BEST PRACTICES FOR INTEGRATED MOSQUITO MANAGEMENT:

A FOCUSED UPDATE

American Mosquito Control Association

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The mention of specific products does not constitute an endorsement by the AMCA or the steering committee.

Surveillance

Summary

- Surveillance for native and exotic species should be part of mosquito control abatement, regardless of immediate threat of disease outbreaks. Surveillance should be developed proactively to justify mosquito control funding requirements and risk for arboviral disease transmission
- Mosquito species composition should be identified at the mosquito control district level
- Egg and immature-stage surveillance
    - Oviposition cups use a variety of substrates that are placed in an artificial container, usually a small black plastic cup or jar
    - Nonlethal oviposition cups pose a risk for becoming larval development sites if left unmaintained in the field for more than a week
    - Sampling for non–container-inhabiting mosquitoes involves the use of dippers, nets, aquatic light traps, and suction methods
        - Efforts must be made to train personnel and standardize techniques to improve intersample reliability
    - For monitoring container-inhabiting *Aedes* spp entomologic indices have been the standard
        - Container indices (container index, Breteau index, House Index) may be used to determine abundance of *Aedes* spp
        - Container indices should be interpreted with caution because they may not correlate well with adult surveillance or be useful in setting nuisance action thresholds
- Adult surveillance
    - Light traps are a critical part of mosquito surveillance for a variety of species
    - Light traps are ineffective in most cases for the surveillance of *Aedes aegypti* and *Aedes albopictus*
    - BG-Sentinel™ (BGS) traps are effective for monitoring *Aedes* spp
    - Gravid *Aedes* traps are useful for surveillance of *Aedes* spp
    - Oviposition cups and BGS traps should be used together to monitor both sexes and all physiologic stages of *Aedes* spp
    - Landing rates are labor-intensive and may be associated with potential health risks to field staff in areas with known arbovirus transmissions

Mapping

- Utilize appropriate map scale to resolve mosquito aquatic habitats, adult populations, control efforts, and insecticide resistance
- Record surveillance and control data at the finest spatiotemporal resolution that is operationally feasible
- Ensure that all data are linked to spatial information for use in geographic information systems
- Quantify mosquito population sizes when possible, using standardized methods that allow comparisons among locations
- Use statistical methods only when supported by observed data; estimates based on modeling should convey the amount of uncertainty

Setting Action Thresholds

- Decisions to initiate control measures are based on analyses of larval or adult mosquito population data obtained through surveillance activities
    - The use of baseline information gathered from historical surveillance data is advisable in establishing an action threshold
- The methodology that will be used to determine if and when control measures are instituted should be based on
    - Larval stages: Dip counts or container indices*
    - Adults: Trap counts, landing rate counts (not recommended; see above), and/or number and pattern of service requests. The decision to apply adulticides must be made based on adult surveillance and not solely on weather patterns and/or temporal frequency intervals (ie, “spraying every Wednesday”)
- Proactively determine threshold values that necessitate control measures
    - Action thresholds should remain flexible to adapt to nuisance levels and potential public health risks
- Thresholds for adulticiding should be the highest
- All mosquito-borne disease cases must be investigated individually, and field data and information that are collected should be used to make management decisions on best response plans

*May not correlate closely with adult catches.

Larval Source Reduction

- Source reduction is the single most effective means of vector control
- Environmental control and source reduction begin with a detailed larval survey, including key container types that serve as sources for mosquitoes
- Consider both natural and artificial containers when making efforts to control container-inhabiting mosquitoes

- Removal of conspicuous open containers may “push” *Ae. albopictus* females to oviposit in cryptic habitats; therefore, it is critical to locate and assess all potential container sources, including those that may be more difficult to identify, access, and treat with larvicides
- Detailed recommendations on large-scale environmental modifications to control freshwater and salt-marsh mosquitoes can be found in other published resources

Biologic Control

- Larger aquatic predators such as *Gambusia* spp may control mosquito larvae to some extent in permanent or semipermanent bodies of water but will not control adult mosquitoes fully
- Smaller aquatic predators (eg, predacious copepods) may control mosquito larvae that develop in containers; however, source reduction is the optimal control strategy for these species of mosquitoes
- Proper agencies must be consulted and the potential environmental impact must be assessed before any biologic control agent is released
- Bats, birds, and dragonfly nymphs are not effective as the major component of a mosquito control program

Chemical Control of Larval and Adult Mosquitoes

- Larval management
  - Choices of larvicides and pupicides are based on the individual needs of mosquito control districts
  - Factors to consider when choosing appropriate agents include efficacy, costs, and regulatory and environmental constraints
  - If practical, direct application of larvicides and pupicides should be considered as part of a comprehensive program to control container-inhabiting mosquitoes
  - Low-volume larvicides should be applied using appropriate equipment and effective droplet sizes (see summary, below). Conventional ultra-low volume (ULV) equipment is generally not appropriate for these applications
  - Hot-spot treatments reduce the time and effort needed for door-to-door campaigns in large areas; combined with use of larval surveillance techniques, aerial photography, and geographic information system modeling, these approaches have been demonstrated to be highly effective
- Adult management
  - Adulticiding should be used when deemed necessary, according to data gathered in surveillance activities or in response to public health needs
  - Efforts must be made to focus adulticide applications within intended target areas
  - ULV space sprays are the only effective means of rapidly reducing transmission risk during arboviral disease outbreaks
  - ULV applications are effective in reducing populations of adult container-inhabiting *Aedes* in peridomestic environments, even when applied at night

o Barrier and residual sprays can provide long-lasting control of adult mosquito populations o Removal trapping may be effective but highly cost- and labor-intensive and should be reserved for use during serious outbreaks of mosquito-borne disease o Lethal ovitraps are an effective and inexpensive method for controlling container-inhabiting mosquitoes
Monitoring for Efficacy and Resistance • To ensure temporal and regional uniformity and to assist in the ability to compare results and assess trends, the American Mosquito Control Association recommends following the procedures for pesticide resistance testing outlined by the US Centers for Disease Control and Prevention • Annual resistance testing should be a routine component of all integrated mosquito management programs and occur prior to the start of each mosquito season • Resistance testing should be conducted before a product is first used • Resistance testing should follow published protocols to provide standardized results • A quick resistance assessment should be conducted prior to emergency adulticiding • Assay results should be reported to MosquitoNET: https://wwwn.cdc.gov/Arbonet/MosquitoNET/
Community Outreach ***General Guidelines and Objectives***[1] • **Educational resources are available from the US Centers for Disease Control and Prevention and other national organizations that can be leveraged locally (for example, view https://www.cdc.gov/zika/comm-resources/toolkits.html)** o These materials should be customized or accompanied by materials that describe your local situation • Education is a continuous process that ideally begins before there is a credible public health threat • Establish and maintain credibility and public trust by providing timely, accurate, and actionable information about what is known and what is not known • Include adequate information to dispel rumors and misinformation • Increase access and knowledge of accurate information about arboviral diseases among populations and community members at risk. Convey appropriate action messages for each audience • Increase knowledge of and support for vector control activities in communities • Increase the capacity of health care providers to share accurate health information about arboviral disease prevention to at-risk populations (eg, pregnant women and women of reproductive age, their partners, and affected populations with regard to Zika virus)

- Motivate action by community leaders and organizations to protect at-risk populations from arboviral diseases (for example, protection of pregnant women from Zika infection)
- Route public messages through the agency Public Information Officer for a consistent message

Planning an Outreach Program

- When planning an outreach program, priorities, resources, and budget should be considered:
    - What is going to make someone care about mosquito control? What is your message?
    - Have you determined who your stakeholders are (or should be)?
    - Do you know the best ways to reach and serve your stakeholders?
    - What are the motivating factors for each stakeholder to become engaged?
    - Have you identified any gaps in your message, current outreach, or use of your programs/services?
- Summarize messages with easy-to-remember phrases (ie, "The *5 P's* of Prevention")

Consider Your Stakeholders

- Stakeholders include persons, groups, or institutions that can affect or be affected by a course of action
    - Stakeholders include community residents, agencies (health departments), local and regional officials, local fire and police departments, leaders of community organizations, and the media, among others
    - Involving other stakeholders in your outreach helps to develop support for the plan and identify barriers to implementation
    - Mitigation planning should also incorporate information from scientific and technical sources and subject matter experts.

Consider Communication

- People: Stakeholders represent different groups, in terms of culture, language, race, values, education, or economics
    - Gender, age, and socioeconomic status may be risk factors for arboviral disease transmission
- Channels: Obvious channels for outreach are schools, clubs, churches, and other organizations. Also consider the following:
    - Municipal departments (such as public works, sanitation, trash removal, and building inspection)
    - "Green" organizations (focused on healthy environment and self-reliance)

  - Youth organizations (such as the Girl Scouts and Boy Scouts)
  - Social organizations (such as Habitat for Humanity)
  - Intern programs (social workers, medical personnel, biologists, etc)
  - Public health organizations (community health clinics, medical reserve corps)
  - Extension programs
  - Citizen scientists
- Live Events: Consider where a presence may be beneficial
  - Ensure a translator is on-site, if needed
  - Memorialize the event, self-promote, and spread the message after the event via recordings or pictures posted to social media; recordings of such events may be leveraged as part of public service announcements (PSAs)
- Social Media
  - Creating user-engaging content through various websites, blogs, and social media outlets to maximize reach at low cost
  - Involve social influencers: Bloggers, newspapers, and local radio/TV stations that can do periodic stories or provide 30-second reminders and PSAs
  - Research organizations or media outlets are already in existence and have an established following. Build link relationships with those sites so that your website can be easily accessed by a simple click

Formulating a Work Plan

- Outreach is an ongoing process. The link below is an example of how to create a holistic work plan for your community outreach so that measurements can be effectively gathered

Enroll America Outreach Work Plan:
https://s3.amazonaws.com/assets.enrollamerica.org/wp-content/uploads/2013/12/Enroll-America-Factsheet-HowToOutreachWorkPlan.pdf

Guidelines for Effective Outreach

Accurate, clear, and timely information is required to reduce public anxiety and give people practical and concrete steps to protect themselves. Getting the word out in a nonstigmatizing manner (educating, not frightening) is critical.

- Meet people where they are
- Be respectful
- Listen to your community

- Build trust and relationships
- Get the word out in a nonstigmatizing manner
- Offer service and information in a variety of locations (including home visits) and at nontraditional times, especially after work hours or on weekends
- Make written information friendly and easy to understand, at an accessible reading level and organized such that important information is summarized at the top of each page
- Provide information in the primary language of those who will use the service
- Adequate follow-up is critical
    - Evaluate effect of the intervention and targeted messaging
- Continually assess whether activities are meeting objectives

Record Keeping

- Operators/applicators should record the following for each application and maintain records for the time specified by the lead state regulatory agency
    - Applicator's name, address, and pesticide applicator certification number (if applicable)
    - Application date, time of day, and weather conditions
    - Product name and Environmental Protection Agency registration number
    - General location of application and approximate size of area treated (spray tracks, as recorded by an appropriate GPS system, are desirable)
    - Rate of material applied and total amount applied
- Records also must be maintained on the certification and recertification of all personnel involved in pesticide application
- Surveillance reports for disease vector and nuisance mosquito species should be maintained to promote systematic analysis of the effects of interventions; factors that should be recorded include
    - Results from mosquito egg, larval, and adult surveys
    - Records of surveillance locations and mosquito collection data
    - Records of virus testing results
    - Results of resistance monitoring of local mosquito populations
- Where possible, integrated mosquito control management systems should also include provisions for
    - Logging/tracking citizen complaints and service requests
    - Maintaining records of nonchemical interventions, including community education, door-to-door outreach efforts, waste tire removals, and container elimination campaigns

INTRODUCTION

The concept of integrated mosquito management (IMM) is central to the goal of mosquito prevention and control. The principles underlying IMM were first enumerated in 1871, but a full realization of the complexity of its components has only come about since the mid-twentieth century. The term *Integrated Mosquito Management* is derived from integrated pest management, which has been defined as a synergistic, ecosystem-based strategy that focuses on long-term suppression of pests or their damage through a combination of techniques, including biologic control, trapping, habitat manipulation, and chemical control.[2] IMM follows a similar paradigm.[3] It is a comprehensive mosquito prevention and control strategy that utilizes all available mosquito control methods, either singly or in combination, to exploit the known vulnerabilities of mosquitoes to reduce their numbers while maintaining a quality environment.

The core of IMM includes 4 critical tactics:

1. Surveillance, mapping, and rational setting of action thresholds
2. Physical control through manipulation of mosquito habitat
3. Larval source reduction and adult mosquito control
4. Monitoring for insecticide efficacy and resistance

IMM places an emphasis on flexibility and adaptability; applying any mosquito control measure on a predetermined schedule absent a documented need is not an acceptable practice. Instead, appropriately designed IMM programs are highly responsive to the local situation, being driven by demonstrated need based on surveillance data, mapping, and action thresholds, and are iteratively and actively monitored for efficacy and resistance.

Both the US Centers for Disease Control and Prevention (CDC) and the Environmental Protection Agency (EPA) recognize the need for chemical control measures for mosquitoes. IMM programs utilize public health pesticides in a targeted manner after surveillance results provide objective evidence that they are required according to established intervention thresholds, and only after the potential public health benefits have been evaluated. In this paradigm, treatments are made with the primary goal of removing only the target mosquito. The modalities for control methodologies are identified and used in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment while effectively managing mosquito populations.

In addition to causing considerable public nuisance, mosquitoes are vectors for arboviral diseases in the United States, highlighted most recently by the increasing incidence of Zika virus infections in the United States and its territories.[4] The mosquito species *Aedes aegypti* and *Aedes albopictus* are the principal vectors for chikungunya, dengue, yellow fever, and Zika viruses.[5] Both species vary considerably in behavior from most native species, particularly with regard to feeding behavior, degree of adaptation to urban and suburban areas, and choice of habitat for oviposition; using natural and artificial water-holding containers (eg, used tires, plastic containers, gutters, and other containers abundant in the peridomestic environment) rather than permanent or transitory groundwater sources. At present, the prevention or reduction of transmission of these viruses, with the exception of yellow fever, is entirely dependent on the control of mosquito vectors and limiting person-to-mosquito contact.[6]

Along with the human health problems posed by *Ae. aegypti* and *Ae. albopictus*, various *Culex* species, including but not limited to *Cx. pipiens, Cx. tarsalis,* and *Cx. quinquefasciatus*, are vectors of varying competence for West Nile virus in the United States.[6] These and other species of mosquitoes capable of vectoring a number of viral encephalitides and parasitic worms can be successfully addressed with conventional IMM modalities.

This document represents a critical update to the 2009 American Mosquito Control Association (AMCA) Best Practices for Integrated Mosquito Management. This update was occasioned by the increasing importance of container-inhabiting *Ae. aegypti* and *Ae. albopictus* mosquitoes as vectors of human disease. In accordance with best practices, this document is based—where possible—on a comprehensive analysis of the mosquito control literature. This evidence-based structure provides a rational foundation for recommendations. With that said, it should be emphasized that this document also leverages the practical experience and best practices of a panel of vector control professionals. Conventional IMM approaches in the United States also address salt-marsh and freshwater mosquitoes—species for which the larval habitats are generally more accessible and predictable.

The recommendations summarized here are intended to be broad guidelines for integrated mosquito control. While all mosquito control programs should strive to employ the full range of IMM techniques, the AMCA recognizes that its full implementation requires a significant expenditure of resources that may be beyond the capabilities of many mosquito control programs, which are generally subject to budget and personnel constraints.

The extent and manner to which control agencies meet or exceed these best management practices should be ultimately based on the best professional judgment of mosquito control program personnel, often undertaken in consultation with local health and government authorities, in addition to available resources.

SURVEILLANCE

Summary

- Surveillance for native and exotic species should be part of mosquito control abatement, regardless of immediate threat of disease outbreaks. Surveillance should be developed proactively to justify mosquito control funding requirements and risk for arboviral disease transmission
- Mosquito species composition should be identified at the mosquito control district level
- Egg and immature-stage surveillance
    - Oviposition cups use a variety of substrates that are placed in an artificial container, usually a small black plastic cup or jar
    - Nonlethal oviposition cups pose a risk for becoming larval development sites if left unmaintained in the field for more than a week
    - Sampling for non–container-inhabiting mosquitoes involves the use of dippers, nets, aquatic light traps, and suction methods
        - Efforts must be made to train personnel and standardize techniques to improve intersample reliability
    - For monitoring container-inhabiting *Aedes* spp entomologic indices have been the standard
        - Container indices (container index, Breteau index, House Index) may be used to determine abundance of *Aedes* spp
        - Container indices should be interpreted with caution because they may not correlate well with adult surveillance or be useful in setting nuisance action thresholds
- Adult surveillance
    - Light traps are a critical part of mosquito surveillance for a variety of species
    - Light traps are ineffective in most cases for the surveillance of *Aedes aegypti* and *Aedes albopictus*
    - BG-Sentinel™ (BGS) traps are effective for monitoring *Aedes* spp
    - Gravid *Aedes* traps are useful for surveillance of *Aedes* spp
    - Oviposition cups and BGS traps should be used together to monitor both sexes and all physiologic stages of *Aedes* spp
    - Landing rates are labor-intensive and may be associated with potential health risks to field staff in areas with known arbovirus transmissions

A scientifically driven surveillance program is the backbone of every mosquito control operation. The primary purpose of mosquito surveillance is to determine the species composition, abundance, and spatial distribution within the geographic area of interest through collection of eggs, larvae, and adult mosquitoes. Surveillance is valuable for[7]:

- Determining changes in the geographic distribution and abundance of mosquito species
- Evaluating control efforts by comparing presurveillance and postsurveillance data
- Obtaining relative measurements of the vector populations over time and accumulating a historical database
- Facilitating appropriate and timely decisions regarding interventions

In addition, mosquito surveillance programs should include an ongoing component of monitoring environmental factors that can influence mosquito populations. These factors include, but are not limited to, rainfall levels, ground water levels, temperature, relative humidity, wind direction and velocity, tidal changes, lunar cycles, storm water and wastewater management, and land use patterns.[8]

Necessity for Proactive Needs Assessment

It is strongly recommended that a proactive needs assessment be developed at least annually to support funding decisions at the local level. The needs of local mosquito control agencies, which can be clearly defined based on data derived from surveillance efforts, should drive the structure, budget, and implementation of integrated mosquito surveillance programs.[8] In actual practice, budget often drives structure and implementation, with the result that mosquito control programs are funded at levels inadequate to provide comprehensive surveillance or control. Ultimately, such an approach may decrease the effectiveness of interventions and increase long-term costs.

Defining the Problem

Identification of problem species is the first step toward defining and developing control efforts.[8] Control efforts are required when a mosquito poses a nuisance or is an economic or health-related pest or vector[8]:

- Nuisance mosquitoes are bothersome in residential or recreational areas
  Mosquitoes can have a large economic impact, as they may reduce property values, slow economic development of an area, reduce tourism, or affect livestock and poultry production
- Health-related mosquito problems refer to the ability of mosquitoes to transmit pathogens that cause mosquito-borne disease

Target species identification is followed by frequent monitoring of selected areas to determine the abundance of adults and larvae.[8] Egg, larval, and adult surveys should be conducted throughout the mosquito season and should be dynamic, with the precise modalities used depending on season (for example, larval surveillance is most important in the early spring and adult surveillance during peak season). The data generated from these efforts may be used to determine both the abundance and seasonal distribution of problem species.[8]

Specimen Collection for Surveillance

The CDC light trap has been the gold standard trap for many mosquito control programs.[9] This trap was developed in the 1960s and designed for arbovirus survey purposes to make it possible to survey areas where electricity was unavailable. CDC light traps use light and carbon dioxide to attract adult mosquitoes. The gravid trap is another gold standard surveillance tool for collecting gravid females, a critical element of disease surveillance. Mosquitoes have different responses to oviposition media based on the composition of microbial fauna in the media. Grass infusion mostly attracts *Culex* mosquitoes to oviposit egg rafts,[10] and oak leaf or bamboo infusion is found to attract *Aedes*.[11] No single type of trap that provides universal performance by collecting each species in the area of interest.

Egg Surveillance

Historically, oviposition cups have provided useful data on the spatial (often in terms of simple presence or absence) and temporal (seasonal) distributions of container-inhabiting mosquitoes.[12] Although oviposition cups are valuable for determining the presence and absence of *Aedes* vectors, they are not always reliable for adult population estimation. For this reason, collections should be made and assessed in tandem with adult data.[12] Focks and colleagues discussed the problems of using data derived from oviposition cups, emphasizing the effect of skip oviposition behavior in some *Aedes* species and competing containers.[13] Based on experience in urban New Jersey, the number of eggs in oviposition cups does not correlate with the number of females, especially during dry summers. Conversely, Suter and investigators showed that egg data were useful to determine efficacy of intervention methods they employed, and determined 2.26 times higher egg density in control compared to intervention site[14]; their findings are in agreement with studies conducted in Italy.[15,16] Based on conflicting results between eggs and adult populations of *Aedes* mosquitoes, caution is warranted when considering either or both of these surveillance methods.

Many techniques are available to sample mosquito eggs.[12,14,17] These methods have, traditionally, been infrequently used as a primary surveillance system for native mosquito species, as they are highly labor-intensive.[8]

Oviposition cups are small, generally dark-colored containers that contain water and a partially submerged substrate on which female mosquitoes lay their eggs.[5,10] Water with organic infusions (hay, grass, or leaves) is, in many cases, more effective than tap water alone.[10,18] Oviposition cups are inexpensive and easily deployed; adequate sampling requires routine trapping at sites representative of the habitats in the community. Lethal oviposition cups are available.[19] Nonlethal oviposition cups are also available but should not be left unmaintained (infusion and substrate changed and reset) for more than a week at a time due to the risk for production of adult mosquitoes.[5]

Oviposition cups have a number of potential limitations.[5] First, the data generated must be interpreted with caution because oviposition cups compete with natural larval habitats, presenting a problem, particularly after source reduction campaigns.[5] Second, microscopy may be needed to accurately count eggs, especially if debris is present on the oviposition surfaces. Third, trained personnel are required to hatch, rear, and identify species.[5]

Larval and Pupal (Immature Stage) Surveillance

Mosquito larvae and pupae can be collected with dippers, nets, aquatic light traps, suction devices, and container-evacuation methods, and are measured in terms of number of larvae per dip.[8] There is no "standard dipper" or "standard dipping technique"; as such, dipping as a sampling method is somewhat unreliable, as collectors must account for differences in the capture environment, mosquito submerging behavior, and stage differences, among other factors.[8] Thus, training, practice, and experience are critical for control programs that use larval density routinely to determine control measures.

Vector monitoring for container-inhabiting *Aedes* has traditionally relied on sampling of immature stages, such as larvae or pupae[20]; however, *Aedes* species present particular challenges for immature-stage surveys.[5] Because water-holding containers come in a wide variety of types, sizes, and shapes, standard dipping equipment is often unwieldy and ineffective. However, a dipper can still be used for deep containers (such as recycling bins), and a suction device (such as a turkey baster) can be used for slender containers (such as hollow fence posts and narrow tires).

Indices that have been used to quantitate *Aedes* include

- The House Index (the percentage of houses that are positive for larvae)
- The Container Index (the percentage of water-holding containers that are positive for larvae)
- The Breteau Index (defined as the number of mosquito-positive containers per 100 houses).

It should be noted that immature container indices have failed to correlate well with adult catches in BG-Sentinel™ (BGS) traps, nor do they appear to correlate with episodes of nuisance action thresholds.[21] Unlu and colleagues found that, although basic larval indices did not correlate with local adult abundance, a significant correlation was observed when only key positive containers were used for calculation of indices.[21]

Adult Mosquito Surveillance

Adult mosquito monitoring is a necessary component of surveillance activities and is directed toward identifying where adults are most numerous. This information drives response to service requests and helps determine whether interventions (source reduction, larviciding, and/or adulticiding) are effective.[8]

Traps are an integral part of a comprehensive mosquito monitoring program.[22] There are a number of useful traps available for monitoring mosquito populations, including the New Jersey light trap (NJLT), portable carbon dioxide encephalitis vector survey trap, ABS trap, CDC light trap, Mosquito Magnet® X (MMX) trap, BGS trap, Fay-Prince trap, propane-driven traps, gravid, resting boxes, and pigeon- or chicken-baited sentinel boxes. Community nuisance complaints are also useful for surveillance.

The NJLT, long considered the gold standard of traps, employs light and is useful for measuring the relative abundance of certain mosquito species, although many insects other than mosquitoes are attracted to these traps.[8] CDC light traps, miniature versions of the NJLT, operate on battery power and can be used anywhere. Mosquito collection numbers may be enhanced with a secondary mosquito attractant, such as carbon dioxide, octenol, or BG-Lure (composed of ammonia, caproic acid, and lactic acid).[23] Truck traps, aspirators, and MMX traps have been used for adult mosquito surveillance.

A different situation pertains to *Ae. aegypti* and *Ae. albopictus*, which are not efficiently captured by commonly used mosquito traps, such as the CDC light trap or NJLT.[5] Although larval surveys have been the standard for monitoring these species, a greater emphasis is now being placed on monitoring adult populations to provide a more direct assessment of the impact of interventions.[20] At present, BGS traps, as well as the gravid *Aedes* Trap (GAT) and CDC-autocidal gravid ovitrap (CDC-AGO), are the most widely used.[5,19,24] A study compared the BGS trap and GAT for monitoring female *Ae*. *albopictus* and concluded that they are best used as complementary approaches to monitor both sexes and all physiologic stages of female *Ae*. *albopictus*. Although the GAT collected lower numbers than BGS, except for one study location, the versatility and lower cost of the GAT suggests that it is a useful and viable alternative to the BGS trap.[20] CDC-AGO traps are relatively new and studies have been conducted to determine their efficacy for surveillance and control.[19]

It is clear that differences exist in collection efficacy for *Aedes* among traps. A study conducted in 2004 compared 7 traps, including the CDC miniature light trap (with and without light), Fay-Prince trap, an experimental moving-target trap, the Mosquito Deleto™, DragonFly®, and Mosquito Magnet® Liberty traps, for monitoring *Ae*. *albopictus* and *Ae*. *aegypti* originating from a large tire repository in Texas.[25] Among the traps tested, the Mosquito Magnet collected significantly higher numbers of females of these 2 species. The Fay-Prince and DragonFly traps collected the second-highest number of mosquitoes. In terms of *Ae. albopictus* capture, no significant differences existed between DragonFly, CDC without light, and CDC with light captures, which were significantly different from Mosquito Deleto. No statistical significance existed between moving-target, Fay-Prince, CDC traps with light and no light for *Ae*. *aegypti*, and Mosquito Deleto traps.

BGS traps are effective in collecting *Ae. aegypti* and *Ae. albopictus*.[5,26-32] They are routinely used in the monitoring of these species and may have applications in control (discussed later in this document). These collapsible, lightweight traps use visual and olfactory lures to enhance collection and also have the advantage of collecting adult females across physiologic states[5,26-28] Although effective, BGS traps are expensive and must be properly maintained[33] and protected against vandalism or damage from wildlife or pets. Care must be taken to select appropriate sites to optimize collection and protect the trap.

Case Study: Efficient and Effective Use of BGS Traps for Surveillance

To expedite selection of *Ae. albopictus* trapping locations during an area-wide project for suppression, Unlu and colleagues selected 4 sites for surveillance.[33] Sites were chosen because of past requests for service related to *Ae. albopictus* and abundance during routine disease and nuisance surveillance.

Each site, including about 1000 individual parcels, was approximately 0.6 x 0.6 km and all were situated at least 0.5 km apart. Each established site was separated into grid cells using natural boundaries and assigned a unique identification number. The mean number of parcels in each cell was estimated with aerial imagery and a parcel layer in ArcMap 9.2™. The authors sampled randomly and weekly across a predetermined grid of cells that included several parcels. This protocol allowed the authors to utilize the BGS traps within the entire sampling site and estimate the abundance of *Ae. albopictus* at each study site. Each week, an Excel® random number generator was used to select cells for sampling. The first 9 randomly generated numbers were assigned to trapping locations at each site (4 sites x 9 traps). The number of available traps determined how many cells were sampled each week within each site. The cells were displayed on the parcel layer so an address for each parcel and features such as roads, schools, and parks that served as visual limits for the trapping location and cells could be properly identified by field crews. The method of proactively identifying trapping site locations outlined above allowed inspectors to locate trapping sites and alternatives quickly and accurately.

Access into residential parcels to deploy traps in urban environments is often difficult because residents are often not home during the day, parcels may be locked or gated, residents may own guard dogs or others pets, or residents are apathetic toward government employees; parcels may be abandoned and pose physical structural hazards or harbor squatters. The authors acquired permission from residents before BGS traps were placed. A notice with a detailed explanation about their surveillance efforts and contact information was placed for residents who were not home during the pretrapping site visit.

The authors experienced a low rate of refusal (≈5%) in the city of Trenton, New Jersey. To increase contact with residents who may have been at work between 7:30 AM and 3:30 PM, staff worked from 4:00 PM to 8:00 PM. Residents were also asked to leave their property unlocked and keep pets indoors during the sampling period. Although compliance was high, if residents did not grant permission, another nearby parcel was quickly chosen. Social apathy or refusal based on government affiliation was not a major concern during surveillance. In general, residents in lower socioeconomic areas welcomed attention. In fact, several residents became interested in the project and regularly asked about the mosquito counts in their own yards and community.

Abandoned parcels posed a problem during these investigations. Neglected and vacant parcels often were dangerous for field crews because of falling structures and other physical hazards, and high rates of squatting increased the rates of trap vandalism. To avoid losing data and expensive BGS traps, they were placed only within occupied parcels.

Most mosquitoes avoid direct sunlight and wind, thus BGS traps should be placed in shaded and sheltered areas. However, heavily urbanized locations may have fewer shaded habitats compared to suburban neighborhoods. If a parcel did not include shade from vegetation, traps were placed in shade created by infrastructures, such as an alcove between adjoining duplexes or row homes. Temperature and humidity also affect success, so if a parcel did not have a suitable location for trap placement, an alternative parcel was used. Because the BGS trap attracts *Ae. albopictus* visually as well as with the lure during operation, traps were not covered during sampling. Traps were operated weekly for 24-hour periods, depending on weather conditions. On the whole, mosquito inspectors located suitable shaded habitats within most preselected parcels, and rainfall did not affect trapping surveillance.

Oviposition cups such as the GAT use organics in water to capture gravid female mosquitoes, including those that have the potential to transmit arboviruses.[8,34] Because females collected by these traps have already blood fed, and thus have a greater probability of an arbovirus being present in their salivary glands, they are useful for ongoing risk assessment.[8] The ovilures used should be tailored to the problem species to enhance catches (for example, hay infusion for *Cx. quinquefasciatus*, alfalfa infusion for *Ae. aegypti*, and oak leaf infusion for *Ae. triseriatus)*.[8] Autocidal gravid traps (discussed below) have been used to control and prevent outbreaks of *Ae. aegypti*.[10,34] Gravid traps are considerably less expensive and easier to use than BGS traps.[34] Ideally, GAT and BGS traps should be used in a complementary way to monitor both sexes and all physiologic stages of *Aedes*.[20] Eggs must be hatched and reared for accurate identification.

Nonlethal oviposition cups should not be left in the field for more than 1 week to 10 days without maintenance due to the risk that they may become a potential larval development site.[35] Issues associated with oviposition cups include correlating adult female counts from egg numbers and the propensity of invasive *Aedes* to exhibit skip-oviposition.

Aspirator devices, such as sweepers, suction traps, and hand-held battery-operated flashlight aspirators, may be used to collect resting mosquitoes on either natural resting harborage or artificial resting structures.[8] Mosquitoes enter the resting box traps in the morning; collection by aspirator is conducted in mid morning to late afternoon when the mosquitoes are inactive.[8] Because adult mosquitoes are collected across a variety of physiologic states (unfed, blood-fed, gravid, males and females), collecting resting mosquitoes has the advantage of providing an accurate representation of the overall vector population.[5,36] Aspirators also have utility in collecting mosquitoes indoors.[5] Although efforts can be made to standardize indoor sampling, there is often substantial variability in the number of mosquitoes collected at each location; thus, sampling large numbers of houses in a short period of time (100-200 houses per neighborhood) is required.[5] Because most locations harbor low densities of mosquitoes, and because there is a wide variety of potential resting sites, outdoor sampling with mechanical aspirators is difficult to standardize and labor-intensive; further, sufficient sample sizes are frequently difficult to obtain.[5] The CDC-Backpack Aspirator has been widely used for indoor collections of certain domestic mosquito species, including *Aedes*; however, it has a number of limitations, including weight and cost. As an alternative, a less expensive, battery-powered, relatively light aspirator, the ProkoPack™, has been developed that efficiently collects adult mosquitoes.[37]

Landing and Biting Counts

Although not recommended by the CDC, many mosquito control programs utilize landing rates for measuring adult mosquito activity.[8] This measure simply quantifies the number of mosquitoes that land on a person in a predefined time period. While effective, landing rates are labor-intensive and may be associated with potential health risks to field staff in areas with known arbovirus transmission. The CDC does not recommend the landing rate technique for this reason.[5]

If landing rates are used, variables to be taken into account include[8]

- Time of observations
- Duration of observations
- Portion of subject's body observed for landing mosquitoes
- Number and type of nearby habitats
- Number of subjects used

Landing protocols must be standardized to acquire meaningful data; they are most effective when the same subject performs repeated measures at a given site, as there is considerable interindividual variability in attracting and collecting specimens.[8]

Handling of Field-Collected Mosquitoes

Disease surveillance relies on detection of arbovirus in collected mosquitoes through detection of proteins, RNA, or disease-causing organisms. Therefore, it is critical that collected mosquitoes be handled in a manner that minimizes exposure to conditions that could degrade the virus, such as heat or successive freeze-thaw cycles. The CDC recommends the following steps for mosquito samples intended for testing[5]:

- A cold chain should be maintained from the time mosquitoes are removed from traps to the time they are delivered to the processing laboratory and through any short-term storage and processing
- Mosquitoes should be transported from the field in a cooler with either ice packs or dry ice
- Mosquitoes should be sorted and identified on a chill table or tray of ice, if available
- Pooled samples should be stored frozen, optimally at -70°C, but temperatures below freezing may suffice for short-term storage

Typically, mosquitoes are tested in pools of fewer than 50, and only female mosquitoes are tested in routine arbovirus screening programs.[5]

MAPPING

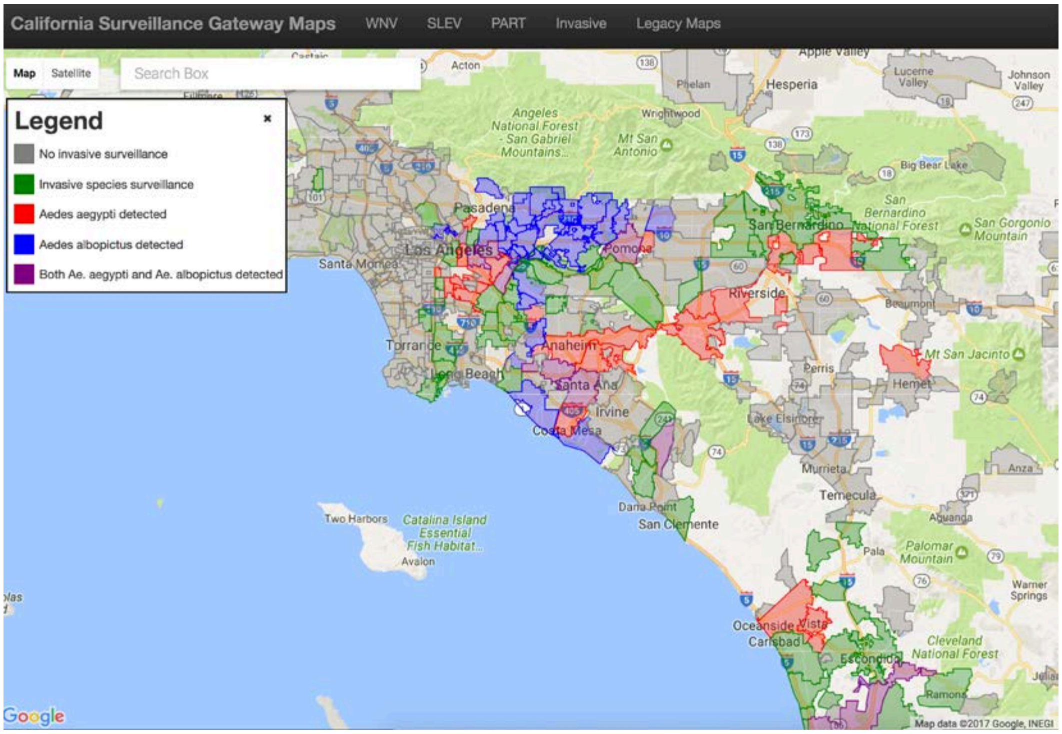
Summary

- Utilize appropriate map scale to resolve mosquito aquatic habitats, adult populations, control efforts, and insecticide resistance
- Record surveillance and control data at the finest spatiotemporal resolution that is operationally feasible
- Ensure that all data are linked to spatial information for use in geographic information systems
- Quantify mosquito population sizes when possible, using standardized methods that allow comparisons among locations
- Use statistical methods only when supported by observed data; estimates based on modeling should convey the amount of uncertainty

Mapping and analysis of spatial data with geographic information systems (GIS) are essential elements of modern mosquito surveillance and control programs. GIS enables decision makers to capture, manage, display, and analyze large quantities of spatial and temporal data in a geographic context. Coupled with remote sensing and decision-support system technologies, GIS provides a powerful platform that can be used not only to enhance surveillance and direct field operations,[38] but also to provide evidence needed to educate the public, government, funding bodies, and other stakeholders.

The routine use of GIS provides many operational advantages for control of invasive mosquitoes[39]:

- Documentation of larval and adult mosquito sources
- Documentation of service requests received from the public
- Visualization and analysis of mosquito distributions and abundance
- Documentation of surveillance and control efforts
- Identification of “hot spots” of mosquito activity or pathogen transmission risk
- Prediction of locations and seasons that are most suitable for invasive mosquitoes
- Resolution of insecticide resistance patterns
- Provision of high-quality printed and digital maps for operational use and education
- Generation of resident lists in specific high-risk areas for targeted notifications or door-to-door surveys
- Enhanced collaboration with other agencies to communicate intentions and coordinate actions across jurisdictional boundaries



California Vectorborne Disease Surveillance System. CalSurv Gateway Maps: Invasive Aedes. 2017; http://maps.calsurv.org/invasive. Accessed January 18, 2017.

There are 3 components involved in the development and application of a GIS[40]:

1. Data acquisition and management
2. Visual presentation
3. Statistical analysis

Spatial data consist of information recorded by mosquito control programs as well as base map layers that provide context. Such data may be acquired by several means. Existing maps or aerial photographs may be digitized and imported into a spatial database. Public domain maps are available on the Internet for all major metropolitan and suburban regions in the United States. Numerous software packages make presentation and basic analyses of spatial data relatively easy (Table 1).[40]

For GIS to be useful for mosquito control, one must first think carefully about the scale at which data are to be recorded, analyzed, and mapped.[38] To the extent that resources allow, it is best to record surveillance and control data at the finest resolution possible to allow for later analyses that may not be foreseen at the time of data collection. Ideally, spatial data should be collected at the level of individual collection locations, sources of larval or adult mosquitoes, or specific locations where control measures have been implemented. Many locations will be recorded as points (eg, trap locations or household inspections), whereas others may be more appropriately recorded as lines (eg, truck-mounted insecticide application routes) or polygons (eg, aerial treatment areas or large larval sources). Spatial data and derived maps can be used as appropriate in the Pesticide Discharge Management Plan.

The use of maps to understand spatial patterns is a simple, straightforward approach to data analysis, as spatial patterns may be self-evident when presented on a map using color gradients, differently sized symbols, or contours. Raw data from trap or control efforts can be mapped directly in GIS software, which can clarify patterns in trap counts or control efforts rapidly without the need for intermediate decisions or other analysis. Superimposing layers on base maps with other geographic features is a qualitative but powerful way to provide data to operational personnel or the public.

In addition to mapping raw data, it is often necessary to perform data analyses that integrate the information from one or more elements of mosquito surveillance and control programs. Spatial tools can provide useful indications to help prioritize public mosquito control measures in areas where nuisance, human-mosquito contact and risk of local arbovirus transmission are likely to be highest. This may include using simple risk models to integrate several surveillance data sets[41] or spatial analyses that help to clarify the relationship between multiple layers of spatial data. For example, GIS has been employed in many areas to understand local factors associated with *Aedes* distribution and abundance.[5,7,8,42-46] More formal data analysis can also be done by modeling, integrating GIS data with standard statistical or mathematical models that capture the dynamics of mosquito populations or pathogen transmission.[47,48] Detailed description of methods for spatial data analysis is beyond the scope of these recommendations.

Operationally, GIS software serves as a spatial toolbox to estimate distances, conduct buffer analyses within special radii, or perform spatial queries that combine data from multiple sources. Results of spatial analyses then can be presented in the form of maps indicating areas of high mosquito abundance or pathogen transmission risk as targets for mosquito control.

For *Ae. albopictus* and *Ae. aegypti*, projected habitat suitability and risk maps have been developed,[49-54] and these are useful at broad scales to guide surveillance or to predict arbovirus transmission risk.[55,56] This is particularly true in temperate habitats where the continued expansion of these species is associated with new public health concerns.[57] Such modeling can be used on a broad scale to predict geographic trends over time, but it also has utility at finer local scales. For example, in areas permanently colonized by *Aedes* species, it is critical to identify potential spatial and temporal hot-spots that may be associated with higher nuisance biting and risk for disease transmission in order to prioritize mosquito control interventions.[42]

Regardless of the GIS or modeling approach taken, it is critical to evaluate the local environment and validate predictions with accurate field entomologic data. The heterogeneity and ubiquity of the larval habitats of *Aedes* species require increased accuracy in predictions so that public health agencies can allocate the most rapid and effective control methods within funding and resource limitations.

Web-Based Mapping and Data Sharing

Online platforms provide powerful opportunities to provide interactive maps to a range of users, from mosquito control professionals to the public, by extending desktop GIS. These systems require back-end GIS expertise to define and maintain the online maps, and ideally they allow end-users to explore spatial data without the need for specialized GIS training.

As a complement to local use of GIS, centralized data management platforms provide the ability to produce state or national maps of invasive mosquitoes or emerging mosquito-borne disease threats. One such system is the CalSurv Gateway, which has been California's official data management system for mosquito and arbovirus surveillance since 2006. Many tools for spatial queries and other calculations are available to registered users, and public-facing online maps provide an overview of *Aedes* surveillance in each city (http://maps.calsurv.org/invasive). Users can click through to local mosquito control agency websites for more information on their city.

The recent emergence of Zika virus as a public health threat to the United States has highlighted the need for a national distribution map of *Ae. aegypti* and *Ae. albopictus.* To address this need, the CDC has established MosquitoNet, a national repository of collection data for these species to inform mosquito control and public-health decisions. This system will complement the ArboNet system, which tracks cases of arboviral diseases and other surveillance data for the United States (https://diseasemaps.usgs.gov/mapviewer/).

Table 1. Examples of Common Software for Use in GIS

Name	**Functionality**	**Provider**	**Website**
ArcGIS	Full-featured GIS (desktop or online)	Environmental Systems Research Institute (ESRI)	http://www.esri.com/software/arcgis
QGIS	Full-featured GIS (desktop or online)	QGIS Development Community (open-source)	http://qgis.org/
GRASS GIS	Full-featured GIS (desktop)	GRASS Development Team (open-source)	https://grass.osgeo.org/
PostGIS	Spatial database management system	PostGIS Development Community (open-source)	http://www.postgis.net/

GIS, geographic information systems.

SETTING ACTION THRESHOLDS

Summary

- Decisions to initiate control measures are based on analyses of larval or adult mosquito population data obtained through surveillance activities
    - The use of baseline information gathered from historical surveillance data is advisable in establishing an action threshold
- The methodology that will be used to determine if and when control measures are instituted should be based on
    - Larval stages: Dip counts or container indices*
    - Adults: Trap counts, landing rate counts (not recommended; see above), and/or number and pattern of service requests. The decision to apply adulticides must be made based on adult surveillance and not solely on weather patterns and/or temporal frequency intervals (ie, "spraying every Wednesday")
- Proactively determine threshold values that necessitate control measures
    - Action thresholds should remain flexible to adapt to nuisance levels and potential public health risks
- Thresholds for adulticiding should be the highest
- All mosquito-borne disease cases must be investigated individually, and field data/information that is collected should be used to make management decisions on best response plans

*May not correlate closely with adult catches.

Decisions to initiate control measures should be based on an analysis of either larval or adult mosquito surveillance or other available field data, as outlined earlier. Programs must establish a mechanism on which decisions to institute control measures are based.[3]

Mosquito control districts should proactively determine the methodology that will be used to determine if and when control measures are instituted. For larval stages of all mosquito species, the standard methodology consists of numbers of larvae and pupae observed in a standard "dip count." Other surveillance and action thresholds may incorporate measures such as the house, container, and/or Breteau indices, or even an egg (ovicup) index. For adults, thresholds may be set based on the number and pattern of service requests, collection rates, or landing rates.

Threshold values for initiating chemical control measures should remain flexible to adapt to nuisance levels and potential public health risks.[3,8] Emergency response plans, including appropriate action thresholds, are valuable in situations when issues of public health are involved.[8] In general, adulticiding should be considered when other control methods are not feasible or have failed previously.[8]

Special considerations pertain to *Aedes* species when setting action thresholds. *Ae. aegypti*, in particular, has a short flight range. As such, large numbers of adult trapping sampling stations are needed to assess adult populations within a local or regional area, which is often impossible for many mosquito control districts. Further, larval indices do not correlate well with adult catches.[21] *Ae. aegypti* has a "nervous" flight/biting behavior and is capable of biting several people in a short period of time. Thus, current entomologic indices may not reliably assess biting or disease transmission risks. In these cases, consideration should be given to setting action thresholds as low as reasonably possible in consideration of disease transmission potential, public service requests, and economics of spray decisions.

Setting a realistic trigger or action threshold for management decisions is highly specific to each mosquito program and must be tailored according to local administrative codes, public acceptance, and public health threat. The CDC has provided guidance on factors to consider when setting action thresholds with regard to Zika virus transmission risk (Table 2).[1] In cases where introduced travel-related or sexually transmitted cases have been reported (Phase Level 1 according to the CDC scheme), it is appropriate to initiate a multimodality adult and larval vector control strategy at and around the site of the case.[1] In cases where there is a suspected or confirmed local transmission or confirmed multiperson local transmission (Phases 2 and 3 in the CDC scheme) immediate vector control actions are warranted.[1] The complete CDC Interim Response Plan is currently available at https://www.cdc.gov/zika/pdfs/zika-draft-interim-conus-plan.pdf.

Table 2. Centers for Disease Control and Prevention Risk Categories for Zika Virus Transmission[1]

Stage	Phase Level	Transmission Risk Category
Pre-incident	**0**	**Preparedness** – vector present or possible in the state
	1	**Mosquito season** – *Aedes aegypti or Aedes albopictus* mosquito biting activity; introduced travel-related, sexually or other body fluid–transmitted cases
Suspected/ confirmed incident	**2**	**Confirmed local transmission** – single, locally acquired case or cases clustered in a single household occurring <2 weeks apart
Incident/response	**3**	**Confirmed multiperson local transmission** – Zika virus illnesses with onsets occurring ≥2 weeks apart but within an approximately 1-mile diameter

All mosquito-borne disease cases must be investigated individually, and field data and information that are collected should be used to make management decisions on best response plans.

All cases are different, and responses must be tailored to the information at hand. Described below are 3 imported Zika cases reported to the Manatee County Mosquito Control District, the field information collected and subsequent response.

Case Studies

Case 1: A middle-aged woman had returned from a Caribbean island vacation in July 2016 and complained to her doctor of feeling ill. The local health department determined the illness to be related to a Zika infection, and the local mosquito control district was notified the same day. The field investigation determined that the patient resided in an affluent, gated neighborhood with a very active homeowners association. No adult *Ae. aegypti* or *Ae. albopictus* larvae were found in the course of an hour-long search over a one-quarter mile radius around the patient's home. No mosquito source containers were located. Since the risk of local disease transmission was very low, no additional control measures were taken.

Case 2: A teenaged boy had returned within his family from a Caribbean vacation, became ill, and was determined to have a Zika infection. Like case 1, the boy resided in an affluent neighborhood and a field investigation found no adults or larvae within the community. However, the boy was active in extracurricular school activities. An investigation around the high school found numerous *Ae. aegypti* and *Ae. albopictus* breeding habitats, as well as some adults of each species. These larval habitats were quickly eliminated; the school's maintenance crew was educated; and a handheld fogger was used to kill the few adults that were found around the agricultural club and athletic fields, which harbored tires used for football practice.

Case 3: A 35-year-old woman returned from visiting extended family in Honduras. After returning home, she felt ill but delayed seeking medical attention. After a week of being ill, she presented to a medical clinic where her state department of public health determined that she had been infected with Zika.

Field investigation found this to be a "worst-case scenario." She resided in a high-density community trailer park. Laundry was often done outdoors, and gray water was openly discharged. Garbage and refuse had accumulated throughout the trailer park. Virtually every home had some degree of mosquito activity, with some homes having hundreds of individual sources (containers). Adult *Ae. aegypti* were present in high numbers. Further, the community of 70 trailers included 4 to 5 "social" areas where residents would gather after work and into the evening.

In response, the mosquito control district quickly assembled 14 employees, who were divided into 4 teams, with each team responsible for 1 section of the community. The response included source reduction of larval habitats; application of chemical larvicides to habitats that could not be eliminated; application of ultra-low volume adulticides via handheld foggers throughout the community and targeted shaded areas; application of long-lasting barrier sprays to hedge rows, shaded areas, and community social gathering sites; and active Zika-prevention education of the residents using bilingual employees and door-hanging leaflets. The area was inspected again 1 day later and again at days 3 and 7. No additional larvae or adults were found. Aerial applications of larvicides and adulticides were considered but were not used, given the apparent success using the approach described earlier. In addition to the 70 trailers within the community, a neighboring community of single-family homes was also inspected and treated similarly.

LARVAL SOURCE REDUCTION

Summary

- Source reduction is the single most effective means of vector control
- Environmental control and source reduction begin with a detailed larval survey, including key container types that serve as sources for mosquitoes
- Consider both natural and artificial containers when making efforts to control container-inhabiting mosquitoes
- Removal of conspicuous open containers may "push" *Ae. albopictus* females to oviposit in cryptic habitats; therefore, it is critical to locate and assess all potential container sources, including those that may be more difficult to identify, access, and treat with larvicides
- Detailed recommendations on large-scale environmental modifications to control freshwater and salt-marsh mosquitoes can be found in other published resources

Larvae of all species of mosquitoes develop in water. Particular species of mosquitoes are adapted to certain types of aquatic habitat, such as pools or ponds of fresh or brackish water with characteristic vegetation, flooded ditches, and small containers of water. To prevent mosquito production, larval source reduction is the most effective means of vector control.[7,58] Larval source management (LSM) involves the removal, modification or treatment, and monitoring of aquatic habitats to reduce mosquito propagation and human-vector contact. Interventions for LSM range from simple—draining aquatic sites or treating them with larvicidal chemicals and removing water-holding containers capable of producing mosquitoes—to complex, such as implementing Rotational Impoundment Management or Open Marsh Water Management techniques.[8]

Detailed recommendations on large-scale environmental modification for the control of freshwater and salt-marsh mosquitoes are beyond the scope of these recommendations (a detailed summary of such methods can be found in the Florida Mosquito Control Handbook).[8] Briefly, source reduction in freshwater habitats (eg, floodplains, swamps, and marshes) typically involves constructing and maintaining channels. These channels or ditches can serve the dual functions of dewatering an area before mosquito emergence can occur and as harborage for larvivorous fish. Ditching and impoundments may be used for salt marsh source reduction. Mosquito production from storm water/wastewater habitats can be a problem but typically can be managed by keeping the area free of weeds through an aquatic plant management program and by maintaining water quality that can support larvivorous fish. Large-scale environmental modification requires close cooperation with local, regional, and national government, and must be conducted with a clear understanding of the potential environmental impact on target and nontarget species.

Source reduction, if carried out comprehensively, is clearly the single most effective control method against container-inhabiting *Aedes* species.[1,59] However, this method is operationally difficult to implement and sustain. Container removal programs and so-called "tip-and-toss" techniques (overturning containers holding water) are effective in eliminating habitat and may be combined with direct larvicide treatments.[35] Given the large number of potential container sources (Table 3) and circumstances where many of these containers are situated on private property, this approach may have only limited success while being labor-intensive and time-consuming, requiring public education efforts (addressed separately in this document) and close cooperation with the community.

Such programs have met with varied success. In central New Jersey, *Ae. albopictus* populations were suppressed (75% fewer adults) by combining source reduction efforts with ultra-low volume (ULV) adulticiding.[60] In China, daily source reduction in a recreational area resulted in only 50% reduction of *Ae. albopictus* for only 2 to 3 weeks.[61] Another study, conducted in Peru, achieved only a 15% reduction in *Ae. aegypti* populations; however, this study targeted only the most productive containers.[62]

Containers harboring *Aedes* can be either natural (eg, tree holes, pitcher plants) or artificial (eg, tires, cemetery vases), and both represent significant sources of disease vectors.[63] Identification and elimination of standing container water sources—even if small—is a critical element of *Aedes* control. A study in a typical New Jersey inner-city urban neighborhood showed that the most abundant containers with *Ae. albopictus* were small trash items (46.5%) and the least abundant were tree holes (0.1%), which were the only natural containers.[21] Other abundant containers included plastic buckets (7.2%), bowls (2.8%), tarps (2.7%), and tires (2.8%). Of the more than 20,000 wet containers inspected, only 2.8% were found to be positive for mosquito larvae, predominantly *Ae. albopictus* (42.3%). It is important to emphasize that containers harboring *Aedes* may not be just "trash"—many of these containers are in use by homeowners (eg, for recycling or water storage) and, thus, cannot simply be eliminated. Where feasible and acceptable, proactively drilling drainage holes in such containers may provide considerable benefit.

The variety and abundance of *Aedes* larval habitats (Table 3), along with their frequent identification in obscure and inaccessible locations (eg, corrugated extension spouts on drainpipes), require a level of control that is not currently possible within most IMM programs. Environmental control and source reduction efforts begin with a detailed larval survey to determine the key container types that serve as sources for local *Aedes* populations. Notably, removal of conspicuous open containers may "push" *Ae. albopictus* females to oviposit in cryptic habitats; hence, it is critical to locate and assess all potential container sources, including those that may be more difficult to identify, access, and treat with larvicides.[35,60]

Table 3. *Aedes* Larval Environments

- Tires, new and used
- Open water storage tanks
- Bottle caps
- Buckets
- Birdbaths
- Coolers
- Fountains
- Gutters and drains with standing water
- Garbage bins and cans
- Houseplant containers and trivets
- Roadside ditches
- Scrap yards with pools in junk
- Fast-food containers and cups
- Cemetery urns
- Unmaintained swimming pools
- Pet bowls
- Septic ditches
- Lawn swales
- Street catch basins
- Depressions in tarp covers
- Rainwater corrugated extension spouts
- Broken appliances
- Vegetation (phytotelmata)
    - Tree holes/crotches
    - Leaf axils
    - Bromeliads

BIOLOGIC CONTROL

Summary

- Larger aquatic predators such as *Gambusia* spp may control mosquito larvae to some extent in permanent or semipermanent bodies of water but will not control adult mosquitoes fully
- Smaller aquatic predators (eg, predacious copepods) may control mosquito larvae that develop in containers; however, source reduction is the optimal control strategy for these species of mosquitoes
- Proper agencies must be consulted and the potential environmental impact must be assessed before any biologic control agent is released
- Bats, birds, and dragonfly nymphs are not effective as the major component of a mosquito control program

Biologic control is defined as using biologic organisms or their by-products to manage vectors, including mosquitoes.[8] It also includes using genetically modified organisms. Mosquitocidal bacteria are discussed in this document separately.

The most readily available large predator for biologic control is *Gambusia* spp (mosquitofish). These small fish are native to eastern North America and are considered an invasive species elsewhere. Typically, *Gambusia* spp are most effective in permanent habitats where *Culex* and *Anopheles* are the primary species and where mosquito densities are not high and vegetation is relatively sparse.[8] Their efficacy in controlling mosquito populations varies widely from excellent to none.[8] *Gambusia* spp do poorly in colder climates and may negatively impact native species.[64]

Biologic control of container-inhabiting mosquitoes is problematic. These sources of water are cryptic and ephemeral, making it not only difficult to identify sources, but also to introduce and sustain biologic control agents. For these mosquitoes, it is generally more effective to simply remove sources from the environment. Smaller predators (eg, *Mesocyclops longisetus* [predacious copepods]) have been used with some success.[65]

Bats,[66] birds,[67] and dragonfly nymphs have been suggested as voracious predators of mosquitoes; however, evidence suggests that this is not true. They are not selective predators of mosquitoes and are not effective as a major component of any control strategy.

CHEMICAL CONTROL OF LARVAL AND ADULT MOSQUITOES

Summary

- Larval management
  - Choices of larvicides and pupicides are based on the individual needs of mosquito control districts
  - Factors to consider when choosing appropriate agents include efficacy, costs, and regulatory and environmental constraints
  - If practical, direct application of larvicides and pupicides should be considered as part of a comprehensive program to control container-inhabiting mosquitoes
  - Low-volume larvicides should be applied using appropriate equipment and effective droplet sizes (see summary, below). Conventional ultra-low volume (ULV) equipment is generally not appropriate for these applications
  - Hot-spot treatments reduce the time and effort needed for door-to-door campaigns in large areas; combined with use of larval surveillance techniques, aerial photography, and geographic information system modeling, these approaches have been demonstrated to be highly effective
- Adult management
  - Adulticiding should be used when deemed necessary, according to data gathered in surveillance activities or in response to public health needs
  - Efforts must be made to focus adulticide applications within intended target areas
  - ULV space sprays are the only effective means of rapidly reducing transmission risk during arboviral disease outbreaks
  - ULV applications are effective in reducing populations of adult container-inhabiting *Aedes* in peridomestic environments, even when applied at night
  - Barrier and residual sprays can provide long-lasting control of adult mosquito populations
  - Removal trapping may be effective but highly cost- and labor-intensive and should be reserved for use during serious outbreaks of mosquito-borne disease
  - Lethal ovitraps are an effective and inexpensive method for controlling container-inhabiting mosquitoes

Larval Management

Direct Application of Larvicides

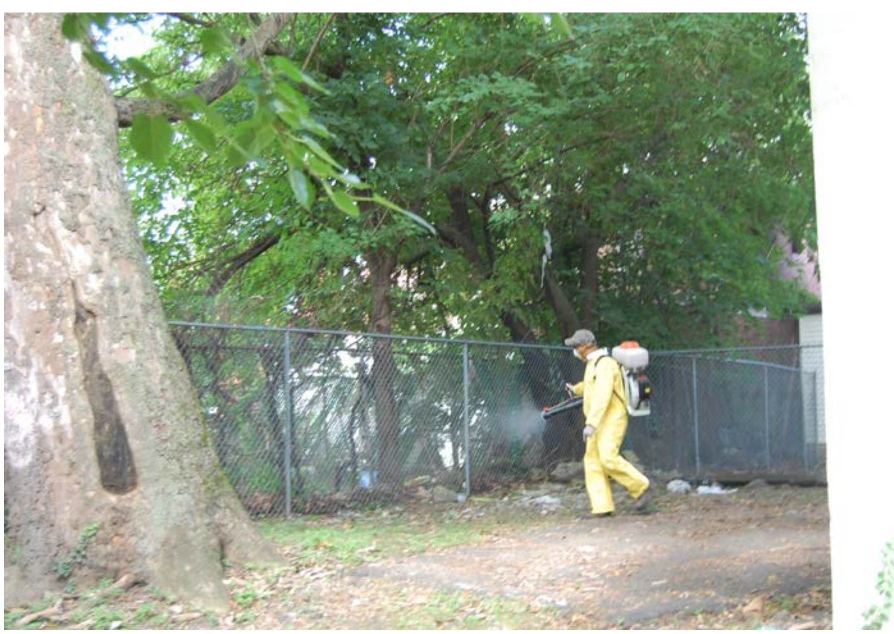
Direct applications of insecticides may be performed by hand or using motorized equipment. Choices of larvicides and pupicides should be based on the individual needs of mosquito control districts, with particular attention paid to regulatory and environmental constraints, cost, and efficacy. Larvicides may be divided into biopesticides and chemical products.[35]

Biopesticide larvicides include

- Microbial control agents such as *Bacillus thuringiensis* (Berliner) serovariety *israelensis* de Barjac (*Bti*), *B. sphaericus* Meyer and Neide (*Bsph*) (*Lysinibacillus sphaericus*), and spinosads derived from fermentation from the soil actinomycete *Saccharopolyspora spinosa* Mertz and Yao
- Insect growth regulators such as methoprene and pyriproxyfen
- Chitin synthesis inhibitors such as diflubenzuron and novaluron

Chemical larvicides include the organophosphates and oils or monomolecular films, which spread on the water surface to form a thin film that prevents gas exchange and leads to eventual suffocation of mosquito larvae.[35]

Larvicides are available in a variety of formulations, including solid granules of various shapes and sizes, water-dispersible granules applied unaltered or in mixture, slow-release briquettes, water-soluble pouches, or pure liquid formulations.[35] Selection of formulation should be driven by careful consideration of the target environment.



For container-inhabiting *Aedes*, given the large number of potential larval sites and the fact that many of these containers are located on private property, direct application may have only limited success and is labor-intensive and time-consuming, while requiring public education efforts (addressed separately in this document) and close cooperation with the community.[35] However, if practical, direct application should be incorporated into an overall IMM approach, because many of the products available are effective and may have a long-lasting residual effect. Because the larval habitats of these species are containers that tend to hold small volumes of water with little to no outflow, most insecticides that infiltrate those habitats exhibit maximum toxicity and persist for a longer period than if they were applied to open water habitats.[35]

Area-Wide Low-Volume Application of Larvicides

Area-wide low-volume (LV) larviciding is effective in delivering insecticides to broad areas, including container habitats that may be inaccessible for direct application efforts.[35] Similar to aerosol ULV adulticiding, where the dispensed small droplets rely on light winds to aid in the spread of droplets, LV larviciding relies on weather conditions for delivery. The major difference between the 2 approaches is droplet size: for ULV adulticiding, a droplet size range of 5 to 25 µm is most efficient, because this size is most likely to stay aloft and deliver a toxic dose to the adult mosquito on contact.[68,69] A larger droplet size (100 to 300 µm) is required for LV applications to create a droplet that is light enough to stay aloft temporarily, but heavy enough to settle into containers harboring *Aedes.*[70] This approach allows for hundreds of residential parcels to be treated in a single nightly application.[60]

Area-wide LV application of larvicides usually uses liquid or emulsified larvicide formulations of *Bti*, such as VectoBac® 12AS or VectoBac® WDG (Valent BioSciences Corp, Libertyville, IL) because of affordability, superior efficacy, reduced nontarget impact, favorable environmental profile, lack of insecticide resistance, and ease of operational use.[60] VectoBac 12AS has a much lower cost per acre than that of VectoBac WDG; however, it can cause spotting on automotive paint and is unsuitable for use in residential areas. VectoBac WDG is more potent at lower concentrations than VectoBac 12AS and is routinely being used by mosquito control programs to target container-inhabiting mosquitoes.

Conventional ULV equipment commonly used in mosquito and vector control programs has insufficient flow rates to apply *Bti*.[70] The Ag-Mister LV-8™ orchard sprayer with 8 nozzles (Curtis Dyna-Fog, Westfield, IN) and the Buffalo Turbine CSM2 Mist Sprayer (Buffalo Turbine, Springville, NY) can deliver increased flow rates and appropriate droplet sizes for peridomestic applications of *Bti*.[70] Aerial equipment also has been used to apply *Bti* in areas where *Aedes* are present and where risks of arboviruses are high.[35]

Beyond the biopesticides, insect growth regulators (IGRs) such as methoprene and pyriproxyfen have been used for area-wide LV applications.[70] Two liquid formulations of methoprene, Altosid® Liquid SR-5 and Altosid® Liquid SR-20 (Wellmark International, Central Life Sciences, Schaumberg, IL), and one formulation of pyriproxyfen, NyGuard® IGR concentrate (McLaughlin Gormley King Co, Minneapolis, MN), have been evaluated in suburban habitats.[60,71] Because lower application rates and flow rates are needed for these formulations, conventional ULV sprayers may be used for area-wide campaigns. The cost per acre for IGRs is generally lower than the cost of *Bti*; however, conducting bioassays is more difficult and time-consuming because of the delayed effects of IGRs and the need for prolonged monitoring to document inhibition of emergence to confirm the effectiveness of applications.

Hot-spot Treatments

Hot-spot treatments rely on ground larval surveillance, aerial photography or imagery, GIS modeling, and adult mosquito or ovitrap surveillance data to pinpoint hot spots within target communities.[71] Such an approach may be particularly useful for container-inhabiting mosquitoes because a small number of sites (such as junkyards, tire recycling sites, some residential sites) may be responsible for the majority of mosquito production in a given area.[35,72]

In the urban habitats of central New Jersey, Unlu and colleagues used a hot-spot approach for *Ae. albopictus* suppression that leveraged data from adult surveillance traps to determine focal locations of infestation (see case study earlier in this document).[73] This approach reduced the use of chemicals and the amount of time spent on source reduction while effectively reducing adult mosquito populations. Notably, targeting hot spots achieved early-season (June to July), area-wide control.

Hot-spot treatments reduce the time and effort needed for door-to-door campaigns in large areas and help ease the pressure on mosquito control inspectors. Furthermore, during public health emergencies in response to arboviral disease cases, areas with human cases can be managed quickly and appropriately. Thus, this approach may be used as an effective tool in an IMM program.

Case Study

Using a Hot-spot Approach to Manage *Aedes albopictus*

Unlu and colleagues (2015) employed a hot-spot approach to controlling *Ae. albopictus* in a suburban environment.[73]

Surveillance was conducted using BGS traps. Trapping locations were selected by overlaying a 175-meter grid over the study sites. These distances were based on the available resources within the county and on knowledge of *Ae. albopictus* flight range. Within the intervention site, 175-meter fishnets resulted in 16 traps. The authors also sampled the control site to compare *Ae. albopictus* populations within the study site. Grids resulted in 24 BGS traps in the control site. Trapping locations were selected by asking permission from residents located near the center of each fishnet grid.

Sampling was performed once a week for 24 hours using BGS traps that were deployed in the shaded areas of backyards (near vegetation) for each parcel selected. The same trapping location was used every week. A trapping site was identified as a hot spot when 5 or more *Ae. albopictus* (ie, intervention threshold) males or females were collected in that one trapping site. After a trapping site was identified as a hot spot, ArcGIS Desktop 9.2 was used to create a 150-meter buffer around that location with three 50-meter increments.

Field crews with maps initiated inspections of selected parcels within the first 50-meter buffer, including front and backyards. After obtaining permission from each owner, control efforts were carried out in as many parcels as possible within each buffer. Field crews were deployed to different parcels to conduct a thorough inspection. Field crews inspected the front and backyards of each parcel, surveying everything that could potentially hold water and produce mosquitoes, such as plant pot saucers, tires, buckets, fence posts, and corrugated extension gutters. After parcels were thoroughly inspected, the alleys were also inspected. During inspections, different control methods (per case) were used, based on the nature of the mosquito infestation. Tires were the only containers removed with the resident’s permission. The remaining containers, both with and without water, were treated with a combination of 2 larvicides and a pupicide based on container type. In addition, overgrown vegetation was managed in abandoned parcels to eliminate mosquito resting areas and detect additional containers hidden under the brush. Barrier spraying was conducted when overgrown vegetation in alleys and abandoned parcels made brush removal unfeasible.

Adult Control

Adulticides are applied to impinge upon the mosquito target in flight or at rest.[35] Adulticiding based on surveillance data is an extremely important part of any IMM program and may form the primary treatment method for many programs where comprehensive larviciding is not practical. Efforts must be made to limit exposure and deposition to target areas.

Adulticides utilized in basic programs are typically applied as a ULV spray, whereby small amounts of insecticide are dispersed by aircraft or truck-mounted equipment. In some jurisdictions, adulticides may also be applied via thermal fogs, utilizing heat to atomize droplets. Adult mosquitoes may also be targeted by barrier treatments, which involve application of a residual insecticide to vegetation or structures where mosquitoes are known to rest. Additional mechanisms, such as removal trapping and lethal ovitraps, are also available.

Handheld and Area-Wide ULV Adulticides
Space sprays use ULV technology (cold fogging or thermal space sprays) and are applied with specialized spray equipment mounted in aircraft, on the back of trucks, or by hand.[8] Released aerosols drift through the target zone, persisting in the air and making contact with flying mosquitoes. Space sprays are short-lived and have negligible residual effects. These modalities remain the only effective means of reducing transmission risk during arboviral disease epidemics. Handheld applications of these agents have the same limitations as door-to-door applications of larvicides; however, this modality may have utility for treating limited areas associated with index disease cases.

The primary aim of area-wide ULV adulticide applications is to deliver an effective droplet size using the least amount of insecticide that will control target mosquitoes.[35] Droplet sizes ranging from 5 to 25 µm are most efficient. Weather conditions must be considered when planning and delivering applications; most often, adulticide applications are conducted in the evening or early morning, when a thermal inversion has occurred to keep the insecticide from dispersing upward and in light winds to aid in carrying droplets.

ULV applications are often believed to be ineffective in controlling diurnally active urban mosquitoes, such as *Ae. aegypti* and *Ae. albopictus,* potentially as a result of structural obstacles that protect gravid or engorged females resting during nighttime ULV applications.[74] However, some evidence suggests that such applications may indeed be effective in reducing adult mosquito populations.[75] There is growing evidence that container-inhabiting *Aedes* in peridomestic environments may be active even at night and that ULV applications within urban and suburban habitats may penetrate into habitats that were previously believed to be inaccessible.[76] Advances in formulations and technology are driving changes in adulticide applications, leading to use of the minimum effective dose for maximum efficacy, precision, and accountability. Furthermore, nighttime ULV adulticiding is proving effective in reducing invasive *Aedes* abundance, and its potential for use as part of IMM programs and during disease epidemics, when reducing human illness is of paramount importance, should be highlighted.

Barrier and Residual Adulticides
Residual spraying is used when a longer-term effect is required. Mosquitoes must land on a surface deposit of the insecticide to absorb a toxic dose. Residual sprays often are referred to as barrier or surface treatments. Because the treated areas are generally small, handheld devices, such as a backpack mist blower or compression sprayer, are employed. The insecticide is applied at a concentration lethal enough so that a mosquito landing on the treated vegetation will absorb a sufficient amount of the active ingredient to cause mortality. Barrier treatments can provide control for days or even weeks, depending on the insecticide formulation. These applications are primarily conducted with synthetic pyrethroids and applied to vegetation, unmovable large containers, external walls of homes and sheds, and fences in residential backyards. Although this method of application may be effective against the targeted species, it remains subject to the labor and time issues associated with any door-to-door application scheme.[74]

Studies suggest that barrier spraying of residual insecticides is effective in reducing biting populations of *Aedes*.[77,78] Indoor residual spraying may not be as effective against exophilic species, such as *Ae. albopictus*; therefore, barrier or residual applications against *Ae. albopictus* should concentrate on focal areas that support large larval populations or selected resting sites for peridomestic adult mosquitoes.

Removal Trapping
Questions remain whether traps such as the BGS and Mosquito Magnet can be used for the management of invasive mosquito species. Mixed results have been obtained with the use of the Mosquito Magnet trap to manage *Aedes* species.[79,80] Traps have been used with success to reduce biting pressure locally from the western treehole mosquito, *Ae. sierrensis* (Ludlow). This species primarily undergoes 1 or 2 generations per season and does not fly far from its larval developmental sites, so removing biting adult mosquitoes through trapping is a viable control option.[79] Similarly, *Ae. aegypti* and *Ae. albopictus* do not fly far from larval developmental sites. Use of BGS traps baited with the BG-Lure has been shown to reduce population abundance[81] and human biting rates compared with no intervention.[82] Recent studies in the United States utilizing Mosquito Magnets, coupled with human-scented and octenol lures, have shown that these traps may outperform BGS traps for capturing *Ae. albopictus* up to 6-fold.[83] Cost and labor are a major issue in using BGS traps for control, because trap density and maintenance requirements are high.

Lethal Ovitraps

Ovitraps are simple, inexpensive devices consisting of a small cup that holds water, often mixed with an ovilure, and provide a substrate on which gravid mosquitoes may lay their eggs.[35] Ovitraps have particular utility for *Aedes* because of their predilection to oviposit in artificial containers. As outlined above, these devices have been used extensively for conducting surveillance for invasive *Ae. aegypti* and *Ae. albopictus*.

Lethal (autocidal) ovitraps, such as the CDC-AGO, combine oviposition stimulants with insecticides or mechanical means of ensuring that the trap does not produce adult mosquitoes. These traps have consistently been shown to be effective in reducing populations of container-inhabiting mosquitoes.[34,84-88] Sustained and effective reductions of *Ae. aegypti* populations (80%) have been achieved by the use of CDC-AGO traps (3 per home) in more than 85% of houses in neighborhoods in southern Puerto Rico.[34]

MONITORING FOR EFFICACY AND RESISTANCE

Summary

- To ensure temporal and regional uniformity and to assist in the ability to compare results and assess trends, the American Mosquito Control Association recommends following the procedures for pesticide resistance testing outlined by the US Centers for Disease Control and Prevention
- Annual resistance testing should be a routine component of all integrated mosquito management programs and occur prior to the start of each mosquito season
- Resistance testing should be conducted before a product is first used
- Resistance testing should follow published protocols to provide standardized results
- A quick resistance assessment should be conducted prior to emergency adulticiding
- Assay results should be reported to MosquitoNET: https://wwwn.cdc.gov/Arbonet/MosquitoNET/

Resistance to insecticides is a potential threat to all mosquito control programs. IMM places a priority on mitigating insecticide resistance by using insecticides rationally, monitoring pesticide resistance routinely, and managing insecticide-resistant populations through better coordination among mosquito control programs, insecticide manufacturers, state agencies, and other stakeholders.

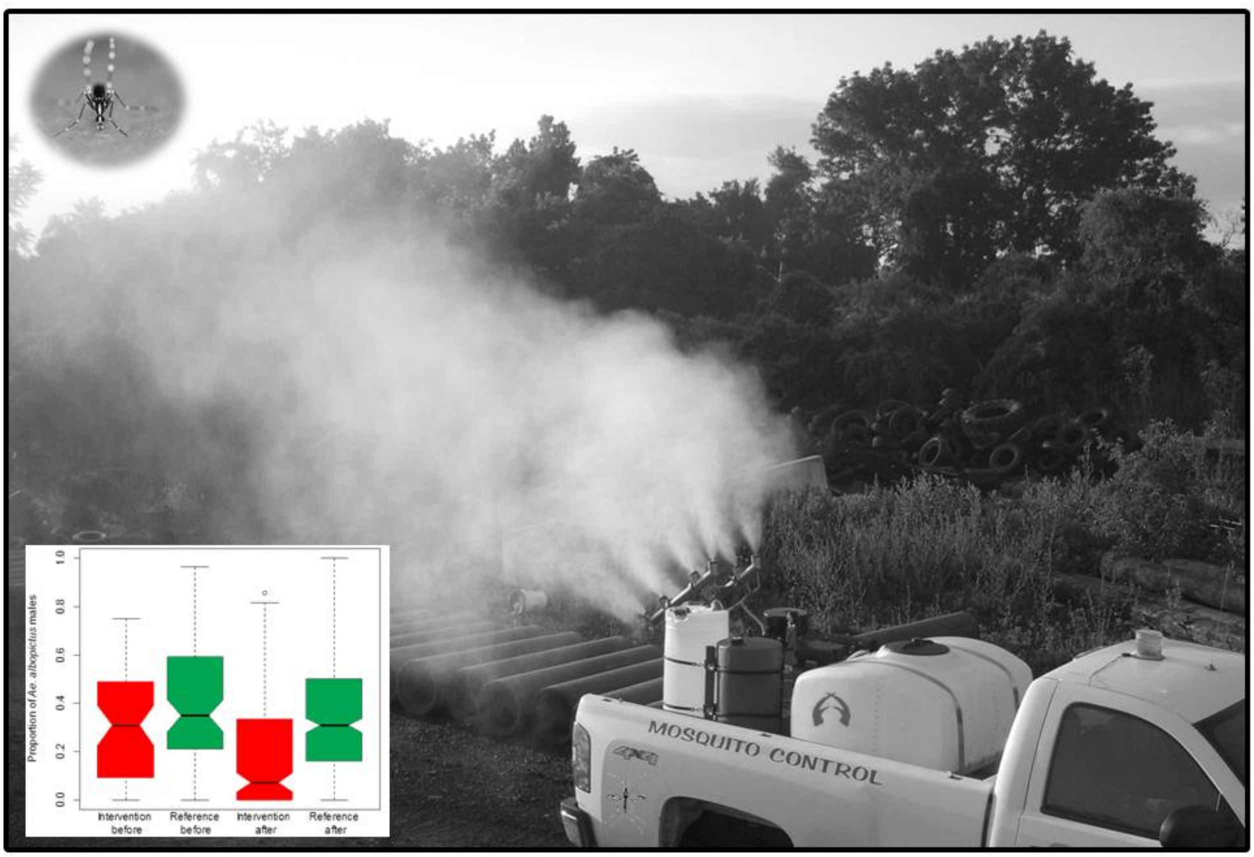
The problem of insecticide resistance among mosquitoes is exemplified by worldwide data gathered during the World Health Organization's effort to control malaria.[89] After many decades of intensive effort, all major vectors of malaria show at least some resistance to all 4 recommended classes of insecticides. Since 2010, 60 countries have reported resistance to at least 1 class of insecticide, with 49 countries reporting resistance to 2 or more classes. However, this is likely an underestimate of the true prevalence of resistance, since many countries do not routinely monitor insecticide resistance locally. Further, the data are frequently not reported in a timely manner, or—in some cases—at all.

Insecticide resistance is broadly categorized into 2 groups: metabolic and target-site.[90] The former occurs when resistant mosquitoes develop enzymes that more rapidly detoxify pesticides, preventing the active ingredient from reaching its physiologic target. The latter is observed when the target of the pesticide on the mosquito is altered by a mutation. For example, mutations of sodium channel receptors produce resistance to pyrethroids, and resistance to organophosphates and pyrethroids results from mutations of the neurotransmitter acetylcholinesterase.

Cross-resistance (ie, resistance to pesticides that share the same mode of action) is common and further restricts the choice of pesticides that can be used.

Behavioral resistance may also occur.[8] For example, when resting surfaces are treated with pesticide, some mosquitoes in the target population may never land on them. This difference in exposure alters survival rates of the next mosquito generation and may increase the frequency of any genetic factors that contribute to the avoidance behavior. If this is true, over time, progressively fewer mosquitoes will be killed by the pesticide.

Detailed recommendations for surveillance and evaluation of pesticide resistance in *Ae. aegypti* and *Ae. albopictus* were released in 2016 by the CDC.[91] A comprehensive discussion of the CDC bottle bioassay can be found online at the link in the reference cited here.[5] To ensure standardized data, the AMCA recommends following the procedures outlined by the CDC.



COMMUNITY OUTREACH

Summary

General Guidelines and Objectives[1]

- **Educational resources are available from the US Centers for Disease Control and Prevention and other national organizations that can be leveraged locally (for example, visit https://www.cdc.gov/zika/comm-resources/toolkits.html)**
    - These materials should be customized or accompanied by materials that describe your local situation
- Education is a continuous process that ideally begins before there is a credible public health threat
- Establish and maintain credibility and public trust by providing timely, accurate, and actionable information about what is known and what is not known
- Include adequate information to dispel rumors and misinformation
- Increase access and knowledge of accurate information about arboviral diseases among populations and community members at risk. Convey appropriate action messages for each audience
- Increase knowledge of and support for vector control activities in communities
- Increase the capacity of health care providers to share accurate health information about arboviral disease prevention to at-risk populations (eg, pregnant women and women of reproductive age, their partners, and affected populations with regard to Zika virus)
- Motivate action by community leaders and organizations to protect at-risk populations from arboviral diseases (for example, protection of pregnant women from Zika infection)
- Route public messages through the agency Public Information Officer for a consistent message

Planning an Outreach Program

- When planning an outreach program, priorities, resources, and budget should be considered:
    - What is going to make someone care about mosquito control? What is your message?
    - Have you determined who your stakeholders are (or should be)?
    - Do you know the best ways to reach and serve your stakeholders?
    - What are the motivating factors for each stakeholder to become engaged?
    - Have you identified any gaps in your message, current outreach, or use of your programs/services?
- Summarize messages with easy-to-remember phrases (ie, “The *5 P’s* of Prevention”)

Consider Your Stakeholders

- Stakeholders include persons, groups, or institutions that can affect or be affected by a course of action
    - Stakeholders include community residents, agencies (health departments), local and regional officials, local fire and police departments, leaders of community organizations, and the media, among others
    - Involving other stakeholders in your outreach helps to develop support for the plan and identify barriers to implementation
    - Mitigation planning should also incorporate information from scientific and technical sources and subject matter experts

Consider Communication

- People: Stakeholders represent different groups, in terms of culture, language, race, values, education, or economics
    - Gender, age, and socioeconomic status may be risk factors for arboviral disease transmission
- Channels: Obvious channels for outreach are schools, clubs, churches, and other organizations. Also consider the following:
    - Municipal departments (such as public works, sanitation, trash removal, and building inspection)
    - "Green" organizations (focused on healthy environment and self-reliance)
    - Youth organizations (such as Girl Scouts and Boy Scouts)
    - Social organizations (such as Habitat for Humanity)
    - Intern programs (social workers, medical personnel, biologists, etc)
    - Public health organizations (community health clinics, medical reserve corps)
    - Extension programs
    - Citizen scientists
- Live Events: Consider where a presence may be beneficial
    - Ensure a translator is on-site, if needed
    - Memorialize the event, self-promote, and spread the message after the event via recordings or pictures posted to social media; recordings of such events may be leveraged as part of public service announcements (PSAs)
- Social Media
    - Creating user-engaging content through various websites, blogs, and social media outlets to maximize reach at low cost
    - Involve social influencers: Bloggers, newspapers, and local radio/TV stations that can do periodic stories or provide 30-second reminders and PSAs

- Research organizations or media outlets are already in existence and have an established following. Build link relationships with those sites so that your website can be easily accessed by a simple click

Formulating a Work Plan

- Outreach is an ongoing process. The link below is an example of how to create a holistic work plan for your community outreach so that measurements can be effectively gathered

Enroll America Outreach Work Plan:
https://s3.amazonaws.com/assets.enrollamerica.org/wp-content/uploads/2013/12/Enroll-America-Factsheet-HowToOutreachWorkPlan.pdf

Guidelines for Effective Outreach

Accurate, clear, and timely information is required to reduce public anxiety and give people practical and concrete steps to protect themselves. Getting the word out in a nonstigmatizing manner (educating, not frightening) is critical.

- Meet people where they are
- Be respectful
- Listen to your community
- Build trust and relationships
- Get the word out in a nonstigmatizing manner
- Offer service and information in a variety of locations (including home visits) and at nontraditional times, especially after work hours or on weekends
- Make written information friendly and easy to understand, at an accessible reading level and organized such that important information is summarized at the top of each page
- Provide information in the primary language of those who will use the service
- Adequate follow-up is critical
    - Evaluate effect of the intervention and targeted messaging
    - Continually assess whether activities are meeting objectives

Public education is a critical component of any mosquito control program. Such programs may include methods that the public can use to reduce larval habitats on private properties and the use of personal protection measures (repellents, clothing, or behavior modifications) to prevent mosquito bites.

Public education and participation are particularly important in light of the problem posed by container-inhabiting mosquitoes because *Ae. aegypti* and *Ae. albopictus* thrive in the peridomestic environment, and their prevalence is closely associated with artificial containers. Such containers are problematic not only because of access issues and quantity, but because even when removed, the mosquitoes may return to the same habitat. Eliminating or reducing artificial container habitats clearly requires public engagement and appropriate education. For these reasons, public education campaigns may be substantially effective as part of an IMM program if community participation and "ownership" can be achieved. Such programs may be passive or active.

Passive education (distribution of educational materials) is not highly effective in engaging the public in control efforts.[92] In one study, 6 communities were randomly selected to receive 1 of 3 strategies: 1) both education and mosquito control 2) education only 3) no education or mosquito control. The education program included a 5-day elementary school curriculum in the spring and 3 door-to-door distributions of educational brochures. The number of mosquito-larval container habitats were counted in 50 randomly selected homes per study area before and after each educational event. Although there were reductions in container habitats in sites receiving education, they were not significantly different from the control. These results suggest that conventional passive public education is not sufficient to motivate residents to reduce backyard mosquito-larval habitats.

Utilize Existing Resources to Maximize Outreach While Minimizing Cost

The CDC has made available a broad range of tailored communication materials to use in readiness for local transmission of arboviral diseases. Many of these materials focus on Zika virus as the arboviral disease of greatest current concern; however, most are applicable in a broad range of situations. A selected list of useful materials can be found below; all are available in PDF format for easy printing and distribution (https://www.cdc.gov/zika/comm-resources/toolkits.html). Many of these materials are available in multiple languages.

• Zika: The Basics of the Virus and How to Protect Against It • Keep Mosquitos Out of Your Septic Tank • Protect Yourself From Mosquito Bites • Help Control Mosquitos that Spread Dengue, Chikungunya, and Zika Viruses • Build Your Own Prevention Kit for Pregnant Women	• Protect Your Family and Community: How Zika Spreads • What you Need to Know About Indoor/Outdoor Spraying • What you Need to Know About Using Adulticides • Accordion-style Insect Repellent Wallet Card • Mosquito Prevention Door Hangers • Zika Basics Flipbook for Community Healthworkers

Active education campaigns have provided better results but are more resource intensive. A more recent study in New Jersey targeting urban and suburban habitats found that using an active community organization (AmeriCorps) for public health education, container removal, tire recycling, gutter cleaning and appropriate drainage, trash can drilling, rain barrel covering, or container elimination demonstrations, and other assistance was much more successful than previously utilized passive means in the same habitats.[93] These results suggest that, although passive education materials may be appropriate for a small proportion of community members, active education campaigns are much more effective on a large community-wide scale.

Examples of Effective Community Outreach Programs

Social Media

- Blogs, Twitter, Facebook: Share information with established blogs and other social media. Include links to your, or other relevant, websites
- Competitions: Announce and conduct contests and neighborhood challenges to clean up potential breeding areas, distribute material, etc
- Videos: Begin a “Submit Your Video” campaign to broadcast and recognize specific

activities and efforts of community groups or individuals

Other Communication/Sharing Channels

- Town hall meetings and discussions in community centers and libraries
- PSAs: Share up-to-date information and reminders via newspapers, TV radio, etc
- Localized Blasts: Leverage municipal phone alert systems during high-risk times
- Inserts included in utility bills
- Welcome Wagon Programs: Partner with local Welcome Wagon organizations to add information about property maintenance and responsibility, community resources, etc, to their packages
- Target Tourists: Tourist information centers, airport and cruise terminals, travel clinics

Live Events/Activities

- Learning sessions or health fairs:
  - For private citizens: Invite community members to a learning session that will provide education
  - For third-party communicators: Hold short educational forums with health care providers, school employees, library employees, and other public intermediaries who can help spread your message. Conduct these during lunch and break times, and entice people to attend with free snacks or beverages
- Street fairs or block parties:
  - Use scheduled events such as fairs, parades, picnics, marathons, and sports events to make a public appearance; distribute mosquito repellent (if permitted within local guidelines); encourage people to clean up trash and turn over containers
  - Approach local businesses about participating in the event
  - Interactive displays: Plan visual demonstrations or games to attract and engage citizens
  - Neighborhood clean-up followed by a community party to play games, listen to music, and share food to celebrate the accomplishment (partner with Keep America Beautiful)
  - Train citizen scientists and hobbyists, such as members of garden clubs and naturalists
- Neighborhood calls to action:
  - Work with organizations such as AmeriCorps to go into neighborhoods and drill holes in cans, clean up areas that are potential risks
- Partner with high schools to organize “clean up” days for student credit for volunteerism or community service programs

- "Go Green" synergy: Partner with "Green" organizations to meld your messages and events with their ongoing efforts (clean up trash, tire disposal areas)

The following are possible locations and partners that can provide resources and/or support to the above examples:

- State, municipal, social service agencies and organizations
- Educational institutions, including day care centers
- Health care facilities
- Law enforcement agencies
- Block captains
- Clubs (Kiwanis, Rotary, Senior Center, and 4-H)
- Local businesses
- Churches (provide training to congregations and/or religious leaders)
- Festivals, fairs, community celebrations, and parades
- Social service outreach (career day open house)
- School events (sports events or campus clubs/activities)

RECORD KEEPING

Summary

- Operators/applicators should record the following for each application and maintain records for the time specified by the lead state regulatory agency
    - Applicator's name, address, and pesticide applicator certification number (if applicable)
    - Application date, time of day, and weather conditions
    - Product name and Environmental Protection Agency registration number
    - General location of application and approximate size of area treated (spray tracks, as recorded by an appropriate GPS system, are desirable)
    - Rate of material applied and total amount applied
- Records also must be maintained on the certification and recertification of all personnel involved in pesticide application
- Surveillance reports for disease vector and nuisance mosquito species should be maintained to promote systematic analysis of the effects of interventions; factors that should be recorded include
    - Results from mosquito egg, larval, and adult surveys
    - Records of surveillance locations and mosquito collection data
    - Records of virus testing results
    - Results of resistance monitoring of local mosquito populations
- Where possible, integrated mosquito control management systems should also include provisions for
    - Logging/tracking citizen complaints and service requests
    - Maintaining records of nonchemical interventions, including community education, door-to-door outreach efforts, waste tire removals, and container elimination campaigns

Accurate record keeping is essential for a mosquito surveillance and control program. At the local level, surveillance data are used to develop accurate distribution and abundance maps, perform statistical analysis to support the decision to initiate control measures (setting action thresholds), and evaluate the impact of control measures. In addition to state regulatory reporting of insecticide applications and applicator training, the CDC has launched the MosquitoNET online portal to collect monthly data for mosquito presence and abundance, and insecticide resistance testing. Arbovirus detection is also reported to the CDC through a national arboviral surveillance system, ArboNet (https://www.cdc.gov/westnile/resourcepages/survresources.html).

It is important to note the difference between a survey and surveillance program. A survey is a one-time gathering of data, often to detect a species presence or absence, whereas a surveillance program is a continuous process to monitor changes in mosquito populations. Additional locations in the surveillance program will increase the likelihood of detecting the presence of a mosquito species; negative surveillance results also yield important information.[91] As suggested by the CDC, each collection should be assigned a unique identification number. This allows for efficient sample tracking within and between years. The following minimum information should be recorded: life stage targeted, collection method, date, location (city/town and county/ parish, address or GPS coordinates), habitat type, and number and type of mosquitoes collected (genus, species, and—when possible—sex and number). Survey, surveillance, and control data should be collected at the finest possible resolution.

If mosquitoes are tested for the presence of arboviruses, the number tested, assay used, and laboratory result should also be recorded. Additionally, when mosquito populations are collected and tested for the presence of insecticide resistance, the above location information should be collected, as well as number of mosquitoes tested, active ingredient, inhibitor, if used, concentration(s) (µg/bottle), time: (between bottle preparation and testing, diagnostic time, and total test time), percent mortality, and, if applicable, time 100% mortality achieved.

Spreadsheet and database software is readily available for data entry and management and can be performed simply in programs such as Microsoft Excel®. Data can be housed locally or in protected online formats (such as Google Docs), and procedures should be created for entry and backup. Extensive external data management support programs are available but are often expensive and unnecessary for most mosquito control programs.

Finally, and perhaps most importantly, pesticide application information should be documented and records maintained as required. The Clean Water Act (1972) regulates point source pollution to or near the waters of the United States, and the National Pollution Discharge Elimination System (NPDES) permit allows for discharges resulting from pesticide applications. Until recently, the mosquito control applications were exempt, since pesticides are regulated by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Mosquito control entities must now apply for an NPDES General Use Permit or through authorized states. Applications must also still comply with all state pesticide regulations, statutes, and FIFRA labeling. Pesticide application records should contain applicator's name, address, and pesticide applicator certification number (if applicable), date of application, product applied name and EPA registration number, rate of material applied, total amount applied, location of application, and approximate size of area treated. Documenting time of day, weather conditions, and spray tracks or blocks, as recorded by an appropriate GPS system, is desirable.

REFERENCES

1. United States Centers for Disease Control and Prevention. Zika CDC Interim Response Plan. https://www.cdc.gov/zika/pdfs/zika-draft-interim-conus-plan.pdf. Accessed January 17, 2017.
2. University of California Agriculture and Natural Resrouces. Statewide Integrated Pest Management Program. Definition of integrated pest management. http://www.plagscan.com/highlight?doc=9872882&source=18. Accessed January 12, 2017.
3. American Mosquito Control Association. Best Practices for Integrated Mosquito Management. http://www.mosquito.org/assets/Resources/PRTools/Resources/bmpsformosquitomanagement.pdf. December 2, 2009.
4. United States Centers for Disease Control. Zika Virus: Case counts in the United States. http://www.cdc.gov/zika/geo/united-states.html. Accessed Novemeber 15, 2016.
5. United States Centers for Disease Control. Surveillance and Control of Aedes aegypti and Aedes albopictus in the United States. http://www.cdc.gov/chikungunya/pdfs/surveillance-and-control-of-aedes-aegypti-and-aedes-albopictus-us.pdf. Accessed November 15, 2016.
6. Hayes EB, Komar N, Nasci RS, Montgomery SP, O'Leary DR, Campbell GL. Epidemiology and transmission dynamics of West Nile virus disease. *Emerg Infect Dis.* 2005;11(8):1167-1173.
7. World Health Organization. Dengue haemorrhagic fever: Diagnosis, treatment, prevention and control. Second edition. 1997.
8. Connely CR, Carlson DB, eds. 2009. Florida Coordinating Council on Mosquito Control. Florida Mosquito Control: The state of the mission as defined by mosquito controllers, regulators, and environmental managers. Vero Beach, FL: University of Florida, Institute of Food and Agricultural Sciences, Florida Medical Entomology Laboratory.
9. Irish SR, Chandre F, N'Guessan R. Comparison of octenol-and BG lure®-baited biogents sentinel traps and an encephalitis virus surveillance trap in Portland, OR. *J Am Mosq Control Assoc.* 2008;24(3):393-397.
10. Reiter P, Amador MA, Colon N. Enhancement of the CDC ovitrap with hay infusions for daily monitoring of Aedes aegypti populations. *J Am Mosq Control Assoc.* 1991;7(1):52-55.
11. Trexler JD, Apperson CS, Zurek L, et al. Role of bacteria in mediating the oviposition responses of *Aedes albopictus* (Diptera: Culicidae). *J Med Entomol.* 2003;40(6):841-848.
12. Fonseca DM, Unlu I, Crepeau T, et al. Area-wide management of *Aedes albopictus*. Part 2: Gauging the efficacy of traditional integrated pest control measures against urban container mosquitoes. *Pest Manage Sci.* 2013;69(12):1351-1361.
13. Focks DA. A review of entomological sampling methods and indicators for dengue vectors. *Geneva: WHO.* 2003.
14. Suter TT, Flacio E, Fariña BF, et al. Surveillance and control of *Aedes albopictus* in the Swiss-Italian border region: Differences in egg densities between intervention and non-intervention areas. *PLoS Negl Trop Dis.* 2016;10(1):e0004315.
15. Facchinelli L, Valerio L, Pombi M, Reiter P, Costantini C, Della Torre A. Development of a novel sticky trap for container-breeding mosquitoes and evaluation of its sampling properties to monitor urban populations of *Aedes albopictus*. *Med Vet Entomol.* 2007;21(2):183-195.
16. Carrieri M, Angelini P, Venturelli C, Maccagnani B, Bellini R. *Aedes albopictus* (Diptera: Culicidae) population size survey in the 2007 Chikungunya outbreak area in Italy. I. Characterization of breeding sites and evaluation of sampling methodologies. *J Med Entomol.* 2011;48(6):1214-1225.
17. Strickman D, Kittayapong P. Dengue and its vectors in Thailand: calculated transmission risk from total pupal counts of *Aedes aegypti* and association of wing-length measurements with

aspects of the larval habitat. *The American Journal of Tropical Medicine and Hygiene.* 2003;68(2):209-217.

18. Gopalakrishnan R, Das M, Baruah I, Veer V, Dutta P. Studies on the ovitraps baited with hay and leaf infusions for the surveillance of dengue vector, Aedes albopictus in northeastern India. *Trop Biomed.* 2012;29(4):598-604.
19. Mackay AJ, Amador M, Barrera R. An improved autocidal gravid ovitrap for the control and surveillance of Aedes aegypti. *Parasit Vectors.* 2013;6(1):225.
20. Johnson BJ, Hurst T, Quoc HL, et al. Field Comparisons of the Gravid Aedes Trap (GAT) and BG-Sentinel Trap for Monitoring Aedes albopictus (Diptera: Culicidae) Populations and Notes on Indoor GAT Collections in Vietnam. *J Med Entomol.* 2016.
21. Unlu I, Farajollahi A, Strickman D, Fonseca DM. Crouching tiger, hidden trouble: Urban sources of *Aedes albopictus* (Diptera: Culicidae) refractory to source-reduction. *PLoS One.* 2013;8(10):e77999.
22. Kline DL. Mosquito population surveillance techiniques. *Technical Bulletin of the Florida Mosquito Control Association 6:2-8.* 2006.
23. Li CX, Smith ML, Fulcher A, Kaufman PE, Zhao T-Y, Xue R-D. Field evaluation of three new mosquito light traps against two standard light traps to collect mosquitoes (Diptera: Culicidae) and non-target insects in northeast Florida. *Florida Entymol.* 2015;98:114-117.
24. Barrera R, Amador M, Acevedo V, Hemme RR, Felix G. Sustained, area-wide control of Aedes aegypti using CDC autocidal gravid ovitraps. *Am J Trop Med Hyg.* 2014;91(6):1269-1276.
25. Dennett JA, Vessey NY, Parsons RE. A comparison of seven traps used for collection of Aedes albopictus and Aedes aegypti originating from a large tire repository in Harris County (Houston), Texas. *J Am Mosq Control Assoc.* 2004;20(4):342-349.
26. Maciel-de-Freitas R, Eiras AE, Lourenco-de-Oliveira R. Field evaluation of effectiveness of the BG-Sentinel, a new trap for capturing adult Aedes aegypti (Diptera: Culicidae). *Mem Inst Oswaldo Cruz.* 2006;101(3):321-325.
27. Williams CR, Long SA, Russell RC, Ritchie SA. Field efficacy of the BG-Sentinel compared with CDC Backpack Aspirators and CO2-baited EVS traps for collection of adult Aedes aegypti in Cairns, Queensland, Australia. *J Am Mosq Control Assoc.* 2006;22(2):296-300.
28. Ball TS, Ritchie SR. Evaluation of BG-sentinel trap trapping efficacy for Aedes aegypti (Diptera: Culicidae) in a visually competitive environment. *J Med Entomol.* 2010;47(4):657-663.
29. Meeraus WH, Armistead JS, Arias JR. Field comparison of novel and gold standard traps for collecting Aedes albopictus in Northern Virginia. *J Am Mosq Control Assoc.* 2008;24(2):244-248.
30. Bhalala H, Arias JR. The Zumba mosquito trap and BG-Sentinel trap: novel surveillance tools for host-seeking mosquitoes. *J Am Mosq Control Assoc.* 2009;25(2):134-139.
31. Farajollahi A, Kesavaraju B, Price DC, et al. Field efficacy of BG-Sentinel and industry-standard traps for Aedes albopictus (Diptera: Culicidae) and West Nile virus surveillance. *J Med Entomol.* 2009;46(4):919-925.
32. Obenauer PJ, Allan SA, Kaufman PE. Aedes albopictus (Diptera: Culicidae) oviposition response to organic infusions from common flora of suburban Florida. *J Vector Ecol.* 2010;35(2):301-306.
33. Unlu I, Farajollahi A. To catch a tiger in a concrete jungle: operational challenges for trapping Aedes albopictus in an urban environment. *J Am Mosq Control Assoc.* 2012;28(4):334-337.
34. Barrera R, Amador M, Acevedo V, Caban B, Felix G, Mackay AJ. Use of the CDC autocidal gravid ovitrap to control and prevent outbreaks of Aedes aegypti (Diptera: Culicidae). *J Med Entomol.* 2014;51(1):145-154.
35. Faraji A, Unlu I. The Eye of the Tiger, the Thrill of the Fight: Effective Larval and Adult Control Measures Against the Asian Tiger Mosquito, Aedes albopictus (Diptera: Culicidae), in North America. *J Med Entomol.* 2016;53(5):1029-1047.

36. Service MW. Importance of ecology in Aedes aegypti control. *Southeast Asian J Trop Med Public Health.* 1992;23(4):681-690.
37. Vazquez-Prokopec GM, Galvin WA, Kelly R, Kitron U. A new, cost-effective, battery-powered aspirator for adult mosquito collections. *J Med Entomol.* 2009;46(6):1256-1259.
38. Eisen L, Eisen RJ. Using geographic information systems and decision support systems for the prediction, prevention, and control of vector-borne diseases. *Annu Rev Entomol.* 2011;56:41-61.
39. Ghilarducci E, Schultz S. Using a geographic information system (GIS) as an important component of a comprehensive integrated vector control program. *Proc Papers Mosq Vect Contr Assoc Calif.* 2011;77:175-176.
40. Gimnig JE, Hightower AW, Hawley WA. Application of geographic information systems to the study of the ecology of mosquitos and mosquito-borne diseases. *Environmental Change and Malaria Risk: Global and Local Implications.* Wageningen UR Frontis Series. 27-39.
41. California Department of Public Health MaVCAoC, University of California. California Mosquito-Borne Virus Surveillance and Response Plan.; 2014. http://westnile.ca.gov/downloads.php?download_id=2958&filename=2014CAResponsePlan.pdf . Accessed January 12, 2017.
42. Manica M, Filipponi F, D'Alessandro A, et al. Spatial and Temporal Hot Spots of Aedes albopictus Abundance inside and outside a South European Metropolitan Area. *PLoS Negl Trop Dis.* 2016;10(6):e0004758.
43. Ferwerda C. Characterizing the relationship between Asian tiger mosquito abundance and habitat in urban New Jersey. MSc, Rutgers University New Brunswick, NJ. 2009.
44. Dowling Z, Ladeau SL, Armbruster P, Biehler D, Leisnham PT. Socioeconomic status affects mosquito (Diptera: Culicidae) larval habitat type availability and infestation level. *J Med Entomol.* 2013;50(4):764-772.
45. Barker CM, Paulson SL, Cantrell S, Davis BS. Habitat preferences and phenology of Ochlerotatus triseriatus and Aedes albopictus (Diptera: Culicidae) in southwestern Virginia. *J Med Entomol.* 2003;40(4):403-410.
46. Barker CM, Brewster CC, Paulson SL. Spatiotemporal oviposition and habitat preferences of Ochlerotatus triseriatus and Aedes albopictus in an emerging focus of La Crosse virus. *J Am Mosq Control Assoc.* 2003;19(4):382-391.
47. Reiner RC, Jr., Perkins TA, Barker CM, et al. A systematic review of mathematical models of mosquito-borne pathogen transmission: 1970-2010. *J R Soc Interface.* 2013;10(81):20120921.
48. Smith DL, Perkins TA, Reiner RC, Jr., et al. Recasting the theory of mosquito-borne pathogen transmission dynamics and control. *Trans R Soc Trop Med Hyg.* 2014;108(4):185-197.
49. Kraemer MU, Sinka ME, Duda KA, et al. The global distribution of the arbovirus vectors Aedes aegypti and Ae. albopictus. *Elife.* 2015;4:e08347.
50. Neteler M, Metz M, Rocchini D, et al. Is Switzerland suitable for the invasion of Aedes albopictus [corrected]? *PLoS One.* 2013;8(12):e82090.
51. Roiz D, Neteler M, Castellani C, Arnoldi D, Rizzoli A. Climatic factors driving invasion of the tiger mosquito (Aedes albopictus) into new areas of Trentino, northern Italy. *PLoS One.* 2011;6(4):e14800.
52. Caminade C, Medlock JM, Ducheyne E, et al. Suitability of European climate for the Asian tiger mosquito Aedes albopictus: recent trends and future scenarios. *J R Soc Interface.* 2012;9(75):2708-2717.
53. Monaghan AJ, Morin CW, Steinhoff DF, et al. On the Seasonal Occurrence and Abundance of the Zika Virus Vector Mosquito Aedes Aegypti in the Contiguous United States. *PLoS Curr.* 2016;8.

54. Donnelly MAP, Marcantonio M, Melton F, Barker CM. Mapping climatic suitability for invasive Aedes aegypti and Aedes albopictus in the United States: a process-based modeling approach. *Proc Mosq Vector Control Assoc Calif.* 2016;84:92-94.
55. Rogers DJ, Suk JE, Semenza JC. Using global maps to predict the risk of dengue in Europe. *Acta Trop.* 2014;129:1-14.
56. Cardoso-Leite R, Vilarinho AC, Novaes MC, Tonetto AF, Vilardi GC, Guillermo-Ferreira R. Recent and future environmental suitability to dengue fever in Brazil using species distribution model. *Trans R Soc Trop Med Hyg.* 2014;108(2):99-104.
57. Schaffner FG, Hendricks G, Scholte E-J, Medlock J, Angelini P, Ducheyne E. Development of Aedes albopictus risk maps, European Centre for Disease Prevention and Control, Stockholm, Sweden.
58. World Health Organization. Larval source management: A supplmentary masure for malaria control. An operational manual. 2013; 128 pp.
59. Hawley WA. The biology of Aedes albopictus. *J Am Mosq Control Assoc Suppl.* 1988;1:1-39.
60. Fonseca DM, Unlu I, Crepeau T, et al. Area-wide management of Aedes albopictus. Part 2: gauging the efficacy of traditional integrated pest control measures against urban container mosquitoes. *Pest Manag Sci.* 2013;69(12):1351-1361.
61. Zhou YB, Zhao T-Y, Leng PE. Evaluation on the control efficacy of source reduction to Aedes albopictus in Shanghai, China. *Chin J Vector Biol Control.* 2009;20:3-6.
62. Wong J, Morrison AC, Stoddard ST, et al. Linking oviposition site choice to offspring fitness in Aedes aegypti: consequences for targeted larval control of dengue vectors. *PLoS Negl Trop Dis.* 2012;6(5):e1632.
63. Skiff JJ, Yee DA. Behavioral differences among four co-occurring species of container mosquito larvae: effects of depth and resource environments. *J Med Entomol.* 2014;51(2):375-381.
64. Segev O, Mangel M, Blaustein L. Deleterious effects by mosquitofish (Gambusia affinis) on the endangered fire salamander (Salamandra infraimmaculata). *Zoo Soc London.* 2008:29-37.
65. Schreiber ET, Hallmon CF, Eskridge KM, Marten GG. Effects of Mesocyclops longisetus (Copepoda:Cyclopidae) on mosquitoes that inhabit tires: influence of litter type, quality, and quantity. *J Am Mosq Control Assoc.* 1996;12(4):688-694.
66. Gonsalves L, Bicknell B, Law B, Webb C, Monamy V. Mosquito consumption by insectivorous bats: does size matter? *PLoS One.* 2013;8(10):e77183.
67. Kale HW. The relationship of purple martins to mosquito control. https://www.pinellascounty.org/PublicWorks/mosquito/pdf/The-Relationship-of-Purple-Martins-to-Mosquito-Control.pdf. Accessed November 15, 2016.
68. Haile D, Mount G, Pierce N. Effect of droplet size of malathion aerosols on kill of caged adult mosquitos. *Mosq News.* 1982;42:576-582.
69. Bonds JA. Ultra-low-volume space sprays in mosquito control: a critical review. *Med Vet Entomol.* 2012;26(2):121-130.
70. Williams GM, Faraji A, Unlu I, et al. Area-wide ground applications of Bacillus thuringiensis var. israelensis for the control of Aedes albopictus in residential neighborhoods: from optimization to operation. *PLoS One.* 2014;9(10):e110035.
71. Suman DS, Farajollahi A, Healy S, et al. Point-source and area-wide field studies of pyriproxyfen autodissemination against urban container-inhabiting mosquitoes. *Acta Trop.* 2014;135:96-103.
72. Unlu I, Farajollahi A, Healy SP, et al. Area-wide management of Aedes albopictus: choice of study sites based on geospatial characteristics, socioeconomic factors and mosquito populations. *Pest Manag Sci.* 2011;67(8):965-974.
73. Unlu I, Klingler K, Indelicato N, Faraji A, Strickman D. Suppression of Aedes albopictus, the Asian tiger mosquito, using a 'hot spot' approach. *Pest Manag Sci.* 2016;72(7):1427-1432.

74. Faraji A, Unlu I, Crepeau T, et al. Droplet Characterization and Penetration of an Ultra-Low Volume Mosquito Adulticide Spray Targeting the Asian Tiger Mosquito, Aedes albopictus, within Urban and Suburban Environments of Northeastern USA. *PLoS One.* 2016;11(4):e0152069.
75. Likos A, Griffin I, Bingham AM, et al. Local mosquito-borne transmission of Zika virus: Miami-Dade and Broward Counties, Florida, June-August 2016. *MMWR.* 2016;65:1032-1038.
76. Farajollahi A, Healy SP, Unlu I, Gaugler R, Fonseca DM. Effectiveness of ultra-low volume nighttime applications of an adulticide against diurnal Aedes albopictus, a critical vector of dengue and chikungunya viruses. *PLoS One.* 2012;7(11):e49181.
77. Trout RT, Brown GC, Potter MF, Hubbard JL. Efficacy of two pyrethroid insecticides applied as barrier treatments for managing mosquito (Diptera: Culicidae) populations in suburban residential properties. *J Med Entomol.* 2007;44(3):470-477.
78. Cilek JE. Application of insecticides to vegetation as barriers against host-seeking mosquitoes. *J Am Mosq Control Assoc.* 2008;24(1):172-176.
79. Kline DL. Traps and trapping techniques for adult mosquito control. *J Am Mosq Control Assoc.* 2006;22(3):490-496.
80. Jackson MJ, Gow JL, Evelyn MJ, et al. An evaluation of the effectiveness of a commercial mechanical trap to reduce abundance of adult nuisance mosquito populations. *J Am Mosq Control Assoc.* 2012;28(4):292-300.
81. Degener CM, Eiras AE, Azara TM, et al. Evaluation of the effectiveness of mass trapping with BG-sentinel traps for dengue vector control: a cluster randomized controlled trial in Manaus, Brazil. *J Med Entomol.* 2014;51(2):408-420.
82. Englbrecht C, Gordon S, Venturelli C, Rose A, Geier M. Evaluation of BG-Sentinel Trap as a Management Tool to Reduce Aedes albopictus Nuisance in an Urban Environment in Italy. *J Am Mosq Control Assoc.* 2015;31(1):16-25.
83. Rochlin I, Kawalkowski M, Ninivaggi DV. Comparison of Mosquito Magnet and Biogents Sentinel Traps for Operational Surveillance of Container-Inhabiting Aedes (Diptera: Culicidae) Species. *J Med Entomol.* 2016;53(2):454-459.
84. Perich MJ, Kardec A, Braga IA, et al. Field evaluation of a lethal ovitrap against dengue vectors in Brazil. *Med Vet Entomol.* 2003;17(2):205-210.
85. Ritchie SA, Long S, Hart A, Webb CE, Russell RC. An adulticidal sticky ovitrap for sampling container-breeding mosquitoes. *J Am Mosq Control Assoc.* 2003;19(3):235-242.
86. Rapley LP, Johnson PH, Williams CR, et al. A lethal ovitrap-based mass trapping scheme for dengue control in Australia: II. Impact on populations of the mosquito Aedes aegypti. *Med Vet Entomol.* 2009;23(4):303-316.
87. Facchinelli L, Valerio I, Pombi M, Reiter P, Constantini C, Della Torre A. Development of a novel sticky trap for container-breeding mosquitoes and evaluation of its sampling properties to monitor urban populations of Aedes albopictus. *Med Vet Entomol.* 2007;21:183-195.
88. Eiras AE, Buhagiar TS, Ritchie SA. Development of the gravid Aedes trap for the capture of adult female container-exploiting mosquitoes (Diptera: Culicidae). *J Med Entomol.* 2014;51(1):200-209.
89. World Health Organization. Insecticide resistance. http://www.who.int/malaria/areas/vector_control/insecticide_resistance/en/. Accessed November 15, 2016.
90. World Health Organization. Test procedures for insecticide resistance monitoring in malaria mosquitos. http://apps.who.int/iris/bitstream/10665/250677/1/9789241511575-eng.pdf?ua=1. Accessed November 15, 2016.
91. United States Centers for Disease Control and Prevention. Guidelines for Aedes aegypti and Aedes albopictus surveillance and insecticide resistance testing in the United States. Atlanta ,

GA: Centers for Disease Control and Prevention; 2016. https://www.cdc.gov/zika/pdfs/guidelines-for-aedes-surveillance-and-insecticide-resistance-testing.pdf, Accessed 20 Dec 2016.
92. Bartlett-Healy K, Hamilton G, Healy S, et al. Source reduction behavior as an independent measurement of the impact of a public health education campaign in an integrated vector management program for the Asian tiger mosquito. *Int J Environ Res Public Health.* 2011;8(5):1358-1367.
93. Healy K, Hamilton G, Crepeau T, et al. Integrating the public in mosquito management: active education by community peers can lead to significant reduction in peridomestic container mosquito habitats. *PLoS One.* 2014;9(9):e108504.