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Modeling Integrated Vector Management of Zika Virus in Harris County and the City of Houston, Texas

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Abstract

The principal vectors of Zika virus, *Aedes aegypti* and *Ae. albopictus*, are widespread in Harris County and the City of Houston, Texas. Eighty nine travel-associated cases of Zika virus have occurred since it was first detected in 2015. Harris County and the City of Houston have two international airports and three marine ports where infected travelers as well as infected mosquito species could be introduced. Should local *Aedes* species become infected, local transmission could rapidly occur and spread in Harris County and the City of Houston. Mosquito surveillance data, abiotic and biotic factors were analyzed using the Bioagent Transport and Environmental Modeling System (BioTEMS) to determine risk of Zika virus, direction of movement, and optimize mosquito/virus surveillance sites and control zones in port areas. Surveillance and control zones for neighborhoods with simulated travel-associated cases were also identified.

Key words: Mosquito; Epidemiology; Vector Control; Arbovirus; Modeling; GIS

Introduction

The first reported travel-associated case of Zika virus (ZIKAV) in the United States occurred in Houston, Harris County, 2015 [1]. In 2015 and 2016, there were 7 and 75 confirmed cases of ZIKAV in Harris County, respectively, all travel-associated. The Mosquito and Vector Control Division (MVCD) of the Harris County Public Health, conducts mosquito-borne disease surveillance on several mosquito-borne viruses, including chikungunya (CHIKV), dengue (DENV), Saint Louis encephalitis (SLEV), West Nile (WNV), and ZIKAV. The MVCD has instituted an active integrated vector management (IVM) program in order to reduce the risk of local transmission of ZIKAV. *Aedes aegypti* (*L.*) and *Ae. albopictus* (Skuse) are potential vectors of ZIKAV and occur throughout Harris County and the City of Houston. In addition to introduction through a travel-associated case infecting local mosquitoes, invasion of infected *Ae. aegypti* and *Ae. albopictus* haplotypes through maritime and air ports pose a risk of introducing ZIKAV into Harris County and the City of Houston.

Ecological niche and dynamic change modeling are often used to predict the potential for invasive species [2, 3] and neural networks are used within the BioAgent Transport and Environmental Modeling System (BioTEMS) to identify areas at risk for introduction or spread of arbovirus infected mosquitoes and provide information for IVM. The BioTEMS has previously been used for modeling biological weapons defense and infectious diseases in several countries [4]. The BioTEMS TIGER model has been used and validated to identify areas at high risk for invasive mosquito species and mosquito-borne diseases, identify surveillance and IVM in several countries, including Brazil and Iran [5, 6]. The TIGER acronym represents the six stages in the invasion of a mosquito species or haplotype: Transport- identifies the point of origin, method and rate of transport to a locality, Introduction- the point or area of initial introduction/immigration of species or haplotypes and preliminary spread into a locality. Gap- determines the area where vector/pathogen infiltrates and initially spreads once it has gained a foothold, Escalade- incorporates abiotic and biotic factors as possible resistance to invasion. Residence and recruitment - incorporates factors and areas where vector/pathogen adds to genetic diversity or becomes endemic and recruits con-specifics/haplotypes [7]. Because of the importance of ports and travel-associated cases as likely means for the introduction of ZIKAV into Harris County and the City of Houston, the BioTEMS TIGER model was used to identify risk areas of ZIKAV virus surrounding several maritime and air ports in Harris County, identify IVM spray zones and surveillance/vector testing sites.

Materials and Methods

The study was conducted in Harris County, Texas by MVCD and MedEnvVet Laboratories personnel. Three maritime port areas, located in Bayport and Baytown, and two airports, William P. Hobby Airport and Bush Intercontinental Airport, were selected for modeling the import, transmission, surveillance, and directional movement of *Ae. aegypti* and *Ae. albopictus* in the event of introduction of ZIKAV. Three sites were selected for modeling IVM in neighborhoods should hypothetical local transmission or travel-associated cases occur. ArcGIS geospatial analysis software (Esri), Statistica software (Statsoft) and BioTEMS were used to analyze data and geographic information.

The Biogent (BG) sentinel trap collections of *Ae. aegypti* (2,444 trap nights) and *Ae. albopictus* (5,144 trap nights) from 2012 through 2016 were used in co-kriging using ArcGIS and BioTEMS analysis. The summary of co-kriging method is shown in Table 1. Collection data from 2017 was used to validate BioTEMS suggested placement of BG sentinel traps. Areas at risk of introduction and spread of Zika virus infected mosquitoes and IVM zones were developed using BioTEMS. The BioTEMS utilizes up to several hundred abiotic and biotic factors to produce risk and vulnerability assessments for biological agents and infectious diseases. Examples of biotic and biotic factors include; pathogen strain, vector/host relationship, vectorial capacity, host/vector physiology, colonization ability, population dynamics of hosts and vectors, soil, shade, and weather conditions, such as wind, temperature, and precipitation. Analytical methods within BioTEMS include; artificial intelligence, fuzzy logic, niche analysis, and general additive regression. The BioTEMS and ArcGIS were used to produce output into Google® Earth.

Results

Mean maximum density of *Ae. aegypti* and *Ae. albopictus* in Harris County and the City of Houston collected from May through September 2017 varied from 13.6 to 44.2 (Figure 1). The areas identified for IVM and predicted direction of dispersal of mosquitoes for the two airports and three marine ports were: Bush Intercontinental Airport (8.4 sq mi, 257°), William P. Hobby Airport (17.1 sq mi, 324°), Baytown (4.2 sq mi, 55°), LaPorte (2.6 sq mi, 4°), and Port Dr (6.9 sq mi 345° and 184°). The size of each area for IVM for hypothetical travel/local transmission were Site 1 (2.2 sq mi, 265°), Site 2 (2.3 sq mi, 288°), and Site 3 (3.3 sq mi, 328°) (Figure2). There were 38 BG surveillance sites identified to supplement current BG sentinel surveillance sites. All but one supplemental site was above the mean number of *Aedes* species expected for an area using co-kriging of 2017 data: Bayport mean (1 of 11 < mean 17.7), William P. Hobby Airport (0 < mean 15.8), and the Bush Intercontinental Airport (0 of 13 < mean 15.8) (Figure 3).

Discussion

As shown in Figures 1 and 2, *Ae. aegypti* and *Ae. albopictus* occur throughout Harris County and the City of Houston with varying degrees of density. Laboratory trials for ZIKAV competency of *Ae. albopictus* colonies collected in Harris County were positive [8]. The vector competency of *Culex quinquefasciatus* (Say) and *Ae. taeniorhynchus* (Weidemann) indicates these phenotypes are refractory to ZIKAV[9]. However, another possible emerging threat of ZIKAV transmission in Harris County may be from *Ae. vexans* (Meigen), as this species has been shown to be a competent although inefficient vector in laboratory trials [10].

The risk of mosquito-borne diseases can vary between demographic groups, income level and location of communities. For example in Baltimore MD, Washington DC, and Savannah GA, poor and minority communities were found to be at higher risk of WNV [11, 12]. The abundance of vectors and increased amplitude of transmission of WNV are likely to be driven by environmental and ecologic factors in Harris County [13]. Dengue virus is another important emerging disease in Texas given the ecology and abundance of competent vectors [14]. Therefore, the risk of transmission and maintenance of ZIKAV will most likely vary among communities within Harris County based upon the composition, density and interaction of mosquito species in the locale with the environment, ecology, demographics and income.

The BioTEMS has been used to analyze various ecological and niche data to accurately predict where introduction of an invasive species may occur, the direction of dispersion of mosquitoes (within <4°) and to identify the optimal areas of integrated mosquito management in Miami, Florida and Cairns, Australia [15, 16]. Variation in the size of IVM areas and the predicted direction of movement by infected mosquitoes from the ports and hypothesized local transmission sites in Harris County indicate the necessity for a flexible, rapid and accurate control and surveillance strategy in order to prevent expansion of ZIKAV from the initial control zone. As shown in the ZIKAV outbreak in Miami in 2016, additional surveillance and control measures were needed in order to identify the source of introduction of ZIKAV and to control the expansion of the transmission zone [15, 17]. As also shown in the three hypothetical travel/local cases in Harris County, an effective IVM response to contain and control ZIKAV will vary by area. The BioTEMS can be used to rapidly identify the most likely direction infected mosquitoes will move and the minimal area to treat and conduct surveillance to reduce the risk of ZIKAV expanding rapidly beyond the initial local area.

Air and maritime ports are the principal routes for invasive species including vector species [18, 19]. These routes also includes ZIKAV which is introduced through travel-associated cases and likely vectors as well. Once introduced, vehicular transport is also likely to disperse infected people and infected mosquitoes [20]. The areas surrounding the two airports analyzed in this study varied in predicted numbers of *Aedes* species, the direction of dispersion, area for IVM and in placement of sentinel/testing sites. Optimizing placement of BG sentinel traps to trap and test mosquitoes for infection is an essential part of IVM. The Houston ports serve ships arriving from areas with endemic ZIKAV transmission. Additional BG sentinel/vector testing sites were identified at the three marine ports in this study. Increased surveillance and control measures around these and other maritime ports in Houston are recommended. Vaux and

Medlock [21] suggested the following surveillance procedures for port areas: 1) establish a baseline of mosquito breeding habitats, 2) conduct active surveillance for invasive mosquitoes at the ports, 3) identify appropriate surveillance methods suited to port environments, and 4) develop the capability and capacity of port health officers to conduct invasive mosquito surveillance. In addition to surveillance, prevention of establishment of invasive species into the port area is critical. Application of pesticides on ships, cargo, and port areas can reduce the risk of invasion by mosquitoes; however, the continuous spraying of pesticides is expensive and may damage the environment. Low cost and environmentally friendly methods using new pesticide technologies can be used to lower the risk of the establishment of invasive species while reducing the local mosquito population. Pesticides with mosquito bait can be delivered using devices, such as the ProVector system, hung in structures to reduce the mosquito population without the need for spraying for up to several months [2].

Additional research using BioTEMS can be used to address the risk of ZIKAV in minority and low income neighborhoods and assist public health officials in targeting control, education, and outreach efforts. The areas around other ports of entry for possible ZIKAV infected mosquitoes should be analyzed to determine the extent of control/surveillance measures and direction of dispersal to minimize the risk of ZIKAV becoming endemic in Harris County and the City of Houston. Coinciding with this effort, hypothetical and actual areas where travel-associated cases have occurred can be used to test modeling and IVM strategies.

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Table 1. Summary of Co-Kriging Method of Mean Number of *Ae. aegypti* and *Ae. albopictus* collected with Biogent Sentinel traps, May through September 2017 in Harris County and the City of Houston.

Searching neighborhood Standard	Type Standard
Neighbors to include 5	Include at least 2
Sector type Four and 45 degree	Angle 0
Major semiaxis 0.7720390082790506	Minor semiaxis 0.7720390082790506
Variogram	Semivariogram
Number of lags 12	Lag size 0.065133
Nugget 277.6690950369342	423.15162956188595
Measurement error [0,0]	Model type Spherical
Range 0.7720390082790506	Anisotropy No
Partial sill 0.11817732396276	0.1458821792466869
0.1458821792466869	0.18008201157498482

Figure 1. Predicted Mean Maximum Density of *Aedes aegypti* and *Ae. albopictus* based on co-kriging of 2017 collections, white area is outside collection area.

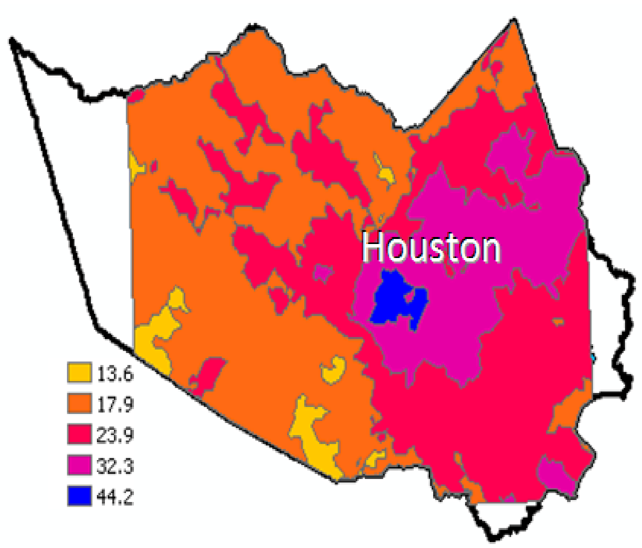

Figure 2. Recommended integrated vector management zones identified using the Bioagent Transport and Environmental Modeling Sysem for selected air and marine port areas (Red polygons), hypothetical travel/local transmission sites (Blue polygons) and likely directional movement of Zika infected mosquito species (Purple lines).

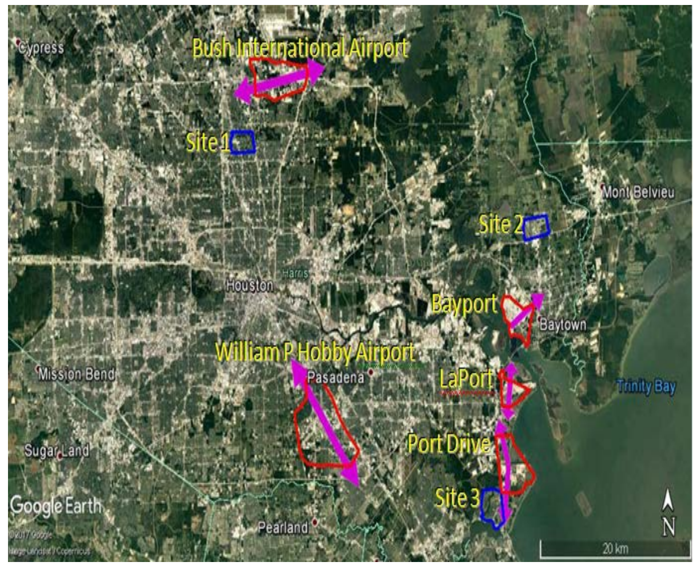

Figure 3. Recommended sites for Biogent sentinel traps and Zika virus surveillance (Red circles) using the Bioagent Transport and Environmental Transport System (P ≤ 0.05, using co-kriging of *Ae. aegypti* and *Ae. albopictus*, mean range 9 to 70) to fill in surveillance gaps.