Visualizing the Spread of West Nile Virus

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Introduction

In 1999, West Nile (WN) fever, a mosquito-transmitted viral infectious disease, was identified for the first time in the Western Hemisphere in New York City (NYC). This was an unprecedented event, as West Nile Virus (WNV) had been considered endemic to the Middle East, Africa, and Asia. The first human cases of this outbreak were identified on August 2, 1999, with additional cases reported until September 22, 1999. Investigators retrospectively identified 61 human cases, 55 of which were hospitalized with infection involving brain tissue ("meningo-encephalitis"), resulting in 7 deaths. Further investigation revealed that a WN epidemic in birds had preceded the human phase of the epidemic by nearly a month. Moreover, the virus was found to be capable of over-wintering in local mosquitoes and thus had gained permanent

Figure 1: Recent publications on WNV in magazines (Smithsonian, July 2003, p 88 – 102 & Time, July 7, 2003, p 84 – 85), newspapers (USA Today, Online, July 15, 2003), and by health agencies (Centers for Disease Control and Prevention, Arizona Department of Health Services & Idaho Department of Health and Welfare).

ecological establishment. This and further events caught the attention of the media, as shown in Figure 1.

The transmission cycle of WNV is complicated. An amplification cycle is the initial event where bird-preferential mosquito vectors (e.g., *Culex* species) transmit the virus within local avian populations. Once the amplification cycle has started, bridging mosquito vectors (e.g., *Aedes albopictus*) feed on infected birds and then bite animals and humans, and so infect them. In humans, the vast majority of West Nile cases present as a mild viral illness. In some patients older than 55 years of age, the virus has a higher tendency to infect the brain tissue, with associated higher death rates. Presently, there is no cure and no vaccine. Preventive measures include spraying for mosquitoes and wearing long sleeved shirts and applying insect repellent.

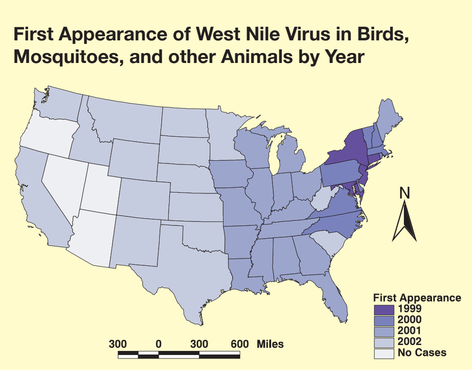

Figure 2a: Spread of WNV in birds, mosquitoes, and other animals since 1999. The initial North – South spread along the East Coast can be explained by migratory pathways of birds. One possible explanation for the quick spread of WNV from the East to the West can be the incidental transportation of infected mosquitoes via airplanes.

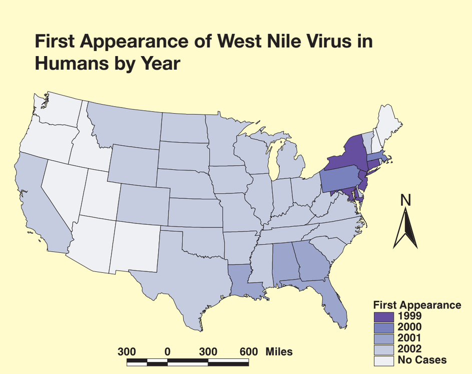

Figure 2b: Spread of WNV in humans since 1999. The first appearance of WNV in humans in a state usually lags the appearance of WNV in birds, mosquitoes, and other animals by a few months up to 1 or 2 years. By the end of 2002, only 11 States had no human WN cases.

The purpose of this poster is two-fold: the first is to demonstrate the appropriateness of statistical visualization techniques to identify WNV spatially; the second is the application of similar statistical techniques to investigate the 2002 outbreak of WNV in the District of Columbia in a spatial and temporal context.

US Analysis

In 2002, 4,156 human cases of WN fever were identified in the US, with 284 deaths. This was the largest insect-vectored meningo-encephalitis epidemic in the known history of the Western Hemisphere and the largest WNV-related meningo-encephalitis epidemic worldwide recorded to-date. Ecological damage has been an unforeseen consequence, with over 140 species of birds, reptiles, and mammals infected and killed by WNV in the US, and over 36 species of mosquitoes are known to be able to transmit the virus. Over 14,000 horses were killed due to WNV since the epidemic began in 1999. West Nile virus has also posed a major threat to endangered species and zoological park animals, with over 100 US zoos reporting cases. The spread of WNV is exemplified by the choropleth maps of the US as shown in Figures 2a and 2b.

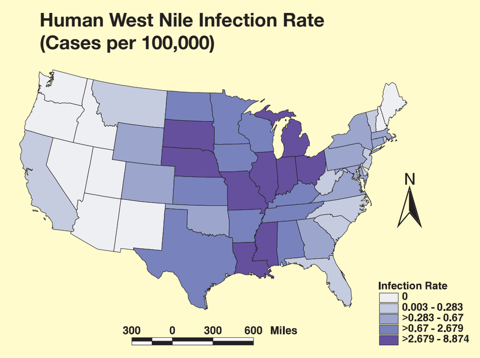

Figure 3a: Human WN infection rates by state, based on data sources from CDC and the U.S. Census Bureau data. Highest rates were observed in the central states. Due to the lack of available data, the rates on this map are not age adjusted.

Figure 3a, a similar representation as Figures 2a and 2b, showing infection rate by state, demonstrates the limitation of choropleth representations. Reference to Figure 3b, however, micromap representation of the same data illustrates the different infection rates somewhat differently, in particular indicating ranking. Of note, in Figure 3b is the high national profile of DC in respect to infection rate.

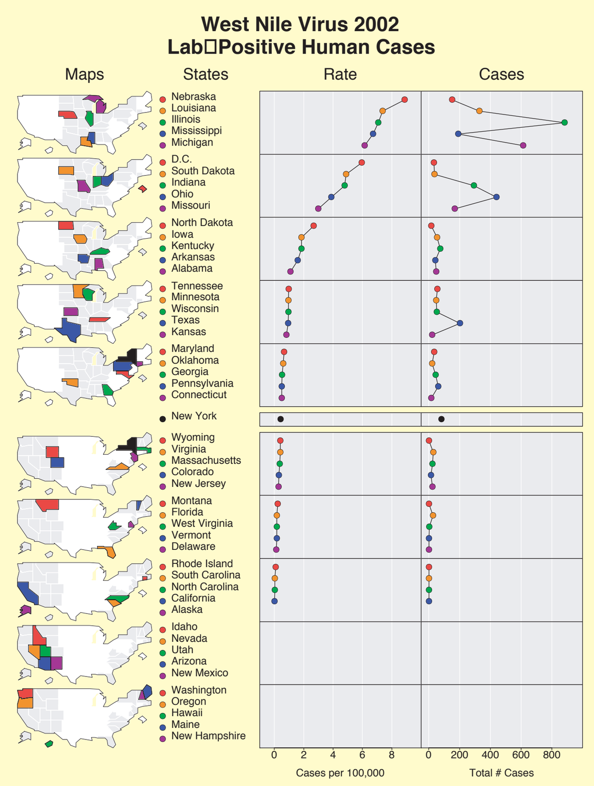

Figure 3b: Linked micromap plots showing the same WN infection rates (as Figure 3a) and total number of human WN cases for states. The micromap plots highlight spatial structures (highest WN rates in the central states, lowest WN rates along the East Coast), spatial outliers (notable DC), and regions commonly overlooked when referencing a choropleth representation as in Figure 3a - i.e., Nebraska with only 152 cases, but highest WN rate. No WN cases have been observed in 2002 in the eleven states listed at the bottom. New York has the median WN rate.

DC Analysis

The first evidence of WNV in the District of Columbia was documented in 2000 with the discovery of 5 WNV positive birds; this number increased to 360 in 2001 with the discovery of 3 positive pools of vector mosquitoes and no animal or human cases. In 2002, the first positive bird was identified on May 2nd, first positive mosquito vectors were found in July, and the first human case was infected in late July. Full ecological establishment of WNV in the District of Columbia occurred in 2002.

For future reference, Figure 4 is a representative map of the Washington, DC area highlighting the eight wards that comprise the administrative units. In addition, both woodland and water bodies are identified for reference, along with the cooperative weather stations (COOP). Data from the COOP stations are part of our enviro-climatic analysis for the DC area.

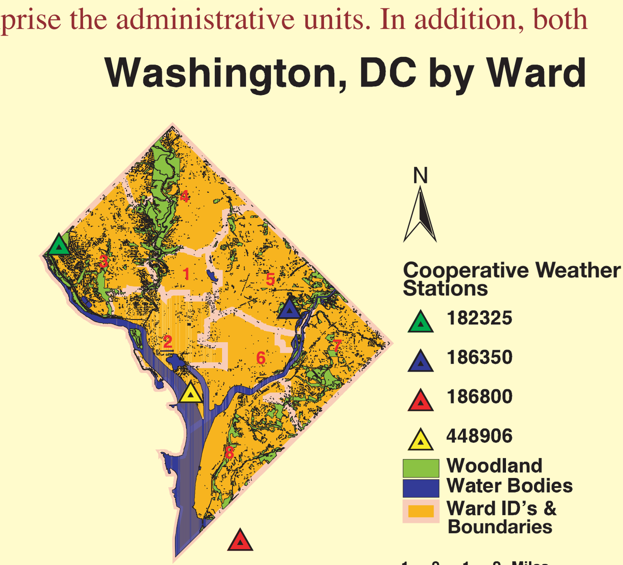

Figure 4: Washington, DC, map, highlighting administrative units (wards), woodland areas and water bodies, and COOP weather stations.

An analysis for DC similar to that for the US is portrayed in Figures 5a and 5b. Figure 5a is quite striking in that it shows that Ward 3 is associated with a ten-fold elevation in WNV-infected birds as compared to the next highest ward. Figure 5b, the number of WNV cases in humans, mirrors the statistics for Ward 3 in that the highest number of human cases occurs in this ward. A further analysis of DC is given by a geographic time series representation of the weekly mosquito WNV-positive rates (Figure 5c). Note that Ward 3 again stands out as an area of high level of infection. This provides the same information as a choropleth map, however this visualization provides the added benefit of noting the timing of mosquito positive rates that reached a critical value.

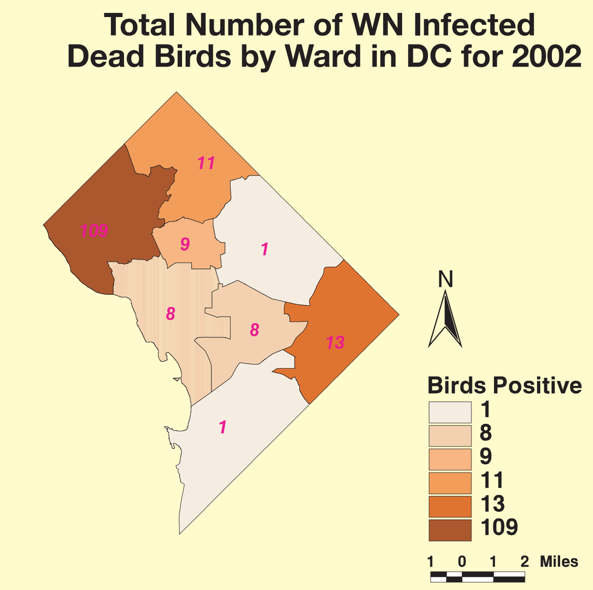

Figure 5a: Total number of WN infected dead birds in DC in the summer of 2002. The highest number was found in Ward 2. The map is based on a convenience sample based on people reporting dead birds. Moreover, only about 75% of reported dead birds could be tested for WNV.

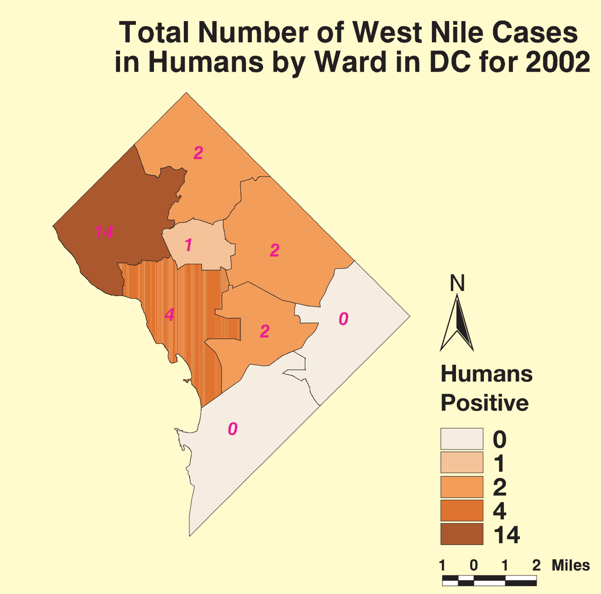

Figure 5b: Total number of WN infections in humans in DC in the summer of 2002. Similar to the bird WN infections in Figure 5a, the highest number was found in Ward 3. The total number of human cases reported on this map is less than the numbers for DC in Figures 3a and 3b. Some of the human cases initially reported eventually turned out to be WN negative.

Figures 5a and b could be shown in a similar manner, and they would show progression of the disease as would be expected (i.e., birds, then mosquitoes, then humans).

A further analysis of the enviro-climatic set is given in Figure 6, panels a to c. The spring seasonal transition in the DC area was noted based on air temperature and remotely sensed Normalized Difference Vegetation Index (NDVI) data: NDVI being an indicator of vegetation cover over the ground. The minor rainy season (panel b) in DC from March to June likely contributed to hydration and subsequent hatching of mosquito eggs. Of note was the observation of a temperature and NDVI peak over July and August. This is an important observation because the ability of a mosquito to transmit WNV is maximized with increases in temperature, specifically 26 to 30 degrees Centigrade. Such high temperatures occurred within the time frame of infection as observed in the bird, mosquito, and human analyses provided earlier. We believe the discovery of positive mosquitoes followed by positive human cases in July, August, and September is directly related to this temperature increase and raises important implications for future mosquito control efforts in DC. The NDVI analysis is supportive in the sense that it is driven by the climate (particularly temperature); whereas temperature is a point measurement of which there are a few stations in the DC area (ref: Figure 4). NDVI is a spatially distributed variable that reflects the spatial complexity of the temperature data more fully.

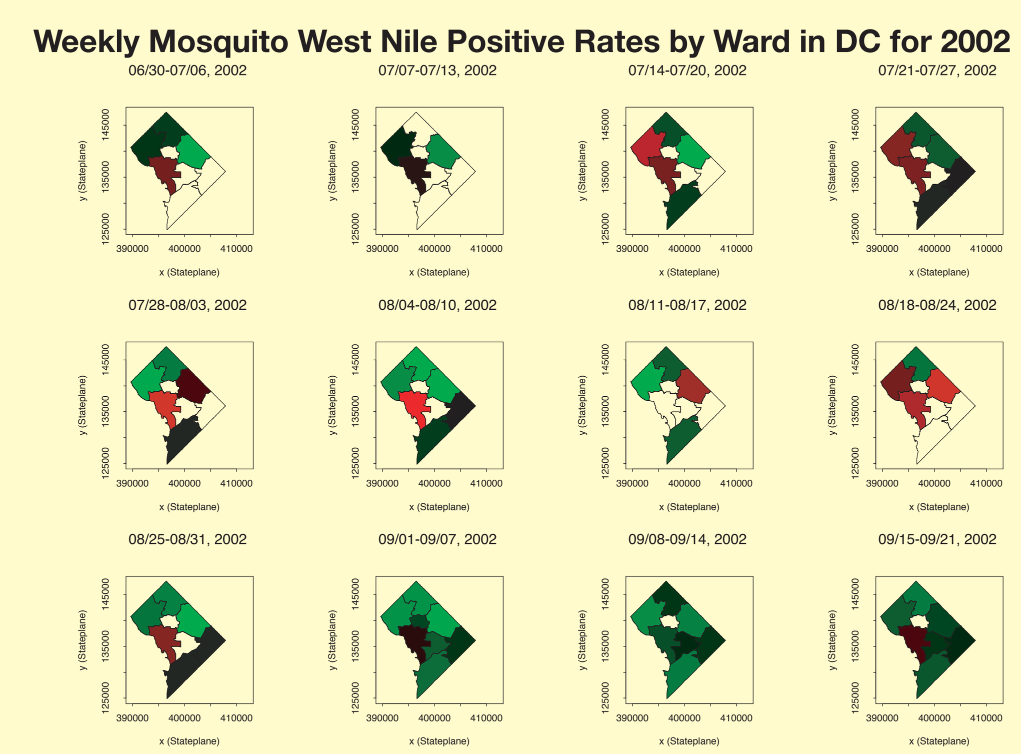

Figure 5c: Geographic time-series of the spread of WN in mosquitoes in the summer of 2002. Red is used to display regions where sampled pools of mosquitoes tested positive. The brighter red, the higher the percentage of positive sampled pools. The brightest red is used, for example, in week 8/4 – 8/10 for Ward 2 where 42% of the sampled pools (11 out of 26) tested positive. Green is used to display regions where all sampled pools of mosquitoes tested negative. The brighter green, the higher the number of negative samples. The brightest green is used in week 8/4 – 8/10 for Ward 4 where all 33 sampled pools tested negative.

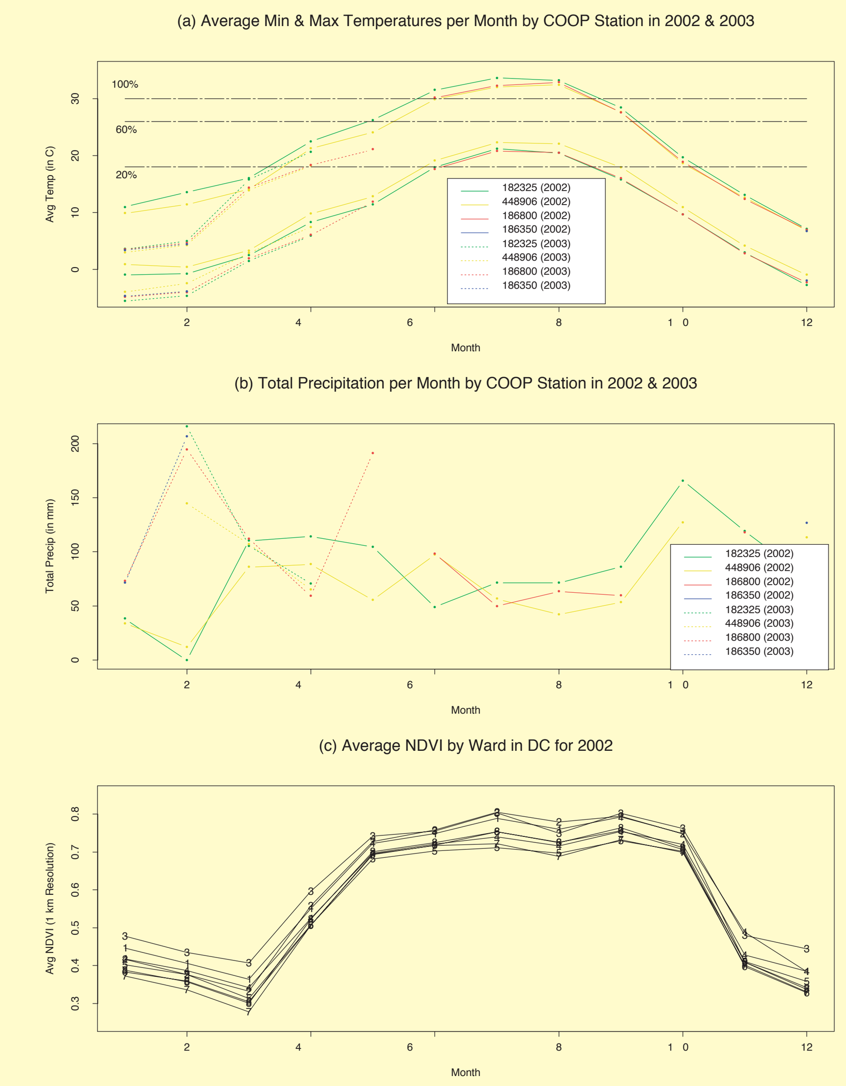

Figure 6: (a) Average min / max temperatures per month, revealing a continuous increase of temperatures from January through July/August. The 2003 min / max temperatures are consistently lower than the 2002 temperatures for the same time period (until May 2003). No further 2003 data is available yet. The dotted percentage lines indicate transmission competency of *Culex pipiens* for WNV based on laboratory data provided by Michael Turell, US Army Medical Research Institute for Infectious Disease. A higher percentage indicates a higher efficiency of the mosquito to transmit the virus.
(b) Total precipitation per month for the entire year of 2002 and part of 2003. There is consistent precipitation each month while the monthly precipitation data for 2003 is markedly higher as far as the record goes.
(c) Average Normalized Difference Vegetation Index (NDVI) by ward for 2002. The average is computed from the second 10 month composite of SPOT reflectance data. The data is consistent with seasonal green-up and green-down and shows that for certain wards (e.g., Ward 3) the green-up is more elevated, hence the possible establishment of more expansive mosquito breeding habitats.

Conclusion

It has been shown that WNV, a spatially and temporally complex phenomenon, can be described well and summarized using statistical visualization techniques. Here we have shown various representations of the data that have provided insight into the spread and ecological establishment of WNV. Similar techniques could be similarly useful in the study of other vectorborne pathogens.

Acknowledgements

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