Published in final edited form as:

J Med Entomol. 2019 September 03; 56(5): 1183–1187. doi:10.1093/jme/tjz134.

Highlights of Medical Entomology 2018: The Importance of Sustainable Surveillance of Vectors and Vector-Borne Pathogens

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Abstract

The theme of the 2018 Entomological Society of America, Entomological Society of Canada, and Entomological Society of British Columbia Joint Annual Meeting was Crossing Borders: Entomology in a Changing World. Following the theme of the meeting, papers selected for the 2018 'Highlights of Medical Entomology' included reports of expanded ranges for *Aedes albopictus* (Skuse) (Diptera: Culicidae), *Aedes japonicus japonicus* (Theobald) (Diptera: Culicidae), *Culex coronator* Dyar and Knab (Diptera: Culicidae), *Mansonia titillans* (Walker) (Diptera: Culicidae), and *Wyeomyia mitchellii* (Theobald) (Diptera: Culicidae); a first report of mosquito feeding on earthworms and leeches; Cache Valley virus detection in *Ae. j. japonicus;* surveillance in high-risk areas of Canada for Lyme Disease; and increasing lone-star tick detections in Connecticut. The selection of papers served as a reminder of the increasingly difficult challenge of sustaining vector surveillance programs. Fluctuating funding and a decline in vector taxonomists and identification expertise contribute to the erosion of vector surveillance.

Keywords

surveillance; state record; county record; vector distribution; taxonomy

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The theme of the 2018 Entomological Society of America, Entomological Society of Canada, and Entomological Society of British Columbia Joint Annual Meeting was Crossing Borders: Entomology in a Changing World. In keeping with the spirit of the theme of the meeting, papers selected for the 2018 'Highlights of Medical Entomology' focused on arthropod surveillance, new county/state/country records and expanding species distributions in the United States and territories. The publication period of highlighted papers summarized here was October 2017–October 2018.

Vector-Borne Diseases

The Centers for Disease Control and Prevention (CDC), Division of Vector-borne Diseases, analyzed trends in human cases of reportable vector-borne diseases in the United States and territories for 2004–2016 and concluded that there is a 'rising threat from emerging vector-borne diseases' (Rosenberg et al. 2018). Most of the diseases were not arboviral. Seventy-

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five percent of the 642,602 reported cases were tick-borne. New or emerging arthropod-borne pathogens affecting humans reported during the 13-yr period included Heartland and Bourbon viruses (tick-transmitted); chikungunya and Zika viruses (mosquito-transmitted); and *Borrelia miyamotoi*, *Borrelia mayonii*, *Rickettsiae parkeri*, and *R* species 364D, and *Ehrlichia muris eauclairensis* bacteria (tick-transmitted). Eighty-two percent of the cases of tick-borne disease were attributed to Lyme disease and the most common mosquito-borne disease was due to infection with West Nile virus. The authors pointed out that due, in part, to mild symptoms in some of the infections, the number of cases reported underestimate the true number of human infections. Part of the CDC strategy to reduce vector-borne diseases includes 'rebuilding comprehensive vector control programs that have eroded over time' (Rosenberg et al. 2018).

Mosquitoes—New State and County Records

While conducting a Zika vector surveillance program, Bradt et al. (2018) reported the first collections and a state record of *Aedes japonicus japonicus* (Theobald), potential vector of La Crosse virus (Westby et al. 2011, Westby et al. 2015), from Ottawa County, Oklahoma, on June 2017. Live specimens were collected from Quapaw (larvae and 1 adult female) and Miami (larvae only) from horse-watering troughs at both sites. Invasive *Culex coronator* Dyar and Knab, a potential vector of West Nile virus (Alto et al. 2014), was identified from containers in Haskell and Cherokee counties. This collection documents an expansion of the range of *Cx. coronator* in the state and raises the number of county records from nine to eleven.

The Navy Environmental Preventive Medicine Unit Six, the Hawaii Department of Health (HDOH) and the United States Geological Survey conducted an intense 4-yr *Ae. j. japonicus* surveillance program on the Hawai'ian islands of Oahu and Kauai, and Harwood et al. (2018) reported their findings. On Oahu, *Ae. j. japonicus* larvae ($n = 60$) were collected from six sites from plastic pools placed in the Ko'olau mountain range and monitored by the HDOH. However, no *Ae. j. japonicus* were collected from adult traps (CDC light traps, BG Sentinel traps) operated at over 47 sites at 16 different locations within the Ko'olau and Wai'anae Mountains and at lower elevations on Oahu. On Kauai, larvae were collected from natural sources including depressions in rock surfaces and potholes. Although light traps, BG sentinel traps, and gravid traps were deployed to collect adult specimens, only three female *Ae. j. japonicus* were collected from a gravid trap in 2017. Harwood et al. (2018) found that larval surveillance was the better method to discover *Ae. j. japonicus* and their report confirmed the expanded range of this species on Oahu and Kauai since the initial discovery on the island of Hawaii in 2003 (Larish and Savage 2005).

Riles et al. (2017) documented the first detection and expanded distribution of *Ae. j. japonicus* in five panhandle counties of northwest Florida: Bay, Okaloosa, Leon, Santa Rosa, and Walton. The initial detection included four adult females taken from a CO_2-baited Mosquito Magnet X trap located at a site described as urban/peridomestic in Okaloosa County. Although the majority of the Florida specimens were collected as adults in Mosquito Magnet traps, adults also were detected in updraft traps, a gravid trap, and a resting shelter. One larval collection in 2015 was made using standard larval dipping techniques and two larval collections were reported from ovitraps in 2014 and 2017. These county records documented a southern U.S. expansion of *Ae. j. japonicus*.

Results of a mosquito surveillance program in Wisconsin conducted in 2016 and 2017 included the first state record of *Aedes albopictus* (Skuse), vector of La Crosse virus (Westby et al. 2015), and 14 new county records for *Ae. j. japonicus* (Richards et al. 2019 – online in October 2018). During the 2016 mosquito season, ovitraps were monitored in 20 counties along the southern and southwestern regions of the state. *Aedes j. japonicus* was collected in 70% of the counties that were monitored. In 2017, ovitrap surveillance was limited to seven counties (Dane, La Crosse, Milwaukee, Racine, Rock, Washington, and Waukesha) but targeted tire handling businesses (i.e., dealers, disposal, storage). *Aedes j. japonicus* was detected in all seven counties and *Ae. albopictus* was identified from egg and larval collections in Waukesha and Dane counties. Follow-up trapping for adult mosquitoes at the *Ae. albopictus*-positive sites netted over 200 adult specimens. This report highlights a northern Midwest U.S. expansion of the range of *Ae. albopictus* and *Ae. j. japonicus*.

The aquatic plant specialist, *Mansonia titillans* (Walker), potential vector of Venezuelan and western equine encephalitis viruses (Mitchell et al. 1985, Mitchell et al. 1987), was detected in five counties in South Carolina (Cartner et al. 2018) representing four new county records (Berkeley, Clarendon, Colleton, and Georgetown) and an expansion of the number of collection sites in Beaufort County. The first report of this species in South Carolina was from Beaufort County in 2015 (Moulis et al. 2015). *Mansonia titillans* is dependent on free-floating aquatic plants including water lettuce (*Pistia stratiotes* L.) and water hyacinth (*Eichhornia crassipes* Martius) for oxygen, and therefore the distribution of the mosquito is limited to the distribution of the host plants. Despite the inclusion of the primary host plants in the United States Department of Agriculture Invasive Species list (NISIC 2018) and their illegal status in many states, both water lettuce and water hyacinth are present in many states and popular in water gardens. Prior to Cartner's 2018 report, the U.S. distribution of *Ma. titillans* included south and central Florida; southeastern Texas; southern Alabama, Georgia, and Mississippi; along the southern border of South Carolina; and an area across northern Alabama and Mississippi (Burkett-Cadena 2013). This 2018 report documented the northern expansion of *Ma. titillans* and highlighted that the failure to detect this species prior to 2017 was likely due to limited mosquito surveillance in the area.

Vajada et al. (2018) reported the first collection of a bromeliad specialist, *Wyeomyia mitchellii* (Theobald), on Guam by the Guam Environmental Public Health Laboratory (GEPHL) within the Guam Division of Environmental Health. Supported by the Pacific Islands Health Officers Association, the newly opened GEPHL conducted a mosquito survey in 2017. Guam experiences high levels of traffic from tourism and military and prior to 2017, 70% of mosquitoes reported on Guam were introduced species. The *Wy. mitchellii* were collected in the larval stage from *Aechmea blanchetiana* (Baker) in Chalan Pago/Ordot municipality and were reared to the adult stage for identification based on morphology. Additional molecular analysis confirmed the species identification. While the date of the initial introduction is not known, the authors suspect that the mosquitoes came into the area through illegal trade of water-holding ornamental plants. They acknowledge that whether the trade is illegal or not, it provides a pathway for introduction of mosquito species that are adapted to containers.

With urbanization and modern mobility, the human-assisted movement of mosquitoes can be rapid, cryptic, and unchecked. The review of 2018 reports of expanded distribution of mosquito species in the United States and territories included five species, all mediated by human activities including movement of water-holding containers and legal and illegal trade in exotic and/or invasive ornamental plants. While the vector status of local populations of these five species will vary and has not been examined for many areas, the potential for the expansion of Cache Valley, La Crosse, Venezuelan equine encephalitis, western equine encephalitis, and West Nile viruses exists. Vigilance in monitoring the expanding ranges of mosquito species and the pathogens they transmit is critical as this surveillance serves as the basis for effective public health mosquito control.

Mosquitoes—Biology and Pathogens

Reeves and colleagues (2018) reported on the first DNA evidence and visual observations of mosquitoes feeding on leeches and earthworms. Prior to 2018, the blood hosts of *Uranotaenia sapphirina* (Osten Sacken) were unknown and were assumed to be vertebrates given the blood-feeding patterns of other Culicidae. All bloodmeal DNA from 72 *Ur. sapphirina* from four Florida counties (Alachua, Columbia, Indian River, and Miami-Dade), confirmed by Sanger sequencing, was positive for annelid DNA. Ninety-three percent were classified as oligochaete earthworms and seven percent were from two species of freshwater leeches. Documentation of the visual observations are included in the supplementary material of their 2018 publication. The function of annelid blood within the mosquito is not known and was not part of the research, but the authors mentioned potential utilities for hydration, energy supplementation, or egg production. The authors pose the idea of 'cryptic species' involvement in arbovirus cycles with *Ur. sapphirina* serving as a kleptoparasite by ingesting pathogen-laden blood from leeches or through infrequent feeding on snakes that are infected with eastern equine encephalitis and other arboviruses. These findings expand the knowledge base of mosquito blood host use; introduce the potential of research on the role of earthworms, leeches, and *Ur. sapphirina* in arbovirus cycles; and highlight the possibility of non-vertebrate blood hosts for other mosquito species.

Yang et al. (2018) detected Cache Valley virus (Family *Bunyaviridae*, Genus *Orthobunyavirus*) in two female *Ae. japonicus japonicus* collected from a forested site during the week of 4–11 August 2015, in Blacksburg, Virginia. After inspecting cell cultures inoculated with samples from ground mosquitoes, plaque assays were used to isolate virus. A laboratory colony of *Ae. japonicus* was established and vector competence was examined by measuring non-disseminated and disseminated infections. Of 74 individuals, 41% exhibited non-disseminated infections; 38% disseminated infections; and Cache Valley virus was detected in the saliva from 28% of the test mosquitoes. The authors recommend additional work to investigate the potential medical importance of these findings.

Tick Surveillance

A map of risk areas for Lyme disease in southern Canada is shown on the official website of the Government of Canada (PHAC 2018). Ripoche et al. (2018) examined three surveillance activities that are used in Canada to determine areas of risk: active tick surveillance, passive tick surveillance, and human cases. Using a 2009–2014 surveillance data set from Quebec, the investigators explored relationships between risk signals of human cases and the different surveillance methods to consider how they might detect new areas of risk. They unexpectedly found that passive tick surveillance was reliable to 'detect areas with at least three human cases', but state that the relationship should be reexamined over time in the event that Lyme disease becomes endemic and to take into consideration changing patterns in the number of ticks submitted for identification. Although the results support use of passive surveillance for early warning of emerging Lyme disease risk, Quebec will continue to use all three surveillance components in an integrated system.

Stafford and colleagues from the Connecticut Agricultural Experimental Station (2018) reported on statewide passive tick surveillance and on a massive infestation of ticks on Manresa Island on Norwalk Harbor Station property decommissioned in 2013. From 1996 to 2017, statewide tick surveillance reported 1,261 *Amblyomma americanum* (L.), with 1,089 acquired in Connecticut and 76% of these from Fairfield County (some ticks that were submitted in Connecticut were acquired in other states). Most submissions of *A. americanum* were from areas where the tick was not previously established (Norwalk, Stamford, and Darien). Tick collections on Manresa Island from a dead white-tailed deer included hundreds of nymphs and adults from the body of the deer as well as from the immediate surroundings of the animal. Subsequent tick sampling on the island indicated high abundance with 3.25 adults and 0.25 nymphs per square meter. *Ehrlichia* was detected in questing ticks from Manresa Island. It was unclear how long this tick species had been on Manresa Island, because this area was not open to the public and a conservation officer reported the infestation in 2017.

The Importance of Sustainable Surveillance

The common thread in the papers highlighted here is vector surveillance. The 2018 publications report important findings on new introductions and expanding distributions, and at the same time, they serve as a reminder about an increasingly difficult challenge in vector control programs: sustainable surveillance.

From a 2017 survey of vector control programs in the United States (n = 1,083 responding out of 1,906 surveyed), the National Association of County and City Health Officials reported that only 54% of these entities conducted regular mosquito surveillance which included mosquito identification, abundance, and distribution data (NACCHO, 2017). Almost 50% of the agencies were not using surveillance to guide the control decisions. Although no details were provided on why surveillance was not a component of the programs, it is likely that both lack of funding and lack of local expertise in mosquito identification were major contributing factors.

Funding for mosquito-borne disease prevention and control increases when there is an introduction of a new pathogen and decreases in subsequent years as human cases decline or the pathogen becomes endemic. With a short-term 'bolus' of funding, what was once a priority is often put on hold for the latest crisis. For example, because a majority of the continental United States had not experienced an *Aedes aegypti* (L.) borne virus since yellow fever virus in the early 1900s, most mosquito control agencies and health departments did not have current information on presence or abundance of this species in their jurisdictions when Zika virus was first detected locally. Surveillance for *Ae. aegypti* had declined in areas outside of southern Florida, Louisiana, and Texas and many programs were focused on *Culex*-based surveillance (West Nile and St. Louis encephalitis virus vectors). In 2016, the switch to container mosquito surveillance for some programs was at the expense of *Culex* surveillance. Indeed, three of the research papers presented in the Highlights lecture (Bradt et al. 2018, Cartner et al. 2018, Richards et al. 2019) reported on work that was funded, in part, by the CDC in response to Zika virus in the United States. Because local transmission of Zika virus has not been reported in the continental United States since 2017 (CDC 2019), surveillance priorities in many states is now reverting to vectors of West Nile and St. Louis encephalitis viruses. As the focus reverts back to important endemic concerns, the U.S. territories continue to battle *Ae. aegypti*-borne diseases and the continental United States continues to be an at-risk country for introductions of new arboviruses by vectors that may not currently be part of a monitoring program. As depletion of funds occurs, we must ask what will become of the surveillance programs and the increased capacity built during periods of increased funding.

In addition to fluctuating funding, the medical entomology profession is experiencing a decline in the number of experts in mosquito taxonomy. During the current decade, three internationally recognized experts in mosquito taxonomy passed away: Dr. Peter Belton on 1 April 2019 (ESBC 2019), Lieutenant Colonel Bruce Harrison (United States, Retired) on 5 December 2018 (NCMVCA 2018) and Dr. Richard F. Darsie, Jr. on 10 April 2014 (Day 2015). Belton, Harrison, and Darsie made major contributions to our understanding of the distribution of mosquitoes in North America north of Mexico. They were dedicated to training students in the science of mosquito identification from mosquito control agencies to formal University settings. Medical entomology and biology departments at universities should consider the importance of arthropod vector taxonomy when new or vacant faculty positions are available.

During the exponential growth of the field of molecular biology, morphological taxonomy has been left behind; and it does not bode well for our future to ignore the important field of mosquito identification. In many University programs, molecular biologist positions are common, whereas positions for taxonomists are rare to nonexistent. Hebert et al. (2003) advocated DNA bar coding as a 'sole prospect for a sustainable identification capability'. While molecular biology techniques have provided complementary insight into insect identification, Wheeler (2008) sees this as a path to a 'dismal, bleak, and defeated future' for taxonomy. Given the size of mosquito catches in vector surveil-lance and control programs, the cost of polymerase chain reaction (PCR)-based techniques (bar-coding) far outweighs the cost of microscopy. Because morphological mosquito identification is the basis of mosquito surveillance, the loss of experts, the loss of positions in the field of mosquito taxonomy, and a lack of training for the next generation of mosquito taxonomists will further erode mosquito surveillance capabilities.

One way in which vector surveillance can be supported is through training of vector control professionals. In 2017, CDC established five regional Centers of Excellence (COEs) in Vector-Borne Diseases to prepare the nation to address vector-borne disease threats (CDC 2019a). One of the goals of the COEs is to train public health entomologists in the skills and techniques required to respond to vector-borne diseases. Since their establishment, the COEs have offered a number of mosquito and tick identification workshops and short courses. In recent years, Georgia Southern University, partially funded by the CDC Southeastern Center of Excellence, has offered a 2-wk tick workshop in Statesboro, Georgia (USNTC 2019). The Florida Medical Entomology Laboratory Advanced Mosquito Identification and Certification course (FMEL 2018) is taught annually, and many state mosquito control associations offer short courses in mosquito identification. These short-term training opportunities are critical to maintaining expertise within vector control programs and health departments.

Vector surveillance drives decision support for vector control. Without surveillance, it is difficult for states to be reimbursed by the Federal Emergency Management Agency for responses to natural disasters such as flooding and hurricanes. Without surveillance, there is no basis for applying insecticides. Without surveillance, we have no measure of expanding ranges of vectors or awareness of introductions of exotic invasive species. Without surveillance, we will be caught off guard when the next new vector-borne pathogen is introduced into the United States.

Acknowledgments

Thanks to Dr. Saul Lozano for comments on an early draft of this manuscript.

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