beekeepers in the State of Maryland register their hives annually with the Maryland Department of Agriculture. Map 11 below depicts the registered beekeepers in 2016 in Maryland. These beekeepers have currently productive hives and relatively established colonies. The quantity of hives per registered beekeeper is not considered in the hive location markers. Although this map was not included in the initial GIS processing and overall suitability analysis, it helps to display where the highest density of beekeepers are and to represent the necessity for attention to the ecological factors and potential dangers that would impede honeybee productivity in specific areas. The percentage of registered beekeepers in each suitability degree was determined to identify if beekeepers are currently in suitable regions and where the highest densities of beekeepers are currently located. Although there are currently 2,690 beekeepers registered in Maryland 1,967 were included in the calculations of percentages due to difficulties with precise location determination from the ArcGIS program.

Theoretical Model

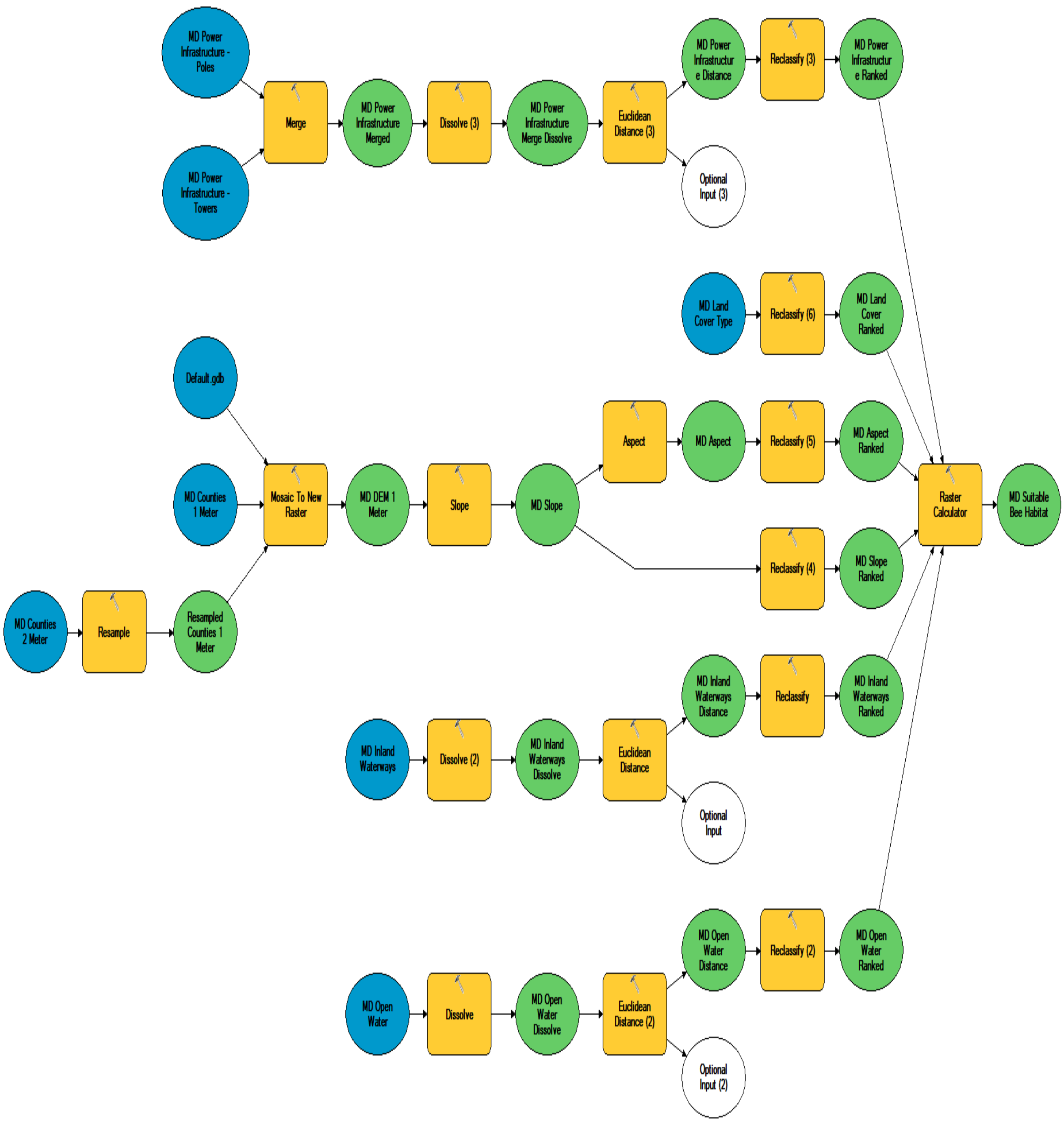
A formula was derived based on the GIS program and tools used in analysis, specifically python scripting. Features that procured a dimensional analysis of "suitable habitat" and locations of these variables are determined from the following formula:

SuitableBeeHabitat= (MD_LandCover) + (MD_Slope) + (MD_Aspect) + (Bee_DisOpenWater) + (Bee_DisInlandWater) + (Bee_DisElectric)

This formula does not require numerical values or units as it is a representation of the layered effect of multiple variables added together to determine the amount or degree of suitable habitat. A model was also constructed as a secondary flow chart representation of the process conducted and inputs and outputs of the overall environmental system of Maryland. This model is derived from the GIS analysis to further indicate system components that affect honeybee productivity. The Theoretical Model derived is exhibited in Figure 13.

The model is the flow chart of the processes used to determine the area and degree of suitability for a state. The variables can only be added into the raster calculator tool after being reclassified into what is specifically being defined, processed for Euclidian distance, additional unwanted featured are dissolved and so on.

Figure 13: Theoretical Model from GIS Analysis- Process Flow Chart



Each component of this chart is a tool that is run in ArcGIS that can be set up and then run consecutively or manually started in the processing methodology. Each arrow shows how a variable can be processed to eventually be used in the raster calculator to determine the amount of cells within the matrix that meet specific criteria. This formula and model can be used in future analyses by adjusting the study location and adding alternative factors that affect the many species under investigation.

In order to determine if the most productive hives are located in most suitable areas, a total of 41 hives were examined by NASA's Bee Net program at various sites throughout Maryland, however three of the hive sites (Millersville, Myersville, and Pikesville) were excluded from this analysis as the data were collected before 2005. The data were collected between the years 2005-2012 with only hive analyzed with data from 2005 and the other 38 hives using data from consecutive years in this range dependent on what data were available. The data were then analyzed to determine the most productive areas as well as contributing factors to this productivity. The amount of area that was found to be most suitable, based on the amount of productivity in the hives, was then quantified using GIS analysis.

"Productivity" was determined based on the average cumulative weight gain per day over a three year time period. According to NASA, the hives were weighed and observed for an average of 156 days a year. This length of time was used as it is the duration of the nectar flow in Maryland when bees accumulate weight gains within the hive. The differences between the average weight gains overtime showed substantial differences in productivity based on location. Again, in this study, productivity is a combination of honey, nectar, and pollen storage, as well as colony size as a function of Queen egg-laying. A typical hive does not accumulate weight gains for about 200 days of the year as the colony is consuming their stores during colder months when they cannot leave the hive, there is a depletion in available food sources to gather when plants are not flowering and the nectar flow has ended, and the queen has ceased egg-laying for the season to conserve energy and heat. The data were collected by NASA for an average of three years for each hive and the majority of the hives were analyzed using three consecutive years of data. The data included in the analysis either consisted of the three most recent years or the most recent data available if three years of data were not provided and then the average weight gain were used in the analysis.

Although the average daily and weekly weight gains were also collected, the average normalized cumulative gain for the duration that the hive was weighed and observed was used to determine the ranking of the most productive and least productive hive sites. Weekly and daily weight gains are much more variable and the cumulative gain identifies the productivity of the hive more accurately. However, the final output of the GIS Analysis did provide a map of these variables. Figure 11 below shows the organization of the data (normalized and adjusted weight gain by hives used in this analysis) collected by NASA in an Area chart which emphasized the differences in data sets over time.

Figure 14: Normalized/ Adjusted Weight Gain of Hives (pounds) at Various Hive Sites

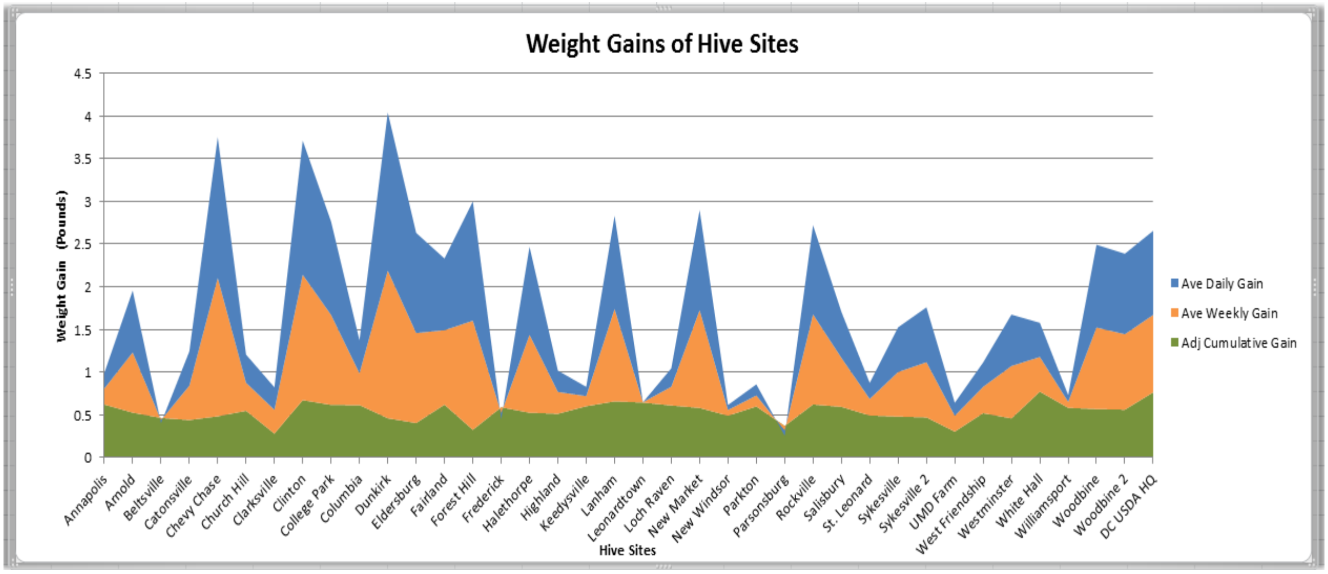
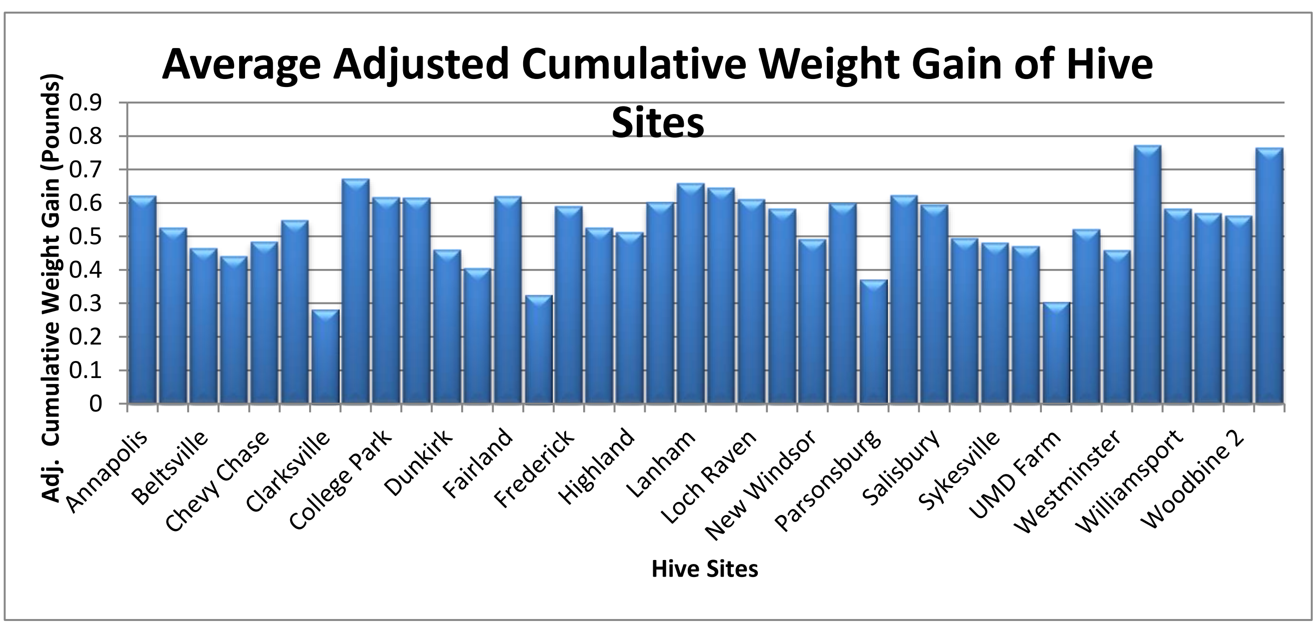


Figure 12 displays specifically the Adjusted and Normalized Average Cumulative Weight Gain, independent of the daily and weekly gains, throughout the duration of the weighing and observing period which was primarily used to compare productivity with the GIS Analysis results.

Figure 15: Average Adjusted Cumulative Weight Gain of Each Hive Site



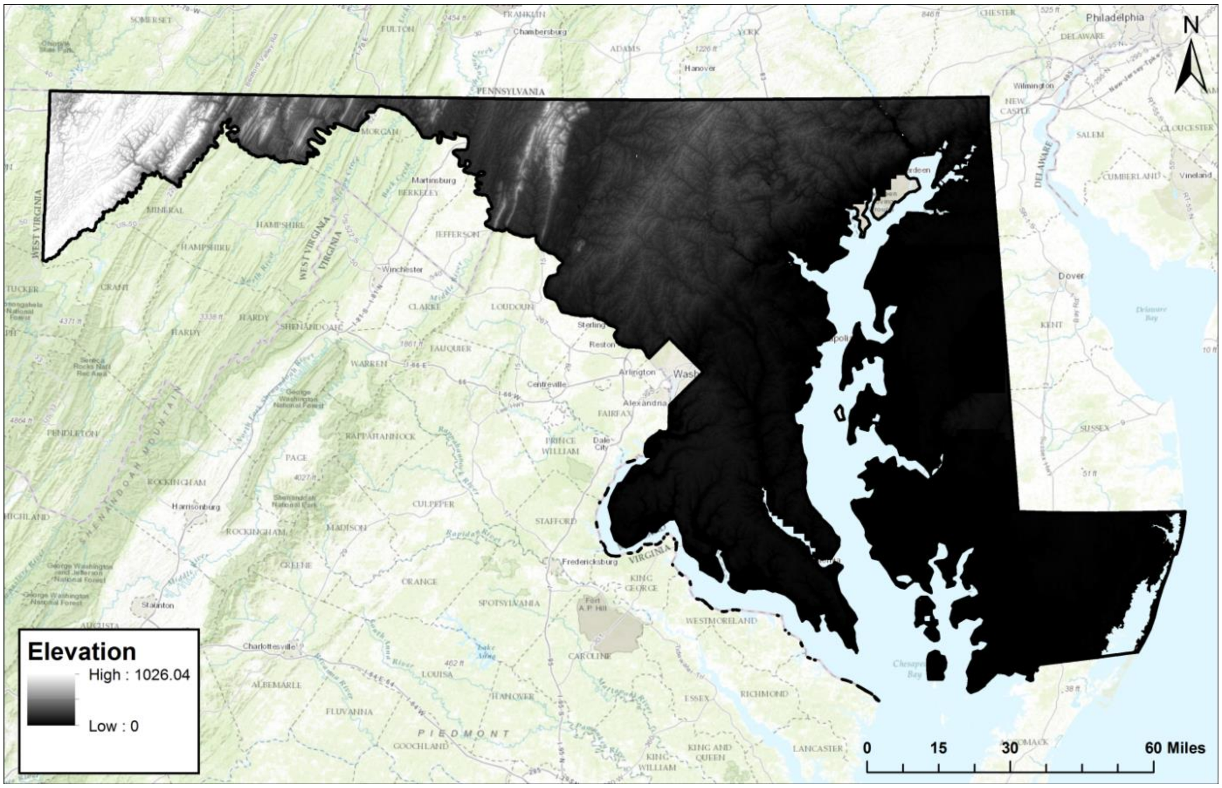
The tool used to extract the secondary variables of productivity and registered beekeepers and compare them with the degrees of suitability was "Zonal Statistics as Table". Pivot tables were then used in Excel to aggregate all of the data. Following organization of the data that were used for GIS Analysis, the hive sites were ranked as the most productive and least productive over time based on these analyses. Appendix 2 displays the rankings of each hive site with a rank of 1 indicating the most weight gain and a value of 38 as the least weight gain.

SECTION III: RESULTS

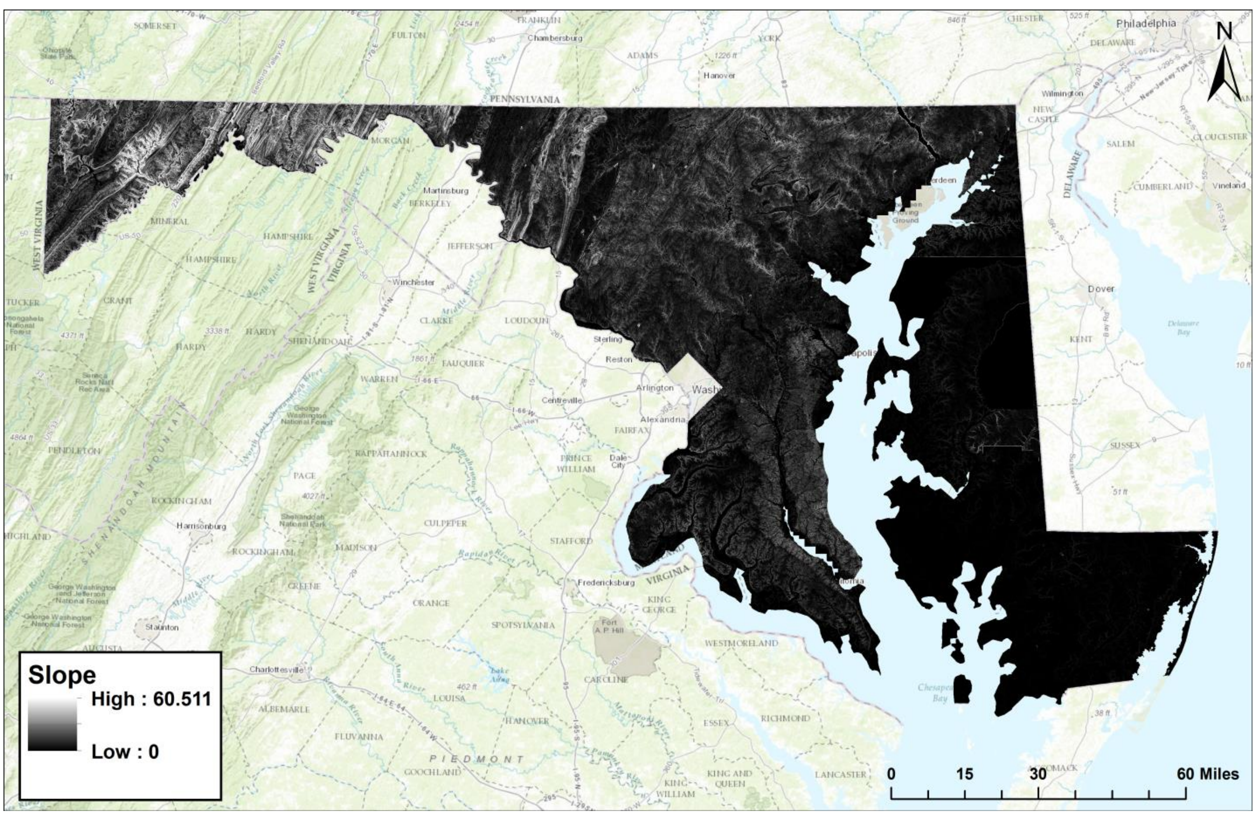
GIS Map Outputs

The following maps are outputs from data used in the GIS Analysis. There are 8 maps for the 6 variables processed as elevation and slope were considered one variable as well as electrical infrastructure and power stations. These maps were layered to form the final Habitat Suitability Map. A summary of the variables included in the analysis, the data origin for each data, and process used for analysis is included in Appendix 2, Tables of Variables and Databases.

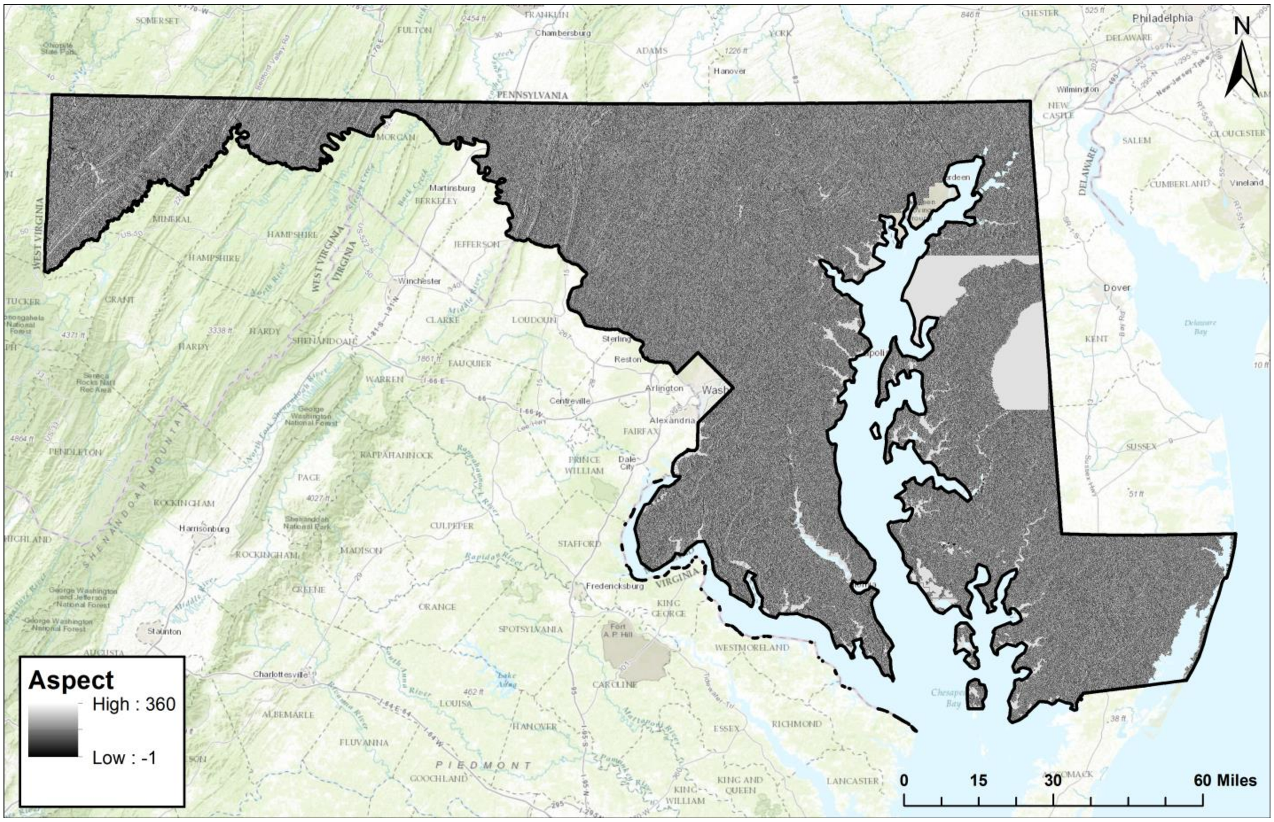
Map 1: Maryland Elevation- DEM



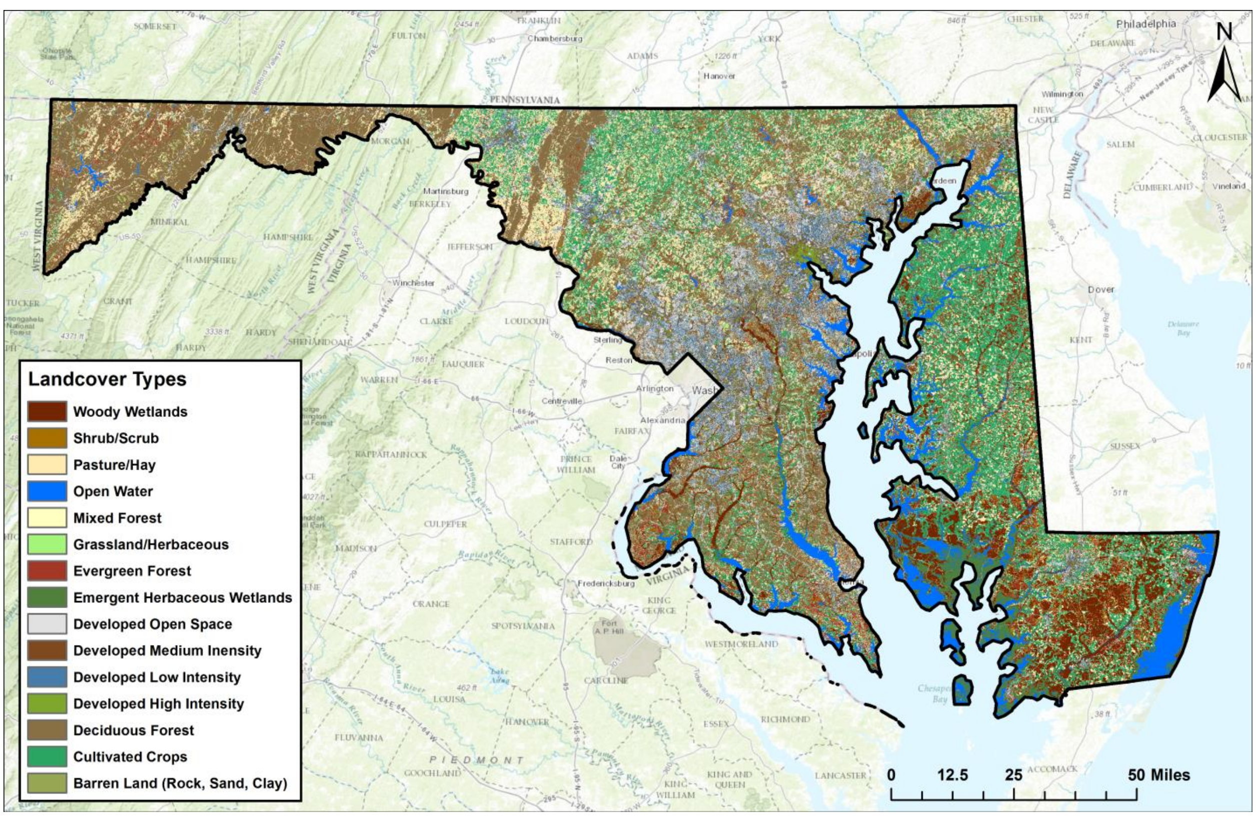
Map 2: Maryland Slope Raster Data Output



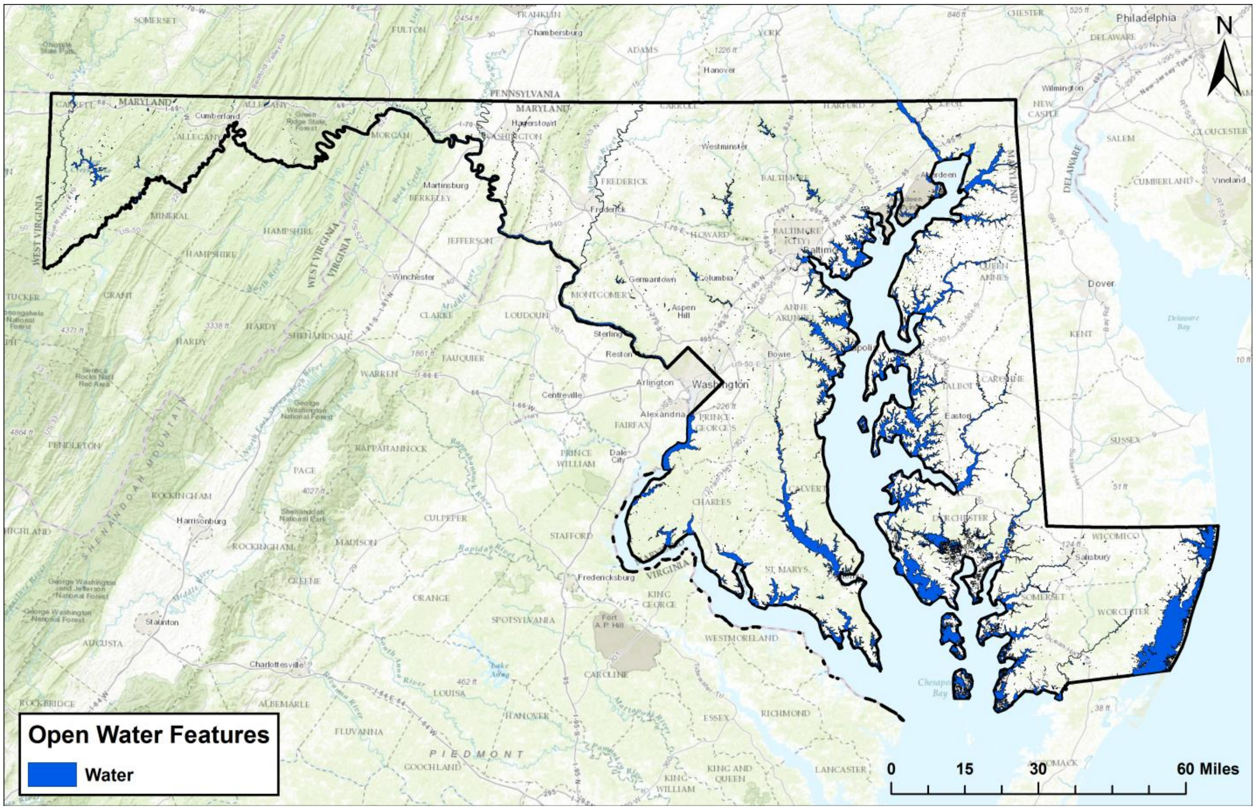
Map 3: Maryland Aspect Raster Data Output



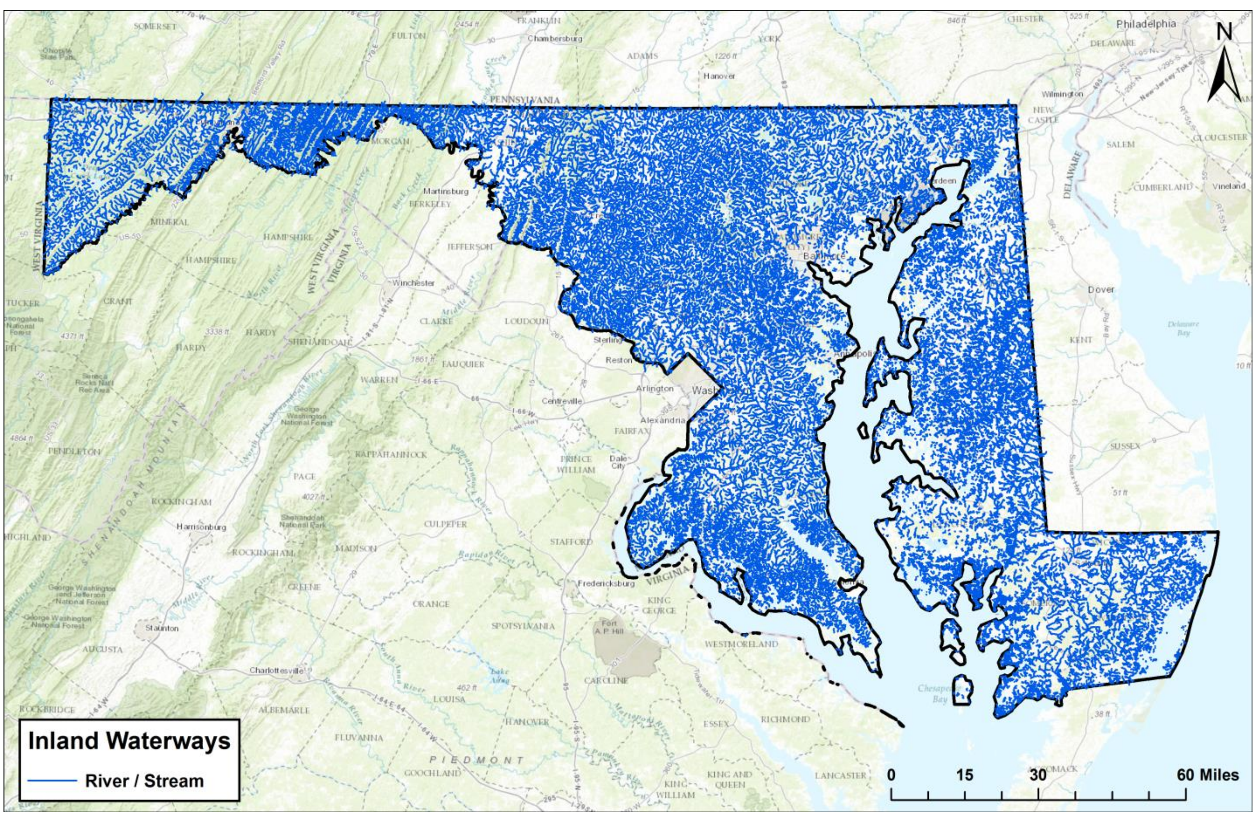
Map 4: Maryland Land Cover Types



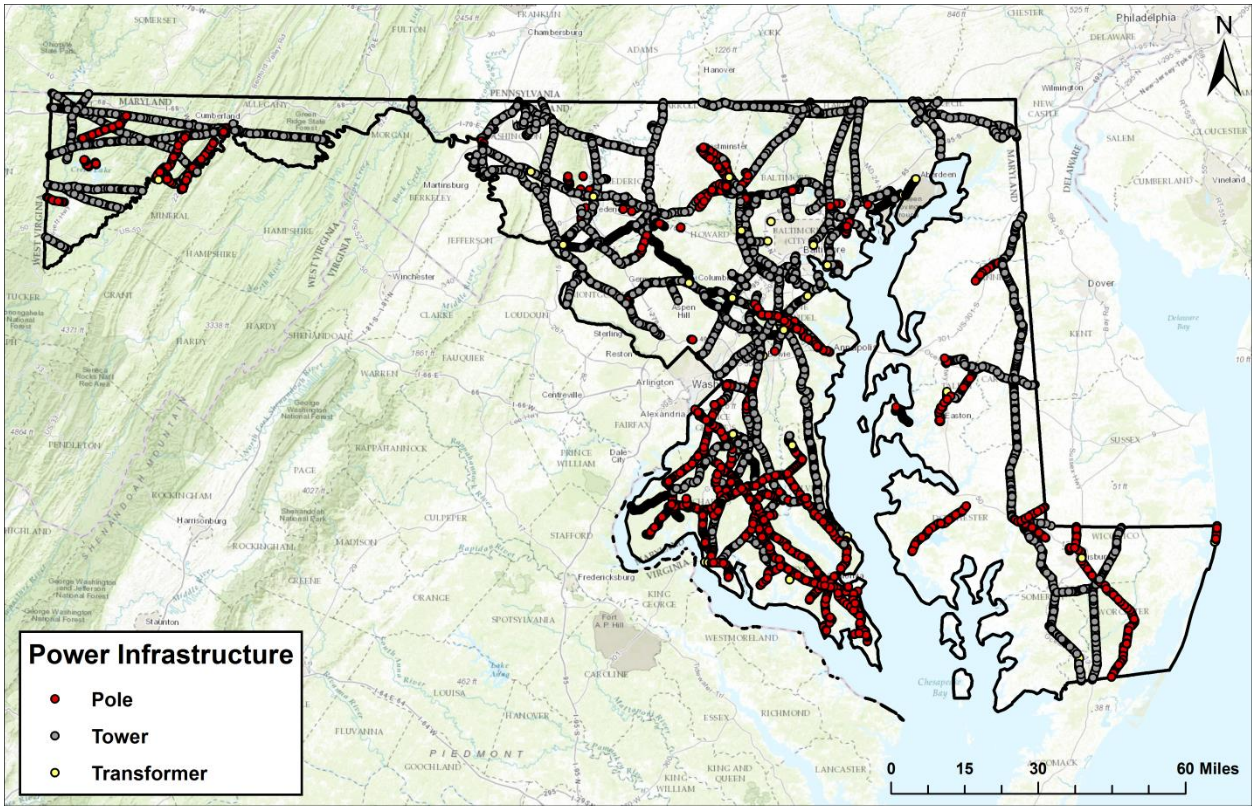
Map 5: Maryland Open Water



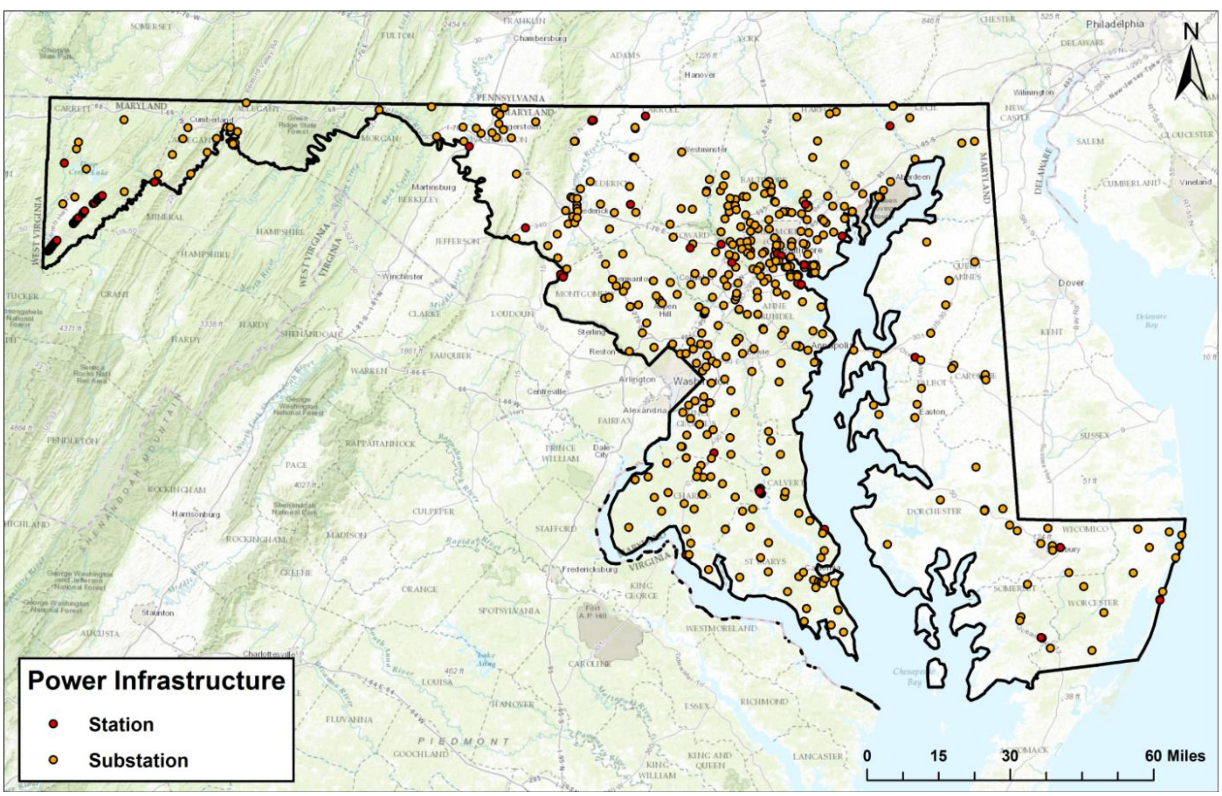
Map 6: Maryland Inland Waterways



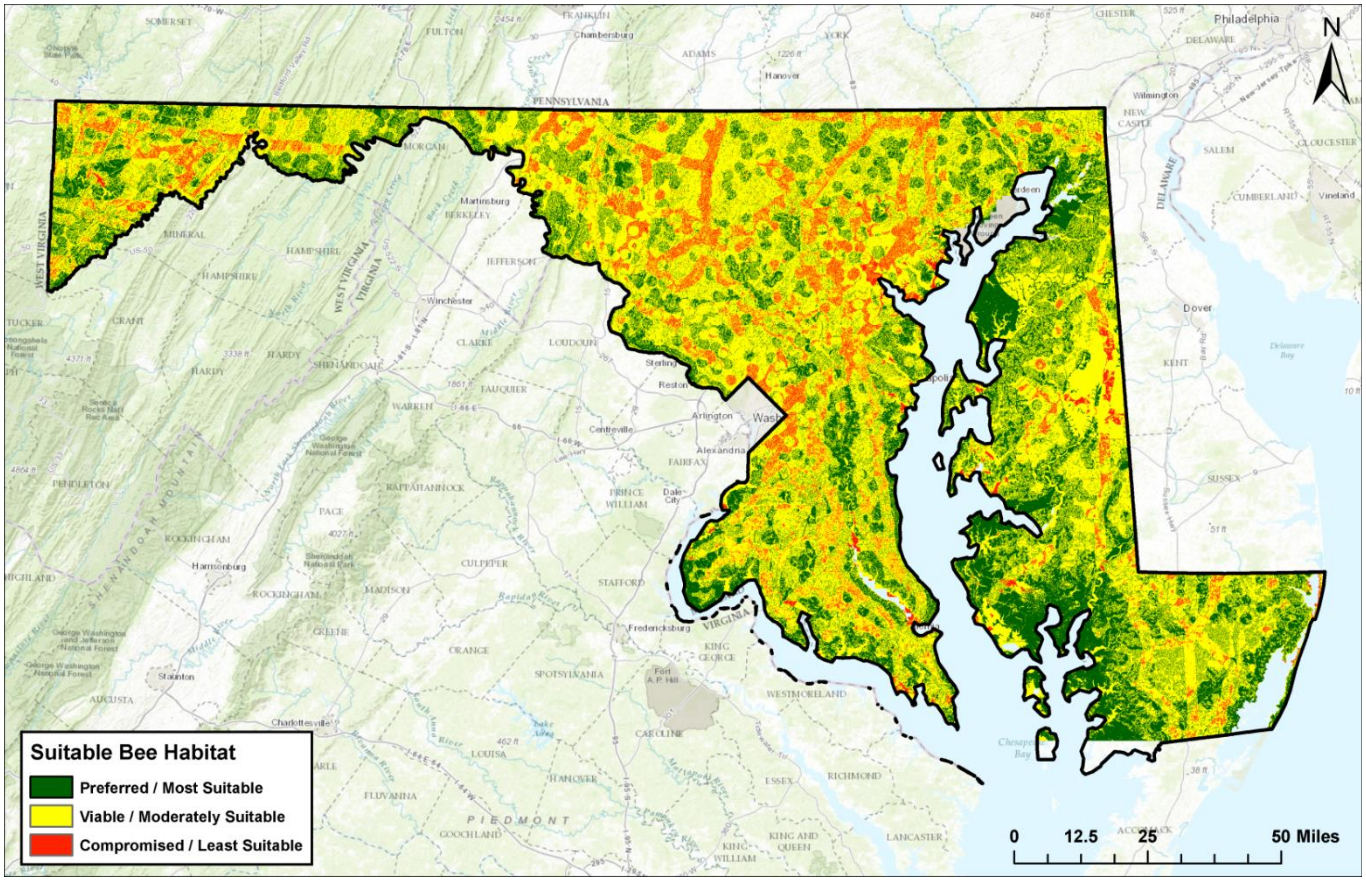
Map 7: Maryland Power Infrastructure (Poles, Towers, Transformers)



Map 8: Maryland Power Infrastructure (Stations and Substations)



Map 9: Maryland Honeybee Habitat Suitability Map



Model results indicate that 42.92% of the area of Maryland is Most Suitable or Preferred for honeybees, while 45.49% is only Moderately Suitable or Viable, and 11.58% is Least Suitable or Compromised (Table 7).

The GIS Raster Calculator Results of matrix values and the area of suitable land are exhibited in Table 6.

Table 6: GIS Raster Calculator Results of Matrix Values and Suitable Land

Raster Score	Area of Score (km²)	Percent of Suitability (%)
6	13,037	0.746
7	1,593,970	9.125
8	5,772,691	33.047
9	904,790	5.179
10	7,042,295	40.315
11	1,953,324	11.182
12	67,234	0.384
13	3,413	0.019
14	900	0.000
15&16 excluded	Total: 17,468,095	Total: 99.9996

Table 7: Percent of Suitable Land Classifications in Maryland

Raster Scores/Values	Percent of Land Suitability (%)	Suitability Classification
6, 7, 8	42.92	Preferable/Most Suitable
9, 10	45.49	Viable/Moderately Suitable
11+	11.58	Compromised/Least Suitable

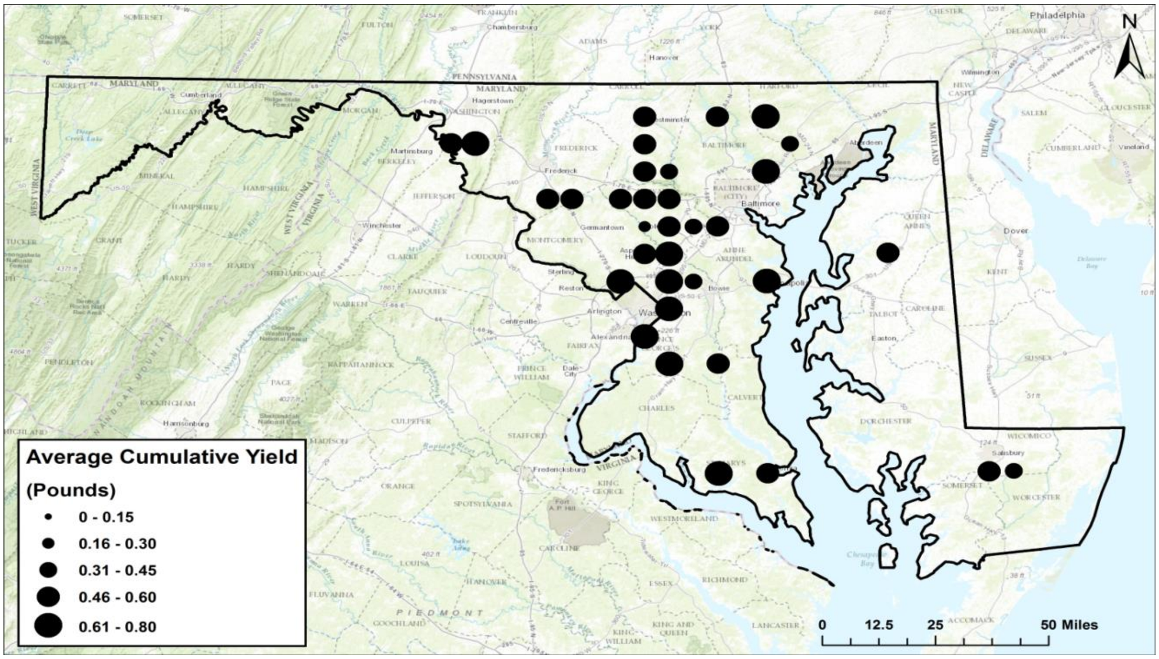
The highest percentage of most suitable land occurs in the Appalachian Plateau, the Ridge and Valley, and the Western side of the Atlantic Coastal Plain Physiographical Provinces. According to the map of land cover uses, these provinces contain mostly deciduous forest, cultivated crops, and mixed forested areas. The province with the highest amount of most suitable land, the Atlantic Coastal Plain, contains the highest aspect values, lowest slope values, and decreasing elevation. Furthermore, the Atlantic Coastal Plain, although very close to the largest open water sources, the suitable land is not impeded by this water source and is within a close proximity to smaller water bodies, streams, and rivers. The most suitable areas were found to contain the lowest density of power stations and electrical infrastructure within the state.

Recalling, the 38 hive sites that have productivity data, the sites with the top five production are White Hall, the USDA headquarters in DC, Clinton, Lanham, and Leonardtown (Map 10). The suitability map confirms that these areas correspond with the values provided by the GIS analysis and do in fact occur in areas classified as most suitable land. Five hive sites with the lowest average cumulative production included: Clarksville, College Park at the University of Maryland Farm, Forest Hill, Parsonsburg, and Eldersburg. The percentage of 32 of the 38 hive sites in each of the three degrees of suitability are displayed in Table 8 and Appendix 4. The percentage was calculated for 32 hive sites and not the full 38 due to issues with raster and matrix differentiation within the GIS program. It was determined that 16% of the hive sites were located in the most suitable areas, 78% were found in moderately suitable habitats, and only 6% of the hive sites, while still productive, were located in the least suitable habitats.

Table 8: Percentage of Hive Sites in Each Degree of Suitability

Number of Hive Sites	Suitability Degree	Percent of Hives
5	Most Suitable	16%
25	Moderately Suitable	78%
2	Least Suitable	6%

Map 10: Proportional Average Cumulative Yield (Productivity) of NASA Hive Sites



Maryland has a high percentage of suitable land based on the variables considered in this analysis. Areas that are at risk of being compromised can be identified from the suitability map. As the interpolated depiction of the hive site productivity displays, the least productive hive sites are clear and are found in areas with the highest population density, a high degree of urbanization, developed open spaces, dense evergreen forests, and a large amount of electrical infrastructure. These areas also have the lowest concentration of areas with mixed and deciduous forests. This map, displaying the generalized depiction of productivity in Maryland, used the Inverse Distance Weighting tool and default settings of the tool in ArcGIS. With a more defined resolution, this map would provide a more accurate depiction of the data sets, however, for our purposes, the map was useful is displaying relative productivity in various regions. This tool enables multivariate interpolation determined by a known scattered set of data points. The resulting generalization has been determined by using a weighted average of the values of these points and refers to the amount of proximity, the inverse distance of each known point, when assigning the weighted perimeter.

Currently, there are 2,690 registered beekeepers in the state (Map 11). It is important for current and future beekeepers to know where the land is suitable or not to determine the best placement for their hives or if their location is not conducive to sustaining a healthy and productive hive determining whether or not their investment may be moot. On the contrary, understanding the habitat suitability of Maryland would benefit commercial and recreational beekeepers alike by identifying where their apiary would potentially be the most productive. Of the 2,690 registered beekeepers, 1,967 were analyzed to determine how their location matches to the habitat suitability map. The percentage of registered beekeepers in each degree of suitability was displayed in Table 9 and Appendix 5. Other benefits of this research helps to indicate why a hive may have failed and factors that influence an established versus lost colony, not only to increase and defend the pollinator population, but to increase honey production and pollination of crops as well.

Map 11: Registered Beekeepers in Maryland in 2016

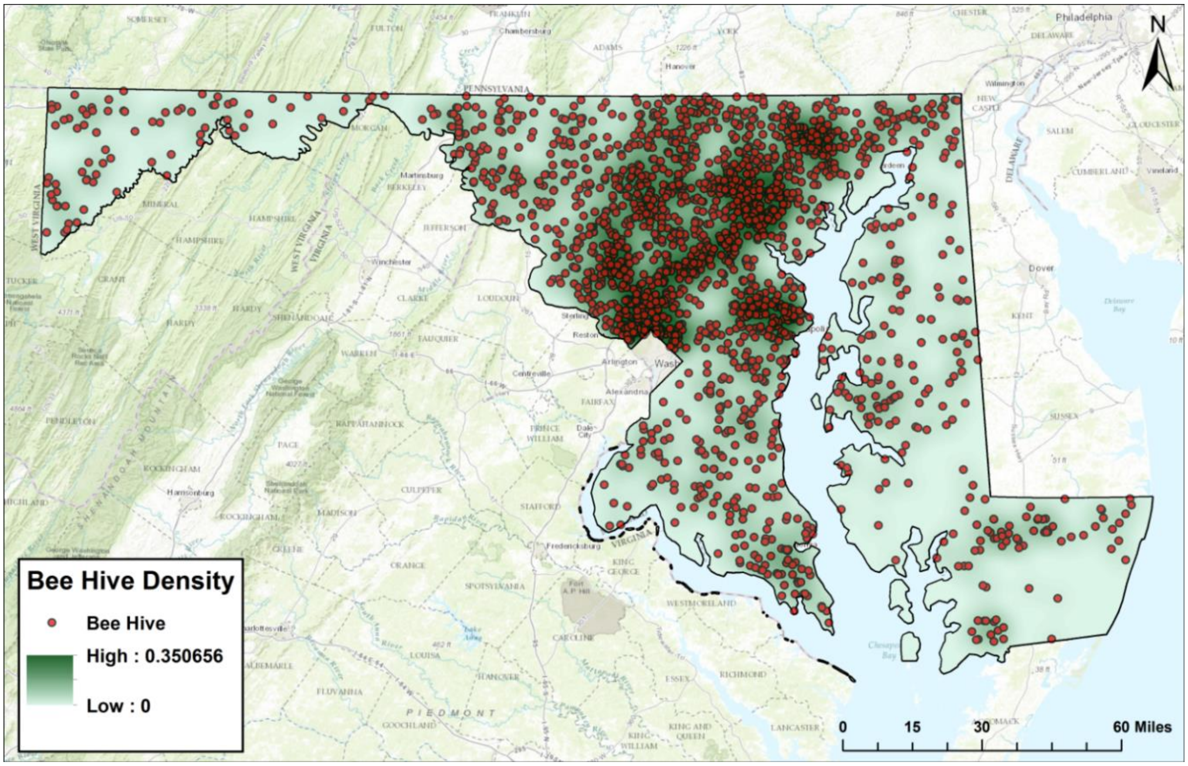


Table 9: Percentage of Registered Beekeepers in Each Degree of Suitability

Raster Score	Number of Registered Beekeepers	Percentage of Registered Beekeepers	Suitability Degree
6,7,8	410	20.84	Most Suitable
9,10	1,332	67.72	Moderately Suitable
11+	225	11.44	Least Suitable

SECTION IV: DISCUSSION

Through this analysis and by comparing the data analysis from NASA's data set to the GIS outputs, the amount of degraded or suitable natural environments and urbanized land in Maryland was quantified. The impact of six variables on the productivity of honeybees was also observed. Once these "critical areas" were determined, GIS mapping helped to localize the least suitable areas and determine possible points with a need for conservation based on the amount of degraded habitat and productivity decline. Through the use of maps, honeybee hives used for data analysis and habitat suitability determination paralleled with additional variables indicated the areas where the honeybees are facing anthropogenic interferences and inadequate natural resources; and inversely, where they are most at-risk in the State of Maryland.

The regions found to be most suitable determined by the GIS analysis were the Atlantic Coastal Plain, especially on the Eastern Shore, the Appalachian Plateau, and the Valley and Ridge Province. Similarly, the Atlantic Coastal Plain and the Valley and Ridge Provide contained the most productive hives. In general, increased productivity is found in areas of the state with lower habitat degradation. Hives were more productive when they are further away from electrical infrastructure, within close proximity of a water source, and are exposed to little interference with urbanized development. Honeybee production controlled by how the land is used and although bees can survive in urbanized and highly developed areas with close proximities to electrical infrastructure, they are much more productive in undisturbed environments or environments have lower anthropogenic inputs. At higher elevations and regions closer to the coastal plain, there is a higher percentage of most suitable or preferred land. These areas are ideal for honeybee colonies to establish their hives. These sites were the furthest away from densely populated areas and were within a close proximity to smaller tributaries that are within 16,093 m of higher order water bodies that lead into the Chesapeake Bay's connected rivers, especially the Potomac River. The length of the Potomac River was within 16,093 m of about 20% of the most productive hives. The Piedmont Province contained the majority of the least productive hives as well as the largest percentage of least suitable land. The least suitable hives were also found in areas with a large amount of developed open space, such as Baltimore. The least productive hives were found in regions with dense evergreen forests and woody wetlands as found in areas close to Ocean City. There was one hive site that was found in areas with conflicting conclusions. The hive site located in Lanham was one of the most productive hives however it is located in an area categorized as developed and urbanized land. This hive may still be productive despite being located in an area where productivity should be low is because it was located in between Greenbelt Park, the Patuxent Research Refuge, and the Lanham Forest Recreation Center. A higher resolution and more refined scale of study may help to refine the results. The results showed that on average, the closer the location of the hive to the center of the state, the less weight the hive gained and the closer to Maryland's outer border, the more productive the hive. These sites had limited access to water and food sources as well as increased exposure to highly developed and predominantly urbanized land. Differentiating the physiographic provinces was extremely helpful in identifying geologic compositions and characteristics in the regions of Maryland. It is expected that the Appalachian Plateau would have also shown productive hive sites with a large average cumulative weight gain had there been data points in this area. Additional hive sites should be added to the analysis to increase the validity of the results. As a whole, 42.92% of Maryland is considered Most Suitable, 45.49% is Moderately Suitable, and 11.58% is Least Suitable or Compromised.

The suitability analysis showed that areas with both high and low elevation, slope, and aspect were productive and suitable areas. These three variables may help to observe land use but do not seem to be directly correlated to productivity as hives thrive in all ranges of the variable characteristics. Open water and inland waterways were found to be related to productivity but not overall suitability. The bees may be able to compensate for exclusion from these variables by other sources of water not considered in this analysis. Land use cover was found in a wide range across the state with the most suitable areas occurring where land cover consists of mixed forest, cultivated crops, and deciduous forest and are far away from developed open spaces as well as evergreen forests. These findings may occur as a result of the food sources found in these areas. Mixed and deciduous forests are found to have a wide variety of plant sources unlike dense evergreen forests. Bees require multiple sources of food in order to obtain the necessary variety of constituents in their diet, exposure to various pathogens that aid in immunity, and to avoid malnutrition in situations that occur such as the pollination of monocultures. Urbanization may contribute to degraded and compromised suitability as trees and potential natural hive sites as well as flowering plants and access to food sources are excavated and relatively absent in these areas. Areas with a large amount of electrical infrastructure, especially towers, substations, and transformers, were determined to impact productivity negatively and areas with less electrical infrastructure were both more productive and more suitable. The GIS analysis overall helped to identify and quantify the suitable habitat however, the productivity and weight gain of the hives may be too variable or affected by unrelated factors as there were scattered results throughout the state. As conducted in this study, productivity should be used to confirm the suitability conclusions but not as a defining variable of suitability.

There were areas in Maryland without weighed and observed hives. The lack of hives in these areas may be due to the land use which is predominately large crop land as well as a more rural area, without a lot of urbanization, and with a lower population. Although it would have been better to have hive sites throughout the entirety of Maryland, the GIS Analysis spanned the entire state and therefore the results included the suitability analysis in the areas without hives. It was interesting that the areas with the least amount of hives and lowest population are some of the most suitable areas indicating urbanization and colonization, especially in Coastal Maryland, have an impact on hive productivity. This impact may be attributed to habitat degradation, hazardous and anthropogenic inputs to the environmental system such as contaminants, pesticides, and pollution, and the depletion of food sources through excavation and development in urbanized areas. Additional studies are needed to confirm these hypotheses and the degree in which urbanization impacts the ability for honeybee colonies to compensate and thrive in their environment. As previously stated, Colony Collapse Disorder is believed to be the result of the combined effects of habitat degradation, pest infestation, diminished immunity, pesticide toxicity, and radiation. This study observed various facets of these triggers; habitat degradation and radiation seem to hold minor influences in the collapse of colonies. The colonies still seem to be somewhat productive, even in areas with increased urbanization, and Maryland as a whole has mostly suitable land to provide for a fecund colony. In previous sections of this paper, it was discussed that colonies plagued by pests and diseases can be treated for these symptoms and potentially dangerous conditions with a variety of treatments. The treatments range from strong and harsh with risky effects on the honeybee colony as well as human populations including CheckMite and Perizin (Karus et al., 1994), to less hazardous and simple treatments such as powdered sugar that pose no threat to the bees or humans (Aliano, 2015). Diseases and compromised immunity can be controlled considerably in most colonies. The likely cause to the majority of these collapsed colonies is the over and improper use of illegal and especially hard pesticides that result in toxicity.

Error Discussion/Future Studies

In order to obtain more precise results, a higher resolution data set could have been used for GIS Analysis with additional resources. Each county in Maryland had access to raster datasets, usually derived from aerial borne Lidar sensors like UAVs or drones or terrestrial borne Lidar sensors that could be generated using Lidar "Point Clouds" software at resolutions including 1 m, 2 m, 10 m, etc. which is unique to this state and would allow the creation of more in depth Digital Elevation Models (DEMs). The project was originally conducted using 1 m resolution datasets and unfortunately not all the variables could be analyzed with this resolution measurement. The GIS Analysis had to be re-conducted using a 30 m resolution dataset. In order to refine these results and find a more accurate representation of the state's suitability, a more defined resolution could be used once additional data are collected in more detailed formats or with the assistance of technological advances such as access to vast amounts of computer storage. Additional processes may be included in additional GIS and habitat suitability studies including an analysis of the statistical significance of a variable to the organism. A more advanced analysis may include the geostatistical procedure of kriging which models interpolated values using regression analysis to determine data-driven weighting and an estimation of error. Additionally, the Maryland State Outline was cut to only include the data falling within the state. In future analysis, a buffer of 10 miles around the state should be included to account for topographical features in nearby regions within the flight path of the bees as well as encroaching electrical infrastructure. It was found that the Eastern Shore was a productive and suitable area however this finding may be overestimated if the farms in those particular areas are using excessive amounts or dangerous types of pesticides. A sensitivity analysis could be conducted to reveal the variation in suitable cover under differing assumptions of the ratings. For example, Land Cover could be processed three separate times to reflect "Cultivated Crops" as Most Suitable, Moderately Suitable, and Least Suitable in order to test if this category had a negative or positive or neutral impact on suitability if pesticides are believed to be used in these fields. Although this study was sufficient in completing the objectives, additional analysis may increase the validity of the results and further explain modeled phenomenon occurring in this research.

This project originally included an analysis of the types of crops and their specific nature as classified by crop land in the land use categories. Unfortunately, this analysis was unable to be conducted due to the limited data sets available that identify specific crops throughout the year and state. However, it was found that the most suitable land occurs in areas with cultivated crops based on the land cover and use data from the MRLC. In future studies, the investigation of agricultural land use and crop types can be conducted to obtain the planted and harvested acreage of a particular crop, the crop's benefit to pollinators or lack thereof, the production per acre of land, and the value of the production to determine the precise economic value of honeybees and other pollinators. Specific crop and plant distribution data were researched via the reports from the Maryland Department of Agriculture, and the Maryland Department of Natural Resources (Delgado, 2011), the U.S. and Maryland Forest Service (Dodds, 1999), FireScience.gov (Stone, 2009) and the Maryland Food System Map (Johns Hopkins Center, 2016). A data set needs to be compiled of specific crop types, amounts, and locations to quantify the economic impact of honeybee pollination behaviors. It is known that bees are the only insect that provide food for humans and are the single largest contributor to crop pollination and produce production. Quantifying the exact amount of economic value the crops possess in each state and the capital agricultural industry and commerce sectors would lose if the population were to decline further could increase interest in the topic and aid in the preservation of the species. Another option would be to compare the gross amount of produce pollinated by honeybees in Maryland and compare this number with other states across the country. This information would identify the economic value of honeybee pollination and quantify the amount of pollination occurring in each state. With more resources and access to data, a crop analysis could assist greatly in identifying suitable habitats, slowing declining populations, increasing pollination efficiency of crops and honey production.

In the future, additional studies may be conducted to analyze the impact of urbanization on native and domesticated honeybee populations and further investigate factors that contribute to habitat suitability. Furthermore, it would be interesting to conduct studies based on land cover changes over time. There are datasets provided by the Multi-Land Resource Consortium that displays how land cover has changed from 1992 to present day. This type of study, identifying how anthropogenic and urbanized sprawl have taken over specific types of land cover and changed their uses, was not conducted in this report as the hive data would not have been consistent with the original data set. Climate was also not included in the analysis because the changes in climate over time are extremely variable across the state of Maryland but may be assed based on the ability of a colony to adapt and thrive in particular microclimates. Furthermore, the physiographic regions were shown to have significant differences in the quantity and degree of suitability. At various elevations, the rock and sediment types present help to identify or predict particular types of vegetation present in these regions. The differences in suitability at higher elevations may be due to variations in the species and population of flowering plants. It would be interesting to include additional vegetation that may be found in these areas based on soil and sediment conditions as well as elevation and zonation further from the coast.

Three hives, for which data were collected during 1952 -- 1964 and were not used in this study, showed immense differences in productivity in the past compared to current measurements of productivity. This study was not intended to compare productivity changes over time and further studies could be conducted to demonstrate the change in suitability from before urbanization to modern characteristics of the State. However, it was interesting to observe that productivity was in some cases 4.6 times higher in previous years than productivity in some of the same areas currently. Additional studies should be conducted to quantify the degree to which land changes has affected the honeybee productivity and pollinator populations.

Research Implications

As previously stated, by utilizing the theoretical model generated by this study, this process can be used to analyze habitat suitability of honeybees in additional areas as well as suitability for additional organisms and other pollinators with similar preferences and requirements. Organisms for which the model can be applied include at-risk pollinators such as endangered bats, birds, butterflies, moths, skippers, and other insects (U.S. Fish and Wildlife Service, 2016).

The formulas generated from this study can be used as a template and model to understand and analyze the habitat suitability of additional states nationwide. The NASA Bee Net provided similar data sets of additional hive sites that are weighed and observed around the country. Land use and cover data sets are available through a variety of resource databases and organizations with paralleled information to continue the expansion of this study.

Additionally, the information provided by this study identified areas that are weakened or compromised in their ability to maintain biotic populations and environments. By using these results, remediation and restoration efforts can be conducted to counteract these effects. Conservation efforts can be implemented for areas that are at-risk of becoming unsuitable or compromised. These efforts could include reducing the amount of infrastructure (commercial, residential, and electrical), replacing vegetation that has been destroyed or depleted, and altering land use changes or development to be attentive to these impacts.

This information can be used towards an Environmental Impact Review and elicit additional conservation through management and protection of these critical areas. The Baltimore County Chesapeake Bay Critical Area Program was intended to protect the natural resources and improve the habitat suitability and therefore, reducing the decline of honeybees in Maryland. Although the past programs to identify critical areas were very helpful, they were established in 1988 and did not consider a modern approach with new technologies to analyze the potentially endangered species of pollinators especially honeybees as a specific entity or a combination of factors and variables contributing to their decline (Baltimore County Government, 2016). Maryland is a relatively suitable state for honeybee production and colonization. However, Maryland experienced the fifth highest amount of colony losses of all the states at a 60.9% loss last year. With the amount of suitable land quantified by this study, Maryland should contain enough resources to enable bee colonies to thrive and compensate for negative factors in a perfect environment or without detrimental anthropogenic influence.

In domesticated Maryland honeybees, habitat degradation, electrical radiation, pollution, and monoculture are factors that contribute to decreased efficiency of a hive but do not seem to be the cause for the losses. Although Varroa mites play a dominant role in diminishing the health of a colony, this study focused on domesticated hives which can be treated for the mites and therefore the mites play a larger role in losses in natural wild colonies. The last factor thought to contribute to CCD is pesticides. Although they were not directly studied in this analysis, this research indirectly points toward them by eliminating other factors of interest. The millions of acres sprayed a year as well as the chemicals used in Maryland need to be more monitored and decreased if possible. Alternative products that are less harmful to bees exist on the market and despite an increase in up-front cost; the long-term cost of losing bee populations outweighs arguments to allow particular pesticides.

Similarly to the United States Geological Survey and their National Wetlands Research Center Habitat Suitability Index Models, this methodology helped to determine species-habitat relationships and evaluate the impacts on wildlife habitat of water or land use changes. This study can be used to increase the understanding of habitat relationships and improve decision making regarding the organism and habitat in question; in this case the honeybee in Maryland. The GIS analysis developed a framework that can be applied to other states. Through this identification of zones of land that are most suitable for the bees to thrive, protection and conservation efforts around these areas should be heighted, areas that are not considered suitable require additional restoration efforts, and eventually, the honeybee decline can be slowed and even stopped.

SECTION V: CONCLUSION

Although there are areas that are suitable for honeybee colonies, Maryland contains areas that are compromised or are only moderately suitable for honeybee productivity. These areas require future conservation efforts. Rather than habitat degradation, monoculture malnutrition, pollution contamination, and radiation from electricity, Maryland bee populations are suffering from predominantly unnatural disruptions and anthropogenic inputs mainly in Central Maryland and the Piedmont Province. Maryland has vast areas dedicated to the cultivation of crops and agricultural endeavors. This state has the potential to act with great force to combat the endangerment of honeybee populations. Bees contribute largely to the balance of environmental systems and to commodity markets. A decline in bee populations gives a warning to the public and scientific communities that ecological and human health risks may be at hand. The conservation of both wild and domestic honeybees is paramount. Just as the study of metal concentrations and their control in soils and ion concentrations and their regulation in water are of paramount priority today, pesticide concentrations in food and their effect on insect and human organisms alike, land use destruction and alteration, and other contributing variables necessitate control and attention with the utmost importance. The shift from profit-driven industries to health conscientious and environmentally concerned populaces will determine the future of both pollinator and human survival.

BIBLIOGRAPHY

Alcock, J. (2013). Animal Behavior: An Evolutionary Approach. *An Evolutionary Approach*, 522.

Alemanno, A. (2013). The Science, Law and Policy of Neonicotinoids and Bees: A New Test Case for the Precautionary Principle. *European Journal of Risk Regulation*, (2), 191–207.

Aliano, N.P., & Ellis, M.D. (2015). A strategy for using powdered sugar to reduce varroa populations in honey bee colonies. Journal of Apicultural Research, 44(2), 54-57.

Baltimore County Government. (2016). Environmental Protection and Stability-Environmental Impact Review. *Environmental Protection and Sustainability. Baltimore County Government*.
<http://www.baltimorecountymd.gov/Agencies/environment/eir/index.html>

Burrough, P. A., and McDonell, R. A. (1998). Principles of Geographical Information Systems. *Oxford University Press*, 190.

Corbet, S.A., et al. (1993). Temperature and the Pollinating Activity of Social Bees. *Ecological Entomology*. (18),17-30.

Dively, G. P., Embrey, M. S., Kamel, A., Hawthorne, D. J., & Pettis, J. S. (2015). Assessment of chronic sublethal effects of imidacloprid on honey bee colony health. *PLoS ONE*, 10(3), 1–25.

Delgado, P., et al., DNR: Maryland. (2011). National Estuarine Research Reserve: A Site Profile. *NOAA Office for Coastal Management/ Chesapeake Bay National Estuarine Research Reserve,* 1-450.

Dodds, K. J., & Smallidge, P. J. (1999). Composition, vegetation, and structural characteristics of a presettlement forest in western Maryland. *Castanea*. 64(4), 337-345.

Favre, D. (2011). Mobile phone-induced honeybee worker piping. *Apidologie*, 42(3), 270–279.

Fishel, F. M., & Ferrell, J. A. (2010). Managing Pesticide Drift. *UF/IFAS Extension*, PI232, 1–16.

Food and Agricultural Organization. (2015). "Honey Bee Diseases and Pests: A Practical Guide." Honey Bee Diseases and Pests: A Practical Guide. *Food and Agricultural Organization*.

Foy, A.S. (2007). A GIS-Based Landscape Scale Model for Native Bee Habitat. *Virginia Tech*.

Genersch, E. (2010). Honey bee pathology: Current threats to honey bees and beekeeping. *Applied Microbiology and Biotechnology*, 87(1), 87–97.

Gill, R. J., Ramos-Rodriguez, O., & Raine, N. E. (2012). Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Nature*, 491(7422), 105–8.

Gunderson, Dan. (2015). USDA Whistleblower Launches New Bee Research Effort. *MPR News*.

Heinrich, B., & Esch, H. (1994). Thermoregulation in Bees. *American Scientist*, 82 (2) 164-170.

Johns Hopkins Center. (2016). The Maryland Food System Map. *Johns Hopkins Center for a Livable Future*. < http://mdfoodsystemmap.org/>

Josephs, L. (2014). Orange Woes, Higher Prices. *Barron's*.

Jacobs, S. (2015). European Hornet. *Penn State University Department of Entomology*. 1-2.

Karaboga, D. (2005). An Idea Based on Honeybee Swarm For Numerical Optimization. *Erciyes University*.

Karus, B., & Berg. S. (1994). Effect of a lactic acid treatment during winter in temperate climate upon Varroa jacobsoni Oud. and the bee (Apis mellifera L.) colony. *Experimental and Applied Acarology*, 18(8), 459-468.

Madden, M. (2009). Manual of Geographic Information Systems. American Society for Photogrammetry. 29(5), 527-585.

Maryland Geological Survey. (2016). Maryland Geology. *Maryland Department of Natural Resources*.

Mattila, H. R., K. M. Burke, and T. D. Seeley. (2008). Genetic Diversity within Honeybee Colonies Increases Signal Production by Waggle-dancing Foragers. *Proceedings of the Royal Society B: Biological Sciences,* 275(1636), 809-16.

McCullough, I., & Young, A. (2008). Habitat Suitability Analysis of the Critically Endangered Florida Panther. *Colby College Department of Environmental Studies.*

McGrath, P. F. (2014). Politics Meets Science: The Case of Neonicotinoid Insecticides in Europe. *Surveys and Perspectives Integrating Environment and Society, (*7.1), 1-11.

Moisset, B. B., & Buchmann, S. (2011). Bee Basics: An Introduction to Our Native Bees. *Bee Basics: An Introduction to Our Native Bees*, 40.

Moore, D. (2001). Honey bee circadian clocks: behavioral control from individual workers to whole-colony rhythms. *Journal of Insect Psychology*, 47 (8), 843-857.

Morse, R.A., & Calderone, N.W. (2000). The Value of Honey Bees As Pollinators of U.S. Crops
in 2000. Pollination, 1-31.

Mortiz, R.F.A, & Southwick, E. E. (1992). Bees as Superorganisms: An Evolutionary Reality. *Springer-Verlag.*

MRLC. (2015). Multi-Resolution Land Characteristics Consortium (MRLC). *MRLC: National Land Cover Database.* <http://www.mrlc.gov/>

NASA, Esaias, W., Nickeson, J. et al. (2015). HoneyBeeNet Database. *National Aeronautics and Space Administration: Goddard Space and Flight Center*. <https://honeybeenet.gsfc.nasa.gov/>

NASS, USDA. (2011). Agriculture in Maryland Statistics for 2011. *United States Department of Agriculture*, 1-64. <https://www.nass.usda.gov/Statistics_by_State/Maryland/Publications/Annual_Statistical_Bulletin/2011/MD%20AG.pdf>

Naug, D. (2009). Nutritional stress due to habitat loss may explain recent honeybee colony collapses. *Biological Conservation*, 142 (10), 2369-2372.

NRDC. (2016). Save Our Bees: Colony Collapse Disorder. *National Resources Defense Council*.

Natural Resources Conservation Service. (2011). Land Use Database. *United States Department of Agriculture.* < http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/>

NOVA. (2000). Hive Temperature. *Public Broadcasting Service.*

Osinski, C. D. (2010). Carry or Not Carry? When the Commodity Market Is under Stress. *INOKS Capital SA*, 1-13.

Owens, K., and Feldman, J. (2004). Getting the Drift on Chemical Trespass: Pesticide Drift Hits Homes, Schools and Other Sensitive Sites throughout Communities. *National Coalition Against the Misuse of Pesticides*. 24(2), 16-21.

Pettis, Jeffery S., Dennis Vanengelsdorp, Josephine Johnson, and Galen Dively. (2012). Pesticide Exposure in Honey Bees Results in Increased Levels of the Gut Pathogen Nosema. *Naturwissenschaften.* 99(2),153-8

Pettis, Jeffery S., Elinor M. Lichtenberg, Michael Andree, Jennie Stitzinger, Robyn Rose, and Dennis Vanengelsdorp. (2013) Crop Pollination Exposes Honey Bees to Pesticides Which Alters Their Susceptibility to the Gut Pathogen Nosema Ceranae. *PLoS ONE.* (8)7, 1-9.

Ratnieks, F. L. W. (2000). How far do bees forage. *Bee Improvement.* (6), 10-11.

Richardson, J. (2012). Have Bees Become Canaries in the Coal Mine? Why Massive Bee Dieoffs May Be a Warning About Our Own Health. *AlterNet (Food).*

Rosenberg, Jay. (2010). Dead Bees. *Hayes Valley Farm.*

Sass, Jennifer. (2011). Why We Need Bees: Nature's Tiny Workers Put Food on Our Tables. *National Resources Defense Council*, 1-2.

Schmidt, L. S., Schmidt, J. O., Rao, H., Wang, W. Y., & Xu, L. G. (1995). Feeding preference and survival of young worker honey-bees (HYMENOPTERA, APIDAE) fed rape, sesame, and sunflower pollen. *Journal of Economic Entomology*, *88*(6), 1591–1595.

Seeley, T. D. (1985). Honeybee Ecology: A Study of Adaptation in Social Life. *Princeton University Press.*

Seeley, T. D. (1995). The Wisdom of the Hive: The Social Physiology of Honey Bee Colonies. *Cambridge: Harvard University Press*.

Seeley, T.D., & Buhrman, S. (1999). Group decision making in swarms of honey bees. *Behavioral Ecology and Sociobiology*, 45 (1), 19-31.

Seeley, T. D., & D. R. Tarpy. (2007). Queen Promiscuity Lowers Disease within Honeybee Colonie. *Proceedings of the Royal Society B: Biological Sciences. (*247)1608, 67-72.

Selby, Gerald. (2005). Ottoe Skipper (Hesperia ottoe W.H. Edwards): A Technical Conservation Assessment. *United States Department of Agriculture Forest Service*. 1-35.

Smart, Matthew D., Jeff S. Pettis, Nathan Rice, Ned Euliss, and Marla S. Spivak. (2016). The Influence of Agricultural Land Use on the Survival and Productivity of Commercial Honeybee (Apis Mellifera). Colonies in the Prairie Pothole Region of the U.S. *University of Minnesota/USDA*. 1-259.

Son, D.J. (2007). Therapeutic application of anti-arthritis, pain-releasing, and anti-cancer effects of bee venom and its constituent compounds. *Pharmacology & Therapeutics*, 115 (2), 246-270.

Stone, Katharine R. (2010). Robinia pseudoacacia. *Fire Effects Information System, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.* <http://www.fs.fed.us/database/feis/plants/tree/robpse/all.html>

Taverna, K., Halbert, J.E., and Hines, D.M. (1999). Eastern Cougar: Habitat Suitability Analysis for the Central Appalachians. *Appalachian Restoration Campaign & Heartwood.*

Time and Date. (2016). Today's Sun Position. *Maryland Sun & Moon Times Today: Time and Date*. <https://www.timeanddate.com/astronomy/usa/baltimore>

Traynor, Joe. (2002). How Far Do Bees Fly? One Mile, Two, Seven? And Why? *Bee Culture/ Bee Source*.

United States Environmental Protection Agency. (2015). Federal Insecticide, Fungicide and Rodenticide Act Compliance Monitoring. *Environmental Protection Agency.*

University of Illinois. (2016). Pollination by Honeybees. *University of Illinois: College of Agricultural, Consumer, and Environmental Sciences.*

University of Kentucky. (2015). Basic Beekeeping Operations. *University of Kentucky: Department of Entomology and Agriculture.*

University of Maryland. (2016). Nation's Beekeepers Lost 44 Percent of Bees in 2015-16. *Bee Informed Partnership at the University of Maryland for the United State Department of Agriculture.*

U.S. Fish and Wildlife Service. (2016). Pollinators Federally-listed as Endangered or Threatened Species. *Endangered Species Program.*

USDA, Kaplan, Kim. (2015). Agricultural Research Service: Honey Bee Health and Colony Collapse Disorder. *United States Department of Agriculture*.

VanEnglesdorp, Dennis. (2016). Sentinel Hives: Guardians of Honey Bees. *University of Maryland.*

VanEngelsdorp, Dennis. (2016). Sentinel Hives. *Dennis VanEngelsdorp Honeybee Epidemiology Lab/ University of Maryland.*

Winston, Mark L. (1987). The Biology of the Honey Bee. *Cambridge: Harvard University Press.*

The World Bank. (2016). GEM Commodities. *The World Bank Group*.

Zissu, Alexandra. (2015). The Buzz About Colony Collapse Disorder. *National Resources Defense Council*.

APPENDIX

Appendix 1: Envirogram

WEB			CENTRUM
3	2	1	

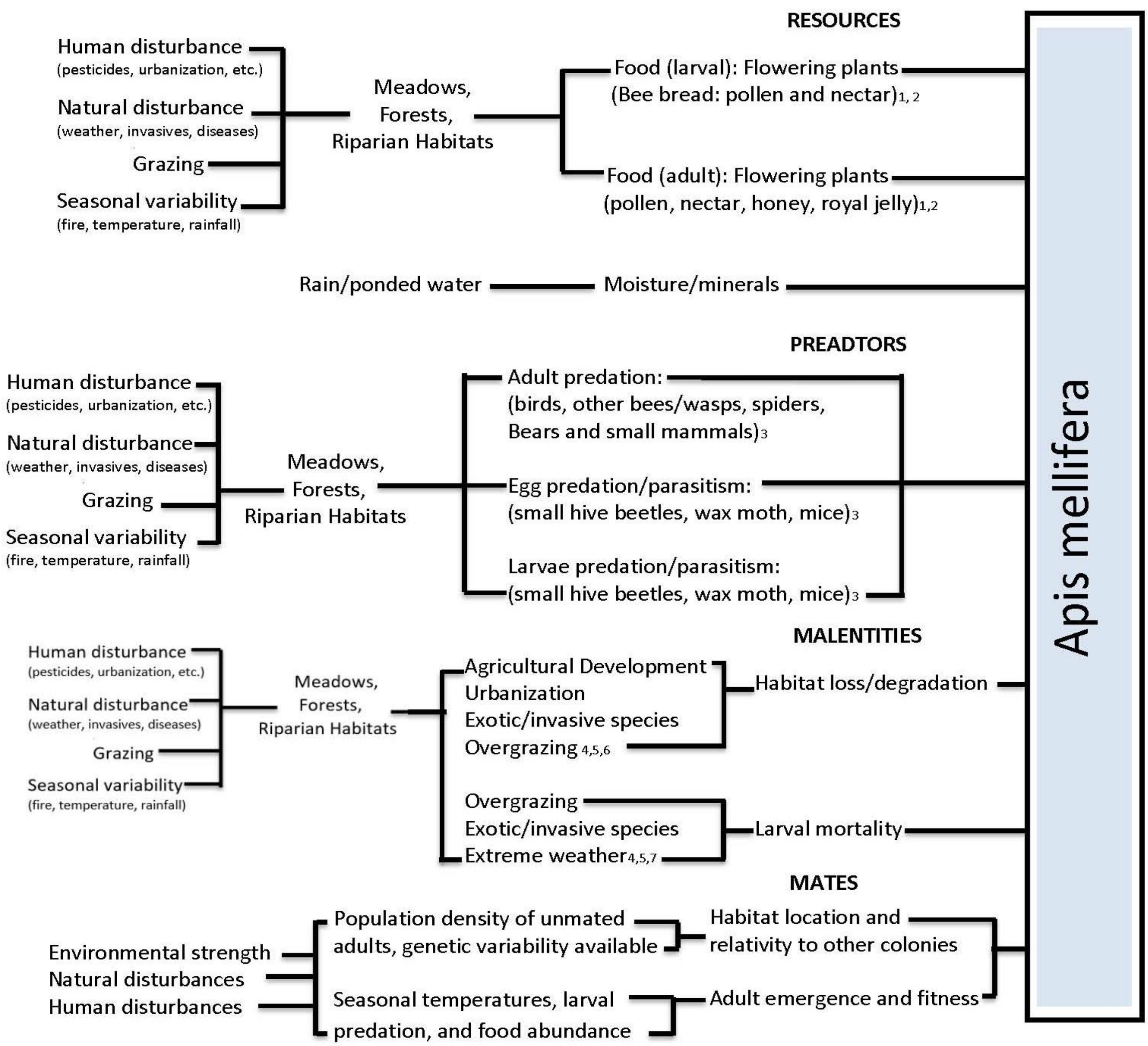


Figure 1: Envirogram for Apis mellifera

1 Schmidt, 1995; 2 Seeley, 1995; 3 Genersch, 2010; 4 USDA, 2015; 5 Selby, 2005; 6 Jacobs, 2015; 7 FAO, 2006. (See References page for complete citations)

Appendix 2: Hive Site Productivity Ranking

Hive Site	Ave. Cum. Gain (Pounds)	Rank
White Hall	0.7716	1
DC USDA HQ	0.7634	2
Clinton	0.6723	3
Lanham	0.6579	4
Leonardtown	0.6448	5
Rockville	0.6219	6
Annapolis	0.6210	7
Fairland	0.6193	8
College Park	0.6163	9
Columbia	0.6150	10
Loch Raven	0.6104	11
Keedysville	0.6011	12
Parkton	0.5987	13
Salisbury	0.5938	14
Frederick	0.5884	15
Williamsport	0.5821	16
New Market	0.5810	17
Woodbine	0.5677	18
Woodbine 2	0.5609	19
Church Hill	0.5478	20
Arnold	0.5259	21
Halethorpe	0.5251	22
West Friendship	0.5198	23
Highland	0.5125	24
St. Leonard	0.4930	25
New Windsor	0.4900	26
Chevy Chase	0.4826	27
Sykesville	0.4800	28
Sykesville 2	0.4698	29
Beltsville	0.4642	30
Dunkirk	0.4598	31
Westminster	0.4582	32
Catonsville	0.4397	33
Eldersburg	0.4042	34
Parsonsburg	0.3703	35
Forest Hill	0.3244	36
UMD Farm	0.3040	37
Clarksville	0.2807	38
* 1 = Highest Gains		
* 38 = Lowest Gains		

Appendix 3: Table of Variables and Databases

Variable	Database	Year
Land Cover	MRLC & NLCD	2011
Distance to Open Water	MRLC & NLCD	2011
Distance to Inland Waterways	State of MD	2015
Slope	State of MD- DEM	2015
Aspect Ratio	State of MD- DEM	2015
Distance to Electrical Infrastructure	Open Source Street Maps	2016
Honeybee Productivity	NASA Bee Lab	2012
Registered Beekeepers	MDA	2016

*DEM: Digital Elevation Model

Appendix 4: Degrees of Suitability of Hive Sites

Hive Site	Raster Score	Suitability Degree
White Hall	9	Moderately Suitable
DC USDA HQ	9	Moderately Suitable
Clinton	9	Moderately Suitable
Leonardtown	9	Moderately Suitable
Annapolis	10	Moderately Suitable
College Park	8	Most Suitable
Columbia	11	Least Suitable
Loch Raven	10	Moderately Suitable
Keedysville	9	Moderately Suitable
Parkton	9	Moderately Suitable
Salisbury	9	Moderately Suitable
Frederick	9	Moderately Suitable
New Market	10	Moderately Suitable
Woodbine	8	Most Suitable
Woodbine 2	10	Moderately Suitable
Church Hill	10	Moderately Suitable
Halethorpe	11	Least Suitable
West Friendship	9	Moderately Suitable
Highland	9	Moderately Suitable
St. Leonard	9	Moderately Suitable
New Windsor	9	Moderately Suitable
Sykesville	9	Moderately Suitable
Sykesville 2	9	Moderately Suitable
Beltsville	10	Moderately Suitable
Dunkirk	7	Most Suitable
Westminster	9	Moderately Suitable
Catonsville	10	Moderately Suitable
Eldersburg	8	Most Suitable
Parsonsburg	10	Moderately Suitable
Forest Hill	10	Moderately Suitable
UMD Farm	10	Moderately Suitable
Clarksville	8	Most Suitable

Appendix 5: Degrees of Suitability of Registered Beekeepers

Raster Score	Number of Registered Beekeepers	Percentage of Registered Beekeepers	Suitability Degree
6	2	0.10	Most Suitable
7	56	2.84	Most Suitable
8	352	17.90	Most Suitable
9	666	33.86	Moderately Suitable
10	666	33.86	Moderately Suitable
11	222	11.29	Least Suitable
12	3	0.15	Least Suitable
TOTAL:	1,967	100.00	-

CURRICULUM VITA

NAME: Casey N. Bartoe

[redacted]

PROGRAM OF STUDY: Environmental Science

DEGREE AND DATE TO BE CONFERRED: Master of Science, 2016

Secondary education: Saint Mary's Annapolis High School, Annapolis, MD June 2009

Collegiate Institutions Attended	Dates	Degree	Date of Degree
Towson University	January 2015	Masters of Science	December 2016
Major: Environmental Science			
Concentration: Biological Resources Management			
Pennsylvania State University	August 2009	Bachelor of Science	May 2013
Major: Bio-Behavioral Health			
Minor: Biology			

Professional publications: N/A

Professional positions held:

Maryland Department of Natural Resources June 2016- Present
Annapolis, MD
Long-Term Contractual Creel Survey Field Interviewer
NOAA and NMFS sponsored studies for Federal Regulations
Access Point Angler Intercept Survey and Marine Recreational Information Program

Arlington Echo Outdoor Research Facility May 2014- August 2015
Millersville, MD
Anne Arundel County Public Schools Long-Term Substitute Teacher
The Pacific Institute of Research and Evaluation May 2012- October 2013
Beltsville, MD/ Pomona & San Diego, CA
Research Technician & Data Analyst
Immunalysis Corporation and Alere Incorporated
NHTSA National Roadside Survey

The Penn State Prevention Research Center August 2009- October 2013
State College, PA
Research Technician, Data Analyst, Roadside Manager
NHTSA National Roadside Survey
Biological & Behavioral Health Studies

The Pennsylvania State University August 2009- May 2013
University Park, PA
Research Assistant & Data Analyst
Host Susceptibility to Paraquat Neurotoxicity
Chronic Mild Stress and Self-Medication/ Addition
Student Stressor and Sleep Deprivation Study
Short- Term International Study Abroad Program- Curacao, Dutch Antilles
Herbivorous Fishes' Feeding Preferences
Coral Diseases and Laboratory Growth

The Law Offices of Timothy D. Murnane May 2006- February 2015
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