Integrated Mosquito and Vector Management Program Plan

APPENDIX

G

BAIR ISLAND INTEGRATED PEST MANAGEMENT PLAN

BAIR ISLAND INTEGRATED PEST MANAGEMENT PLAN

INTRODUCTION

Bair Island is a 3,000-acre parcel located in Redwood City, along the shore of San Francisco Bay at the mouth of Redwood Creek. It is part of the Don Edwards Wildlife Refuge. This site is made up of a series of former salt ponds, constructed in the 1940's and drained in 1965. Water that collects behind the dikes on Bair Island serves as an ideal habitat for mosquito larvae and has the potential for producing huge populations of vector mosquitoes. The Don Edwards Wildlife Refuge is unusual among refuges in that it is located immediately adjacent to a major metropolitan area. Furthermore, the mosquitoes that develop here include aggressive, day–biting species that migrate far from their breeding habitat to feed. The San Mateo County Mosquito and Vector Control District has been controlling mosquitoes at Bair Island since the mid-1970's. It manages these mosquitoes under the integrated pest management program described in this report.

Site Description

Bair Island is made up of a series of former salt evaporation ponds surrounded by dikes. It is bounded on the south by Redwood Creek. On the north, Steinberger Slough separates the property from the residential development of Redwood Shores. The salt ponds of Bair Island were given letter designations (i.e.: A9, A10, A11, A12, B1, B2, B3), which are used today to refer to specific parts of the property (Figure 1). Two sloughs, running east to west, divide the property into 3 sections: Inner, Middle and Outer Bair Island. Inner Bair Island (pond A12) is a 300-acre parcel lying adjacent to Highway 101. It is the only portion of the site that is accessible by land. Middle Bair Island consists of ponds A9, A10, and A11. It lies between Corkscrew Slough and Smith Slough. The B ponds (B1, B2, and B3) make up Outer Bair Island, which lies closest to the open waters of San Francisco Bay. Middle and Outer Bair Island are completely surrounded by water and can only be reached by boat or aircraft.

There are currently 4 species of mosquitoes on Bair Island: *Aedes (formerly Ochleratatu) squamiger* (winter salt marsh mosquito), *Ae. dorsalis* (summer salt marsh mosquito), *Culiseta inornata* (cool weather mosquito), and *Culex tarsalis* (encephalitis mosquito). These mosquitoes differ in seasonality, host seeking behavior and other aspects of their biology. A brief description of each is included in the surveillance section of this report.

History

Major mosquito production at Bair Island began in the 1970's after commercial salt production ceased. In 1965, the salt ponds were drained, tide gates were neglected or removed entirely and the interior of the ponds became completely isolated from the surrounding sloughs. The dikes, constructed to retain seawater for salt production, now served to trap rainwater, creating large expanses of standing water without natural predators (fish). The winter rains created large shallow ponds that lasted from late October until June. Initially the lack of vegetation and high salt content prevented the development of mosquitoes at the site. However, in the early 1970's, emergent vegetation and large cracks in the floors of the ponds created an ideal habitat for mosquitoes.

The District first became aware of mosquito problems at Bair Island following a dramatic rise in the number of service requests in the surrounding cities. Technicians collected winter salt marsh mosquitoes at many of these residences. A subsequent search for possible larval sources revealed large populations of larvae on Bair Island. Attempts to treat Bair Island with backpack sprayers failed due to the size of the area that needed to be covered. In 1991, the District contracted with a helicopter service to treat the property. Helicopter application has become the standard for treating this property whenever the extent of larval development exceeds 50 acres.

In 1998 and again in 2006, large numbers of adult winter salt marsh mosquitoes (*Ae. squamiger*) were able to escape control and emerge from the marsh. Extensive adulticiding was required in the surrounding cities to bring them under control.

From 1991 to 2004, mosquito development on Bair Island occurred almost exclusively during winter and spring. When winter rains ceased, the interior of the salt ponds would dry out and the remaining areas had strong tidal influence and were not suitable for larval development. In 2002, a newly completed restoration project allowed bay water to inundate a large area of high marsh on pond B1 with little return flow. Standing water now covers a large portion of this salt pond throughout the year, and serves as habitat for the summer salt marsh mosquito (*Ae. dorsalis*). This species exploits water that collects when extreme high tides flood depressions in the high marsh. Multiple generations are produced during summer months, completing development in less than 2 weeks. *Aedes dorsalis* is an aggressive daytime biter that disperses many miles from the marsh to feed. In 2004 and 2005, these mosquitoes inundated the communities of Redwood Shores, Foster City and San Carlos, causing a high volume of complaints from residents of these cities. Carbon dioxide traps detected high numbers of *Ae. dorsalis* adults, and the District found it necessary to conduct ground fogging in these communities.

District personnel are currently working with the U.S. Fish and Wildlife Service and the California Department of Fish and Game to develop a restoration plan that will restore strong tidal flows to all of Bair Island. This should dramatically reduce the area in which mosquitoes develop. However, at the present time, mosquitoes developing at this site have a major potential impact on the surrounding communities and must be kept under control. This is the largest source of salt marsh mosquitoes in San Mateo County. The district controls mosquitoes on Bair Island through an integrated vector management program that employs a variety of different methods to maintain mosquito populations below threshold levels. The program focuses on immature stages, controlling mosquito larvae before they can emerge as biting adults. Surveillance of larvae and adult mosquitoes is used to direct the timing and geographic extent of larvicide applications and to monitor the success of control efforts. The primary materials applied are specific to mosquitoes and have minimal effects on nontarget organisms. These materials include 2 kinds of bacteria (*Bacillus thuringiensis israelensis* and *Bacillus sphaericus*) and a growth regulator.

SURVEILLANCE

Surveillance is an essential part of the District's mosquito control program. Information gained through surveillance is used to direct the location, timing and choice of appropriate control measures. This reduces the geographic extent and duration of pesticide use by restricting treatments to areas where mosquito populations exceed established thresholds. The following section describes how mosquito populations are monitored on Bair Island and the surrounding communities. Information on the species, density, and stages of mosquitoes detected by surveillance is used to select an appropriate control strategy from integrated pest management alternatives.

Mosquito Species Occurring at Bair Island

Mosquito species differ in their biology, disease potential and susceptibility to larvicides. There are 20 different species of mosquitoes present in San Mateo County; 4 of these are targeted for control on Bair Island. Below is a brief description of their biology and distribution:

***Aedes squamiger* – Winter Salt Marsh Mosquito.** Larvae develop in rainwater that collects in salt marsh depressions between November and March. Eggs are laid in these depressions during the spring. They hatch in winter when flooded by rainwater. Larvae develop over the winter to emerge in mid-March. Adults are relatively long-lived, sometimes lasting through May or June. Females disperse inland along streams and then spread out into surrounding residential neighborhoods to seek a blood meal. These mosquitoes can fly 15 miles or more from the larval source. They are aggressive biters and known carriers of both West Nile virus and California Group Encephalitis viruses.

***Aedes dorsalis* - Summer Salt Marsh Mosquito.** This species uses many of the same marsh habitats as *Ae. squamiger*, as well as intertidal marshes. Numerous generations can be produced from flooding tides between April and October. Dispersal paths are random, but adults favor resting areas with large grassy regions. Aedes dorsalis females are aggressive biters capable of dispersing 15 miles or more from their larval source. They can harbor West Nile virus, Western Equine Encephalitis, and St. Louis Encephalitis as well as California Group Encephalitis viruses

***Culex tarsalis* – Encephalitis Mosquito.** This species breeds in almost any type of flooded pool, including salt marsh, if the salt content does not exceed 1.0 percent. Multiple generations are produced between February and November in rainwater impounds in the pickleweed marsh. This mosquito is an efficient vector of West Nile virus, Western Equine Encephalitis virus and St. Louis Encephalitis virus. These viruses are maintained in wild bird populations. Breeding of this species in areas occupied by large populations of migratory birds near dense human population centers is of particular concern to public health.

***Culiseta inornata* – Winter Mosquito**. This species breeds in almost any ground depression, but seems to excel in habitats favored by *Ae. squamiger*. Females lay eggs during the cool seasons and multiple generations develop and emerge from October through May. Adults tend to stay within 1 – 2 miles of their larval source. They are capable of transmitting West Nile virus and feed preferentially on mammals.

Techniques Used to Monitor Mosquito Population Density

Temporal and spatial changes in mosquito populations on Bair Island are measured by:

1) Sampling of immature mosquito populations
2) Sampling of adult mosquitoes
3) Analysis of requests for mosquito control services

Sampling Immature Mosquitoes

The District's program focuses on controlling mosquitoes in the larval stage and uses information gathered by inspections to determine where and when larvicides will be applied. District mosquito control technicians inspect Bair Island on a regular basis throughout the year. Teams of 3-4 people will travel to the islands by boat and inspect a number of sentinel locations in which mosquitoes have been known to develop in the past. Sampling is done with standard 1-pint dippers. The dipper has a cup of molded plastic attached to either a telescoping aluminum handle or a hardwood dowel. The length of dipper handles can vary from 3-4' for obtaining shoreline samples to 4-6' for sampling hard to reach areas. The dipper is used to obtain a standard volume of source water that may or may not contain immature salt marsh mosquitoes. Samples are examined in the laboratory to determine the abundance, species, and life-stage of mosquitoes present. This information is compared to historical records and used as a basis for treatment decisions

Immature mosquitoes are not uniformly distributed, but are aggregated in clumps or pockets protected from predators. They are often found along the edges of impounds, in emergent vegetation and floating debris. District mosquito control technicians focus on sampling mosquitoes in these areas by dipping the shoreline vegetation and progressing outward to isolated tufts of emergent vegetation in open water. Water that accumulates in cracks on the floor of the old salt pans also provides a sheltered environment for larvae.

Technicians use a sequential sampling technique modified from sampling procedures developed for agricultural use. The object of sequential sampling is to establish a mechanism of implementing control options, based upon estimated abundance of target populations. Immature mosquito population estimates are obtained by averaging the number of larvae or pupae collected in ten or more individual dips.

Much of Bair Island is separated from the mainland by sloughs. Mosquito control technicians use a 14-foot aluminum boat with a 25 hp outboard motor to reach the area. Once every week to 10 days, 4-5 people will cover the entire area on foot, searching for larvae. They collect samples and return them to the laboratory for identification. The average number of immature mosquitoes per dip is recorded for each section of the parcel, along with the species found.

Sampling Adult Mosquitoes

Populations of adult mosquitoes are monitored primarily by carbon dioxide-baited traps. Supplemental information is obtained by observation of biting mosquito populations (landing counts) and analysis of telephone service request records. These methods are described in detail below.

The District monitors adult mosquito populations on Bair Island and in the surrounding areas. Historical data has demonstrated that mosquitoes from this location can spread to specific areas surrounding the property. For example, large densities of summer salt marsh mosquitoes in Redwood Shores, Foster City and San Carlos have been traced to larval sources on Bair Island. Winter salt marsh mosquitoes have been observed to spread from Bair Island along Redwood and Cordilleras Creeks into the cities of Redwood City, San Carlos and Belmont.

Carbon Dioxide –Baited Traps

These traps, sometimes referred to as CDC or Encephalitis Virus Surveillance (EVS) traps) collect host-seeking female mosquitoes. The mosquitoes are attracted to the trap by the sublimation of dry ice into carbon dioxide gas (CO_2), which simulates the exhaled respiratory gasses of birds and mammals. The trap consists of a central 6” diameter plastic cylinder housing a battery-driven motor and 2-blade fan. The trap is suspended below an insulated container filled with dry ice. A mesh bag is attached to the bottom of the cylinder to collect the mosquitoes. Mosquitoes attracted to the CO_2 are drawn in through the top of the trap and forced downward by the fan into the collection bag. Female mosquitoes thus collected are identified to species and counted. Samples are quantified as the number of females collected per trap-night. A single trap night being defined as 1 trap deployed overnight. Traps are deployed weekly throughout San Mateo County.

Service Requests

Information on adult mosquito abundance from traps is augmented by tracking mosquito complaints from residents. Analysis of service requests allows district staff to gauge the success of control efforts and locate undetected sources of mosquito development. The District conducts public outreach programs and encourages local residents to call. When such requests are received, technicians visit the area, interview residents and search for sources that may have been missed. Residents are asked to provide a sample of the insect causing the problem when possible. Carbon dioxide-baited traps are often placed at the location of the complaint to assess mosquito density and determine the species present. Identification of samples from residents and traps provides information that is used to locate the source of the complaint. For example, larvae of the salt marsh species (*Ae. dorsalis* and *Ae. squamiger*) develop exclusively in brackish water in salt marshes. When either of these species are present, the search for their source focuses on nearby salt marshes downstream of the collection site. In contrast, *Cx. pipiens* (the northern house mosquito) usually develops in containers, storm drains, or water under homes, and does not travel more than 1 1/2 miles. When this species is collected at a residence, the larval source can usually be found within a block or two of the collection site.

The frequency and geographic distribution of requests can also reveal information. A high concentration of calls in a specific area within a short time usually indicates a fly-off of adult mosquitoes from an uncontrolled larval source. The district follows up on these situations with intensified trapping and investigation to determine the cause. This situation occurred in 1998, 2004 and 2006 with winter salt marsh mosquitoes and in 2004 and 2005 with summer salt marsh mosquitoes.

Direct Observation - Landing Rates

Landing rates are used as a supplementary method for measuring adult mosquito activity. The technique involves counting the number of mosquitoes that land on a person within a given amount of time. Landing rates are particularly effective for monitoring salt marsh mosquitoes, which readily bite during daylight hours. This method is used as a direct observation of the number of host seeking mosquitoes present. When an increase in service requests indicates a potential fly-off of adult salt marsh mosquitoes from Bair Island, mosquito control technicians will travel to Bair Island to estimate the density of host-seeking salt marsh mosquitoes present. This information is used to supplement carbon dioxide-baited traps in the decision to apply treatment for adult mosquitoes.

Detection of Disease-Causing Agents

Mosquitoes from Bair Island are potential vectors of encephalitis viruses and therefore pose a potential threat to public health. The District protects public health by maintaining adult mosquito populations below threshold levels and monitoring for the presence of mosquito-borne disease agents. There are 3 mosquito-borne viruses of public health concern in San Mateo County: West Nile virus (WNV), Western Equine Encephalitis virus (WEE), and St. Louis Encephalitis virus (SLE). All 3 viruses are carried in birds. West Nile virus is the primary concern in San Mateo County at this time. It has been detected in wild birds collected throughout the county and is transmitted by a wide range of mosquito species. Migratory waterfowl, shorebirds and raptors on Bair Island have the potential for infecting mosquitoes that develop there. The District monitors for the presence of these viruses in three ways:

1. **Dead birds** - Testing of dead wild birds is used to detect WNV in the county. This is the most sensitive method of detecting the presence of WNV and is usually the first indication of the presence of virus. Unlike WEE and SLE, this virus kills birds, and it can be detected readily in their tissues. Birds in the corvid family (crows, ravens and jays) and raptors are especially susceptible. However, the virus has also been detected in shorebirds and waterfowl. The District conducts public education to solicit submission of dead birds by the public. Residents are directed to call the California Department of Health Services if they find a dead bird ((877) WNV-BIRD). This information is conveyed to the District, which collects the bird and submits it for testing. West Nile virus has been detected in dead birds collected in Redwood City, Foster City, and San Mateo.

2. **Mosquito pools** - The District also tests mosquitoes directly for the presence of virus. Host-seeking adult mosquitoes are collected with carbon dioxide-baited traps. The live mosquitoes are anesthetized with tri-ethyl-amine (TEA), sorted to species, and grouped into pools of 50. These pools are then tested for the presence of virus and a minimum infection rate is calculated. Mosquito traps are set on a regular basis throughout the county including communities surrounding Bair Island: Redwood City, Redwood Shores, Foster City, San Carlos, and San Mateo. This method is not as efficient at detecting the presence of virus, but is used to supplement information gained by testing wild birds.

3. **Sentinel Chickens** - Sentinel chickens are an indirect way of monitoring for the presence of virus in the mosquito population. Chickens are maintained in outdoor cages where they are exposed to host-seeking mosquitoes. If bitten by an infected mosquito, these birds will develop an immune response. Blood samples are taken from the chickens every 2 weeks to test for exposure to WNV, WEE, or SLE. The district maintains flocks of chickens (10 chickens in each flock) at 4 locations: Cooley Landing (East Palo Alto), Searsville Lake (Woodside), Web Ranch (Ladera), and west of San Francisco Airport (San Bruno). Chickens have been used for many years to monitor mosquito populations in California for WEE and SLE. They have not proven to be an effective early warning system for detecting WNV.

CONTROL OF IMMATURE MOSQUITOES

The District's integrated vector management program focuses on controlling mosquitoes in the larval stage, before they emerge as biting adults. The decision to apply larval control and the choice of control strategy is based on a number of criteria:

- Mosquito species present and their density
    - Disease potential
    - Flight range
- Stage of development
- Proximity to populated areas
- Size of source and extent of area colonized by mosquitoes
- Presence/absence of predators
- Presence/absence of sensitive/endangered species

Control strategies are selected to minimize their impact on the environment while maximizing the degree of control. The method used is based on the criteria above as well as:

- Habitat type
- Water conditions
- Cost and feasibility
- Site accessibility

Potential control strategies include physical alteration of the site to discourage mosquito development (source reduction or physical control), application of biological agents (biological control), and application of chemicals (chemical control).

The nature of mosquito development sites on Bair Island has a great deal of impact on the strategies selected to control mosquitoes there. Much of the site is surrounded by large channels and not accessible to land vehicles such as trucks. Any equipment or material used there must be carried across the water by boat or plane. In winter, there are over 2,000 acres of mosquito habitat on Bair Island. When mosquitoes are present in all or most of this area, it must be treated rapidly before biting adults can emerge. Bair Island is also home to at least two endangered species (clapper rails and salt marsh harvest mice) as well as abundant populations of shorebirds, waterfowl, and other animals.

Strategies for Control of Immature Mosquitoes

Physical Control

The goal of physical control is to eliminate or reduce mosquito production at a particular site through alteration of habitat. Physical control is usually the most effective mosquito control technique because it provides a long-term solution. Physical control can reduce or eliminate the extent of mosquito development habitats to reduce the need for chemical applications. Physical alterations to a particular site are the responsibility of the property owner. The District encourages property owners to conduct physical control activities whenever possible. However, other factors, such as specific wildlife habitat requirements must be considered before physical changes to a site can be made. The District is providing input on the upcoming restoration of tidal flow to Bair Island. If sufficient water movement can be restored to these areas, the need to apply chemicals to control mosquitoes there will be greatly reduced.

Physical control programs may be categorized into three areas: "maintenance", "new construction", and "cultural practices" such as vegetation management and water management. Maintenance activities are conducted within tidal, managed tidal and nontidal marshes, seasonal wetlands, diked, historic baylands and in some creeks adjacent to these wetlands. The following activities are classified as maintenance:

- Removal of sediment from existing water circulation ditches
- Repair of existing water control structures
- Removal of debris, weeds and emergent vegetation in natural channels
- Clearance of brush for access to streams tributary to wetland areas
- Filling of existing, nonfunctional, water circulation ditches to achieve required water circulation dynamics and restore ditched wetlands.

Biological Control

Biological agents for control of mosquito larvae include predatory fish, predatory aquatic invertebrates and mosquito pathogens. The sites in which mosquitoes develop on Bair Island primarily consist of seasonal impounds and areas with very limited tidal flow. These areas seldom contain fish because they are dry out periodically. Therefore, fish are not a viable alternative for larval control at this site. In areas where strong tidal flow has been restored and fish are present, mosquito development does not occur. Aquatic invertebrates that prey on mosquito larvae are sometimes present in tidal marshes along San Francisco Bay. However, they are rarely present at sites of mosquito development in numbers sufficient to reduce populations of larval mosquitoes. Mosquitoes are usually the first insects to colonize seasonal or tidal impounds. The seasonal abundance and developmental rates of predatory aquatic invertebrates usually lags behind that of the mosquito populations. Introduction or augmentation of natural predators has been suggested as a means of biological control. However, there are currently no commercial sources since suitable mass-rearing techniques are not available. The presence and abundance of natural predators in sources containing mosquito larvae is noted and taken into account during the larval surveillance process. Conservation of natural predators, whenever possible, is achieved through use of highly target-specific pesticides including bacterial insecticides, with minimal impacts on nontarget taxa.

There are two types of bacteria that are commercially available for mosquito control Bacterial insecticides contain naturally produced bacterial proteins that are toxic to mosquito larvae when ingested in sufficient quantity. Although they are biological agents, such products are labeled and registered by the Environmental Protection Agency as pesticides and are considered by some to be a form of Chemical Control. These bacteria are discussed in the next section.

Chemical Control

Classification of Mosquito Control Products

In accordance with provisions of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), and the California Pesticide Law, California has established the Department of Pesticide Regulation to recommend which U.S. Environmental Protection Agency (EPA) products to register in California.

The EPA classifies pesticides by their toxicity. This classification and corresponding "signal word" must appear on the pesticide's label (see *Applying Pesticides Correctly*, USDA/EPA, 1992). The categories used in such a classification are as follows:

Category III —Materials in this category have the lowest level of toxicity. Products in this category range from essentially nontoxic to mammals to ones that are slightly toxic when taken orally, dermally, or through inhalation. When applied to skin or eyes they either cause little or no irritation. These products must contain the signal word "Caution" on the label. Most of the pesticides used by the District fall into this category.

Category II —These products are moderately toxic. Any product, which is moderately toxic orally, dermally, or through inhalation or causes moderate eye and skin irritation, will be labeled "Warning." The probable lethal dose for these products ranges between 1 teaspoon to 1 ounce.

Category I — These pesticides are highly toxic. This category contains materials that are highly toxic orally, dermally, or through inhalation or cause severe eye and skin burning. A taste to a teaspoonful taken by mouth could kill an average-size adult. The label on these products must contain the signal word "Danger." None of the materials used by the District for mosquito control on Bair Island fall into this category.

Materials Used to Control Immature Mosquitoes (Larvicides)

Two of the materials used by the District are bacterial spores, similar to products used in organic agriculture. Bacteria are single-celled parasitic and saprophytic microorganisms that exhibit both plant and animal properties. They range from harmless and beneficial to intensely virulent and lethal. The bacteria *Bacillus thuringiensis* (Bt) is a beneficial species and is the most widely used agricultural microbial pesticide in the world. It is highly toxic to insects, but has little or no toxicity to other organisms. This bacteria was originally isolated from natural lepidopteran (butterflies and moths) die-offs in Germany and Japan. Products containing Bt have been commercially available since the 1950s. In 1976, Dr. Joel Margalit and Mr. Leonard Goldberg isolated from a stagnant riverbed pool in Israel a subspecies of *B. thuringiensis* that had excellent mosquito larvicide activities. It was given the name *Bacillus thuringiensis israelensis* (Bti) and later designated *Bacillus thuringiensis* Serotype H-14. Both designations may be found on the labels of mosquito larvicide formulations containing Bti.

A second bacteria, *Bacillus sphaericus*, also exhibits mosquito larvicide properties. It is closely related to Bti.

Bacillus thuringiensis israelensis (Bti)

This organism produces a resting stage or spore whose walls contain five different microscopic protein pro-toxins packaged inside one larger protein crystal. The gut of mosquito larvae is unique in that it is an extremely alkaline environment (the stomach of vertebrate animals is acidic). When the crystal is ingested by mosquito larvae, the five proteins are released in the alkaline environment of the larva's gut. The five proteins are then converted into five different toxins by specific enzymes present in the gut of larvae. Once converted, these toxins work to destroy the gut wall. This leads to paralysis and death of the larvae.

Bti is grown commercially in large fermentation vats using sophisticated techniques to control environmental variables such as temperature, moisture, oxygen, pH, and nutrients. The process is similar to the production of beer, except that Bti bacteria are grown on high-protein substrates such as fishmeal or soy flour, and the spore and its toxins are the end products. At the end of the fermentation process, Bti bacteria exhaust the nutrients in the fermentation machine, producing spores before they lyse and break apart. Coincidental with sporulation, the delta endotoxin is produced. The spores and delta endotoxins are then concentrated via centrifugation and microfiltration of the slurry. It can then be dried for processing and packaging as a solid formulation, or further processed as a liquid formulation. Since some fermentation medium (*e.g*. fishmeal) is always present in liquid formulations, they generally smell somewhat like the medium.

Formulations and Dosages

The District uses both liquid and granular formulations of Bti. Liquids produced directly from concentrated fermentation slurry tend to have uniformly small (2-10 micron) particle sizes, which are suitable for ingestion by mosquito larvae. They are active and available to larvae for a few days following applications. Granules are formulated from Bti primary powders and an inert carrier such as clay or ground corncobs. Products containing Bti are virtually nontoxic to mammals and are categorized as category III pesticides, carrying the word "" on the label.

Timing of Application

Since 4th instar mosquito larvae quit feeding before becoming pupae, it is necessary to apply Bti or Bs before this point in their development. Mosquito larvae also undergo a period of reduced feeding or inactivity before molting from 1st to 2nd, 2nd to 3rd, and 3rd to 4th instars. If bacterial products are applied at these points in their development, the toxic crystals may settle out before the larvae resume feeding, and efficacy may be reduced. Kills are usually observed within 24 hours of toxin ingestion. Therefore, district mosquito control technicians inspect treated sites 2-4 days after each treatment to assess the success of control.

The amount of toxin contained within products made from Bti is reported indirectly as the result of at least two different bioassays and are difficult to equate to one another. Prepared volumes of toxins are applied to living mosquito larvae. The resulting mortality is expressed International Toxic Units (ITUs) and *Aedes aegypti* International Toxic Units (AA-ITUs). These measurements are only roughly related to observed efficacy in the field and are therefore inappropriate to consolidate and report on, like other toxicants.

Bti Liquids:

Currently, two commercial brands of Bti liquids are available to the District: Teknar Hp-D®, and Vectobac 12AS®.

Dosages and Formulations:

Labels for all three products recommend using 4 to 16 liquid oz./acre in unpolluted, low-organic water with low population of early instar larvae (collectively referred to below as clean water situations). Vectobac 12AS® (but not Teknar Hp-D®) labels also recommend increasing the range from 16 to 32 liquid oz./ac. when late 3rd or early 4th instar larvae predominate, larval populations are high, water is heavily polluted, and/or algae are abundant. The recommendation to increase dosages in these instances (collectively referred to below as dirty water situations) also is seen in various combinations on the labels for all other Bti formulations discussed below.

Target Species

Bti adversely affects larval stages of insect species in the order Diptera, suborder Nemotacera, families Culicidae (mosquitoes) and Simuliidae (black flies). Bti has been shown to be effective for numerous species of mosquitoes, including members of the genera Aedes, Anopheles, Culex, Culiseta, and Psorophora, which are commonly targeted in California.

Use: Products containing Bti are ideally suited for integrated vector management programs because the active ingredient does not interrupt activities of most beneficial insects and predators. Since Bti has a highly specific mode of action, it is an insecticide of minimal environmental concern. Bti controls all larval instars, provided the insects have not quit feeding, and can be used in almost any aquatic habitat with no restrictions. It may be applied to irrigation water and any other water sites except treated finished drinking water. Bti is fast-acting and its efficacy can be evaluated almost immediately. It usually kills larvae within one hour after ingestion, and since each instar must eat in order to grow, Bti usually kills mosquito larvae within 24 hours of application. Bti leaves no residues and is quickly biodegraded.

Bti labels carry signal word “Caution”. However, the four-hour Inhalation LC 50 in rats is calculated to be greater than 2.1 mg/liter of air. This was the maximum attainable concentration and did not cause any adverse effects. The acute dermal LD 50 in rabbits is greater than 2,000-mg/kg body weight (the highest concentration tested) and the material is nonirritating to the eye or skin. This is equivalent to a 220-pound individual spilling more than a half-gallon of Bti liquid onto the body or into the eyes. The acute oral LD 50 in rats is greater than 5,000 mg/kg body weight (similar to an individual drinking over five quarts), suggesting the material is practically nontoxic in single doses. Common table salt has a LD 50 of 4,000 mg/kg of body weight.

Bti applied at label rates has virtually no adverse effects on applicators, livestock, or wildlife, including beneficial insects, annelid worms, flatworms, crustaceans, mollusks, fish, amphibians, reptiles, birds, and mammals. However, nontarget activity on larvae of insect species normally associated with mosquito larvae in aquatic habitats has been observed in larvae in the order Diptera, suborder Nematocera, families Chironomidae (Midges), Ceratopogonidae (Biting Midges), and Dixidae (Dixid Midges). These nontarget insect species, taxonomically closely related to mosquitoes and black flies, apparently contain the necessary gut pH, and enzymes to activate delta-endotoxins. However, the concentration of Bti required to cause these effects is 10 to 1,000 times higher than normal rates used to control mosquitoes.

Concerning the use of Bti, timing of application is extremely important. Optimal benefits are obtained when treating 2nd or 3rd instar larvae. Treatments at other development stages may provide less than desired results. Therefore, a disadvantage of using Bti is the limited window of time available for treatment.

Bacillus sphaericus

Bacillus sphaericus is a commonly occurring spore-forming bacterium found throughout the world in soil and aquatic environments. Like Bti, some strains of Bs produce a protein endotoxin in the spore coat. The bacteria are grown in fermentation vats and formulated for end use with processes similar to that of Bti. A standard bioassay similar to that used for Bti has been developed to determine preparation potencies. The bioassay uses 3rd to 4th instar larvae of the mosquito *Culex quinquefasciatus*. The endotoxin destroys the insect's gut by a process similar to that of Bti. However, it is active against a narrower spectrum of mosquito species. Species in the genera Aedes and Ochlerotatus have lower susceptibility to Bs and District field tests have shown that commercially available formulations of Bs are not effective against the saltmarsh species *Aedes squamiger*. The toxin of Bs is active only against the feeding larval stages and must be partially digested before it becomes activated.

Formulations and Dosages

VectoLex-CG®: This is a granular formulation of Bs (strain 2362). The product has a potency of 50 BSITU/mg (Bs International Units/mg) and is formulated on 10/14-mesh ground corncob carrier. The VectoLex –CG® label carries the "" hazard classification.

Dosages: VectoLex-CG® is designed to be applied from the ground (by hand or truck-mounted blower) or aerially at rates of 5-10 lb./acre. Best results are obtained when applications are made to larvae in the 1st to 3rd instars. Use of the highest rate is recommended for dense populations of larvae. *Bacillus sphaericus* products take a little longer to eliminate larvae than do Bti products (2-3 days rather than a few hours). Therefore, follow-up surveillance is done 3 days after application.

Target Species: *Bacillus sphaericus* affects the larval stage of insects in the order Diptera, suborder Nematocera, family Culicidae (mosquitoes). Culex species are the most sensitive to Bs, followed by Anopheles and some Aedes species. In California, mosquitoes in the genera Culex and Anopheles may be effectively controlled. Several species of Aedes, including *Ae. squamiger* and *Ae. dorsalis (*salt marsh species found on Bair Island) are not susceptible. Therefore, the use of this material is restricted to times and places when these species are not present, such as the seasonal freshwater ponds on pond B1. In contrast to Bti, Bs is virtually nontoxic to black flies (Simuliidae).

Use: *Bacillus sphaericus* has demonstrated the unique property of being able to control mosquito larvae in highly organic aquatic environments, including sewage-waste lagoons, animal-waste ponds, and septic ditches. In some habitats, control can persist for 2-4 weeks after a single application at labeled rates. Field evaluations with VectoLex-CG® have shown that Bs may undergo limited recycling in certain organically rich environments.

VectoLex-CG® has been extensively tested and has shown no adverse effects on mammals or nontarget organisms. *Bacillus sphaericus* technical material was not infective or pathogenic when administered as a single oral, intravenous, or intratracheal installation in rats. No mortalities or treatment-related evidence of toxicological effects were observed. The acute oral and dermal LD 50 values are greater than 5000 mg/kg and 2000 mg/kg, respectively. The technical material is moderately irritating to the skin and eye. Oral exposure of Bs is practically nontoxic to mallard ducks. No mortalities or signs of toxicity occurred following a 9,000 mg/kg oral treatment. Birds fed diets containing 20% wt./wt. of the technical material experienced no apparent pathogenic or toxic effects during a 30-day treatment period. Mallards given an intraperitoneal injection of Bs demonstrated toxicological effects including hypoactivity, tremors, ataxia, and emaciation. The LD 50 value was greater than 1.5 mg/kg. Although viable spores were cultured from treated birds, replications were not evident, since low numbers of cultured organisms were reported.

Acute aquatic freshwater-fish toxicity tests were done on bluegill sunfish, rainbow trout, and Daphnia. The 96-hour LC 50 and NOEC value for bluegill sunfish and rainbow trout was greater than 15.5 mg/l.; the 48-hour EC 50 and NOEC value for Daphnia was greater than 15.5 mg/l. Acute aquatic salt water-fish toxicity tests were done on sheep head minnows, shrimp, and oysters. The 96-hour LC 50 value for both sheep head minnows and shrimp was 50 mg/l. The 96-hour EC 50 value for oysters was 42 mg/l, with a NOEC of 15 mg/l.

Invertebrate toxicity tests were done on mayfly larvae and honeybees. The LC 50 and NOEC value for mayfly larvae was 15.5 mg/l. Honeybees exposed to 10E4-10E8 spores/ml for up to 28 days demonstrated no significant decrease in survival when compared to controls. Acute toxicity of Bs to nontarget plants was evaluated in green algae. The 120-hour EC 50 and NOEC values were greater than 212 mg/l.

Bacillus sphaericus will not regenerate in salt water, and is not effective against salt marsh species of Aedes. Cycling is limited to permanent freshwater bodies, and if organics are very high, recycling may be minimal.

Methoprene

Methoprene is a true analogue and synthetic mimic of a naturally occurring insect hormone called juvenile hormone (JH). JH is found during aquatic life stages of the mosquito and in other insects, it is most prevalent during the early instars. As mosquito larva mature, the level of JH steadily declines until the 4th instar molt, when levels are very low. This is considered a sensitive period when all the physical features of the adult begin to develop. Methoprene in the aquatic habitat can be absorbed on contact and the insect's hormone system becomes imbalanced. When this happens during the sensitive period, the imbalance interferes with 4th instar larval development. One effect is to prevent adults from emerging. Since pupae do not eat, they eventually deplete body stores of essential nutrients and then starve to death. For these and perhaps other reasons, methoprene is considered an insect growth regulator (IGR). The EPA has approved the use of Altosid in habitats containing fish.

Formulations: Currently, five formulations of methoprene are sold under the trade name of Altosid®. Only 2 of these are appropriate for treatment of large scale areas such as those found at Bair Island: Altosid Liquid Larvicide (A.L.L.) ® and Altosid Pellets®.

Early methoprene manufacturing produced equal quantities of two mirror-image molecules called r- and s-isomers. The racemic isomer (r-methoprene) is not active on mosquitoes, but is present today in Altosid Briquets® (along with the active isomer s-methoprene) because it is part of the original EPA label package. The other products are newer or have been revised and contain only s-methoprene as their active ingredients (AI). Altosid® is a category III pesticide, labels contain the signal word "Caution". These products are virtually nontoxic to mammals. The acute oral and dermal LD 50 values are greater than 5,000 mg/kg and 2,000 mg/kg, respectively. This was the highest dose tested and had no detectable effect.

Altosid Liquid Larvicide® (A.L.L.) and A.L.L. Concentrate®: These two flowable formulations have identical components except for the difference in the concentration of active ingredients. A.L.L. contains 5% (wt./wt.) s-methoprene while A.L.L. Concentrate® contains 20% (wt./wt.) s-methoprene. The balance consists of inert ingredients that encapsulate the s-methoprene, causing its slow release and retarding its ultraviolet light degradation.

Dosages: Use rates are 3.0 to 4.0 ounces of A.L.L. 5% and 0.75 to 1.0 ounce of A.L.L. Concentrate (both equivalent to 0.01008 to 0.01344 lb. Active Ingredient) per acre, mixed in water as a carrier and dispensed by spraying with conventional ground and aerial equipment. Because the specific gravity of A.L.L. is similar to that of water, it tends to stay near the target surface. No rate adjustment is necessary for varying water depths when treating species that breathe air at the surface.

Target Species: Liquid formulations are designed to control fresh and saline floodwater mosquitoes with synchronous development patterns. They are also effective against species with asynchronous development in semipermanent water. However, liquid formulations break down rapidly (within 3-5 days) and therefore may require repeated applications under these conditions.

Use: Methoprene is safe for workers and the environment. No specific safety precautions or equipment are recommended. In all situations, safety considerations and good common sense should prevail. Methoprene does not bioaccumulate. It remains effective for the prescribed period and then degrades into simpler compounds. Its mode of action allows mosquito larvae to accomplish their ecological assignments and then remain present in the water for an extended time as natural food for predators in the system.

An operational disadvantage of using methoprene is that the applicator cannot detect a control failure until it is too late for additional larviciding. A lack of emerging adults is the only true verification of proper treatment.

Altosid Pellets®: Altosid Pellets® were approved for use in April 1990. They contain 4% (wt./wt.) s-methoprene (0.04 lb. AI/lb.), dental plaster (calcium sulfate), and charcoal. Altosid Pellets® are designed to slowly release s-methoprene as they erode. Under normal weather conditions, control can be achieved for up to 30 days. However, pellets are much more expensive than liquid formulations. Large-scale applications are cost prohibitive and the District rarely uses them on large sources such as Bair Island.

Dosages: Label application rates range from 2.5 to 10.0 lbs./acre (equivalent to 0.1 to 0.4 lb. AI/acre), depending on the target species and habitat.

Use: Information on the Use Altosid Pellets® is the same as those for the liquid formulation. The pellet formulation provides control of larval mosquitoes for a much longer period of time than the liquid. However, they are also much more expensive.

Duplex:

Bti liquid may also be "Duplexed" with the methoprene (Altosid Liquid Larvicide® discussed below). Because Bti is a stomach toxin and lethal dosages are somewhat proportional to a mosquito larvae's body size, earlier instars need to eat fewer toxic crystals to be adversely affected. Combining Bti with methoprene (which is most effective when larvae are the oldest and largest) allows less of each product to be applied than if either one was applied alone.

Surface Oils

Mosquito Larvicide GB-1111®

This product is a petroleum-based "napthenic oil". The "napthenic oil" designation characterizes petroleum-oil-refining processes. The product is most often referred to as Golden Bear 1111® or simply GB-1111®. This is a category III product and contains the signal word "Caution" on its label.

Dosages: GB-111® contains 99% (wt./wt.) oil and 1% (wt./wt.) inert ingredients including an emulsifier. The nominal dosage rate is 3 gal./acre or less. Under special circumstances, such as when treating areas with high organic content, up to 5 gal./acre may be used.

Target Species: GB-1111® is effective on a wide range of mosquito species. Applied to breeding areas, GB-1111® is an effective material against any mosquito larvae and pupae obtaining atmospheric oxygen at the water surface. It can even be used in treating adult mosquitoes as they emerge.

Use: GB-1111® is a material with good spreading characteristics, which breaks down to nontoxic byproducts within 1-2 days. It acts as both a pupacide and a larvicide and can even affect emerging adults. It is used when pupae are present or when applications of other larvicides have failed to effectively control emerging mosquitoes.

This oil produces a visible sheen on the water surface. It breaks down within 48 hours. GB1111® is less selective than bacterial larvicides or methoprene, and will temporarily impact other aquatic insects that live on the surface of standing water.

Equipment used to Apply Larvicides

The San Mateo County Mosquito Abatement District use a variety of larviciding equipment for both aerial and ground applications necessitated by the wide range of breeding habitats, target species, and by budgetary constraints. The District will typically use more than one type of application equipment. There are advantages and disadvantages to each application system used and to the aerial and ground treatments themselves.

Ground Application Equipment

The District uses a four-wheel-drive truck as a primary larviciding vehicle. The truck contains a chemical-container tank, a high-pressure / low-volume electric or gas pump, and a spray nozzle. It is driven along the dike on pond A12 (inner Bair) for applications to the borrow ditch on the inboard side of the dike.

The District uses Argo all-terrain-vehicles to apply larvicides to areas on the interior of A12 that are not accessible from the perimeter dike. A chemical container is mounted on the Argo, a 12-volt electric pump supplies a high-pressure / low-volume flow, with a hose and spray tip that allow for application while steering the vehicle with one hand. These vehicles put less than 1 lb of pressure per square foot on the ground surface and have minimal impact on marsh vegetation.

Additional equipment used in ground applications includes hand-held sprayers and backpack blowers used by mosquito control technicians traveling on foot. Applications of this type are extremely labor-intensive and used only when mosquito breeding is limited to areas along the dike.

Aerial Application by Helicopter

Aerial larviciding on Bair Island is accomplished by rotary aircraft. A helicopter can apply both solids and liquids. A variety of nozzles and metering systems can be adapted, depending upon target configuration and size. The District uses aerial application when breeding areas are inaccessible to ground-based vehicles or exceed 30 acres in area. The District applies larvicides by helicopter to the 1,700 acres of standing water on middle and outer Bair Island. The District does not have a helicopter of its own, nor a qualified pilot. It contracts with an agricultural flying service from the central valley that specializes in mosquito control applications.

Applications to Bair Island usually consist of liquid formulations of Bti or methoprene. Granular applications can either be sand, a pellet, or a corncob granule supplied by a manufacturer. Most granular formulations are applied at 6 to 15 lb/acre. While granules have less drift and can penetrate vegetative cover, they are generally bulky (e.g. corncob) or heavy (e.g. sand), and usually expensive.

In treating mosquito species on Bair Island, complete coverage of the breeding area is critical. Missing just a tiny fraction of the target area can result in the emergence of huge numbers of biting adults. While many pilots claim that they can fly accurate swaths based on their skill alone; experience has shown that this rarely happens. For that reason, some type of guidance system is necessary when performing aerial larviciding over large areas. Helicopter applications conducted by the District use a Global Positioning System (GPS) to guide the application. GPS uses a series of satellites orbiting the earth. A GPS receiver picks up the radio signal from several satellites and converts that information into a location, with accuracy up to several feet. New computer programs can take the mission parameters (e.g., treatment area, coordinates of treatment area, swath width, etc.) into account and accurately track the aircraft flight relative to the target flight, thus providing the pilot with almost instant necessary course corrections.

There are several advantages to using aerial applications. They 1) allow large areas to be treated rapidly with limited manpower, 2) are more practical than ground application for remote or inaccessible areas, such as Middle and Outer Bair Island when large amounts of material must be carried to the site and 3) have less impact and disturbance to wildlife. However, helicopter applications are very expensive (over $1,000 per hour for flight time) and cannot be conducted under conditions of high wind (over 15 mph) or heavy fog.

Currently used mosquito larvicides, when applied properly, are efficacious and environmentally safe. These agents have been successfully integrated into mosquito control programs. Typically, there is less concern for the drift of mosquito larvicides than for adulticides, due to application technique and their specificity for mosquitoes. Mosquito larvicides are usually applied directly into natural and artificial aquatic habitats as liquid or solid formulations, and aerial drift is negligible.

A variety of aquatic habitats, ranging from small domestic containers to larger agricultural and marshland areas, are treated with larvicides. Natural fauna inhabiting these sites may include fish and invertebrates, particularly insects and crustaceans. The habitats targeted for larviciding on Bair Island are seasonal. Permanent aquatic sources usually contain natural mosquito predators such as fish, and do not require further treatment, unless littoral vegetation is so dense that it prevents natural predation. Temporary sites such as the diked marshes of Bair Island produce prolific numbers of floodwater mosquitoes. These sites are generally very low in species diversity and lack predators due to the time needed for most species to locate and colonize them. While floodwater mosquitoes develop during the first week post-inundation, it may take two to three weeks for the first macro-invertebrate predators to become established (Walton et al. 1990). Many nontarget species exploiting temporary aquatic habitats are capable of recovering from localized population declines via recolonization from proximal areas. These materials have no phytotoxic effects when applied properly.

Control of Adult Mosquitoes (Adulticiding)

Adulticiding refers to the application of aerosolized materials to control host-seeking adult mosquitoes. In San Mateo County, these materials are applied only when methods used to control larvae fail and large populations of adults emerge in areas close to human habitation. The District rarely applies adulticides to Bair Island itself, but it has occasionally needed to apply them to residential areas of the surrounding communities, to control mosquitoes emerging from Bair Island.

The efficacy of adulticiding is dependent upon a number of factors. First, the mosquito species to be treated must be susceptible to the insecticide applied. Some District mosquitoes are resistant or more tolerant to some adulticides, thus affecting the selection of the chemical. Adulticides are applied by hand-held units when applied to limited areas, or by truck mounted sprayers when applications are made on a larger scale.

Each chemical application has its own set of conditions that determine success or failure. The application must be at a dosage rate that is lethal to the target insect and applied with the correct droplet size. The most common form of adulticiding is ultra low volume (ULV). Typically with ground applications, vegetated habitats may require up to three times the dosage rates that open areas require.

This is purely a function of wind movement and its ability to sufficiently carry droplets to penetrate foliage.

Environmental conditions may also affect the results of adulticiding. Wind determines how the ULV droplets will move from the spray equipment into the treatment area. Conditions of no wind will result in the material not moving from the application point. High wind, a condition that inhibits mosquito activity, will disperse the insecticide too widely to be effective. Light wind conditions (<10 mph) are the most desirable because they move the material through the treatment area and are less inhibiting to mosquito activity.

ULV application is avoided during hot daylight hours because thermal conditions will cause the small droplets to quickly rise and become completely ineffective on the adult mosquitoes. Generally, applications are made at night, when a thermal inversion is present, keeping the material near to the ground.

Materials Used to Control Adult Mosquitoes

Pyrethrins and Pyrethroids: General Description

Natural pyrethrins (pyrethrum) are extracted from chrysanthemum flower heads, mainly *Chrysanthemum cinerarnaefolium*, grown commercially in parts of Africa and Asia. The six pyrethrins are esters of three cyclopentenolone alcohols: Pyrethrolone, cinerolone, and jasmolone combined with either chrysanthemic acid or pyrethric acid. In spite of the different isomers possible, the six natural pyrethrins are invariably dextrorotatory isomers of the *trans* form of the carboxylic acids. Synthetic analogues of the natural pyrethrins (pyrethroids) reached commercial success in the 1950's. The first commercial product, allethrin, represented the ester of racemic allethrolone with racemic *cis/trans*-chrysanthemic acid. Bioallethrin is the same ester formed from the natural dextrorotatory trans form of chrysanthemic acid. Other 'first generation' synthetic pyrethroids such as phenothrin and tetrathrin, like the natural pyrethrins, are relatively unstable in light. During the 1960's and 1970's, great progress was made in synthetic light-stable pyrethroids. This was done primarily by Japanese workers studying phenylacetic acid esters (which led to fenvalerate) and by the Elliot team at Rothamsted with esters of the dichlorovinyl analogues of chrysanthemic acid (which led to permethrin and cypermethrin). These photostable pyrethroids represent the 'second generation' of these compounds.

Pyrethroids exhibit rapid knockdown and kill of adult mosquitoes, characteristics that are a major benefit in their use. The mode of action of these compounds is related to their ability to affect sodium-channel function in the neuronal membranes.

Synthetic pyrethroids are not cholinesterase inhibitors, are noncorrosive, and will not damage painted surfaces. They are less irritating than other mosquito adulticides and have a less offensive odor. In comparison to other adulticides, pyrethroids may be effectively applied at much lower rates of active ingredient per acre. The synthetic pyrethroids are mimics of natural pyrethrum, a botanical insecticide. Natural pyrethrum, sold under several trade names, is registered in California, but is used sparingly due to higher cost.

Natural Pyrethrins

Pyrenone 25-5 is a California-registered natural pyrethrin formulation, with a label containing a "Caution" statement. Pyrenone 25-5 contains 5% pyrethrin and 25% piperonyl butoxide. Pyrenone 25-5 is applied as a ULV spray with a dosage per acre of typically 0.87 oz/acre (equivalent to 0.0027 lbs of pyrethrins and 0.0135 pounds of piperonyl butoxide per acre).

Pyrenone 25-5 is labeled for use by government mosquito control programs controlling mosquitoes on residential, industrial, recreational and agricultural areas as well as swamps, marshes, overgrown waste areas and pastures where adult mosquitoes occur. This Public Health Insecticide may be used over agricultural crops because the ingredients are exempt from tolerance when applied to growing crops.

Resmethrin

Resmethrin, a 1st generation synthetic pyrethroid, is the active ingredient in Scourge. Resmethrin provides rapid knockdown and quick kill of all species of adult mosquitoes, and is also effective against many other flying or crawling insects, although it is slower acting than natural pyrethrins. Resmethrin exhibits very low mammalian toxicity, degrades very rapidly in sunlight and provides little or no residual activity. Scourge (the commercial product used for mosquito control) contains 4.14% resmethrin, 12.54% piperonyl butoxide, 5% aromatic petroleum solvent (a mixture of hydrocarbons) and other inert ingredients. Scourge is labeled with the signal word "Caution". The maximum rate of application is 0.007 lbs per acre of active ingredient.

Laboratory studies indicate that resmethrin is potentially toxic to fish. However, with rapid photo degradation in water and low-use rates for mosquito control, the risk impact to fish is minimal. The high cost of resmethrin is also a disadvantage of this adulticide.

Equipment Used to Apply Adulticides in San Mateo County

Ultra Low Volume (ULV)

When adulticides are used in San Mateo County they are appl;ied from ground-based equipment in San Mateo County in the for of Ultra Low Volume Fog or ULV. The optimum size droplet for mosquito control with ULV applied at ground level has been determined to be in the range of 8-30 microns. The amount of material applied during ground adulticiding operations for control of adult mosquitoes rarely exceeds 1 oz. per acre (this is in contrast to agricultural fogging applications where materials may be applied at up to 36 oz per acre.

Benefits and Risks of the ULV Treatments

Any mosquito adulticiding activity that does not follow reasonable guidelines, including timing of applications, avoidance of sensitive areas, and strict adherence to the pesticide label, risks affecting nontarget insect species. Ground adulticiding, however, can be a very effective technique for controlling most mosquito species in residential areas economically and with negligible nontarget effects.

A benefit of ULV aerosols is that they do not require large amounts of diluents for application, are therefore much cheaper, and environmentally safe.

Any discussion of risk versus benefits needs to note that this form of control has been in extensive use for more than 40 years. There have not been any glaring adverse impacts attributed to ground adulticiding when it was done properly.

Because adulticiding is primarily carried out within populated areas, humans, and domestic animals are exposed to drifting and deposited insecticide droplets. Since adulticides are usually applied during the night or twilight hours, nocturnal and crepuscular animals may have a greater chance for direct exposure. Fortunately, due to dispersal characteristics of ULV sprays, very little insecticide deposits per unit area. It must be realized that droplet size is of greatest consequence to deposition rates and ultimately the degree of exposure to nontarget organisms. Most modern adulticides are short-lived in the environment, degrading rapidly when exposed to sunlight, water, or soil microbes. Biomagnification has not been documented to occur for currently used adulticides.

Drift

A major problem inherent to mosquito adulticiding is controlling/predicting the distribution of the pesticide spray during and after applications. This is because adulticides are applied by atomizing technical solution into micron-size droplets that are intended to drift across target areas such as a city block or larger area. Deposition of these droplets occurs within and beyond the target area as dictated by droplet mass (*i.e.*, terminal fall velocity), and prevailing meteorological conditions. Adequate drift of small (<10mm VMD[volume median diameter]) droplets through the target area is essential for efficacious mosquito control, yet 10 micron droplets may be calculated to drift 500 meters (0.3 miles) when applied by ground equipment and a wind speed of 4 km/h (Tietze *et al.* 1994). Under the same conditions, a one-micron droplet is expected to drift about 2000 meters (1.2 miles). These drift characteristics distribute the insecticide across a wide area, but may lead to incidental deposition into wetlands and other sensitive habitats.

The influence of meteorological conditions on spray drift cannot be understated (Armstrong 1979). Air temperature at ground level relative to that above it dictates air stability and consequently, patterns of drift and deposition. Higher temperatures on the ground will cause the spray cloud to become entrained in rising thermal currents, thus interfering with the intended horizontal drift pattern. Wind speed and directionality are important for obvious reasons.

In addition to the size of the droplet and meteorological conditions, the amount deposited depends upon application strategy (*i.e.*, ground or aerial treatments), type of equipment used, method of calibration, and flow rate (Dukes *et al*. 1990). For example, aerial applications using flat-fan nozzles produce larger droplets than do truck-based applications using a ULV fogger. LECO sprayers produce a different droplet spectrum from Biomist sprayers, and in the case of the LECO, higher pressures produce greater numbers of smaller droplets. Drift and deposition is influenced by the presence of structures such as trees and buildings that create complex airflow patterns and vortices that may promote channeling of the spray cloud and deposition.

Environmental Risk

The Environmental Hazards section of mosquito adulticide labels instructs applicators to avoid direct application over water or drift into sensitive areas (*i.e.*, wetlands) due to the potentially high toxicity of these compounds to fish and invertebrates. The habitats to be avoided include lakes, streams, and tidal marshes. Thus, any deposition of adulticides into these areas should be indirect and unintentional. A fundamental conflict is evident when considering that aerial applications of adulticides target active adult mosquitoes that may have emerged from the same aquatic resources that are to be protected from exposure to these compounds. The problem is further compounded by the complex interweaving of aquatic habitats and urban areas typically found along California coasts. The proximity of residential communities to saltmarsh and freshwater habitats increases the potential for direct overspray or unintentional drift into these sensitive areas.

It should be evident that control of mosquitoes should be accomplished during their larval stage, before they emerge as adults. The materials available for larval control have less impact on the environment and can be applied to a much smaller area than those used for adult control.

CONCLUSIONS

Mosquito development on Bair Island has a significant potential impact on the surrounding communities. The parcel contains almost 3,000 acres of mosquito habitat in close proximity to human populations. The mosquitoes that develop on Bair Island include species that travel great distances and feed readily on people. Bair Island has large populations of migratory birds that have the potential for harboring mosquito-borne viruses. At least one of these (WNV) is known to occur regularly in birds in San Mateo County. The District has conducted surveillance and control operations on Bair Island for over 30 years and has documented evidence of the impact that mosquitoes from this site can affect the surrounding communities.

The District's control program on Bair Island focuses on eliminating immature mosquitoes before they can emerge. This reduces the amount of pesticide that must be applied and allows the use of less toxic materials. Surveillance plays a fundamental role in the control program and allows the District to target control work to areas where mosquito development is occurring. The materials used by the District for control of larval mosquitoes are very specific and have minimal impact on other organisms. They include bacteria, a growth regulator, and a surface oil. The District uses a tiered approach to selecting larviciding materials. Bacterial larvicides are used when possible, methoprene is applied if later stage larvae are present, and if mosquito pupae are present Larviciding oil (GB1111) must be used. When control of immature mosquitoes has not been successful, adults emerging from Bair Island have had to be controlled through the widespread application of adulticides in the surrounding cities. Although it is generally safe, the material used for control of adult mosquitoes is not as target specific as those used for larval control and may affect other insects. Control of adult mosquitoes in their adult stage is used only when all other methods have failed.

The restoration of full tidal flow to the salt ponds of Bair Island will have a significant effect on the amount of material that must be used to control immature mosquitoes there. The District has been working with the US Fish and Wildlife Service and California Department of Fish and Game to develop a restoration plan that will decrease the need for mosquito control at the site. The District is also assisting the Service and the Coastal Conservancy on a project to control invasive cordgrass surrounding to restoration area. The dikes of Bair Island cannot be breached until the invasive cordgrass has been eliminated from the area. The District is participating in the program to encourage opening the ponds to tidal flow as soon as possible.

Acknowledgements

Several previous documents were used in the preparation of this Vector Management Plan. Much of the detailed information on mosquito control materials was obtained from the Mitigated Negative Declaration prepared by members of the Mosquito and Vector Control Association of California, and staff from the Mosquito Abatement Districts of the Coastal Region including Contra Costa County MVCD, Solano County MAD, Santa Clara County VCD, Marin-Sonoma VCD, Napa County VCD, Alameda County MAD and Santa Cruz County MAD. Information was also used from a document prepared by the Florida Coordinating Council on Mosquito Control, University of Florida entitled "Florida Mosquito Control".