ILLINOIS NATURAL HISTORY SURVEY

BIENNIAL REPORT, 2016-2018

WASTE TIRE AND EMERGENCY PUBLIC HEALTH FUNDS

LEGISLATIVE MANDATE:

"TO PROVIDE FOR RESEARCH ON DISEASE VECTORS ASSOCIATED WITH USED AND WASTE TIRES AND THE DISEASES THEY SPREAD."

ILLINOIS
Illinois Natural History Survey
PRAIRIE RESEARCH INSTITUTE

REPORT TO GOVERNOR BRUCE RAUNER AND THE ILLINOIS GENERAL ASSEMBLY

SUMMARY OF ACCOMPLISHMENTS BY THE MEDICAL ENTOMOLOGY PROGRAM

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Cover photo by Alex Wild, used under a non-profit use license: *Aedes triseriatus*, the eastern treehole mosquito, the primary vector of La Crosse encephalitis virus in Illinois.

September 2018

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Summary of Accomplishments

Overview:

- The Medical Entomology Program has for 28 years served the State of Illinois by providing applied field and lab research on mosquito vectors so as to more effectively detect, prevent, and control vector-borne diseases and invasions in Illinois (pp. 11-13).
- We maintain state-of-the-art facilities, including Biosafety Level 2 and Arthropod Containment Level 2 areas, a high-throughput molecular lab, an arsenal of mosquito traps, and environmental chambers with long-term colonies of mosquitoes. We can collect, process, and identify field-collected vectors; identify their pathogens and elucidate their genetics; and experimentally infect vectors to ask questions about behavior, risk, and control. In addition, we use mathematical modeling approaches to answer questions about optimal vector control strategies (pp. 13-14).

  The necessity of understanding vector distributions in our state and the development of novel vector control methods is a matter of urgency in Illinois. This is due to concerns about insecticide resistance in the major West Nile virus vectors, the increase in abundance and spread of the Asian tiger mosquito and several tick species, for which currently no (cost-)effective control methods exist, and the emergence or threat of several vector-borne diseases. The INHS Medical Entomology Program is uniquely situated and expertly staffed for tackling these challenges on multiple fronts, from vector and pathogen detection to control and collaborative outreach.

Activities for the 2016 - 2018 period:

Infrastructure and funding

- We developed and submitted three grant proposals; two were funded on (1) insecticide resistance monitoring within Illinois and (2) tick surveillance and screening in Illinois.

- We revised Institutional Biosafety Committee (IBC) protocols to continue work in the Lab with virus-infected mosquitoes and wrote new IBC protocols for the processing and identification of ticks and screening for tick-borne pathogens.

- We expanded expertise and personnel through the hire of two postdocs and two vector biologists. The Program Director, Dr. Christopher Stone, achieved affiliate status in the University of Illinois Urbana-Champaign (UIUC) Department of Entomology that allows him to serve as faculty advisor to graduate students. He is currently serving on three student dissertation committees.

- We extended the research capacity of the Lab by acquiring new research equipment including a gas chromatography - mass spectrometry system to investigate mosquito and tick attractants (e.g., for traps) and repellents (e.g., for personal safety). Through a scientific equipment request to INHS budget committee we were able to obtain a state-of-the-art Nikon microscope, to be used for identification, dissection, experimental manipulation, and documentation of vectors (e.g., ticks and mosquitoes) and their pathogens.

- We maintained, initiated, and extended collaborations with public health and mosquito abatement districts across Illinois, the Illinois Department of Public Health (IDPH), the CDC Upper Midwestern Regional Center of Excellence for Vector-Borne Disease, the Lincoln Park Zoo, the Great Lakes Naval Station, and the UIUC Department of Entomology.

Research Outputs

- Members of the Medical Entomology Program published 12 peer-reviewed publications and two technical reports over the 2016–2018 period. Research outputs were presented at 5 national and regional conferences, and in a seminar at the UIUC Department of Entomology.

- We documented the spread of the Asian tiger mosquito throughout Illinois and are currently estimating the biting and pathogen-transmission potential of it in residential neighborhoods. Our study documented the Asian tiger mosquito in 13 new counties, indicating this invasive mosquito is extending its range and increasing in number in Illinois (p. 15).

- We performed a population genetics analysis of Asian tiger mosquito populations in Illinois, to understand where this species is being introduced into our state, how to prevent further introductions, and how to stop its spread. Our results indicate it has been introduced at least 4 separate times in southern and central Illinois and these populations might be adapting to the Illinois climate. Future research will refine our understanding regarding the means of introductions and whether they can survive the Illinois winter (p. 16).

- We found that the Asian tiger mosquito and the northern house mosquito (a major West Nile virus vector) in Illinois are becoming more resistant to commonly-used insecticides. Future research will expand our testing to more mosquitoes across the state and develop methods to combat insecticide resistance (pp. 16-17).
- We found that the removal of plants used by male and female mosquitoes for nectar (which gives them fuel for flight) can drastically reduce the life span of mosquitoes and their ability to infect people. Future research will explore how to incorporate plant management in an integrated vector control approach (pp. 17-18).
- We found that estimating the number of mosquitoes in a given area (e.g., through mosquito field collections) can be a more effective trigger for control measures than using reported numbers of infected mosquitoes or human illness. We also found that because infected humans can move much further, on a daily basis, than mosquitoes can fly, control responses should cover wider areas than are conventionally used (pp. 18-20).
- We found that whether mosquitoes prefer to bite humans or other animals depends on the ratio of humans to other animals in a given area and how accessible humans are to mosquitoes. Future research will investigate whether we can influence mosquitoes to bite animals other than humans, which would strongly diminish their capacity to transmit diseases to humans (p. 20).
- We found that mosquito microbiomes are strongly influenced by the environments in which mosquitoes develop, and that the two vectors of greatest concern in Illinois (the Asian tiger mosquito and northern house mosquito) have very different microbiomes than other mosquitoes (perhaps due to their preferences for urban areas). Future research will focus on how we can manipulate mosquito microbiomes to turn them into less effective vectors (pp. 20-21).
- We are currently identifying ticks, collected by residents and professionals across Illinois, and screening them for pathogens. Pending funding, future research will further our work on documenting ticks and their pathogens in Illinois and extend our capacity for

developing control methods and conducting outreach and collaboration.

- We are actively investigating novel control methods, including environmental management approaches and mosquito manipulations, and the development of better traps for vectors (e.g., by using attractive plant chemicals).

INHS Medical Entomology Program

MOSQUITO-BORNE DISEASES continue to pose a significant public health threat globally as well as within the United States. Concerns about arboviral epidemics[1] are particularly relevant for Illinois, which over the period 2004-2016 fell within the top 20% of reported disease cases due to mosquito-borne diseases (see Figure 1). To a large extent, this is due to local transmission of West Nile virus, with numbers of disease cases spiking in certain years, as well as other locally-transmitted mosquito-borne viruses (e.g., La Crosse and St. Louis encephalitis viruses). These viruses are likely underreported as they often lead to relatively mild symptoms in humans; however, severe, neuroinvasive, and fatal cases occur in Illinois each year.

[1] due to an arthropod-borne virus

Travel-related or imported cases are also of concern, in particular for those pathogens which have a locally-established competent vector[2]. This was brought into focus by the recent Zika virus epidemic. In 2016, 41,680 cases of Zika infection in humans were reported to the National Notifiable Disease Surveillance System.[3] Most of these cases were acquired during travel to South America or within U.S. Territories, with active transmission occurring in Florida and Texas.

[2] an organism, such as a mosquito or tick, which transfers a pathogen from one infected human or animal to another

[3] R. Rosenberg, N. P. Lindsey, M. Fischer, C. J. Gregory, A. F. Hinckley, P. S. Mead, G. Paz-Bailey, S. H. Waterman, N. A. Drexler, G. J. Kersh, et al. Vital signs: Trends in reported vectorborne disease cases-United States and Territories, 2004–2016. *Morbidity and Mortality Weekly Report*, 67(17):496, 2018

The large volume of international travelers to our state could introduce arboviruses such as Zika, dengue, or chikungunya. For instance, during the Zika epidemic in Brazil (2014-2015) an estimated 50,000 - 150,000 international air travelers passed through Chicago departing from airports in areas in Brazil with ongoing Zika transmission.[4] Further, one of the major vectors of these viruses is the Asian tiger mosquito, *Aedes albopictus*. This invasive mosquito has spread across the United States over the past three decades and now appears to be firmly established in the southern and central parts of Illinois where it is rapidly increasing in abundance. Work in our Program indicates the range of this mosquito in Illinois is also expanding. This highlights the need for robust outbreak preparedness strategies and continued improvements in vector surveillance and control methods.

[4] I. I. Bogoch, O. J. Brady, M. U. Kraemer, M. German, M. I. Creatore, M. A. Kulkarni, J. S. Brownstein, S. R. Mekaru, S. I. Hay, E. Groot, et al. Anticipating the international spread of Zika virus from Brazil. *The Lancet*, 387(10016):335–336, 2016

THE MEDICAL ENTOMOLOGY PROGRAM at the Illinois Natural His-

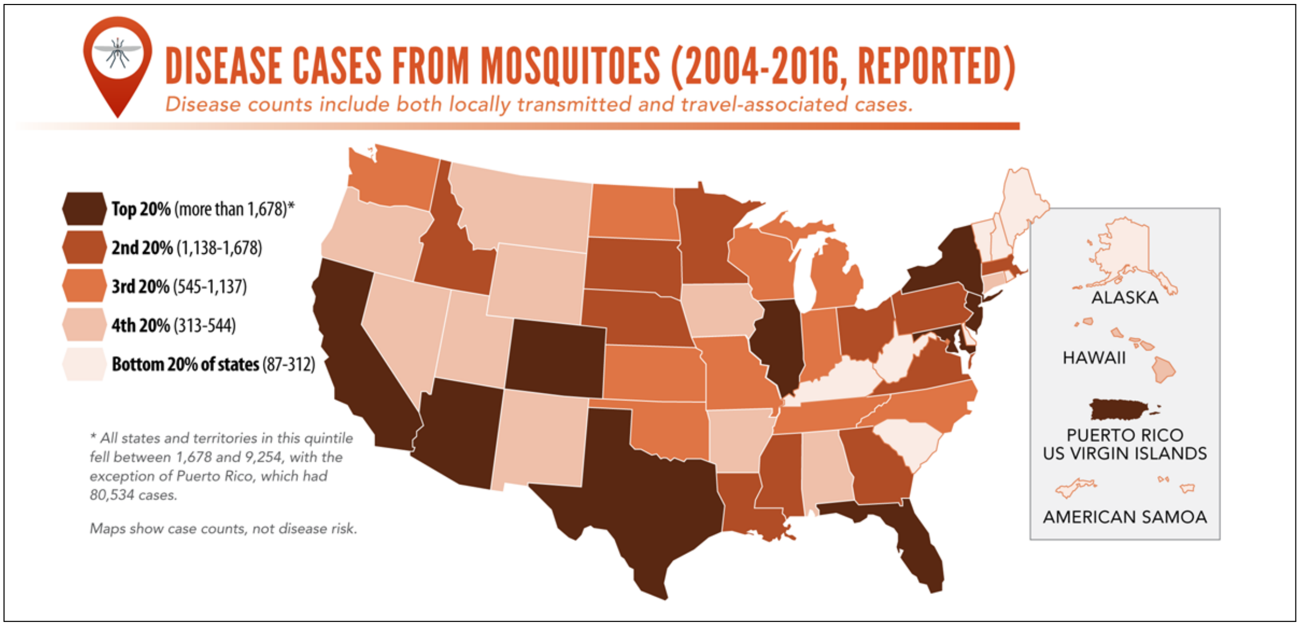

Figure 1: The number of reported mosquito-borne disease cases per state and territory over the period 2004-2016. With 2,582 reported disease cases over this period, Illinois is among the states with the highest mosquito-borne disease burdens in the United States. Source: CDC Vital Signs, May, 2018.

tory Survey (INHS) conducts research on vectors associated with used and waste tires and the diseases they cause. More than 14 million waste tires are generated annually within Illinois and are considered a serious public health issue because they serve as ideal incubators for a wide range of vectors. Mosquitoes that thrive in waste tires notably include a number of important disease vectors: the Asian tiger mosquito *Aedes albopictus*, the Asian rock pool mosquito *Aedes japonicus*, the eastern tree-hole mosquito *Aedes triseriatus*, the northern house mosquito *Culex pipiens*, and the white-dotted mosquito *Culex restuans*. These mosquito species are considered threats to human and wildlife health because of their ability to transmit locally present dog heartworm, Eastern Equine Encephalitis virus, La Crosse encephalitis virus, St. Louis Encephalitis virus, West Nile virus, and introduced (exotic) dengue, chikungunya and Zika viruses.

In 1989, Illinois passed the Waste Tire Act (ILCS 5/53 to 55.7a) to address issues associated with solid waste hazards. Funds associated with this legislation are devoted to (a) the removal of used and waste tire dumps to reduce threats to public health, (b) mosquito abatement, and (c) research on mosquitoes associated with waste tires and the diseases they cause.

This led to the establishment of the Medical Entomology Program at the INHS to conduct research on mosquito species associated with waste tires, establish their susceptibility to insecticides, evaluate alternative control methods in the laboratory and field, and improve

Figure 2: Used tire collection sites are ideal breeding sites for invasive mosquitoes, such as the Asian tiger mosquito, and provide a means for vectors to spread throughout the state.

methods for surveillance and monitoring of mosquito vectors and pathogens. Over the following 28 years, the Program evolved into a multidisciplinary group of research scientists, technical personnel, students, and hourly academic staff, who conduct research on a broad range of questions regarding the biology and behavior of mosquito vectors, the transmission and management of mosquito-borne pathogens, and their impact on human health. More recently, with funding provided by the IDPH, the Program has begun investigating tick-borne pathogens in Illinois.

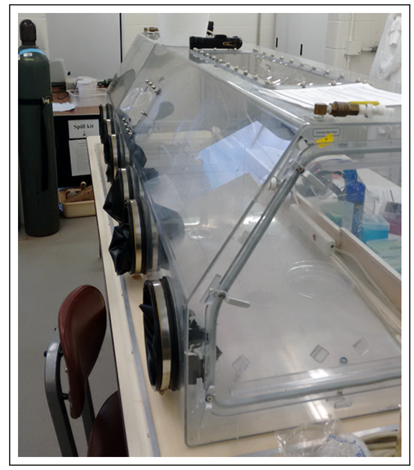

Figure 3: The Medical Entomology Lab includes Biological Safety Level 2 and Arthropod Containment Level 2 spaces where studies with infected vectors can be performed. Handling of infected vectors occurs within a glove box (pictured).

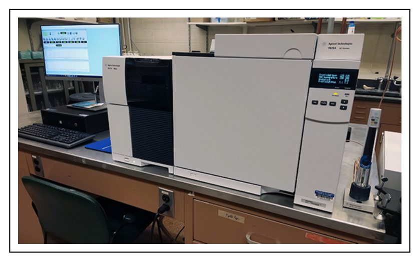

Figure 4: A new area of focus is the development of attractive bait stations and lures, based on the smells of hosts, plants (e.g., as nectar sources), and egg-laying sites. A recently acquired gas chromatography - mass spectrometry system will facilitate research into this useful area of applied vector biology.

Research capacity and future directions

The Medical Entomology Program is uniquely suited to tackle the major challenges confronting vector-borne pathogen surveillance and control in Illinois. The Program has built up a roster of experienced vector-borne disease biologists and an extensive set of scientific facilities and equipment devoted to surveillance and research of vectors. This allows the Program to leverage its existing resources to address emerging and shifting priorities in the vector-borne disease landscape in Illinois.

With the appointment of Dr. Christopher Stone as new Director of the Program in June 2017, research priorities are shifting to focus more strongly on understanding variation in risk of human exposure to vector-borne diseases, and the development of cost-effective surveillance, prevention, and control methods. These efforts are informed by a detailed understanding of the biology and behavior of vectors, application of cutting-edge molecular methods, and mathematical modeling. For example, studying the attraction of vectors to different resources (hosts, nectar sources, egg-laying sites, resting sites), and determining what makes a certain resource more attractive than others, will allow for the development of improved lures for surveillance and novel toxic bait stations. Planned directions in progress include: assessing how the changing landscape of Illinois affects the presence and abundance of vector species and pathogens; monitoring virus genetic diversity to see whether new and possibly more dangerous strains are circulating in vector populations; monitoring insecticide resistance in IL mosquito populations and developing strategies to prevent insecticide resistance; developing new control methods and traps based on our understanding of vector behavior and attraction to hosts; and leveraging the facilities of the Medical Entomology Program to build additional capacity for tick and tick-borne pathogen surveillance, diagnostics, and development of novel tick control strategies.

SURVEILLANCE AND DIAGNOSTICS capacity in the Lab consists of a wide range of field-collection equipment (e.g., traps), state-of-the-art microscopes to allow for rapid identification/documentation and dissection of specimens, and ultralow freezers for long-term storage of specimens without degradation of DNA or (viral) RNA.

The Lab is Biosafety Level 2 and Arthropod Containment Level 2 certified, which provides the capacity to screen vectors for pathogens, determine hosts by DNA sequencing of blood meals of collected vectors, as well as test the capacity of invasive or native vectors to transmit circulating or emerging pathogens. Additionally, the Lab has capacity for high-throughput detection of vector-borne pathogens (e.g., mosquito- and tick-borne viruses or bacteria).

Figure 5: Taxonomic identifications of field-collected specimens of mosquitoes, ticks, and other vectors. Here, ticks are identified using a state-of-the-art research stereomicroscope.

COLLABORATIONS of the Program include local public health departments, mosquito abatement districts, and the Illinois Department of Public Health. We also collaborate on projects with the CDC Upper Midwestern Regional Center of Excellence for Vector-Borne Disease and other local, national, and international vector-borne disease research groups and networks. For instance, we are active participants in the VectorBiTE ("Vector Behavior in Transmission Ecology") research coordination network, which ensures that data collected in Illinois can be included in appropriate national and international databases and facilitate analysis of trends in mosquito populations across state boundaries.

The Medical Entomology Program has a long history of service to the State of Illinois, for instance by offering a pathogen screening service to aid districts lacking testing capacity or requiring confirmation of test results. The Program has also long been involved with the Illinois Mosquito and Vector Control Association and its annual meetings, to facilitate communication with and uptake of research findings by public health and mosquito abatement districts.

The Medical Entomology Program is situated, through historical associations, research, and current capacity, to fulfill a unique and much-needed role on the investigation and mitigation of a wide range of vector-borne diseases in Illinois. As is evident through our current collaboration on tick-borne diseases with the IDPH, with additional funding our existing capacity can be leveraged to address diseases propagated by vectors other than mosquitoes.

Overview of Research Outputs

Invasive mosquito surveillance

The worldwide range expansion over recent decades of important mosquito vectors, such as the yellow fever mosquito *Aedes aegypti*, the Asian tiger mosquito *Ae. albopictus*, and the Asian rock pool mosquito *Ae. japonicus* poses a serious threat to global health. With their introduction and expansion, these tire-breeding species have altered the epidemiology of vector-borne diseases through their capacity to transmit native and introduced pathogens. Public concerns about these invasive mosquitoes and pathogens transmitted by them have only been intensified by the recent epidemics of Zika virus in Central and South America.

Figure 6: Image of the BG Sentinel trap (on the ground) to collect adult female mosquitoes and an oviposition container (on the tree) used to collect eggs.

Effective implementation of vector control relies on a thorough understanding of the identity, abundance, and distribution of vector species. We therefore conducted seasonal surveys, in collaboration with the IDPH, for *Aedes* mosquitoes in selected residential areas of the state beginning in 2016 and currently ongoing. To gain more insight into the invasion history and origins of *Ae. albopictus*, we also investigated the population genetics of several local populations.

Aedes albopictus was found to be ubiquitous in 18 counties the Lab actively sampled in south-eastern Illinois, providing the first records of occurrence for 11 of these locations.[5] This species was also detected in 15 counties for which we received specimens collected through routine surveillance and shared by local public health departments or mosquito abatement districts. No positive virus infections were found among these collections, a result of being able to run only a limited number of traps per county and the low prevalence of infection typically found in mosquitoes (even when active transmission is occurring). Illinois needs more sensitive pathogen surveillance methods, that can be scaled-up to broader areas, to serve as an early-warning system when high human-infection periods begin.

[5] C.-H. Kim and C. Stone. Surveillance of *Aedes aegypti* and *Aedes albopictus* in the State of Illinois. Technical report, Illinois Natural History Survey, 2018

We identified at least four distinct genetic lineages of *Ae. albopictus* present in Illinois, with different geographic areas having different

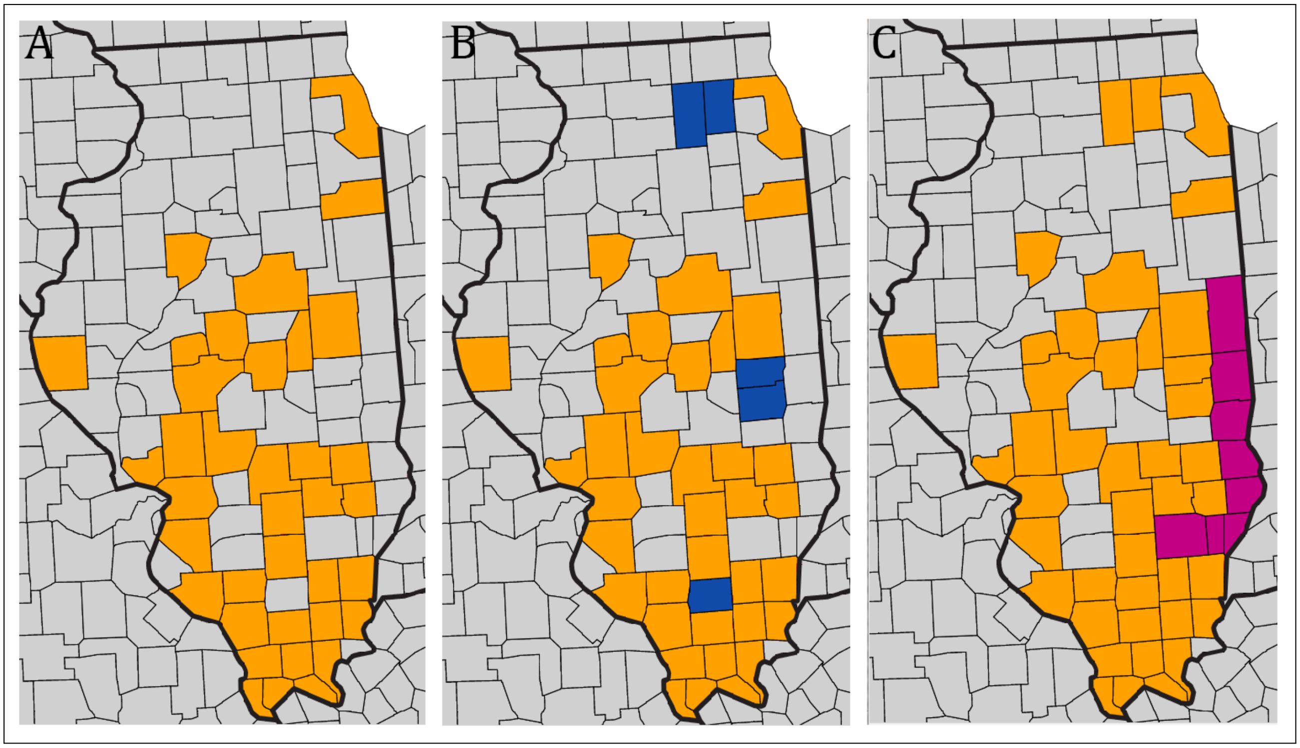

Figure 7: Occurrence records of the Asian tiger mosquito *Aedes albopictus* in Illinois. A: Counties with *Ae. albopictus* prior to 2016. B: Counties with blue color that were newly confirmed for the presence of *Ae. albopictus* in 2016. C: Counties with red color that were newly confirmed for the presence of *Ae. albopictus* in 2017.

genetic backgrounds. This suggests that the composition of this vector in Illinois is the result of a complex and dynamic invasion history, representing at least four different invasions over the course of several years. This implies *Ae. albopictus* is entering the state through multiple avenues that remain to be elucidated.

Future research in our Lab will address how these genetic differences relate to the increase in abundance of *Ae. albopictus* in Illinois in recent years, where and when *Ae. albopictus* is entering the state, what the best ways are to prevent invasions and control these mosquitoes, and whether there are differences among these populations in their potential to transmit vector-borne diseases or persist over Illinois winters.

Insecticide resistance monitoring

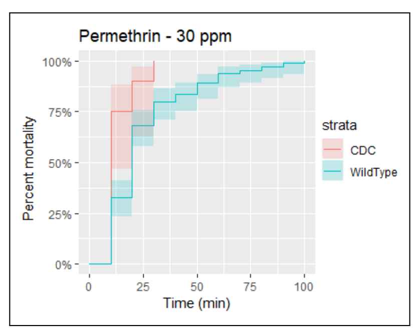

Figure 8: Emerging resistance in *Culex pipiens* from Chicago to permethrin, a commonly-used insecticide.

The development of resistance to insecticides in mosquito populations is a major concern for public health programs. Knowing whether mosquitoes remain susceptible to commonly-used insecticides allows control programs to know whether they should shift resources to methods that remain effective. Resistance monitoring is therefore particularly useful if done consistently on a year-to-year basis.

We tested the insecticide susceptibility status of six Illinois populations of the Asian tiger mosquito, *Ae. albopictus*, and a population from the North Shore of Cook County of the northern house mosquito, *Culex pipiens*.[6] Our results suggest that several of the more southern populations of *Ae. albopictus* are indeed more tolerant to these insecticides, compared to a susceptible reference strain obtained from the CDC. This was also the case for the field-collected *Cx. pipiens*. This indicates an emerging level of resistance in these populations.

[6] C.-H. Kim and C. Stone. Insecticide resistance surveillance of a zika virus vector, *Aedes albopictus*, in the State of Illinois. Technical report, Illinois Natural History Survey, 2018

We are currently expanding on these initial results by collecting and monitoring the susceptibility of a wider range of populations of both species from southern, central, and northern parts of Illinois, in collaboration with several IL public health and mosquito abatement districts. Sustained monitoring of these populations over time will be critical.

Future research in our Lab will focus on developing and refining control tactics to delay the further development of insecticide resistance in these populations.

Figure 9: A mosquito feeding on *Lantana camara*. While female mosquitoes of most species rely on blood to develop eggs, they require nectar-meals to survive and fly. Eliminating preferred nectar-sources could therefore limit the pathogen transmission potential of mosquitoes.

Integrated control of mosquitoes

Integrated vector management is a promising control approach that minimizes the use of chemical insecticides, and thereby the formation of insecticide resistance. An integrated management strategy entails aspects of environmental management to decrease mosquito populations and relies on coordination among various disciplines. The management or removal of invasive alien plants provides an intriguing and promising example of such an integrated control strategy.[7] Many invasive plants radically alter landscapes, often in ways that benefit vector populations; for instance, by providing harborage and nutrition in the form of nectar. As a result, such plants can increase pathogen-transmission rates by boosting mosquito survival and reproduction. This relationship between mosquitoes and invasive plants indicates that management of certain plant species can control vectors.

[7] C. M. Stone, A. B. Witt, G. C. Walsh, W. A. Foster, and S. T. Murphy. Would the control of invasive alien plants reduce malaria transmission? a review. *Parasites & Vectors*, 11(1):76, 2018

To test this idea, we followed groups of mosquitoes for three weeks in field-based enclosures holding nectar-poor and nectar-rich plant species and kept track of daily mortalities, biting rates on humans, and egg output – three components that in large part determine the pathogen-transmission potential of mosquito populations.[8] Mosquitoes survived much longer in nectar-rich environments than nectar-poor ones. This translated to greater estimated transmission potential in the nectar-rich environments. Thus, changes in plant

[8] B. Ebrahimi, B. T. Jackson, J. L. Guseman, C. M. Przybylowicz, C. M. Stone, and W. A. Foster. Alteration of plant species assemblages can decrease the transmission potential of malaria mosquitoes. *Journal of Applied Ecology*, 55(2):841–851, 2018

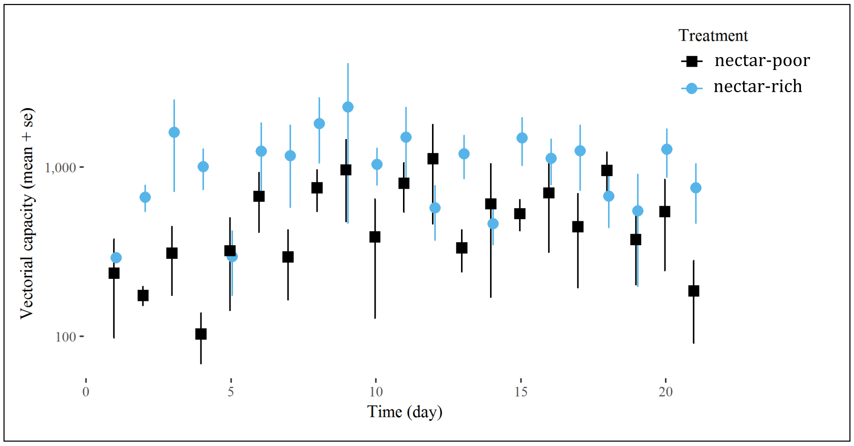

Figure 10: The pathogen-transmission potential of groups of mosquitoes was found to be greater over a 3-week period in environments where preferred nectar-bearing plants were present, compared to environments in which only poor nectar-bearing plants were available. A considerable reduction in mosquito-pathogen transmission would be expected following removal of preferred plants.

communities (e.g. due to introduction of exotic species) can increase vector-borne pathogen transmission and a reduction of favorable nectar sources can reduce transmission.

As a specific example, a local field study performed in Mahomet, IL, led by the University of Illinois Department of Entomology, showed that removal of invasive honeysuckle can lead to significant reductions in abundance of West Nile virus vectors and other mosquitoes.[9] This highlights that this is an intervention that could potentially be a highly useful component of an integrated vector management strategy in Illinois.

[9] A. M. Gardner, E. J. Muturi, L. D. Overmier, and B. F. Allan. Large-scale removal of invasive honeysuckle decreases mosquito and avian host abundance. *EcoHealth*, 14(4):750–761, 2017

Future research in our Lab will explore how much of a reduction in West Nile prevalence can be achieved if plant elimination is scaled-up over a larger area, and whether removal of other invasive plants can have similar effects.

Optimizing vector-borne disease surveillance and control

Vector control practices often vary significantly among different jurisdictions and are executed independently and at different scales and intensities. For instance, different types of surveillance information (e.g. number of human infections or adult mosquitoes) and thresholds (e.g., a target number of infections, or the number of successive weeks with infected mosquitoes) can trigger the implementation of control measures. To address these disparities, we investigated whether using certain types of surveillance data to trigger vector control were more effective than others.[10]

[10] S. R. Schwab, C. M. Stone, D. M. Fonseca, and N. H. Fefferman. The importance of being urgent: The impact of surveillance target and scale on mosquito-borne disease control. *Epidemics*, 23:55–63, 2017

Our results indicate that earlier implementation of control after an escalation of disease risk achieves much greater reductions in human infections than delayed control implementation. Triggering control based on estimates of total mosquito abundance was more effective than methods based on numbers of infected humans or mosquitoes, likely because it led to earlier implementation of control. We conclude that existing surveillance data from mosquito abatement districts can be used more effectively to optimize disease control efforts. Specifically, using mosquito abundance data to trigger control is likely to lead to more effective prevention of outbreaks of mosquito-borne diseases.

HUMAN MOVEMENT AND COMMUTING PATTERNS can affect the intensity and spread of vector-borne diseases. We asked whether more effective disease control strategies can be designed by taking human movement into account. To answer this question, we developed a spatial model of vector-borne disease transmission, allowing for movement of humans among communities.[11] We varied two aspects of vector control strategies: (1) how wide is the control implementation area (e.g., if an infection occurs in a community, do neighboring communities also take precautionary control measures?) and (2) what proportion of communities has capacity/willingness to implement control?

[11] C. M. Stone, S. R. Schwab, D. M. Fonseca, and N. H. Fefferman. Human movement, cooperation and the effectiveness of coordinated vector control strategies. *Journal of The Royal Society Interface*, 14(133):20170336, 2017

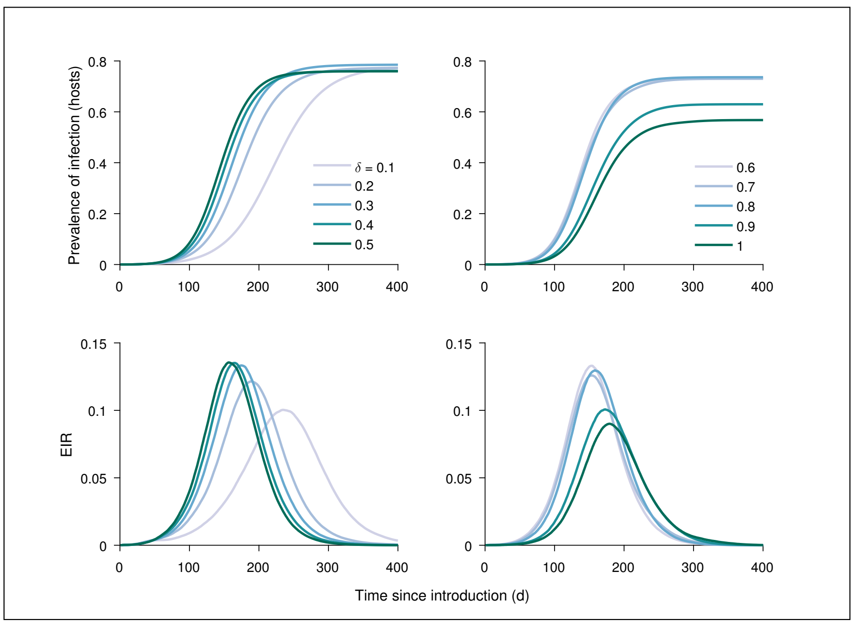

Figure 11: Average Zika infection in humans over time in the absence of vector control, where the proportion of humans that commutes on a daily basis varies from one-tenth to half the peope commuting (left) and half to all of the people commuting (right). The lower panels show the average number of infectious bites received per human per day, over time. This shows that the frequency of humans commuting between neighborhoods has a strong impact on the course of an epidemic.

We found that implementing control over a wider area than normally targeted could provide tangible benefits and prevent far more human cases than control responses limited to the neighborhood where an infected case is detected. Our results suggest that communication and cooperation among neighboring jurisdictions (e.g., among municipal health departments or mosquito abatement districts) can lead to more effective strategies for vector-borne disease control in modern commuter-linked communities. However, for wider control to occur a large proportion of neighborhoods or communities must have the capacity to participate in vector surveillance and control activities. Thus, increasing support for areas currently lacking in vector surveillance and control capacity is likely to ensure that control activities in regional areas will be more effective.

Future research in our Lab will expand on these results by considering financial and economic costs associated with different strategies. We will also expand on this to consider vector-borne diseases, such as West Nile virus, which can be transported over long distances by their wildlife reservoirs.

Environmental and genetic basis of mosquito vector efficiency

Mosquitoes bite a wide range of animals and research has shown they prefer some animals (e.g., humans) to others. Biting preferences of mosquitoes have an exceedingly strong effect on their pathogen-transmission potential. Small changes in the proportion of bites taken on humans, as opposed to other animals, can strongly increase or decrease transmission. We developed a mathematical model to better understand how differences in mosquito biting preferences among species arise, how this depends on the numbers and composition of animal species in a given area, and whether certain vector management approaches (e.g., repellents, screening) can influence mosquito biting preferences.[12]

[12] C. Stone and K. Gross. Evolution of host preference in anthropophilic mosquitoes. *Malaria Journal*, 17(1):257, 2018

We found that intensive vector control can lead to a shift in mosquito biting behavior, and if these efforts are maintained sufficiently long, it is possible to create lasting changes in mosquitoes so that they become less likely to bite humans. Thus, it may be possible to design vector control in such a way to lead to long-term changes in mosquito behavior that leads to less human biting.

Future research in our Lab will explore how to exploit this for populations of the Asian tiger mosquito and the primary West Nile virus vector in the U.S., *Cx. pipiens*.

Mosquito microbiomes

The microbial communities that reside in mosquitoes can impact transmission of mosquito-borne pathogens, for instance by making mosquitoes more or less susceptible to infection, or by altering their life span. An improved understanding of the diversity of mosquito microbiomes, leading to a deliberate alteration of those microbiomes, can lead to the development of novel vector control methods at a local scale. This burgeoning field is at the forefront of vector biology, though by far most of the work done to date has focused on vectors of global health concern (e.g., malaria and dengue vectors). Several studies performed at the INHS Medical Entomology Lab have begun characterizing the microbiomes of important species in Illinois.

These studies included a characterization of the microbiomes of 12 mosquito species collected in residential areas in Champaign County, Illinois.[13] Notably, the microbiomes of *Cx. pipiens* and *Ae. albopictus* differed significantly from other mosquito species. In another study, mosquitoes collected from six locations within the U.S. harbored distinct microbial communities, suggesting that differences within species are strongly tied to location and environment.[14] At the same locations, gut microbiomes of offspring were similar to those of their parents.[15] This last result is highly pertinent, as we think insecticide use (e.g., on agricultural fields) can affect the microbial composition of nearby aquatic habitats, likely altering the microbiome of mosquitoes developing in such habitats.[16] Thus, agricultural pesticides could have a local effect on mosquito ability to transmit pathogens effectively.

Future research in our Lab will focus on documenting and understanding variation in microbiomes of the major Illinois vectors, determining whether certain bacteria affect the ability of mosquitoes to transmit viruses, or alter their life span or biting preferences, and test whether certain bacteria can be introduced to mosquitoes, making them potential targets for novel vector control methods.

[13] E. J. Muturi, J. L. Ramirez, A. P. Rooney, and C.-H. Kim. Comparative analysis of gut microbiota of mosquito communities in central illinois. *PLoS Neglected Tropical Diseases*, 11(2):e0005377, 2017

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