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Utilization of Remote Sensing to Analyze *AEDES* Mosquito Egg Abundance With Combined Weather Variables in Two Southeastern Coastal Cities

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UTILIZATION OF REMOTE SENSING TO ANALYZE *AEDES* MOSQUITO EGG ABUNDANCE WITH COMBINED WEATHER VARIABLES IN TWO SOUTHEASTERN COASTAL CITIES

by

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ABSTRACT

Several vector-borne diseases have recently resurfaced, and many have suddenly spread to new areas in the United States (U.S.) due to climate change and tropicalization. Two vectors of public health importance are *Aedes aegypti* and *Aedes albopictus*. The Southeastern region of the U.S. appears to be a preferential ecological niche for both *Aedes* species. *Aedes aegypti* and *Aedes albopictus* are highly susceptible to environmental conditions, such as humidity, precipitation, temperature. Remote sensing technology has proven to be useful for estimating vector populations. Miami-Dade County is an established hotspot for disease transmission. Charleston County is newly vulnerable due to similar environmental conditions. We set out to assess the two cities' *Aedes aegypti* and *Aedes albopictus* populations by looking at these ecological dynamics and land use-land cover characteristics. Our study found that there is a statistically significant association between most our weather variables in Charleston County. In contrast, 'average weekly minimum temperature' was the only statistically significant weather variable in Miami-Dade County. Additionally, In the model we found that 'high intensity developed' areas (0.0381 p-value) and 'precipitation' (<.0001 p-value) were the only variables that had a statistically significant association with mosquito egg abundance. Inconsistencies in observed effects could be due to interactions between multiple climatic factors. There is a clear need for further observational studies of the impact of climate change on mosquito populations particularly in the Southeast region of the U.S.

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CHAPTER 1

INTRODUCTION

Aedes albopictus and *Aedes aegypti* globally transmit arboviruses of public health importance (Kamal et al., 2018). While the continental U.S. has historically seen local *Aedes* arboviral transmission, these human cases have been rare (CDC, *ArboNET Disease Maps*). Yet, *Aedes* mosquito habitats are projected to steadily expand northward in the continental US over the next century (Khan et al., 2020). The Southeastern U.S. is particularly vulnerable to *Aedes*-transmitted vector-borne diseases (VBDs) given year-round high temperatures, humid environments, and proximity to endemic VBDs areas (Wilke et al., 2018). In fact, this region has already experienced rapid and significant *Aedes* mosquito expansion and establishment. *Aedes* mosquito populations are susceptible to changes in environmental conditions, and these shifting environmental variables can be used to streamline *Aedes albopictus* and *Aedes aegypti* surveillance. A greater understanding of the associated ecological dynamics and land use-land cover characteristics associated with *Aedes* population hotspots is warranted.

There is a current gap in the literature involving the application of remote sensing for vector surveillance. There is a need to define *Aedes albopictus* and *Aedes aegypti* hotspots and influences in emerging urban Southeastern areas compared to already established hotspots. Here we aim to investigate statistical correlations of land classifications and weekly weather variables (temperature, humidity, precipitation, windspeed), with *Aedes albopictus* and *Aedes aegypti* eggs abundance. We hypothesize that (1) areas with ‘Open Water’ and (2) areas classified as ‘High Intensity Developed’ will have higher *Aedes* egg abundance, and (3) cumulative high temperature-high humidity-high rainfall areas will also positively influence *Aedes* mosquito egg abundance. Understanding these complex dynamics is essential for mosquito control efforts to hinder arbovirus transmission.

CHAPTER 2

BACKGROUND

Methods & Aim

This review aims to acquire the background, surveillance, and environmental influences of *Aedes aegypti* and *Aedes albopictus* in the Southeast United States (U.S.) based on existing literature. Searches were primarily conducted using the PubMed-MEDLINE (http://www.ncbi.nlm.nih.gov/pubmed) and Google Scholar databases (https://scholar.google.com/). The review included the combination of the terms: (*Aedes* mosquitoes OR *Aedes* aegypti OR *Aedes* albopictus) and (climate change OR changing climate OR precipitation OR urbanization OR humidity OR temperature OR windspeed). The search was narrowed to English articles and aimed to focus on the last ten years (2021-2011). Presenting the most recent literature is essential to ensure context accuracy and when correctly identifying existing literature gaps. An emphasis was placed on searching for articles that conducted research in North American countries and territories.

Global Vector-borne Diseases

A vector is an organism that transmits viruses, bacteria, or parasites to humans or other warm-blooded hosts. Among these organisms are mosquitoes, ticks, sandflies, and fleas. The World Health Organization (WHO) predicts that vector-borne diseases (VBDs) account for more than 17% of all infectious diseases worldwide (WHO, *Vector-Borne Diseases*). In 2019, Malaria generated 229 million cases and 409,000 deaths, making it the most deadly VBD (CDC, *CDC - Parasites - Malaria*). The prevalence of VBDs is highest in tropical and subtropical regions, with most deaths occurring in sub-Saharan Africa (Zerbo et al.). VBDs disproportionately impact the world's poorest communities due to displacement, insufficient personal hygiene practices, inadequate housing, and lack of general resources (Nigusie et al.). Nevertheless, all humans are susceptible to VBD transmission. Several VBDs have recently resurfaced, and many have suddenly spread to new areas such as Malaria and Dengue (Wilson et al.). Several of these factors have contributed to the heightened incidence of many endemic VBDs (Kilpatrick and Randolph). Numerous VBD outbreaks have been reported since 2014, including Dengue, Chikungunya, Yellow Fever, and Zika (WHO, *Vector-Borne Diseases*). Dengue is the fastest-growing VBD globally, rising eightfold in the last two decades, from 505,430 cases in 2000 to 5.2 million cases in 2019 (Zeng et al.). The rapid increase in cases has made prevention increasingly complex (Wilson et al.). During the 2017 World Health Assembly, the 'Global Vector Control Response' was proposed as a strategic plan to reduce global VBDs by strengthening vector surveillance and control (WHO, *Global Vector Control Response*). This initiative will need to be reviewed considering the reallocation of many resources for COVID-19. It will be necessary to establish a new baseline effort after the pandemic to serve as a benchmark for evaluating the effectiveness of future vector control efforts.

Mosquito-borne Arboviruses in the United States

Arthropod-borne viruses, or arboviruses, are transmitted by arthropods to vertebrate hosts (Artsob et al.). There are over 100 arboviruses known to cause diseases in humans (Artsob et al.). As a result of the lack of specific treatments, arboviruses remain incurable (Beckham and Tyler). Only supportive care is available, including bed rest and acetaminophen for fever and pain relief (Beckham and Tyler). Infected mosquitoes are the most prominent type of arthropod that spreads disease. The Centers for Disease Control and Prevention (CDC) has labeled mosquitoes the most dangerous animal on earth, killing more humans than any other animal in recorded history (CDC, *Fighting the World's Deadliest Animal*). There are over 200 types of mosquitoes in the U.S. and its' territories (CDC). The most common types of mosquitoes that spread disease in the U.S. are *Aedes, Culex, and Anopheles* species mosquitoes (CDC). These mosquitoes transmit a wide variety of diseases, and each has specific characteristics. Up until the discovery of West Nile virus in New York City in 1999, most arboviruses disease activity was concentrated aboard in tropical climates (Weaver and Reisen). However, the U.S. has experienced unprecedented emergence of arboviral diseases (Wilder-Smith et al.).

An increasing public health concern in the U.S. is the emergence of arboviruses. West Nile virus is the leading cause of domestically acquired arboviruses in the U.S. (Goldstein). However, the other most notable arboviruses are Dengue, Chikungunya, Yellow Fever, and Zika, all transmitted by *Aedes* species mosquitoes (Wilder-Smith et al.). There was approximately 93% of U.S. arboviral cases from April through September 2018, coinciding with peak mosquito season (McDonald). In 2018, 2,813 domestic arboviral disease cases were reported to the CDC (Vahey). There were cases reported from all states except Hawaii and New Hampshire (McDonald). Out of 3,142 counties in the U.S., 27% reported at least one case of an arboviral disease (McDonald). The U.S. is becoming increasingly vulnerable as arbovirus cases rise. Due to the severity and lack of effective treatment of arboviruses diseases, surveillance is essential to promote prevention efforts.

Introduction to Aedes albopictus and Aedes aegypti

The two most prevalent mosquito species in the U.S. are *Aedes aegypti* and *Aedes albopictus* (Khan et al.). Both species transmit a variety of arboviral diseases to humans. *Aedes aegypti* and *Aedes albopictus* are unique in quickly adapting to new environments (Reinhold et al.). *Aedes aegypti* is nicknamed the Yellow Fever mosquito because it primarily transmits Yellow Fever, Dengue, Chikungunya, and Zika (Massad et al.). *Aedes albopictus* is nicknamed the Asian Tiger mosquito and mainly transmits only Chikungunya and Dengue (Kamal et al.). The *Aedes* mosquito originated in tropical regions like Africa and Southeast Asia, but now *Aedes* mosquito populations can be found worldwide (Ryan et al.). Human interventions, such as urbanization and globalization, have led to the spread of *Aedes* mosquitoes beyond their native ranges (Kraemer et al.). In contrast with other mosquito species, adult *Aedes* mosquitoes have narrow bodies (Rogers). Adult *Aedes* mosquitos can also be recognized by alternating light and dark bands on their abdomen and legs (Rogers). *Aedes albopictus* and *Aedes aegypti* are similar in appearance, but *Aedes albopictus* is smaller and has a white stripe along the top of the thorax (Carpenter and LaCasse).

Life Cycle

In *Aedes* mosquitoes, there are four life stages (egg, larva, pupa, and adult) (CDC, “Mosquito Life Cycles | CDC”). The entire *Aedes* mosquito life cycle takes approximately 8-10 days (CDC, “Mosquito Life Cycles | CDC”). The female *Aedes* mosquito lays between 50 and 120 black eggs on sides of these containers near the waterline (CDC, “Aedes Aegypti and Ae. Albopictus Mosquito Life Cycles | CDC”). These insects breed in small natural or artificial containers, including planters, plastic containers, and tires (CDC, *Zika, Mosquitoes, and Standing Water | Blogs | CDC*). The eggs adhere to the container walls and are then immersed in the water (CDC, “Mosquitoes in the US | CDC”). If fully submerged in water, eggs hatch into larvae within 48 hours (Zheng et al.). In the Southeast U.S., *Aedes* mosquito eggs can even survive through winter, which is unique compared to other mosquito species (CDC, “Aedes Aegypti and Ae. Albopictus Mosquito Life Cycles | CDC”). *Aedes* mosquito eggs are resistant and can be easily accidentally transported, which has assisted them in migrating around the world (Eritja et al.). The eggs of both *Aedes aegypti* and *Aedes albopictus* can survive in tiny pools of water, such as the bottom of a canned soda (CDC, “Aedes Aegypti and Ae. Albopictus Mosquito Life Cycles | CDC”). The temperature determines the rate of development of the eggs into full-grown larvae (Rafael Marinho et al. . After hatching, the young mosquito larvae are fully adapted to living underwater (CDC, “Mosquito Life Cycles | CDC”). Following the larval stage, the pupa remains living in the water (CDC, “Mosquito Life Cycles | CDC”). Pupae are in a resting and non-feeding stage of development (Prabakaran et al.). However, the pupae can respond to light changes and movement (Prabakaran et al.). After emerging from the water, adult *Aedes* mosquitoes mate, and the females feed on blood within two days (Rogers). The female mosquito seeks water sources to lay eggs after feeding (CDC, “Mosquitoes in the US | CDC”). *Aedes aegypti* and *Aedes albopictus* do not travel long distances, sometimes only living within a few blocks their whole life (CDC, “Mosquito Life Cycles | CDC”).

Host Preference

Mosquito species differ in feeding preferences, which determine their contact rates with pathogens and vertebrate hosts (Cebrián-Camisón et al.). Mosquito population dynamics are subject to daily as well as seasonal meteorological variability (Hemme et al.). *Aedes aegypti* feeds almost exclusively on humans, thus thriving in urban settings (Gubler). *Aedes aegypti* will preferentially feed on humans, even in the presence of alternative hosts (Gunathilaka et al.). It is believed that *Aedes aegypti's* preference for humans can be explained by just two ecological factors—dry season intensity and regional human population density (Rose et al.). Human generated water containers have led to the domestication of *Aedes* mosquitoes and are closely associated with the species becoming dependent on humans (Powell et al.). It has been found that the odorant receptor pathway is crucial for an anthropophilic vector mosquito like *Aedes aegypti* to discriminate human from non-human hosts (DeGennaro et al.).

Often considered a secondary vector of human arboviruses, *Aedes albopictus* lives in a broader range of environments, including rural and suburban ones, and bites a wide variety of hosts (Rose et al.). *Aedes albopictus* is an opportunistic feeder (Faraji et al.). *Aedes albopictus* is the only *Aedes* mosquito species to feed on ectotherms (Cebrián-Camisón et al.). *Aedes aegypti* is considered a more suitable vector for arboviruses (Rodrigues et al.). However, *Aedes albopictus* can vector many of the same viruses with the ability to expand its range (Brady et al.).

Ecology

In order to rest and find hosts, *Aedes aegypti* prefers to inhabit human habitations (Getachew et al.). As a result, *Aedes aegypti* is often found inside buildings. Densely populated areas in which water supplies, waste management, and sanitation are inadequate, *Aedes aegypti* flourishes (Kolimenakis et al.). *Aedes albopictus*, in contrast, possesses a different ecology due to its ecological plasticity (Waldock et al.). *Aedes albopictus* competes more successfully for food resources than other *Aedes* species (Bonizzoni et al.). *Aedes albopictus*, has a very broad host range and attacks humans, livestock, amphibians, reptiles, and birds (Kweka et al.). *Aedes albopictus* inhabits densely vegetated rural areas, however, they can colonize many types of man-made sites and urban regions (Kweka et al.). Human activities are highly correlated with the rate at which *Aedes aegypti* and *Aedes albopictus* spread to new areas outside of their native ranges (Kraemer et al.). The domestic behavior of these species may provide both protection from the environment as well as a large number of breeding sites (Zahouli et al.)

Competence

Aedes mosquitoes are highly aggressive endophytic day biters that spread diseases like Chikungunya, Dengue, and Zika. (Roiz et al.). The anthropophilic biting behavior of the *Aedes aegypti* mosquito is highly efficient in transmitting arboviruses to humans, making these diseases of high public health importance (Rose et al.). These arboviruses are thought to be transmitted less effectively by *Aedes albopictus* than by *Aedes aegypti*. Nevertheless, arboviral infection susceptibility varies greatly between geographic regions and various viral strains. According to a 2014 study by Carrington and Simmons, when viremic blood arrives at the mosquito midgut, the extracellular virus binds to undefined receptors on the cellular surface of the midgut epithelium. The study notes that if the virus can successfully infect and replicate within midgut epithelium cells then a new progeny virus is shed into the hemocoel where it can disseminate and infect secondary tissues, including the salivary glands. Once sufficient virus replication has occurred in the salivary glands, the virus may be transmitted to a new host via the saliva of the infected mosquito (Carrington and Simmons). Understanding the biological processes of these mosquitoes is vital to public health in assisting in the manufacture of possible vector control methods.

Secondly, *Aedes albopictus* and *Aedes aegypti* are likely to exhibit genetic diversity among their populations (Shin and Jung). The differentiation among populations suggests that the co-evolution of *Aedes* mosquitoes and arboviruses does not favor a single pathway within the mosquito (Souza-Neto et al.). We must recognize that co-evolution of mosquitoes and viruses is an outcome of diverse and possibly broad-range processes (Rückert and Ebel). Lastly, vector control strategies encounter operational challenges due to the emergence and development of insecticide resistance (Chanda et al.).

Diseases Of Public Health Importance

The virus responsible for Chikungunya disease is the Chikungunya virus. Typically, the disease occurs in Africa, Asia, and India, but several countries in the Americas were affected by a significant outbreak in 2015 (WHO, *Chikungunya Fact Sheet*). The most common Chikungunya symptoms are fever and joint pain (CDC, *Chikungunya Virus | CDC*). In areas where Dengue and Zika are common, Chikungunya can often be misdiagnosed due to shared clinical features (WHO, *Chikungunya Fact Sheet*). The number of fatal cases associated with Chikungunya is rare and is almost always related to other underlying health conditions (Lima Neto et al.). Nonetheless, more than 30% of infected individuals experience chronic severe joint pain and inflammation that may persist for years (Cunha et al.). As a result of the lack of medical treatment for Chikungunya and other VBDs, Chikungunya is likely to spread to new regions, raising the global burden (Caglioti et al.).

Dengue is widespread in tropical and subtropical climates, mainly affecting urban and semi-urban areas (WHO, *Dengue and Severe Dengue*). Dengue is the most prevalent arbovirus disease globally (Kading et al.). There are four Dengue serotypes, making it possible to be infected four separate times (Yung et al.). Previous case reports indicate that serotype two infection results more severe disease outcomes than the other serotypes (Balmaseda et al.). While most Dengue infections produce only mild symptoms, Dengue can develop into a potentially fatal complication called Severe Dengue (Murugesan and Manoharan). In the case of Severe Dengue, early detection of disease progression and the availability of proper medical treatment result in death rates below one percent (WHO, *Dengue and Severe Dengue*). Many circumstances are contributing to the expansion of Dengue. Most Dengue infections in the U.S. are imported from countries where the disease is endemic (Bouri et al.). It is crucial to surveil for Dengue early to detect outbreaks and prevent further spread.

The Zika virus has made the most recent major headlines due to the outbreak in South America, which started in December 2015. The World Health Organization (WHO) proclaimed the outbreak as a public health emergency in February 2016 (WHO, *Zika*). The Zika virus has been detected in 86 total countries and territories (Bhargavi and Moa). According to the most recent available data, Zika was reported in several states in the Southeastern U.S. in 2018 (CDC). The majority of those infected with the Zika virus do not experience any symptoms (WHO, *Zika*). Symptoms include fever, conjunctivitis, joint pain, and headaches, lasting two to seven days (Petersen et al.). Zika has been reported to have been contracted by women who have been sexually involved with partners who suffer from Zika (Musso et al.). Furthermore, pregnant women may transmit this virus to their fetus since the virus can cross the placental barrier and cause congenital infection (Calvet et al.). Infected pregnant women have suffered from fetal complications such as congenital microcephaly, Guillain-Barre syndrome, and even fetal death (Oliveira Melo et al.). Zika is the first arbovirus to cause congenital disabilities and the only VBD known to be transmitted sexually (Mead et al.). It is imperative that further research be conducted to examine the influence of Zika virus infection on pregnancy outcomes (WHO, *Zika*).

Aedes Mosquito Disease Spread into The Southeast

There have been nine different VBDs discovered in the U.S. and U.S. territories between 2004 and 2016 (Rosenberg). The *Aedes aegypti* mosquito can primarily be found in Florida, Texas, and other Southern states (Zettel and Kaufman). *Aedes albopictus,* however, can be seen as far north as New York State (Yee). The future distribution of the *Aedes aegypti* and *Aedes albopictus* mosquitoes in the U.S. has been predicted using regional models. Regardless of the geographical location, there was an apparent trend north (Ding et al.). According to the models, the Southeastern and Southern regions of the U.S. appear to be the preferential ecological niches for both *Aedes* species (Ogden et al., Brady and Hay). The models indicate that the Southeast region of the U.S. is particularly vulnerable to the transmission of diseases (Eisen and Moore). This raises significant public health concerns since 27% of Zika cases in the U.S. occur in the

Southeast (CDC). Additionally, Dengue and Chikungunya are predicted to spread to higher latitudes and higher elevations in the U.S. as a result of climate change (Messina et al.). Another recent study suggests that the current climate is able to support Dengue transmission throughout the Southeastern U.S. (Butterworth et al.). The distribution and abundance of the *Aedes aegypti* once decreased rapidly in the U.S. after the introduction of *Aedes albopictus* in the 1980s (Reiskind and Lounibos). However, recent research suggests that some local microclimates in the U.S. primarily support *Aedes aegypti* populations (Hopperstad and Reiskind). This interaction might allow an increase in *Aedes aegypti* abundance in the U.S. in the coming years.

The proximity of Miami-Dade County, Florida, to the Caribbean region and Latin America, where endemic VBDs occur, makes the county a hotspot for VBD transmission (Wilke et al.). Miami-Dade County also provides year-round ideal environments for *Aedes* mosquitoes (Wilke et al.). Miami-Dade County experienced three outbreaks simultaneously in 2020: SARS-CoV-2, West Nile, and Dengue viruses (SECVBD). *Aedes* mosquitoes in this region will likely travel northward to neighboring states in the next decades. The Southeast will likely continue to experience VBD transmission and become an established source for invasive vector species. Detecting and controlling VBDs in the Southeast will depend on ongoing surveillance to detect outbreaks early, increase capacities, and improve preparedness in the future.

Climate Change

Throughout the Southeastern U.S., climate change has resulted in rising sea levels, higher temperatures, extreme heatwaves, heavy precipitation, and decreased water availability (USGCRP). Urban cities in the Southeast are the most at risk for these effects

(USGCRP). A number of factors have contributed to the acceleration of climate change, such as urbanization and globalization (Ebi and Nealon). If current trends in greenhouse gas emissions continue, temperatures may rise by 5°C (9°F) by the end of the 21st century (USGCRP). Climate change directly impacts local and regional weather conditions. Previously stable geographical distributions are being disrupted (WHO). Climate change also exerts a range of other indirect effects that may affect land use and irrigation practices (Campbell-Lendrum et al.).

Although environmental changes may destroy many species, mosquitoes appear to benefit from climate change (Deichstetter). In warm climates, mosquito populations more likely to expand (Deichstetter). Previous studies demonstrate that weather conditions significantly impact *Aedes* mosquito abundance (Estallo et al.). Mosquitoes are highly susceptible to environmental conditions, such as humidity, precipitation, temperature (Caminade et al.). A variation in the weather significantly impacts when and where mosquitoes flourish (Ogden). Climate change has dramatically impacted the distribution, activity, and survival of *Aedes* mosquitoes (Reinhold et al.).

Recent studies show that climate change contributes to an increase in the global burden of VBDs (Colón-González et al.). This suggests that VBDs may expand to new geographical areas. It is expected that the abundance of *Aedes albopictus* will increase by 50% by the end of the century in regions with suitable environmental conditions (Rochlin et al.). An additional 30 million individuals will be exposed to VBDs as a result of the expansion (Rochlin et al.). It is crucial to understand the ecological dynamics of these climate impacts to identify hotspots of vulnerability in the Southeast U.S. Further research is essential to ensure continued progress in reducing the burden of VBDs in the face of the additional environmental challenges caused by climate change.

Tropicalization

Tropicalization refers to the transformation of temperate ecosystems by organisms moving poleward in response to rising temperatures (Osland et al.). A place is defined as tropical by obtaining a mean temperature year-round at 64 degrees Fahrenheit (Somma). Tropicalization is a term that has been used predominantly in the marine biology field but is making its way into discussions of all ecosystem types (Osland et al.). In response to climate change, which lessens the frequency and intensity of killing freezes, tropical plants and animals that once could only survive in a few parts of the U.S. mainland are expanding their range northwards (Osland et al.). Both *Aedes albopictus* and *Aedes aegypti* are a tropical/subtropical species (CDC, "Potential Range of Aedes Mosquitoes in US | CDC"). There is a growing body of evidence pointing to a warming winter as a primary factor driving mosquito range expansion poleward (Osland et al.). Assessing the ecological implications of the tropicalization of North America would provide critical knowledge to public health to lessen disease transmission (Osland et al.).

Temperature

In the past century alone, the earth's average surface temperature has risen about 1.18 degrees Celsius or 2.12 degrees Fahrenheit (NASA). Temperature is the most influential environmental factor affecting the biological processes of mosquitoes (Alto and Bettinardi). Temperature is recognized to have a more substantial influence on mosquito abundance than precipitation (Tran et al.). As worldwide temperature increases, *Aedes* mosquitos display shorter development periods in all life cycle stages, leading to increased *Aedes* mosquitos population growth (Lai). Temperature affects the survival, development rate, mortality, and spread of the *Aedes* species. Since mosquitoes encounter daily and seasonal thermal fluctuations, they experience a range of temperatures that affect their behavior (Carrington et al.). Optimal temperatures for development, longevity, and fecundity are between 22°C (71.6°F) and 32°C (89.6°F) (Rafael et al.). Previous evidence states that regions with near 30°C (86°F) may experience declining *Aedes* populations (Upshur et al.). Feeding rates increase with temperature between 20°C (68°F) and 30°C (86°F) (Lemoine et al.). *Aedes aegypti* eggs survive at 7°C (44.6°F) for a 24h cold period, while *Aedes albopictus* eggs can survive at constant temperatures as low as −5°C (23°F) for an exposure period of 30 days in a lab setting (Tippelt et al.). *Aedes albopictus* has adapted rapidly to colder regions than *Aedes aegypti* (Hanson and Craig). One research study found that strains of *Aedes albopictus* have acclimated to a higher survival rate in North American than in tropical locations (Hanson and Craig). These adaptations have allowed the mosquito to prosper in more habitats quickly. The projected trend of temperature increase follows the growing probability of *Aedes* mosquito distribution and abundance (Liu-Helmersson et al.). Other studies using similar methodologies have reached similar conclusions regarding optimal behavior temperature for *Aedes aegypti* and *Aedes albopictus*. Even though results slightly differ between studies, the results are still representative. These differences are usually roughly only two degrees, resulting in a minimal impact. This offers valuable insight into establishing that temperature influences the abundance of *Aedes* mosquitoes.

Precipitation

Aedes aegypti and *Aedes albopictus* are ectotherms that depend upon water sources to complete their life cycles; therefore precipitation plays a critical role in mosquito abundance (Ezeakacha and Yee). The relationship between rainfall and *Aedes* mosquito affluence is complex and specific (Morin et al.). Several studies support strong associations between accumulated rainfall and higher *Aedes* mosquitos abundance (Asigau and Parker; Poh et al.; Roiz et al.). Precipitation accelerates the population growth of *Aedes* mosquitoes by forming additional breeding sites (Kache et al.). One study found that one month following floods resulted in a significantly greater abundance of *Aedes aegypti* eggs (Nosrat et al.). Evidence suggests that as global climate change intensifies, so will the frequency of extreme climate events, including floods (Tabari, 2020). Other likely future scenarios include vaster annual precipitation, more frequent summer droughts, and more significant storms (Houghton et al.). Predicted changes in precipitation vary regionally and have high variability (Alto and Juliano). Already there is an increasing trend in overall global rainfall (Myhre et al., 2019). However, some areas have become overall wetter, and others have become overall drier (Skliris et al., 2016). Water availability during extreme climate events can have important implications for VBDs transmission (Fouque and Reeder). Previous studies indicate that accumulated rainfall increases *Aedes* mosquito habitats, but floods and excessive rainfall flush breeding sites, thus reducing mosquito populations (Koenraadt and Harrington). All these precipitation factors have an impact on VBD transmission and survival. Additional research in other countries and regions will likely clarify any ambiguities.

Humidity

Although the effects of temperature and precipitation on *Aedes* mortality have been extensively investigated, the effects of humidity are less clear. A combination of higher precipitation rates and higher temperatures results in increased humidity (Morin et al.). Research studies have demonstrated a temperature-dependent relationship between humidity and the survival of female *Aedes* mosquitoes (Schmidt et al.). Mosquito activity has been shown to increase with humidity, but the effect depends on the mosquito species and local factors (Bashar and Tuno). It has been shown that high humidity is associated with greater *Aedes* mosquito feeding activity survival and egg development (Morin et al.). Although *Aedes aegypti* eggs thrived across a wide range of humidity and temperature combinations, *Aedes albopictus* eggs experienced high mortality at conditions that were less than 95% humidity when temperatures were greater than 22°C (71.6 °F) (Juliano et al.). Other studies have shown that the optimal humidity range for mosquito flight activity is between 44% and 69%, with 65% being the most suitable (Jemal and Al-Thukair). Other studies have had conflicting results illustrating the complex interactions between climatic factors (da Cruz Ferreira et al.).

Windspeed

Mosquitoes can fly at a speed of about 1 to 1.5 miles per hour (mph) (AMCA). It is commonly assumed that higher wind speeds favor the passive migration of mosquitoes; however, mosquitoes avoid areas where wind speeds approach their own. The wind serves as a natural mosquito repellant because it makes it more difficult for these insects to fly. The results of one study suggest that higher wind speeds are associated with fewer Dengue cases, while low-moderate wind speeds are associated with more cases of

Dengue (Salim et al.). It is hypothesized that high wind speeds reduce the ability of *Aedes aegypti* to fly, thereby limiting host exposure to the vector (Salim et al.). This conclusion can also be applied to *Aedes albopictus*. A low to moderate wind speed may affect the interactions of Dengue virus with hosts and, consequently, increase Dengue infections (Salim et al.). Based on the results of a similar study, wind speed has the greatest impact on Dengue incidence among all other weather factors (Sulekan et al.). It is important to note that any negative effect of wind speed may be attributable to local environmental factors that might interfere with the impact of this variable on *Aedes* oviposition activity (Santos et al.).

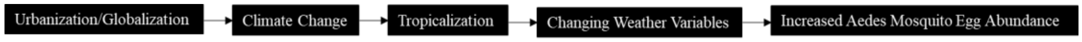

Figure 2.1 Flow Chart Describing Factors That Influence The Increase Of *Aedes* Mosquito Populations:

CHAPTER 3

METHODS

Study Areas

In spring of 2019, Florida International University (FIU) and the University of South Carolina (UofSC) began collaboration to assess the population genetics, insecticide resistance, and distribution of *Aedes* mosquito species in the Southeast U.S. The study sites selected for this study were Miami-Dade County, Florida and Charleston County, South Carolina. Sample collection occurred in both urban areas, although their urban building composition varies greatly between the two areas. Miami-Dade County is a large, rapidly growing metropolis, home to 2.7 million residents and new construction (US Census, *U.S. Census Bureau QuickFacts*). In contrast, Charleston County is home to a moderate-size city of 411,000 residents with centuries-old buildings and considerable historical preservation ordinances limiting new construction (US Census, *U.S. Census Bureau QuickFacts*). Miami-Dade and Charleston counties were ideal locations because they offered contrasting landscapes that still have year-round high temperatures, humid environments, and suggestive evidence of re-emerging *Aedes* populations.

Meteorologic Data Collection:

To model egg abundance rates, we selected several meteorological variables in accordance with the most recent literature. The meteorological data of temperature, humidity, precipitation, and wind speed were obtained from the closest meteorological stations. Weather data was collected from the nearest NOAA National Centers for Environmental Information weather stations to the mosquito collection site from each day collected. Weekly average temperature, humidity, precipitation, and wind speed in Charleston and Miami-Dade counties were used to model the association between *Aedes* mosquito egg abundance from June 2019 - August 2019. Weather data collected in conjunction with mosquito collection site was included as a variable in the regression analysis.

Mosquito Collection

Collection was focused in the summer months due to peak mosquito activity during June 2019 - August 2019. Summer months also correlate with increased human outdoor activity and exposure. Mosquito ovicups were placed in 43 residential sites in and around Miami-Dade County in conjunction with the Flordia *Ae. aegypti* Genome Group (FLAGG) internship with the DeGennaro Laboratory of Tropical Genetics. In the FLAGG project, student volunteers are given kits that contain necessary materials to set up ovicups at their residence over the summer. All surveying participants were provided instructions and sampling materials necessary to set up ovicups. Ovicups were deployed in the morning on Thursdays and collected on Sunday. Ovicups were constructed from a plastic black drinking up, labeled with FIU contact information with two holes drilled in the sides for water drainage; inside each cup was a strip of germination paper (approximately 25.4 cm x 8.9 cm). Cups were filled with 200ml tap water. Volunteers were encouraged to set ovicups in a shaded area that is protected by rainfall and wind close to an indoor location. It was also recommended that volunteers remove any other potential breeding sites from the location, to ensure there was no competition between the ovicup and other sites. When collected, water was dumped from each ovicup, and the germination paper was placed inside a single, labeled Whirl-Pak® bag (Nasco Sampling/Whirl-Pak, Madison, WI, USA). Samples were dropped off at FIU's DeGennaro Laboratory of Tropical Genetics once a month. Once samples were transported to the laboratory, germination papers were allowed to air dry for 24 hours outside of their bags. After 24 hours, all mosquito eggs were counted under a dissection scope in the laboratory. There was no differentiation made between broken/hatched/unhatched eggs. Eggs hatched, eggs already hatched, and those damaged were all counted.

Mosquito ovicups were placed in 35 sites in and around Charleston's peninsula. Sites included cemeteries, elementary schools, and various sites on The Citadel's campus. Ovicups were constructed from a plastic black drinking up, labeled with FIU and UofSC's contact information with two holes drilled in the sides for water drainage; inside each cup was a strip of germination paper (approximately 25.4 cm x 8.9 cm). Cups were filled with tap water enough so that the germination paper was halfway covered in water. Ovipcup placement was targeted for shaded brush, under trees (specifically oaks), or in tires when available. Ovicups were deployed in the morning on Mondays and collected on Fridays. When collected, water was dumped from each ovicup, and the germination paper was placed inside a single, labeled Whirl-Pak® bag (Nasco Sampling/Whirl-Pak, Madison, WI, USA). Once transported back to the University of South Carolina's Nolan Vector-Borne and Zoonotic Diseases Laboratory, germination papers were allowed to air dry for 24 hours outside of their bags. After 24 hours, mosquito eggs were counted under a dissection scope in the laboratory. After the initial eggs count, the eggs were then shipped to the FIU's DeGennaro Laboratory of Tropical Genetics in Miami, Florida.

Remote Sensing

Remotely sensed data can supply spatial information to study the epidemiology of many vector-borne diseases. Previous studies have proven the utility of remote sensing technology in assessing vector populations on a large spatial scale. Land cover data was collected from the 2019 National Land Cover Database (NLCD). We calculated the percentage of each land cover class within circular buffers of 300 meters around each collection site coordinate. The ArcGIS Pro Version-9.3 software was used to produce map layers. We also used the ArcGIS geoprocessing tool, Kernel Density, to calculate density from each point using the kernel function.

Statistical Analysis

Using SAS v9.4 statistical software, negative binomial regression analysis was performed to measure the overall effect of land classification and weather variables (temperature, humidity, precipitation, and wind speed) on mosquito abundance between Charleston, South Carolina and Miami-Dade, Florida during Summer 2019. We modeled the association between weekly weather variables and weekly mosquito egg abundance. Multivariate negative binomial regression models were fit having the number of eggs as the response and city and weather variables as predictors. A stepwise model selection procedure was used to select the final model. Next, the land cover variables were added as additional predictors and the model selection process was repeated. Finally, multivariate negative binomial regression models were fit to the data from each city separately, first including only the weather variables and then adding the land classification variables. Exceptions to the ovicup cup exposure time for each city were not found for any of the collection sites. Our city variable was indicated as Charleston (1) and Miami (0). Parameters with a p-value <0.05 were considered statistically significant.

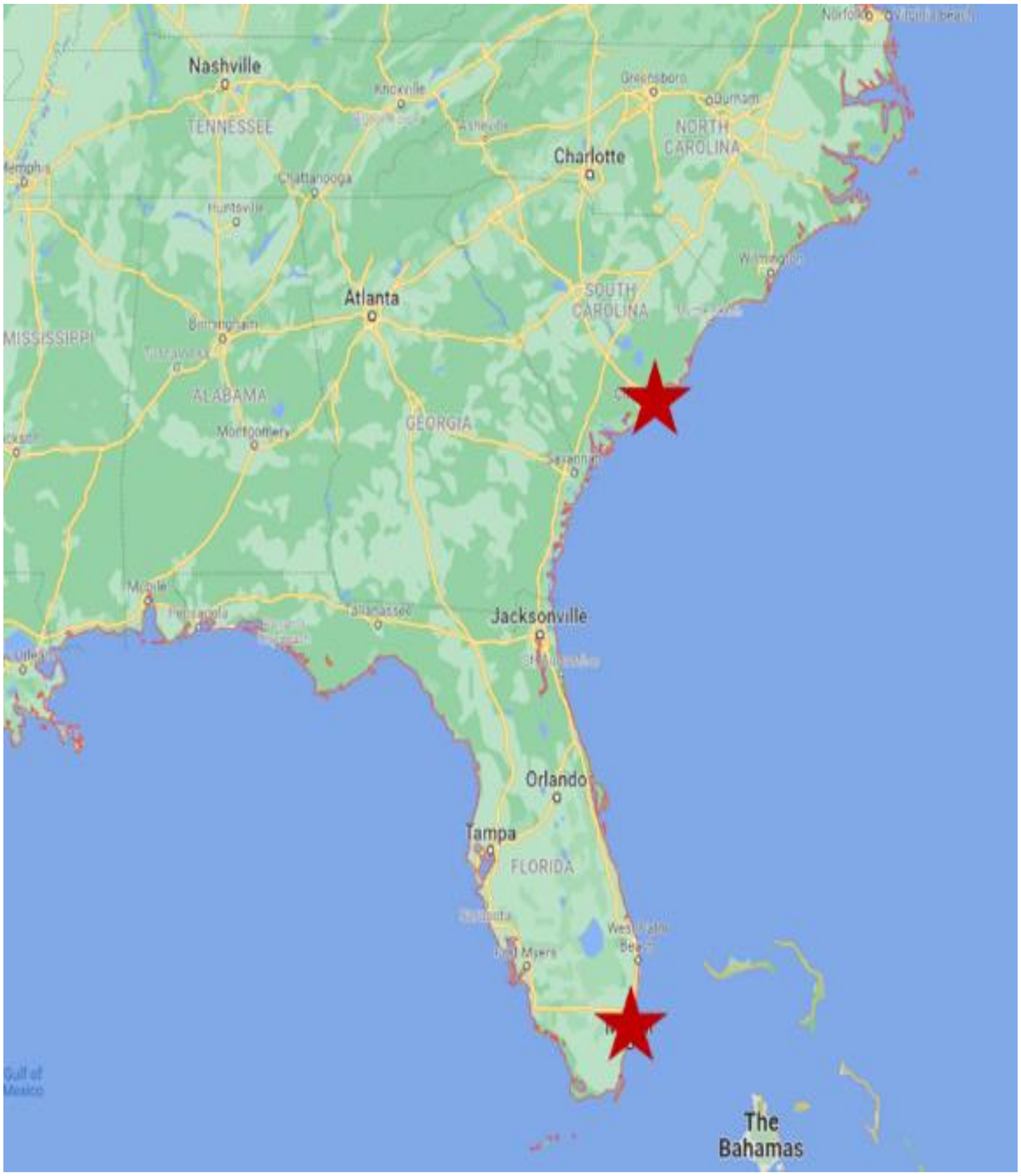

Figure 3.1. Map of Miami-Dade County & Charleston County

Figure 3.2 Ovicup Set-Up

CHAPTER 4

RESULTS

We identified two weather stations in Charleston County closest to our collection sites that were used in the statistical analysis: Downtown Charleston, S.C. U.S. (32.775, -79.9239) and Charleston Intl. Airport, S.C. U.S. (32.89943, -80.04075). Charleston Intl. Airport was only near one collection site that was also our most north point: Point 1 (32.84916, 80.00936). We identified three weather stations in Miami-Dade County that were found to be closest to our collection sites and possessed all our weather variables: Miami International Airport, F.L. U.S. (25.7881, -80.3169), Miami Opa Locka Airport, F.L. U.S. (25.90694, -80.28028), and Miami Kendall Tamiami Exec Airport, F.L. U.S. (25.6475, -80.43306). Homestead A.F.B., F.L. U.S. (25.48333, -80.38333) was also identified as a close weather station, but the station did not have record of all our weather variables, so it was not included in the statistical analyses. We used the proximity analysis feature within ArcGIS pro to assess the closest weather station to each collection site. Miami Opa Locka Airport was closest to 4 collection sites: (Points: 3, 4, 7, 23, 32). Miami Kendall Tamiami Exec Airport was closest to 17 collection sites (Points: 1, 2, 5, 6, 9, 16, 19, 21, 29, 30, 33, 34, 35, 36, 38, 40, 41). Miami International Airport was closest to the most collection sits at 19 total sites: (Points: 8, 10, 11, 12, 13, 14, 15, 17, 18, 20, 22, 24, 25, 26, 27, 28, 31, 37, 39). Day weather data was collected via National Oceanic and Atmospheric Administration (NOAA) 's Climate Data Online. Daily weather data were averaged per week for ten weeks within June 2019- August 2019.

There were 886 total eggs collected in Miami-Dade County and 8,613 eggs collected in Charleston County, for a total of 9,499 eggs. Miami-Dade County had 41 collection sites, and Charleston County had 36 collection sites. The largest number of eggs collected at a single site in Charleston County was 1,423 eggs at Magnolia Cemetery. The largest number of eggs collected at a single site in Miami-Dade County was 131 eggs in the suburb of Homestead.

Over the ten weeks, on average over a 24-hour reading, Charleston County had a maximum temperature of 88.95 degrees Fahrenheit, had a minimum temperature of 74.90 degrees Fahrenheit, 0.15 inches of rain, had a 74.83% relative humidity, and had wind speeds of 6.63 miles per hour. Over the ten weeks, on average over a 24-hour reading, Miami-Dade County had a maximum temperature of 91.92 degrees Fahrenheit, minimum temperature of 77.09 degrees Fahrenheit, 0.34 inches of rain, had a 70.65% relative humidity, and had wind speeds of 5.73 miles per hour. Miami-Dade County had a higher average maximum temperature, average minimum temperature, and precipitation while Charleston had a higher average wind speed and relative humidity.

For our statistical analyses, we used negative binominal regression to assess the association between our weekly mosquito egg collection site abundance and weekly weather variables. We failed to find a statistically significant association when combining the counties. However, ‘average weekly minimum temperature’ was found to have a statistically significant association (0.0189 p-value) with weekly mosquito egg abundance in Miami-Dade County. In Miami-Dade County, for every one unit increase in ‘average weekly minimum temperature’, the mean abundance of mosquito eggs collected decreased by a factor of 0.803 eggs. The weather variables, ‘average weekly minimum temperature,’ ‘average weekly precipitation,’ ‘average weekly windspeed,’ and ‘average weekly relative humidity’ all were found to have a statistically significant association between weekly mosquito egg collection site abundance in Charleston County with each variable having a p-value of <0.0001. In Charleston County, for every one unit increase in ‘average weekly minimum temperature,’ the mean abundance of mosquito eggs collected increased by a factor of 1.02 eggs. For every one unit increase in ‘average weekly precipitation’, the mean abundance of mosquito eggs collected decreased by a factor of 0.799 eggs. For every one unit increase in ‘average weekly windspeed,’ the mean abundance of mosquito eggs collected decreased by 0.977 eggs. For every one unit increase in ‘average weekly relative humidity,’ the mean abundance of mosquito eggs collected increased by 1.02 eggs.

Lastly, we conducted a multivariate regression model assessing mosquito abundance egg vs land classification and weather variables within a 300-meter buffer using stepwise negative binomial regression. For our second combined statistical analysis, we found that ‘high intensity developed’ areas (0.0381 p-value) and ‘precipitation’ ($<.0001$ p-value) were the only variables that had a statistically significant association with mosquito egg abundance. For every one unit increase in ‘high intensity developed’ areas, the mean abundance of mosquito eggs collected decreased by a factor of 0.983 eggs. For every one unit increase in ‘precipitation’, the mean abundance of mosquito eggs collected decreased by a factor of 1.91e-5 eggs.

Table 4.1 List Of Weather Station Locations Used In Analysis

Weather Stations Locations	Lat.	Long.
Charleston County		
DOWNTOWN CHARLESTON, SC US	32.775	-79.9239
CHARLESTON INTL. AIRPORT, SC US	32.89943	-80.04075
Miami-Dade County		
MIAMI INTERNATIONAL AIRPORT, FL US	25.7881	-80.3169
MIAMI OPA LOCKA AIRPORT, FL US	25.90694	-80.28028
MIAMI KENDALL TAMIAMI EXEC AIRPORT, FL US	25.6475	-80.43306

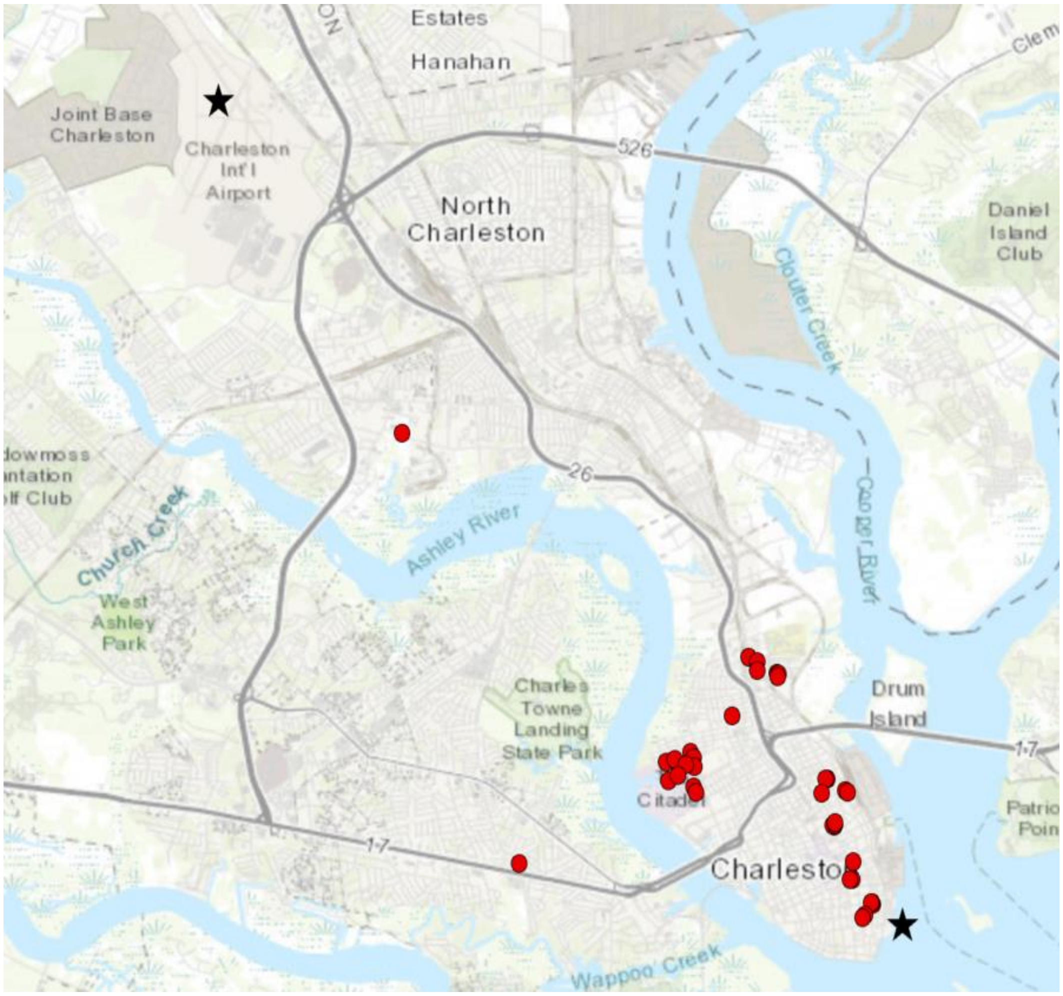

Figure 4.1 Charleston County Mosquito Egg Collection Sites In Relation To Weather Stations

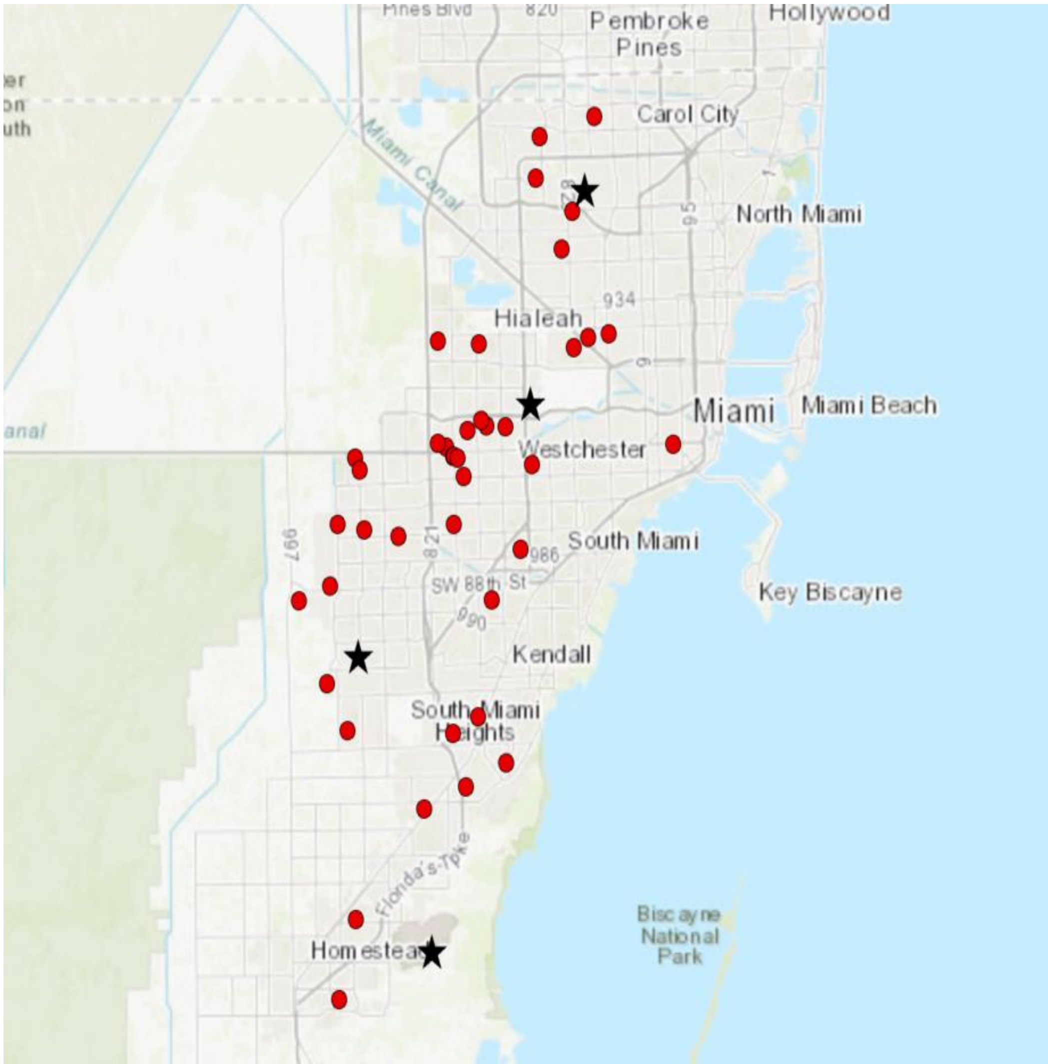

Figure 4.2 Miami-Dade County Mosquito Egg Collection Sites In Relation To Weather Stations

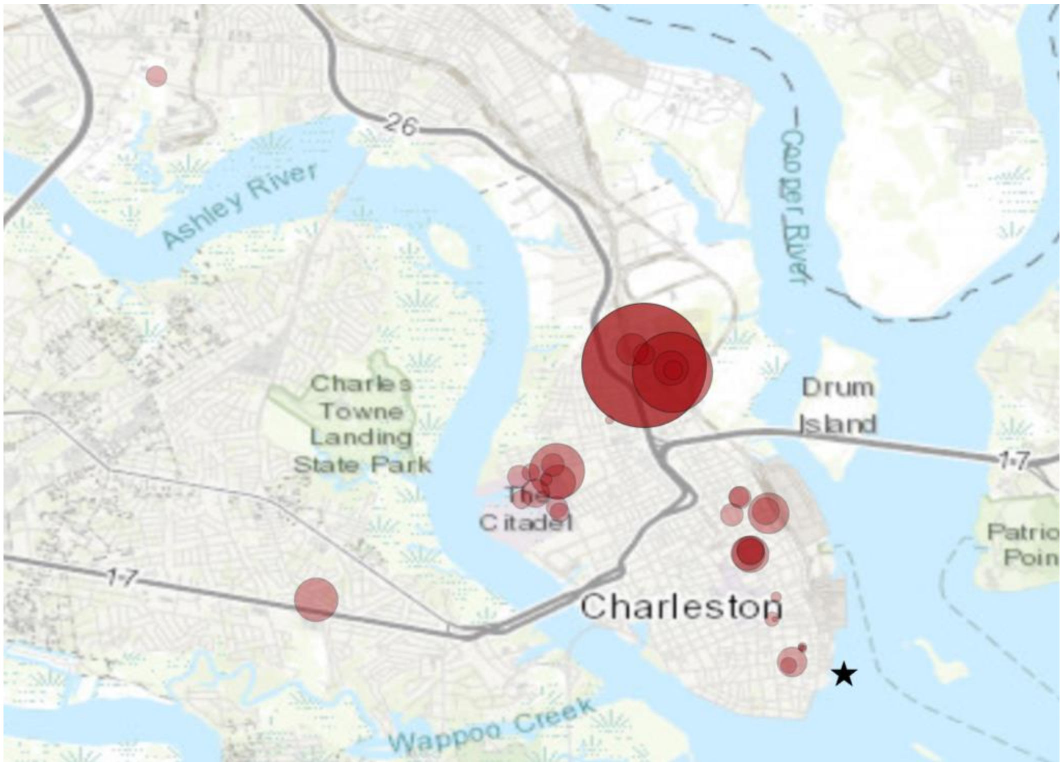

Figure 4.3. Charleston County Mosquito Egg Collection Sites Proportional To The Amount Collected Using Shape Size Intensity

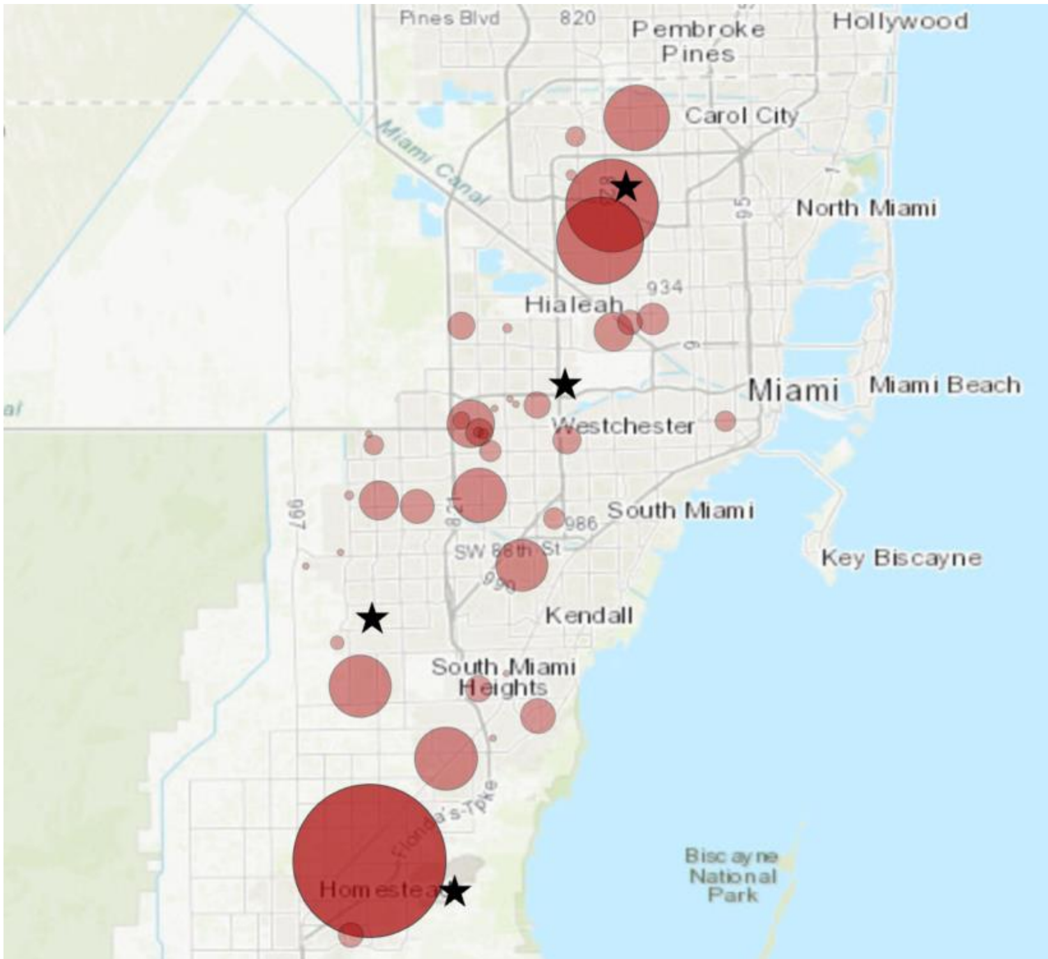

Figure 4.4. Miami-Dade County Mosquito Egg Collection Sites Proportional To The Amount Collected Using Shape Size Intensity

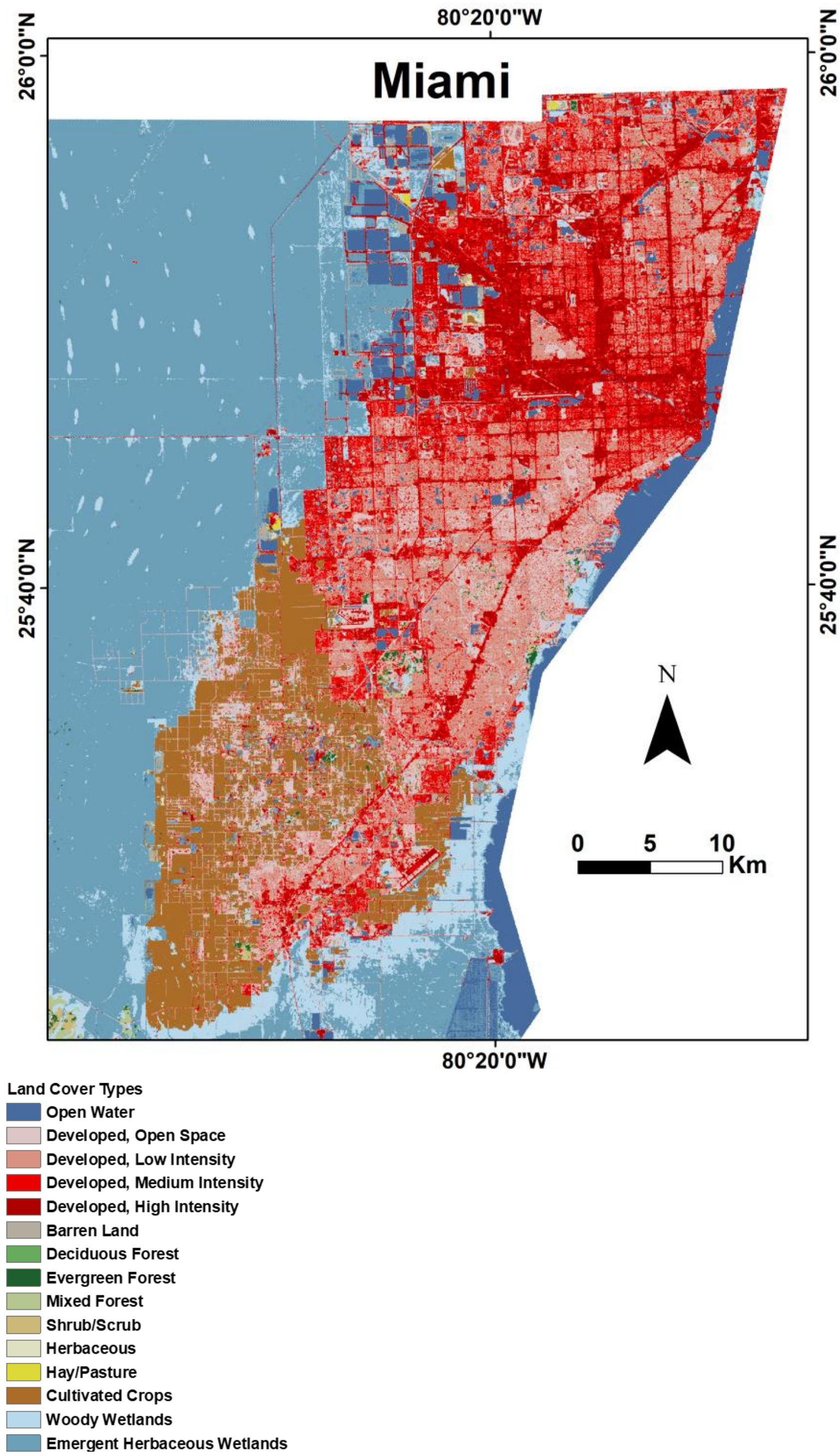

Figure 4.5. Land Classification Of Miami-Dade County

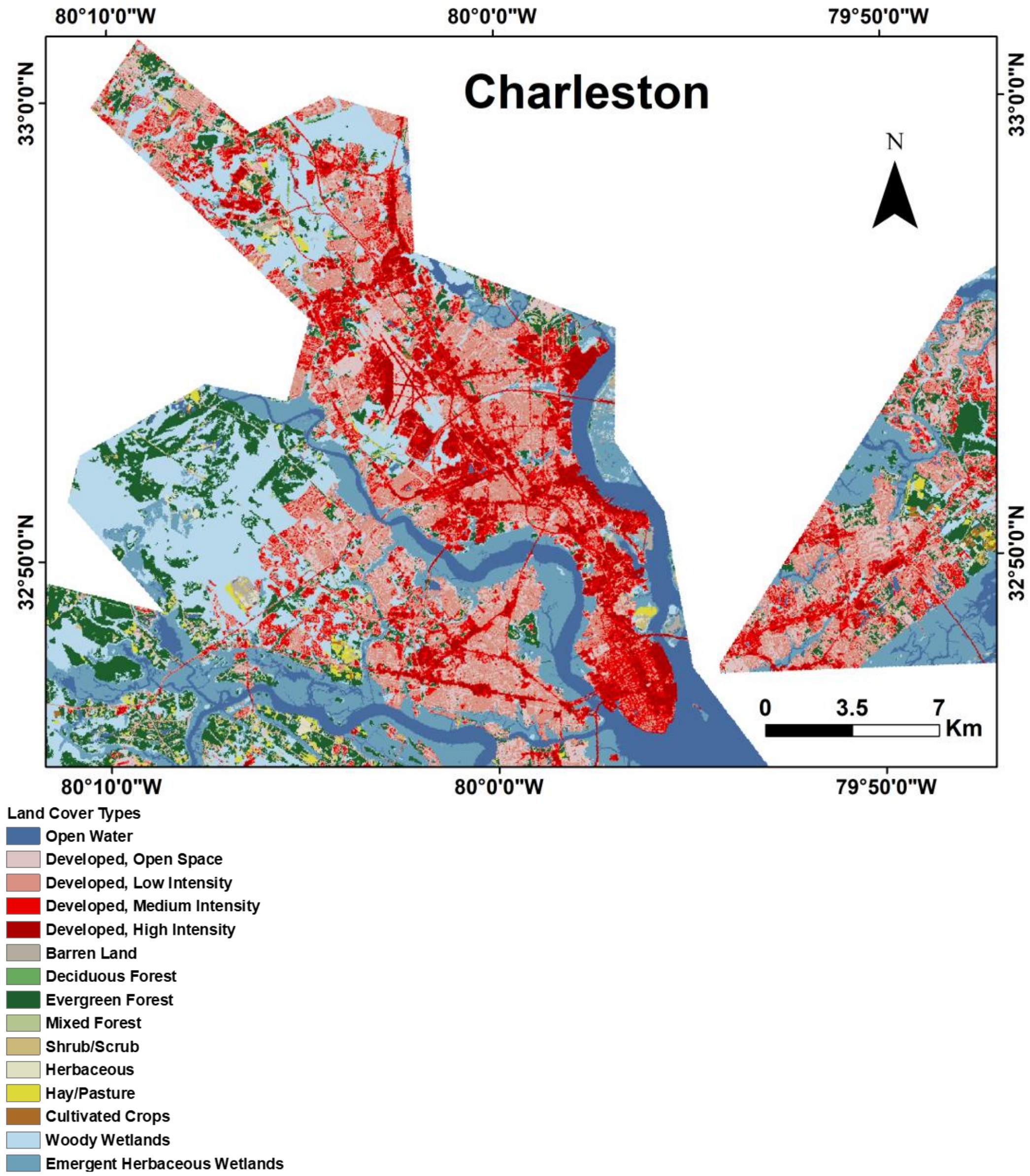

Figure 4.6. Land Classification Of Charleston County

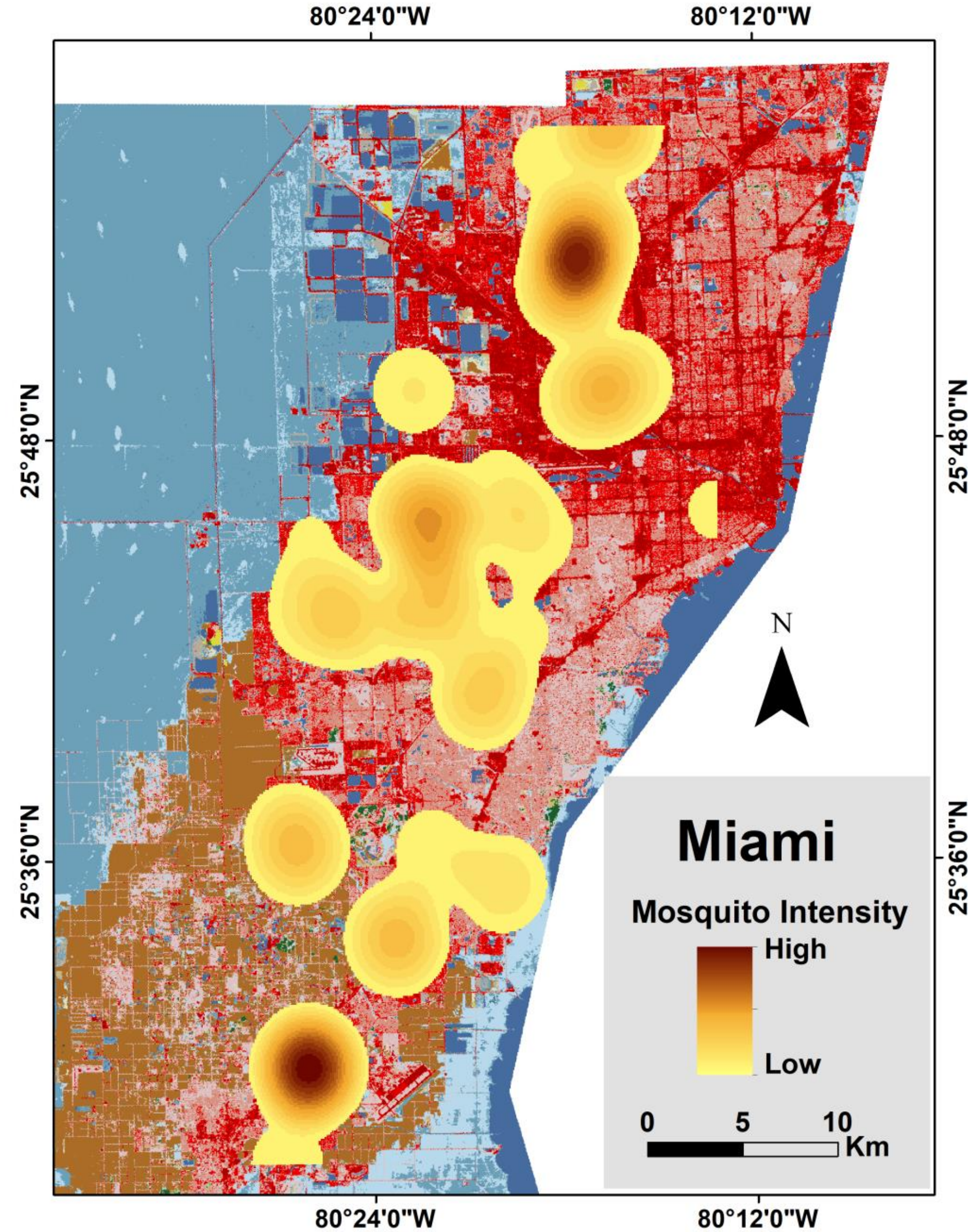

Figure 4.7 Miami-Dade County Mosquito Egg Collection Sites Proportional To The Amount Collected Using Color Intensity

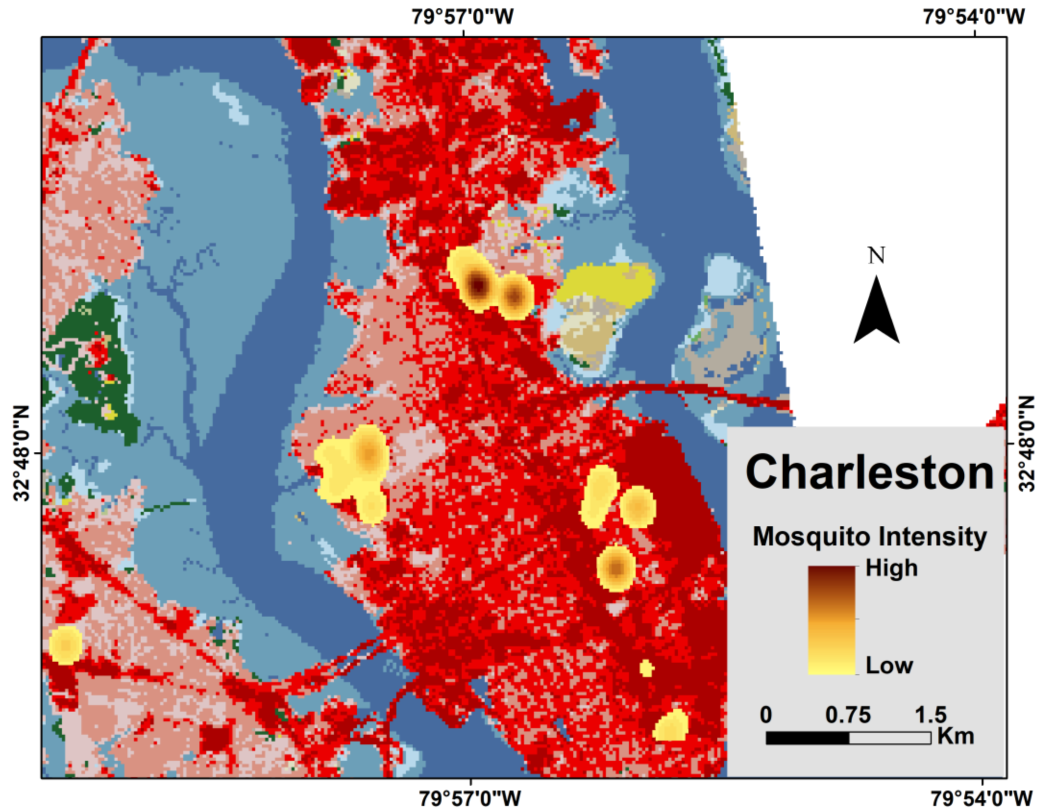

Figure 4.8 Charleston County Mosquito Egg Collection Sites Proportional To The Amount Collected Using Color Intensity

Table 4.2 Miami-Dade County Weekly Mosquito Egg Collection Count

Miami-Dade County Weekly Mosquito Egg Collection Count											
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Total
Point1	0	0	0	0	0	0	0	0	6	0	6
Point2	0	0	0	0	0	8	7	0	4	5	24
Point3	0	0	0	0	6	31	16	20	4	0	77
Point4	0	0	0	3	0	4	4	0	0	0	11
Point5	0	12	0	0	11	2	5	0	101	0	131
Point6	0	0	2	0	4	24	3	0	7	0	40
Point7	9	23	5	0	0	17	7	8	2	0	71
Point8	0	6	10	0	0	12	6	0	2	0	36
Point9	0	19	0	6	0	0	0	0	0	0	25
Point10	0	0	0	0	0	13	0	0	0	0	13
Point11	0	20	11	0	0	10	1	0	0	0	42
Point12	0	0	0	0	19	0	6	0	4	0	29
Point13	0	0	2	11	0	0	0	0	0	0	13
Point14	0	6	4	0	4	3	0	0	2	0	19
Point15	0	0	0	0	3	0	0	0	0	0	3
Point16	0	0	0	0	0	0	1	0	1	0	2
Point17	0	0	0	0	0	13	4	0	0	0	17
Point18	0	0	0	0	7	10	0	1	0	0	18
Point19	0	0	20	0	10	4	0	0	15	0	49
Point20	0	0	11	0	0	0	9	0	0	2	22
Point21	0	0	0	0	0	0	0	0	0	0	0
Point22	0	0	0	0	0	0	0	0	0	0	0
Point23	5	6	0	0	11	11	11	4	4	0	52
Point24	0	4	5	0	0	0	0	0	0	0	9
Point25	0	0	0	0	0	0	0	0	18	0	18
Point26	0	5	0	0	1	6	0	0	0	0	12
Point27	0	0	0	1	0	1	0	0	0	0	2
Point28	0	0	0	0	0	0	0	0	0	0	0
Point29	22	0	12	4	1	3	2	0	6	0	50
Point30	0	0	0	0	0	0	0	0	0	0	0
Point31	0	0	0	0	0	3	0	0	0	0	3
Point32	0	0	0	0	0	0	0	0	0	3	3
Point33	0	0	0	0	16	0	0	0	1	0	17
Point34	0	0	0	0	0	0	0	0	0	0	0
Point35	5	0	10	1	0	0	0	0	0	0	16
Point36	0	0	0	0	0	0	0	0	0	0	0
Point37	0	0	0	0	0	0	0	0	0	0	0
Point38	0	5	5	3	1	6	9	0	0	0	29
Point39	0	3	0	0	0	13	0	0	0	0	16

Point40	0	0	0	0	0	0	0	0	0	0	0
Point41	0	4	0	0	0	7	0	0	0	0	11
Total	41	113	97	29	94	201	91	33	177	10	886

Table 4.3 Charleston County Weekly Mosquito Egg Collection Count

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Total
Point1	32	10	3	23	2	8	15	7	15	53	168
Point2	50	41	23	61	47	53	24	83	26	12	420
Point3	16	3	28	28	22	32	72	0	41	84	326
Point4	7	65	1	0	0	11	60	0	17	17	178
Point5	126	192	197	151	142	127	139	62	95	192	1423
Point6	23	16	55	23	0	48	48	26	7	26	272
Point7	11	21	11	29	0	18	12	18	13	13	146
Point8	117	106	113	66	0	43	114	76	64	100	799
Point9	38	11	26	13	16	22	12	34	6	9	187
Point10	15	8	29	17	20	20	18	8	13	19	167
Point11	31	27	6	18	0	14	0	14	31	89	230
Point12	22	32	118	6	0	38	10	55	25	66	372
Point13	0	0	57	35	16	65	15	14	0	3	205
Point14	24	0	0	26	43	20	18	25	46	82	284
Point15	0	81	58	20	27	0	60	63	1	0	310
Point16	24	10	0	71	0	12	9	22	42	39	229
Point17	40	24	11	24	42	29	15	0	28	23	236
Point18	0	6	0	0	0	0	14	3	2	0	25
Point19	0	11	3	0	3	0	0	0	8	0	25
Point20	0	2	1	12	7	0	0	18	6	44	90
Point21	4	0	7	9	0	0	12	0	0	2	34
Point22	0	0	4	24	0	0	0	6	0	0	34
Point23	0	0	0	9	3	0	0	1	3	8	24
Point24	75	10	50	17	0	7	5	21	61	0	246
Point25	4	16	0	32	18	9	3	21	0	2	105
Point26	2	0	0	19	0	81	0	14	22	33	171
Point27	0	0	0	25	0	52	2	24	13	28	144
Point28	0	6	3	42	0	53	0	1	10	3	118
Point29	13	22	0	14	25	0	0	0	13	18	105
Point30	67	0	15	56	0	26	0	0	0	0	164
Point31	0	9	14	6	6	23	48	11	3	41	161
Point32	46	25	54	33	24	64	6	67	68	97	484
Point33	16	0	18	52	51	85	23	89	26	0	360
Point34	5	6	3	0	3	0	22	31	15	3	88
Point35	30	7	26	21	14	24	11	10	74	9	226
Point36	0	22	2	0	0	3	20	6	4	0	57
Total	838	789	936	982	531	987	807	830	798	1115	8613

Table 4.4 Summary of Miami-Dade County Weather Data

Summary of Miami-Dade County Weather Data											
Weather Variable	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Average
Maximum Temperature	90.43	93.33	92.08	92.06	92.76	90.95	92.61	92.14	90.24	92.57	91.92
Minimum Temperature	76.14	77.24	77.58	79.83	75.19	76.14	76.64	76.38	77.67	78.10	77.09
Precipitation	0.69	0.22	0.29	0.02	0.45	0.52	0.42	0.50	0.11	0.20	0.34
Windspeed	5.72	5.85	5.25	8.36	5.36	6.39	3.22	4.55	6.84	5.80	5.73
Relative Humidity	74.00	65.29	69.50	64.29	71.00	71.57	75.57	72.71	69.71	72.86	70.65

Table 4.5 Summary of Charleston County Weather Data

Summary of Charleston County Weather Data											
Weather Variable	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Average
Maximum Temperature	89.07	89.64	90.75	92.07	88.14	85.86	91.29	89.29	88.29	85.14	88.95
Minimum Temperature	73.50	74.07	75.75	76.21	73.64	74.14	75.86	76.86	76.57	72.43	74.90
Precipitation	0.16	0.00	0.25	0.32	0.13	0.04	0.17	0.42	0.03	0.01	0.15
Windspeed	7.54	6.41	5.87	5.93	8.16	5.59	5.91	6.50	6.53	7.83	6.63
Relative Humidity	75.57	69.00	76.25	74.57	69.00	74.71	75.29	80.71	77.86	75.29	74.83

Table 4.6. Association Between Weekly Mosquito Egg Collection Site Abundance And Weekly Weather Variables Using Negative Binomial Regression

Association Between Weekly Mosquito Egg Collection Site Abundance And Weekly Weather Variables Using Negative Binomial Regression															
	Combined County**					Miami-Dade County					Charleston County				
Weather Variable	Estimate	SE	95% CI		p-value	Estimate	SE	95% CI		p-value	Estimate	SE	95% CI		p-value
Average Weekly Maximum Temperature	-0.066	0.039	-0.143	0.010	0.088	-0.185	0.120	-0.420	0.050	0.124	0.034	0.030	-0.025	0.093	0.258
Average Weekly Minimum Temperature	-0.089	0.050	-0.187	0.010	0.077	-0.219	0.093	-0.402	-0.036	**0.019**	0.021	0.005	0.012	0.030	**<.0001**
Average Weekly Precipitation	-0.174	0.422	-1.001	0.653	0.681	-0.157	0.676	-1.483	1.168	0.816	-0.224	0.052	-0.326	-0.122	**<.0001**
Average Weekly Windspeed	-0.005	0.056	-0.114	0.103	0.923	-0.005	0.093	-0.187	0.177	0.958	-0.023	0.005	-0.033	-0.012	**<.0001**
Average Weekly Relative Humidity	0.037	0.024	-0.010	0.083	0.126	0.083	0.053	-0.021	0.186	0.119	0.022	0.005	0.012	0.032	**<.0001**

*Bolded Items are Statistically Significant

**Adjusted for Mosquito Egg Collection Site Exposure Time

Table 4.7 Mosquito Abundance Egg Vs Land Classification & Weather Variables Within A 300 Meter Buffer Using Stepwise Negative Binomial Regression

Combined County Mosquito Egg Abundance Vs Land Classification & Weather Variables Within A 300 Meter Buffer Using Stepwise Negative Binomial Regression

Variable	Estimate	SE	95% CI		Chi-Square	p-value
Developed, High Intensity	-0.0167	0.0080	-0.0325	-0.0009	4.3000	**0.0381**
Precipitation	-10.8631	1.0911	-13.0017	-8.7245	99.1200	**<.0001**

CHAPTER 5

DISCUSSION

There are over 200 types of mosquitoes in the U.S. and its territories (CDC). An increasing public health concern in the U.S. is the emergence of arboviruses. *Aedes albopictus* and *Aedes aegypti* globally transmit arboviruses of great public health importance including Dengue, Chikungunya, Yellow Fever, and Zika. These diseases are predicted to spread to higher latitudes and higher elevations in the U.S. as a result of climate change and tropicalization. An additional 30 million individuals will be exposed to VBDs as a result of the expansion (Rochlin et al.). The Southeastern U.S. is particularly vulnerable to *Aedes*-transmitted VBDs given year-round high temperatures, humid environments, and proximity to endemic VBDs areas (Wilke et al.). *Aedes aegypti* is particularly dangerous as it feeds almost exclusively on humans and thus thrives in urban settings. However, *Aedes albopictus* can vector many of the same viruses with a greater ability to expand its range (Brady et al.). Miami-Dade County is already considered a hotspot for disease transmission via *Aedes albopictus* and *Aedes aegypti*. Charleston County is particularly vulnerable due to the similar environmental conditions. The most important factors influencing *Aedes* mosquito abundance according to past literature are temperature, humidity, precipitation, and windspeed. Our results confirm these findings for Charleston County. Our model showed that 'high intensity developed' areas are most likely to influence *Aedes* mosquito abundance as well as, 'precipitation.'

Our hypothesis was partially incorrect. We hypothesized that (1) areas with 'open water' and (2) areas classified as 'high intensity developed' will have higher *Aedes* egg abundance, and (3) cumulative high temperature-high humidity-high rainfall areas will also positively influence *Aedes* mosquito egg abundance. There was not a statistically significant association with greater mosquito abundance with 'open water' land classifications. However, 'high intensity developed' areas deemed to have a statistically significant association. A decrease in mosquito egg abundance was unexpected for 'high intensity developed' areas. It was previously stated that areas that are highly developed usually attract higher mosquito abundance. Lastly, the relationship between 'average weekly minimum temperature,' 'average weekly precipitation,' 'average weekly windspeed,' and 'average weekly humidity' were only statistically significant in Charleston County. Again, 'average weekly precipitation', 'average weekly windspeed', and 'average weekly relative humidity' all showed to decrease mosquito egg abundance. This result is also unexpected as these weather variables traditionally have been shown to increase mosquito egg abundance. Our findings reflex our choice to use weekly averages in the analysis, which can't pick up on day-to-day weather variable fluctuations and are more likely to reflect seasonal patterns. The weather variable, 'average weekly minimum temperature,' was the only weather variable in Charleston County that increased mosquito egg abundance.

Our results not all being statistically significant and being contradictory to previous literature could be due by many factors. The most obvious is our study areas covered a massive geographical area and that the two sites used different mosquito collection methods. In Charleston County, collection sites were set up by a trained entomologist at various locations on the peninsula, whereas in Miami-Dade County, they were placed at residential homes via undergraduates. The collection sites were also set out at different times throughout the summer and exposed for varying lengths of time. Duration exposure was controlled for in the statistical analysis but still could have had a small impact on egg abundance. It is likely that the different methods contributed to different levels of abundance. By making collection instructions more uniform, bias could have been reduced. Our buffer size of 300 meters used in the remote sensing analysis might have also been too wide allowing for increase variability.

Our study was limited to a single summer's worth of data. Climate conditions in the Southeast can vary widely. Without enough long-term evidence, findings can contradict. Any inconsistent effects observed could be due to complex interactions between climatic factors. Long-term observational studies are needed to monitor climate-change environmental impact. It is also difficult to know whether existing vector control programs are being conducted in the given study region. Government lead vector control programs could also profoundly affect the abundance of *Aedes* mosquitos in the area. Vector control programs are especially common in Miami-Dade County where we saw dramatically less egg abundance.

Lastly, the counties of Miami-Dade and Charleston have different architecture and infrastructure. The city of Miami is considered one of the youngest major cities in the U.S. while the city of Charleston is one of the oldest. The city of Miami has more new construction than Charleston. Charleston County has many unique building restrictions preventing new developments. For example, Charleston's County ordinances specify that buildings cannot exceed the height of Saint Matthew's Lutheran Church (Egan).

Charleston County also has many areas outside of downtown that are protected by conservation efforts (NPS). This paper highlights the many risks that Charleston County faces for VBD transmission. Past literature point to a clear threat for greater *Aedes* mosquito abundance due to the county's environmental factors.

Surveillance efforts are threatened by the wide altering variety of potential *Aedes* mosquito habitats due to climate change (Rochlin et al.). Remote sensing is a map-based tool that can study mosquito disease distribution and dynamics and serve as a potential solution to improve past vector borne surveillance methods (Hugh-Jones). Remote sensing and geographic information systems (GIS) can track environmental conditions that drive VBDs outbreaks in real-time, enabling researchers to improve risk assessments (Ceccato et al.). We recommend researchers that want to use remote sensing for vector collection start by analyzing a small geographical area.

Public health agencies in Charleston and Miami-Dade counties need to prepare for a migration of *Aedes albopictus* and *Aedes aegypti* upward. It is crucial to understand the ecological dynamics of these climate impacts to identify hotspots of vulnerability in the Southeast U.S. Further research is essential to ensure continued progress in reducing the burden of VBDs with the additional environmental challenges caused by climate change and tropicalization.

CHAPTER 6

CONCLUSION

This paper demonstrates that environmental variables have a vital impact on *Aedes* mosquito populations. The most important factors increasing *Aedes* mosquito abundance are temperature, humidity, wind speed, and precipitation. Larger numbers of *Aedes* mosquitoes result in higher VBD transmission risks. A continued rise in mosquito populations is expected in the future due to climate change putting more people at risk. The Southeast U.S. must continue to monitor *Aedes* mosquito abundance to detect potential disease hotspots and prevent further spread. The importance of early prevention strategies using environmental variables such as these cannot be overstated. Due to the reallocation of many resources for COVID-19, vector control programs will need to be reviewed. Evaluating the effectiveness of future vector control efforts will require establishing a new baseline effort after the pandemic.

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