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The risk for dengue outbreak was assessed in North Central Texas in 2006 in response to increased case numbers in Texas and Mexican states in 2005. Data were collected from 54 sites in Dallas County, TX using oviposition traps and estimates from U.S. Census and Sourcebook America databases. Higher vegetation and shade displayed more *Aedes* species; standing water also showed more *Aedes albopictus*. Lower home values and lower incomes corresponded to more *Aedes aegypti*; lower household density displayed more *Aedes albopictus*. Other socio-economic and demographic factors did not have significant association with abundance. The methodology of this study may serve as a model for assessment of dengue vector abundance in other regions

THE POPULATION ABUNDANCE AND ASSOCIATED GEOGRAPHIC AND DEMOGRAPHIC FACTORS OF THE DENGUE VECTORS, *AEDES AEGYPTI* AND *AEDES ALBOPICTUS*, IN DALLAS COUNTY, TX, USA

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CHAPTER I

INTRODUCTION

Dengue incidence is rising worldwide and in North Central Texas. The presence and abundance of mosquito vectors for this disease in Dallas County, TX have not been documented. The relationships of habitat and demographic factors with dengue vector abundance in the region are unknown. Human immigration from endemic countries and global climate trends raise concerns about the risk for dengue outbreaks in North Central Texas. Methodology for accurate prediction of dengue outbreaks does not currently exist.

Statement of Purpose

The intent of this study was to prove that dengue vectors are present in Dallas County, to test the geographic and demographic characteristics of Dallas County as predictors of dengue vector populations in North Central Texas, to describe the areas at highest risk for dengue outbreak, and to develop an effective methodology for achieving these same goals in other regions.

Hypotheses

1. The population abundance of the dengue vectors, *Aedes aegypti* and *Aedes albopictus* are associated with geographic and demographic factors in Dallas County, TX.

2. Geographic and demographic factors can be utilized as predictors of *Aedes aegypti* and *Aedes albopictus* populations and identifiers of the communities at greatest risk for dengue outbreaks in Dallas County, TX.

Delimitations

Six zip codes were selected for sample collections to represent Dallas County as a whole. This decision influenced the outcome of the study as certain zip codes presented variation of mosquito population abundance which differed from that of the entire county. The six sample zip codes in this study were selected based on the socio-economic status of local residents. Within each zip code, nine sites were selected at random for placement of 108 ovitraps throughout Dallas County. Due to the random selection of ovitrap locations as well as the weekly rotation of distilled and hay infusion substrates at each of the 54 sites, the outcomes of this study were generalized to the entire *Aedes* mosquito population in Dallas County.

Limitations

The sample size may have limited the ability to generalize the study findings to all zip codes within Dallas County. The lack of precipitation during both 2005 and 2006 limited the ability to observe and record the average oviposition behavior of dengue vectors. Use of the General Estimation Equation distribution allowed for analysis by zip code clusters, however this distribution is typically used in cases where there are many more clusters than independent variables. In this study, analysis of 5 variables with 6 clusters may limit the validity of the analysis results.

Assumptions

The climactic factors of temperature and rainfall for June through November, 2006 were typical for these months, and thus, the study results were considered as viable predictors for vector population abundance. The demographic data, excluding home value, were zip code averages gathered from a public-access database (Ergonomics and Safety Research Institute, 2005); these averages were assumed to be representative of the individual sample sites. The data were assumed to follow a Poisson distribution for the purposes of data analyses.

Definition of Terms

Anthroponotic: disease transmission between humans via an arthropod vector without an additional animal reservoir (Ekanayake et al., 2006; Solutions, 2003)

Household density: number of persons per household (ESRI, 2005)

Oviposition: mosquito egg-laying

Ovitraps: open containers painted flat black and filled with water into which a paper strip was inserted as a substrate for oviposition by female *Aedes* mosquitoes; also called oviposition traps

Population dynamics: seasonal fluctuation of mosquito population due to variation in activity and oviposition

Premise Condition Index (PCI): index of 3 to 9 assigned to a location based on the factors of house condition, degree of shade, and oviposition activity (Nogueira et al., 2005)

Social-environmental factors: environmental characteristics of human dwellings with a relationship to local demographics and socio-economic status; demographics with a vector-borne disease predictive value (Barcellos et al., 2005)

Zoonotic: disease transmission between non-human animals via an arthropod vector where humans are a dead-end host (Ekanayake et al., 2006)

Importance of the Study

Using the data collected in Dallas County via ovitraps and site surveys, this study assessed the significance of primary geographic (National Oceanic and Atmospheric Association, 2006; United States Environmental Protection Agency, 2005) and demographic factors (Dallas County Appraisal District, 2007; ESRI, 2005) for influence on dengue transmission by the mosquito vectors, *Aedes aegypti* and *Aedes albopictus*. The study correlated vector abundance with geographic and demographic factors to identify the best predictors for dengue outbreaks in North Central Texas. This information can make suggestions about the prevention and control of dengue outbreak and the effective management of dengue vectors to local public health and mosquito control agencies. The methodology used here may serve as a model for the assessment of social-environmental predictors in other locations.

CHAPTER II

LITERATURE REVIEW

Following is an overview of the current literature regarding dengue fever, its epidemiology, and its economic impact. Also detailed are the mosquito vectors of the disease, Texas vector survey conclusions, the demographic factors related to vector competency, and trends of immigration from dengue-endemic countries.

Epidemiology

Dengue is the most common vector-born viral disease of humans worldwide. Around 50 million infections are estimated to occur in tropical & subtropical regions each year. In 2001, over 600,000 reported cases occurred in the Americas alone. Dengue is a unique disease due to its urban nature and lack of a vaccine (Lenhart et al., 2005). Though it was nearly eradicated prior to 1977, dengue is now wide-spread and epidemics are documented in all countries throughout the Western Hemisphere except Bermuda, Canada, the Cayman Islands, Chile, and Uruguay. The global incidence of dengue represents a pandemic that is being facilitated by a number of factors. Increased air travel, urbanization, population growth, a rise in the use of disposable, non-biodegradable containers around human dwellings, and a lack of effective mosquito control are some factors contributing to this increase (Center for Disease Control , 1994).

The dengue increase throughout the tropics has been noted as a risk to travelers and residents of the U.S. visiting places where *Aedes aegypti* is present. In the U.S. alone, 400 cases of imported dengue were reported from 1977 thru 1992, and 1980 marked the year of the first locally-acquired case in this country since 1945. Texas was the site of the next locally-acquired U.S. case in 1986. This was closely followed by additional local cases in Brownsville, Corpus Christi, and Laredo for a total of 9 in 1986. The next locally-acquired case of dengue was not reported until 1992. During this period, U.S. residents reported a number of both severe and fatal cases after traveling to endemic countries (CDC, 1994).

Following this series of locally-acquired dengue cases, public health officials grew concerned about increased border crossings and the year-round presence of the primary dengue vector, *Aedes aegypti,* in southern Texas and Mexico. During intense dengue transmission in the Mexican border states in 1980, 1986, and 1995, cases of the disease in Texas rose accordingly. After a Tamaulipas outbreak of 4758 dengue cases in August of 1995, the Texas Department of State Health Services (TDSHS) detected 29 new cases in Texas. All of these cases were women over 20 years of age, and 7 were assumed to be locally-transmitted due to no travel history. In the same year, the Pan American Health Organization (PAHO) reported close to 240,000 cases in Central and South America (CDC, 1996). There was a lull in U.S. dengue cases until 1999, when an outbreak of 12 cases occurred in Laredo, TX. Investigated by the Centers for Disease Control and Prevention, the outbreak was blamed on high dengue case numbers across the border that year (Zewe, 1999). In the same year, another local case of dengue in Texas was reported. Between 2001 and 2004, 77 cases were reported in the U.S. (CDC, 2005b). The year 2005 brought a significant rise in U.S. dengue incidence with a total of 96 cases and 1 fatality (CDC, 2006b). Twenty-nine of these cases took place in Texas, 22 were reported in Cameron County, and all but 2 of the Texas cases were imported. That year, all but 3 of the cases were reported in North Central Texas, in Tarrant, Denton, and Cooke Counties, and resulted from importation from dengue-endemic countries (Marabota, Martinez & TDSHS, 2006).

Economic Impact

Whether due to imported or locally-transmitted cases, dengue outbreaks introduce a significant economic burden. Based on estimated daily adjusted life years in Latin American countries between 1984 and 1994, this disease produced morbidity on par with tuberculosis and malaria (Meltzer *et al.*, 1998). Developed by the World Bank, DALY's serve to compare the impact of diseases in different locations. For a given population, DALY's sum the years of life lost to premature mortality and the years of health lost to disability from infection. The indicator weights the importance of a healthy life according to age. Some costs of disease that are taken into account include food, transportation, hospital bills, and loss of work and/or opportunity from decreased productivity. Quantifying the impact of individual diseases in different locations helps to prioritize the allocation of resources to public health problems (Murray, 1994).

Based on DALY's, dengue imposes more of a burden than a number of other diseases which currently receive more resources (D. V. Clark et al., 2005). The 1977 outbreak in Puerto Rico equated to 658 DALY's per 1 million persons, equal to the burden from malaria or tuberculosis during the same period (Gubler, 1998). In Puerto Rico from 1984 to 1992, the DALY's for dengue were similar to the years of life and health lost from sexually-transmitted diseases, intestinal helminths, and a combination of 5 childhood diseases (Meltzer et al., 1998). For Thailand in 2001, endemic dengue was estimated at 427 DALY's per million people (D. V. Clark et al., 2005). Based on actual dollar amounts, responding to dengue outbreaks is costly for a variety of nations around the world. The 1977 outbreak in Puerto Rico was estimated to cost between \$6.1 and \$15.6 million dollars, the 1980 outbreak in Thailand cost \$6.8, the 1981 outbreak in Cuba cost \$103 million, and the 1994 outbreak costs in Nicaragua totaled \$2.7 million. The approximate cost per case for these outbreaks ranged from \$30 to \$300 (Meltzer et al., 1998).

The loss of life and health to individuals and society due to dengue outbreaks is alarming. Dengue's impact on standard of living and quality of life worldwide is cause for concern. Influenced by factors including habitat, travel, immigration, greenhouse gases, and climate, increasing dengue incidence in recent decades raises a number of public health concerns. If indeed the quality of life impact of this disease parallels that of pandemics like malaria and tuberculosis, further prevention steps must be taken. The immediate answer to dengue prevention, a vaccine (Poovorawan et al., 2006), is considered by experts to be at least 10-15 years in the future for developed countries and likely twice that for underdeveloped countries due to tighter economic constraints (Gubler et al., 2001). In lieu of complete prevention, epidemic avoidance through prediction of outbreaks is essential as a means of reducing the mortality and morbidity of dengue (De Mattos Almeida et al., 2007).

Dengue Vectors

Aedes aegypti is considered a highly competent vector of both dengue and yellow fever and is found in every country in the Western Hemisphere except Canada. Repeated attempts to eradicate this disease vector from the United States have failed, and the species is currently established in the southern states from Texas to South Carolina. *Aedes albopictus*, another container-breeding *Aedes* mosquito, was first reported in Texas and believed to be imported from Southeast Asia around 1985 via shipments of tire casings (Francy et al., 1990; Rodhain, 1996). The dengue virus has been isolated from field-collected *Aedes albopictus*, thus this species is considered a potential vector of dengue (Chow et al., 1998; Rosen et al., 1983; Thavara et al., 2001). *Aedes albopictus* is ecologically distinguished from *Aedes aegypti* as it prefers a less-urban habitat (Tsuda et al., 2006), lower host density, and more vegetation (De Lima-Camara et al., 2006). The distribution of dengue fever and associated mosquito vectors is concentrated near the equator and ranges roughly 35 degrees north and south latitude from this line (CDC, 2006a).

Vector Surveys

Aedes aegypti and *Aedes albopictus* surveys have been carried out previously in Texas, however most of these occurred in the southern regions of the state including Laredo (Reiter et al., 2003), Galveston County (Micks & Moon, 1980), and counties adjacent to the Rio Grande River (Rawlings et al., 1998; Womack, 1993). The most recent study of *Aedes aegypti* oviposition closest to North Central Texas was performed in 1966 in Austin, TX, located 315 kilometers to the south of Dallas

County. This study attempted to correlate oviposition of the *Aedes aegypti* species with climactic factors in Central Texas between June 23 and November 21, 1966. *Aedes aegypti* oviposition decreased during periods of little to no rainfall but sharply increased two weeks after significant rainfall. Egg laying also declined with cooler temperatures in the Austin study (Hoffman & Killingsworth, 1967). Additional geographic or habitat factors influencing *Aedes aegypti* population dynamics include vegetation density, degree of shade, relative humidity, abundance of water-holding containers, and ambient temperature (Barrera et al., 2006; G. G. Clark & Quiroz Martinez, 2001; De Garin et al., 2000; Scott et al., 2000; Thavara et al., 2001). This Dallas County investigation is the first ever dengue vector abundance study to be documented north of Austin.

Demographic Predictors

Socio-economic level and related community demographics have been effectively employed as supplemental predictors of *Anopheles* mosquito vector populations in assessments of malaria. Demographic variables including ethnicity, marital status, age, and language spoken at home have all been successfully correlated with malaria vector populations in Africa (Minja, 2001). Malaria and dengue are unique among the vector-borne diseases in that they are anthroponotic and share human-to-human disease transmission. In this mode of transmission, the insect vector obtains the virus directly from the human host through a blood-meal and may transmit the virus to the next human host (Ekanayake et al., 2006; Solutions, 2003). Most vector-borne zoonotic disease cycles involve a non-human intermediate host as the viral reservoir, so disease transmission to humans is more cumbersome. When humans are the primary host and a non-human reservoir is not required, outbreaks can be more rapid and harder to control (CDC, 2006a).

Demographic parameters have not yet been widely explored as a means to assess and predict dengue outbreaks, however the viral transmission method shared by dengue and malaria encourages this approach. The Mexican Ministry of Health explored with some success the relationship between dengue vectors and social factors in a 1995 study (Gomez-Dantes et al., 1995). More recently, high percent oviposition by *Aedes aegypti* was correlated with poor housing conditions in Brazil via the Premise Condition Index (PCI) (Nogueira et al., 2005). The urban nature of *Aedes aegypti* and *Aedes albopictus* warrants further investigation of the demographic variables associated with dengue in North Central Texas.

Immigration from Endemic Countries

Vector population establishment is a concern to U.S. health departments due to the high dengue incidence in Mexican states sharing U.S. borders (International, 2005). Burdened by a population growing three times faster than the rest of the country, and witnessing an estimated 1.1 million northbound crossings per day, the U.S.-Mexico border region is producing a number of growing environmental problems. Air and water quality, water availability, animal control, and disease vector management present formidable challenges to not only public health professionals, but also to the medical community, environmental scientists and engineers, landowners, and businesspeople. The North American Free Trade Agreement of 1994 and the resulting trade growth is one culprit of these environmental issues. Repeated attempts have been made to coordinate public health efforts and policies on both sides of the border, however bi-national cooperation remains a significant challenge (Homedes & Ugalde, 2003). Trade agreements like NAFTA often boost border traffic significantly, so it comes as no surprise that immigration from Mexico has jumped since institution of the agreement (Waterman, 2004).

Immigration to North Central Texas from Latin America reflects the changes brought about by NAFTA (Dallas, 2001). In 1990, the U.S. Census showed 11% of persons in Dallas County to be foreign-born, with over half of those having relocated from their county of origin in the past decade (Bureau, 1990). By the next national census in 2000, the immigrant population in Dallas has risen to account for over 24% of the total (Bureau, 2000). By 2002, 35% of persons in Dallas were foreign-born immigrants, and 3 years later this group grew to include 40% of those in Dallas. By comparison, 2004 immigration in the rest of the state accounted for only 15.2% of the population (International, 2005), up from 11% in 1990 (Bureau, 2000). Of the Dallas immigrants in 2005, nearly 75% originated in Mexico or another country in Latin America. Growth in the foreign-born population of North Central Texas is projected to increase through 2025, and by 2040 the Hispanic population is expected to nearly double its current size.

This unprecedented immigration to North Central Texas and Dallas County has implications for vector-born disease. The incidence of dengue in this region is currently low, stable, and represents a fraction of the total cases statewide. However, the anthroponotic mode of transmission of the dengue virus via *Aedes aegypti* and

Aedes albopictus requires recognition of not only locally-transmitted cases but also of imported cases. If a competent mosquito vector is active and sufficient breeding habitat and hosts are available, transmission of the disease is possible (Coosemans & Van Gompel, 1998). Introduction of the virus into a vector population outside endemic areas by a human host could lead to an outbreak. Of the four regions with highest rates of immigration into North Central Texas, Latin America, Asia, Europe, and Africa, in descending order (Bureau, 2000), all but Europe have recently witnessed both outbreaks and full-scale epidemics of dengue. Endemic dengue incidence continues through the present day (CDC, 2005a) and presents an ongoing risk to non-endemic regions with both an active vector population and a source of infection. Dallas, the largest metropolitan area in North Central Texas and the eighth largest city in the United States, contains both risk factors (International, 2005).

Reports from around the globe cite the climate-related expansion of dengue vector range and disease incidence (Anyamba et al., 2006; Gubler et al., 2001; Patz et al., 2000). Successful correlation of appropriate demographic parameters with dengue vector abundance would create a tool to predict the location and timing of dengue outbreaks (Gomez-Dantes et al., 1995; Nogueira et al., 2005). Immigration from endemic countries to North Central Texas may aid the spread of dengue by importing the virus (International, 2005). These points encourage an updated examination of the potential for dengue transmission in North Central Texas.

CHAPTER III

METHODOLOGY

A survey of the population abundance of dengue vectors was made using oviposition traps to collect eggs of dengue vector species *Aedes aegypti* and *Aedes albopictus*. The process of larval identification required for this survey method is a time-consuming but effective means of sampling container-breeding, diurnal mosquito species such as those which transmit the dengue virus.

Population and Sample

Dallas County is located in North Central Texas at 32°46'45" North Latitude, 96°43'58", West Longitude and sits between 76 m and 152 m above sea level. Six zip codes in Dallas County (75210, 75217, 75203, 75211, 75137, 75115) were selected for this study. Within each zip code, nine sites were chosen randomly for a total of fifty-four fixed sample sites in Dallas County.

Protection of Human Participants

The IRB protocol number signifying approval of this study is 2006-121.

To comply with HIPPA regulations and to protect the confidentiality of individuals within the six communities where study samples were collected, no personal identifier information whatsoever were recorded for this study. It is assumed that the potential benefits of this study outweighed any potential risks.

Data Collection Procedures

Oviposition activity was monitored in Dallas County from June 2, 2006, to November 2, 2006, with oviposition traps. Each trap consisted of a black-painted, 360 ml aluminum soda can containing approximately 270 ml of either distilled or infusion water. Each trap contained a 2 cm x 12 cm strip of 35.5 kilogram heavy weight seed germination paper that was labeled with a unique code and attached to the inside wall with a paperclip. Six zip codes in Dallas County (75210, 75217, 75203, 75211, 75137, 75115) were selected based on median income level (ESRI, 2005). Within each of the zip codes, nine sites were chosen randomly for a total of fifty-four fixed sample sites in Dallas County. At each site, traps were installed along public alleyways and pavements and at the base of homogeneous plant cover in shaded locations. Two traps were placed at each site, one containing distilled water and the other containing a 10% Saint Augustine grass infusion. Each distilled-infusion pair was placed on properties at an approximate distance of 10m apart, and the respective locations were alternated weekly. The traps were serviced weekly, refilled, and the egg strips were replaced. Oviposition data was recorded as missing for a given week if the trap was found absent, crushed, or without a strip. The egg strips were examined with a stereomicroscope in the laboratory, and the total number of *Aedes* eggs was counted. The total number of eggs was recorded, and if no eggs were found on the strip, the number was recorded as zero.

After transport to the laboratory, each egg strip was placed in a growth chamber with a 16/8 photoperiod and incubated for approximately two weeks at 24°C and 85% humidity. Each strip was then immersed in a glass jar filled with 500 ml of de-oxygenated water for 2 hours, and the larvae from each jar were transferred into a shallow tub (10 cm x 10 cm x 9cm) and labeled with the corresponding code. Larvae were reared with a feeding schedule and after approximately five days reached the third to fourth instar of development. From each sample, a maximum of 20 fourth instar larvae were randomly selected and identified to species based on the characteristics of comb scales and abdominal projections (Christophers, 1960). The proportion of *Aedes albopictus* to *Aedes aegypti* larvae was multiplied by the total number of eggs for the site and week to represent the relative proportion of *Aedes albopictus* and *Aedes aegypti.*

The response variables measured at each site were: the total number of eggs (E = total sum of weekly egg counts) during the main season of adult infestation (June through October), the total number of *Aedes aegypti* (AE = total sum of weekly *Aedes aegypti* identified), and the total number of *Aedes albopictus* (AL = total sum of weekly *Aedes albopictus* identified). Independent variables recorded on-site from August 10-18, 2006 included: vegetation cover (V = percent vegetation cover 1m or taller within 10m radius of trap), shade (SH = percent daylight hours trap shaded), standing water (W = percent water remaining when trap serviced), containers (C = containers capable of holding water within 10m radius of trap), and pets (P = number of dogs and/or horses within 10m radius of trap). Home value was also recorded for the address corresponding to each trap site (DCAD, 2007).

Instrumentation

Geographic location data was obtained with a hand-held global-positioning unit *Garmin GPS III* (Garmin International, Inc. 1200 East 151st St, Olathe, KS 66062), and site coordinates were plotted for reference. Demographic data were recorded by zip code and included: median home value, median household income, population density, household density, and percent Hispanic population (ESRI, 2005). Climate data included temperature and precipitation and were obtained for Dallas County from 1976-2006 (NOAA, 2006). Site specific data were recorded and organized using Microsoft Excel 2003 (Microsoft, 2003). Analysis was carried out with SAS 9.1 software (SAS, 2002-2004).

Statistical analysis

The significance of response variables *Aedes* eggs, *Aedes aegypti*, and *Aedes albopictus* was assessed according to habitat data obtained at each site and demographic data averages for each zip code. Predictors were assessed through descriptive statistics, and the data were fitted to a regression model. Standard Poisson distribution with a log link function was selected for habitat predictors due to the "count" nature of the dependent variables. The goodness of fit for this model was checked with Pearson Chi-Square criteria. A generalized estimation equation (GEE) Poisson regression model was chosen to assess demographic variables due to the clustered nature of zip code data (Twisk, 2003).

Summary

The abundance parameters of vector oviposition activity were monitored weekly with 108 traps at 54 sites in 6 different zip codes. Oviposition site information was assessed via observation. Demographic and socio-economic information for zip codes were obtained from public access databases (DCAD, 2007; ESRI, 2005) and analyzed for significance.

CHAPTER IV

RESULTS

From 54 sample sites, a total of 2275 egg strips were obtained of which 88% (95% CI: 88.7% – 88.8%) were positive for eggs. During the 22 weeks of sampling, an average 103 out of 108 possible egg strips were successfully recovered from traps weekly. From all egg strips, 63,703 total eggs collected and all were flooded for hatching. From these, 19,480 larvae emerged, which represents a hatching rate of 1 out of every 2.3 eggs (30.6%). The average number of all *Aedes* species eggs on each strip was 26.8 per week (95% CI: 24.3 – 29.3). The average number of *Aedes aegypti* eggs on each strip was 6.5 per week (95% CI: 6.3 – 6.7), which represented 24% of the total oviposition. The average number of *Aedes albopictus* eggs on each strip was 20.3 per week (95% CI: 17.9 – 22.6), which corresponded to 76% of the total oviposition.

Dengue vector overall abundance in 2006 (Figure 1) peaked in the second week of June, decreased in the latter part of the month, rose in July, decreased again through August and early September, and produced a small peak during late September and October. Individual species abundance followed this general trend with an average proportion of 1:3 *Aedes aegypti* to *Aedes albopictus* throughout the 22 week study period. Highest oviposition for each species differed, with *Aedes albopictus* reaching a maximum (82.5 per site) during the second week of June, and *Aedes aegypti* recording a maximum (15.3 per site) during the second week of

October. In the final eight weeks of the study, *Aedes aegypti* abundance deviated from the overall *Aedes* pattern by continuing to increase in mid-September, peaking in mid-October, and declining at the end of October. Conversely, *Aedes albopictus* abundance peaked in the middle of June and declined through the end of the study.

Of the habitat predictors (Table 1), vegetation, shade, standing water, containers, and pets displayed significant ($p<.05$) relationships to both total *Aedes* oviposition and *Aedes albopictus* oviposition through regression analysis. This was observed in the way that high vegetation, shade, and standing water, along with fewer containers and pets, led to greater overall *Aedes* and *Aedes albopictus* abundance. Predictors of vegetation, shade, standing water, and containers displayed significant ($p<.05$) relationships to *Aedes aegypti* oviposition. This was seen in the way that high vegetation and shade as well as low standing water and fewer containers led to greater *Aedes aegypti* abundance. For the demographic predictors (Table 2), none showed a significant relationship to total *Aedes* oviposition. Significant ($p<.05$) interaction was present between Hispanic population and income. For *Aedes aegypti*, predictors of home value and income showed significant ($p<.05$) relationships to oviposition in the way that low home value and income correlated with greater *Aedes aegypti* oviposition. Interaction was present between Hispanic population and home value for this species. For *Aedes albopictus*, only household density showed a significant ($p<.05$) relationship with oviposition. This was seen through low household density leading to greater abundance. Interaction was apparent between Hispanic population and income as well as between Hispanic population and household density for this species.

Between June and October of 2006 (Figure 2a), there was an average temperature of 22.3 degrees C in June, 25.6 degrees C in July, 26.0 degrees C in August, 19.2 degrees C in September, and 13.9 degrees C in October. These figures were typical for these months of the year for both the past 10 (Figures 2b) and the past 30 years. During the same study period, total precipitation in Dallas County (Figure 3a) was recorded as 8.6 mm in June, 45.2 mm in July, 13.2 mm in August, 66.0 mm in September, and 110.0 mm in October. The month prior to the trial period, 48.3 mm rainfall was recorded in May. These precipitation figures were unusually low for these months of the year, particularly for June and August. 2006 recorded the third least total precipitation in the past 10 years (Figure 3b), and precipitation in 2005 represented both the least in the past 10 years and the 6th least in the past 100 years (NOAA, 2006).

In summary, results showed that dengue vector abundance was highest (73 eggs) during the second week of June, decreased in July and maintained 12-31 eggs after July. *Aedes albopictus* was more abundant than *Aedes aegypti* except in October. *Aedes albopictus* abundance was highest in June and decreased through October. Habitat assessment confirmed that sites with higher vegetation and shade had a higher number of *Aedes albopictus* and *Aedes aegypti* ($p<.05$), while sites with more standing water also had a higher number of *Aedes albopictus* ($p<.05$). Analyses also revealed that lower home value and lower income corresponded to a higher number of *Aedes aegypti* ($p<.05$), and homes with a lower household density corresponded to a higher number of *Aedes albopictus*. Other socio-economic and demographic factors did not have statistically significant association with dengue vector abundance.

Temperatures for the five months of the study were normal compared to the past 10 years, but precipitation was abnormally low in the months of June and August.

Figure 1a. *Aedes* species Abundance in Dallas County, 2006

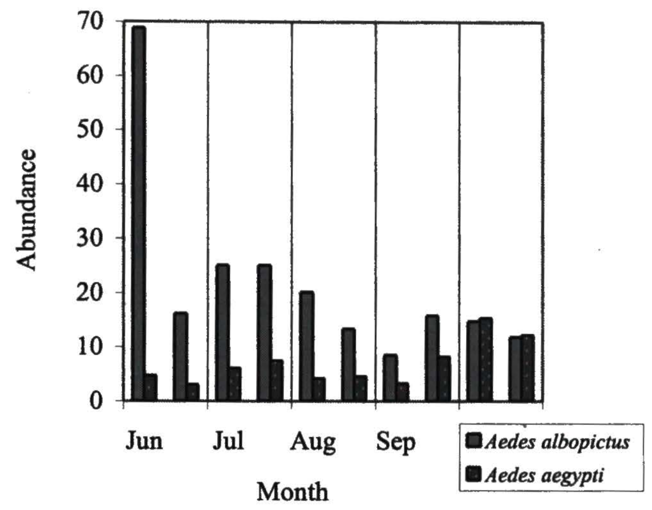


Figure 1b. Climate Averages, Dallas County, 2006

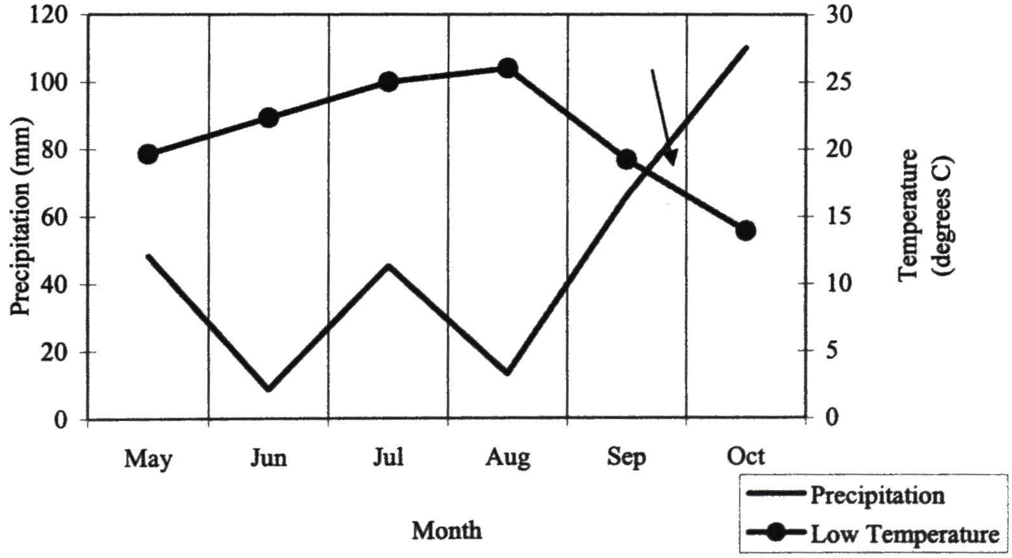


Table 1. Summary of habitat predictors for *Aedes* species oviposition and population dynamics, Dallas County, TX, 2006

N = 1188			E (μ=26.811)		AL (μ=20.2784)		AE (μ=6.5326)	
Indepdent Predi	μ	SE	Model Estimate	*P*	Model Estimate	*P*	Model Estimate	*P*
Vegetation %	20.9	10.2	0.0056	<.000 * +	0.0026	0.0001 * +	0.0137	<.0001 * +
Shade %	56.6	21.3	0.0083	<.000 * +	0.0107	<.0001 * +	0.0023	0.0012 * +
Water Un-evap %	23.4	18.6	0.0018	<.000 * +	0.0042	<.0001 * +	-0.0065	<.0001 *
Container #	10.4	14.5	-0.0064	<.000 *	-0.0068	<.0001 *	-0.0054	<.0001 *
Pet #	1.5	1.8	-0.0176	<.000 *	-0.0188	<.0001 *	-0.0078	0.2290

*Statistically significant differences by Poisson regression (p<.05)

+Statistically significant and regression coefficient supports hypothesis

Table 2. Summary of demographic predictors for zip code clusters (n=6) of *Aedes* species oviposition and population dynamics, Dallas County, TX, 2006.

N = 1188			E (μ = 26.8)				AL (μ = 20.3)				AE = (μ = 6.5)			
Independent Predictor	μ	SE	Estimate	Z	Pr > |Z|		Estimate	Z	Pr > |Z|		Estimate	Z	Pr > |Z|	
homevalue	79	48.3	0.0014	0.58	0.5624		0.0035	1.26	0.209		-0.0067	-4.69	<.0001	* +
income	43	19.2	0.0011	0.39	0.6979		0.0058	1.47	0.1408		-0.0148	-4.86	<.0001	* +
PH	3	0.39	-0.1847	-1.9	0.0626		-0.428	-2.62	0.0088	*	0.5352	1.65	0.098	
BP	38	22.8	0.0012	0.98	0.3253		0.0016	0.44	0.6591		0.0001	0.01	0.9933	
HP	40	26.9	-0.0021	-1.3	0.207		-0.0054	-1.84	0.0664		0.0078	1.78	0.0746	
HP* income			-0.0001	-2.4	0.0145	* +	-0.0002	-2.25	0.0246	* +	0.0002	1.22	0.2228	
HP* homevalue			0	-1.7	0.0954		0	-0.83	0.4044		-0.0001	-2.7	0.007	* +
HP*PH			-0.0006	-1.5	0.1396		-0.0015	-2.14	0.0327	*	0.0021	1.86	0.0634	

*Statistically significant differences by GEE Poisson regression (p<.05)

+Statistically significant and regression coefficient supports hypothesis

Figure 2a. Monthly Low Temperatures 1996 - 2006, Dallas County, TX

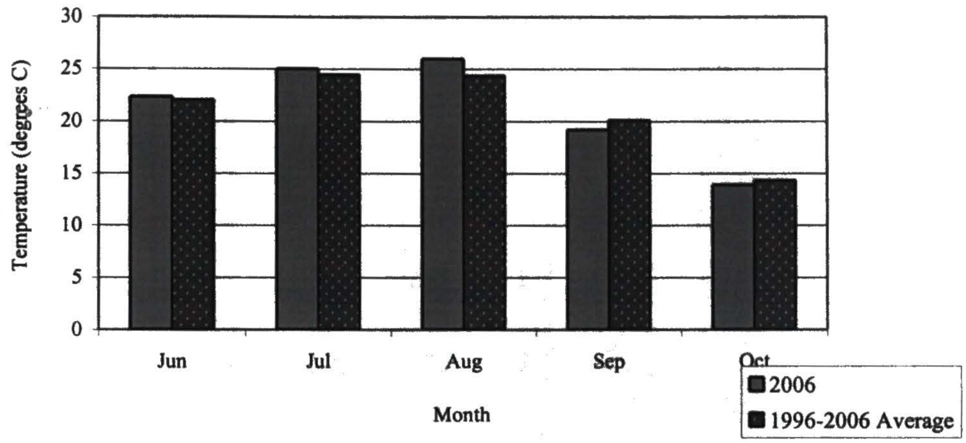


Figure 2b. Annual Low Temperatures June-October, Dallas County, 1996-2006

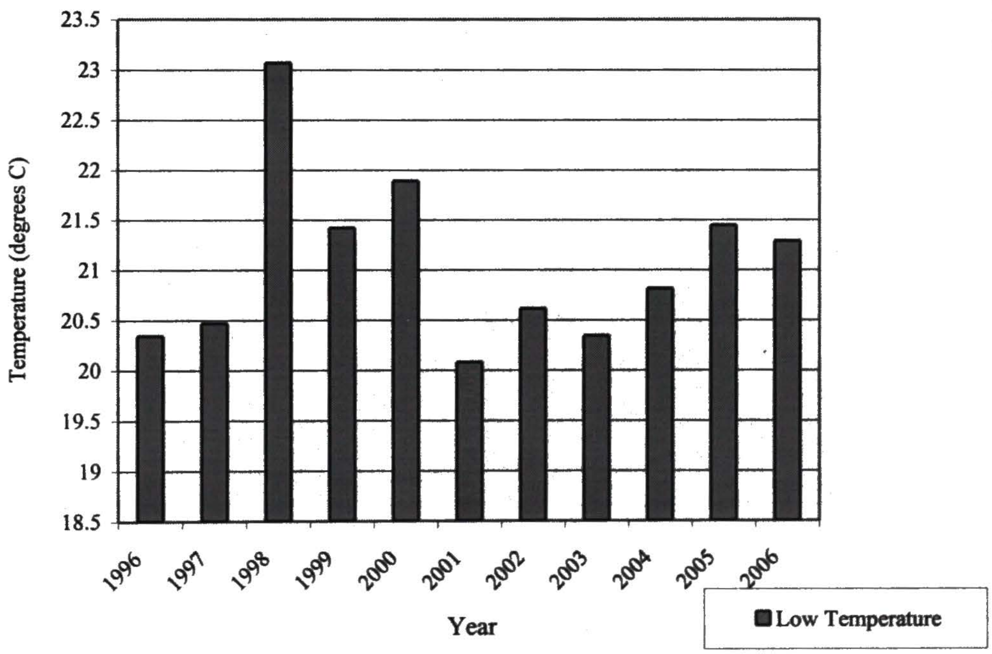


Figure 3a. Monthly Precipitation in Dallas County, 1996-2006

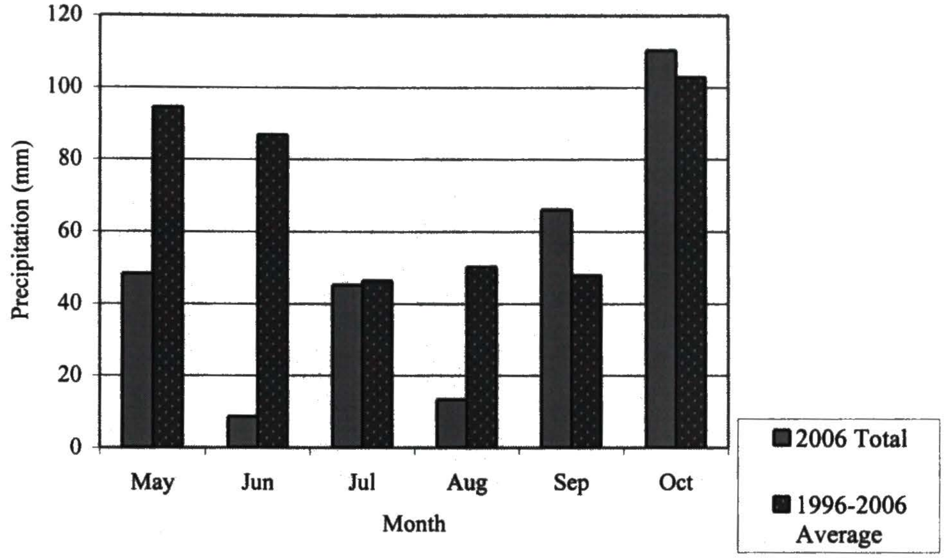


Figure 3b. Annual Precipitation in Dallas County, 1996-2006

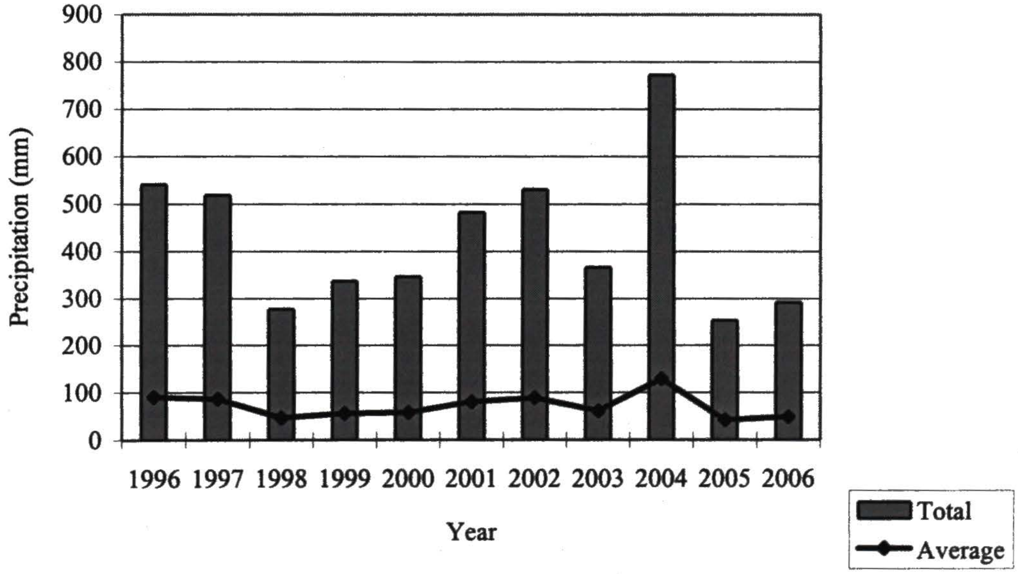
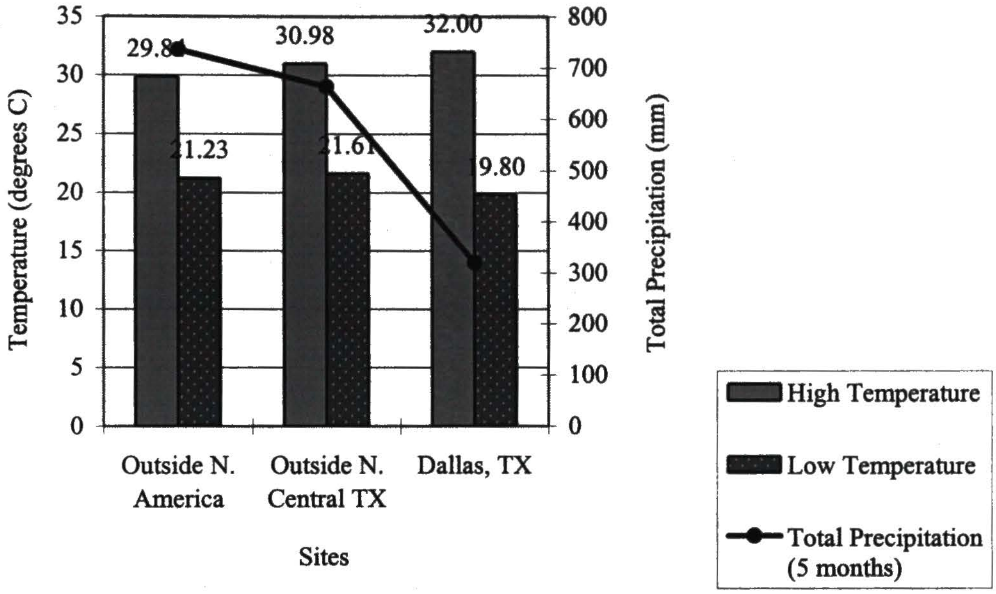


Figure 3. Average Temperature and Total Precipitation during Mosquito Breeding Season, 9 Dengue Epidemic Sites, 1970-2000



CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a brief synopsis of conclusions based on the initial objectives of the study. These are followed by an in-depth discussion of the results obtained, the factors associated, and the implications of these findings.

Summary

The purpose of this study was to assess Dallas County for dengue vector abundance, to test geographic and demographic characteristics as predictors of dengue vector populations, to describe high risk areas, and to develop an effective methodology for dengue risk assessment. These objectives were achieved through monitoring the mosquito vector population for 22 weeks with oviposition traps. The species abundance trends were described and associated with habitat and demographic factors to suggest the best social-environmental predictors of dengue vector populations.

Conclusions

Hypotheses	*Aedes aegypti*	*Aedes albopictus*
The abundance of dengue vectors associated with geographic factors.	Accepted Geographic associations: - dense vegetation - more shade - less standing water - fewer containers	Accepted Geographic associations: - dense vegetation - more shade - more standing water - fewer containers - fewer pets
The abundance of dengue vectors associated with demographic factors.	Accepted Demographic associations: - lower home value - lower income	Accepted Demographic associations: - lower household density
Geographic and demographic factors can be employed as predictors of dengue vector populations.	Accepted Predictors: - dense vegetation - more shade - less standing water - lower home value - lower income	Accepted Predictors: - dense vegetation - more shade - more standing water - lower household density
Geographic and demographic factors can be used to estimate the risk for dengue outbreaks in non-endemic areas.	*Further study, larger sample size needed.* The above factors may be suitable for estimating outbreak risk. Predictive ability will be stronger under the following climate conditions: - 21 to 30 ° C mean temperature range - 660 mm or more annual precipitation	*Further study, larger sample size needed.*

Discussion and Implications

Risk of Dengue Outbreak

Compared to endemic areas, the incidence of dengue in the United States is low. In locations such as Brazil, the Dominican Republic, and the U.S. Territory of Puerto Rico, annual case numbers from the years 2000-2005 regularly exceeded 100 cases per 100,000 persons and have been as high as 445 cases per 100,000 persons in

Brazil (W. H. Organization, 2007a). In contrast, the U.S. incidence of dengue may appear inconsequential. Indeed the risk for infection is notably lower than in endemic countries. However, nearly a third of the U.S. cases in 2005 were identified in Texas (29 cases) and over 10% of these were diagnosed in North Central Texas (Marabota Martinez & TDSHS, 2006). Immigration from endemic countries into Texas is already high and on the rise, increasing the chance of imported cases (International, 2005). In addition, climate change due to global warming is a very real possibility (Patz et al., 2000). Increasing disease incidence, high immigration from endemic countries, and recent concern about global warming and climate change (Gubler et al., 2001) led to this investigation of predictors for dengue outbreak in North Central Texas.

Climate Sensitivity

According to experts from the public health and medical geography communities, the risk of dengue outbreaks has steadily risen since the mid-1970's. To blame are the discontinuation of vector-eradication programs, urbanization, global population growth, increased travel, and increased range of mosquito vectors (Anyamba et al., 2006; Gubler, 1998; Gubler et al., 2001). Climate change in particular can be linked directly to mosquito range and habitat expansion. Seasonal variation of temperature and rainfall coincides with the annual cycles of most vector-borne diseases. These variations have a significant impact on both the vector transmitting the disease and the pathogen causing it. Though part of the disease cycle occurs in warm-blooded hosts such as humans or other mammals, the arthropod cycle is cold-blooded and remains highly responsive to environmental changes.

Increased temperatures may or may not raise the incidence of a vector-borne disease like dengue. The daily maximum and minimum temperatures in a given location impact the pathogen's rate of multiplication and infection of vector salivary glands (Day, 2005). In this way, temperature heavily influences dengue transmission rates. Rainfall, humidity, wind speed, and photoperiod are also key factors. Interaction between factors determines the competency of dengue virus transmission. In laboratory settings, virus replication increases directly with temperature, and General Circulation Models (GCMs) suggest that a slight rise in temperature might enhance the potential for epidemics. However, laboratory settings are capable of adjusting temperature while maintaining humidity constant. Likewise GCMs must take into account a number of site specific transmission determinants in order to be accurate (Gubler et al., 2001). More intense temperatures can dry out soil more quickly and reduce humidity through increased evaporation rates; decrease in the arthropod vector population is a likely consequence (Patz et al., 2000). One example is that the summer temperature in the Southeastern U.S. is consistently 2-3 degrees C above that of islands in the Caribbean. In spite of both warmer temperatures and increased immigration from endemic countries, the United States reports a lower incidence of the disease than the islands over the past twenty years. A variety of geographic and demographic factors appear to be at work, however disease transmitted by arthropod vectors is undoubtedly sensitive to climate (Gubler et al., 2001).

The climate sensitivity and vector competency of arthropod vectors is closely tied to climate fluctuation. Climate fluctuates based on complex relationships between both natural and man-made factors. Interactions between sea ice, oceans, earth's atmosphere, land features, fossil fuel combustion, biomass combustion, industrial pollution, deforestation, volatile organic compounds, and halogens all influence climate to varying degrees. A result of these interactions is plant diversity, which is a factor of humidity, precipitation, sunlight, wind, temperature, and soil type. Plant diversity largely determines the organisms in an ecosystem. In the appropriate ecosystem, disease vectors will thrive, and as habitat range expands, the carrying capacity of the habitat should increase (Sibly et al., 2005). While vector populations will likely spread as habitat expands, they will not spread based simply on warmer temperatures. Dengue vectors *Aedes aegypti* and *Aedes albopictus* are not exceptions to these ecological patterns. Warmer temperatures in conjunction with increased and more frequent total precipitation , however, would likely increase the range of the dengue vectors (Patz et al., 2000). To what extent this balance between climate and habitat is responsible for increased dengue incidence worldwide during the past two decades remains to be seen.

Climate Change in North Central Texas

A review of the climate trends in Dallas County was used to evaluate recent changes in temperature and precipitation in North Central Texas. Figures 2a and 2b summarize the average low temperatures for June through October, 1996-2006, in this region. Low temperatures were consistent with no discernible warming trend over the past 10 years. Comparable to the previous 10 years, 2006 was a relatively average year in terms of low temperatures for the months shown. The same comparison for the past 30 years likewise reveals that low temperatures for these months were consistent and no warming trend is perceived.

Conversely, the year 2006 did report uncharacteristically low levels of precipitation. Of the past 10 years, 2006 was the third lowest in average precipitation (48.6 mm/month) for the months May through October and the fourth lowest in total annual precipitation (755.7 mm). Incidentally, 2005 recorded the lowest average and total precipitation (42.1 mm/month; 482 mm total) during the previous 10 years. The 2005 to 2006 period should therefore be considered a drought. In the context of the past 30 years, 2006 ranked as the fourth lowest for average precipitation from May through October, and as the ninth lowest for total annual precipitation. Over the past 100 years, 2006 average precipitation ranked relatively low at the 16th lowest, while precipitation in 2005 was 6th lowest. These records showed the past two years to be an exceptionally dry period. The question of whether these low precipitation levels equate to long-term climate change, or whether these years simply represent a dry period in the weather cycle, is debatable. What is clear is that the lack of moisture during the 2005-2006 breeding seasons should be noted as an important factor in producing the low abundance data recorded for this study. It may also represent an early sign of global warming in the region.

To contrast the climate in Dallas with other locations where dengue is endemic and outbreaks were recorded, a basic comparison of temperature and precipitation is shown in Figure 3. The average high and low temperatures and annual precipitation of

Dallas, TX from the past 30 years were compared with the same data from a selection of countries. Thailand, Taiwan, Singapore, Cuba, Brazil, Paraguay, Puerto Rico, and Mexico have each been identified as sites of one or more dengue epidemics over the past three decades (CDC, 2005a). The cities of Reynosa and Tampico, Mexico were also assessed due to high dengue case numbers in 1995 (CDC, 1996). Laredo, TX was included since it was the site of the most recent 1999 dengue outbreak in Texas (Zewe, 1999).

The contrast of temperature and precipitation between Dallas and the nine dengue endemic/outbreak sites was slight but noticeable. Outside of North Central Texas, high temperatures averaged 1.0 degree C cooler, and low temperatures averaged 1.8 degrees C warmer. Comparing Dallas with six locations outside of North America strengthened this temperature trend. Endemic locations averaged 2.2 degrees C cooler for the high and 1.4 degrees warmer for the low. Total precipitation showed a wider gap. Dallas recorded less than half the total average precipitation (320 mm) of the nine other sites (662.8 mm) and less when compared with the sites outside of North America (735.2 mm) (W. M. Organization, 2007b; Weatherbase, 2007). This comparison showed that average temperatures from the past 30 years in Dallas, TX were more extreme than those in sites where dengue is endemic, suggesting that the Dallas temperature range is less than ideal for transmission of the dengue virus. Annual precipitation in Dallas fell well short of levels recorded where epidemics have occurred. Given the historically low incidence of dengue, North Central Texas sites where *Aedes* species were surveyed may be too arid to support viral transmission.

In dengue endemic locations like Puerto Rico, dengue incidence tends to peak during the summer months when rainfall and humidity are highest (Gubler et al., 2001). In Dallas, the dengue vector population in 2006 peaked in June (Figure 1). Little precipitation was recorded that month (8.64 mm), but a significant amount of rain was recorded in May (48.3 mm). At the beginning of June, average low temperatures climbed above 20 degrees C and much of the previous month's moisture and standing water were likely retained. The resulting peak in *Aedes* species oviposition is thus logical and might have been maintained at high levels through subsequent oviposition had the area seen more immediate precipitation. July recorded an additional 45.2 mm of precipitation that was reflected in the slight rise in *Aedes* abundance for both species that month. August produced very little moisture (13.2 mm) and a consequent drop in abundance. The large amounts of total precipitation recorded for September (66.0 mm) and October (110.2 mm) were not reflected by increases in overall oviposition, presumably due to the cooler nighttime temperatures which fell once again below 20 degrees C by the middle of September.

Aedes aegypti oviposition did not follow the overall *Aedes* species trend during the months of September and October. From the beginning of September, abundance for this species rose continuously for 6 weeks, possibly in response to the increased precipitation. Oviposition of *Aedes aegypti* then peaked and declined in mid-October. For both *Aedes* species from June to October, higher precipitation combined with temperatures over 20 degrees C appeared to promote oviposition. The temporal abundance of dengue vectors in Dallas, TX therefore followed a similar pattern to temporal abundance in endemic areas. Given favorable changes of the temperature extremes and precipitation levels in North Central Texas, observed trends of vector abundance support the possibility of dengue outbreaks in the Dallas area.

A brief examination of global climate change puts the North Central Texas climate trends into context. During the twentieth century, increased average daily temperatures were recorded worldwide, and temperatures in general appear to be warmer than any period for the past 600 years. Some scientists predict that by the year 2100, there will be an average 2 degree C increases in temperatures worldwide. These possibilities raise a number of concerns. Warm air can retain more moisture than cooler air, so a possible global warming trend is likely to lead to increased humidity levels and changes in existing ecosystems. In addition, warmer temperatures are expected to cause rising sea levels, increased evaporation rates, increased frequency of droughts and floods, and longer recovery times for holes in the stratospheric ozone layer. Some global implications of a warming trend are the potential for increased transmission of infectious diseases and the expansion of the traditional range of these diseases into temperate regions. Conceivably, warmer average temperatures would stimulate the activity of mosquito populations. Arthropod development rate, blood-feeding frequency, and parasite development will all increase with warmer temperatures. Pathogen multiplication within the salivary glands will likewise be enhanced. One critical temperature-related factor likely to suppress mosquito abundance is rapid evaporation of water. Increased temperatures decrease overall humidity and accelerate evaporation. Less standing water decreases the potential sites for *Aedes* oviposition (Patz et al., 2000).

Global climate change induced by man as well as by cyclical patterns is thought to influence dengue outbreaks worldwide (Gubler, 1998). Numerous human activities have been cited as responsible for climate change and warming trends. Examples include the burning of fossil fuels and biomass, industrial output of CO_2, deforestation, and the release of volatile organic and halogenated compounds (Patz et al., 2000). Recurring climate cycles such as El Nino have also been shown to impact infectious disease, and recent studies have predicted increasing dengue incidence for the upcoming 2007-2008 El Nino cycle. Countries including Indonesia, Malaysia, Thailand, the Southeast Asian islands, and northeast Brazil are thought to be at increased risk for dengue outbreaks and other public health concerns due to this 7 year climate condition (Anyamba et al., 2006).

Outbreak Prediction

Disease surveillance and monitoring is the basis for successful prediction of outbreaks. Though performed by some municipalities and larger counties, surveillance of mosquito-borne disease is typically a low priority, and funding varies from year to year. Active programs conducting routine disease surveillance detect outbreaks early, and they enable the ongoing research required to increase understanding of the factors related to outbreaks and epidemics. To increase understanding and to predict dengue outbreaks, further research is needed. Climate change, its impact on disease vectors ecosystems, and the relationship between climactic factors and vectors are not fully understood. Most critical for dengue prediction is a more thorough understanding of the socio-economic determinants of dengue. Overall, assessments which take a global approach to local environmental and demographic factors will prove most successful in predicting dengue outbreaks (Gubler et al., 2001).

The need for accurate predictors of dengue outbreaks is today more pressing than ever. A half century ago, the threat of infectious disease was waning, and the number of deaths from vector-borne disease had plummeted in comparison to any previous time in recorded history (Weiss & McMichael, 2004). Today's re-emergence of old diseases like dengue as well as newer epidemics reflect changes in human ecology that are characterized by social-environmental factors (Barcellos et al., 2005). Rural-to-urban migration has led to higher population densities in urban settings. Greater individual mobility and trade are on the rise. Rampant deforestation continues, and climate changes are being noted. In response, cases of established diseases are increasing and spreading geographically.

Some blame these increases on better monitoring technology, but more likely is that social factors are promoting the spread of infectious disease. With population growth and urbanization, dengue incidence increases through expansion of the ideal habitat for the mosquito vector. Increased population size and density create unprecedented opportunities for disease transmission due to the close proximity of hosts and vector habitat (Weiss & McMichael, 2004). Vegetation, shade, standing water, evaporation rates, and other habitat factors which influence dengue vectors in endemic locations are well documented in the literature (Barrera et al., 2006; Clark & Martinez, 2001; De Garin et al., 2000; Scott et al., 2000; Thavara et al., 2001) as well as confirmed through this study. Less well-studied are the social and demographic factors influencing dengue vectors. Understanding the interactions between social factors and vectors as well as the ecology of disease will facilitate prediction of the nature and location of disease outbreaks (Weiss & McMichael, 2004).

Social-environmental Predictors

To forecast an infectious disease based solely on human factors presents a formidable challenge. It requires the ability to anticipate a likely arthropod behavior based on observed human behavior. Though an apparent sleight of hand, the capacity to estimate the expansion of *Aedes aegypti* and *Aedes albopictus* mosquito populations by studying the dynamics of humans is logical, measurable, and scientific. A review of the biology of these two *Aedes* species reveals several key points. Dengue vectors show the most favorable development, longevity, and fecundity rates at temperatures between 21 and 30 degrees C (Beserra et al., 2006). Both prefer habitat with vegetation and shade, although *Aedes aegypti* may prefer urban settings compared to the *Aedes albopictus* preference for rural areas (De Lima-Camara et al., 2006; Tsuda et al., 2006). Both reproduce by laying eggs in artificial water-holding containers (Simard et al., 2005). Both species are day-time biters (Schultz, 1989; Thavara et al., 2001).

Traditional human settlements are similar to the environment just described. Common habitat factors are shade and the vegetation that creates it, as well as proximity to a forest where cooking fuel is close at hand (Madulu, 1995; Ouedraogo, 1991). The human tendency to collect, sort, and organize their possessions and to discard their trash creates an abundance of artificial containers (Hwang & Roam, 1994; Pai et al., 2006). With rainfall, these containers serve as vector oviposition sites. Since humans are most active during the day, they provide readily available hosts to the female *Aedes* mosquito seeking a blood-meal during peak feeding times (Schultz, 1989). These shared habitat preferences facilitate the parasitic relationship between humans and the *Aedes* mosquito species of interest.

Following correlation of the habits and habitat of human hosts and the dengue vector species, identification and measurement of the related social factors leads a step closer to outbreak prediction. Measurement of habitat factors is tedious but not difficult. The greater challenge is posed by identification and measurement of reliable human factors which indicate the conditions necessary for vector oviposition, virus development, and disease transmission. Specific conditions are required for successful transmission of the dengue virus. Oviposition demands the presence of a breeding population of the vector species, accessible and exposed containers that hold water, sufficient precipitation to fill them, and an evaporation rate that allows standing water to be present. Virus development necessitates a human source and an appropriate arthropod vector in which virus development can occur (Day, 2005). Disease transmission requires a temperature range in which the virus titer achieves a threshold high enough to infect the next host via the feeding cycle of the mosquito (Beserra et al., 2006; Monath, 1994). Access of the vector to a sizeable population of human hosts is also necessary.

A synopsis of these biological requirements for the dengue vector and virus reveals two categories: biological requirements which are directly influenced by human factors, and requirements which are indirectly influenced by humans. The presence of artificial water-holding containers, homeowner habits, and cultural customs related to landscaping are directly influenced by humans. The availability of human hosts carrying the dengue virus and access to dense human populations likewise result directly from human lifestyle patterns (Teixeira Mda et al., 2005). The remaining factors that promote dengue development and transmission are related indirectly to the social behavior of humans. Introduced vector populations occur inadvertently via importation and shipping from endemic areas (Monath, 1994). Shifts in the amount of precipitation, temperature levels, and evaporation rates also occur indirectly through urbanization and other human activities (Patz et al., 2000).

The influence of human factors on the biological and ecological requirements for dengue holds the key to prediction of dengue outbreaks. The related human factors must be quantifiable, accurate, and available to prove useful, and they must identify vector habitat. Demographic indicators show the most promise as human predictors of *Aedes aegypti* and *Aedes albopictus* populations. Demographics are quantifiable and accurate with proven methodologies, and they are readily available through continually-updated census sources. How accurately demographics identify vector habitat is currently under study. According to researchers in endemic areas like Brazil, a heavier disease burden is reported for those urban areas with higher rates of poverty and less effective public health policies (Caiaffa et al., 2005). Older age, low education, and low income are correlated with dengue infection risk in some areas of Brazil (Siqueira et al., 2004). In Belo Horizonte, Brazil between 1996 and 2002, the factors most characteristic of locations with the highest dengue incidence were low education level, low income, high household density, and high proportion of children and elderly women (De Mattos Almeida et al., 2007). In the development of prevention and control measures in Villavicencio, Colombia, social and cultural factors were also shown to be important (Suarez et al., 2005).

Some contradiction is noted for demographic indicators in relation to low socio-economic status. Instead of the positive correlation one might expect between population density and dengue, the opposite was observed in some cases. The Belo Horizonte study in Brazil produced an uncertain correlation between dengue incidence and population density (De Mattos Almeida et al., 2007). In addition, a 2002 Puerto Rico study reported that while vector presence was correlated with home density, actual dengue cases were related to high income (Barcellos et al., 2005). This may be due to the greater travel ability of those in high income areas with resulting exposure to dengue endemic areas of the country. A similar income trend was observed in Dallas County. When correlated with dengue vector abundance, income produced mixed results according to species.

In Dallas County, median home value, median income, population density, household density, and persons of Hispanic origin were identified and tested as potential demographic predictors for dengue vectors in North Central Texas. Hispanic origin was tested along with the standard socio-economic indicators due to 2001-2005 immigration from Central and South American and the Caribbean being documented as the source of over 60% of imported dengue cases in the United States. Immigrants from endemic countries in Asia and Africa could also be carriers of the virus, but the rate of immigration from those regions produced less than 20% of the U.S. dengue cases 2001-2005 (CDC, 2005b, 2006b).

The vector abundance trends measured in Dallas County mimic patterns from dengue endemic countries and the demographic predictors documented in those locations. The socio-economic indicators of low home value and low income showed a strong, positive relationship with *Aedes aegypti* oviposition. Generally speaking, these demographic categories should specify older homes with more vegetation and unkempt premises. Abundance of containers might accompany homes in this group. Conversely, the Dallas County indicator of low household density showed a moderate relationship with *Aedes albopictus* oviposition. This relationship may reflect the specie's documented preference for a more spacious, suburban habitat (De Lima-Camara et al., 2006; Tsuda et al., 2006).

Placed in the proven context of abundant vegetation, shade and standing water, the results of this study suggest that home value, income, and household density may serve as effective social-environmental predictors. The areas of Dallas County described by these 6 indicators may be at greater potential risk for outbreaks of dengue. These demographic characteristics are routinely measured to describe communities around the world and thus offer a readily available means of suggesting the habitat preferred by dengue vectors. Despite the abnormally dry conditions of 2005 and 2006, the 6 factors indicated a strong relationship with *Aedes aegypti* abundance. Predictive ability of these and other social-environmental indicators is expected to grow stronger during a year displaying more typical precipitation trends.

Conclusions

The methodology developed to assess the risk for dengue outbreak in Dallas County in 2006 offers several key benefits. It establishes a baseline of site-specific habitat factors which can be updated annually. It utilizes demographic information from public-access databases and avoids the challenges presented by personal identifiers as well as the time investment of individual surveys. Lastly, it can be performed as part of a routine dengue surveillance program and employ standard resources and existing staff knowledge to develop a greater awareness of dengue outbreak potential.

Recommendations

A social-environmental approach to dengue surveillance promises to enable more accurate prediction of dengue outbreaks in areas where the disease is not endemic. The results and experience gained through this assessment of Dallas County encourage further study with a larger sample size to account for variability throughout North Central Texas. Assessment should be performed during a year with average precipitation and compared with the 2006 study to survey the dengue vector population under conditions that promote increased oviposition. Particular emphasis should be placed on more fully understanding the complex relationships between demographic factors and dengue vector ecology. Finally, more community education should be performed to assist in source reduction, and more Spanish-speaking public health and mosquito surveillance staff should be recruited to facilitate these efforts amongst the growing Hispanic immigrant population.

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