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Landscape and demographic determinants of *Culex* infection with West Nile virus during the 2012 epidemic in Dallas County, TX

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ABSTRACT

In 2012, the United States experienced one of the largest outbreaks of West Nile virus (WNV)-associated deaths, with the majority occurring in Dallas County (Co.), Texas (TX) and surrounding areas. In this study, logistic mixed models were used to identify associations between the landscape, human population, and WNV-infected *Culex quinquefasciatus* mosquitoes during the 2012 WNV epidemic in Dallas Co. We found increased probabilities for WNV-positive mosquitoes in north and central Dallas Co. The most significant predictors of the presence of WNV in *Cx. quinquefasciatus* pools were increased urbanization (based on an index composed of greater population density, lower normalized difference vegetation index, higher coverage of urban land types, and more impervious surfaces), older human populations, and lower elevation. These relationships between the landscape, sociodemographics, and risk of enzootic transmission identified regions of Dallas Co., TX with highest risk of spillover to human disease during the 2012 WNV epidemic.

1. Introduction

West Nile virus (WNV) is a zoonotic pathogen that circulates in an enzootic cycle between avian hosts and mosquitoes and is occasionally transmitted outside the enzootic cycle to dead-end hosts like horses and humans (Weaver and Reisen, 2010). *Culex* mosquitoes are the primary enzootic vectors for WNV in North America (Colton and Nasci, 2006; Turell et al., 2005; Weaver and Reisen, 2010), as well as capable bridge vectors to humans (Hamer et al., 2008; Hribar et al., 2001; Kilpatrick et al., 2005). In the southeast United States, including Texas (TX), *Culex quinquefasciatus* is the major mosquito vector in the transmission cycle (Andreadis, 2012; Lillibridge et al., 2004; Molaei et al., 2007).

The occurrence and distribution of WNV depends on the presence of competent mosquito vectors, available susceptible avian hosts, and their potential interactions, all of which are influenced by various aspects in the landscape and anthropogenic behaviors (DeGroote and Sugumaran, 2012; Degroote et al., 2014; Epstein and Defilippo, 2001; Kuhn et al., 2005; Ruiz et al., 2004). The physical features of the environment capable of influencing mosquito and bird communities include elevation, vegetation (Normalized Difference Vegetation Index [NDVI]), and impervious surfaces, which can mediate climate events to provide potential habitats for immature development of *Cx. quinquefasciatus*. Urbanization can alter the climate within cities to form "heat islands," where temperatures increase in areas with higher urbanization leading to enrichment of standing water to promote the life cycle of the mosquito (Reisen, 2010). In particular, *Cx. quinquefasciatus* prefer water habitats with high organic content, which is characteristic of human-modified urban and peridomestic areas (Bolling et al., 2005; Gibbs et al., 2006; Hahn et al., 2015; Hongoh et al., 2009; Hribar et al., 2001; Reisen et al., 2008a; Reisen et al., 1992; Reiter and LaPointe, 2007). Social demographic predictors associated with certain populations may additionally contribute to potential habitats for mosquitoes and avian hosts (Bisanzio et al., 2011; Brownstein et al., 2002; Diuk-Wasser et al., 2006; Ruiz et al., 2004).

Abbreviations: AICc, Akaike's Information Criterion (corrected); DEM, digital elevation model; IR, infection rate; NDVI, normalized difference vegetation index; PC1, urbanization principal component group 1; qRT-PCR, quantitative reverse-transcriptase polymerase chain reaction; WNV, West Nile virus; WNND, West Nile neuroinvasive disease.

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Previous studies have explored the relationships between demographic and environmental variables with human WNV cases (Chuang et al., 2012; DeGroote et al., 2008; Degroote et al., 2014), but relatively few studies have explored these factors as they relate to WNV infection in *Culex* mosquitoes, especially in the southern United States. While spatial heterogeneity of WNV infection in mosquitoes has been studied previously in other states such as Illinois and California, this topic remains unexplored in the state of TX, especially in relation to the state's largest epidemic of WNV human cases and deaths in 2012 (Reisen et al., 2008b; Ruiz et al., 2004).

The magnitude of the 2012 WNV epidemic was unexpected given that the original introduction of WNV into the region occurred a decade previously and WNV activity was generally low leading up to the epidemic. This epidemic reported the greatest number of deaths due to WNV compared to previous epidemics, reporting 286 human deaths throughout the United States (CDC, 2018). Dallas County (Co.) was an outlier in 2012, reporting the greatest number of cases and deaths for any county in one of the largest epidemics of WNV (396 human cases of WNF and WNND and 19 human deaths) (CDC, 2015). The total economic cost due to the 2012 epidemic in TX was approximately $47.6 million for vector control and hospital management (Chung et al., 2013; Murray et al., 2013).

Given the extent of the 2012 WNV epidemic, our objective in this study is to better understand the static landscape and demographic factors that might have played a role in the ecology of the mosquito vector *Cx. quinquefasciatus* during this epidemic in Dallas Co., TX and to develop models that can predict WNV-infected *Cx. quinquefasciatus*. The models developed in this study can be integrated into mosquito surveillance programs as a cost-effective strategy for more directed control of WNV vectors and improved predictive capabilities of WNV outbreaks in Dallas Co.

2. Materials and methods

2.1. Mosquito data

We compiled data from multiple entities in Dallas Co. (Fig. 1). Mosquito trapping occurred weekly throughout Dallas Co., using one gravid trap per location. A total of 506 unique trap locations were set throughout Dallas Co. in 2012 (Fig. 1). Some trap locations had data for only one trap night and other trap locations were visited repeatedly up to 34 total visits between May and December. After the traps were collected, the mosquitoes were identified according to species and sex and then sorted into pools of $\leq$ 50 mosquitoes. Dallas County Health and Human Services and the Texas Department of State Health Services (DSHS) tested female mosquito pools for WNV using quantitative reverse-transcription polymerase chain reaction (qRT-PCR) and/or virus isolation (Beaty, 1989; Chung et al., 2013; Lanciotti et al., 2000). DSHS conducted qRT-PCR to detect WNV in the pool with a confirmation test using virus isolation due to the high volume of mosquito pool testing requests and the need to disseminate results quickly in 2012. Dallas Co. performed qRT-PCR tests only.

To determine the temporal distribution of WNV throughout the epidemic, the infection rate (IR) per week was calculated using the Biggerstaff Pooled Infection Rate Excel add-in developed by the Centers for Disease Control and Prevention, using the Maximum Likelihood Estimation method (Biggerstaff, 2009; Chiang and Reeves, 1962; Gu et al., 2003). The IR measures the proportion of infected mosquitoes from pooled samples (CDC, 2013; Gu et al., 2003). To investigate the spatial distribution of the WNV IR for each trap location throughout the county, the IR per unique trap identification number was calculated using the same Excel add-in.

2.2. Layer processing

Mosquito trap data and landscape layers were organized and processed using ArcMap 10.2.2 (Esri, Redlands, CA). All layers were projected to NAD 1983 State Plane Texas North Central FIPS 4202 Feet. The raster layers were resampled to a resolution size of 250 m x 250 m.

Predictors from national and local databases were utilized to describe the environmental and socioeconomic landscapes (Table 1). These landscape and demographic variables have been investigated in prior studies (Chuang et al., 2012; Chuang and Wimberly, 2012; Cooke et al., 2006; DeGroote and Sugumaran, 2012; DeGroote et al., 2008; Degroote et al., 2014; Deichmeister and Telang, 2010; Mongoh et al., 2007; Reisen et al., 2008b; Ruiz et al., 2004, 2007).

Landscape variables of interest included elevation, impervious surfaces, land cover, NDVI, and distance to water bodies. The land cover datasets were obtained from the Multi-Resolution Land Characteristics Consortium and the land cover classes were reclassified into developed land (urban, classes 21–24) versus non-developed (non-urban) land cover types. From this reclassification, a percentage of urban land cover was used to represent the level of developed land around each trap. The dataset describing the water bodies in Dallas Co., TX was gathered from the North Central Texas Council of Governments. Distance to water bodies described the distance between the center of trap locations and the nearest water body. Demographic variables from the 2012 American Community Survey were measured at the census block group level. Demographic layers included median age, median income, and population density (Table 1).

A 750-m buffer was applied around each trap location to capture the physical and socioeconomic landscape around each trap. This buffer represents the approximate flight range of *Cx. quinquefasciatus* mosquitoes (Medeiros et al., 2017). Information describing the environment and demographics within the buffer were extracted using ArcGIS.

2.3. Model creation

To find the best-fit model that describes the significant landscape and sociodemographic variables associated with the presence of WNV-infected pools of mosquitoes, logistic mixed models were used. The factors that were considered in the model included elevation, percentage of impervious surfaces, percentage of urbanized land cover, NDVI, distance to water bodies, median age, median income, and population density. To reduce the number of predictors entering the models and to avoid autocorrelation between the fixed effects, a principal component analysis (PCA) was conducted. To mitigate the risk of collinearity, a PCA approach was used to ensure that the different variables in the model were orthogonal. A PCA group called "urbanization" (*PC1*) included variables related to the urban landscape such as land cover, impervious surfaces, NDVI, and population density. The variables that comprise this PCA have individually been investigated as risk factors for WNV and *Culex* abundance (Cooke et al., 2006; DeGroote et al., 2008). The loadings from this PCA group were entered in the logistic regression. Median population age and income were additionally included as demographic variables in the models, which have been previously explored in relation to WNV (Degroote et al., 2014; Ruiz et al., 2004). Fixed effects about the physical landscape such as distance to water bodies and elevation were included in the models as independent variables (Eisen et al., 2008; Nolan et al., 2012).

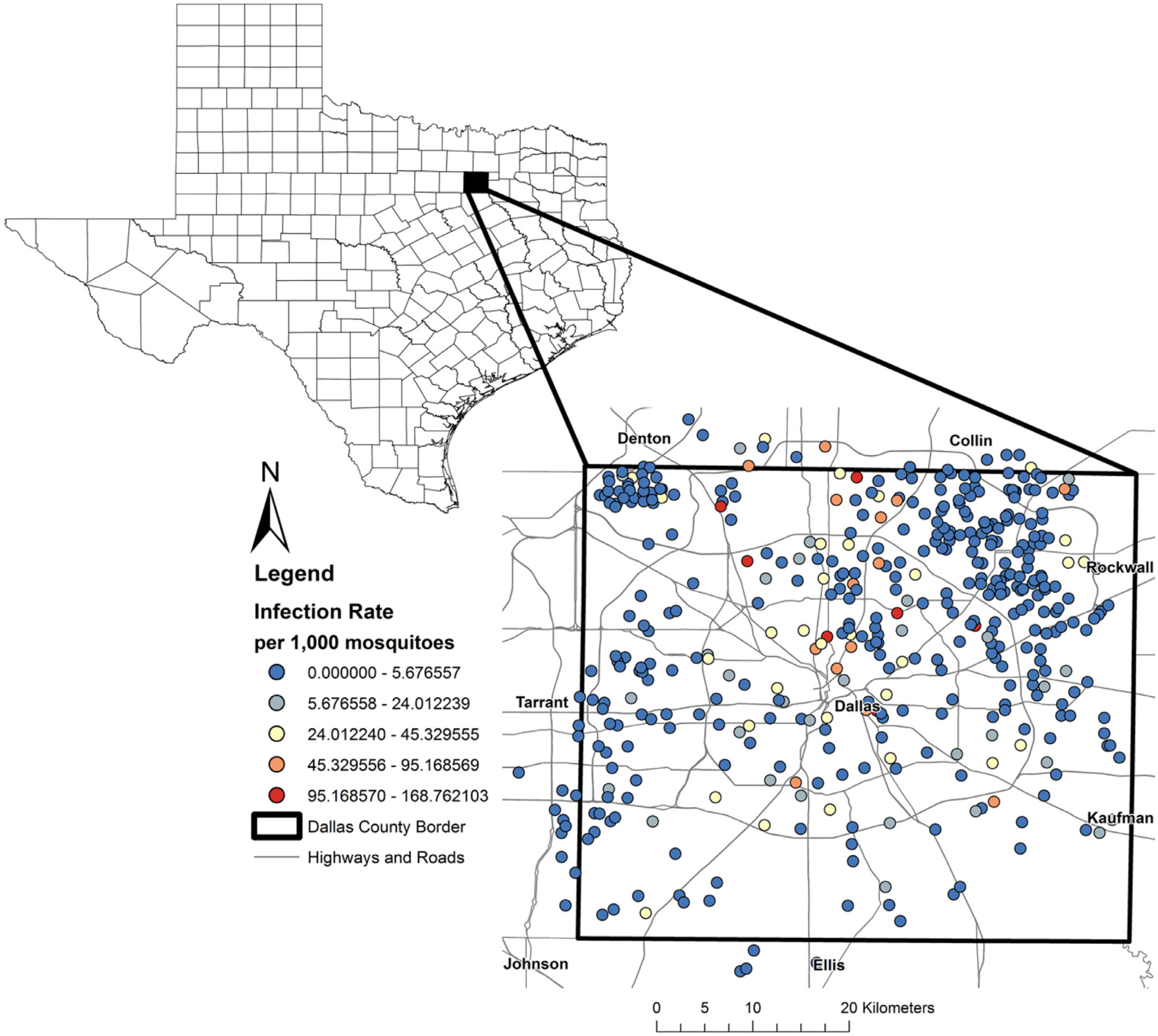

Fig. 1. Map of Dallas County, TX and gravid trap locations within the county. Point locations of the 506 trap locations in 2012 are shown with an infection rate (IR) estimated for each trap. The IR was summarized per trap location for 2012. Higher IR's are located throughout central and north Dallas County.

Table 1
Predictor variables and their sources used in the model creation steps.

Variables	Source
Digital elevation model (DEM)	National Elevation Database
Impervious surfacesLand cover	Multi-Resolution Land Characteristics Consortium (2011)
Normalized difference vegetation index (NDVI)	eMODIS (2012)
Distance to water bodies	North Central Texas Council of Governments
Demographic (census block groups) Median age Median income Population density	American Community Survey (2012)

As part of the experimental design, two random effects were included in the models. Trap week was included as a random effect to control for seasonal effects across the data. In addition, a nested random effect structure was used to control for spatial autocorrelation, which was assumed *a priori*. Smaller blocks (4.60 km × 5.07 km per block) were nested within larger blocks (18.40 km × 20.29 km per block) across the study area (~ 3364.74 km^2), such that there were 4 × 4 small blocks in each large block and 3 × 3 large blocks encompassing the study area. Each trap location was given a unique group number within the large block and another unique group number representing the small block nested in the large block. This nested random effect structure ("Small block:Big block") is a blocking scheme that assumes the data points within the small blocks in the same large block are more similar to one another overall and that individuals from two different large blocks are less similar from one another, independent of the fixed effects

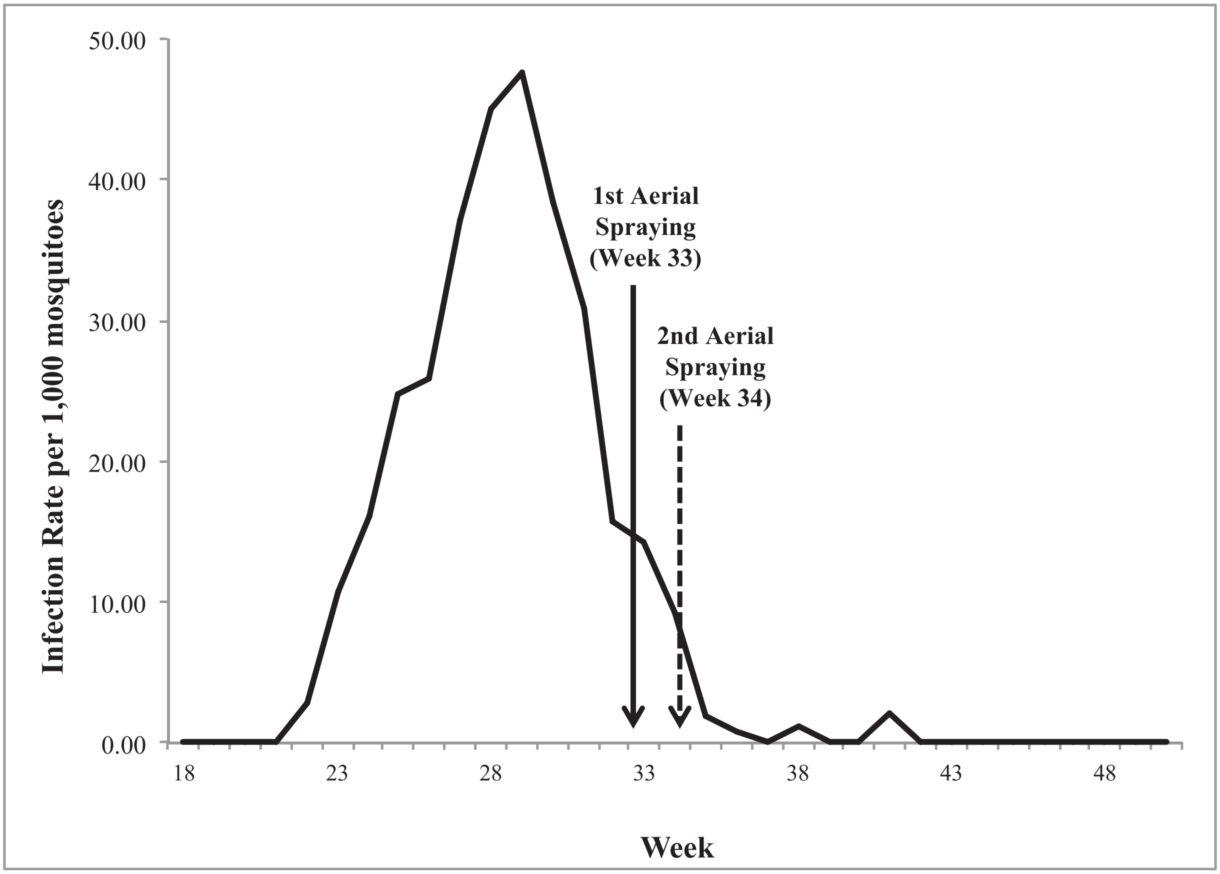

Fig. 2. WNV infection rate in Dallas County, TX in 2012. Weeks 20–37 (May-September 2012) represent the peak of WNV activity. To control mosquito populations, two major aerial spraying events occurred in the county, with the first spraying in week 33 (August 16–20) and the second spraying in week 34 (August 22–26).

across the landscape. Since the pools had a variable pool size of 1–50, an offset function was added to the model to control for the variance in pool size. The outcome variable for our models was the probability of a positive mosquito pool with a negative pool designated as 0 and a positive pool designated as 1. The dataset includes data during the peak season for *Cx. quinquefasciatus* mosquito and WNV activities in 2012, which corresponds to weeks 20–37 (Fig. 2).

Akaike's Information Criterion (AICc) corrected for small sample size to distinguish a best-fit model from other candidate models, with the smallest AICc value representing a model with better fit. The AICc measures the relative quality of models for a given set of data to determine which model(s) fit the data best (Bozdogan, 1987). Models were created using the *lme4* package in program R (Bates et al., 2015). A bootstrapping method was used to calculate 95% confidence intervals for each predictor estimate in the best-fitting model.

To generate a risk map describing the probability of finding a WNV-positive pool based on the coefficients of the best-fit model, the log link functions were entered into ArcGIS. We derived the log-odds from the logistic regression using the following logit link (Diuk-Wasser et al., 2006; Peper et al., 2018):

$$\ln(\mu) = \beta_0 + \beta_1 \mathrm{x}_1 + \beta_2 \mathrm{x}_2 + \ldots + \beta_k \mathrm{x}_k \tag{1}$$

where μ represents whether a pool tested positive ($\mu = 1$) or negative ($\mu = 0$), β_0 represents the intercept (or when $\ln(x) = 0$), $\beta_1 \ldots \beta_k$ are the coefficients for each predictor variable, $x_1 \ldots x_k$, where a unit increase in x results in the multiplicative effect on the probability of a positive mosquito pool (μ).

The final model was transformed into the probability of a mosquito pool testing positive for WNV by the binomial function:

$$p = \; exp(\mu)/1 + exp(\mu) \tag{2}$$

where μ represents the log-link function from Eq. (1). The probability was then transformed into a percentage by multiplying probability p by 100 to represent the percent probability that a WNV-positive mosquito pool will be present based on the significant fixed effects.

3. Results

In 2012, 25,917 female mosquitoes of all species were organized into 2642 pools of $\leq$ 50 mosquitoes and tested for WNV. Approximately 10% of the pools (267 pools) tested positive for WNV. The majority of the mosquitoes (88%) that were pooled and tested were identified as *Cx. quinquefasciatus* (22,156 mosquitoes). A total of 1634 pools containing at least 1 *Cx. quinquefasciatus* mosquito were tested for WNV and 256 pools (16%) tested positive for WNV. *Cx. quinquefasciatus* pools accounted for the majority of the WNV-positive pools in 2012 (96%). During the 2012 season, 175 unique trap locations had at least one mosquito pool test positive (Fig. 1).

Spatially, the highest infection rates occurred in north and central Dallas Co. (Fig. 1). WNV activity was highest between May and September between weeks 20–37 (Fig. 2). The county experienced the highest infection rate during the week of July 16–22 (week 29), with a peak of 47.66 per 1000 individuals for the infection rate. Truck-based mosquito adulticide occurred in July and August (Chung et al., 2013), but the first major aerial spraying across the county occurred during the week of August 16–20

Table 2
PCA loadings for variables listed in the urbanization group. *PC1* explained 66% of the variance, therefore, the loadings from *PC1* were chosen to represent urbanization in the logistic regression.

Variables	Loadings$_{PC1}$
Land cover	0.514
Impervious surfaces	0.573
NDVI	−0.465
Population density	0.438

(Week 33), which had an infection rate of 14.28 (Fig. 2, solid arrow) (Ruktanonchai et al., 2014). The second major aerial spraying in Dallas Co. occurred during the week of August 22–23 (week 34), which had an infection rate of 9.36 (Fig. 2, dashed arrow) (Ruktanonchai et al., 2014).

To represent the amount of development or urbanization, loadings from *PC1* were chosen to enter the logistic regression as they explained 66% of the variance (Table 2). *PC1* consisted of positive loadings of land cover, impervious surfaces, and population density and a negative loading of NDVI.

A total of 32 models were compared using the AIC. These models were all possible additive combinations of the fixed effects. The best-fit model included urbanization (*PC1* score), median age, and elevation (Tables 3 and 4). The AICc of the best-fit model is fairly distinguishable in fit compared to the next-best models, where the ΔAICc is $\geq$ 2.0 (Table 3). Urbanization (Estimate: 0.436, 95% CI (0.232, 0.659)) and median age (Estimate: 0.272, 95% CI (0.089, 0.508)) had positive associations with the probability of a pool being infected with WNV, while elevation (Estimate: −0.220, 95% CI (−0.438, −0.019)) had a negative association (Table 4). In the model, the variance for the random effect of Small block:Big block was $1.063e^{-8}$. The variance for the random effect of week was 2.494.

The following log-link function based on Eq. (1) is derived from the logistic regression using the estimates from the best-fit model, is corrected for the offsets, and is scaled by the mean divided by the covariates:

$$\begin{aligned} ln(\mu) = &-2.19 + 0.43 \times (PC1/1.62) + 0.30 \\ &\times ((Med\ Age - 36.88)/6.45) + (-0.20) \\ &\times ((DEM - 161.34)/21.58) + 0.94 \\ &\times ((15 - 15.48)/15.37 \end{aligned} \tag{3}$$

where *PC1* represents the urbanization principal component group, *MedAge* represents the median age of the population, and *DEM* represents elevation. The final equation that was used to produce the map was transformed into the binomial function using Eq. (2).

The final risk map highlights areas that had greater probabilities of detecting a WNV-positive mosquito pool based on the significant factors identified from our models (Fig. 3, S1). The risk of WNV-positive *Cx. quinquefasciatus* ranged from 0.28% to 85.3%, with the greatest risk detected around the city of Carrollton in north Dallas Co. and within the city of Dallas. The southern region of Dallas Co. had lower probabilities compared to the northern counterpart. Based on these results, we can draw conclusions about the landscape and population demographics that were associated with WNV-infected mosquitoes during the 2012 epidemic.

4. Discussion and conclusions

This study investigated landscape and demographic factors related to the probability of finding a WNV-positive mosquito pool during the 2012 WNV epidemic in Dallas Co., TX. Our study found an increased probability of WNV-positive mosquito pools in areas with higher urbanization, older populations, and lower elevations. Based on these findings, our best-fit model identified north and central Dallas Co. as areas with the greatest risk of finding a WNV-positive pool of *Cx. quinquefasciatus*, with the highest risk at 85.3%. Each factor from the model includes variables that could influence the life cycle of the mosquito as well as the interactions between the vector and avian hosts that allow WNV to circulate in the enzootic cycle.

The urbanization index (*PC1*) had the largest effect on the probability of finding a positive mosquito pool, with the amount of urbanized land cover having the greatest influence within the principal component. The variables in *PC1* included positive loadings for land cover, impervious surfaces, and population density and negative loadings for NDVI. NDVI measures the amount of vegetation present, therefore with increasing impervious surfaces and developed land and higher population density, we expected NDVI to decrease. These components directly affect the life cycle of *Cx. quinquefasciatus* because this species of mosquito prefers breeding habitats in urban areas particularly characterized by human habitations, urban catch basins, and storm drains (Andreadis, 2012; Molaei et al., 2007). Urban and peridomestic environments may form habitats by collecting water and allowing organic contents to enrich, which are characteristic breeding grounds for *Cx. quinquefasciatus*. Other studies have yielded similar results, concluding that WNV and its vectors are found in urban environments (Bolling et al., 2005; Bowden et al., 2011; Cooke et al., 2006; Gibbs et al., 2006; Hribar et al., 2001). Furthermore, *Cx. pipiens*, the main WNV vector in the northeast United States and a close relative of *Cx. quinquefasciatus*, has also been positively linked to urbanization and the amount of development in Connecticut (Andreadis et al., 2004).

Avian reservoir populations are also affected by urbanization. Urbanization and development cause fragmentations in the landscape and create adjacent ecotones, which can also alter bird populations and thusly, the transmission dynamics and dispersal of WNV across the landscape (Coppedge et al., 2001; Marzluff, 2001; Reisen, 2010; Wiens, 1995). As the landscape becomes more fragmented, adjacent bird populations may congregate in the same area because of increased habitat loss and overall reduce WNV transmission if these birds have low reservoir competence or alternatively increase WNV transmission if the bird populations are capable of producing high viremias of WNV (Allan et al., 2009). The overuse of certain avian hosts in urban areas such as the American robin (*Turdus migratorius*), which is considered a superspreader of WNV, and concurrent underuse of other species with lower reservoir competence such as the great-tailed grackle (*Quiscalus mexicanus*) or European starling (*Sturnus vulgaris*) also alter the transmission dynamics of WNV (Hamer et al., 2009; Komar et al., 2018). The effects of urbanized cities on the avian community structure and resulting WNV transmission dynamics during the 2012 epidemic warrant further investigation.

Similarly, median age of the population had a positive correlation with the probability of finding a WNV-positive pool. Overall, the relationship between the median age of the population and *Cx. quinquefasciatus* populations has not been studied thoroughly in TX. Certain behaviors associated with age can mediate *Cx. quinquefasciatus* habitats, the resulting abundances, and their interactions with avian hosts, which can lead to greater amplification of WNV in the enzootic cycle and eventual spillover to human populations. Outdoor activities common among older populations, such as yard work or development of yard structures that collect water or food, can contribute to mosquito abundance and increase risk for human spillover of WNV by bringing amplification and accidental hosts and vectors together (Blaine et al., 2010; Ruiz et al., 2004).

The best-fit model suggested a negative association between elevation and *Culex* spp. WNV infection rate, which is consistent with observations in prior studies (Bisanzio et al., 2011;

Table 3
Model comparisons between the best-fit model and similar models. The best-fit model is bolded. The **Δ**AICc of the best-fit model in bold is fairly distinguishable in fit compared to the next best model. “Number of Parameters” refers to the number of parameters tested in the model, excluding the intercept. A total of 32 models were compared in this study. This table does not display the complete list of all the models that were compared.

Fixed Effects	AICc	ΔAICc	Weight	Number of Parameters	Log Likelihood	Deviance
Urbanization, median age, DEM	**821.1**	**0.0**	**0.316**	**3**	**−403.5**	**807.0**
Urbanization, median age, median income, DEM	823.1	2.0	0.118	4	−403.5	807.0
Urbanization, median age, distance to water, DEM	823.2	2.0	0.115	4	−403.5	807.0
Urbanization, median age	823.8	2.7	0.083	2	−409.5	811.7
Intercept	836.2	15.1	<0.001	0	−414.1	828.2

Table 4
Best-fit model estimates with 95% confidence intervals. Urbanization, median age, and elevation were significant predictors of the 2012 WNV epidemic in Dallas County, TX. Urbanization and median age have positive associations with the probability of finding a positive mosquito pool and elevation had a negative relationship.

Variable	Estimate	95% CI
Urbanization (*PC1*)	0.436	(0.232, 0.659)
Median age	0.272	(0.089, 0.508)
Elevation	−0.220	(−0.438, −0.019)
Intercept	−4.463	(−5.297, −3.713)

Chuang et al., 2012; Gibbs et al., 2006; Mongoh et al., 2007; Ruiz et al., 2010). In combination with other physiographic elements, higher elevation may limit WNV transmission since these elevations have lower temperatures, subsequent smaller mosquito abundances, and differences in avian species composition (Gibbs et al., 2006). Similarly, elevation could mediate the effect of precipitation by collecting water at lower elevations to enrich with organic materials needed for mosquito population survival (Ruiz et al., 2010). Elevation by itself may not play a significant role in Dallas and surrounding areas since there is $a \leq 100$ m difference between the highest and lowest points. Instead, lower elevation and increased urbanization are likely mediating the effects of precipitation, similar to what was found in Chicago, IL (Ruiz et al., 2010).

Aerial spraying occurred late in the season during weeks 33 (August 16–20) and 34 (August 22–23), which corresponds to the time period when the infection rate was already decreasing after a peak infection rate in week 28 (July 8–14) (Fig. 2) (Ruktanonchai et al., 2014). The WNV season in mosquitoes had already dramatically decreased by the time spraying events occurred, making it difficult to discern if the aerial spraying was truly effective in reducing the infection rate of WNV or if the infection rate decreased due to the seasonality of *Cx. quinquefasciatus*. Additionally, ground-based adulticide conducted in July and August in response to the increasing vector index (Chung et al., 2013)

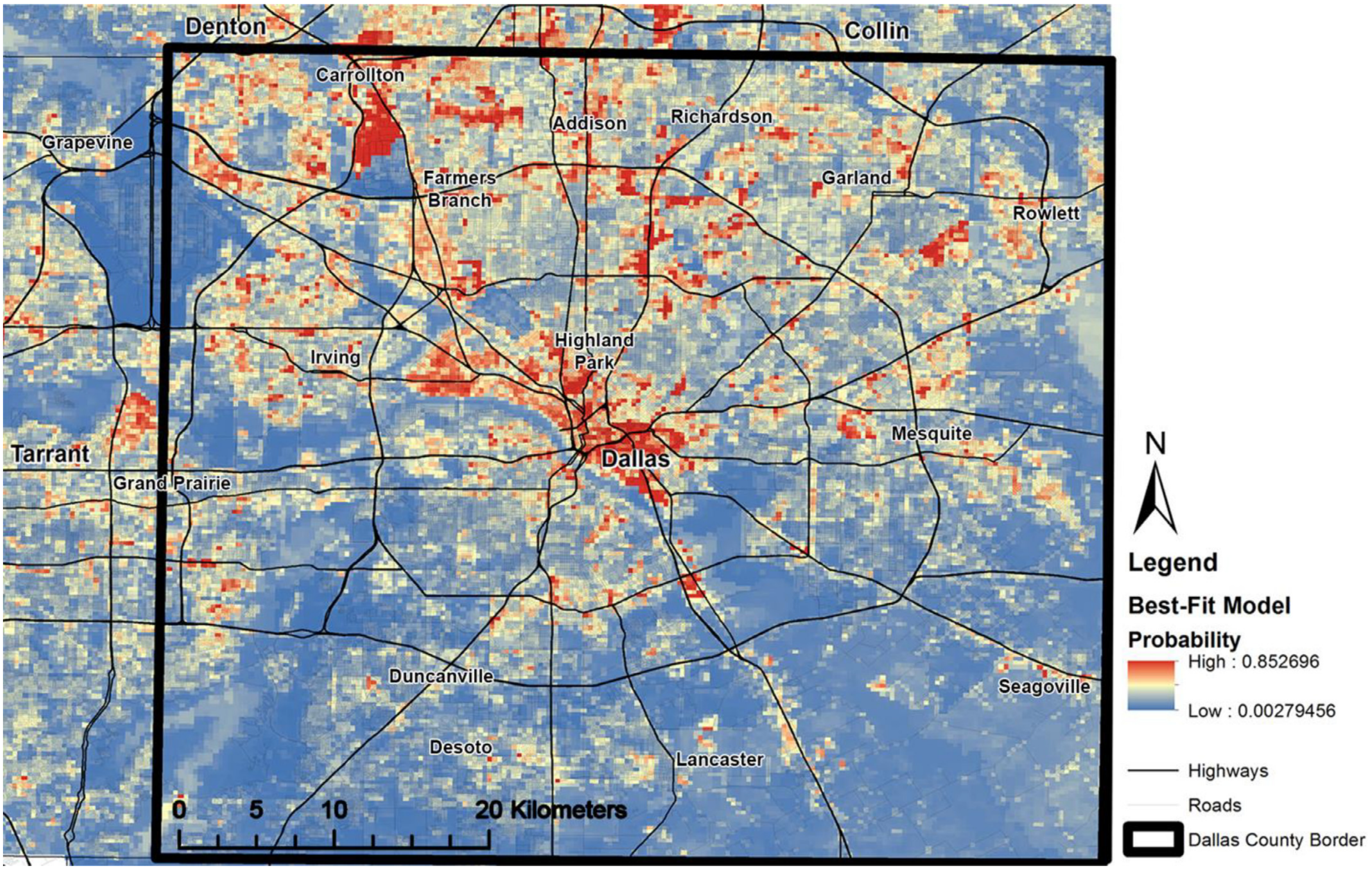

Fig. 3. Probability map of the best-fit-model measuring the probability of finding WNV-positive *Cx. quinquefasciatus* during the 2012 epidemic of WNV in Dallas, TX. The darker red colors represent areas of higher risk based on greater levels of urbanization, larger populations of elderly individuals, and lower elevations. A second version of this map is available in the Supplementary Material (Fig. S1).

could have influenced vector abundance prior to the aerial spraying. Nonetheless, the associations between features of the landscape and human demographics with mosquito infection rates of this study are likely revealing patterns that were not influenced by artifacts of vector control activities.

Without an available vaccine for humans, mosquito control and public awareness campaigns are currently the most effective ways to prevent and/or minimize WNV human cases. Understanding the ecology of WNV dynamics with the mosquito, environment, and social demographics plays a key role in effective intervention campaigns. Furthermore, predicting when and where WNV in mosquitoes occurs may provide an early warning system to control mosquitoes before bridge transmission to humans and to alert the public with the appropriate messages to reduce the risk of exposure. This study provides one of the first efforts to model *Culex* infection during the 2012 WNV epidemic for Dallas Co., TX. Future efforts should concentrate on establishing long-term mosquito surveillance databases, modeling WNV for early detection in other major metropolitan areas of TX, and utilizing quantitative measurements to identify a threshold for early control protocols. While this study only focused on one year, these findings provide the first steps to understanding the ecology of WNV in *Cx. quinquefasciatus* mosquitoes during the 2012 epidemic in the hopes of preventing another devastating event in a major county such as Dallas Co., TX.

Declaration of Competing Interest

The authors declare that they have no competing interests.

CRediT authorship contribution statement

Karen C. Poh: Methodology, Software, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Matthew C.I. Medeiros:** Methodology, Software, Formal analysis, Writing - review & editing. **Gabriel L. Hamer:** Conceptualization, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declarations

Ethics approval and consent to participate: Not applicable. The study did not include identifiable human material and data.

Consent for publication

Not applicable.

Availability of data and material

The database utilized in the model is publically available from OAK Trust Digital Repository through Texas A&M University. Data are available at: https://oaktrust.library.tamu.edu/handle/1969.1/169350. Trap locations have been removed due to sensitivity of those data.

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sste.2020.100336.

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