Limited Spillover to Humans from West Nile Virus Viremic Birds in Atlanta, Georgia

Rebecca S. Levine, Daniel G. Mead, and Uriel D. Kitron

Abstract

West Nile Virus (WNV) is a mosquito-borne pathogen that impacts the health of its passerine bird hosts as well as incidentally infected humans in the United States. Intensive enzootic activity among the hosts and vectors does not always lead to human outbreaks, as is the situation throughout much of the southeastern United States. In Georgia, substantial yearly evidence of WNV in the mosquito vectors and avian hosts since 2001 has only led to 324 human cases. Although virus has been consistently isolated from mosquitoes trapped in Atlanta, GA, little is known about viral activity among the passerine hosts. A possible reason for the suppression of WNV spillover to humans is that viremic birds are absent from high human-use areas of the city. To test this hypothesis, multisession, multihabitat, longitudinal WNV surveillance for active WNV viremia was conducted within the avian host community of urban Atlanta by collection of blood samples from wild passerine birds in five urban microhabitats. WNV was isolated from the serum of six blood samples collected from 630 (0.95%) wild passerine birds in Atlanta during 2010–2012, a proportion similar to that found in the Chicago, IL, area in 2005, when over 200 human cases were reported. Most of the viremic birds were Northern Cardinals, suggesting they may be of particular importance to the WNV transmission cycle in Georgia. Results indicated active WNV transmission in all microhabitats of urban Atlanta, except in the old-growth forest patches. The number of viremic birds was highest in Zoo Atlanta, where 3.5% of samples were viremic. Although not significant, these observations may suggest a possible transmission reduction effect of urban old-growth forests and a potential role in WNV amplification for Zoo Atlanta. Overall, spillover to humans remains a rare occurrence in urban Atlanta settings despite active WNV transmission in the avian population.

Key Words: West Nile Virus—Viremia—Spillover—Northern Cardinal—Urban—Zoo—Atlanta, Georgia.

Introduction

Emerging infectious zoonotic diseases can quickly devastate naïve wildlife populations and result in public health emergencies. Over the past decades, new diseases have emerged and become concentrated in areas undergoing rapid anthropogenic change, such as urban settings, deforested regions, and areas undergoing intensive farming. When these novel pathogens are successfully introduced into such disturbed settings, they can become established and spread rapidly due to the high density and diversity of both susceptible hosts and disease vectors. Urban settings, in particular, comprise a plethora of disturbed ecosystems and a diversity of wildlife, and the introduction of emerging infectious diseases provides abundant opportunities for pathogen amplification and rapid spread of disease, with major impacts on both human and wildlife health.

Since its introduction to the continental United States in 1999, West Nile virus (WNV) has become enzootic and endemic, spreading from coast to coast in just 4 years (Hayes et al. 2005). Over 36,000 people have been infected (with >1500 fatal cases) (Centers for Disease Control and Prevention 2013), and certain US bird species (crows, blue jays) have been strongly affected (Centers for Disease Control and Prevention 2002). In the eastern United States, WNV transmission between vectors (Culex mosquitoes) and hosts (passerine birds) occurs mostly during late summer in urban settings (Centers for Disease Control and Prevention 2013). Human cases of WNV are the result of spillover from this epizootic cycle, where spillover is defined as occurring when a
pathogen is transmitted from an animal to a human, which results in an infection in the human without causing any substantial further human-to-human transmission (Fenton and Pedersen 2005, Lloyd-Smith et al. 2009). Human cases do not necessarily follow intensive enzootic activity, as is the situation in the state of Georgia (and much of the southeastern United States) where WNV is well-documented in the mosquito vectors and avian reservoir hosts (Gibbs et al. 2006a, Vazquez Prokopec et al. 2010), but where a total of only 324 human cases have been reported since 2001 (Centers for Disease Control and Prevention 2013).

In Atlanta, Georgia’s major urban center, yearly routine mosquito surveillance has consistently demonstrated active WNV infection in *Culex* mosquitoes. In addition, both passive dead bird surveillance as well as active live bird surveillance also indicated consistent yearly WNV infection among avian hosts in Atlanta, although budget cuts and other factors have forced suspension of all avian surveillance since 2007 (Allison et al. 2004, Gibbs et al. 2006a, Bradley et al. 2008, Vazquez Prokopec et al. 2010). Consequently, little is known about the prevalence and transmissibility of WNV in avian hosts in Atlanta, particularly in the 6 years since 2007, during which the contributing factors causing yearly recurring WNV outbreaks of widely varying severities have been poorly understood (Centers for Disease Control and Prevention 2013). A possible reason for the suppression of WNV spillover to humans is that viremic birds are absent from high human use areas of the city, resulting in a low probability of exposure to mosquitoes and subsequently to humans (Fenton and Pedersen 2005, Lloyd-Smith et al. 2009). To test this hypothesis, we conducted multiseason, multihabitat, longitudinal WNV surveillance for active WNV viremia within the avian host community of urban Atlanta.

**Materials and Methods**

Between early May and early November of 2010–2012, we collected blood samples from wild passerine birds in five urban microhabitats of Atlanta, GA—mixed-use parks, divided into wooded and water sections; residential areas; old-growth forests; and Zoo Atlanta (Fig. 1). The park and residential sites were treated as matched blocks, with residential sampling conducted in the neighborhoods directly east of the parks in areas similar in size to the parks. Parks were divided

**FIG. 1.** Map of study sites in urban Atlanta, GA, 2010–2012. Grant and Piedmont Parks each included two sampling zones, for a total of nine study sites: (1) a water feature and surrounding built structures; (2) a wooded area and associated walking paths.
into two zones. Park–Water contained an artificial water feature (pond or lake) surrounded by public restrooms and other built facilities (public swimming pool, tennis courts, gazebos, or large parking lots); Park–Woods comprised a wooded area with paved walking paths that experienced far less human use.

During 2010, each habitat type was represented by a single replicate and was sampled in the same order once every 3 weeks between 06:00 and noon, with the residential and park sites represented by the Grant Park (Atlanta’s oldest and fourth-largest urban park) area. Samples were collected from 10 properties in the residential zone. This area was selected based on its previous determination as a WNV hotspot and the residents’ familiarity with previous WNV surveillance studies (unpublished data). In 2011, we added a replicate for each habitat type, with the additional residential and park sites represented by the Piedmont Park (Atlanta’s third-largest urban park) area. Samples were collected from 11 properties and one community garden in the residential zone. Sampling in the Grant Park area was repeated in 2011, with eight properties sampled in the residential zone. With the addition of site replicates in 2011, we reduced the frequency of sampling in each site to once every 4.5 weeks in the same order. In 2012, only a single site (the water zone of Grant Park) was sampled (once every 3 weeks).

Birds were captured using nylon mesh mist nets. After extraction, birds were identified to species, measured, aged, sexed, banded, sampled (by jugular venipuncture), and released (Emory University’s Institutional Animal Care and Use Committee permit 2001632, Georgia Department of Natural Resources Scientific Collecting Permit 29-WBH-12-1, and Federal Bird Banding Permit 23673). Following collection, blood samples were transported on ice to the laboratory, where they were centrifugated at 10,000 rpm for 10 min for serum collection. After centrifugation, serum was removed and frozen at −80°C until further processing.

Serum samples were screened for circulating virus by inoculating 10 µL of serum into 2 mL cultures of 2-day-old Vero Middle America Research Unit (MARU) cells. Cultures were examined daily for 14 days for evidence of cytopathic effects (CPE). If CPE were noted, cells were tested for WNV inactivated fetal bovine serum, 200 units/mL penicillin, 200 µg/mL streptomycin, and 500 ng/mL amphotericin B). Cultures were inactivated on day 6 postadsorption by adding 2 mL of 5% buffered formalin along with 0.25% crystal violet for plaque visualization. After 24 h, plates were rinsed with water and examined for plaques. Dilutions in which 20–100 plaques were distinguishable were used to determine WNV titers (log_{10} plaque-forming units [pfu]/mL) (Allison et al. 2004).

Statistical analyses comparing differences in proportions for resulting confirmed viremia frequency data were calculated using Pearson chi-squared tests conducted in JMP Pro, Version 10 software (SAS Institute 1989–2013).

## Results

During the 3-year study period, 630 unique birds, representing 41 species, were sampled (Table 1). Active WNV infection was detected in 6 of 630 birds (0.95%), from which virus was isolated (Table 2), a proportion within the range found in the Chicago area in 2005 (1.1%) and 2006 (0.3%).

<table>
<thead>
<tr>
<th>Species common name</th>
<th>Species name</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Cardinal</td>
<td>Cardinalis cardinalis</td>
<td>156</td>
</tr>
<tr>
<td>American Robin</td>
<td>Turdus migratorius</td>
<td>131</td>
</tr>
<tr>
<td>Carolina Wren</td>
<td>Thryothorus ludovicianus</td>
<td>47</td>
</tr>
<tr>
<td>Northern Mockingbird</td>
<td>Mimus polyglottos</td>
<td>44</td>
</tr>
<tr>
<td>Brown Thrasher</td>
<td>Toxostoma rufum</td>
<td>41</td>
</tr>
<tr>
<td>Gray Catbird</td>
<td>Dumetella carolinensis</td>
<td>37</td>
</tr>
<tr>
<td>European Starling</td>
<td>Sturnus vulgaris</td>
<td>26</td>
</tr>
<tr>
<td>Swainson’s Thrush</td>
<td>Catharus ustulatus</td>
<td>17</td>
</tr>
<tr>
<td>Common Grackle</td>
<td>Quiscalus quiscalis</td>
<td>16</td>
</tr>
<tr>
<td>Blue Jay</td>
<td>Cyanocitta cristata</td>
<td>14</td>
</tr>
<tr>
<td>Eastern Towhee</td>
<td>Pipilo erythropthalmus</td>
<td>14</td>
</tr>
<tr>
<td>Tufted Titmouse</td>
<td>Baeolophus bicolor</td>
<td>11</td>
</tr>
<tr>
<td>Wood Thrush</td>
<td>Hylcocilla mustelina</td>
<td>11</td>
</tr>
<tr>
<td>Song Sparrow</td>
<td>Melospiza melodia</td>
<td>9</td>
</tr>
<tr>
<td>Eastern Bluebird</td>
<td>Sialia sialis</td>
<td>6</td>
</tr>
<tr>
<td>Gray-Cheeked Thrush</td>
<td>Catharus minimus</td>
<td>5</td>
</tr>
<tr>
<td>Hooded Warbler</td>
<td>Setophaga citrina</td>
<td>5</td>
</tr>
<tr>
<td>White-Breasted Nuthatch</td>
<td>Sitta carolinensis</td>
<td>5</td>
</tr>
<tr>
<td>Brown-Headed Cowbird</td>
<td>Molothras ater</td>
<td>3</td>
</tr>
<tr>
<td>Eastern Phoebe</td>
<td>Sayornis phoebe</td>
<td>3</td>
</tr>
<tr>
<td>Great-Crested Flycather</td>
<td>Myiarchus crinitus</td>
<td>3</td>
</tr>
<tr>
<td>House Finch</td>
<td>Haemorhous mexicanus</td>
<td>3</td>
</tr>
<tr>
<td>Ovenbird</td>
<td>Seiurus aurocapilla</td>
<td>2</td>
</tr>
<tr>
<td>Red-Bellied Woodpecker</td>
<td>Melanoperes carolinus</td>
<td>2</td>
</tr>
<tr>
<td>White-Throated Sparrow</td>
<td>Zonotrichia albicollis</td>
<td>2</td>
</tr>
<tr>
<td>Yellow-Shafted Flicker</td>
<td>Colaptes auratus</td>
<td>2</td>
</tr>
<tr>
<td>Black-and-White Warbler</td>
<td>Mniotilta varia</td>
<td>1</td>
</tr>
<tr>
<td>Chestnut-Sided Warbler</td>
<td>Setophaga pensylvanica</td>
<td>1</td>
</tr>
<tr>
<td>Downy Woodpecker</td>
<td>Picoides pubescens</td>
<td>1</td>
</tr>
<tr>
<td>House Sparrow</td>
<td>Passer domesticus</td>
<td>1</td>
</tr>
<tr>
<td>House Wren</td>
<td>Troglodytes aedon</td>
<td>1</td>
</tr>
<tr>
<td>Indigo Bunting</td>
<td>Passerina cyanea</td>
<td>1</td>
</tr>
<tr>
<td>Kentucky Warbler</td>
<td>Geothlypis formosa</td>
<td>1</td>
</tr>
<tr>
<td>Magnolia Warbler</td>
<td>Setophaga magnolia</td>
<td>1</td>
</tr>
<tr>
<td>Mourning Dove</td>
<td>Zenaida macroura</td>
<td>1</td>
</tr>
<tr>
<td>Northern Waterthrush</td>
<td>Pterosticus ludoviciana</td>
<td>1</td>
</tr>
<tr>
<td>Rose-Breasted Grosbeak</td>
<td>Phaeucticus olivaceus</td>
<td>1</td>
</tr>
<tr>
<td>Red-Eyed Vireo</td>
<td>Vireo olivaceus</td>
<td>1</td>
</tr>
<tr>
<td>Red-Winged Blackbird</td>
<td>Agelaius phoeniceus</td>
<td>1</td>
</tr>
<tr>
<td>Veery</td>
<td>Catharus fuscescens</td>
<td>1</td>
</tr>
<tr>
<td>Yellow-Bellied Sapsucker</td>
<td>Sphyrapicus varius</td>
<td>1</td>
</tr>
</tbody>
</table>

Total 630
when over 200 human cases were reported annually. Four of
the six viruses were isolated from 156 samples (2.56%) taken
from Northern Cardinals, significantly more than in the 474
samples taken from other bird species ($\chi^2=5.7$, $p<0.05$). One
of 131 (0.76%) American Robins and 1 of 47 (2.13%) Carolina
Wrens were also viremic. Although only 25.7% (162/630) of
samples were taken from hatch-year birds, all but one of the
six WNV isolates were obtained from hatch-year birds, which
were viremic significantly more often than the 421 older birds
(age could not be determined for 47 birds) from which only
one isolate was obtained ($\chi^2=9.3$, $p<0.01$).

The old-growth forest sites were the only habitat from
which no virus was isolated (out of 97 samples). Two isolates
were obtained from 58 Zoo Atlanta samples (3.45%) and two
from 122 park-woods samples (1.64%). One isolate was ob-
tained from 126 residential area samples (0.79%) and one from
227 park-water samples (0.44%). No significant differences
between microhabitat type and viremia were detected ($\chi^2=6.0$, $p>0.1$). Four of the six isolates were from 2011 (0.95% of
418), two from 2010 (1.42% of 141), and none from 71
samples in 2012, with no significant difference in proportion of
viremic birds over the 3 study years ($\chi^2=1.0$, $p>0.5$).
Significantly more (4/6) viruses were isolated from the 72 samples
taken in August, compared to the 558 samples collected in other
months ($\chi^2=18.3$, $p<0.0001$). Detectable viremia levels ranged
from $10^{3.69}$ to $10^{4.69}$ pfu/mL (mean $=10^{4.11}$ pfu/mL).

**Discussion**

This is the first report of WNV isolates from live passerines
in the state of Georgia, and demonstrates active WNV trans-
mision in Atlanta, with detectable viremia observed in approx-
imately 1% (6) of the 630 birds we captured. These viremia levels
from passerines in Atlanta were similar to those from Chicago,
but the Chicago area reported more than eight times as many human cases (a difference that cannot be ac-
counted for by human population size differences alone)
(Hamer et al. 2008). Thus, despite transmission in the avian
population, spillover to humans is a much rarer occurrence in
urban Atlanta settings. Our results further confirm that WNV
transmission peaks during August, and that hatch-year birds
are important amplifying hosts for WNV (Hamer et al. 2008).

Several studies indicate the significance of American Ro-
bins as superspreader hosts of WNV (Kilpatrick et al. 2006,
Hamer et al. 2009, Simpson and Hurtado 2011), but our results
suggest that important regional differences in host impor-
tance may exist. Coupled with findings from two studies of
WNV antibody prevalence among songbirds in Georgia
showing Northern Cardinals having by far the highest ser-
oprevalence (Gibbs et al. 2006, Bradley et al. 2008), our study
indicates that Northern Cardinals play an important role in
WNV transmission in Georgia. While we isolated virus from
only a single American Robin (whose titer was too low for
detection by plaque assay), most of the isolates (and a pro-
portion significantly higher than any other avian species)
were from Northern Cardinals, which have been shown to be
moderately competent as reservoir hosts (Kilpatrick et al.
2007). The four cardinals (2.6% of all of our Northern Cardinal
samples) that were viremic had a mean viremia of $10^{3.66}$ pfu/
ML, above the recently proposed $10^{3.4}$ pfu/mL minimum titer
for WNV transmission to feeding mosquitoes (Komar et al.
2003, Wheeler et al. 2012). It is also highly likely that titers
obtained as part of this study are lower than at the time of
sampling, due to three to four previous freeze–thaw cycles
resulting from separate diagnostic testing of samples. Taken
together, our results indicate that even moderately competent
hosts such as Northern Cardinals may be important for the
WNV transmission cycle in Georgia, and we conclude that
regional variations in host contribution, with particular at-
tention to Northern Cardinals, should be considered.

Finally, our results indicate active WNV transmission in all
microhabitats of urban Atlanta, with the exception of the old-
growth forest patches. Although no significant associations
between viremia and microhabitat type were detected with
the small sample size, the number of viremic birds was
highest in Zoo Atlanta, where 3.5% of samples were viremic, a
trend that may suggest a potential role in WNV amplification
for the Zoo. Zoos represent exclusive settings in which unique
combinations of carefully maintained habitats exist together,
which include the comingling of exotic and native species,
captive and free-roaming wildlife, public and private spaces,
anthropogenically changed and natural environments, and
insular and connected ecosystems.

Such close proximity of “ecotones” with contrasting re-
ources results in favorable habitats for arthropods while also
facilitating their movement between habitats and enhancing
their exposure to pathogens; consequently, urban zoos are
habitats that may be particularly prone to arthropod-borne
diseases. In addition to facilitating transmission through their
mixed characteristics, many zoos are built on historical hot-
spots of human arthropod-borne diseases and are located in
or near human population centers and transportation nodes
(Adler et al. 2011, Tuten et al. 2012). Given this potential for
elevated transmission of arthropod-borne diseases such as
WNV in zoos, it is perhaps not surprising that we identified
Zoo Atlanta as the habitat with the greatest proportion of

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### Table 2: West Nile Virus Viremia Titers in Wild Passerines Sampled in Atlanta, GA, 2010–2012

<table>
<thead>
<tr>
<th>Species common name</th>
<th>Species name</th>
<th>Age</th>
<th>Location captured</th>
<th>Sample year</th>
<th>Sample month and day</th>
<th>Virus titer ($\log_{10}$ pfu/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Cardinal</td>
<td><em>Cardinalis cardinalis</em></td>
<td>Hatch-year</td>
<td>Park–Woods</td>
<td>2010</td>
<td>August 13</td>
<td>3.74</td>
</tr>
<tr>
<td>American Robin</td>
<td><em>Turdus migratorius</em></td>
<td>Hatch-year</td>
<td>Park–Woods</td>
<td>2010</td>
<td>September 1</td>
<td>Below detectable levels</td>
</tr>
<tr>
<td>Northern Cardinal</td>
<td><em>Cardinalis cardinalis</em></td>
<td>Hatch-year</td>
<td>Residential</td>
<td>2011</td>
<td>July 28</td>
<td>3.47</td>
</tr>
<tr>
<td>Northern Cardinal</td>
<td><em>Cardinalis cardinalis</em></td>
<td>Hatch-year</td>
<td>Zoo Atlanta</td>
<td>2011</td>
<td>August 3</td>
<td>1.69</td>
</tr>
<tr>
<td>Carolina Wren</td>
<td><em>Thryothorus ludovicianus</em></td>
<td>After Hatch-Year</td>
<td>Zoo Atlanta</td>
<td>2011</td>
<td>August 3</td>
<td>4.69</td>
</tr>
<tr>
<td>Northern Cardinal</td>
<td><em>Cardinalis cardinalis</em></td>
<td>Hatch-year</td>
<td>Park–Water</td>
<td>2011</td>
<td>August 9</td>
<td>3.87</td>
</tr>
</tbody>
</table>

pfu, plaque-forming units.
viremic birds. The Grant Park area, in which Zoo Atlanta is located, may represent a hotspot of WNV transmission in Fulton County, Atlanta, because there is evidence of relatively high infection rates across hosts and vectors there.

In a study examining the spatial distribution of WNV infection in Atlanta among mosquitoes, humans, and corvid birds (based on dead bird reporting), 6.1–12.0 infected mosquitoes per 1000 were detected in this area, along with significant local clustering of WNV infection. In that study, significant positive spatial clustering of both WNV human incidence and WNV corvid death ratio was also found in the same location, along with a human incidence rate that was 6.5 times higher than the average rate for Atlanta as a whole (Vazquez Prokopec et al. 2010). While the data from that study are too coarse to implicate any of our Grant Park microhabitats, including Zoo Atlanta as a WNV transmission source, they do demonstrate a pattern of consistently high levels of infection in both hosts and reservoirs in the area. Therefore, measuring the role of Zoo Atlanta in the transmission of WNV in Atlanta may be a productive avenue for future research.

No viremic birds were found in the old-growth forest sites. This finding may simply result from a lack of sufficient samples from this microhabitat type that would allow us to detect viremia or it may represent a trend suggesting a possible transmission reduction effect of urban old-growth forests. Other studies provide conflicting results regarding the effect of forests on WNV transmission. One study in Georgia found birds in forested habitats showing WNV seroprevalence at levels nearly as high as birds from urban and suburban sites (Gibbs et al. 2006b), whereas another identified a larger proportion of urban tree cover as significant factor in WNV infection spatial clusters (Vazquez Prokopec et al. 2010). A study from South Dakota even identified forests as a factor contributing to a positive association with WNV risk (Chuang et al. 2012). Increased vegetation levels, especially in urban areas, provide optimal habitats for avian hosts of WNV and facilitate contact between bird species that congregate in these areas, thereby aiding in transmission amplification (Messina et al. 2011). On the other hand, several studies have found significantly reduced WNV incidence in humans (Brown et al. 2008, LaBeaud et al. 2008, Bowden et al. 2011, DeGroote and Sugumaran 2012) or prevalence in birds (Bradley et al. 2008, LaDeau et al. 2011) with increasing forest cover. The negative relationship between WNV transmission and forest habitats may be attributed to the effect of urbanization on increasing the prevalence of preferred larval habitats for the WNV vector species, comprising artificial structures (catchment basins and sewer networks) that fill with eutrophied shallow water, which are rare or absent from forests (LaDeau et al. 2008). These conflicting results with regard to the effect of forest cover on WNV transmission may relate to differing spatial resolutions of the various studies, because they range in scale from considering the presence of forested areas from relatively large-scale county resolutions to much coarser-scale regional resolutions. However, the effect of forest cover at any of these spatial scales may not be reflective of the role of old-growth forest patches within the fine-scale urban habitat mosaic. Therefore, whereas our results show an absence of WNV viremic birds from urban old-growth forest habitats of Atlanta, further study is warranted to determine their overall role within the city and whether they may provide a transmission reduction effect.

Conclusions

This study confirms active WNV transmission in urban Atlanta. We identified detectable viremia in avian hosts at a level comparable to that in cities with much higher rates of WNV spillover to humans, thereby indicating that lack of transmission in the host population does not explain the absence of spillover. We suggest that Northern Cardinals may be particularly important to the WNV transmission cycle in Georgia, and future research is needed to assess the extent (if any) to which their role in transmission can explain the lack of widespread WNV spillover to humans in the southeastern region. Finally, our identification of trends in varying avian viremia levels from different urban microhabitat types within Atlanta, coupled with probable differences in the avian species compositions that reside in these heterogeneous habitats (especially when considering the exotic hosts present in Zoo Atlanta), indicate that future studies on the role of specific habitat types within the fine-scale urban mosaic may shed further light on human risk for WNV and are warranted.

Acknowledgments

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Author Disclosure Statement

No competing financial interests exist.

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