INTEGRATED VECTOR MANAGEMENT IS CRITICAL FOR PROTECTING PUBLIC HEALTH

MVCAC

Mosquito and Vector Control Association of California

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MOSQUITOES ARE THE WORLD'S DEADLIEST ANIMAL

Despite their small size, mosquitoes have a tremendous impact on human health. When a female mosquito takes a meal of human blood to develop her eggs, she can transmit potentially devastating pathogens. Worldwide mosquito-borne diseases kill over one million people each year.[1] Most of these are caused by malaria, a debilitating parasite that, though rarely encountered in California today, was the driving force behind the formation of mosquito control districts in the 1920s.

West Nile virus, the most prevalent mosquito-borne disease in the state, has sickened nearly 7,000 Californians and killed over 300 residents since it was first detected in 2003. There are no human vaccines to protect against many mosquito-transmitted viruses which are costly to treat and can have long-term health and economic consequences.[2]

The recent establishment of the invasive mosquitoes, *Aedes aegypti* and *Aedes albopictus*, in California presents additional challenges. In addition to being persistent day-biting nuisances, these mosquitoes are capable of transmitting several imported pathogens including Zika, dengue, and chikungunya viruses.[1] These pathogens are associated with debilitating diseases, with Zika virus being linked to birth defects when women are infected during pregnancy.[3] These pathogens have the potential to be introduced into the local mosquito population if mosquitoes take blood meals from infected travelers returning from a region where transmission is occurring.

A vector control technician dips water to check for mosquito larvae.

Photo credit: San Gabriel Valley Mosquito and Vector Control District

The risk that unchecked mosquito populations pose to public health is significant and there must be a variety of tools available through an Integrated Vector Management approach in order to effectively protect public health.

MOSQUITOES ARE PROLIFIC AND ADAPTIVE

California is home to more than 50 mosquito species[4], and each one uses sources of standing water to breed. From date palm groves to tidal marshes to tule-laden ponds, millions of mosquitoes emerge each year to bother and sicken residents. Two of the most abundant and widespread mosquito species in the state, *Culex tarsalis* and *Culex pipiens/quinquefasciatus*, are the primary vectors of a number of mosquito-transmitted encephalitis viruses, including West Nile virus.[5]

In addition to being able to exploit natural and agricultural water sources, some mosquitoes have adapted to thrive in man-made water sources in urban and suburban areas. Chief among these are some of California's newest arrivals, *Aedes aegypti* and *Aedes albopictus*.[6] These invasive mosquitoes can develop in very small amounts of water that collect in pots, plant saucers, rain barrels, corrugated tubing connected to yard drains, and even tree-holes and leaf axils of landscape plants.[7] *Aedes* eggs are laid above the water line in containers and can last for months before hatching when submerged in water. After rain or irrigation, a single residential yard can have hundreds of potential mosquito sources. Water conservation and other water management practices can considerably reduce mosquito production and the risk of mosquito-borne diseases.

MOSQUITO AND VECTOR CONTROL DISTRICTS FACE A DAUNTING TASK

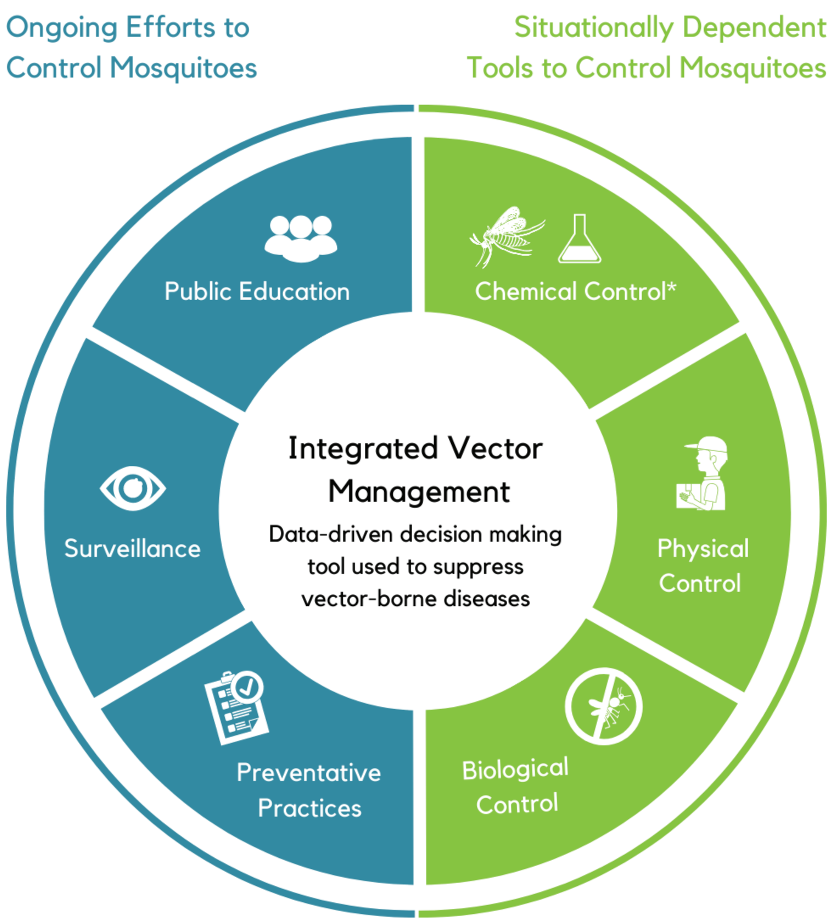
In agricultural and residential pest control, low levels of pest infestation may be tolerated. However, the tolerance for mosquitoes is different as they can pose a risk to human health. Unfortunately, even large mosquito and vector control districts lack the resources to prevent all mosquito-borne disease risks within their jurisdictions. The spread of invasive *Aedes* mosquitoes and the desperate need to prevent the emergence of Zika, dengue, and other viruses has further strained mosquito and vector control districts' limited resources. There is not one solution to controlling mosquitoes – the most effective way to protect public health is to follow Best Management Practices[8] through strategic application of an Integrated Vector Management (IVM) program.[9]

IMPACT OF INVASIVE *AEDES*

Invasive *Aedes* require unique surveillance and control methods which put a significant burden on local mosquito and vector control districts. For example, a Southern California district's operational expenses increased by 34% in one year to deal with these invasive mosquitoes. All districts with invasive *Aedes* detections have had to increase staff, equipment, and traps, and develop additional outreach efforts and materials.

THE VARIED TOOLS OF IVM

Integrated Vector Management is an evidence-based, data-driven decision making tool used to suppress vector-borne diseases. IVM prioritizes surveillance of mosquito populations, removal of breeding sites, public outreach, and education campaigns. IVM incorporates various tools to target mosquitoes at different life stages which can include chemical control. When implementing a control program, districts continually evaluate the strengths, weaknesses, risks, and resource cost of each type of intervention to determine what combination in a given area is most appropriate for the current risk posed to public health from mosquitoes and the pathogens they transmit.[10, 11]



All components of IVM target mosquitoes at their different lifecycle stages, but chemical control is the sole means of eliminating adult mosquitoes over a large area.

COMPONENTS OF INTEGRATED VECTOR MANAGEMENT

Public Education

Involves outreach and community engagement to encourage the public to protect themselves from mosquito bites and prevent mosquito breeding.

Tactics can include earned media, social media outreach, paid advertisements, youth programs, and attendance at community events.

Surveillance

Mosquito abundance and disease surveillance enables districts to make informed decisions about where to focus resources and what level of intervention is required.

Surveillance data also helps districts evaluate the efficacy of the control measures.

Preventative Practices

Integrates vector management strategies into land use and local and regional planning activities.

Encourages good water management and mosquito-prevention habits.

Benefits: can reduce the need for pesticide applications.

Drawbacks: requires considerable public investment, time, and ongoing support for lasting change.

Biological Control

Natural approach that uses predators, such as mosquitofish, to reduce mosquito larvae and pupae. May involve other native fish to minimize adverse impacts to aquatic species.

Benefits: potential long-term and recurring control once successfully established.

Drawbacks: may not adequately eliminate mosquito larvae.

Physical Control

Changes a landscape to eliminate current and future mosquito production. May require support of the property owner or use of enforcement authority.

Benefits: complete elimination of mosquito larvae when effective.

Drawbacks: resource costs including specialized equipment and trained employees; inability to physically modify all sources of standing water; can be time intensive.

Chemical Control

Larviciding

Uses pesticides targeted at localized water sources that have mosquito larvae. Eliminates mosquitoes at the larval stage when they do not have the ability to feed on humans or animals and spread diseases.

Benefits: wide variety of products with high efficiency, specificity, and residual control.

Drawbacks: can be labor intensive to identify and target water sources containing mosquito larvae.

Adulticiding

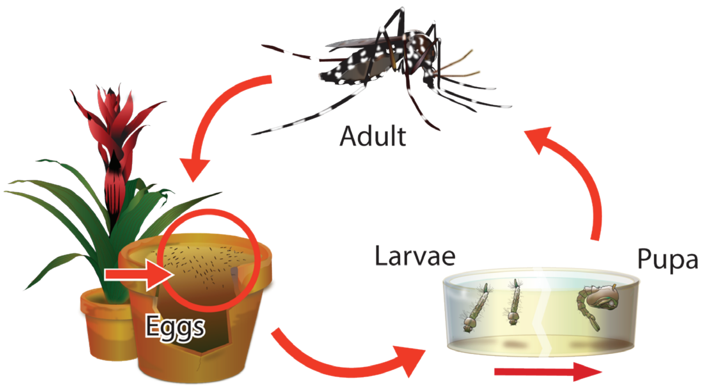
Requires precise timing of insecticides applied in very tiny droplets known as Ultra Low Volume (ULV) application. Sole means of quickly eliminating adult mosquitoes over a large area.

Benefits: reduces transmission of West Nile virus and other mosquito-borne pathogens; minimal public health risks.

Drawbacks: environmental conditions may affect efficacy.

USING SURVEILLANCE AND RISK ASSESSMENTS TO DIRECT MOSQUITO CONTROL OPERATIONS

Many mosquito and vector control districts provide service over large areas with a multitude of known mosquito sources. With newly-created mosquito sources caused by unmaintained swimming pools, residential and agricultural over-irrigation and stormwater capture, treatment and infiltration devices, it is vital to focus efforts where they are most needed. This is achieved through comprehensive surveillance of mosquito populations at all stages of the mosquito's life cycle.[12]



Life cycle: mosquitoes can develop from eggs to biting adults in just 5-7 days.

LARVAL SURVEILLANCE

Almost any standing water that persists for more than a few days has the potential to produce mosquitoes. The factors that favor mosquito development are multifaceted and are an ongoing focus for research, but a number of recurring mosquito source types have been identified in residential, industrial, agricultural, and natural settings. Districts identify these locations and regularly assess the population of mosquito larva, which are then identified by type (genus or species) and life stage. Records of these assessments and the sources from which they arose are maintained often in a georeferenced database for ease of review.

The purpose of larval surveillance is to determine both short-term and long-term actions. Larval surveys can indicate periods of high population that determine when a particular source should be inspected, how often it should be inspected, and help identify factors (i.e. over-irrigation) that can be eliminated by working with the landowner. They can also help determine which control tools districts should use. For example, more immediate and aggressive control measures will be needed if the water source has disease vectors. Surveillance data is also used to evaluate the efficacy of control efforts by determining the extent and duration of larval suppression.

Vector control professionals often use a 'dip count' which measures the number of mosquito larvae collected per dip of water to evaluate mosquito populations.

Photo credit: Orange County Mosquito and Vector Control District

ADULT MOSQUITO SURVEILLANCE

One of the largest components of any vector control operation is surveillance directed at adult mosquitoes because this is the stage that mosquitoes transmit diseases. Since identifying all potential mosquito sources is not possible, districts rely on monitoring adult mosquito activity to identify and prioritize problem areas.

A vector control technician sets a mosquito trap.

Photo credit: San Gabriel Valley Mosquito and Vector Control District

An adult mosquito surveillance program consists of a combination of fixed sites and "floating" sites that are identified in response to resident reports, technician inquiries, human or animal disease detections, or other indicators. Fixed sites provide consistent population data for set areas and serve as a baseline for comparing year-to-year activity. Floating sites allow for quick assessment of potential problem areas and can be used to evaluate the need for additional control or surveillance activities. Adult mosquito surveillance can aid in the identification and treatment of previously undetected larval sources.

There are a variety of traps used to capture adult mosquitoes, but most target one of two adult mosquito behaviors: host-seeking (female mosquitoes looking for a blood meal) and oviposition (females seeking a water source where they can lay their eggs). Traps are placed over a short period of time and contain live mosquitoes when recovered. Samples are sent to district labs where they can be sorted, counted, identified by species, and tested for mosquito-borne viruses.

Laboratory staff sort, count and identify adult mosquitoes.

Photo credit: Contra Costa Mosquito and Vector Control District

DISEASE SURVEILLANCE AND RESPONSE

Mosquito and vector control districts are charged under the California Health & Safety code with protecting Californians against the discomforts, health risks and economic effects of vector-borne diseases.[13] Some districts have the capability to test their own mosquito samples for mosquito-borne viruses and others partner with the California Department of Public Health (CDPH) and the Center for Vectorborne Diseases (CVEC) at the University of California Davis for mosquito sample testing.

West Nile virus is currently the most common mosquito-borne disease in California and is a key target of surveillance efforts. In addition to testing mosquito samples, districts also test dead birds reported by the public[14] and some districts use sentinel chickens to detect active transmission of West Nile virus.[15] Records of viral infection in humans may also be reported by local health districts. While these reports can serve as definitive proof of active virus transmission between mosquitoes and humans, they are often of limited utility in directing operations due to time elapsed between patient infection and the district's notification of the confirmed disease case.[16] Because of this, earlier indicators of disease activity such as mosquito samples and dead birds are used to inform effective intervention efforts.[17]

CALSURV: STATEWIDE SURVEILLANCE DATABASE

California started the first statewide mosquito abundance and disease surveillance database called CalSurv.[20] Surveillance and operations data from local districts are entered into the database for rapid reporting and analysis which aids in the direction of vector control programs. Districts can also access past surveillance data to track trends in mosquito activity or use in applied research. CalSurv's data visualization capabilities help districts use surveillance data to determine the most appropriate and effective IVM control components. CalSurv has expanded and now there are similar systems in Arizona, New Jersey, Tennessee, Utah, and Guam.

Comprehensive mosquito abundance and disease surveillance data allows districts to make informed decisions about where to focus resources and what level of intervention is required. This can be particularly important when considering costly and publicly visible interventions such as large scale area spraying or door-to-door inspection teams. To ensure consistent responses, CDPH has developed a number of disease response plans that factor in a variety of surveillance data and environmental conditions to determine a risk level associated with disease transmission.[12, 18, 19] These plans are widely used by districts and are often incorporated into local operation plans.

PREVENTATIVE PRACTICES: SOURCE PREVENTION AND ELIMINATION BY AN ENGAGED POPULACE

Preventative practices involve a wide range of efforts focused on encouraging good water management and mosquito prevention habits. Best Management Practices[8] (BMPs) have been developed for common land uses that typically create mosquito sources providing details on changes in practices and land modifications that can readily decrease mosquito production and protect public health. Greater support for integration of BMPs is needed at the political and regulatory levels to ensure integration of sound vector management strategies into local and regional planning efforts.

For residential and suburban areas, preventative practices are typically focused on eliminating man made container sources in and around the home. This includes discarding unnecessary containers that can hold water and frequently dumping or draining water sources that cannot be eliminated as mosquitoes can develop from eggs to biting adults in just 5-7 days.

When successful, preventative practices to control mosquitoes have minimal costs, are more sustainable, and reduce the need for pesticide applications. However, successful preventative practices control programs require considerable public investment and ongoing support for lasting change.[22] Districts' capacity for outreach varies, with larger and better funded districts typically having a greater ability to implement a robust public outreach program.

PREVENTATIVE MOSQUITO CONTROL SAVES TIME AND RESOURCES

When the economic downturn of 2007-2008 led to a rapid increase of foreclosures, mosquito and vector control districts quickly realized that unmaintained swimming pools at vacant properties were producing thousands of mosquitoes within a matter of days. Recognizing that waiting for resident complaints or fortuitous trap placement was insufficient, districts sought to identify unmaintained pools before mosquitoes began to emerge. This entailed high elevation aerial photography and outreach to real estate and community partners to identify foreclosed and abandoned homes and allow technicians to systematically inspect these sources.[21]

Tools for outreach and community engagement include comprehensive earned and social media, paid advertisements, youth programs, and attendance at community events. This outreach is designed to encourage the public to protect themselves from mosquito bites by using CDC-approved repellents, wear protective clothing, prevent mosquito access to the home, and avoid outdoor activities during peak periods for disease-transmitting species.

Successful mosquito and vector control requires an engaged community actively thinking about and eliminating mosquito sources. Forming strong working relationships with community groups and other government agencies effectively expands the mosquito control workforce well beyond a local district's staff. The challenge of keeping the public informed and motivated, however, limits the overall impact of preventative practices on mosquito populations and makes the use of additional interventions necessary.

Public outreach, from billboards to social media to community events, is an integral component of IVM.

Photo credit: Sacramento-Yolo Mosquito and Vector Control District

PHYSICAL CONTROL: CHANGING THE LANDSCAPE TO PREVENT RECURRENCE

Physical control involves modifying a mosquito source to eliminate or significantly reduce current and future mosquito production. At the smallest scale this can involve dumping and draining backyard container sources[23] and on a larger scale it can involve managing water flows in salt marshes or levelling flooded grounds.[24] While some of these interventions permanently eliminate future production of mosquitoes on the property, others require periodic maintenance to remain effective.

Limitations of physical control include resource costs and the ability to physically modify mosquito sources. Removing water from backyard container sources, while effective, requires many employees to complete door-to-door inspections. Larger scale projects often require specialized equipment and trained employees. One example is when districts send staff into a flood control channel with hand tools and equipment to remove vegetation and sediments during non-storm periods to keep the water flowing.

Vector control staff use ditching to restore tidal flow to a coastal marsh.

Photo credit: Marin/Sonoma Mosquito and Vector Control District

In addition, not all sources of standing water can be physically modified. Flood-irrigated agricultural sources such as rice and natural standing water sources such as peripheral river seepage points or wetlands cannot be drained or significantly modified without severely interfering with their intended purposes. Even when a source is eligible for physical control significant modification to the property requires cooperation by the property owner. Districts typically try to do this through affirmative outreach and engagement though districts have the power to enforce changes through statutory abatement.[25] The effectiveness of both physical control and preventative practices is dependent on the community's receptiveness to district outreach and engagement efforts and their tolerance for use of enforcement authority against the few property owners that are unwilling to comply.

TIDAL RESTORATION PROJECTS CAN PREVENT MOSQUITO BREEDING

Abandoned salt ponds around the San Francisco Bay have become seasonal wetlands breeding large numbers of saltmarsh mosquitoes in the winter months. These mosquitoes can fly up to 15 miles inland presenting a severe biting nuisance to nearby residential areas. In the 1990s, tidal restoration projects around the Bay – including disking, ditching, dredging, and the installation of tidegates and siphons – permanently reduced the number of acres of mosquito breeding habitat in abandoned salt ponds. This saved tens of thousands of dollars and eliminated the need for ongoing pesticide applications in these areas.

BIOLOGICAL CONTROL: TAKING ADVANTAGE OF MOSQUITOES' NATURAL PREDATORS AND PARASITES

Biological control is defined as using a vector's natural enemies to reduce the population of the target vector typically with the assistance of human activity.[26] Fish have long been used to manage immature mosquito larvae and pupae. Mosquitofish (*Gambusia* sp.) remain the most widely used fish for mosquito control because of their hardiness, high potential for reproduction, and ability to feed readily on mosquito and other insect larvae.[27, 28, 29, 30, 31, 32]

Mosquitofish feed on mosquito larvae and pupae. They provide effective control when used alone or with larvicide applications in a variety of standing water habitats ranging from ornamental ponds to neglected swimming pools. However, mosquitofish do not serve as a cure-all for ongoing mosquito management. Mosquitofish should be used thoughtfully and strategically in appropriate sources to minimize any adverse impacts to other aquatic species, and when available, other native fishes should be considered for mosquito management.

A vector control technician releases mosquitofish into an abandoned swimming pool.

Photo credit: Contra Costa Mosquito and Vector Control District

Another component of biological control is encouragement of local, non-introduced predator populations. Several native aquatic invertebrates regularly prey on mosquito larva and in sufficient numbers can greatly reduce the production of a mosquito source. Mosquitoes tend to utilize recently-flooded and marginal waterways that other species are not as adept at colonizing. As such, it can be beneficial to create deep water continually-flooded predator reserves to facilitate rapid introduction of predator species upon flooding of adjacent lands.

Biological control is a vital part of IVM as it is one of the few approaches that provides the opportunity for long-term and recurring control once successfully established. It also tends to be popular with the public offering a more "natural" approach to mosquito control. The limitations in its degree of control and areas of use, however, require additional control methods to ensure adequate suppression of vector populations.[33]

OTHER "MOSQUITO EATERS"

While mosquitofish are an effective biological control tool, many organisms that people think of as 'mosquito eaters' aren't actually effective predators. Bats, birds, and dragonflies eat mosquitoes, but these animals have varied diets which means they don't eat enough mosquitoes to provide effective mosquito control.

CHEMICAL CONTROL: TO SPRAY OR NOT TO SPRAY?

Chemical control methods are a major point of focus in mosquito and vector control operations, garnering both positive and negative attention. Public health pesticides play a vital role (though not a sole role) in IVM plans due to their versatility, effectiveness, and rapid deployment in comparison to other control methods. Yet pesticides have had a tumultuous history (mostly outside of public health) with an ever-changing regulatory landscape that creates uncertainty for users and the public alike.

Toxicity is a complex topic that involves a number of factors including the type and degree of exposure, dosage, and the biological traits of the target organism.[34] Products used in public health mosquito control are specifically formulated for elimination of mosquitoes and when used in accordance with the label they pose minimal risks to human health and non-target organisms. The use of these products for mosquito control is supported by the U.S. Centers for Disease Control and Prevention and the U.S. Environmental Protection Agency.[35, 36]

Public health pesticides play a vital role in IVM.

Photo credit: Placer Mosquito and Vector Control District

As applied to mosquito control, there are two main categories of pesticides: "larvicides"[37] which are used to control mosquitoes in their aquatic immature stages and "adulticides"[38] which target mosquitoes in their terrestrial adult stage.

LARVICIDES: CONTROL TARGETED DIRECTLY TO THE STANDING WATER SOURCE

General categories of larvicides include: surfactants/suffocants (oils that suffocate the immature mosquito), insect growth regulators (products that interfere with larval growth and development), and bacterial-origin larvicides (products that contain insect toxins derived from bacteria). Within these categories there are many active ingredients and different formulations used for various methods of application and duration of effectiveness. Most larvicides are biorationals which means they are relatively non-toxic to humans and have minimal environmental impacts. Since each type of larvicide can only target certain stages of mosquito larvae and pupae an active control program requires the whole range of available tools.

WIDE-AREA LARVICIDING

Most mosquito larvicide applications occur directly to water sources, but mosquito control programs may also treat large areas with larvicides using truck-mounted equipment or helicopters. These applications can disperse small amounts of mosquito larvicide across many acres of land which helps prevent mosquito breeding in hidden water sources.[39]

Eliminating mosquitoes at the larval stage whenever possible is a core principle of IVM. To this end, mosquito and vector control districts focus their chemical control components primarily on larviciding. The reason for this is simple: at the larval stage the mosquitoes are concentrated in their water source and do not have the capability to feed on humans and animals and spread mosquito-borne pathogens.

A vector control technician treats a stormwater catch basin with a larvicide tablet.

Photo credit: Contra Costa Mosquito and Vector Control District

However, the main advantage of targeting larvae is also its greatest limitation: the water source containing the larvae must be identified and directly targeted. Whether a single storm drain treated by hand or acres of flooded field treated by plane, the larvicide product must find its way into the water. Use of larvicides also poses a challenge for resource management. Long-term residual products can allow for sustained control of a standing water source, but come at a significantly higher cost than short term products. Districts must not only identify active sources, but determine what type of treatment is required based on the mosquito production level and likelihood of recurrence. Districts work to continually identify, control, and when feasible remove active mosquito sources. Despite these efforts, not all sources can be discovered and adult mosquitoes will emerge heightening the public health risk.

A helicopter is used to apply larvicide to a marsh.

Photo credit: San Mateo County Mosquito and Vector Control District

ADULTICIDES PROVIDE WIDE-AREA APPLICATION, BUT HAVE A NARROW USE

Adulticiding involves the use of insecticides typically applied in very tiny droplets, a process known as Ultra Low Volume ("ULV") application.[40] During application adult mosquitoes come into physical contact with these droplets exposing them to the toxins. Since efficacy of adulticide applications relies in large part on the number of droplets that impact a flying adult mosquito, adulticiding requires precise timing. Most applications are made when there is the most mosquito activity and may be adjusted to correspond with environmental conditions.[41] Even when applications are made at optimum times, they will not be able to completely eliminate the adult mosquito population in the targeted area. Nonetheless, successful adulticiding has been correlated with reducing the presence of pathogens in mosquitoes within the areas that were treated.[42]

Adult mosquito control can be conducted using trucks or aircraft.

Photo Credit: San Joaquin County Mosquito and Vector Control District

There are a very limited number of active ingredients that can be used in adulticides that both control mosquitoes and protect public health. Most products used are either pyrethrins or pyrethroids which interfere with nerve function in targeted insects.[43] Unfortunately, mosquito populations can develop resistance to any or all of these products. While not widely used in California, organophosphate adulticide use is on the rise as considerable resistance to pyrethrins and pyrethroids is being detected in mosquito species that are a public health concern throughout the state.

Since adulticide applications are often made over large areas and are frequently focused in populated areas to reduce local disease transmission, the public is more likely to be exposed to these products. As a result, adulticiding operations often garner significant attention from the public, some of it negative. Districts work diligently to keep residents informed of their operations and, where feasible, avoid spraying when large crowds of residents may be outside. Districts take measures to ensure proper and safe application of products and adverse impacts on humans are not a realistic concern for adulticiding operations.[44] The products used present a minimal risk to the public's health and numerous studies have shown that ULV applications result in rates of exposure too low to be of public health concern.[45] Research also shows that large scale adulticiding events do not result in increased reports of adverse effects among people in the treated areas. When compared to the risks associated with unchecked virus transmission by mosquitoes, the use of adulticides as part of a comprehensive IVM program are easily justified, if not demanded.[46] Adulticiding remains the sole means districts have for rapidly targeting adult mosquitoes and has been demonstrated to reduce the transmission of West Nile virus and other mosquito-borne pathogens.[47, 48, 49]

EVALUATING EFFICACY OF OPERATIONS AND ENSURING ONGOING VIABILITY

Control of mosquitoes and other vectors is an ongoing process throughout the organism's active season.[50] Equally important to identifying and controlling mosquitoes are consistent evaluations of efficacy. The preceding sections have outlined advantages and disadvantages for various control techniques, but this is not a static assessment. What is the most effective tool for controlling mosquitoes in a particular situation involves a great number of variables, and an effective mosquito control program must constantly adapt to changing conditions.

Research and evaluation ensures that mosquito control operations continue to be viable despite ongoing challenges.

Photo credit: San Joaquin County Mosquito and Vector Control District

Evaluating efficacy of mosquito control measures will typically involve all aspects of larval and adult surveillance. By comparing assessments before and after treatment, the degree of reduction can be determined. When there hasn't been a significant reduction in mosquitoes, districts will determine whether there was an error in application (requiring retreatment and possibly revised protocols), a previously unknown source contributing to the problem or most problematically an indication of a pesticide resistant mosquito population.

Some mosquitoes have developed resistance to products used to control them at both the larval and adult stages.[51,52] To avoid promoting resistance, districts rotate products that have different means of killing mosquitoes. This can be difficult with adulticiding since there is a limited number of active ingredients. By capturing samples from known sources in the wild and comparing them against laboratory-raised mosquitoes that are known to be susceptible to various products districts can evaluate where resistance is appearing geographically and adjust their control programs accordingly. A similar process can be utilized during actual operations to determine whether a product is effectively reaching the target and whether the local mosquito population is susceptible to the product.[53] These evaluations provide beneficial information that allow for immediate adjustments to be made during an active mosquito season.

Districts may also carry out applied research projects related to various aspects of the IVM program. Whether designing or testing new surveillance equipment, measuring and classifying mosquito sources, or evaluating novel control techniques, these innovations are essential to maintaining a viable management program.

INTEGRATED VECTOR MANAGEMENT IS A SHARED RESPONSIBILITY

Integrated Vector Management is a rational decision-making process that utilizes public education, surveillance, source reduction and different control methods to reduce mosquito populations and protect public health. Cooperation between districts, elected officials, regulatory agencies, stakeholders and the general public is essential for successful implementation of IVM practices.

Ongoing public education to ensure there is accurate information is critical as is ensuring that residents have the tools to report mosquito activity and prevent mosquito breeding. All Californians must do their part by dumping and draining standing water so they can help eliminate mosquitoes from their communities.

At the same time, it's essential that mosquito and vector control districts have adequate funding to implement all of the various IVM tools needed to protect public health. With the introduction of new mosquito species and increased potential for mosquito-borne disease transmission in California, mosquito and vector control districts are facing new challenges and have increasingly limited resources to implement IVM. Onerous regulations and inadequate funding levels can compromise districts' ability to suppress mosquito populations and prevent the spread of mosquito-borne diseases.

Integrated Vector Management is a shared responsibility. By working together to strengthen collaboration, promote community engagement and education, and ensure there are adequate resources and funding for mosquito and vector control districts, we can minimize the risk mosquitoes pose to human health.

INVASIVE MOSQUITOES REQUIRE INNOVATIVE SOLUTIONS

Invasive *Aedes* mosquitoes (i.e. *Aedes aegypti* and *Aedes albopictus*) exploit small and cryptic water sources and have shown resistance to many commonly used insecticides, limiting the efficacy of traditional control approaches. One technique that is currently being evaluated in California is a form of Sterile Insect Technique that utilizes different strains of a naturally-occurring bacteria called Wolbachia.[54] When *Aedes aegypti* or *Aedes albopictus* males are infected with a particular strain of Wolbachia and then are released to breed with wild female mosquitoes infected with a different strain of Wolbachia the resulting offspring are not viable. Initial trials in Los Angeles County and Fresno County show great promise, but there are still logistical and regulatory hurdles to overcome. Implementation will likely have considerable costs and will require partnerships between local agencies and the state to ensure success.

FOOTNOTES

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