Environmental Management of Mosquito-Borne Viruses in Rhode Island

HOWARD S. GINSBERG, PhD; ALAN GETTMAN, PhD; ELISABETH BECKER, MPH; ANANDA S. BANDYOPADHYAY, MBBS, MPH; ROGER A. LEBRUN, PhD

ABSTRACT

West Nile Virus (WNV) and Eastern Equine Encephalitis Virus (EEEV) are both primarily bird viruses, which can be transmitted by several mosquito species. Differences in larval habitats, flight, and biting patterns of the primary vector species result in substantial differences in epidemiology, with WNV more common, primarily occurring in urban areas, and EEEV relatively rare, typically occurring near swamp habitats. The complex transmission ecology of these viruses complicates prediction of disease outbreaks. The Rhode Island Department of Environmental Management (DEM) and Department of Health (DoH) provide prevention assistance to towns and maintain a mosquito surveillance program to identify potential disease risk. Responses to potential outbreaks follow a protocol based on surveillance results, assessment of human risk, and technical consultation.

KEYWORDS: arbovirus, mosquito, West Nile Virus, Eastern Equine Encephalitis Virus

INTRODUCTION

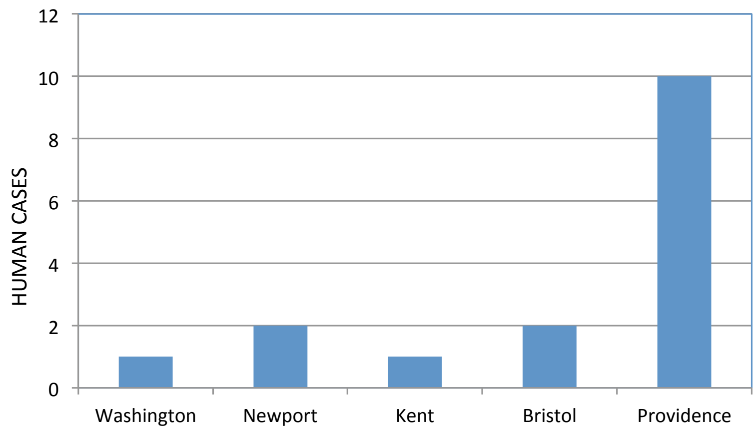
The major mosquito-borne viruses in Rhode Island are West Nile Virus (WNV) and Eastern Equine Encephalitis Virus (EEEV). EEEV rarely infects humans, with an average of fewer than ten cases per year nationwide.[1] However, it often causes permanent neurological deficits or death,[2] so public health agencies typically respond when surveillance reveals the presence of EEEV. WNV is less virulent, with serious symptoms primarily in older patients,[3] but it is far more common, causing one to several thousand cases per year in the United States.[1,3] In this report we describe the transmission dynamics, infection patterns, and the surveillance and management programs for these arboviruses in Rhode Island.

EPIDEMIOLOGY OF ARBOVIRAL DISEASES IN RHODE ISLAND

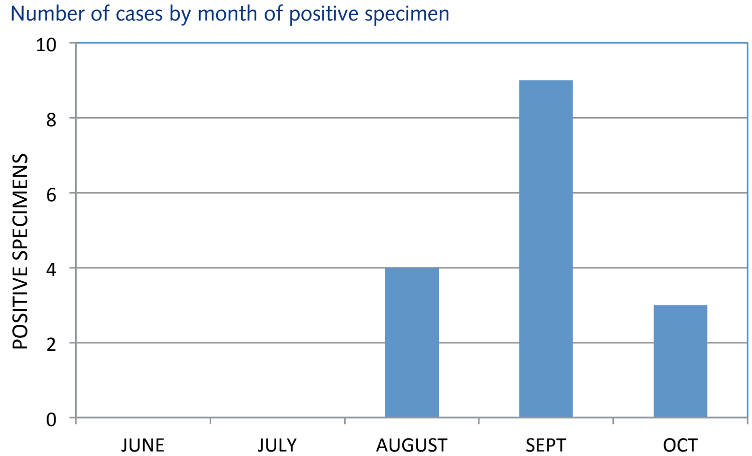
The RI Department of Health reports that in 2000–2012, a total of 16 cases of disease from WNV (Fig. 1) and one case from EEEV were confirmed in Rhode Island. Ten of these patients developed WNV meningitis, five WNV fever (which is not reportable in RI), and one WNV meningo-encephalitis. Nine of the 11 neuroinvasive WNV cases were among patients >50 years of age, reflecting the national pattern of increased neuroinvasive disease from WNV infection in older patients.[4] The majority of WNV cases were reported in Providence, with no discrepancy in disease between men and women. All cases were reported in the late summer/early fall (Fig. 1).

Figure 1. Human illness from West Nile Virus infection, Rhode Island, 2000-2012.

Number of cases by county



Number of cases by month of positive specimen



Natural transmission dynamics of WNV and EEEV

Seasonal patterns of enzootic viral amplification and transmission to humans

WNV and EEEV are both transmitted among birds in enzootic cycles by bird-feeding mosquitoes.[1,5] In both cases, prevalence of infection builds over the season in wild bird populations. For the pathogen to infect humans, a mosquito species with a broad host range needs to acquire the virus by feeding on a bird, then transmit it to a human in a subsequent blood meal, thus acting as a "bridge vector" from the enzootic cycle to humans. This seasonal pattern explains why most transmission to humans occurs in late August and September (Figs. 1B, 2B).

Competence to serve as reservoir hosts varies among bird species.[6,7] Viremia high enough to assure a reasonable probability for a naïve mosquito to pick up the virus is short-lived; typically 2-5 days in most bird species that serve as reservoirs. Therefore, human exposure is difficult to predict, because it requires the coincidental occurrence of large numbers of a bridge vector mosquito species seeking blood meals at just the time and place that a reasonable proportion of birds is viremic. Once a mosquito has fed on a viremic bird, the virus needs to overcome the mosquito's defenses, replicate, and invade the salivary glands before it can be transmitted.[8] This extrinsic incubation period (the time from when the mosquito acquires the virus from an infected bird to when it is infectious to another host) is temperature dependent,[9] lasting roughly ten days during the summer in Rhode Island. The identities of the enzootic and bridge vector species, and their natural histories, help explain the epidemiological trends observed in human cases.

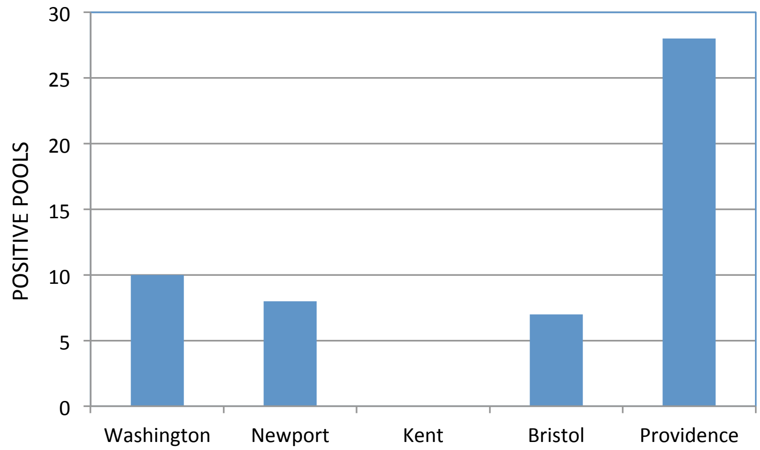
Natural histories of major vector species

Larval mosquitoes live in standing water, where most filter-feed on organic particles in the water column and obtain air from the surface through breathing siphons. Adults feed on nectar, and females feed on vertebrate blood to provide proteins and lipids for egg development. The enzootic vector of EEEV is the bird-feeding mosquito *Culiseta melanura*, a forest-dwelling species that lives in freshwater swamps, where the larvae inhabit water in holes at the bases of trees.[10,11] One reason that human infections are rare is that human populations are generally not concentrated near swamp habitats. Several species can serve as bridge vectors, including *Aedes vexans*, *Ae. sollicitans*, and *Coquillettidia perturbans*.

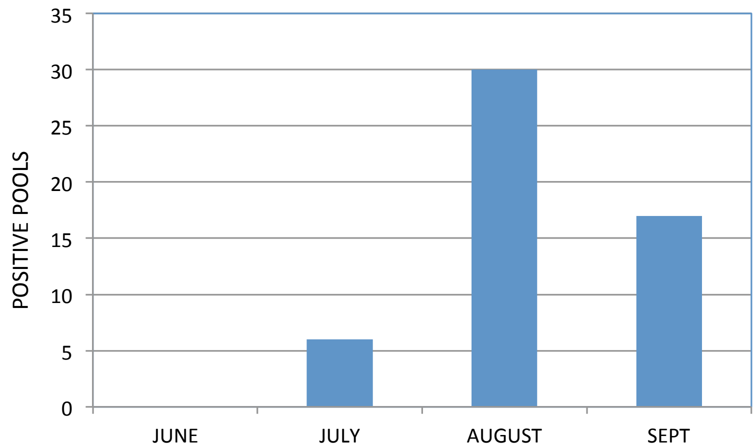
Prediction of disease outbreaks is complicated by the fact that these species respond to different environmental conditions.[12] Cs. *melanura* tends to do well when water levels are high in freshwater swamps. *Cq. perturbans* larvae inhabit freshwater wetlands with emergent vegetation and adults emerge incrementally over the season, typically peaking in late July.[10,11] *Ae. vexans* lays eggs above the water level in hollows and puddles. This species responds to rainfall because the eggs hatch when the water levels rise. *Ae. sollicitans* lays eggs on muddy spots on salt marshes (when not flooded), and emerges in large numbers after high tides (at full moon or new moon) that flood the marshes and inundate the eggs. Larvae go through four instars, pupate, and emerge as adults a week or so after the flooding event. The adults then seek nectar meals, mate, sometimes disperse, and then seek blood meals, so biting activity typically peaks about a week and a half after the eggs are flooded. A rainfall event or flood tide will lead to an emergence of *Ae. vexans* or *Ae. sollicitans* only if mosquito eggs are already present in the flood zone. Even after a flooding event, puddles sometimes dry quickly, precluding adult emergence. As such, it is difficult to predict emergences of these species more than a week ahead of time. An emergence of floodwater mosquitoes can cause an enormous nuisance problem, but these newly emerged females are generally not infected. A few weeks later the numbers of mosquitoes have declined due to dispersal and mortality so the nuisance level is much

Figure 2. Mosquito pools positive for West Nile Virus, Rhode Island, 2000-2012.

Number of positive pools by county



Number of positive pools by month



lower, but these older mosquitoes have taken blood meals and lived through the extrinsic incubation period, so the risk of pathogen transmission is higher.

The first sign that EEEV is present is generally infection in *Cs. melanura*. Since this species feeds on birds, positivity does not necessarily imply a risk to humans, but it does demand increased attention to surveillance. When EEEV appears in bridge vector species a management response is required, ranging from public warnings to mosquito control.

The ecology of WNV transmission differs markedly from EEEV because different species of mosquitoes are involved.[14] The enzootic vector is *Culex pipiens*, which is highly abundant in urban areas, where the larvae live in stagnant water in sewer catch basins, clogged rain gutters, artificial containers, and even sewage treatment facilities.[9] The primary reservoir species are birds that occur in urban areas, such as robins and house sparrows.[15,16,17] Since the enzootic cycle occurs in close proximity to large numbers of humans, any bridge vector that acquires the infection has a reasonably high probability of biting a human and transmitting the virus. Thus WNV causes many more human cases than EEEV, and in the eastern U.S. WNV is concentrated in urban areas. Important bridge vectors appear to be *Cx. salinarius*, a coastal high marsh species, *Ae. vexans*, and the enzootic vector *Cx. pipiens*, which feeds primarily on birds early in the summer, but shifts in late summer to biting mammals.[15] The three most common *Culex* species, *Cx. pipiens*, *Cx. restuans*, and *Cx. salinarius*, are competent WNV vectors in lab studies,[13] so positivity in any *Culex* sample requires increased attention, with the response depending on prevalence of infection and abundance in areas with large human populations.

Surveillance and management of mosquito-borne pathogens

Rhode Island's mosquito surveillance program

The Office of Mosquito Abatement Coordination (MAC) is housed in the DEM's Division of Agriculture. From early June to late September, mosquito traps are set once weekly statewide by MAC seasonal staff. Female mosquitoes from each trap are separated by species and grouped into pools. Each pool is a sample that contains the catch of one species from one trap at one site on one date (typically ≤50 specimens per pool). The risk of transmitting EEEV or WNV to humans varies among mosquito species, so virus isolation from a rare species, or one that exclusively bites birds, will guide a different response than an isolation from a species known to be an important vector to humans.

Pools are delivered to the RI State Health Laboratory in Providence weekly (average of 1,710 pools per year), where they are processed and placed in a cell culture medium that supports the growth of EEEV, WNV, Highlands J and Jamestown Canyon virus. Positive cultures are identified using IFA. Results are reported to the MAC Office as they are revealed during the following week.

Decision-making for mosquito management

Mosquito management is best directed at larvae as they are located in discrete habitats, allowing well-targeted interventions with environmentally benign larvicides. In areas where viral circulation is frequent, reducing larval numbers can lower disease risk by reducing numbers of adults. Management of adults can be directed at mosquitoes with high viral prevalence, but adults disperse widely, and area-wide applications of the broad-spectrum pesticides available to control adults can affect nontarget species, with attendant environmental impacts. Therefore, adult mosquito control is used only when transmission of pathogens to humans is imminent.

The state assists communities to reduce mosquito production in catchment basins by providing 2/3 funding toward the purchase of environmentally benign larvicides formulated for that important urban habitat. The 90-day, slow-release briquettes are placed in catch basins in mid-June by Department of Public Works employees of participating municipalities. The state also engages in saltmarsh water management projects, using specialized low ground pressure equipment to alter the terrain to augment fish predation of mosquito larvae. This approach, known as open marsh water management (OMWM) reduces mosquitoes without insecticides,[18] reduces annoyance from mosquito biting activity in coastal areas, and reduces the need to spray adult mosquitoes for disease prevention.

Mosquito management is guided by a written response protocol (Table 1), which outlines appropriate responses under various levels of disease risk. This document was modeled on Centers for Disease Control and Prevention (CDC) and Association of State and Territorial Health Officials (ASTHO) guidelines and tailored to conditions in Rhode Island. Decisions involve consultation with the Mosquito-Borne Disease Advisory Committee, a group of DEM and DoH officials, URI and federal entomologists, which makes recommendations to the DEM and DoH Directors. General guidelines are used to judge transmission risk (Table 2), but the natural variability in transmission patterns requires that specific conditions must be considered each year in management decisions. Time of season, mosquito density, distribution and species composition, levels of positivity in surveillance samples, along with current and predicted weather conditions all contribute to the assessment of disease risk. Thus, one isolation of EEEV from a bird-biting species in September represents a much lower risk than multiple EEEV isolations from mammal-biting species in August. The former finding would yield a press release noting a low level of risk, while the latter finding would prompt DEM and DoH officials to issue urgent warnings, suggest community actions, and consider implementing emergency mosquito control activities.

Interventions can range from public warnings, "Smart Scheduling" to avoid outdoor events at times of peak mosquito biting activity, intensified surveillance and if warranted, pesticide applications. Rhode Island DEM and DoH issue weekly press releases during the mosquito season that recommend sanitation practices to lower mosquito numbers (especially around the home), and provide information about mosquito activity, viral isolations, risk of transmission to humans, and appropriate precautions to prevent human exposure to arboviruses. The RI Mosquito Abatement Board (MAB), an 11-member board established by state law, regulates the rare use of adulticides by communities. Large-scale adulticide applications can be performed by the state, but such interventions are utilized only in cases of extreme risk of epidemic activity.

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Table 1. Mosquito Borne Disease Management Protocol

- Educate the general public to adopt personal protective behavior and to eliminate mosquito breeding environments at home, as follows:

Prevailing Risk	Actions
Low	• **DOH/DEM** web sites are kept up-to-date throughout the year. • **DOH** offers printed materials to nursing homes, primary medical care practices, and [through primary and secondary schools] to all families of school-age children.
Medium	• **DEM** issues **regular** press releases on activities associated with mosquito surveillance and abatement.
High	• **DEM** issues **special** press releases at times of high risk for the transmission of mosquito-borne illnesses to humans.

- Larvicide storm drains and similar natural environments, as follows:

Prevailing Risk	Actions
Low Medium	• **DEM**, in collaboration with municipalities and with DOT, assures that all storm drains in the state are treated with larvicide in June-September, inclusive.
High	• **DEM** consults with all appropriate entities about larviciding all mosquito-breeding environments that contribute to a high risk of the transmission of mosquito borne illnesses to humans.

- Adulticide geographic areas by ground or aerial spraying, as follows:

Prevailing Risk	Actions
Low	• Adulticiding is not generally recommended for low-risk situations, with some exceptions to abate mosquito nuisances (regulated by **DEM**).
Medium	• DEM convenes the MBD Advisory Group to make routine risk assessments. • The MBD Advisory Group briefs DEM, DOH, and the Governor's Office immediately on the results of all routine risk assessments that include recommendations for use of adulticides to reduce MBD risks. • DEM advises and guides municipalities about the desirability of ground spraying by municipal governments, if and as recommended by the MBD Advisory Group. • DOH assists DEM in crafting and disseminating risk communications for the press and general public.
High	• DEM convenes the MBD Advisory Group to make special risk assessments. • The MBD Advisory Group briefs DEM, DOH, and the Governor's Office immediately on the results of all special risk assessments. • DEM advises and guides municipalities about the desirability of ground spraying by municipal governments, as may be recommended by the MBD Advisory Group. • DEM seeks permission from the Governor's Office for aerial spraying, as may be recommended by the MBD Advisory Group. • DOH assists DEM in crafting and disseminating risk communications for the press and general public.

Table 2. Guidelines to assess risk of arboviral transmission to humans.

Variable	Low Risk Indicators	Medium Risk Indicators	High Risk Indicators
Physical Environment			
- Temperature @ dusk	**< 55° F**	**55° - 70° F**	**> 70° F**
- Wind Velocity	**> 20 mph**	**10-20 mph**	**< 10 mph**
- Relative Humidity	**Low**	**Average**	**High**
- Habitat	**Open, unshaded**	**Partial Sun**	**Woods, deep shade**
- Proximity	**> 2 miles**	**1-2 miles**	**< 1 mile**
- Time of Day	**Mid-day**	**[Other times]**	**Dusk**
Surveillance Data			
- Mosquito Density*	**< 20 / CDC Trap**	**20-50 / CDC Trap**	**> 50 / CDC Trap**
- Mosquito Species	**None**	**Bird-biting**	**Cross-biting**
- Infected Mosquitoes	**None**	**WNV; Highland J**	**EEE**
- Infected Mammals**	**None**	**WNV**	**EEE**
- Age of Mosquitoes	**Newly emerged adults**	**Newly emerged - 2 wks**	**> 2 wks*** **
Season			
- Month	**November - June**	**July, October**	**August, September**

* A good indicator of "nuisance"
** Including human cases
*** Rationale: Mosquitoes have had an opportunity for ~ 2 blood meals.

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Authors

Howard S. Ginsberg, PhD, is a Research Ecologist with the U.S. Geological Survey, Patuxent Wildlife Research Center. He serves as Unit Leader of Patuxent's Rhode Island Field Station, and Professor in Residence at the University of Rhode Island.

Alan Gettman, PhD, is the Rhode Island Mosquito Abatement Coordinator, Division of Agriculture, Department of Environmental Management.

Elisabeth Becker, MPH, is an Epidemiologist with the Rhode Island Department of Health.

Ananda S. Bandyopadhyay, MBBS, MPH, formerly an Epidemiologist with the Rhode Island Department of Health, is currently Program Officer, Polio Research, at the Bill and Melinda Gates Foundation.

Roger A. LeBrun, PhD, is Carnegie Professor of Life Sciences in the Department of Plant Sciences & Entomology, University of Rhode Island.

Correspondence

Howard S. Ginsberg, PhD
USGS Patuxent Wildlife Research Center
RI Field Station, Woodward - PSE
University of Rhode Island
Kingston RI 02881
401-874-4537
hginsberg@usgs.gov