Applied Geography 51 (2014) 58–64

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

# A comparison of three approaches to identify West Nile Virus mosquito space-time hotspots in the Houston Vicinity for the period 2002–2011

Andrew Curtis [a,*], Xinyue Ye [a,1], Elyse Heob [b,2], Joseph Targhetta [b,2], Vence Salvato [b], Martin Reyna [b], Rudy Bueno Jr. [d], Louisa Holmes [c,3]

[a] Department of Geography, Kent State University, Kent, OH 44242, USA
[b] Harris County Public Health and Environmental Services Mosquito Control Division, 3330 Old Spanish Trail, Bldg. D, Houston, TX 77021, USA
[c] Center for Tobacco Control Research & Education/Department of Medicine, University of California, 530 Parnassus Avenue, Suite 366, San Francisco, CA 94143-1390, USA
[d] GIS, Health and Hazards Lab, Kent State University, USA

*Keywords:*
Geographic information systems
West Nile Virus
Houston
Hotspot analysis

ABSTRACT

From 2002 to 2011, West Nile virus mosquitoes (WNV) has been ever-present in traps across Harris County, TX which contains the city of Houston. Disease-positive trap locations have peaked twice, from 2002 to 2006 and then again from 2009 onwards. This paper will examine fine scale spatial and temporal patterns in disease-positive mosquito traps for the Houston area across this time frame, using three different analytical approaches: kernel density, spatial filtering and SaTScan. The purpose of this paper is twofold. Firstly, to identify spatial and space-time clusters of WNV in order to spatially prioritize subsequent research for causative associations. Secondly, to compare the effectiveness of three methods that vary in complexity and ease of use in order to suggest a transferable methodology for mosquito control and environmental health departments across the United States with only lower level GIS skillsets. This paper also illustrates a successful ongoing academic and mosquito control collaboration with the Harris County Public Health Services Mosquito Control Division's (MCD) program.



## Introduction

Previous research has identified the Houston area as having the most temporally stable human West Nile Virus hotspot within the United States (in terms of absolute counts) for the period 2000–2008(Carnes & Ogneva-Himmelberger, 2011). The authors also suggested that there was a need for finer scale analysis within such hotspots, in other words to geographically contextualize the hotspot, find the *hotspots within the hotspot*. This suggestion for more fine spatial scale WNV research has been echoed elsewhere (Bradley, Gibbs, & Altizer, 2008; LaBeaud et al., 2008; Mostashari, Kulldorff, Hartman, Miller, & Kulasekera, 2003; Rochlin, Turbow, Gomez, Ninivaggi, & Campbell, 2011). Fine scale spatial analysis can help reveal the specific geographic features that contribute to hotspot generation and stability (Amore et al., 2010), considering not only features such as organic rich water bodies, sewers and storm drains, but exactly which ones to target. This understanding of spatial nuance in a disease map can be used to better direct intervention strategies.

The Harris County Public Health Services Mosquito Control Division's (MCD) program covers the 3rd largest county by population in the United States and encompasses an area of approximately 1800 sq. miles. A variety of different habitats comprise the service region, and 55 different mosquito species have been identified. Although this county continues to experience a notable WNV risk, it is also typical of many other environmental health units across the United States. Precise and detailed analysis of surveillance data is essential to protect the public from existing and emerging vector-borne disease threats. For this paper, traps containing WNV across the period of 2002–2011 are analyzed in both space and time. More specifically, this paper asks the question, do those trap locations with WNV cluster in space and time or are they randomly

* Corresponding author. Tel.: +1 330 672 2045.
*E-mail addresses:* acurti13@kent.edu, acurti1@gmail.com (A. Curtis), eheob8@gmail.com (E. Heob), rbueno@hcphes.org, jtarghetta@hcphes.org (J. Targhetta), vsalvato@hcphes.org (V. Salvato), mreyna@hcphes.org (M. Reyna), rudybuenojr@gmail.com (R. Bueno), louisa.holmes@ucsf.edu (L. Holmes).
[1] Tel.: +1 330 672 7939.
[2] Tel.: +1 713 440 4800.
[3] Tel.: +1 617 251 4355.

http://dx.doi.org/10.1016/j.apgeog.2014.02.003
0143-6228/

distributed across all trap locations? Causative factors potentially explaining these patterns, such as biological, environmental, meteorological, or through human agency are beyond the scope of this paper. Rather this investigation is focused on identifying the pattern as a first step before causative investigations. We are also mindful of the criticism that there is still disconnect between most spatially focused vector research and actual operational implementation (DeGroote, Larson, Zhang, & Sugumaran, 2012 #89). Therefore, the analytical approaches used here range from relatively easily created "heat maps" of intensity to more sophisticated space-time methods incorporating python programming. The results from these model comparisons are presented as suggestions for varying skillsets relevant to advancing control strategies (LaBeaud et al., 2008; Mostashari et al., 2003; Ozdenerol, Bialkowska-Jelinska, & Taff, 2008).

Spatial patterns of WNV have previously included where and when virus risk is greatest (Rochlin et al., 2011; Zou, Miller, & Schmidtmann, 2007); the temporal and spatial stability in mosquito populations (Andreadis, Anderson, Vossbrinck, & Main, 2004; LaBeaud et al., 2008); on-the-ground associations with different environmental "landscapes" (Alma & Christopher; Nolan et al., 2012; Zou, Miller, & Schmidtmann, 2006), and built environmental (Vazquez-Prokopec et al., 2010) and socioeconomic factors (LaBeaud et al., 2008; Ruiz, Tedesco, McTighe, Austin, & Kitron, 2004; Ruiz, Walker, Foster, Haramis, & Kitron, 2007) that might help explain mosquito and/or disease presence (Liu & Weng, 2009). Spatial inquiry can also inform vector control policy (Tedesco, Ruiz, & McLafferty, 2010), including where to prioritize limited control resources (Jones et al., 2011; Unlu et al., 2011). The most "applied" or "relevant" work combines many of these features into online decision support systems providing near real-time surveillance and warning (DeGroote et al., 2012; Gosselin, Lebel, Rivest, & Douville-Fradet, 2005).

There are several differences in the challenges facing mosquito control across the United States. Some of these include geographically varying disease threat in terms of the actual disease (for example Dengue), or the primary WNV species. For different primary vectors there are variations in associated local environment and climatic patterns, and the spatial interplay between built environment and socioeconomic factors (Bowden, Magori, & Drake, 2011). This means that while some universal spatial insights are more generalizable, especially between similar urban areas such as Chicago, Detroit and Cleveland (LaBeaud et al., 2008; Ruiz et al., 2007) where consistent WNV patterns were found with older housing stock, older sewer systems and associated vegetation, there is arguably a need for every mosquito control board to be able to perform some form of local area spatial analysis for their own niche.

Traditional spatial research into the geography of the West Nile disease include WNV (usually collected at trap locations) (Liu & Weng, 2012), avian infection (Cooke, Grala, & Wallis, 2006; Gibbs et al., 2006; Hamer et al., 2011) or different forms of dead bird surveillance (Liu & Weng, 2009; Mostashari et al., 2003), human case addresses (Nolan et al., 2012; Ruiz et al., 2007), or combinations of the above (Ghosh & Guha, 2010; Ruiz et al., 2004; Winters et al., 2008). Potential data problems can arise with any of these, though arguably the potential bias with passive dead bird surveillance, and confidentiality issues with human case data, make these less commonly used as a standard data set for fine scale analysis. A further consideration is whether longitudinal data are available, as these can help identify consistent spatial concentrations of disease which helps reduce uncertainty associated with a cross-sectional only analysis. There are several examples of such West Nile longitudinal research including investigations into the evolutionary dynamics of the virus in avian populations in Chicago from 2005 to 2007 (Amore et al., 2010), changes in general avian indicators (Gibbs et al., 2006), abundance of vectors from 2005 to 2007 in Virginia (Deichmeister & Telang, 2011), patterns in human cases from 2002 to 2009 for the Houston metropolitan area (Nolan et al., 2012); 2002–2006 for Iowa (DeGroote, Sugumaran, Brend, Tucker, & Bartholomay, 2008); 2003–2007 for South Dakota (Chuang, Hockett, Kightlinger, & Wimberly, 2012), and 2000–2008 for national levels (Carnes & Ogneva-Himmelberger, 2011). A few studies have even utilized multiple types of longitudinal data such as WNV pools, dead birds and human cases, for the period 2002–2007 in the Twin Cities, Minnesota (Ghosh & Guha, 2010). The investigation of the Houston area presented here provides one of the longest time-frames previously analyzed (2002–2011), especially at such a fine spatial scale (see also Nolan, Schuermann, & Murray, 2013). GIS manipulation and analysis of these West Nile related data range on a continuum from the simple to complex; buffering (Deichmeister & Telang, 2011) overlay (Cooke et al., 2006) to nonparametric tests such as Chi Square (Deichmeister & Telang, 2011), interpolation, logistic regression (Gibbs et al., 2006), quadrat analysis (LaBeaud et al., 2008), principal components factor analysis (Ruiz et al., 2007), genetic algorithms combined with computational neural networks (Ghosh & Guha, 2010), or the development of other multiple criteria decision analysis or weighted linear combination matrices where ecological constraints, or expert insights are used to develop spatial matrices of potential presence (Clements & Pfeiffer, 2009). Local area spatial analyses have included spatial scan statistics (Brownstein et al., 2002; LaBeaud et al., 2008; Mostashari et al., 2003; Rochlin et al., 2011), measures of spatial autocorrelation such as the Getis-Ord (Gi) analysis (DeGroote et al., 2008; Nolan et al., 2012), and local indicators of spatial association (LISA) (Ruiz et al., 2004). A few studies have compared results between multiple models to ensure such spatial pattern robustness. For example weighted mean center, standard deviational ellipses, Global Moran's *I* and Getis-Ord Gi* to identify national scale hotspots (Carnes & Ogneva-Himmelberger, 2011).

This paper will search for local area patterns of mosquitoes testing positive over time, using three types of model approaches ranging from relatively simple heat maps to a more complex space-time model. Data will also be manipulated temporally in a GIS by year, for the entire time period (2002–2011) and through spatial programming. The resulting spatial patterns will be compared across analytical approaches. It should be noted, however, that although identifying both spatial and temporal stability is useful in terms of understanding causative factors and targeting intervention, these data are not collected primarily with such longitudinal studies in mind. Although there is general stability in mosquito trap placement across time, some locations will vary between years, and in the frequency with which each is tested. The placement rationale also has limitations, not least of which is whether the land is private or public. Therefore, the traps generating these data would not meet traditional sampling protocol, but these data can still reveal important insights if worked within an appropriately conservative analytical frame. This frame involves a variety of data manipulations, different analytical techniques, and "bracketing" inputs within each model type so that (spatially) common threads can be identified through all.

## Materials and methods

### *Study area*

The Houston area has generated considerable mosquito disease research, not just for WNV but also Dengue and St Louis Encephalitis (SLE) (Bell, Christensen, Holguin, & Smith, 1981; Fredregill, Motl, Dennett, Flatt, & Bueno Jr., 2011; Kuno, 2012; Lillibridge