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Research article

Spatial autoregression of property values surrounding georeferenced equine deathsdue to eastern equine encephalitis: Florida, 2004 - 2016.

Margaret Child, Samuel Alao, Benjamin G. Jacob.

Department of Global Health, University of South Florida.
University of South Florida, 12901 Bruce B. Downs Boulevard, Tampa, FL 33612.

Corresponding Author: mmchild@health.usf.edu

Abstract

Eastern equine encephalitis virus (EEEV) is a zoonotic alphavirus and arbovirus that is currently endemic in wildlife throughout the Americas. EEEV is capable of infecting a wide range of species, but the virus's life cycle is maintained via a bird-mosquito interaction, with *Culiseta melanura* as the primary vector. The disease is mostly asymptomatic in birds yet highly virulent for equine species, with mortality rates in horses ranging from 75 to 90%. There is an effective vaccine that the American Association of Equine Practitioners recommends biannually for all *Equus* species that reside in or travel to at-risk areas. Using estimated property values as a proxy for socioeconomic status, spatial autoregression modeling found a correlation between 2016 property values and equine cases in the state of Florida for the previous twelve years, from 2004 to 2016. This analysis revealed 1.9 times more clustering tendencies in low socioeconomic areas.

Keywords: Eastern equine encephalitis, alphavirus, arbovirus, *Culiseta melanura* eqiune, spatial autoregression, socioeconomic status

Introduction

Eastern equine encephalitis virus (EEEV) is a member of the *Togaviridae* family and is closely related to western equine encephalitis virus and Venezuelan equine encephalitis virus(CDC, 2016). Eastern equine encephalitis (EEE) is maintained via mosquito-avian cycle between the primary vector *Culisetamelanura* and passerine birds (Vander Kelen et al., 2012). Research has also indicated that *Culexerraticus* mosquitos are a contributing vector species as well (Jacob et al., 2010).

EEE infections are rare in humans, with symptoms including chills, fever, malaise, arthralgia, and myalgia. Approximately one third of all human infections result in death, usually 2 to 10 days after onset (CDC 2016). Of those who do not die, a significant number of infected individuals are left with mental and physical debilitations (CDC 2016). Symptoms in equines are similar, including fever, depression, and loss of appetite, blindness, and abnormal sensitivity to lights and sounds, with an estimated mortality rate of 75 to 90% (USDA, 2008).

An average of 8 human cases of EEE are reported annually in the United States, with transmission most commonly occurring around freshwater hardwood swamp habitats in the Atlantic and Gulf coast states, as well as the Great Lakes region (CDC, 2016). Proximity to tree plantations is also associated with an elevated risk of EEE in both horses and humans (Vander Kelen et al., 2012).For most of the United States, EEE infections peak in August and September (Letson, Bailey, Pearson, & Tsai, 1993); however, EEE cases in the state of Florida peak in June and July (Bigler, Lassing, Buff, Lewis, & Hoff, 1975). Florida is unique in that supports year-round transmission of EEEV (Vander Kelen et al., 2012), with evidence supporting snakes play a role as over-wintering hosts for the virus (Bingham et al., 2012).In 2015, 33% of all US equine fatalities due to EEE occurred in Florida (USDA, 2016).

Although socioeconomic status (SES) has been shown to influence to overall human health indicators, there is limited research regarding the effects of SES on the health of dependent domestic animals. Research has linked livestock health as reflective of human SES(Thumbi et al., 2015)andthere is a reported increase in rabies incidence ratesin canines from areas associated with lower SES (Fung et al., 2014; Widdowson, Morales, Chaves, & McGrane, 2002).

Materials and Methods

There were 604equine cases of confirmed EEE in Florida between the years 2004 and 2016. Street addresses and GPS coordinates of all infected horses with laboratory-confirmed EEEV were obtained from the Division of Disease Control and Health Protection at the Florida Department of Health. Estimated property values were acquired from real estate websites Zillow (www.zillow.com) and Trulia (www.trulia.com). The dataset was then sorted and stratified below and above 2 standard deviations based on property values from the median. The property values derived in the statistical process were applied as figures for low socioeconomic (<$103,456.25; obs=143) and high socioeconomic (>$277,973; obs= 192). The Pearson product moment correlation coefficient [Moran's Index(I)] allowed for determination of clustering tendencies of equine deaths due to EEEV categorized by property values between high socioeconomic georeferenced geolocations and low-valuedgeoclassified territories within Florida.

PROC VARIOGRAM in SAS was employed in generating Moran's I by computing the cross mean adjusted values that are geographic neighbors (i.e. ranges from -1 for negative spatial autocorrelation to 1 for positive spatial autocorrelation and a value of 0 signifying a randomly chaotic distribution of equine deaths based on property values across Florida geographical landscape). Distance between centroids was defined as n by n geographical weight matrix C, whose c_{ij}values were 1 when the equine deaths geolocations I and j were deemed close, and 0 otherwise. Moran's equations were adopted for spatial dependency.

$$\text{Moran's Coefficient} = \frac{\sum_{i=1}^{n}(yi-\bar{y})\sum_{j=1}^{n}c_{ij}(y_j-\bar{y})^2/\sum_{i=1}^{n}\sum_{j=1}^{n}c_{ij}}{\frac{\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}{n}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2/n}} \qquad (1)$$

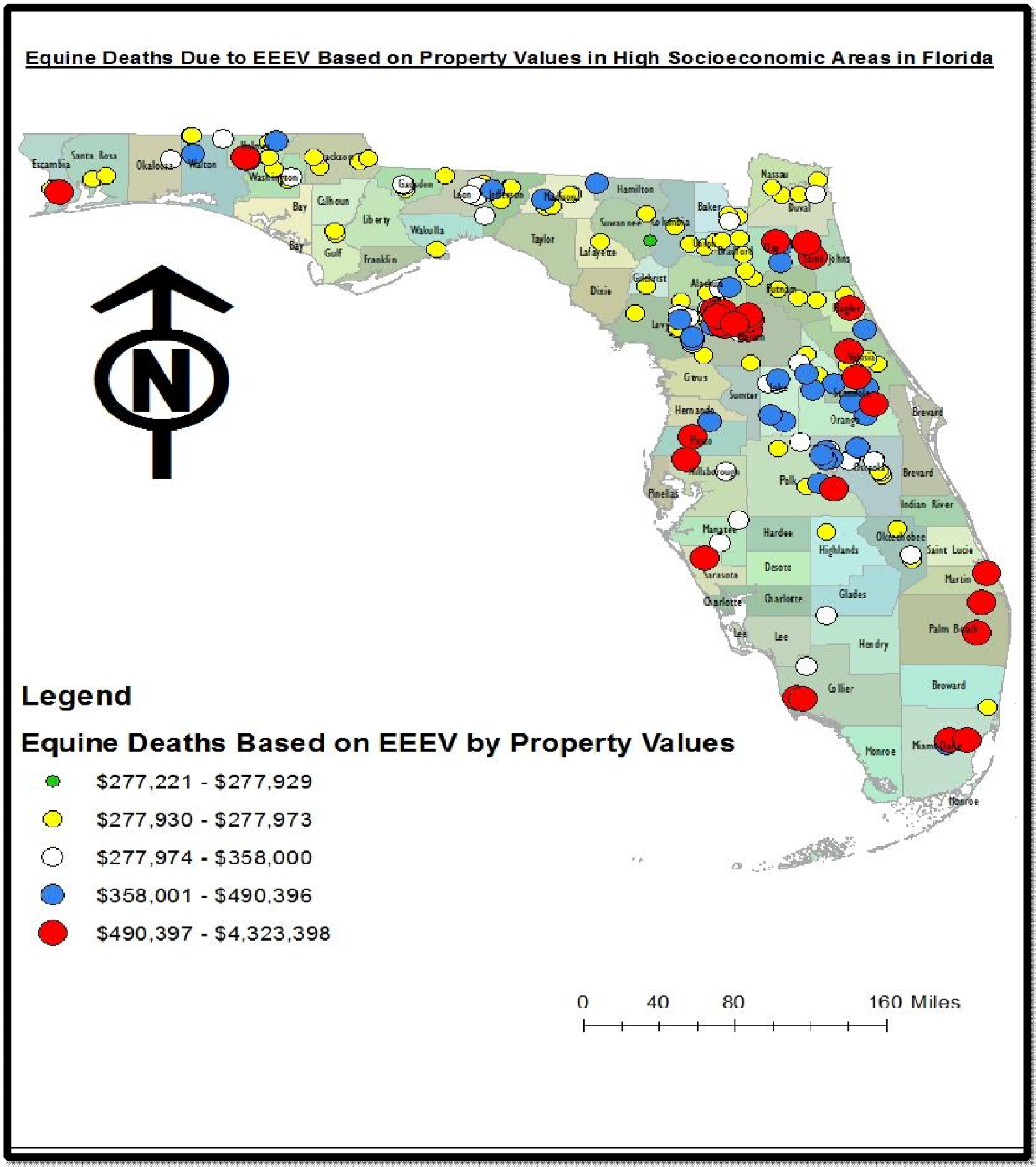
where $_{ij}$ is the spatial weights stored in the symmetrical matrix C and $\sum^{n}{}_{i=1}\sum^{n}{}_{j=1}c_{ij}$ is the average cross product term signified by 1 in the equation (Griffith, 2013). Spatial autocorrelation serves as a diagnostic tool for model misspecifications, uncommon variances and extreme observations. Moran's scatter plot expresses the levels of spatial associations of each observation with its neighbor (Griffith, 2013). Similarly, the LAGDISTANCE OPTION indicated the neighborhood size in the PROC VARIOGRAM procedure necessary for the computation of autocorrelation index. The binary, row-averaged weights created for the autocorrelation statistics generated a Moran's coefficient equivalent to the regression slope of the Moran scatter plot.

The Outpair option enabled the calculation of distance between points and the pairwise dataset contained coordinates for both georeferenced geolocations (i.e. a dataset of n observations generated a pairwise dataset of size n (n-1)). PROC UNIVARIATE of the pairwise distance between the centroids points equine deaths based on property values resulted in elucidative quartiles, with other measures of variability and moments of interest in plotting variogram to its corresponding distance.

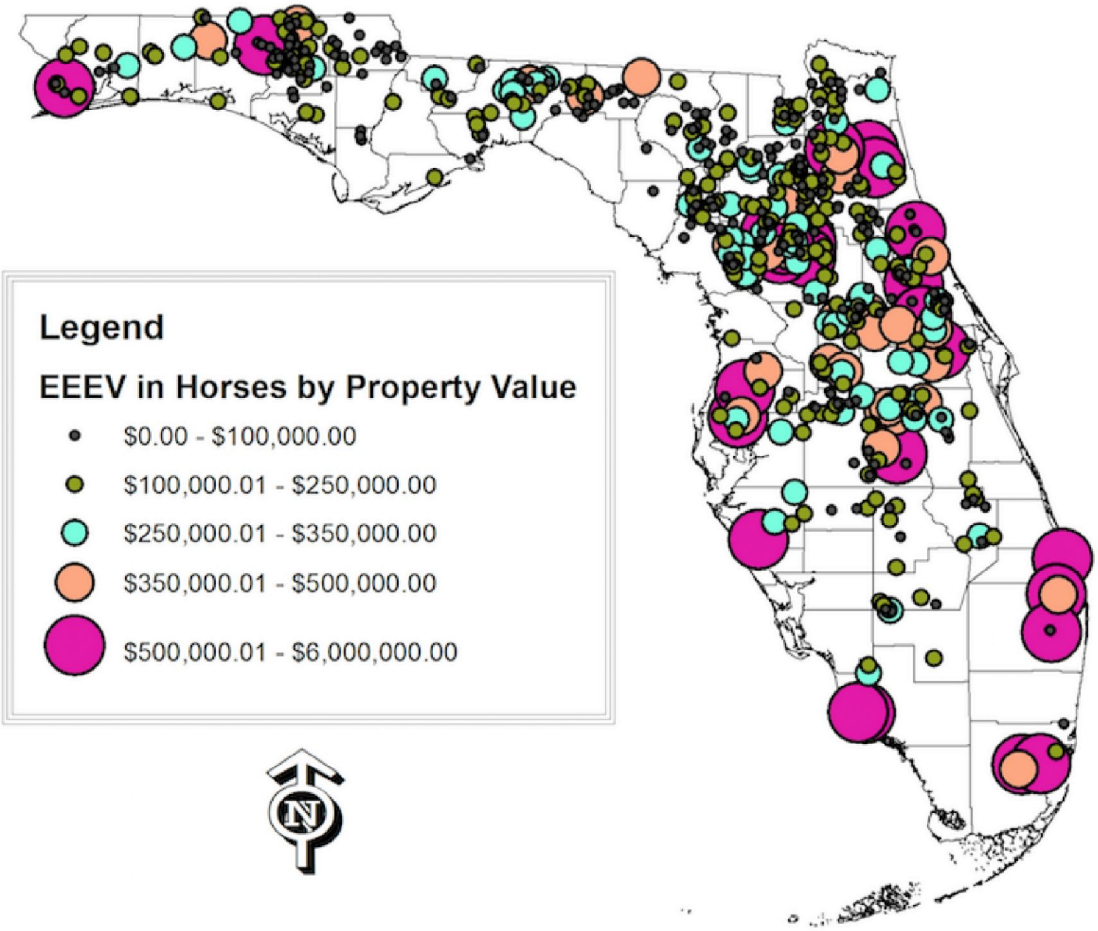
Results

The observed Moran's I was used to quantitate clustering tendencies for the stratified georeferenced centroids for equine deaths in low socioeconomic geolocations(Moran's I=0.0287; *P* = 0.1542) compared to high socioeconomic geographic landscapes in Florida (Moran's I= 0.0151; *P*=0.3385). Equine deaths within property values of low socioeconomic geolocation demonstrated a weak estimated positive spatial autocorrelation, while random/chaotic spatial autocorrelation was observed in high socioeconomic geosampled landscapes. This analysis revealed 1.9 times more clustering tendencies in equine deaths in geoclassified low socioeconomic centroids based on property value contrast to those in higher-valued geographic strata.

Figure 1.



Autocorrelation Statistics					
Strata	**Coefficient**	**Observed**	**Std Dev**	**Z Score**	**Pr> |Z|**
HSES	Moran's I	0.0151	0.0133	0.957	0.3385
LSES	Moran's I	0.0287	0.0251	1.42	0.1542



Note: This additional map was created to illustrate the financial disparities among cases and visually display which areas would benefit most from a public health initiative such as a discounted or free equine vaccine intervention.

Discussion

Mosquito prevalence and socioeconomic status have been linked in terms of human disease, as in the case of malaria's association with a region's macroeconomics (Somi et al., 2007). Dowling et. al (2013) found a link between socioeconomic status and presence of mosquito larval habitats. Although many studies have linked socioeconomic status and human health, this area of research is lacking regarding domestic animal health, particularly when it comes to arboviruses. Besides access to vaccines and other veterinary services, additional SES factors that could influence risk factors include habitat insecticide spraying and other public health vector control methods that might have more resources allocated in areas of high SES, as well as an individual horse owner's ability to provide insect repellant and stabling methods that reduce mosquito access. Other potential risk factors include a horse owner's perceived risk of EEE in their geographic area, as well as the owner's education regarding equine disease risk and vaccinations.

Because EEEV risk factors include the size of local equine populations, and exposure to certain species of mosquitoes, geographic distributions of these groups ultimately will impact upon the geographic distribution of unvaccinated equines and their associated deaths. The distribution tends to be clustered at the county-level with this effect perhaps being controlled by standardization of case counts. Furthermore, the usage of EEEV control programs (i.e. georeferenced equine vaccination data) tends to have socioeconomic/demographic dimensions with spatial expressions. All of these factors impact contagion diffusion, inducing positive spatial autocorrelation. Meanwhile, factors such as property values result in leaps across geographic space (i.e., hierarchical diffusion), which may initially introduce a negative spatial autocorrelation dimension into the geographic distribution of EEEV (i.e., an unvaccinated equine's death location being surrounded by neighboring locations with no cases). As these diffusion paths become reinforced through cyclical repetition over time, accompanied by repeated annual waves of local contagion diffusion, a more uniform geographic distribution of EEEV reservoirs may materialize, causing the negative spatial autocorrelation dimension to fade away. In the end, equine cases should be characterized by positive spatial autocorrelation reflecting annual economic cartographic patterns. Public health programs should also attempt to quantitate the size of mosquito populations at the county level.

Study Limitations

Since there is no standardized definition of property values that indicate socioeconomic status, these defined variables are highly subjective. The study also presumes that the value of the land that the infected horse was located on is indicative of its owner's socioeconomic status.

Conclusion

Eastern equine encephalitis is a serious viral illness in horses with both public health and financial implications. This study suggests there is a correlation between socioeconomic status and incidence of eastern equine encephalitis in domestic horses. This study suggests that horse owners in lower-SES regions are less likely to vaccinate, thus causing higher incidence rates of EEE among their horses. Future studies should include variables such as proximity to affordable veterinary services, as well as the owners' perceived threat of illness in their horses. Additional statistical analyses should be conducted as well, including a Bayesian analysis. Addressing these questions can allow for a well-informed and effective intervention to address this severe yet preventable illness among Florida equines.

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