SPATIO-TEMPORAL DYNAMICS OF AEDES TAENIORHYNCHUS MOSQUITO IN SARASOTA COUNTY, FLORIDA

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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To my friends and family

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Aedes taeniorhynchus is a potential mosqutio vector that can spreads important human and animal arboviruses in Florida, such as West Nile viruses, St. Louis encephalitis, and Rift Valley fever. To support the control and prevention of mosquito-borne diseases, I explored the spatio-temporal dynamics of the Ae*des taeniorhynchus* mosquito in Sarasota County, Florida with the aid of Geographic information technology. Population-weighted centroids from Sarasota mosquito management trap sites were calculated and used to show locations of density and movement across the study region. Distances and movements were calculated between sequential centroid locations, and then compared with daily wind directions and speed. Daily tide and precipitation levels were compared to trapped Ae*des taeniorhynchus* population numbers to analyze correlations between the two.

Results show that the highest population numbers for *Aedes taeniorhynchus are consistent during* the typical Florida summer months of elevated in May, June, July, and August. The map of population-weighted centroids displayed a marked dispersion to inland areas from the Gulf of Mexico coast over time. Surprisingly, there are no

statistical correlations found between Ae*des taeniorhynchus* dispersal and daily wind speed, along with wind directions in Sarasota County, Florida. However, there are stronger relationships between Ae*des taeniorhynchus* population size and tide levels, as well as precipitation levels.

With international travel on the rise and possible introduction of other arboviruses, Florida residents are facing an elevated risk of imported mosquito-vectored illness. Knowledge of the temporal and spatial distribution of Ae*des taeniorhynchus* would be critical for categorizing areas of varying risk for disease transmission. Since *Aedes taeniorhynchu*s is a coastal species with the capacity to transmit indigenous and exotic arboviruses and there is a potential for an introduction of exotic diseases into the United States through shipping ports, enhanced surveillance and control measures need to be established in Florida. My thesis is one such example of vector surveillance and shows the capability for understanding aerial movement of disease carrying vectors.

CHAPTER 1
INTRODUCTION

Background

Mosquito-borne diseases involve the transmission of viruses and parasites from animal-to-animal, animal-to-person, or person-to-person, by the means of mosquito vectors. These diseases are of great concern to the socio-economy of the Florida State. Since the introduction of West Nile virus (WNV) in 2001, a total of 309 infection cases and 19 fatalities have been reported in Florida [1], [2]. Outbreaks of St. Louis Encephalitis virus (SLEV) have decreased in recent years but epidemics have still been documented in Florida, for example,223 human cases during1990 [3]. Eastern Equine Encephalitis (EEE) is another mosquito-borne disease widely reported in Florida, with an average of 70 human cases per year [4]. With an increase of international travel and possible introduction of other arthropod-borne viruses (arboviruses), Florida residents are facing an elevated risk of imported mosquito-vectored illness [5].

Aedes taeniorhynchus, also known as the black salt marsh mosquito, is often associated with salt marshes along coastal areas in North, Central and South America, including Florida [6].Its potential of vectoring human and animal arboviruses has been well documented [7]. For instance, the SLEV, Everglades, and WNV have all been isolated from *Aedes taeniorhynchus* in Florida. Recent studies in the laboratory environment have found that it can also transmit epizootic strains of Venezuelan equine encephalomyelitis, eastern equine encephalitis, and Rift Valley fever viruses [7]. Capable of vectoring multiple existing and emerging disease agents, this species of mosquitoes has brought potential risk to the public health of Florida.

To address this potential risk, Sarasota County, Florida, has initiated a mosquito management program for disease surveillance and prevention, habitat elimination, larval management, and spraying. The effectiveness of this program is highly dependent on the knowledge of how mosquito populations distribute over time and space, including the *Aedes taeniorhynchus* species. The driving forces behind its distribution vary dramatically between locations and are complicated by various factors, such as blood meal availability, wind, rainfalls, flooding, and human transportation, etc.[6], [7]. For the Sarasota County, little is known about the spatio-temporal dynamics of *Aedes taeniorhynchus* population and movement. The lack of such knowledge prevents the county government from effectively evaluating risks of mosquito-borne diseases and implementing control/surveillance strategies [8].

Study Objectives

To fill this knowledge void, my objectives of this research have two folds.

1) I attempt to describe the spatio-temporal dynamics of *Aedes taeniorhynchus* mosquito in Sarasota County, Florida, based on trap data from 1992-1994 and a GIS approach.
2) I intend to explain the observed patterns using statistical analysis and tide, precipitation, and wind datasets.

Thesis Structure

The thesis is organized in six chapters. Following this introduction chapter, a literature review chapter introduces detailed information about the *Aedes taeniorhynchus,* relevant studies on this species, and mosquito control methods. Chapter 3 describes the methodology for analyzing spatial-temporal dynamics of *Aedes taeniorhynchus* population and movement. The chapter that follows (Chapter 4) present and discuss analysis results. The last chapter concludes this thesis and articulates the implications from findings.

CHAPTER 2
LITERATURE REVIEW

Characteristics of Aedes taeniorhynchus

Aedes taeniorhynchus, also known as the black salt marsh mosquito, is normally associated in high numbers with salt marshes along coastal areas in North, Central and South America [7]. They are characterized by bands of white scales across the upper sides of abdominal segments [9]. It has the potential to be a critical vector of important human and animal arboviruses. Further, SLEV, Everglades, and WNV have all been isolated from it in Florida, and the species can transmit epizootic strains of Venezuelan equine encephalomyelitis, eastern equine encephalitis, and Rift Valley fever viruses in the lab [7].

The life cycle of *Aedes taeniorhynchus* lasts about three weeks with some having the ability to live even longer [10]. There are four stages in the life cycle, namely egg, larvae, pupae, adult. Female adults of this species often lay their eggs on dry ground, where the eggs would emerge when flooded by rain or tide water [10]. The egg placement is generally along a contour line at a specific elevation relative to the high water line, and in depressions in the upper regions of salt marshes or mangrove swamps [9]. It takes approximately 4 days for eggs to hatch into larve, the second stage in the life cycle. Even though the larvae can develop in any salinity from fresh to ocean water, breeding is known to take place only in regions along the coast [10]. Mosquito larvae usually develop into adults in about 7-10 days [11]. The newly emerged mosquitoes stay in the area where they developed into adults for a period of 12-24 hours. Over the next few days they will disperse over a large area [10].

Studies on Mosquito Dispersal

Mosquito movement by flight is often referred to as the dispersal or migration. Williams [12] uses the term dispersal to commonly describe random flights that are often a factor of wind direction, while migration is considered to be a purposeful flight linked to the biology and survival of the species. For my thesis I use the term dispersal as described by Service, *et al.* in the book *Mosquito Ecology* [13]. Service *et al.* defined the dispersal as the full range of mosquito movement that covers a distance of just a few meters or many kilometers from a starting location.

Mosquito dispersal can be goal-orientated with a variety of objectives ranging from nectar-feeding, blood-feeding, mating, or looking for a suitable location to lay eggs. Other dispersal behaviors seem to be more random because they seem to serve no special biological purpose and are mostly driven by wind. Most of these wind driven flights are involuntary and are characterized by a lack of control as to where the mosquito may end up [14]. Examples of the long distance dispersal of mosquitoes can be seen amongst the species found in coastal salt marshes. One such case is with *Aedes taeniorhynchus,* and the mass exoduses for which they are known [10]. *Aedes vigilax* has been discovered more than 60 miles from its coastal breeding sites and also on a boat 20 miles from the shore [15]. In another instance, *Aedes sollicitans* have been caught 28 miles out at sea [16] and also 110 miles inland from the shore [17].

Wind is not the only mechanism that drives mosquito movement. Human involvement from ships, trains, aircrafts, and other vehicles can also play a factor in species dispersal. A memorable example is the introduction of *Anopheles gambiae* from Africa to Brazil via shipping route. The arrival of efficient malaria vectors caused the largest epidemic of malaria seen in the Americas infecting as many as 290,000 people killing at least 26,000 [18]. More recent examples involve the airport malaria cases from which infected mosquitoes are transported to non-malarious countries such as France, Switzerland, Belgium, England, Russia and the Netherlands [19].

It is important to know the spatial and temporal patterns of mosquito species as a key factor in mosquito control and also disease surveillance. The biomarker approach has been widely used to understand the dispersal of mosquitoes [15], [16]. The biomarker approach, also referred to as the mark-recapture methods, was originally designed to estimate population size but is frequently used to study mosquito dispersal, feeding behavior, and also survival rates. This type of study involves the marking of lab raised mosquitoes to be released into the wild for a recapture at alternate trap sites [14]. A variety of methods and techniques for marking mosquitoes have been developed to evaluate movement including dyes, dusts, and radioactive isotopes [13]. Based on the mark-recapture data the population density can be plotted against the log of distance from the release point. A statistical model ($y = a + b\log x$) then can be built to fit the plotted trend, assuming the population decreases by a constant amount for equal multiples of the distance from the release point. Here, y is the number of insects caught at distance x from the origin of dispersal, while a and b are constants [13]. The alternative is to plot log population against distance. This model ($\log y = a + bx$) infers a decrease in population (y) by a constant proportion for each measure of distance from the release point (x). Although the bio-marker approach is efficient to study mosquito population dynamics, it has several downfalls. The principle disadvantage of mark-recapture methods is the necessity to recapture a relatively large proportion of the sample population in order to attain acceptable levels of accuracy. First, it is known that marking can affect mosquitoes so they do not disperse in their natural routines. The handling of mosquitoes can affect them in such a way that they do not disperse far, or it can excite them and result in excessive dispersal [20]. Second, the marking of a species can decrease its lifespan thus reducing numbers available for recapture on successive days [14]. The use of laboratory reared mosquitoes to be released in the wild may also produce adults that have abnormal survival rates and dispersal. The third issue is relevant to the dimensions of the study area. Past studies assume that marked mosquitoes are limited to the study area, which is often a short distance from the release point [14]. These studies often ended up with very small recapture rates which lead to the question of what happened to the uncaught marked mosquitoes. It is not known if they are still located within the study area and have evaded recapture, or completely emigrated from it all together, leading to biases in subsequent analysis.

Mosquitoes and the Environment

Numerous studies have investigated the role of environmental data on mosquito species [21], [22], [23]. Many have focused on the role of weather and populations numbers in terms of disease spread. Takeda et al. [24] correlated changes in climate to multiple arboviruses and their vectors in Rhode Island. Ross River virus cases have been linked to ongoing winter and spring rainfall which in turn allows for a magnification of the virus in the abundant water sources [25]. Tide and precipitation levels have been linked to *Aedes taeniorhynchus* population size [26]. Ritchie *et al.* [11] has shown that summer tidal levels are a direct influence on the hatching of large broods of *Aedes taeniorhynchus* in Florida mangroves.

Numerous studies have shown a relationship between disease vectors and precipitation [27], [28], [29]. Research conducted in the state of Florida has also publicized the role of high rain fall along with mosquito counts [30], [31]. The rainy season in Florida spans from May-October which covers the four month study period for the three years examined [32].

Effect of Wind on Mosquito Movement

There have been a wide-range amount of studies published on the topic of wind-driven insect movement. It is reported that flight behaviors among insects can rival the sophistication that has been seen in migrant birds and increase migration distance by 40% [33]. Some insect species migrate only a short distance between habitat locations but some are able to disperse on large scales that cover countries and continents [34]. Chapman *et al*. indicated that major wind-borne migration of *P. xylostella* from the Netherlands to southern England was responsible for the establishment of the U.K. population [35]. Insect movement has been measured using different techniques ranging from Malaise traps [36] to airplanes equipped with nets [37] to radar equipment [38].

Downwind movement is not the only direction in which insect species will migrate. It has been published that the pollen beetle, *Meligethes aeneus*, will migrate upwind towards oilseed rape fields [39]. In a mark-release-recapture study carried out in New Hampshire on the tree hole mosquito *Ochlerotatus triseriatus*, recaptures in the study were not related to the prevailing wind direction [40]. Another mark-release-recapture study from Australia involving *Aedes aegypti,* which is in the same genus as my study species, indicates a statistically significant trend for upwind flight [41].

Mosquito Surveillance and Control Programs

Since the arrival of early European settlers, mosquitoes have engaged in a prominent role in Florida's history, both as pests and disease vectors. In the late 19th

century, outbreaks of yellow fever across the state took a tremendous toll on the population. In the city of Jacksonville alone, with a population of 26,800 during this time, the 1888 Yellow fever epidemic caused 5,000 people to fall ill resulting in 400 deaths and 10,000 people fleeing the city [42]. These disease outbreaks led to the establishment of the Florida State Board of Health (FSBH) in 1889. The Florida Anti-Mosquito Association (FAMA) was formed in 1922. Early control efforts focused on dewatering of ditches along with some dredge and fill work. The positive effects from these efforts led to the creation of state funds in 1953 which allowed for permanent control work and the establishment of the Entomological Research Center in Vero Beach [42].

Collecting adult mosquitoes can yield important information to a surveillance area. Increases in populations can be observed at specific trapping locations time. Once populations have been detected and identified, control measures such as larviciding and adulticiding can be easily put in place. Knowing what species of mosquito is breeding can help vector control find the breeding source and take the correct control measures. After detection of populations, mosquitoes can also be tested for the presence of disease. The detection of a virus in a mosquito population that actively seeks human blood meals indicates a true potential for human disease outbreaks. Trap collections not only determine where control measures are needed, but also determine the effectiveness of control measures already in place [42].

The New Jersey Light Trap(Figure 2-1) continues to be the most widely used adult mosquito trap in Florida. Adult mosquitoes are attracted to the all metal trap by a 25-watt light bulb attached beneath a wide conical top. Mosquitoes are attracted to the light source then drawn into the trap by a downward blowing fan through a screened funnel. Once trapped by the fan the mosquitoes die within the killing jar containing an adulticide [42]. In addition to mosquito trapping, placing sentinel chickens for an extended period across a variety of location is another method widely used for mosquito disease surveillance. The chickens are bled once every two weeks year round except during the winter months. Blood samples are processed and tested and results are used to place proper control measures where viral activity is present [42].

Sarasota's mosquito management program is based on integrated pest management methods. These methods make use of biological, cultural, physical, and chemical tools while emphasizing health and safety to the community. The county employs a "precision targeting" approach that consists of four parts; prevention, habitat elimination, larval management, and spraying. The county focuses on prevention by advising developers and civil engineers to build and maintain storm water systems that do not create optimal mosquito habitat while habitat elimination puts the emphasis on controlling exotic plant species that support mosquito larvae. Sarasota County also regularly inspects for mosquito larvae and treat stagnant water that support growth. Spraying for adults is only done when necessary and is carried out corresponding to state guidelines. Mosquito management for Sarasota also works closely with other county health department offices to monitor and prevent the spread of vector borne diseases [43].

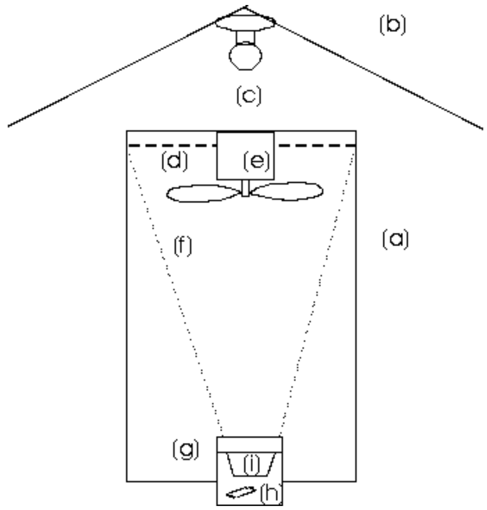


Figure 2-1. Components of a Mosquito Light Trap [44]. A) Vertical metal cylinder, B) conical roof, C) 25 watt light bulb attracts mosquitos, D) mesh screen to exclude larger insects, E) fan with electric motor, F) fine mesh funnel, G) Killing agent, H) insecticide strip inside jar, I) ventilated plastic cup to separate insects from killing agent.

CHAPTER 3
STUDY AREA AND DATA COLLECTION

Study Area

Sarasota County is located near the center of Florida's western coast, roughly 60 miles south of Tampa Bay (Figure 3-1). The county covers a total area of approximately 725 square miles with 37 miles of open shoreline along the Gulf of Mexico [45]. A few prominent cities situated within the county are Sarasota, Venice, and North Port, as well as the town of Longboat Key. The county has a total population of about 381,000 permanent residents year round. During the winter months the population size can reach to more than 450,000 due to visitors from up north heading down south for a warmer weather [45].

Sarasota has a humid subtropical climate, with hot summers, mild winters, and high humidity year round. The rainy season lasts from June to September which encompasses all of the Florida summer months. As with most of Florida's west coast, Sarasota is lined with salt marshes along the coast. These coastal marshes are communities of vegetation in areas alternately swamped and drained by tide water. The name salt marsh summarizes conditions of the habitat and type of vegetation that encompass it. The salt marshes are filled with mostly grassy vegetation and can experience the effects of both salt and fresh water. Both Sarasota's temperature and abundance of salt marshes make it an ideal habitat for salt marsh breeding mosquito species.

Mosquito Trap Data

In order to analyze spatial-temporal distribution of *Aedes Taeniorhynchus* population, I have collected the mosquito trap data in Sarasota County, Florida, from

1992-1994. Mosquito trap data was created by the counties mosquito management program, and distributed by the United States Department of Agriculture's (USDA) Center for Medical, Agricultural, and Veterinary Entomology (CMAVE) in Gainesville, Florida. The data shows the count number of each mosquito species caught daily in light traps spanning the months between March to December and the years of 1992-94. Out of the 44 different species accounted for in the data *Aedes taeniorhynchus* was selected to be a focus of this study due to its flight range and ability to vector dangerous arboviruses in the state. Sarasota County sets and collects the mosquito traps in 50 consistent locations throughout the county with the exception of the area covering the Myakka River state park (Figure 3-1). Each trap location is found in a different area in the county referred to as a zone. There are 50 different zones in the county with each identified by a letter and number combination, for example, R7. Each zone corresponds with one trap site located in the area. For this study, only four months with the largest mosquito populations, namely, May, June, July, and August, were used for analysis (Figure 3-2). It is believed that these four months are the most representative to the spatial-temporal distribution of *Aedes taeniorhynchus* population.

Environmental Data

To explore the driving forces of population dynamics amongst *Aedes taeniorhynchus,* a variety of environmental datasets were collected, including the wind, tidal, and precipitation datasets of Sarasota County from 1992-1994. Their basic characteristics are summarized in Table 3-1. Specifically, the wind data was obtained from the National Data Buoy Center under the National Oceanic and Atmospheric Administration's (NOAA) [46]. The data recorded at station VENF1 located in Venice, Florida, was used to represent Sarasota County, which contains information on hourly wind speed and degree direction. Historical tide data was retrieved from NOAA's tides and currents historical data sets [46]. Due to the data availability, only the data from Station No. 8726520 about 40 miles north in St. Petersburg, Florida was used. The tidal data sets consisted of daily high and low values measured in feet from 1992-1994. For precipitation data I used the Southeast Regional Climate Center's climate database (CLIMOD). The historical data sets were from Station No. 089176 located in Venice, Florida and contained daily precipitation levels measured in inches. Locations for data sources are displayed below (Figure 3-3).

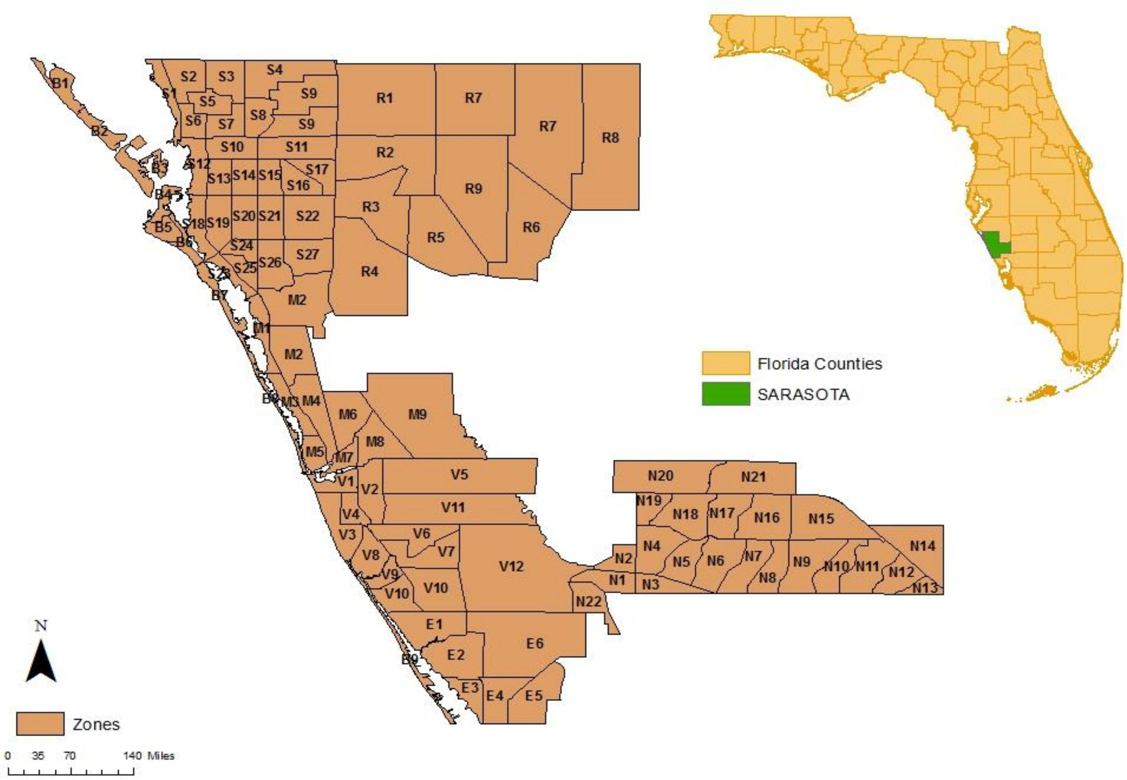


Figure 3-1. Sarasota mosquito management zone locations with county location shown in green on Florida state map.

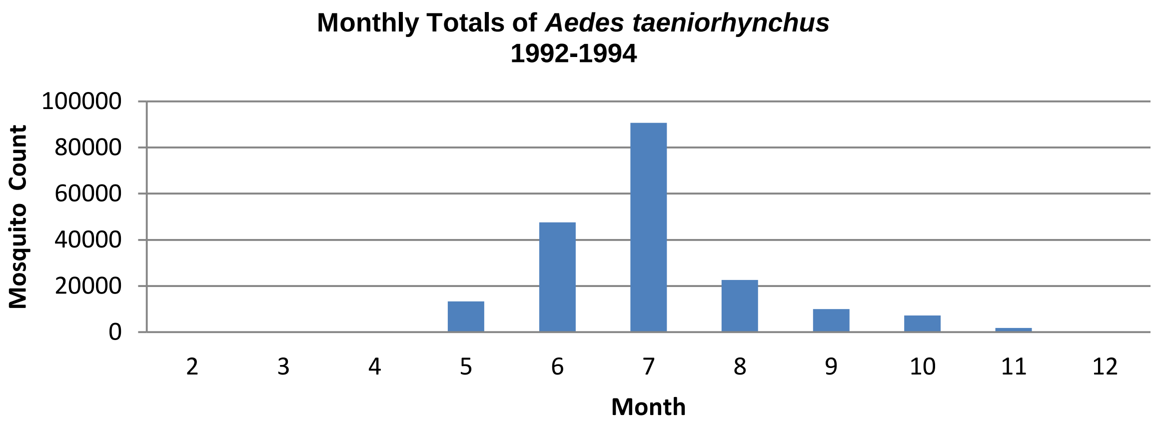


Figure 3-2. Total monthly mosquito counts from 1992-1994

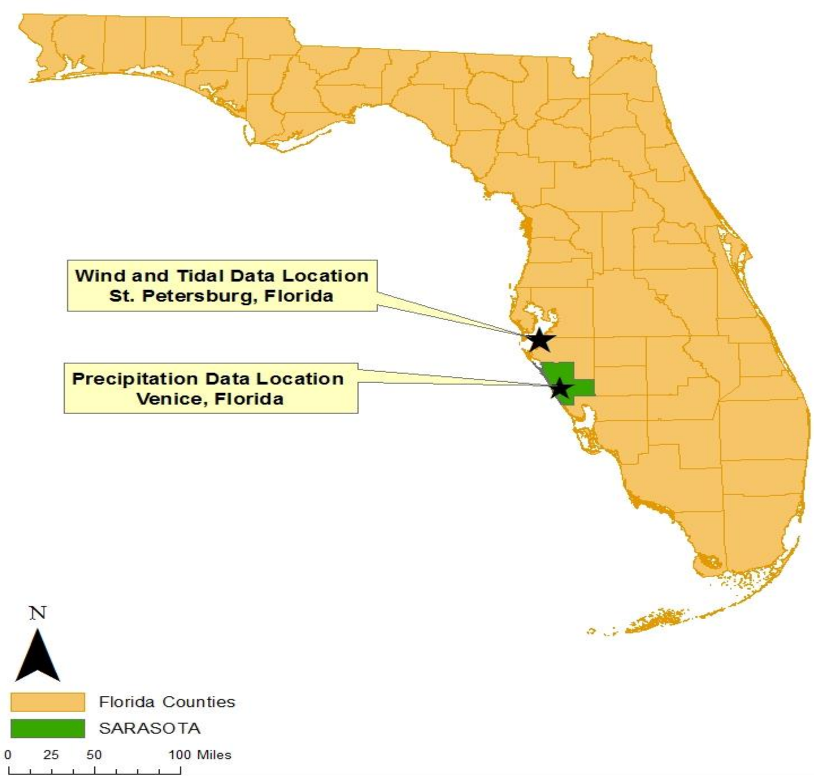


Figure 3-3. Locations for data sources used in the project. Station No. 089176 located in Venice, Florida. Station No. 8726520 in St. Petersburg, Florida.

Table 3-1. Description of data used in thesis

Data Name	Description	Temporal Resolution	Spatial resolution	Source
Mosquito Trap Data	Daily mosquito counts	Daily	Trap zones	USDA
Wind	Hourly wind speeds and directions	Hourly	Nearest weather station	NOAA
Tide	Historical tide levels	Daily	Nearest tidal station	NOAA
Precipitation	Precipitation levels	Daily	Nearest tidal station	CLIMOD

CHAPTER 4
METHODOLOGY

Analysis of Spatio-Temporal Dynamics of *Aedes taeniorhynchus*

To describe the spatial-temporal dynamics of *Aedes taeniorhynchus,* I examined the movement of population centroids and the population distributions over time. As shown in Figure 4-1, for each observation day, the weighted centroid method was employed to estimate the population centroid, and meanwhile the inverse distance weighing (IDW) method was used to interpolate the population distribution. The details of both methods are described below.

Population-Weighted Centroid

I used the Sarasota mosquito management zones to georeference mosquito trap data from 1992 to 1994. Each zone location, which is represented by a polygon, within Sarasota County contains one corresponding mosquito trap site. Each trap stays in a fixed position within each zone unless forced to move due to county development or damage to a particular trap site. Since no specific latitudes and longitudes were recorded for trap locations, I calculated the centroid values of each zone in ESRI ArcGIS 10.0, as a possible substitute. I then joined all relating mosquito trap information to the centroid points thus giving values to all locations such as dates and counts of mosquitoes collected.

To investigate mosquito dispersal patterns, I calculated a series of population weighted centroids for each collection date. By weighting the centroids by population I could represent the population centroid for an area rather than the geometric centroid. Population centroids are a useful tool in portraying the general trend of population movements [47]. When modeling migration or dispersion it is assumed that population-weighted centroids are the most suitable out of the other methods available for calculating areal centroids [48]. They are related to the distribution of the population within each area and can also be used for the calculation of migration distance [49].

The population weighted mean centroid locations of the mosquito population in Sarasota County can be found by multiplying the *X* and *Y* coordinates for each of the zones centroid population associated with that point. The mean of the weighted *X* coordinates and the means of the weighted *Y* coordinates define the location of the weighted mean center [50]. The equations for the population-weighted mean center are shown in Equation 4-1

$$\overline{X}_w = \frac{\sum wX}{\sum w} \quad \text{and} \quad \overline{Y}_w = \frac{\sum wY}{\sum w}. \qquad 4\text{-}1$$

In the two formulas above *X* and *Y* are the coordinates of the centroids within each zone, and w is the population size that is to be multiplied by the coordinates [50].

Inverse Distance weighting

To investigate if the population-weighted centroids are representative of actual distribution of populations, a series of inverse distance weighted (IDW) maps was produced with contour lines showing varying mosquito densities. The IDW method has worked well in previous studies to interpolate mosquito densities across a landscape. Tachiiri et al. [51] used the IDW in the creation of a raster-based mosquito abundance map to evaluate West Nile virus risk in British Colombia. Allen and Shellito [52] used IDW, among other methods, to characterize abundance patterns of mosquito vectors of West Nile virus in Chesapeake, Virginia.

Inverse distance interpolation is a weighted average of neighboring values. The weight given to each observation is inversely proportion to the distance between that observations whereabouts and the initial grid point at which interpolation is sought after [53]. The equation for IDW is shown in Equation 4-2

$$\hat{Z}_{ID_p} = \frac{\sum_{i=1}^{N} Z(s_i) d_{0,i}^{-p}}{\sum_{i=1}^{N} d_{0,i}^{-p}} . \qquad 4\text{-}2$$

In this formula $d_{0,i}$ is the distance from the initial location to the ith data location s_i. The coefficient p is the weighting power and manages how fast the weights tend to zero as the distance increases, based on the assumption that observations are more similar the closer together they are.

Exploring Effects of Environmental Factors on the Spatio-Temporal Dynamics of *Aedes taeniorhynchus*

To explore the driving forces that changes the spatial-temporal dynamics of *Aedes taeniorhynchus,* I examined associations between 1) the daily displacement of population centroids and the wind speed, 2) the moving direction of population centroids and daily prevailing wind direction, 3) the daily population size and precipitation, and 4) the daily population size and tidal height (Figure 4-1). The details of methodology design are described below.

Calculating Moving Distance and Direction of Population Centroids

I used the ArcGIS distance tool to measure the distance between the population-weighted centroid points. This tool helps draw a line or polygon on the map and obtain its length or area. The great circle distance between points was given in meters for this study and can be calculated by using Equation 4-3

$$\cos d = (\sin a \sin b) + (\cos a \cos b \cos |c|) \qquad 4\text{-}3$$

where a and b are the latitudes, in degrees, of the respective coordinates and $|c|$ is the absolute value of the difference of longitude between the respective coordinates [54].

Secondly, the moving directions of population centroids between sequential centroid dates were estimated by Equation 4-4:

$$\tan^{-1}(\cos(lat1)\sin(lat2) - \sin(lat1)\cos(lat2)\cos(lon2 - lon1)\sin(lon2 - lon1)\cos(lat2)). \quad 4\text{-}4$$

Because arctangent in excel returns the values of this equation in the range of -180º to +180º, I had to normalize the results to a compass bearing in the range of 0º to 360º. To do this I had to convert from the radian value given to degrees then utilize the modulo operation in excel. The modulo operation finds the remainder of division of one number by another. The syntax of the MOD (modulo) function is Equation 4-5

$$\mathrm{X} = \mathrm{MOD}(\theta + 360, 360) \text{ [55].} \qquad 4\text{-}5$$

The results of these angle computations were used for correlation analysis with wind data and will be discussed further in the following section of this chapter. The angle calculations were evaluated in Microsoft excel by using the latitude and longitude values at sequential population-weighted centroid locations.

Wind Speed and Direction

To analyze how wind affect *Aedes taeniorhynchus* movement, I calculated the daily wind direction and average wind speed during the study period, and attempted to relate them to the movement of mosquito population centroids. With this information I sought to answer what role, if any, the wind speed and direction play in the movement of *Aedes taeniorhynchus* throughout Sarasota County, Florida. Based on the hourly wind directions and speeds, an hourly wind vector was produced for each mosquito observation date by plotting each hourly observation on the same line chart. The direction of the vector took the hourly wind direction, and the length of the vector was the hourly wind speed multiplied by an hour. A number of consecutive hourly wind vectors constitute a daily wind vector (Figure 4-2).

Based on the daily wind vector, the daily wind direction was calculated via the straight line from the value at point X_1, Y_1 (the starting location) to X_2, Y_2 (the ending location) on Figure 4-2. The equation in Microsoft excel used to calculate the angle was Equation 4-6.

$$\theta = \tan^{-1}((Y_1 - Y_2)/(X_1 - X_2)). \qquad 4\text{-}6$$

Due to the default setting in used in excel to return values in radians I converted all outputs from the formula to degrees. The next step was to adjust the angle based on the quadrant by either subtracting 360 – degree, or 90 – degree, or 90 + degree, or finally 270 – degree depending on what original quadrant the value was found.

Subsequently, I pairwise the wind directions to the moving directions of population centroid at the same observation date, and used correlation coefficients to measure the association between them. Since data for mosquito counts was not available every day, as was the case with the wind data, I designated two dates for the wind to be compared to the mosquito movement direction. Because the mosquito movement direction was calculated between two collection dates, the two wind directions selected were both between the two sequential count dates. The first wind direction for analysis was the day before the second collection date in each mosquito movement direction, given this direction is the closest observation to the collection date.

The second was the day between the two collection dates that bore the highest average wind speed amongst all the days between the mosquito counts. This selection took into account the effects of the strongest winds on mosquito dispersal. If by chance the day before the mosquito collection was the day with the highest average wind speed, then only one direction was used during that time frame. A series of scatter-plots were produced to graphically depict the relationship between the wind directions and mosquito moving directions, and the correlation coefficients R^2 were estimated to indicate the strength of relationships.

Wind Speed and Population Moving Distance

Wind speed in relation to the moving distance of *Aedes taeniorhynchus* was also taken into consideration for this study. Similar as described in the above section, the wind speed selected was a date between the two sequential mosquito count dates. The day selected bore the highest average wind speed amongst all the days between the mosquito counts. The wind speeds were then compared to the distance between each sequential mosquito centroid location to see if a higher wind speed equated to a longer distance between daily centroid locations. A series of scatter-plots were produced to graphically depict the relationship between the wind speeds and mosquito moving distances, and the correlation coefficients R^2 were estimated to indicate the strength of relationships.

I first compared all three years, 1992-1994, to the date with the highest averaged wind speed. Next I explored the relationship between extreme high wind values and moving distance. I defined an extreme high wind value as one standard deviation above the mean. I also investigated the association, if any, of extreme low wind values with moving distance. Extreme low wind values are defined as one standard deviation below the mean. Scatterplots were also produced to show eastern movements only and their relationship to wind speed. This was to remove all movement related to an angle on the negative x-axis (on Figure 4-2), The positive x-axis shows movements away from the coast. Anything west of the coast is located in the gulf of Mexico and was not sampled.

Tide and mosquito population

To examine the effect of tide on *Aedes taeniorhynchus* population, I used the maximum daily tide data in Sarasota County provided by NOAA. Daily tide data, along with the mosquito data, from May to August of 1992-94 was assembled into a scatter plot. To asses tidal values with mosquito levels in this manner a time lag had to be applied to the mosquito data to account for the species incubation period (time between when eggs are laid and when they hatch) [56]. Given previous studies conducted on *Aedes taeniorhynchus* during the Florida summer months a lag time of seven days was selected to weigh against the tidal values [57]. After adjusting for the time lag a regression line was calculated to show correlation between count numbers and tide events.

Precipitation and Population size

As was the case with the tidal data, the precipitation levels were plotted in a scatterplot and regressed against the time lagged mosquito counts. Once again the daily precipitation levels were analyzed with mosquito abundance numbers as well as only the “extreme” precipitation levels characterized by one standard deviation above the mean value.

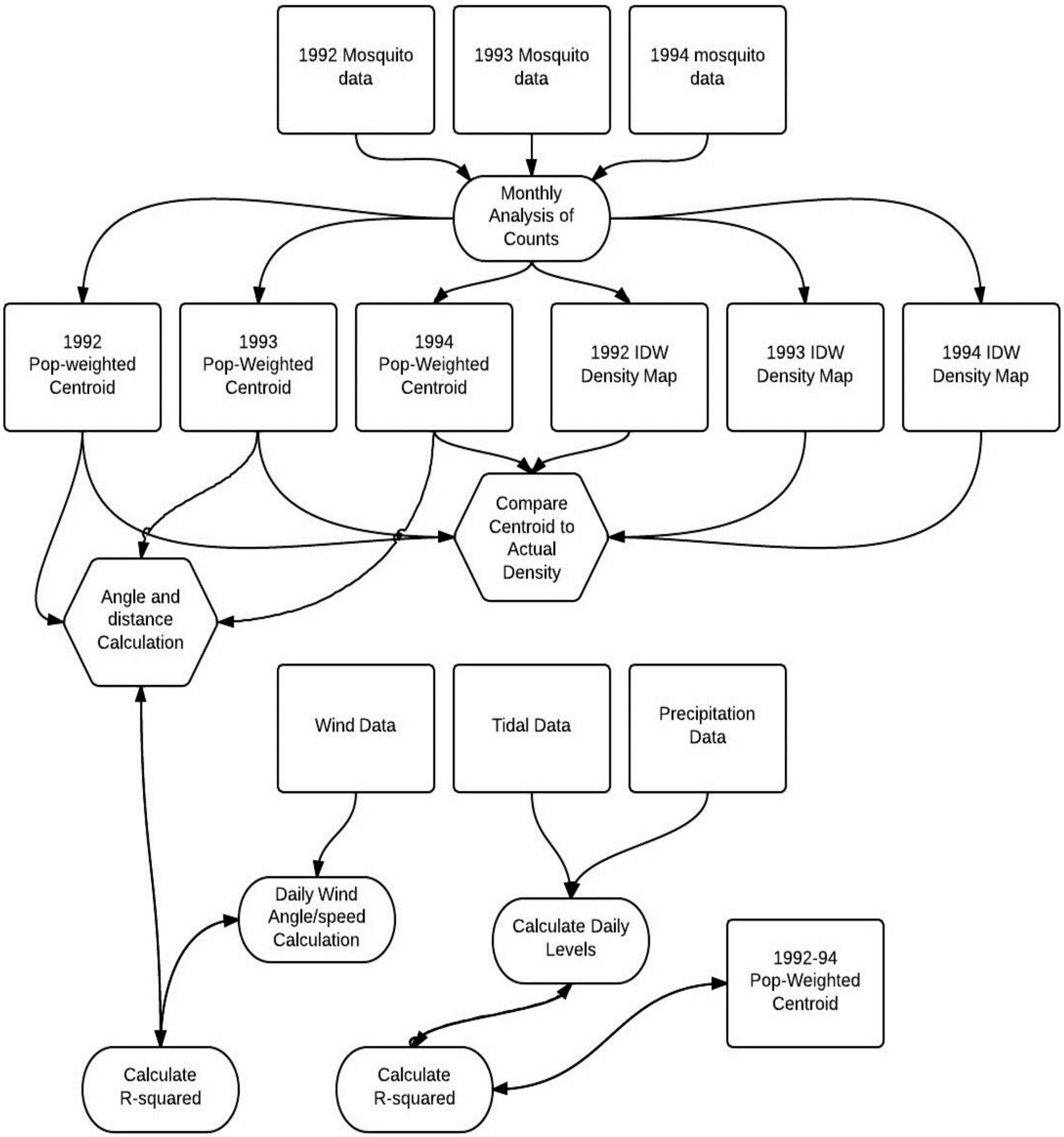


Figure 4-1. Methods displayed as a flow chart

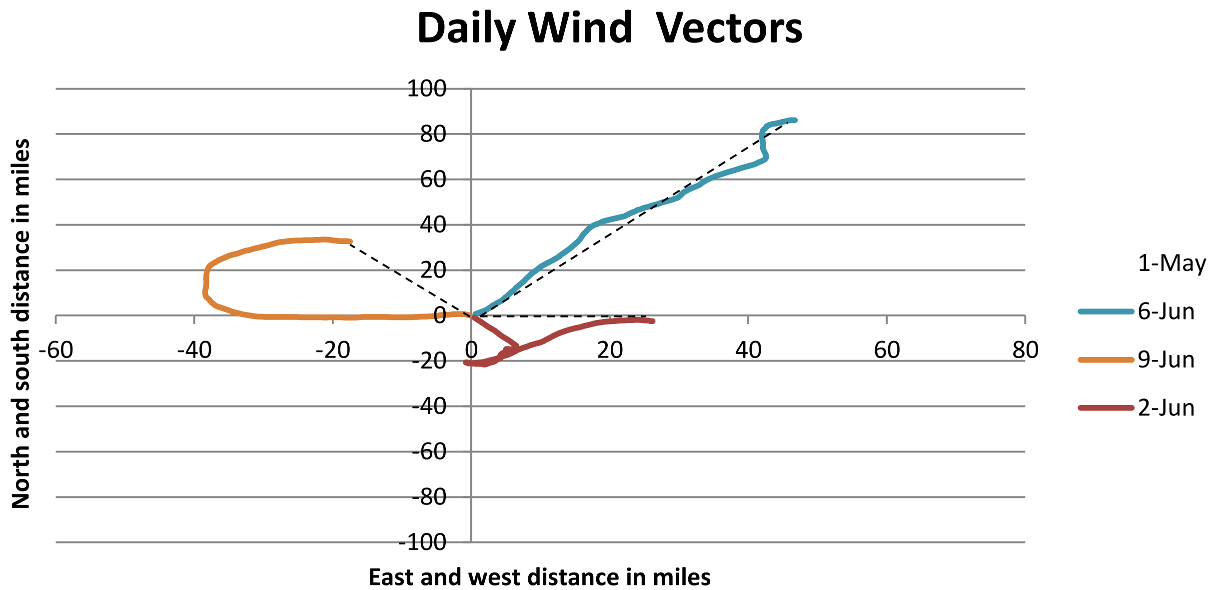


Figure 4-2**.** Examples of daily wind vectors created from hourly speed and directional data

CHAPTER 5
RESULTS AND DISCUSSION

Spatial-temporal Dispersal of *Aedes taeniorhynchus*

From the maps produced I can see that the population-weighted centroids are an accurate reflection of actual mosquito densities across Sarasota Counties. The first example of this can be seen in the IDW map from June 10, 1992 (Figure 5-1 A). From the date on this map you can see that the largest density of *Aedes taeniorhynchus* is located in the south-western portion of the county along the coast. The population-weighted mean center is very close to the actual location containing the highest mosquito density. Four days later on the 14th of June you can see that the density levels have increased in the eastern portion of the map while decreasing on the west coast (Figure 5-1 B). This result is suggestive of a decrease in the population due to an eastern dispersal from the coast. On June 17th the population density is highest again along the coast (Figure 5-1 C). Moving forward in time to the 21st of June you can see the total population numbers decreasing by the density is continuing the eastern dispersal trend (Figure 5-1 D). Figure 5- to 5-4 below further show how populations of *Aedes taeniorhynchus* will move back and forth starting from the coast to the eastern points in the county. The maps also illustrate how the population-weighted centroids are a reasonable tool to describe movement patterns of *Aedes taeniorhynchus*, particularly when only mosquito management trap data is available.

The pattern from the IDW maps tells a similar story to that of the population-weighted mean center maps. *Aedes taeniorhynchus* populations emerge along the coast then disperse inland. The seesaw nature of the map densities is indicative of population emergence and die-off. Once a population emerges along the coast it will disperse inland and die-out. New populations will follow a similar cycle of emerging along the coast then dispersing east.

The weighted centroids from April to August are shown in Figures 5-5, 5-6, and 5-7 for year 1992, 1993, and 1994, respectively. From each figure, a well-defined east to west movement repetition can be observed. A clear example of this can be seen in the last four centroid locations in the 1992 map (Figure 5-5). Starting with point 30 along the western coast I notice an eastern dispersal of the population going to point 31. There was a slight western pull back toward the coast with point 32 followed by a large eastern dispersal going to point 33 then 34 on the far eastern boarder of the county. The same patterns can also be identified in the 1993 movement map (Figure 5-6). A good example of eastern dispersal is seen by starting at point 24 in the north-west section of the map then move north-east to point 25. The next point, 26, moves south-east towards the maps center. Point 27 is found to the east of 26 while 28 is on the far eastern edge of the map. This is a clear picture of population movement traveling east from the western coast. The points depicted in 1994 (Figure 5-7) are also indicative of population movement. Looking at point 4 in the north-west section the next count date, point 5, moves south-east while point 6 travels south-west back towards the coast. The next point, number 7, is found back east almost in the center of the map. Moving further east towards the edge of the map is where point 8 is found. The three points, 6-8, show an eastern dispersal that ranges from the western coast to the eastern section of Sarasota County. A possible explanation is the emergence of new populations in salt marshes along the coast followed by a western dispersal. The movement pattern of the population-weighted centroids and the pendulum like movement tells a story that follows what I expected with this particular study species. *Aedes taeniorhynchus* is a known coastal salt marsh breeder so it makes since to conclude that populations arise along the eastern coast of Sarasota County and then disperse inland to the west. This portrayal of mosquito movement shows the range and possible dangers associated with vector disease spread with *Aedes taeniorhynchus.*

The population-weighted centroid maps for all three years show movement across the county. 1992 and 1993 show similar movement directions while 1994 seems to have more of a sharp depiction of west/east movement back and forth across the county. One hypothesis for this could be due to some environmental changes to the landscape such as the clearing of forested area or suburban development which could aid in mosquito movement. Perhaps looking into the effects of the El-nino Southern Oscillation on mosquito populations could help explain the movement patterns seen. There was a moderately strong El-nino event in 1994 so this could explain the slight differences seen in the mosquito movement directions during this time.

Association between Wind Direction and Mosquito Moving Direction

According to the correlation analysis results in Figure 5-8 and 5-9, I found no correlation between the daily wind directions and between sequential movements of population-weighted mosquito centroid locations. Figure 5-8 plots wind direction observations at the day before mosquito collection dates (DBC) against the moving direction of mosquito centroid at collection dates. The correlation analysis yielded an $R^2 = 0.0225$, which is extremely low considering a R^2 value of 1 = perfect correlation. Figure 5-9 compares the mosquito moving direction to the wind direction at the date of the highest averaged wind speed (HAWS) between two mosquito collections. Correlation between the HAWS dates and centroid movement was quite low with an $R^2 = 0.007$. I also separated the population-weighted centroid data and only looked into the comparison of daily wind directional movement with only eastern movement of mosquito centroid locations. This was an attempt to remove the western mosquito movement out of the scenario which is mostly due to new populations emerging along the coast pulling the centroids west. I defined an eastern as any movement along the positive x-axis. As before two sets of wind data were used. Using DBC movements with the eastern centroid movements yielded another very low value of $R^2 = 0.0199$ (Figure 5-10). Similar results were found using the HAWS data set with eastern centroid movements. The comparison produced and $R^2 = 0.0223$ (Figure 5-11).

Assessing the results above, the data does not support a relationship of any kind between daily wind directional movement and the population-weighted centroids. It could be that *Aedes taeniorhynchus* populations in Sarasota County are not dispersed by wind and other factors are at play in the role of dispersal. Other factors in mosquito ecology such as blood meal seeking or mating flights, regardless of wind directions, could be the intentional driver in *Aedes taeniorhynchus* populations in Sarasota County.

The large geographic range of the mosquito collection data could be an impediment on the analysis of dispersal amongst *Aedes taeniorhynchus* populations in Sarasota County. Daily wind movement and the temporal time frame of the mosquito collections could not accurately portray mosquito dispersal across the county as a whole. Future studies conducted on a smaller spatial and temporal scale could render different results.

Association between Daily Wind Speed and Mosquito Dispersal Distance

Correlations between the wind speed and moving distance of population-weighted centroids result in low R^2 values. When comparing movement between all sequential centroid locations from all three years to the days between the collection dates with the highest average wind speeds, the resulting value is $R^2 = 0.0103$ (Figure 5-12). The correlation analysis between the extreme high wind speeds and the centroid moving distance results in a higher correlation $R^2 = 0.0399$ but still not statistically significant (Figure 5-13). Figure 5-14 examines the relationship between the extreme low wind speeds and the mosquito centroid moving distance, and the correlation analysis produces the lowest correlation yet with $R^2 = 0.0004$ (Figure 5-14).

To remove any pull of the centroids back to the coast I only looked into distance associated between centroids on the positive x-axis, that is to say eastern movements. When comparing all three years of eastern movement distances to wind speeds collected on the day between counts with the highest average the resulting correlation value is $R^2 = 0.0204$ (Figure 5-15). Lastly I explored the relationship between the distances for eastern movement and extreme high wind values. The correlation analysis resulted in the highest $R^2 = 0.0839$ but still very low in terms of being significant (Figure 5-16).

Considering the low R^2 values between all correlations performed between wind speed values and distances between population-weighted centroid locations, I would fail to reject the null hypothesis that there is no relationship between the two. It is noteworthy to mention the increase in R^2 values between the extreme low wind to distance ($R^2 = 0.0004$) and the extreme high wind to eastern movement distance ($R^2 =$

0.0839). Even though both are not remotely close to a perfect correlation value of 1.0, the increase is notable. Given the results between movement and wind speed values mentioned in this section, and wind direction values in the previous, it seems as though the dispersal of Ae*des taeniorhynchus* populations in Sarasota County are goal oriented and not randomized flights determined by wind.

Association between Tide and Precipitation Levels and Mosquito Populations

Figures 5-17, 5-18, 5-19 display the association between tide, precipitation, and Ae*des taeniorhynchus* populations in year 1992, 1993, and 1994, respectively. For year 1992, the results of the correlation between tide and species abundance after the 7 day time lag are $R^2 = 0.1818$, while the correlation value for precipitation are $R^2 = 0.2649$ (Figure 5-17). The correlation amongst the tide levels for 1993 tell a similar story with an $R^2 = 0.1206$ but the precipitation value drops to an $R^2 = 0.0056$ (Figure 5-18). The results for 1994 yield similar values to that of the year before with tide at an $R^2 = 0.1175$ and precipitation at $R^2 = 0.0372$ (Figure 5-19).

Even though the R^2 values show fairly weak correlation, with the exception of precipitation to count during 1992, the charts show tide and precipitation are a good indicator if you concentrate on the peaks. A seven day time lag was placed on counts based on past literature review, but the life cycle of Ae*des taeniorhynchus* is not exactly 7 days for each and every generation of the mosquito. Looking at the tide level spike in early June of 1992, you can see a spike in Ae*des taeniorhynchus* numbers starting around the 10th of that month. Very notable spikes in tide and precipitation levels occur at the end of June in 1992. On the 5th of July you can see a very large increase in population numbers which seems to be a result of the high tide and precipitation level during the end of June. 1993 shows a similar relationship between tide and counts. The largest spike in Ae*des taeniorhynchus* population numbers on June 27th occurs 5-7 days after a spike in tidal levels. What's interesting about 1993 is the amount of rain that occurred on July 10th and is not followed by a spike in Ae*des taeniorhynchus* numbers. You can see that during this time tide levels surrounding July 10th are very low. In 1994 you can see a large spike in tide levels peaking on May 26th. On June 8th you can see a spike in population numbers. The next population spike can be seen on June 25th and follows a period of high tide levels that start about 7 days before on the 18th. A spike in precipitation also occurred on the 16th which could have helped elevate Ae*des taeniorhynchus* numbers on the 25th.

Based upon the date shown it would seem that high tide values are a better predictor for large Ae*des taeniorhynchus* populations over precipitation. Females of this species are known to lay eggs in salt marshes along coastal regions. When these regions are inundated with tidal waters the eggs are able to emerge and disperse.

Limitations and Future Research

Several limitations should be considered when interpreting these results. The temporal span of the mosquito collections was not even across all weeks throughout the years of the study. More systematic mosquito collections dates could facilitate additional space-time analysis. Also, the IDW maps are isotropic which assumes all directions are the same. This is one example of a limitation while using this method. Future work could involve the use of Kriging as an interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. Even though the use of a 7 day time lag is supported in the literature, a different numbers of days could produce higher R^2 values when comparing to precipitation and tide. Another critique is that the collection area for Sarasota County excludes Myakka River State Park which is located in the center of the county. Information on mosquito populations is not known for this section of Sarasota County. Lastly, the geographical scale of analysis could be too large to properly analyze a relationship between wind and mosquito dispersal. Wind could only be a factor associated at distances less than the distance between centroid locations.

Directions for future research could include a study performed from the analysis of Ae*des taeniorhynchus* populations that have been systematically sampled at stationary trap locations, for example, every day, throughout the summer months in Florida. A study that has access to a full 360 degree sample area including traps located over the ocean would be ideal to compile a complete depiction of Ae*des taeniorhynchus* population dispersal. I would also like to incorporate landscape type and human distribution into a future dispersal study. Urban environments and forested areas may affect the distance and direction at which mosquitoes disperse. City buildings and dense vegetation could affect prevailing wind directions and thus alter the path to which Ae*des taeniorhynchus* populations will disperse.

Sarasota County could benefit from the knowledge gained in this study. The population-weighted centroids show a trend in movement from the coast towards inland so the implementation of more mosquito traps in this direction could be beneficial for collection data. Information on high population locations is very important to effectively implement targeted control strategies against mosquito populations.

I would also like to include more research in the future on the effects the El-nino phenomenon has on mosquito populations and dispersal across Sarasota County.

Perhaps the 1994 event brought about events that created optimal conditions for an eastern dispersal from the coast that was not present in the previous two years.

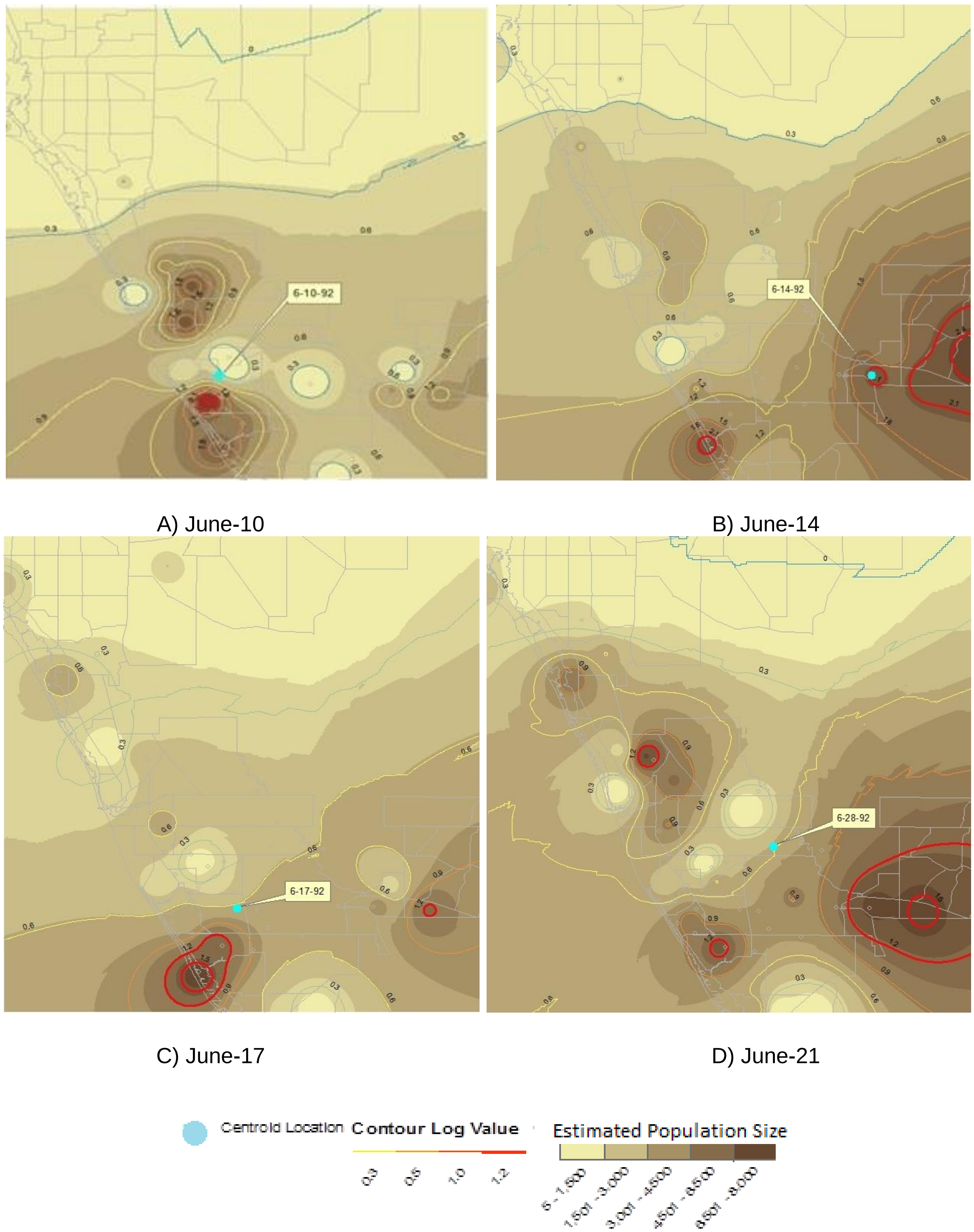


Figure 5-1. IDW maps showing Aedes taeniorhynchus estimated population sizes in relation to the population weighted centroid locations. The darker the color on the map, the larger the mosquito population. Figure A, from June 10, 1992, shows population levels highest at the coat. Figure B, from June 14, 1992, shows the population has moved inland. Figure C, from Jun 17, 1992, shows populations levels have been pulled back towards the coast. Figure D, from June 21, 1992, shows a movement inland once again. The contour loge value is the logged count of mosquito populations while the count is the estimated number of mosquitoes.

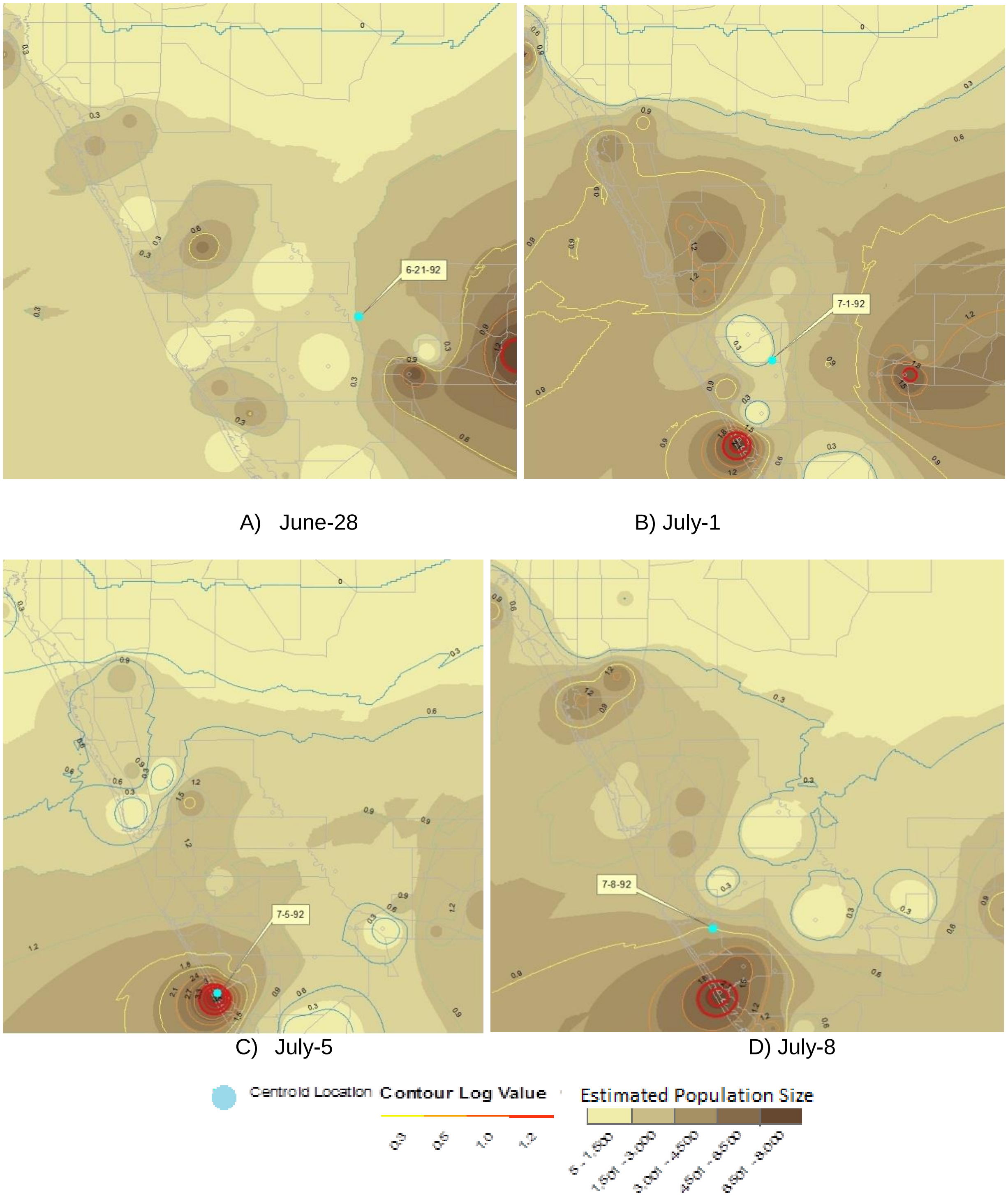


Figure 5-2. IDW maps showing Aedes taeniorhynchus estimated population sizes in relation to the population-weighted centroid locations. The darker the color on the map, the larger the mosquito population. Figure A, June 21, 1992, shows the highest population levels inland from the coast. Figure B, July 1, 1992, shows density levels back along the coast. Figure C, July 5, 1992, shows the continuation of highest populations along the coast. Figure D, July 8, 1992, shows an inland dispersal of numbers. The contour loge value is the logged count of mosquito populations while the count is the estimated number of mosquitoes.

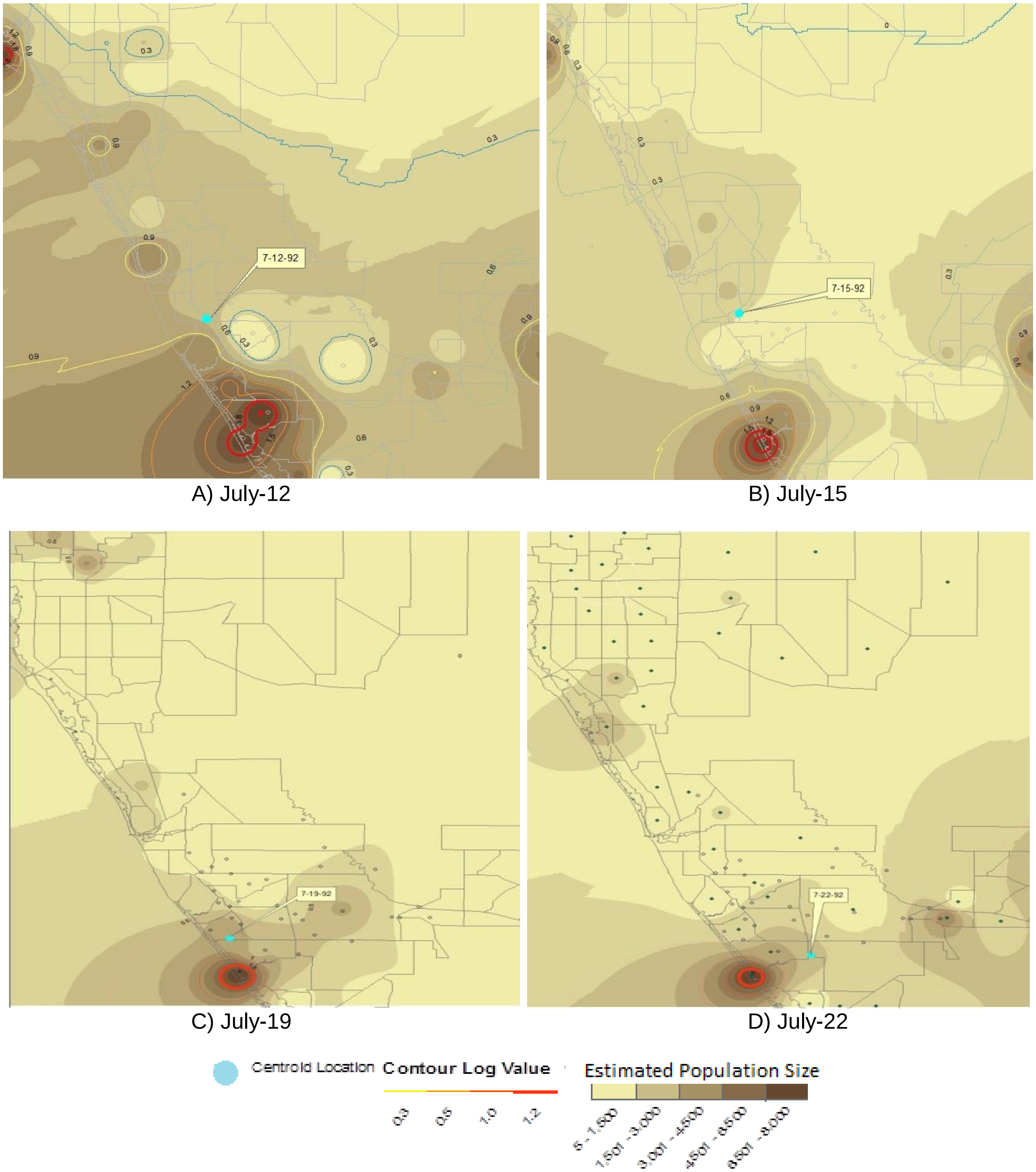


Figure 5-3. IDW maps showing Aedes taeniorhynchus estimated population sizes in relation to the population-weighted centroid locations. The darker the color on the map, the larger the mosquito population. Figure A, July 12, 1992, shows species numbers along the coast. Figure B, July 15, 1992, shows population levels staying along the coast. Figure C, July 19, 1992, shows a slight southern movement of the centroid location and population levels. Figure D, July 22, 1992, shows a slight inland dispersal occurring. The contour loge value is the logged count of mosquito populations while the count is the estimated number of mosquitoes.

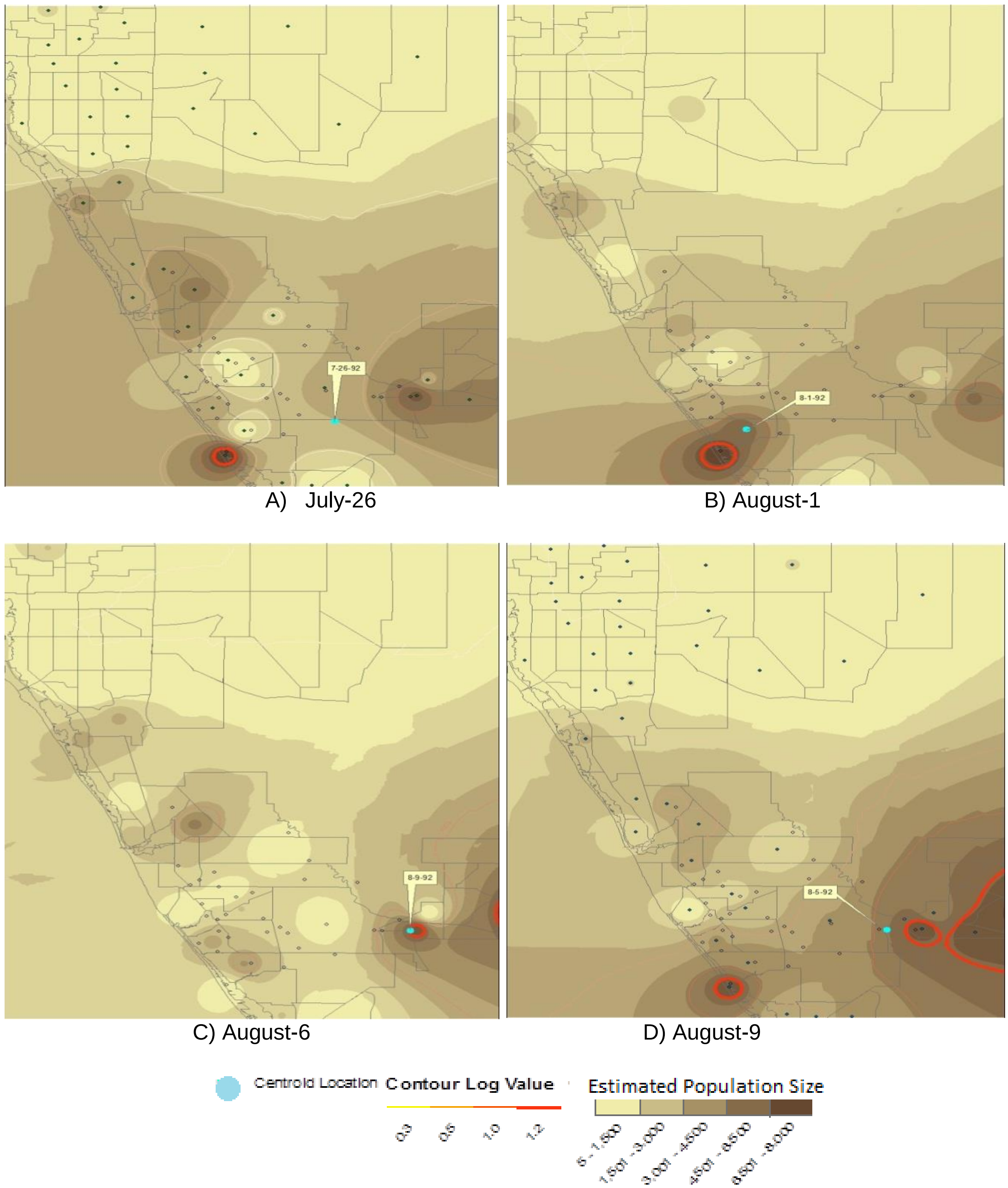


Figure 5-4. IDW maps showing Aedes taeniorhynchus estimated population sizes in relation to the population-weighted centroid locations. The darker the color on the map, the larger the mosquito population. Figure A, July 26, 1992, shows populations numbers moving inland from the coast. Figure B, August 1, 1992, Shows a population levels rising along the coast. Figure C, August 6, 1992, shows population levels dispersed inland from the previous count. Figure D, August 9, 1992, shows population locations rising back up along the coast again. The contour loge value is the logged count of mosquito populations while the count is the estimated number of mosquitoes.

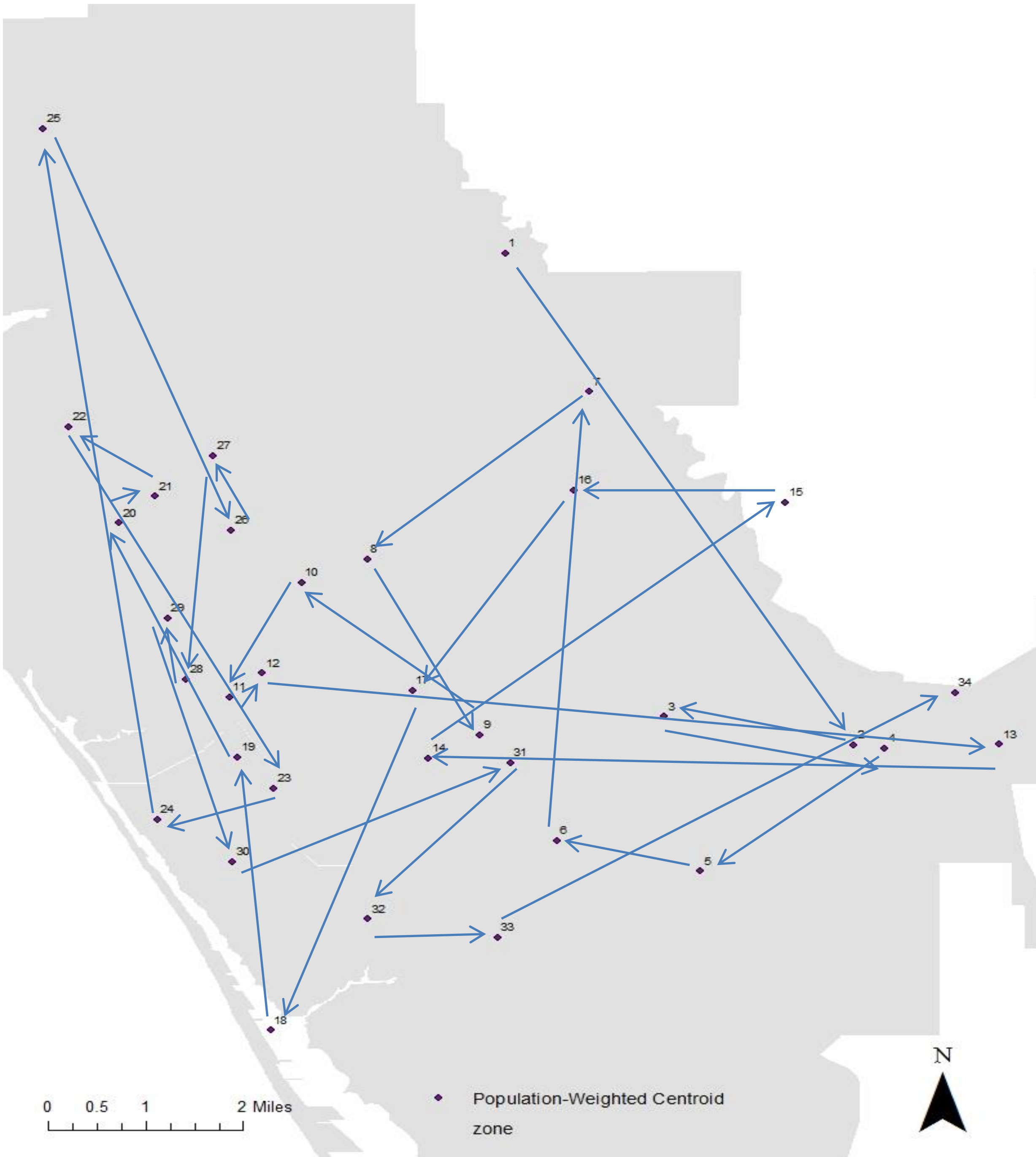


Figure 5-5. Population-weighted centroid map of Ae*des taeniorhynchus* for 1992. The arrows show movement between centroid locations. The numbers indicate centroid locations over time.

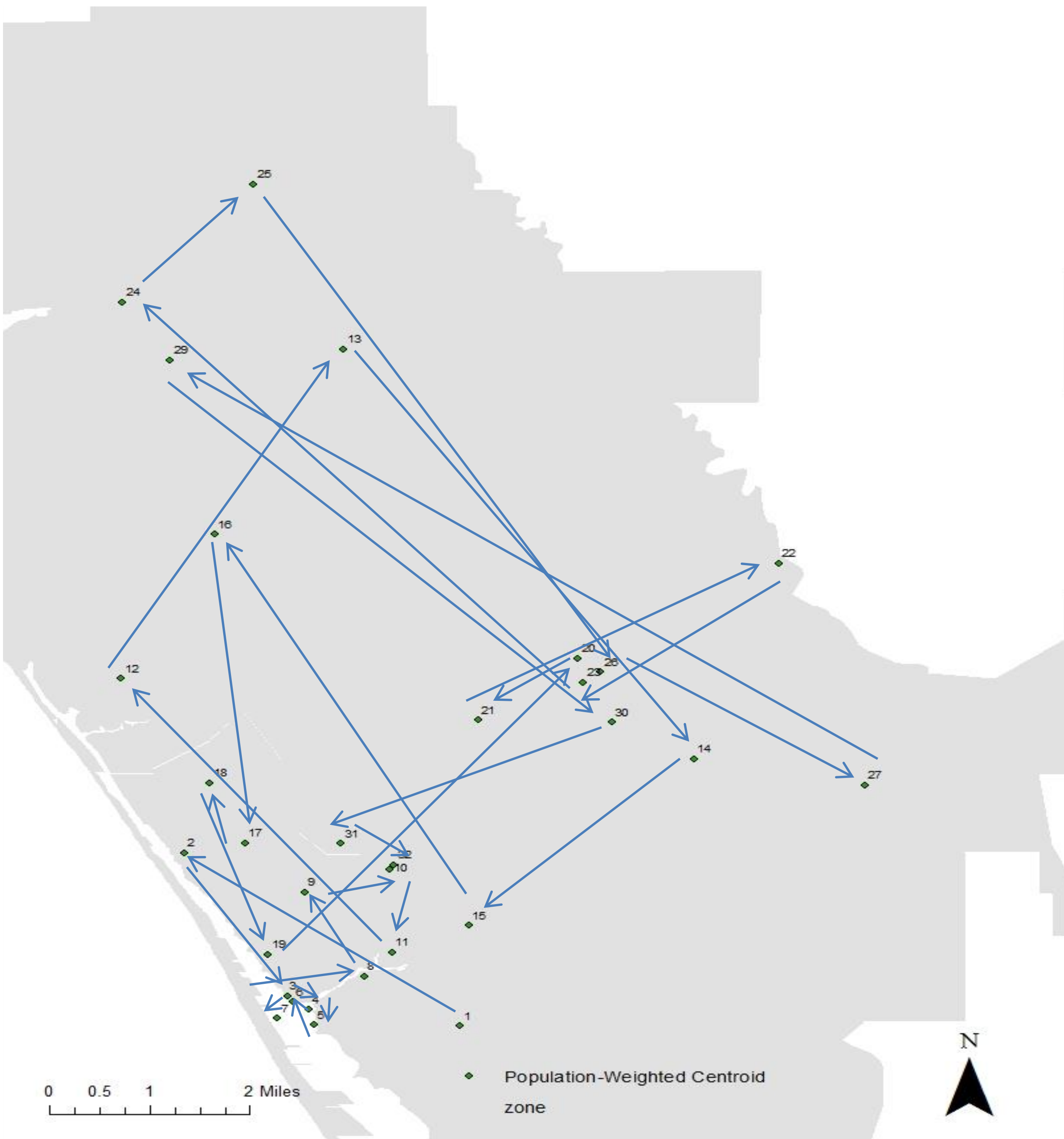


Figure 5-6. Population-weighted centroid map of Ae*des taeniorhynchus* for 1993. The arrows show movement between centroid locations. The numbers indicate centroid locations over time.

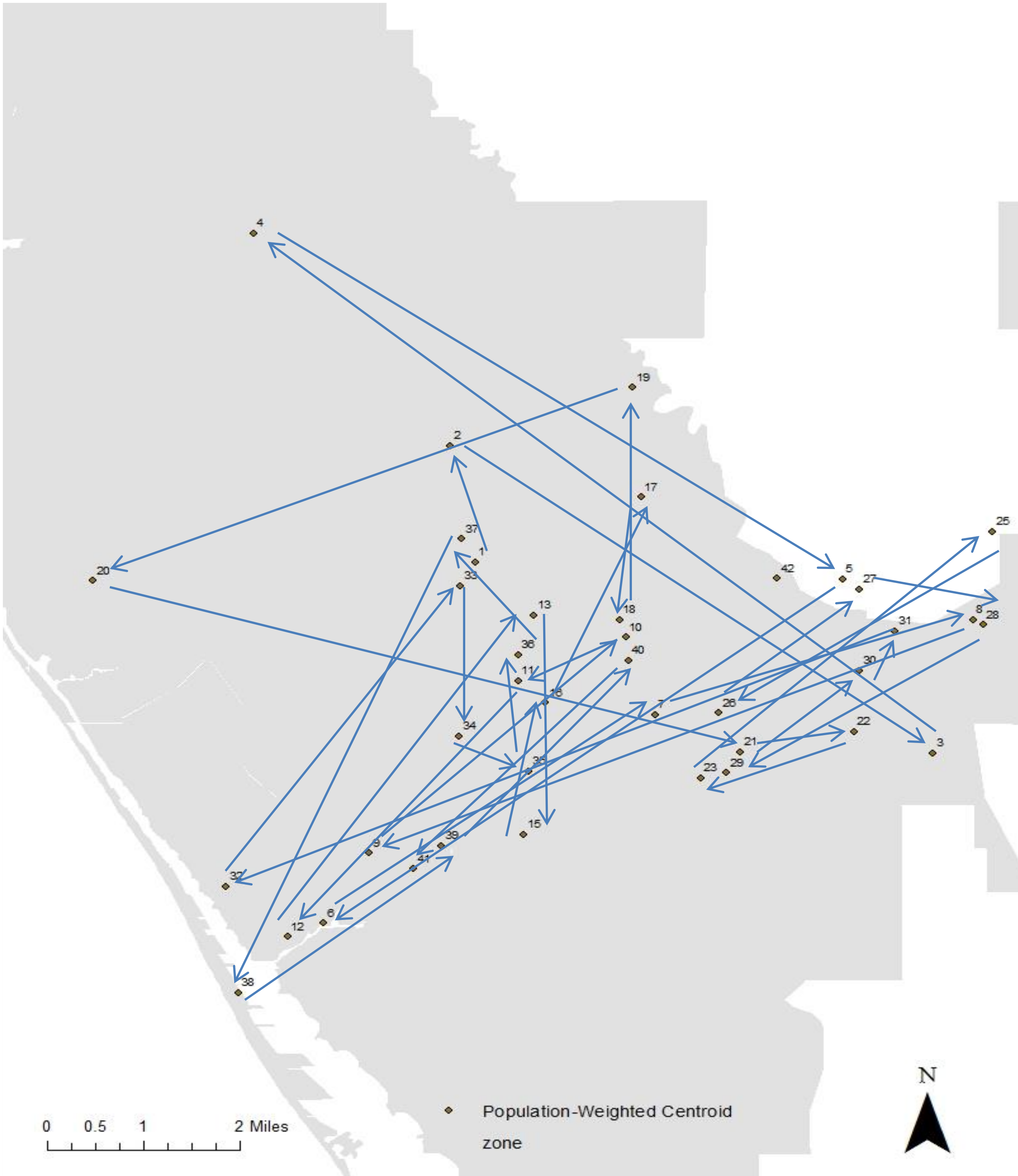
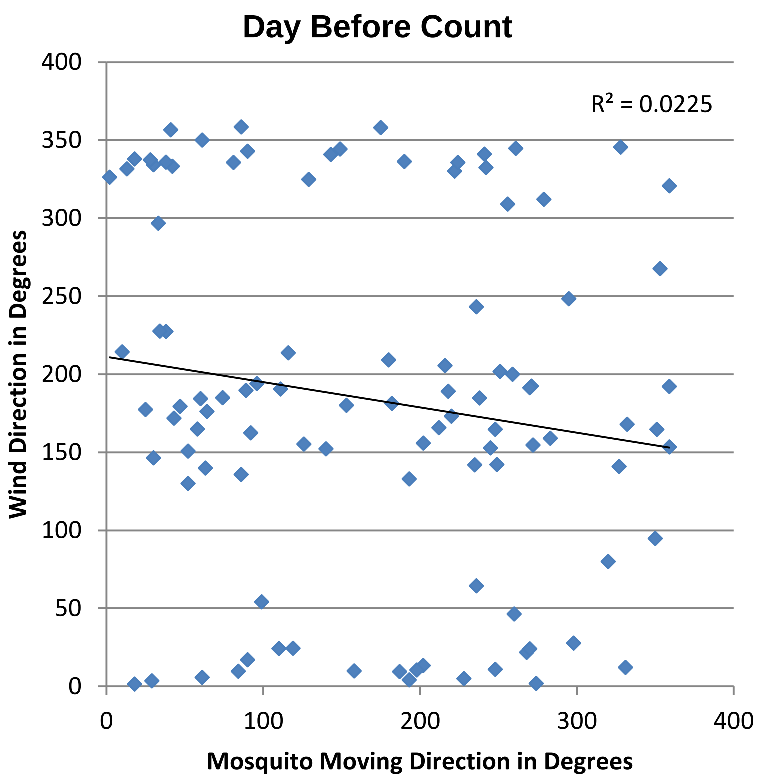


Figure 5-7. Population-weighted centroid map of *Aedes taeniorhynchus* for 1994. The arrows show movement between centroid locations. The numbers indicate centroid locations over time.



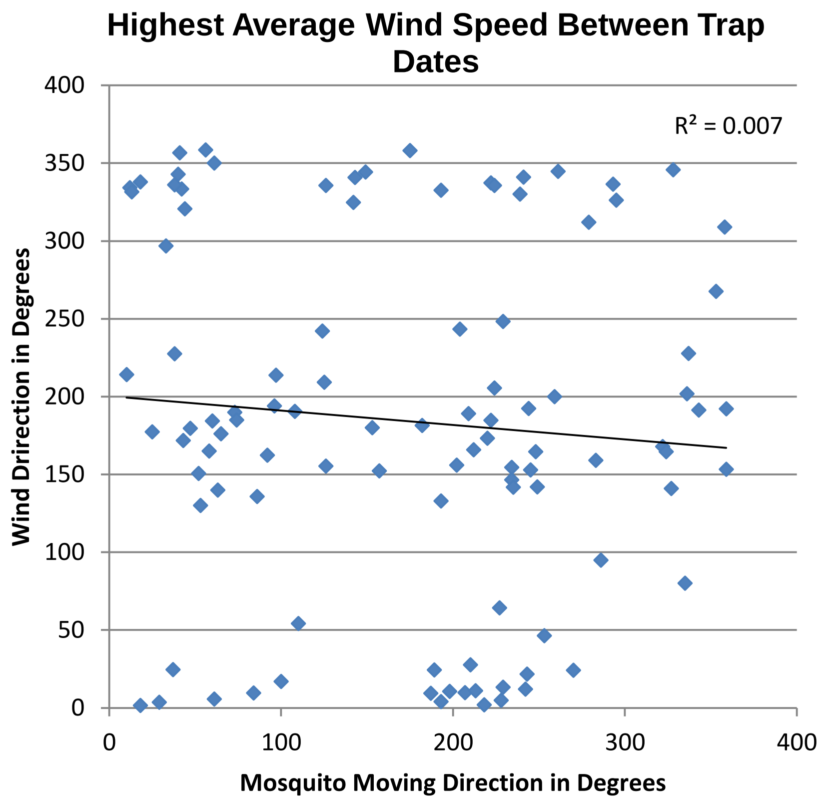


Figure 5-8. Wind direction in relation to mosquito moving direction. Units are in degrees moving counter-clockwise with 0 indicating due north.

Figure 5-9. Wind direction in relation to mosquito moving direction. Units are in degrees moving counter-clockwise with 0 indicating due north.

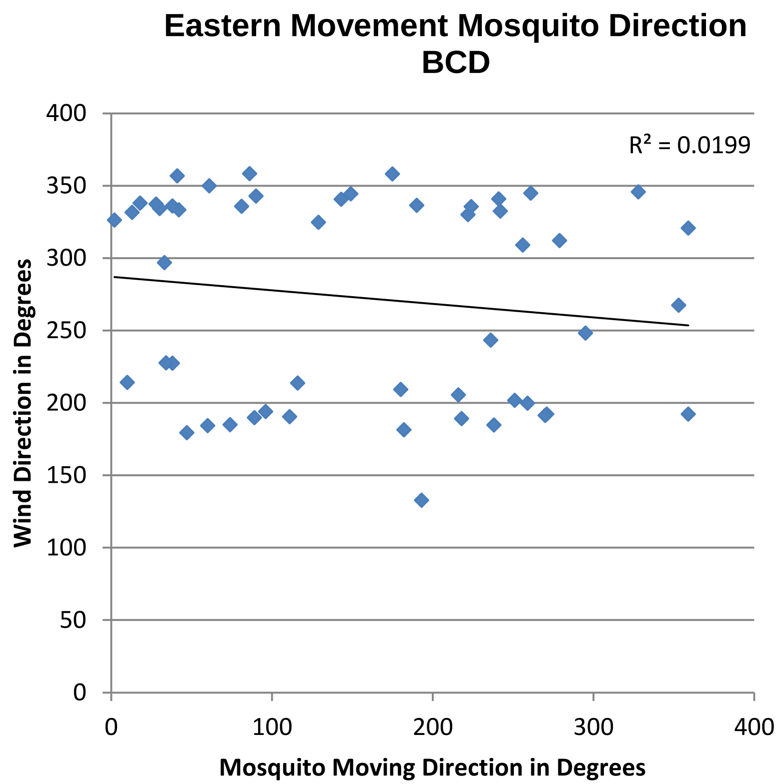


Figure 5-10. Mosquito eastern movement to wind direction. Units are in degrees moving counter-clockwise with 0 indicating due north.

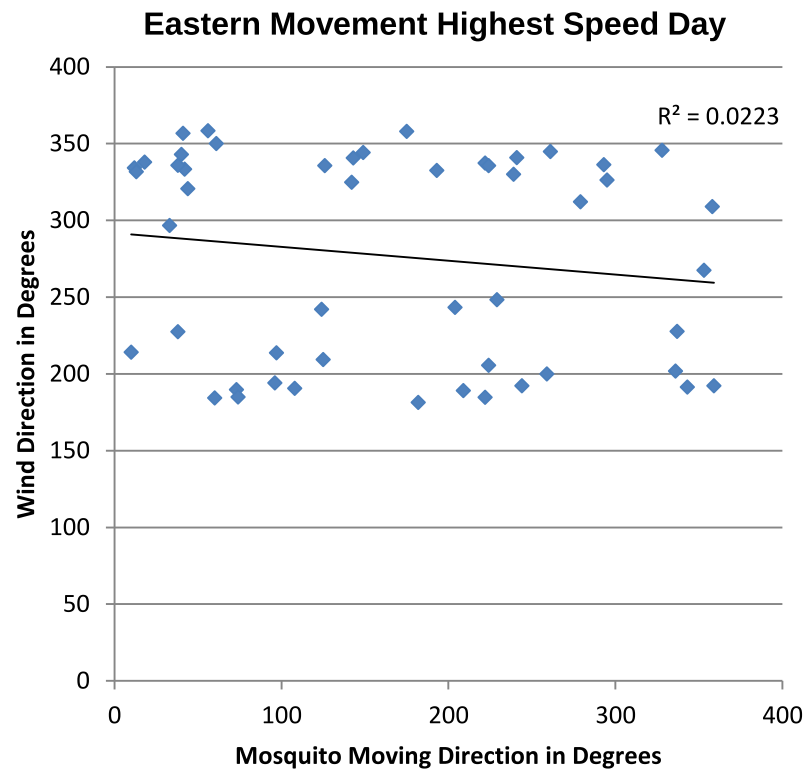
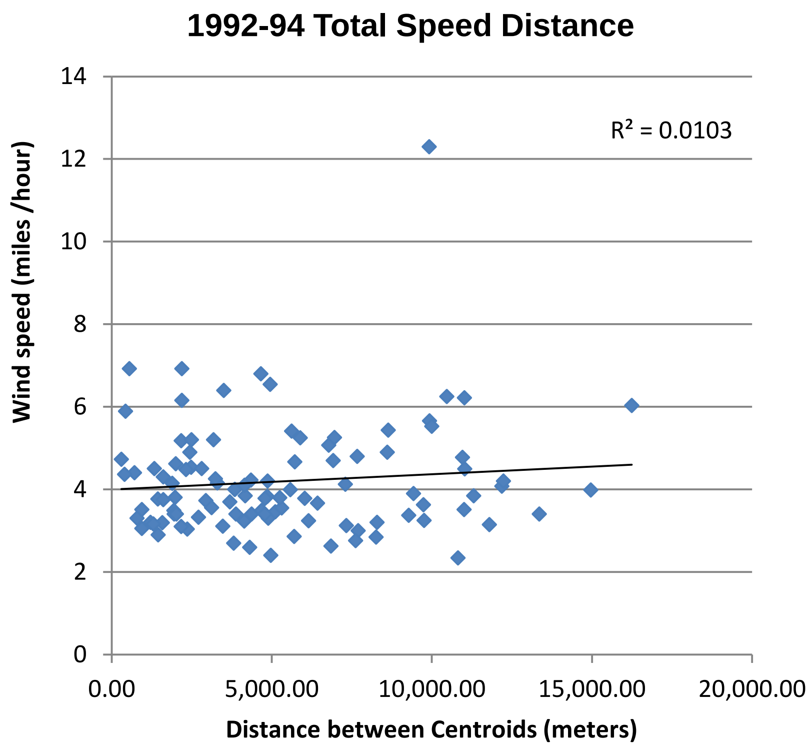


Figure 5-11. Mosquito eastern movement to wind direction. Units are in degrees moving counter-clockwise with 0 indicating due north.



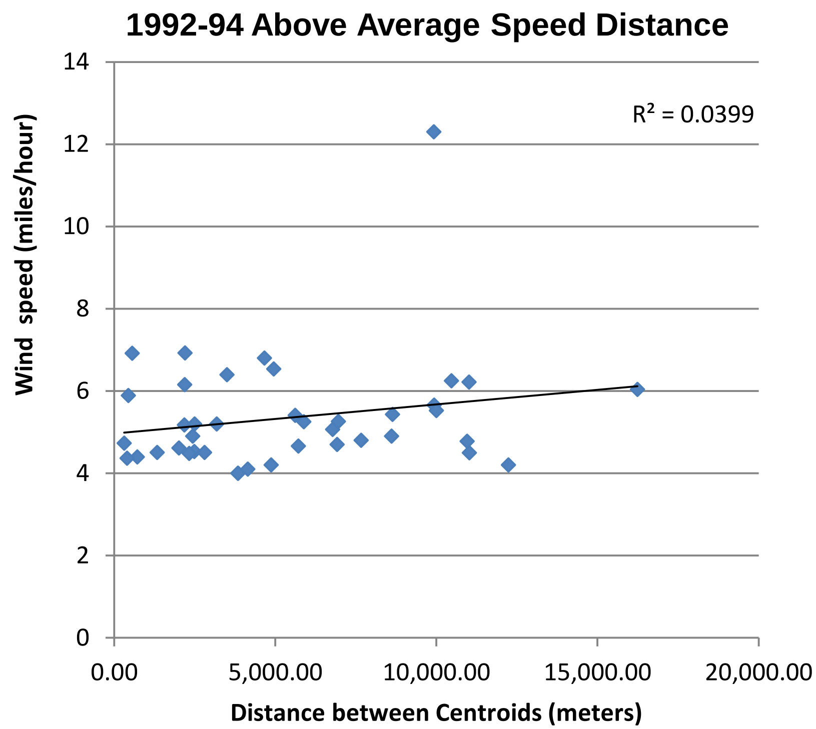


Figure 5-12. 1992-1994 Wind speed to distance between centroids

Figure 5-13. Above average wind speed to moving distance between centroids

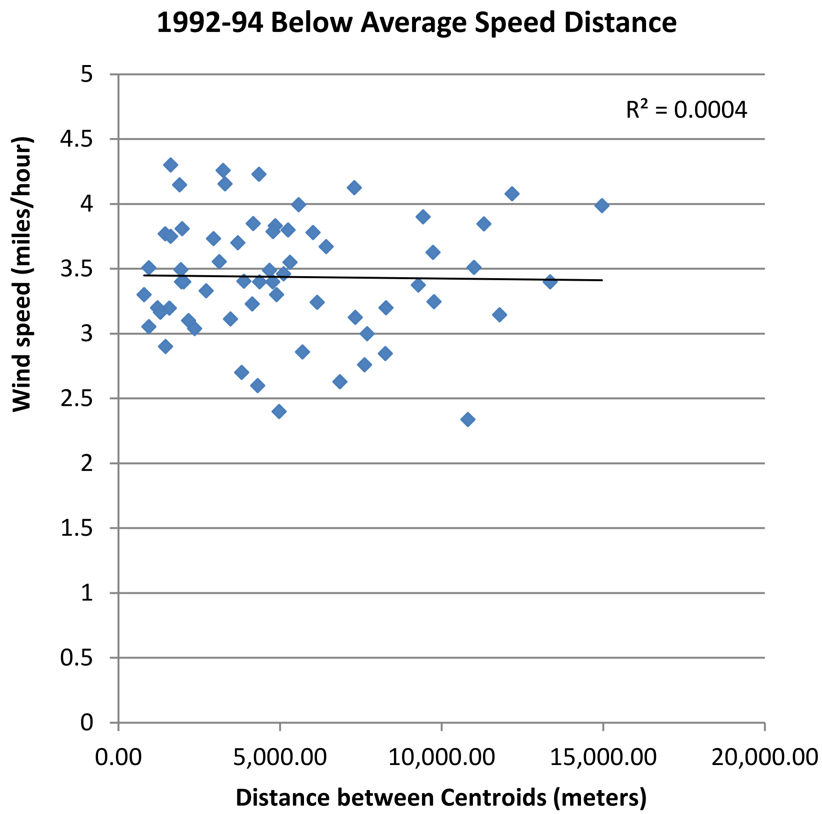


Figure 5-14. Below average wind speed to distance between centroids

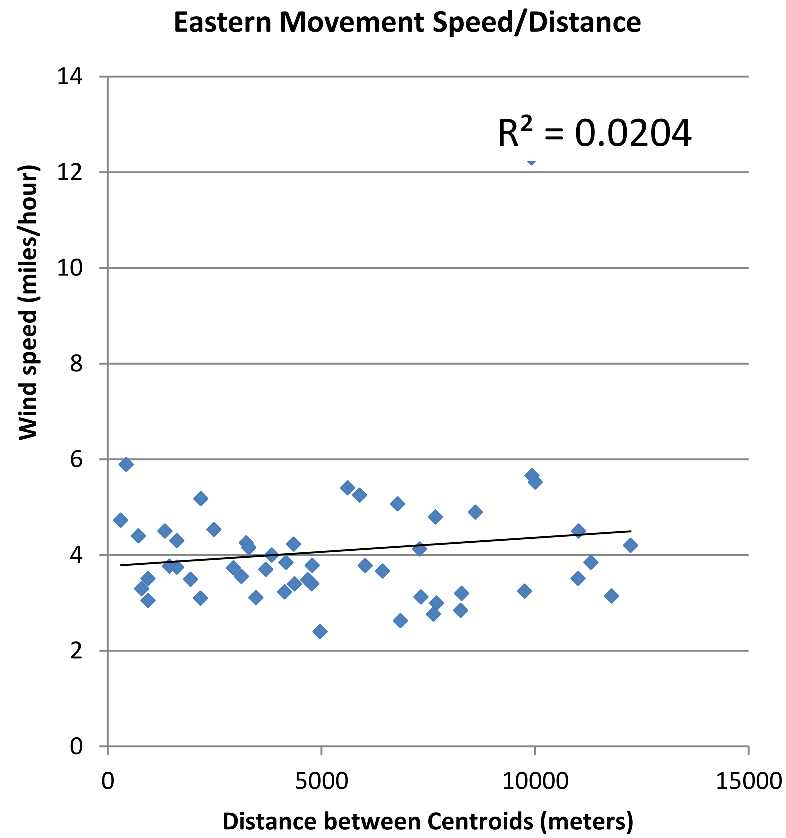


Figure 5-15. Eastern movement directions, wind speed to distance

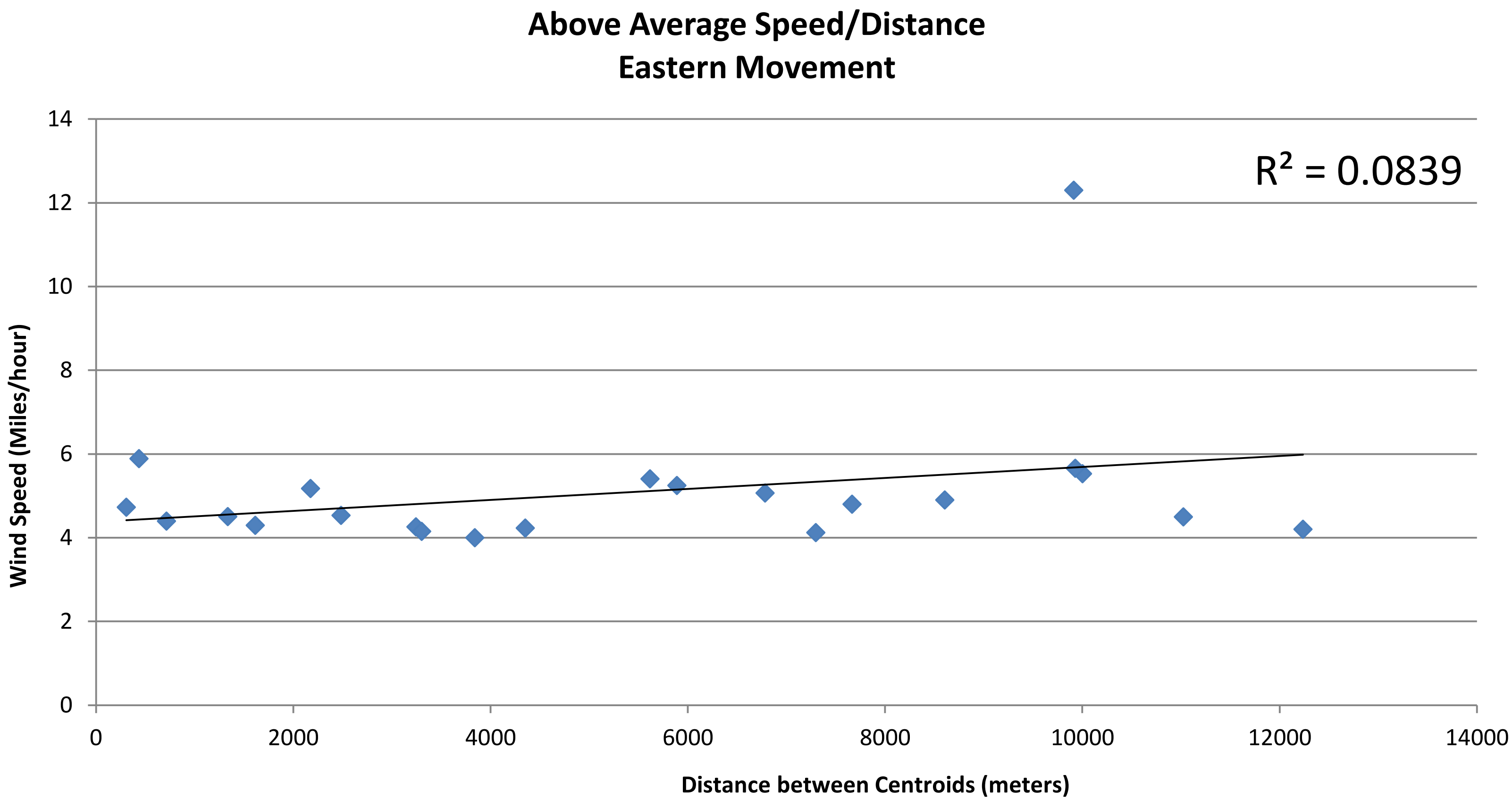


Figure 5-16. Above average wind speed to eastern movement distance of studied mosquitoes

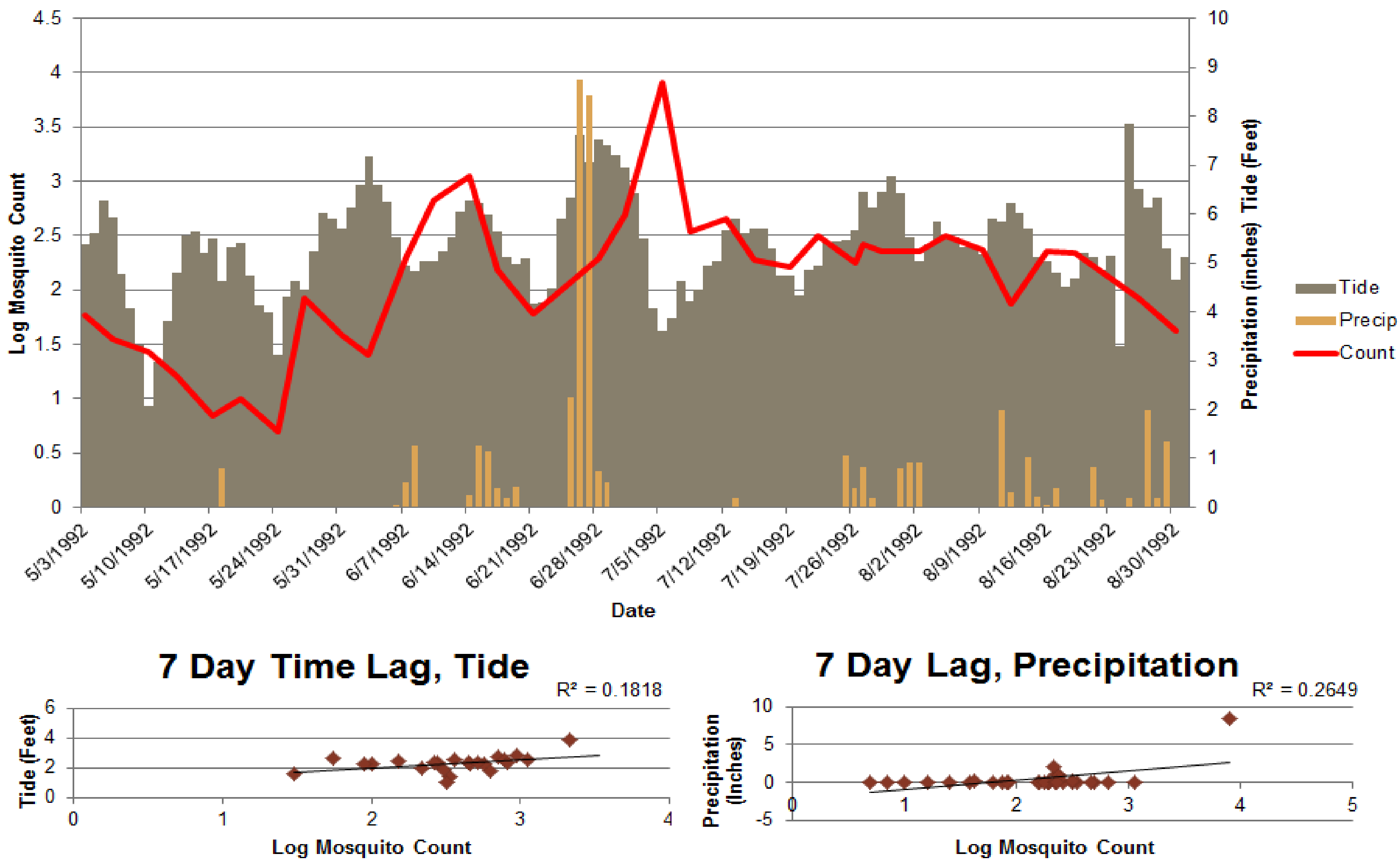


Figure 5-17. Precipitation and tide to counts with 7 day lag shown on scatter plots, 1992

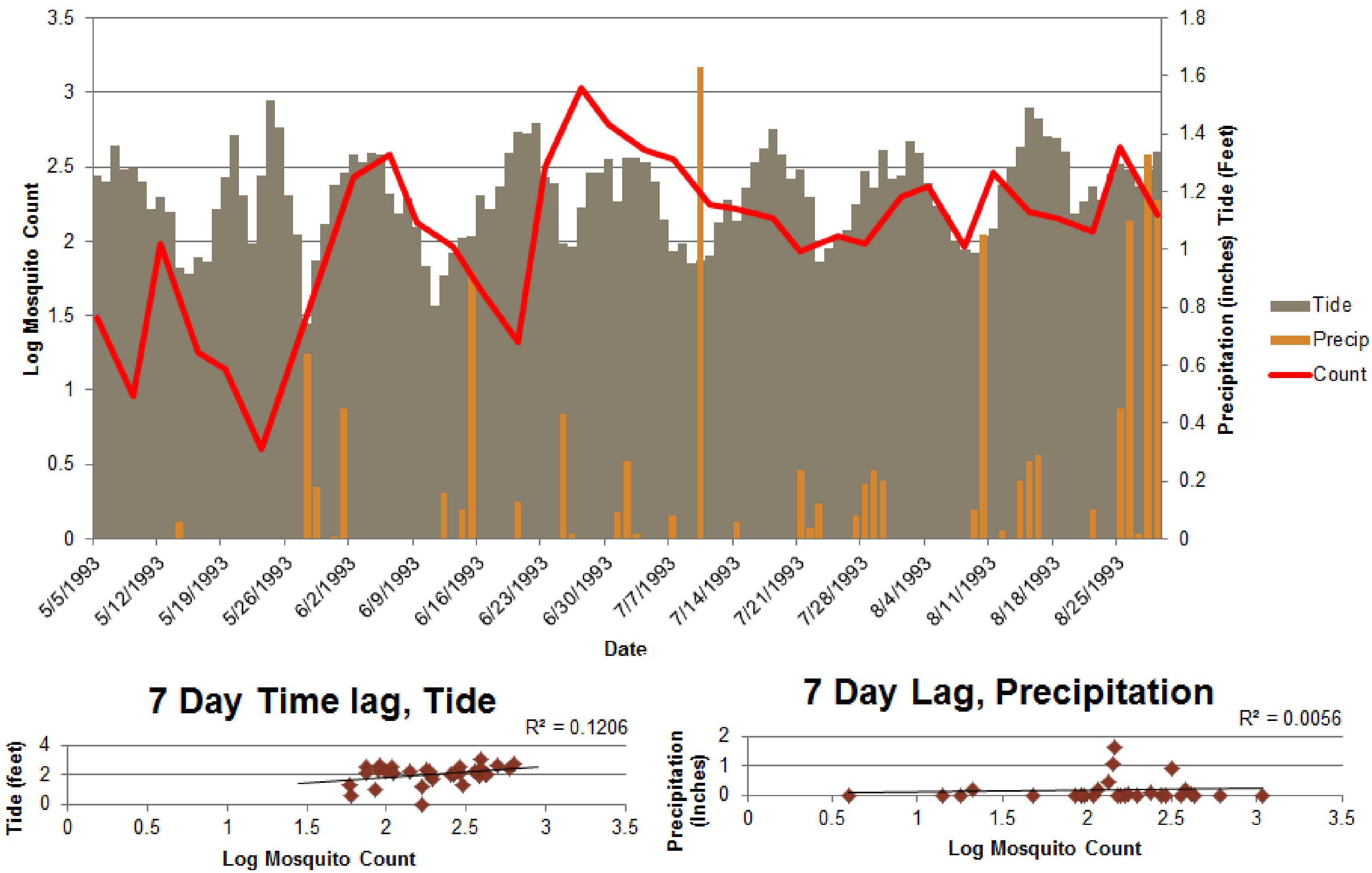


Figure 5-18. Precipitation and tide to counts with 7 day lag shown on scatter plots, 1993

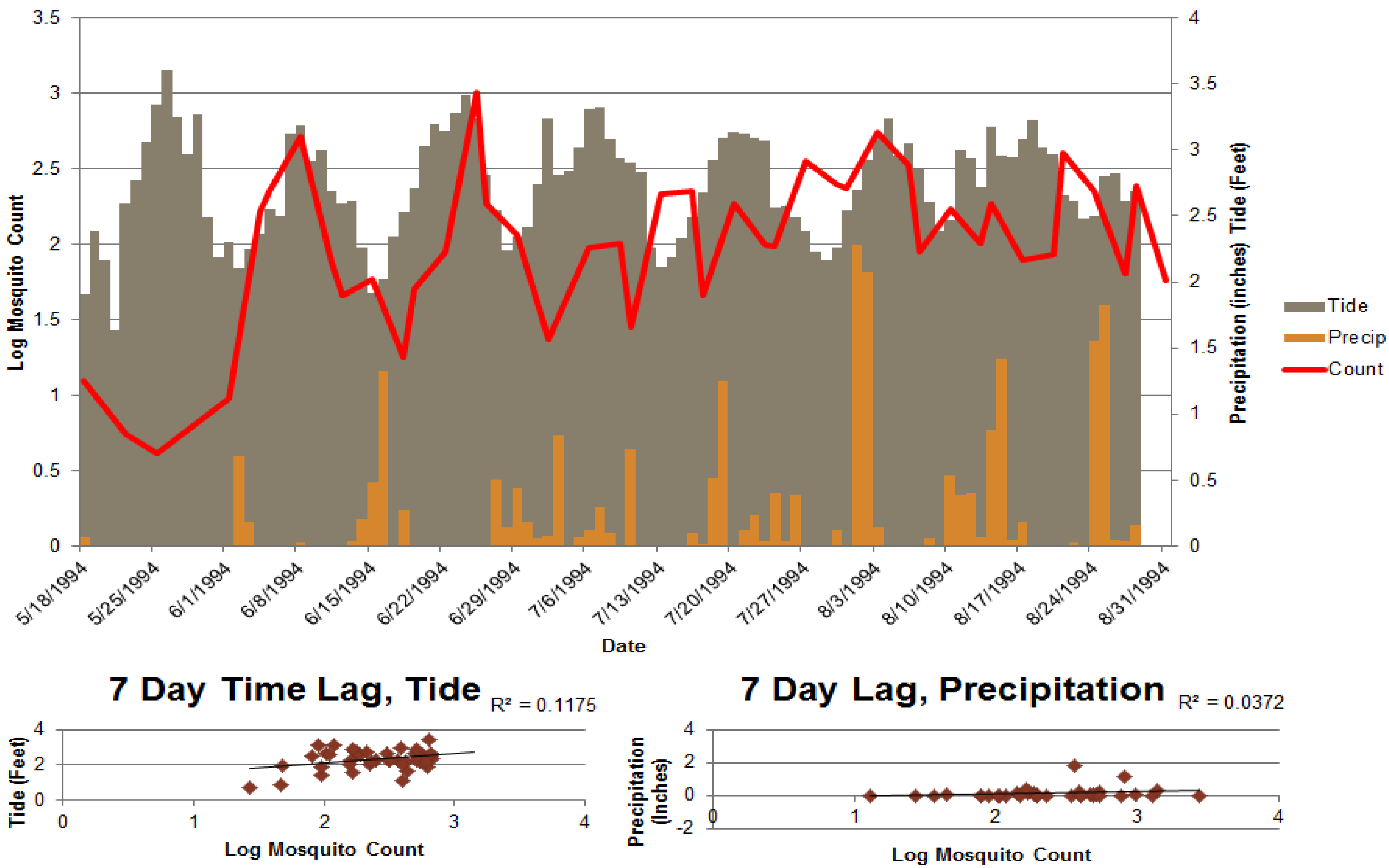


Figure 5-19. Precipitation and tide to counts with 7 day lag shown on scatter plots, 1994

Table 5-1. Hypothesis testing for R^2 statistics under the null hypothesis that $R^2=0$

Association	R^2	F statistic	P value
Day before count wind direction-Mosquito Movement direction (Figure 5-8)	0.0225	2.3	0.132
Highest average wind speed-Mosquito movement (Figure 5-9)	0.007	0.705	0.403
Day before count wind-Eastern mosquito movement (Figure 5-10)	0.0199	0.69	0.41
Highest average wind speed- Mosquito movement direction toward east (Figure 5-11)	0.0223	0.86	0.358
Wind Speed-Mosquito moving distance (Figure 5-12)	0.0103	1.527	0.219
Above Average Wind speed- Mosquito moving distance (Figure 5-13)	0.0399	2.11	0.154
Below Average speed- Mosquito distance (Figure 5-14)	0.0004	0.388	0.536
Eastern movement speed-Mosquito distance (Figure 5-15)	0.0204	0.94	0.337
Above Average speed-Mosquito distance eastern movement (Figure 5-16)	0.0839	2.4	0.137
Tide-Mosquito count 1992 (Figure 5-17)	0.18	2.12	0.124
Precipitation-Mosquito count 1992 (Figure 5-17)	0.26	3.2	0.097
Tide-Mosquito count 1993 (Figure 5-18)	0.12	2.11	0.156
Precipitation-Mosquito count 1993 (Figure 5-18)	0.0056	0.388	0.403
Tide-Mosquito count 1994 (Figure 5-19)	0.1175	2.34	0.105
Precipitation-Mosquito count 1994 (Figure 5-19)	0.0372	2.12	0.154

CHAPTER 6
CONCLUSIONS

The primary goal of this thesis was to explore the spatio-temporal dynamics of the Ae*des taeniorhynchus* mosquito in Sarasota County, Florida. Population-weighted centroids from Sarasota mosquito management trap sites were calculated and used to show locations of density and movement across the study region. Distances and movements were calculated between sequential centroid locations and then compared with daily wind directions and speed. Daily tide and precipitation levels were compared to trapped Ae*des taeniorhynchus* population numbers to analyze correlations between the two. There are three major findings from this research:

1) Ae*des taeniorhynchus* populations emerge along the coast then disperse inland as seen from the population-weighted centroid maps. The population-weighted centroid maps are found to be a reasonable tool to describe the movement patterns, particularly when only mosquito management trap data is available.

2) There is no statistical correlation found between Ae*des taeniorhynchus* dispersal and daily wind speed, as well as directions in Sarasota County, Florida. Correlations between wind data and the population-weighted centroids using R^2 Values were extremely low. Previous studies also show similar results to my findings. In a mark-release-recapture study carried out in New Hampshire on the tree hole mosquito *Ochlerotatus triseriatus*, recaptues in the study were not related to the prevailing wind direction [40]. Another mark-release-recapture study from Australia involving *Aedes aegypti,* which is in the same genus as my study species, indicates a statistically significant trend for upwind flight [41].

3) There are stronger relationships between Ae*des taeniorhynchus* population size and tide levels, as well as precipitation levels. This result is supported by previous findings which show population spikes of Ae*des taeniorhynchus* after periods of high tide or precipitation levels [8], [10]. Another reason is that females often lay eggs in the ground and hatch 2-3 days after being flooded by rain or tide [11].

Arboviruses are of great concern to the state of Florida. Disease such as WNV, SLEV, and EEE are found throughout the state. With international travel on the rise and possible introduction of other arboviruses, Florida residents are facing an elevated risk of imported mosquito-vectored illness. Knowledge of the temporal and spatial distribution of populations of potentially important disease carrying mosquito vectors is important for categorizing areas of varying risk for disease transmission. Since *Aedes taeniorhynchu*s is a coastal species with the capacity to transmit indigenous and exotic arboviruses, and there is a potential for an introduction of exotic diseases into the United States through shipping ports, enhanced surveillance and control measures need to be established. My thesis is one such example of vector surveillance and show the capacity for studying aerial movement of disease carrying vectors.

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BIOGRAPHICAL SKETCH

Mike Falkner entered the University of Florida’s Master of Science program after completing his bachelor’s degree at the University of Sydney. Prior to his enrollment is the geography department he worked on mosquito research for the United States Department of Agriculture in Gainesville, Florida. After graduation he plans to continue is travels around the globe and enter a PhD program studying vector disease.