THE BIOLOGY AND CONTROL OF MOSQUITOES IN CALIFORNIA

California Department of Public Health
Vector Control Technician Certification
Training Manual
Category B

BIOLOGY AND CONTROL OF MOSQUITOES

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Information on the certification examination for public health pesticide applicators may be obtained from the California Department of Public Health, Vector-Borne Disease Section, 1616 Capitol Avenue, MS7307, P.O. Box 997377, Sacramento, CA 95899-7377; (916) 552-9730 (http://www.cdph.ca.gov/certlic/occupations/Pages/VectorControlTechnicianProgram.aspx).

Information concerning the laws and regulations pertaining to pest control, pesticide application, and pesticide safety may be obtained from the California Department of Pesticide Regulation, 1001 I Street, P.O. Box 4015, Sacramento, California 95812-4012 (http://www.cdpr.ca.gov/docs/license/liccert.htm).

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INTRODUCTION

Arthropods are a huge group of invertebrate animals (animals without backbones) that include insects, arachnids (ticks, mites, and spiders), crustaceans (crabs, lobsters, and shrimp) and others. There are literally millions of species of arthropods, all sharing the characteristics of a hard exoskeleton and jointed legs. Many arthropods are pests of one kind or another, especially on agricultural crops and farm animals. Some arthropods are direct pests of people, their pets, and wildlife. The most serious pests from the standpoint of public health are those that transmit pathogens that cause human diseases such as malaria, yellow fever, and West Nile **virus**. Pests that transmit pathogens in this way are called **vectors**. Of all the arthropods, there is no group of more importance as public health pests than mosquitoes. As vectors, their only serious rivals in importance are ticks.

Mosquitoes are insects in the order Diptera, family Culicidae. There are approximately 3,500 described species of mosquitoes in the world, about 50 of which occur in California. Not all these are of public health importance, either because they occur only in remote areas far from large populations of people, or because the female mosquitoes rarely, if ever, bite people. On the other hand, a number of species are severe pests and vectors, and life as we know it where they occur would be much degraded were it not for the concentrated efforts of mosquito abatement agencies in the state.

In this manual, pests refer to arthropods that are of direct public health importance. Mosquito pests that transmit organisms that result in infectious diseases in humans and other vertebrate animals are known as *vectors*. A vector is defined in the California Health and Safety Code as: "any animal capable of transmitting the causative agent of human disease or capable of producing human discomfort or injury, including but not limited to, mosquitoes, flies, mites, ticks, other arthropods, and rodents and other vertebrates."

Organized control of mosquitoes began in California more than 100 years ago. The first organized mosquito control efforts were in the salt marshes of San Rafael in 1904. The San Rafael Improvement Association hired an inspector to treat the marshes with oil under the supervision of Professor C.W. Woodworth of the University of California at Berkeley. This work was done primarily by Woodworth's assistant, Henry Quayle. In 1910, malaria in Penryn in Placer County resulted in a community organization to control anopheline mosquitoes in an area from Newcastle to Loomis. This work was under the direction of Professor W.B. Herms.

During the following years a number of tax-supported mosquito abatement districts were formed. Many of them are in the Central Valley of California, where mosquitoes are a particularly serious problem. In 1930, most of these districts joined together to form the California Mosquito Control Association. This association is now called the Mosquito and Vector Control Association of California, and presently (2008), there are 61 corporate members representing mosquito and vector control programs. Approximately 36 million California citizens (about 85% of the total population of the state) are protected from mosquito by the efforts of some type of organized mosquito abatement program.

Certification to apply public health pesticides in California is based on successful testing in several areas: A. Pesticide Application and Safety Training, plus one of the following: B. Mosquito

Biology and Control, C. Arthropods of Public Health Significance, or D. Vertebrates of Public Health Significance. Individuals employed by public agencies must be certified by the California Department of Public Health to apply public health pesticides without supervision of a certified applicator.

This manual is designed to help prepare individuals for testing for competence under B. Biology and Control of Mosquitoes. It is a revision of the manual titled: "The Biology and Control of Mosquitoes in California" edited by Stephen L. Durso. A considerable amount of information was drawn upon from this earlier manual for this revision. **Bolded words** can be found in the glossary.

Acknowledgements: I am very grateful to the many people who helped me in the preparation of this training manual, especially Dr. Marco Metzger, California Department of Public Health (CDPH), who rewrote much of Chapter 7, Physical Control, and furnished new photographs. Dr. William Reisen and Dr. Christopher Barker of UC Davis, Dr. Mark Novak, Dr. Vicki Kramer, Tim Howard, and Mike Niemela (CDPH) read several chapters and furnished comments. Daniela Mulhawi (CDPH) recreated and formatted many of the images. Thanks also to Dr. Branka Lothrop for her photos of the biological control program at the Coachella Valley Mosquito and Vector Control District. Special thanks to Jonathan Kwan (CDPH) who was very helpful throughout the writing process, and furnished considerable guidance.

Chapter 1

BIOLOGY OF MOSQUITOES

MORPHOLOGY

An understanding of the morphology of mosquitoes is important to the identification of mosquitoes. Some morphological characters are shared among all mosquito species, while others form the basis of descriptions of groups of mosquito species, or of individual species. Identification of mosquitoes is discussed in Chapter 4.

ADULT CHARACTERS

As with nearly all other insects, adult mosquitoes have three distinct body regions: head, thorax, and abdomen (Fig. 1.1). Male and female mosquitoes differ in a number of ways that are useful in distinguishing between them. **Sexual dimorphism** is the term used to describe situations where characters differ between males and females.

The head bears many of the structures associated with sensory perception. The most prominent features of the head are a pair of huge compound eyes that occupy much of the head surface, and long plumose (feather-like) antennae. The male antennae tend to be much more plumose than those of females (Fig. 1.2).

Other prominent features of the heads of mosquitoes are the palpi and the proboscis. These also vary between male and female mosquitoes, with the female having short palpi and a long stiletto-like proboscis that in most species contains structures known as stylets that are adapted for penetrating the skin of vertebrate animals for the purpose of obtaining blood (Fig. 1.3). Most male mosquitoes have long hairy palpi and a long fleshy proboscis that is adapted for taking nectar and other fluids from flowers and fruit.

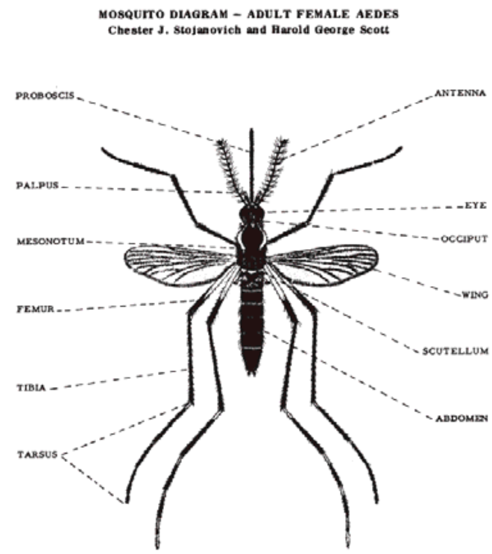


Fig. 1.1 The major morphological structures of an adult female mosquito.

The structure of the feeding organs of male and female mosquitoes is a complex and interesting subject. Generally, these organs consist of the proboscis (a Latin term for beak or snout) and two muscular pumps that are situated in the head. The proboscis of both males and females is made up of a bundle of individual components. The female mosquito inserts only some of these structures when feeding. These structures collectively are called stylets. The active piercing organs are the movable toothed maxillary stylets. The female mosquito inserts these paired structures into the skin in alternating fashion, with the teeth on one stylet anchoring itself to the flesh of the victim while the other stylet is pushed deeper until the stylets eventually penetrate a vein.

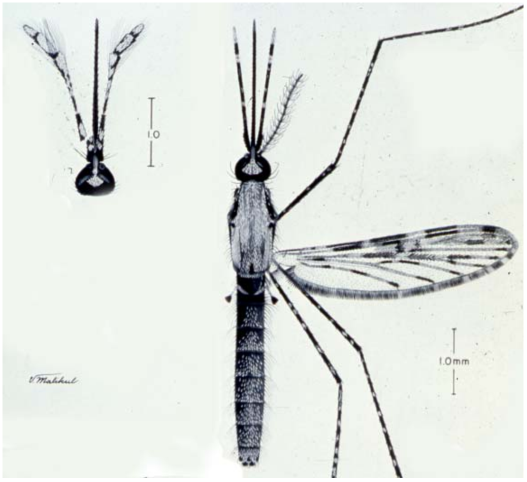


Fig. 1.2 Drawing showing male (L) and female (R) heads.

The thorax supports a pair of wings and a pair of unusual organs called the halteres. These structures are found in all flying Diptera and are adaptations of the second pair of wings possessed by most other flying insects. Most insect morphologists believe that the halteres are used for balance. The wings of mosquitoes vary extensively among species, and are used frequently for identification. The extent and coloration of wing scales are especially useful for this.

The abdomen of mosquitoes is long and tapering, and bears the reproductive structures. The reproductive structures of males are very complex, and in most cases are unique to the many species of mosquitoes. In some instances of closely related species (e.g., *Culex pipiens* and *Culex quinquefasciatus*), there is no other way to distinguish them morphologically. Closely related species that are very difficult to separate by conventional methods are called **sibling species**.

LARVAE

Mosquito larvae differ greatly in appearance and morphology from adults (Fig. 1.4). Larvae are adapted for an aquatic existence, and their feeding and breathing structures reflect this. In

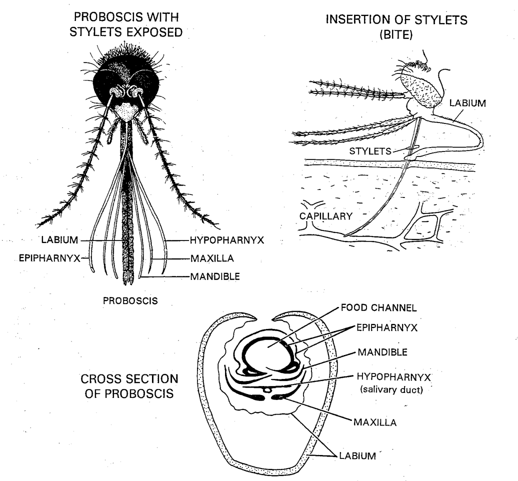


Fig. 1.3 Female Mosquito Mouthparts

general, mosquito larvae are easier to identify to species than are adults. This is because of the characteristic patterns of setae (hairs) that can be studied in microscopic slide-mounted specimens. It is easy to prepare larvae (either whole larvae or cast larval skins) for microscopic study, and these preparations are very durable.

As in the case of adult mosquitoes, larvae (also called wigglers) have a head, a thorax, and an abdomen.

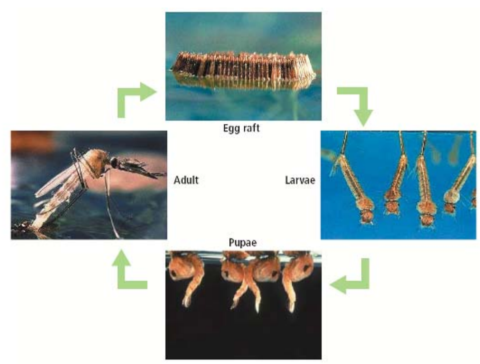


Fig. 1.4 The life cycle stages of mosquitoes.

The head of mosquito larvae is adapted for filtering particulate matter from water surfaces for feeding. Because of this, the mouth parts are situated dorsally (uppermost) in contrast to adult mosquitoes, which have their mouthparts directed **ventrally** (downward). Larvae have eyes consisting of a group of light-sensitive simple structures, but what looks like actual compound eyes are the developing compound eyes of the adult beneath the larval cuticle. The other prominent feature of the heads of mosquito larvae are the brushes associated with the mouth. These brushes move continually while feeding, creating a current to bring particulate food into the mouth.

The thorax of mosquito larvae is a simple ovoid (egg-shaped) structure. It is interesting to examine 4th-stage larvae under a microscope using light transmitted from below because the wings and other adult structures have begun to develop in this stage and can be readily seen.

The larval abdomen consists of a number of segments, each bearing setae, some of which appear star-like or leaf-like. There is some disagreement as to the function of these structures. The most distinctive feature of culicine larvae (the major group of mosquitoes that includes species in the genera *Culex*, *Aedes*, and others) is the air tube. Culicine larvae hang from the surface of the water at an angle, and breathe through the air tube, the tip of which reaches to the water surface. Anopheline (mainly the genus *Anopheles*) lack an air tube.

PUPAE

Mosquito pupae (also called tumblers) do not offer many characters useful for identification. Pupae do not have a distinct head and thorax, rather a composite structure called the cephalothorax. The pupa has two respiratory trumpets projecting from the cephalothorax, and two large structures called paddles that project from the tip of the abdomen.

EGGS

Mosquito eggs vary significantly among the major groups of species, and in some cases among the individual species (Fig. 1.5). Eggs of species in the genera *Culex* and *Culiseta* are long tapered structures that are deposited on the surface of the water. These eggs are deposited a hundred or so at a time and held together by surface tension to form structures called rafts.

Eggs of species in the genus *Aedes* and some other genera are deposited individually and appear to be very similar in shape and structure to the naked eye. However, microscopic examination shows very distinctive patters on the chorion (egg shell) that can be used for identification.

Eggs of anopheline mosquitoes are also deposited individually, but on water surfaces. To keep them afloat, these eggs have structures on their sides called floats.

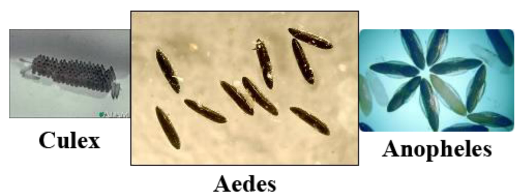


Fig. 1.5 Eggs of the main genera of mosquitoes.

DIGESTION AND NUTRITION

LARVAE

Mosquito larvae drink water and most species eat particulate food (diatoms, microcrustaceans, etc.) present in their aquatic habitats. These larvae have mandibles adapted for chewing and scraping, and they feed by creating a current of water with the movement of brush-like structures on the mouthparts. A few species of mosquitoes (e.g., *Toxorhynchites* spp.) are predaceous on other aquatic arthropods; these larvae have mandibles adapted for tearing and shredding. The amount of food available to larvae is one of the factors that determine the time needed to complete larval development. If food is limited, larval development time is extended.

PUPAE

The digestive tract is changed from that of a larva to that of an adult during the pupal stage, and consequently, pupae do not feed. They do maintain water balance during the 1-2 days of the stage, probably by absorption through the pupal integument.

ADULTS

Both male and female adult mosquitoes drink water and feed on sources of sugar such as flowers or fruit. Most female mosquitoes require vertebrate blood to develop eggs for reproduction, and except under special situations, blood does not contribute to nutrition. Both males and females use the proboscis for feeding, but the females of most species have the proboscis further modified for piercing of vertebrate skin and penetration of blood vessels. Mosquitoes in the genus *Toxorhynchites* do not feed on vertebrate blood. As mentioned above, their larvae are predaceous, and sufficient protein is carried over to adult females for egg development. **Autogeny** is the term used to describe the development of eggs to maturity without a blood meal, and this trait appears in many species under various circumstances.

Blood taken into the digestive tract goes to a different place than do sugars. Blood goes directly to the midgut, sugars go to a structure called the ventral (underside) diverticulum. This is accomplished by a series of receptors located at the entrance of the crop. These receptors act in the role of traffic officer and control a valve that sends the liquids to their proper destination.

Some female mosquitoes store reserves to survive hibernation. These mosquitoes can convert proteins present in late-season blood meals to fat. Such females are very heavy (2-3 times normal body weight) at the beginning of winter, and very light when hibernation is broken in the spring.

EXCRETION AND WATER BALANCE

Mosquitoes face many problems in maintaining water balance. Adult mosquitoes drink water through their proboscis to maintain the proper amount of hydration much as other terrestrial animals do. However, this task is much more difficult for larvae. Larvae that live in freshwater habitats tend towards excess water uptake and loss of ions through osmosis. **Osmosis** is the biological mechanism by which water passes through semi-permeable membranes from the side of the membrane having a lower concentration of ions to the side of the membrane having the higher concentration of membranes. The way to remember this is to realize that the water tends to dilute out areas of high ionic concentration. Freshwater mosquito larvae take in too much water because the ionic balance is greater within their bodies than it is in the water they are living in. Freshwater larvae adapt to this situation by restricting water uptake, producing dilute urine, and taking up ions through large bladder-like organs called **anal papillae**. That is why anal papillae tend to be much larger in larvae in freshwater than in those in saline habitats.

Larvae in saline habitats have a very different problem. They tend to lose water, especially when salinity is so high that the ionic concentration of the water exceeds that of their bodies, and they tend to have too high an ionic concentration. To compensate for this, larvae in such habitats drink large amounts of water and by selective removal of ions by a set of organs called the **Malpighian tubules** and by the rectum. These species tend to have very small anal papillae to reduce water loss while they are in saline habitats. Mosquito species such as *Aedes dorsalis*, which can survive in water with high saline concentrations, can also develop in non-saline habitats, but they do not compete well with strictly freshwater species. It is interesting to note that when species such as *Ae. dorsalis* do occur in freshwater, they have large anal papillae.

THE NERVOUS SYSTEM

Mosquitoes in all stages have a well-developed central nervous system. Larvae have a brain and a nerve mass called a **ganglion** in the head, connected to a ventral ladder-like paired and segmented nerve cord that reaches all the way to the end of the abdomen. There is a pair of ganglia in each abdominal segment. The central nervous system of adult mosquitoes is much the same as the larval system, and it is one of the systems that undergoes little change during the pupal stage. At the time of pupation, some of the ganglia apparently fuse and may change location.

SENSORY PERCEPTION

Adult mosquitoes have well developed compound eyes and apparently well-developed vision. They also have a variety of receptors on their antennae that can detect odors and water vapors. The antennae of female mosquitoes play an important role in location of hosts for blood meals. Adult females also have receptors on the tips of their abdomens that can detect the nature of potential sites for oviposition (egg laying). This is an area in the biology of mosquitoes that is not well understood, but could offer promise for new control methods of **vector** species. One development that is based on the ability of female ovipositing mosquitoes is the oviposition trap containing an oviposition attractant used to monitor populations of certain species of *Culex* females.

BLOOD FEEDING

The mechanism by which blood-seeking female mosquitoes locate potential hosts has been studied for many years, but much remains to be learned. One of the best mosquito repellents ever developed, DEET, has been used for more than 50 years, but exactly how it works is still not completely understood. Many years ago scientists showed that blood-seeking females are attracted by moisture, carbon dioxide, and warmth. This is still the best available explanation. Other substances, such as lactic acid, a component of human sweat, also seem to be attractant.

Some mosquito species are broadly selective of hosts for blood feeding. *Culex quinquefasciatus*, the southern house mosquito, feeds almost entirely on birds. *Aedes sierrensis*, the western tree hole mosquito, feeds only on mammals. It is now believed that there is little evidence of a "host preference" in most mosquito species, and that other factors, such as host availability and the effectiveness of blood feeding defensive mechanisms are the most important determinants of the hosts for mosquitoes.

The act of blood feeding in mosquitoes is facilitated by **salivary glands**, a set of organs in the thorax of adults. Salivary glands are also very important in the transmission of disease pathogens because the pathogens can be injected into the blood stream at the time of feeding. This type of transmission is called **salivarian.** It is the most common type of transmission, and all arboviruses are transmitted in this way, as are malarial parasites.

REPRODUCTION

Mosquitoes utilize sexual reproduction to produce new generations. Sperm from male mosquitoes is deposited in structures called **spermathecae** located at the tip of the abdomen of females. Fertilization of eggs takes place at the time of oviposition, not during mating. The numbers of spermathecae vary from one to three. *Culex* females have three, *Anopheles* females have only one.

A single female usually deposits from 100 to 150 eggs at a time. Over the course of her life she may deposit 3 to 4 batches of eggs.

Mating between males and females nearly always takes place in midair swarms. Once a female is inseminated, she remains for life and her spermathecae contain sperm.

LIFE CYCLE

EGG STAGE

The egg-laying habits of female mosquitoes vary widely from species to species. Some female mosquitoes lay eggs on water surfaces (e.g., *Anopheles*), others lay single eggs on moist soil (e.g., *Aedes*). From eggs deposited on water surfaces, larvae usually hatch within a day or so, but eggs laid on soil surfaces do not hatch until the surfaces are flooded, which may occur months, or even years, later. The environmental cues female mosquitoes use to find suitable sites for oviposition remain only partially known. Color, moisture, and volatile chemical stimulants appear to play a role in certain species. Efforts to explain the occurrence of various mosquito species in different aquatic habitats based strictly on oviposition cues have been unsuccessful.

LARVAL STAGES

Small larvae that are nearly invisible to the naked eye hatch from eggs. Larvae molt three times to become fourth-stage larvae. Several days later, this larval form molts again to become a pupa. The time required for development of the larval stages depends on several factors, the most important of which is water temperature. Availability of food and larval density are also factors. Water temperature and food are inversely related to time of development; larval density is directly related.

Most mosquito species have larvae that are restricted to fresh water. However, larvae of a few species can develop under other conditions, e.g., brackish or salt water or water polluted with organic solids.

ADULTS

Adult mosquitoes emerge 1–2 days after the appearance of pupae, with males emerging first. This is because the males need a head start to allow time for their genitalia to harden and rotate into position for copulation. In the summer, the entire life cycle, from egg to adult, may be completed in 10 days or less. Females feed on vertebrate blood for the development of eggs. This behavior by females is the single most important characteristic of mosquitoes from the human standpoint.

SEASONAL DEVELOPMENT

Some species of mosquito have but a single generation per year (**univoltine**), whereas others have many (**multivoltine**), depending upon the length of the season favoring the activity of the adult stages. To avoid seasons of the year not favorable to adult activity (usually the winter), mosquitoes may have some kind of **diapause** mechanism. In *Aedes* and related genera, the diapause mechanism usually involves the egg stage. In temperate and subarctic regions *Aedes* populations may survive winters as desiccation-resistant eggs, sometimes under the surface of snow or along river flood plains. The larvae then hatch in the spring after the eggs are flooded from melted snow or after flooding of the riverbanks.

Culex and *Anopheles* females usually survive unfavorable periods as diapausing or quiescent adult females. Male mosquitoes usually do not survive unfavorable periods, so it is necessary for insemination to occur before the onset of diapause.

Some mosquito species survive unfavorable periods as diapausing larvae (e.g., species of *Aedes, Anopheles, Culiseta*). Diapause can be variable in some species, depending upon the latitude at which they occur, with diapause occurring in the larval stage at warmer latitudes and in the egg stage at cooler ones.

There is considerable variation in the environmental and physiological control of diapause. In nearly all diapausing mosquitoes studied, diapause is triggered by exposure of one or more of the life cycle stages to day length. In *Culex* species, and other mosquitoes that overwinter as adults, exposure of late-stage larvae and of pupae to short daily photophases occurring in autumn results in diapause in adult females. This diapause is manifested by lowered activity levels, inhibition of blood-feeding drive, and the arrest of follicle development in ovaries. In some *Aedes* species, the short autumn days experienced by females result in deposition of eggs that are in a diapause state. The larvae in these eggs do not hatch until after a period of exposure to near-freezing temperatures lasting several months. In other species of *Aedes,* diapause results from exposure of the eggs themselves to short day lengths. Still other *Aedes* species have larvae that enter diapause triggered by their exposure to short day lengths.

As with other aspects of reproduction and development, diapause is controlled directly by **neurohormones**. Diapause can be induced in most diapausing species by exposure to juvenile hormone or one of its analogs.

Many tropical and subtropical species, such as *Aedes aegypti,* the yellow-fever mosquito, do not have a diapause mechanism. Still other tropical species have mechanisms for avoidance of hot, dry seasons, but these mechanisms have been little studied.

Chapter 2

ECOLOGY OF MOSQUITOES

WHAT IS ECOLOGY?

Ecology is a Greek word, and literally it means the study of the household. The generally accepted definition of ecology as a science is the study of the distribution and abundance of life and the interactions between organisms and their environment. The ecology of mosquitoes involves the distribution and abundance of immature and adult populations of mosquitoes and how these are influenced by geographic distribution, elevation, weather and climate, vegetation, and seasons. Ecology is a complex and somewhat imprecise science. For example, the same factors that can control vegetation patterns may also control the distribution of mosquito populations. However, there may be direct controlling effects of vegetation on mosquitoes, such as when aquatic vegetation provides protection of mosquito larvae from predators. This is a relatively simple example, but in many instances the web of cause and effect can be extremely involved, and discovering clear-cut cause and effect relationships nearly impossible. In spite of this, many valuable lessons have been learned from the study of ecological patterns, some of which have translated into improved mosquito abatement methods.

BIOREGIONS

Many different classifications for biological regions of the world have been developed. Most have attempted to explain the **flora** (the plant species that inhabit a given region) based on climatic factors of temperature and precipitation. In California, a system developed by the Inter-agency Natural Areas Coordinating Committee (INACC) recognizes 10 major zones Klamath, Modoc, Sacramento Valley, Bay-Delta, Sierra, San Joaquin Valley, Central Coast, Mojave, South Coast, and Colorado Desert (Fig. 2.1). INACC has made shape files available on the website http://gis.ca.gov. The files can be found by doing a search on INACC bioregions. Each of these bioregions has a characteristic mosquito fauna and the zones provide a convenient backdrop for studies on the factors that influence the geographic distribution of mosquito species and populations. The INACC regions have been adopted by the California Diversity Council for use as bioregion boundaries.

Fig. 2.1 Bioregions of California used by Inter-agency Natural Areas Coordinating Committee (INACC) of California.

WEATHER AND CLIMATE

It is difficult to provide precise definitions that will clearly distinguish between weather and climate. Generally, weather is used to describe short term conditions that are present in a given area, while climate describes the longer term conditions that characterize areas.

RELATION TO VEGETATION

Mosquitoes have definite relationships to vegetation in most of their life cycle stages. Larvae are seldom found in water lacking emergent or submergent vegetation of some kind. It has been shown in both artificial and natural settings that predators consume mosquito larvae much more readily in open water situations. This relationship may pertain even to eggs and pupae. Adult mosquitoes use vegetation in various forms for resting sites, and adult females of some species utilize tree holes as oviposition sites. The California tree hole mosquito, *Aedes sierrensis*, lays eggs in tree holes in the late summer and fall when the holes are dry, and when winter rains flood the hole the eggs hatch and the larvae develop to the pupal stage in the water.

Water that is held by living plants is called phytotelmata. Treeholes are an example of this found in California. In warmer parts of the world, and especially in the wet tropics, many species are associated with plants in this way (Fig. 2.2, 2.3). One such species is *Aedes albopictus* that has invaded California in the past as eggs held in ornamental bamboo plants.

Fig 2.2 Collecting mosquito larvae from an aerial bromeliad, an example of phytotelmata.

Fig 2.3 Blossoms of a Heliconia plant, Darien Province, Panama

SEASONALITY (PHENOLOGY)

Nearly all species of mosquitoes have definite patterns of seasonality. These patterns vary somewhat depending upon the geographic region inhabited by individual populations. Some species produce only a single population in a year. These species are termed ***univoltine.*** Some species, such as *Aedes tahoensis*, the larvae of which develop in melted snow, have life cycles that are not capable of additional generations, even under highly favorable weather conditions. This phenological pattern is termed **obligatory univoltine.**

Other species, especially those having very large geographic distributions, may have many generations in warmer parts of their range (**multivoltine**), but have only a single generation in colder regions. However, if weather conditions are unseasonably warm, a second generation may ensue. This pattern would be called **facultative univoltine**.

In the far southern part of California, many species are active almost all through the year, going into short periods of hibernation only during the coldest winter months.

Diapause is a term used to describe the suspension of certain physiological activities in mosquitoes in connection with **hibernation** (a period of inactivity during the winter) or **aestivation** (inactivity during the summer). *Aedes* species often have eggs in a diapause state as a winter survival mechanism. Some species produce eggs that respond to short day-lengths by entering a diapause state, in others, females respond to day-length by producing diapausing eggs.

In many *Culex* and *Culiseta* mosquitoes, hibernation is spent by diapausing adult, inseminated females. In most instances, late-stage larvae and pupae are photoperiod sensitive, and females will enter diapause depending upon whether or not immature stages are exposed to photophases below some critical level. Hibernation extracts a heavy price on female mosquitoes, and many females that enter hibernation in the fall die from starvation or predation. Only a small proportion remains in the spring to begin a new year's generation of mosquitoes.

COMPETITION

When populations of two different mosquito species occupy the same habitat in the same area, one of the populations often dominates the other, sometimes to the total exclusion of the other. This is an example of competition between the two populations. One well known example of this kind of competition is that shown in Florida after the invasion of the USA by the Asian tiger mosquito, *Aedes albopictus*. In this case the tiger mosquito was in direct competition with the yellow fever mosquito, *Aedes aegypti*. As a result of this competition, over the next few years following the invasion of the Asian tiger mosquito, populations of the yellow fever mosquito disappeared from northern Florida. This particular situation is an example of **competitive displacement**. Competition between populations of different mosquito species is an important determinant of the geographic distribution of many mosquito species.

Chapter 3

PUBLIC HEALTH IMPORTANCE OF MOSQUITOES

MOSQUITOES AND DISEASE

WHAT IS DISEASE?

The definition of a disease is any departure from good health. By this definition, a broken leg, a vitamin deficiency, an allergic reaction, and an infection are all diseases. And so they are.

NON-INFECTIOUS DISEASES

Some people regard only the diseases caused by pathogenic microorganisms (**infectious diseases**) to be important when assessing the public health importance of mosquitoes, but this is a short-sighted viewpoint. There are other diseases caused by mosquitoes that are not infectious:

1. Hypersensitivity. Some people and other animals become **hypersensitive** to mosquito bites as a result of repeated exposure to their bites. This can also occur in people that work in mosquito control or mosquito research through constant dermal or respiratory contact with mosquitoes, or even with just their wing scales. Hypersensitive reactions are allergic reactions, and the consequences of these reactions vary from mild to extremely serious.
2. Secondary infections. Secondary infections occur when microbial organisms present on the skin of an individual enter the wound created by a mosquito bite. This often occurs as a result of scratching the bite. Although this is an example of an infectious disease, its connection with the mosquito is secondary.
3. Extreme discomfort. Some people react more strongly to mosquito bites than others. In these people, welts, swelling, and severe itching can result. This is probably a type of allergic reaction, but not necessarily a hyperallergic reaction.
4. Entomophobia. This is an emotional or psychological reaction and is manifested by extreme fear of insects. Attacks by mosquitoes can trigger this reaction in some people.

INFECTIOUS DISEASES

As discussed earlier, female mosquitoes of nearly all species require blood from vertebrate animals to develop their eggs, and many species bite people, their pets, and livestock for this purpose. The most important result of this behavior is the transmission of microorganisms that cause diseases such as malaria, filariasis, yellow fever, and dengue. These and other mosquito-borne diseases can have serious and sometimes fatal consequences in people. These diseases can also have an impact on livestock, pets, and wildlife. Malaria is perhaps the greatest cause of human disease and death in the world.

Yellow fever, a **virus** disease, has virtually disappeared from the USA because of the availability of an extremely effective vaccine. This vaccine may provide lifelong immunity from a single inoculation. Unfortunately, the availability of the vaccine is limited on a worldwide basis and there are many unvaccinated people living in areas where the mosquito **vector**, *Aedes aegypti,* is common. Yellow fever is an extremely serious disease. There is no available treatment, and infections in humans are frequently fatal. Periodic epidemics continue to occur in various tropical countries. *Ae. aegypti* is common in urban and suburban areas of the tropics and subtropics. The larvae of this species occur in water in various types of artificial containers such as shallow wells, water urns, discarded containers, and tires. It is very difficult to control.

There are many other mosquito-borne diseases, several of them caused by viruses. Some of these viral diseases, such as Japanese encephalitis, La Crosse encephalitis, **West Nile fever**, Ross River disease, and Rift Valley fever, affect large numbers of people in parts of the world where they occur.

The virus disease known as dengue, transmitted mostly by the yellow fever mosquito, is a rapidly expanding problem in the world and now is considered second in importance only to malaria among mosquito-borne diseases. The increase in global human travel resulting from expanded rapid air transportation has been paralleled by the increase in the number of viral strains causing dengue and the increase in the number of cases of a particularly serious form of the disease called dengue hemorrhagic fever. This form of the disease is most serious in children and is a significant cause of mortality.

TYPES OF TRANSMISSION

The interactions between mosquito hosts and the pathogens they transmit are highly variable. Three basic types of transmission mechanisms are involved: (1) **propagative transmission**, in which the pathogen multiplies within the mosquito but does not undergo any changes in developmental form; (2) **developmental transmission**, in which the pathogen undergoes developmental changes, but does not multiply; and (3) **propagative-developmental transmission**, in which the pathogen multiplies and undergoes changes in developmental forms. Transmission of arboviruses is an example of propagative transmission. The virus is taken up by a female mosquito from a viremic host during blood feeding, multiplies many times, and eventually infects the salivary glands of the host. When the female mosquito takes another blood meal, she may infect a new host by injection of saliva.

Malarial parasites are transmitted by mosquitoes by propagative-developmental transmission. The life cycle of the malaria parasite is very complex.

The only example of developmental transmission is that of filarial worms by insects. In California, the dog heartworm is transmitted in this way.

Some pathogens are transmitted to the offspring of female mosquitoes via infected eggs. This type of transmission is known as **transovarial transmission**.

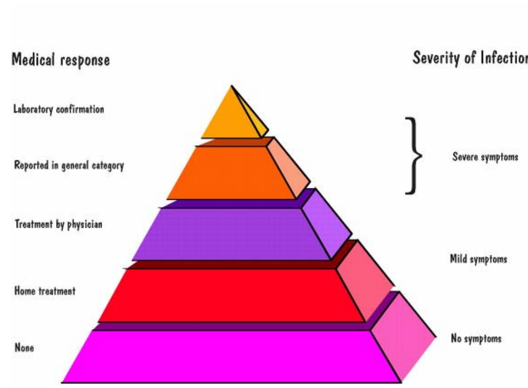


Fig 3.1 A pyramid of infection to illustrate unapparent to apparent infection ratios.

Types of Infections

All diseases have a characteristic that is called the **in apparent to apparent disease ratio**. This characteristic is estimated by epidemiology studies, and is affected by things like the degree of immunity in a human population. Most arboviruses that result in human diseases have a very low ratio, usually from 1:100 to 1:1,000. This means that for every person infected with a pathogen only 1 in 100 or 1 in 1,000 developed disease **symptoms**, respectively.

The concept of the ratio of unapparent to apparent cases for a particular disease is best illustrated by a graphical infectious disease pyramid (Fig. 3.1). This particular pyramid uses people infected with West Nile virus (WNV) in the USA as an example.

The small apex of the pyramid shows that serious symptoms occur in less than one percent (about one in 150 people) of individuals infected with **WNV**. Severe symptoms include high fever, headache, neck stiffness, stupor, disorientation, coma, tremors, convulsions, muscle weakness, vision loss, numbness and paralysis. These symptoms may last up to several weeks, and neurological effects may be permanent. These are the cases that will have laboratory confirmation, and usually hospitalization of the patients.

The middle of the pyramid shows the larger number of people who will have milder symptoms. For WNV infections, up to 20 percent (about one in five) of the people who become infected will display symptoms including fever, headache, body aches, nausea, vomiting, and sometimes swollen lymph glands or a skin rash on the chest, stomach and back. Symptoms generally last for a few days, although some people have been sick for several weeks. Although some of these people will seek medical attention, some will not. Also, some of these cases will be reported based on laboratory confirmation, and some will not.

The large base of the pyramid represents the large number of people who will have no symptoms. Approximately 80 percent of people (about 4 out of 5) infected with WNV will not have any symptoms at all. These people will rarely be seen by a physician, and if a case in this category is detected it will be based on an immunological test done for some other purpose, such as a blood screen done on a donor.

All arbovirus diseases of vertebrate animals have two phases: infection of the vector (the mosquito or other arthropod) and infection of the host (the human or other vertebrate that becomes ill). Arbovirus vectors rarely develop any signs of disease, although careful studies have shown that they may undergo subtle negative effects from infections.

MOSQUITO-BORNE DISEASES OF CALIFORNIA

The pathogens transmitted by mosquitoes in California and the diseases caused by the pathogens are shown in Table 3.1.

ARBOVIRUSES

In California, the most important infectious diseases associated with mosquitoes are those resulting from infection by **arboviruses**. Arbovirus is the term applied to viruses that are associated with arthropods. The most important group of arbovirus vectors worldwide are mosquitoes. Ticks are the second most important group.

Dozens of arboviruses have been isolated from samples of mosquito adults and larvae. Although all the viruses detected in California have names (e.g., Jamestown Canyon virus, Northway virus, Buttonwillow virus, etc.), only a few are known to cause diseases in humans or other animals of economic value. The most frequently contracted diseases associated with mosquitoes in California are West Nile fever, St. Louis encephalitis, and western equine encephalomyelitis. It is important to remember that in only a few cases is the name of the virus and the name of the disease caused by the virus the same. Unfortunately, in California, this is the case for both western equine encephalomyelitis and St. Louis encephalitis. This results in considerable confusion. It is also good to remember that mosquitoes do not transmit diseases — they transmit pathogens such as arboviruses that cause diseases.

Mosquito-borne arbovirus transmission cycles all follow a characteristic pattern. Mosquitoes become infected when they feed on infected vertebrates (usually birds in the case of California arboviruses). For this to happen, the vertebrates must be circulating the arbovirus in their blood streams. This is called a **viremia**, which may last for several days. In the case of West Nile virus, some birds develop a viremia, others do not. Also, some bird species develop a fatal infection, others do not. If the viremia is high enough at the time the female mosquito takes a blood meal, and if the mosquito is a competent vector, a generalized infection occurs, and virus eventually infects the salivary glands of the mosquito.

Vertebrate animals that are susceptible to infection become infected when the infective mosquito (a mosquito that has infected salivary glands) injects viral particles from the salivary glands in the process of taking a blood meal. Most arboviruses are neuroinvasive, which means that the viruses may infect the nervous system of the host, causing diseases such as **encephalitis**.

Two blood meals are usually required for a mosquito to successfully transmit an arbovirus: one to become infected, and a second to transmit the arbovirus to a susceptible vertebrate. Some mosquitoes have been shown to take more than a single blood meal during a single gonotrophic cycle, but this is uncommon. Nevertheless, it is possible for certain species of mosquito to transmit certain viruses after only one blood meal. These mosquitoes can transmit their infections from infected females to their offspring, and the next generation of female mosquitoes is infected when they emerge. This is known as **transovarial transmission (TOT)**. TOT occurs in California serogroup viruses at a very high frequency, and probably in other arbovirus groups, but at a low frequency.

Most infections of arboviruses result from the bite of an infected arthropod, but there are other less common routes of infection. As with nearly all blood-borne infections, blood transfusions, organ transplants, and the transfer of pathogens from mother to fetus may result in infections.

Arboviruses can not be spread through casual contact such as touching or kissing a person with the virus, or by breathing in the virus.

The **incubation period** (the period between the time a person is bitten by an infected mosquito until that person develops symptoms of a disease) ranges from 3–14 days in most arbovirus diseases of humans.

California Encephalitis

There have been only four confirmed cases of California encephalitis in the state. Three cases occurred in the Central Valley in the 1940s, and a fourth case was diagnosed in a resident of Marin County in 1998. The causative agent of California encephalitis is the California encephalitis virus. The virus was discovered in 1943 and named in 1945 after the three cases of encephalitis were associated with the virus by serological tests.

Although only a handful of human cases have been associated with this virus, the virus has been isolated from mosquitoes many times throughout the Central Valley, mainly from *Aedes melanimon*.

The California encephalitis virus is a member of the California serogroup of viruses in the genus *Bunyavirus*. There are two other mosquito-

Table 3.1. The most important mosquito-borne disease pathogens in California, the diseases that result from infections, and the primary vectors.

Pathogen	Disease	Vectors
California encephalitis virus	California encephalitis	*Aedes melanimon* (?)
St. Louis encephalitis virus	St. Louis encephalitis	*Culex tarsalis, Cx. quinquefasciatus*
Western equine encephalomyelitis virus	Western equine encephalomyelitis	*Culex tarsalis*
West Nile virus	West Nile fever, West Nile neuroinvasive disease	*Culex tarsalis, Cx. pipiens, Cx. quinquefasciatus*
Plasmodium vivax, *P. falciparum*	Malaria	*Anopheles freeborni, An. punctipennis*
Dirofilaria immitis	Dog heartworm	*Culex* spp., *Aedes* spp.

transmitted viruses in this serogroup, Jamestown Canyon virus (JC) and Morro Bay virus (MB). Although JC has been incriminated as a cause of human disease in the midwestern USA, there has never been a confirmed human case in California. Antibodies to JC have been detected in people exposed to the bites of snow pool *Aedes* mosquitoes in the Sierra Nevada (forest rangers, etc.). Antibodies to MB have been detected in many different domestic animals along the south California coastal counties, but as with JC, there have been no human cases.

Western Equine Encephalomyelitis

Western equine encephalomyelitis occurs over much of the Western Hemisphere. It was first recognized as a human and equine disease caused by infection by a mosquito-transmitted virus in 1930. The virus has the same name as the disease it causes. It is classified in the family Togaviridae, genus *Alphavirus*. It is related to eastern equine encephalomyelitis virus, Chikungunya virus, and Ross River virus. Thousands of people and horses have died from severe infections due to **western equine encephalomyelitis** virus (**WEE**) in California, most in the Central Valley. As with many arbovirus infections in people, only a fraction of people infected suffer from severe disease. The apparent to in apparent disease ratio is age-dependent. It is highest in you children less than 4 years of age, and highest in humans over 14 years of age. Responses to infection range from in apparent to headache, to meningitis, to encephalitis. Recovery with life-long immunity is the usual course, but infections, especially in young children, can result in neurologic **sequelae** (long-lasting nervous system afflictions such as palsy) after recovery.

In California, as in most of western North America, the primary vector of WEE is *Culex tarsalis*. Birds are the primary vertebrate hosts for the virus, and probably serve as amplifying hosts in the springtime. Small mammals may also be involved in some areas, with mosquitoes such as *Aedes melanimon* and *Aedes dorsalis* serving as vectors (Fig. 3.2).

Human cases of western equine encephalomyelitis have become relatively rare in recent years in California. This is probably related to changes in housing standards and the activities of local mosquito abatement agencies in the state, many of them with control programs targeted against *Culex tarsalis*. Horse cases are also down from historic levels. This is certainly helped by the development of an effective vaccine for horses, and the strong emphasis on horse vaccination (Fig. 3.3).

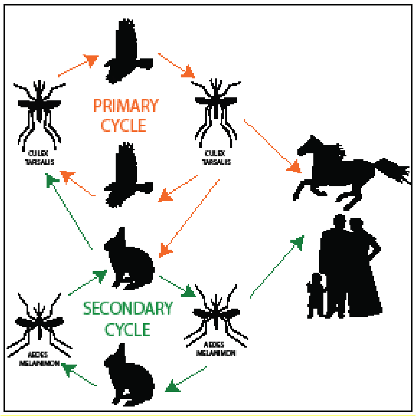


Fig. 3.2 The transmission cycle of western equine encephalomyelitis virus.

Fig. 3.3 A young horse dying from infection with western equine encephalomyelitis virus.

St. Louis Encephalitis

Before the invasion of West Nile virus into California in 2003, St. Louis encephalitis virus was the leading cause of human disease in California. Since its discovery in the USA in the 1933 it has been responsible for several large disease outbreaks. The virus occurs from southern Canada south to Argentina. In California, the last important outbreak occurred in 1989. Signs and symptoms in humans range from mild fever and headaches to encephalitis and death. Horses are not considered to be susceptible to infection by SLE. The transmission cycle for SLE is similar to that of WEE, with birds as the main vertebrate hosts (Fig. 3.4). In the USA, SLE is often a rural disease, and its distribution tends to be in the warmer, more southerly regions.

The virus is a member of the genus *Flavivirus*. Other members of this genus include yellow fever and West Nile viruses.

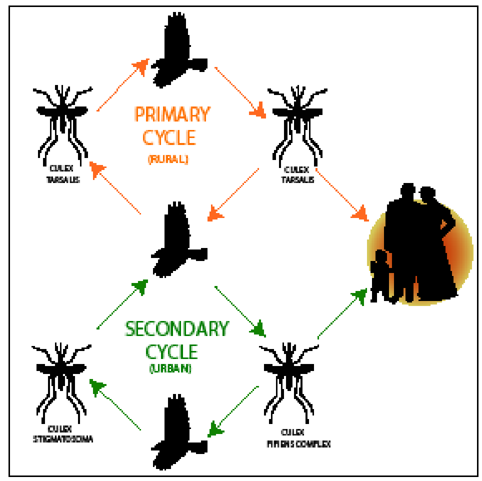


Fig. 3.4 The transmission cycle of St. Louis encephalomyelitis virus

While studying an outbreak of SLE and WEE in the Yakima Valley of Washington in 1940, Dr. William C. Reeves and Dr. William McD Hammon discovered that the vector of SLE and WEE was primarily the mosquito *Culex tarsalis*. Later, Reeves established a laboratory in Bakersfield, California, and found that *Cx. tarsalis* was also the main vector in that area. Subsequent research done in southern California has shown that *Culex quinquefasciatus*, the southern house mosquito, may be an important urban vector.

West Nile Virus

West Nile virus (WNV or WN) is also a member of the genus Flavivirus. WNV was first isolated in Uganda in 1937. Human and equine outbreaks have been recorded in portions of Africa, southern Europe, North America, and Asia. WNV was first detected in North America in 1999. Just how WNV was introduced into North America is not known. It may have been through international travel of infected persons to New York, importation of infected birds or mosquitoes, or migration of infected birds. In humans, WNV infection usually produces either no or a mild to moderate flu-like disease with fever, sometimes accompanied by a rash. However, it can cause severe and even fatal disease affecting the brain or spinal cord (**West Nile neuroinvasive disease**) in a small number of people. In the USA approximately 7% of all seriously ill patients have died, and the fatality rate among patients with West Nile neuroinvasive disease is about 10%. People who are infected with WNV and have flu-like symptoms are said to have West Nile fever.

Unlike WNV within its original geographic range in the eastern hemisphere, or SLE in the western hemisphere, mortality in a wide variety of bird species has been a hallmark of WNV activity in the USA. The reasons for this are not known; however, public health officials have been able to use bird mortality (particularly birds in the family Corvidae) to track the movement of WNV. As of September 2005, WNV has been shown to affect almost 300 species of birds, but most birds survive WNV infection. This has been shown in studies of resident birds within the regions of most intensive virus transmission where a high proportion of these birds developed antibodies against WNV. The contribution of migrating birds in the natural transmission cycle and dispersal of both WNV and SLE is poorly understood.

WNV is transmitted principally by several species of the genus *Culex*, the usual vectors of SLE. Thirty-six species of mosquitoes have been shown to be infected with WNV in nature. Not all of these species are important vectors, but it does suggest that many different vertebrate animals may serve as hosts to the virus in the USA. At least 27 species of mammals have been shown to be susceptible to WNV infection and disease has been reported in 20 of these (including humans and horses). Although the vast majority of infections have been identified in birds, West Nile virus has been shown to infect horses, cats, bats, chipmunks, skunks, tree squirrels, and lagomorphs.

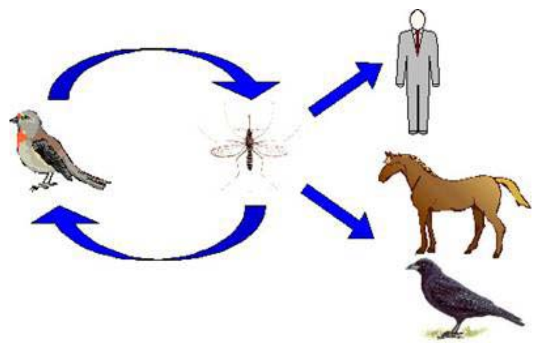


Fig. 3.5 The transmission cycle of West Nile virus.

West Nile virus primarily infects birds. Humans and horses become infected with WNV as a result of the bite of an infected mosquito (Fig. 3.5). Mosquitoes become infected when they feed on infected birds, which have been infected from bites of other infected mosquitoes and are circulating the virus in their blood for a few days. This situation is called a viremia. Hosts that become infected but do not develop a viremia cannot pass the virus on to uninfected mosquitoes, and are thus called **dead-end hosts**.

As discussed above, the risk of humans contracting either West Nile fever or West Nile neuroinvasive disease by WNV is low in the USA. Less than 20 percent of people who are bitten by infected mosquitoes develop any symptoms of the disease and relatively few mosquitoes are actually infected. As with all diseases caused by mosquito-borne pathogens, the risk of infection and disease increases with exposure. Therefore, people who spend a lot of time outdoors are more likely to be bitten by mosquitoes. They should take special care to avoid mosquito bites.

In the USA all donated blood is checked for WNV before being used. The risk of getting an arbovirus infection through blood transfusions and organ transplants is very small, and should not prevent people who need surgery from having it. Transmission during pregnancy from mother to baby or transmission to an infant via breastfeeding is extremely rare.

Malaria

Malaria is one of the most important diseases in the world. Several hundred million people are infected with malarial parasites, resulting in over 2 million fatalities annually, mostly in tropical countries in Africa and Asia. Malaria is especially serious in pregnant women and young children. Typically, more than a million children die each year from this disease. The economic development of a number of tropical countries is badly hindered by malaria because of the burden of chronic malaria infections in working-age men and women.

Before World War II, malaria was an important disease in California associated with mosquitoes. Because of a variety of factors, including intense mosquito control efforts directed at mosquito species that transmit the malarial parasite, locally-transmitted malaria (cases of malaria resulting from bites by infectious mosquitoes in the area where the victim comes down with the disease) is now rare in California. There are hundreds of malaria cases reported in the state each year, but nearly all of these are cases of **imported malaria** (cases of malaria resulting from contracting the diseases outside California by travelers who come down with the disease after their return).

Malarial parasites have a very complex life cycle, involving both multiplication of parasites and development of life cycle stages (Fig. 3.6). Anopheline mosquitoes are the vectors of human malaria, and because the sexual stages and fertilization occur within mosquitoes, by definition they are the definitive hosts. Parasite forms called microgametocytes (male sex cells) and macrogametocytes (female sex cells) occur in the peripheral blood of humans and are taken up by mosquitoes. Fertilization of the female cells by the male cells occurs within the gut of the vector mosquito. After several life cycle changes, and multiplication of forms within cysts on the gut wall, forms of the parasite called sporozoites enter salivary glands of the mosquito and infect new hosts during blood feeding.

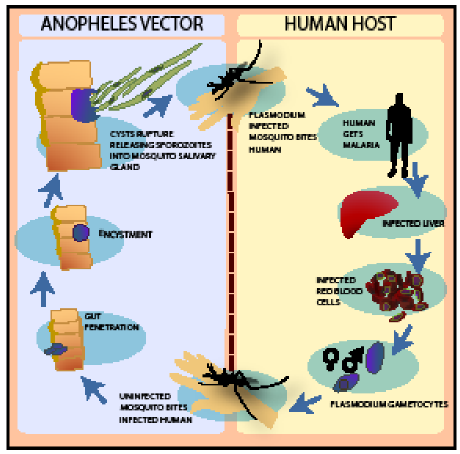


Fig. 3.6 The transmission cycle of malaria.

The use of antimalarial drugs is an important preventive measure, and people planning trips to malarious areas of the world should be prepared to take drugs as prescribed by a physician. Some malarial parasite are resistant to certain drugs, and before taking drugs to prevent malaria, people should always check first to make sure that the particular drug is effective for the parasite and part of the world to be visited.

Dog Heartworm

Filariasis is a general term applied to infection of vertebrate animals by many different species of parasitic worms belonging to the superfamily Filaroidea. A form of mosquito-borne filariasis is called lymphatic filariasis because infection can cause impairment of the lymphatic system. Lymphatic filariasis is a chronic disease that can lead to the well-known disfigurement of humans called elephantiasis. Another type of filariasis called dog heartworm occurs in dogs, other canids (e.g., wolves and coyotes), and felids (e.g., domestic cats). Heavy infections can result in large buildups of adult worms (*Dirofilaria immitis*) in the cardiopulmonary system and can be fatal (Fig. 3.7).

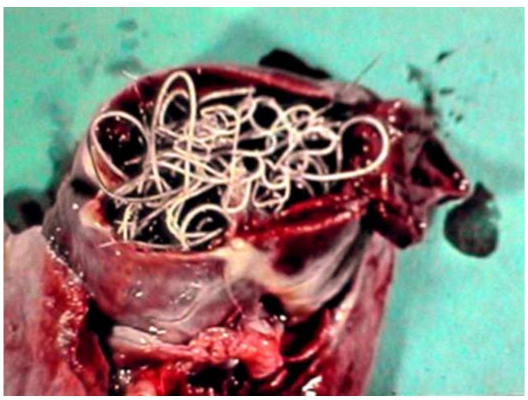


Fig. 3.7 A heavy infection of Dirofilaria immitis in the pulmonary artery of a dog.

Parasitic adult worms can live for many years in the pulmonary artery of vertebrate hosts. These infestations may result in serious disease for the host; infected dogs that are untreated may die. Treatment also has risks, especially in advanced cases. The best defense against heartworm disease is the use of prophylactic treatment given monthly.

The life cycle of these parasitic worms is very interesting. Worms, called microfilariae, occur in the blood of infected vertebrate hosts and are taken up by female mosquitoes in a blood meal. Within the mosquito, the filariae molt several times until they eventually become infectious larvae. These larvae migrate down the proboscis of the mosquito and enter the feeding wound caused by the mosquito during a subsequent blood feeding. Within the vertebrate host, these larvae may eventually develop into adult male and female worms that mate and produce microfilariae. It is the presence of large numbers of adult worms that results in the symptoms of dog heartworm.

TREATMENT FOR MOSQUITO-BORNE DISEASES IN CALIFORNIA

ARBOVIRUSES

There are no specific treatments for human diseases caused by infection by arboviruses. In severe cases, intensive supportive therapy is indicated, often involving hospitalization, intravenous fluids, airway management, respiratory support (ventilator), prevention of secondary infections (pneumonia, urinary tract, etc.), and good nursing care

Horses can be protected from infection by WEE and WNV by effective vaccines. The WNV vaccine does not protect horses against infection by eastern equine encephalitis virus, Venezuelan equine encephalitis virus, or WEE, because there is no **cross-immunity** conferred between WNV and these viruses. Also, there currently is no approved vaccine for general human immunization against any of these viruses, although people who work with viruses in the laboratory can be immunized.

MALARIA

Malaria can be treated with any one of several effective drugs. Some of these drugs are used prophylactically (as a preventive treatment) and others therapeutically (as a curative treatment). Some drugs are effective for both uses. Malarial parasites have developed physiological resistance to certain classes of drugs, and alternatives must be used in such cases. The latest information of prevention and treatment of malaria is available from the Centers for Disease Control and Prevention via their website.

CANINE FILARIASIS (DOG HEARTWORM)

Canine filariasis is a disease that can be prevented effectively in dogs by prophylactic doses of Ivermectin. The disease can also be controlled in dogs with filarial infections if the disease has not progressed too far. Dogs that have suffered from heavy infestations of filariae for long periods may have heavy buildups of adult worms in the pulmonary artery of the heart, and recovery is difficult in these situations even if treated with large doses of anti-filaremic drugs. One of the reasons for this is that there may be serious reactions in dogs from the large masses of dead and dying filariae.

Chapter 4

CLASSIFICATION AND IDENTIFICATION OF MOSQUITOES

HOW ANIMALS AND PLANTS ARE CLASSIFIED

Animals and plants are classified using a system now called the Linnaean system of taxonomy. This system was devised by the Swedish botanist Carolus Linnaeus (aka Carl von Linne) and accepted generally by scientists from the date of Linnaeus's 10th edition of his book *Systema Naturae* published in 1758. In this system, each recognizable form of living organism is named (or described, in taxonomic jargon) as a **species**. Closely related species are grouped into a **genus**, related genera into a **family**, families into an **order**, orders into a class, classes into a **phylum**, and finally phyla into **kingdoms.** For many years, only two kingdoms were recognized: Animalia, for animals, and Plantae, for plants. In recent years, more kingdoms have been created to accommodate things like **viruses** and fungi. Although the system has constantly been tinkered with by "splitters" and "lumpers" over the years, the basic system created by Linnaeus remains basically unchanged. The tinkering has resulted in numerous groupings with a prefix "super" or "sub" (e.g., subgenus).

Using this system, human beings would be classified as follows:

Kingdom: Animalia

Phylum: Chordata

Subphylum: Vertebrata

Class: Mammalia

Order: Primata

Family: Hominidae

Genus: *Homo*

Species: *Homo sapiens*

Sharp-eyed readers will want to know why the species name uses the name of the genus in addition to the name of the species. This is because of another convention that goes back to the time of Linnaeus called the system of **binomial nomenclature**. This convention dictates that plants and animals are given a name consisting of two words: a genus and a species. This two-word name is known as the **scientific name** of the organism. Organisms often have common names, but only the scientific name has any formal standing in the taxonomy of animals and plants. For example, the most important **vector** of the yellow fever virus in the world is known by its common name, the yellow fever mosquito. Its scientific name is *Aedes aegypti*.

Scientific names of most organisms, including mosquitoes, have a long form and a short form. The long form of the yellow fever mosquito is *Aedes* (*Stegomyia*) *aegypti* (L.). The short form is just *Aedes aegypti*.

Scientific names are always in Italic type when they appear in print. In the long form for mosquito names the subgenus name is always enclosed in parentheses. The subgenus is a grouping of closely related species, and subgenera are grouped into a genus. This is part of the tinkering mentioned above. The letter "L" at the end stands for Linnaeus, who is the original describer of this species. The "L" is in parentheses to indicate that Linnaeus originally described the species in another genus (*Culex*). The long form of a mosquito species name ordinarily is used only in taxonomic literature. Usually the short form is used consisting of just the genus and species names, and after the species is listed once in an article the generic name can be abbreviated like this: *Ae. aegypti*.

One final rule of bionomial nomenclature: genus names always begin with an upper case letter, species names do not.

WHAT ARE MOSQUITOES

Mosquitoes are small flying insects and are related to other members of the order Diptera, the "two-winged flies." They are further classified in the family Culicidae. The immature stages, called larvae and pupae, are aquatic and live in stagnant (still, not flowing) or nearly stagnant water sources in every biogeographic region of the world. Adult female mosquitoes of most species feed on blood of vertebrates, including humans, and this habit has resulted in great economic and public health significance for this group of insects.

There are well over 3,000 species and subspecies of mosquitoes in the world. They occur in a variety of habitats, ranging from deserts at or below sea level to high mountain meadows at elevations of 10,000 feet or more. Adult mosquitoes are terrestrial flying insects; immature stages are aquatic. Larvae and pupae of the various species can be found in ponds, ditches, puddles, swamps, marshes, water-filled rot holes of trees, rock pools, axils of plants, pools of melted snow, water in discarded tires, tin cans, and other artificial containers. Some species are most active and in the warmest part of the year, whereas others are adapted to cool temperatures. Many species of mosquitoes are rarely encountered and seldom pose a threat to the health or well-being of humans and domestic animals. However, other species are abundant, frequently encountered, and readily attack people, their pets, and their livestock. Some of these species transmit microbial organisms that cause malaria and encephalitis and other severe diseases of humans and other vertebrates. Mosquitoes also are commonly used as research objects in a wide range of biological studies.

CLOSE RELATIVES OF MOSQUITOES

Mosquito adults are small flying midge-like insects. Most female mosquitoes can be differentiated from similar insects by the presence of a long slender proboscis that is adapted for piercing skin and sucking blood, and long slender wings that are covered with small scales. Male mosquitoes also have scale-covered wings, but their proboscis is adapted for sucking plant juices and other sources of sugars. Most male mosquitoes can also be differentiated from females of the same species by their generally smaller size and by the presence of much longer and hairier maxillary palps (a pair of segmented appendages that extend from the head on either side of the proboscis). The immature stages of mosquitoes, the larvae and pupae, vary in color from yellowish tan to black. Most mosquito larvae have a distinctive siphon, or air tube, at the rear of their bodies, but some species lack this tube, notably species in the genus *Anopheles*.

Other insects that resemble mosquitoes and may be mistaken for them include crane flies, gnats of various types, black flies, sewer flies, and midges. (Fig. 4.1). All of these small flies lack scales on their wings except for sewer flies. These flies frequently fly up through drains in shower rooms and public rest rooms. They can be recognized by their generally hairy bodies and leaf-shaped wings.

Crane flies are very common, and are larger than all but a few species of mosquitoes. Crane flies have very long wings and long fragile legs.

The flies that most closely resemble mosquito adults are the **non-biting midges**, or chironomids. They are roughly the same size as mosquitoes, but lack scaled wings. Also, they do not have an extended proboscis modified for sucking blood. Because midge larvae are found frequently in the same aquatic habitats as mosquito larvae, they may be affected by the same control methods used to control mosquitoes. This represents a special challenge for mosquito technicians in certain circumstances.

Biting midges, also called ceratopogonids, are also severe pests of people and other animals. The adults of these biting insects are so small that their presence is noticed only by the pain of their bite. For this reason they are also called “no-see-ums”. Biting midges usually have wings with pigmented spots (picture wings), but these are rarely visible with the naked eye.

Black flies, also called buffalo gnats, are smaller than most mosquito adults, and have a characteristic humped back (thorax). Female black flies have a short proboscis that is adapted for slashing and tearing rather than piercing. Female black flies are persistent biters of people and other animals. Black flies do not have scaled wings. Because the larvae are found only in moving streams, the adults are usually encountered near such habitats.

CLASSIFICATION OF MOSQUITOES

Mosquitoes are classified into three subfamilies, each with different characteristics in all of their life cycle stages. The species of importance from the standpoint of public health are contained in the subfamilies Anophelinae (called anophelines) and Culicinae (called culicines). Females of species in a third subfamily, Toxorhynchitinae, lack mouthparts adapted for sucking blood from vertebrates. The larvae of this subfamily are predaceous on other aquatic organisms and have been proposed as biological control agents of mosquito larvae.

Culicine adult females have a proboscis developed for piercing the skin of vertebrates and sucking their blood. While feeding, their bodies are usually arranged somewhat parallel to the skin surface of their hosts. Anopheline adult females also have a proboscis adapted for piercing vertebrate skin, but they orient themselves at about a 45° angle while blood feeding.

Common genera of the Culicinae include *Culex, Aedes, Psorophora, Mansonia, Haemagogus, Sabethes, Coquilletidia,* and *Culiseta.* Most species in the Anophelinae are contained in the genus *Anopheles.* The subfamily Toxorhynchitinae contains only the genus *Toxorhynchites.* The common genera of the Culicidae can be recognized by various features of the head, legs, abdomen, and wings (Fig. 4.2, 4.3).

Anopheline larvae lack an air tube and consequently rest parallel to water surfaces. Culicine larvae have an air tube extending from the posterior section of their body and in most species hang at rest from water surfaces at an angle of approximately 45° (Fig. 4.4). Larvae of *Coquilletidia* and *Mansonia* have air tubes adapted for piercing submerged plants to obtain air for breathing. They are rarely found at water surfaces.

Genera of mosquito larvae can be identified based on various morphological features, especially the patterns and numbers of hairs on the head, thorax, and abdomen (Fig. 4.5). The eggs of mosquitoes also vary. Females of culicine species deposit single eggs *(Aedes, Psorophora),* boat-shaped rafts of 100 or more eggs *(Culex, Culiseta),* or clusters of eggs attached to floating plants *(Mansonia, Coquilletidia).* Anopheline eggs also are laid singly, but have elaborate floats extending from the sides of the eggs. Anopheline eggs are often found in clusters on water surfaces, forming interesting geometric patterns.

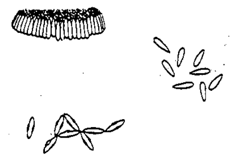
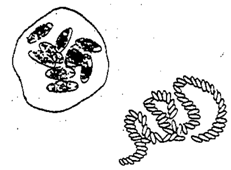
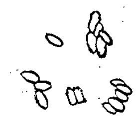
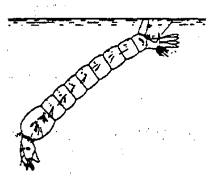
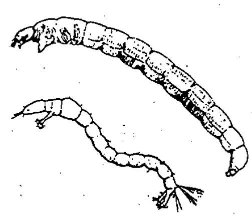
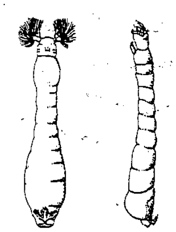
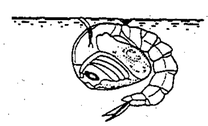
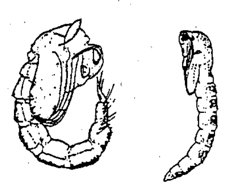
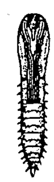
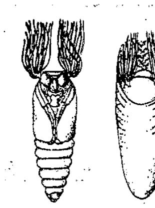
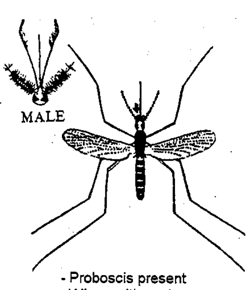
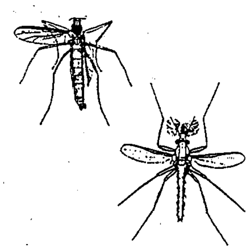
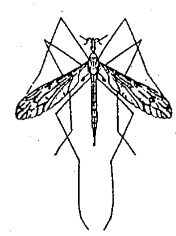
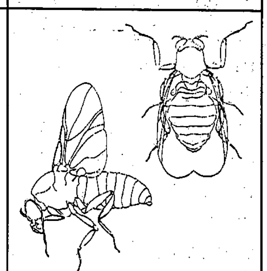
	MOSQUITOES (CULICIDAE)	MIDGES (CHIRONOMIDAE)	CRANE FLIES (TIPULIDAE)	BLACK FLIES (SIMULIIDAE)
EGGS	 - Laid singularly or in rafts on water surface or singularly in soil - Some can dry out - Some undergo diapause	 - Laid singularly, in gelatinous masses, or in strings on water surface -Cannot dry out	 -Laid singularly on water surface or in damp soil - Cannot dry out	 -Laid singularly on water surface or onto wet substrate - Cannot dry out - Some undergo diapause
LARVAE	 - Head and thorax prominent - Breathe through siphon at surface - Active swimmers	 -Head prominent, thorax indistinct - Prolegs on thoracic and last segments - Breathe through skin at bottom - Active swimmers/crawlers	 - Head and thorax indistinct - Last segment with spiracles - Active crawlers	 - Head and thorax prominent - Prolegs on thoracic segments - Club-shaped abdomen with hooks - Stationary or drifters
PUPAE	 - Very mobile - Rounded cephalothorax	 - Very mobile - Long abdomen	 - Limited mobility - Body cigar-like	 - Non-motile in cocoon - Trailing respiratory organs
ADULTS	 - Proboscis present - Wings with scales - Wings extend to tip of abdomen - Males with plumose antennae	 - Proboscis absent - Wings without scales - Abdomen longer than wings - Males with plumose antennae	 - Proboscis present or absent - Wings without scales - Wings longer than abdomen - Legs very long and fragile	 - Proboscis short and non-piercing - Wings without scales - Wings extend to tip of abdomen - Enlarged thoracic segment

Fig. 4.1 Some small flies that are related to resemble mosquitoes.

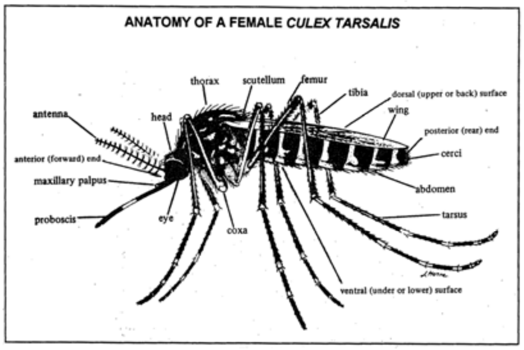


Fig. 4.2 External anatomy of Culex tarsalis

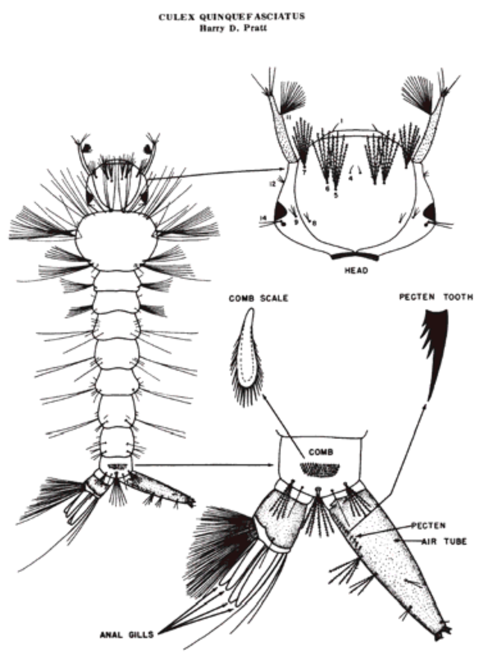


Fig. 4.4 External anatomy of mosquito larvae

Toxorhynchites eggs are also laid singly, usually on water surfaces.

HOW TO IDENTIFY MOSQUITOES

Mosquitoes (and all other animals and plants) are identified in one of about four ways. In most instances, the use of a microscope is needed to make the following types of comparisons:

- Unknown specimens are compared with drawings or photographs of known species and identifications are based on distinct and easily observed characters. For example, the yellow fever mosquito has a distinct marking on the top of its thorax in the shape of a lyre (an ancient musical instrument). No other mosquito species has this marking.
- Unknown specimens are compared with preserved and identified specimens from a museum collection.
- A published key is used that guides the user through a series of two-option choices based on morphological characters. These choices are called couplets and ordinarily take the following form:

  1. Legs all dark 3

  2. Legs with white bands 12

  The user of the key chooses one of the options, which leads to another set of couplets, then another, and another, until eventually the user arrives at (one hopes) the correct scientific name of the previously unknown specimen.
- Unknown specimens are sent to a specialist known as a taxonomist for identification. Most taxonomists work in natural history museums or natural history departments of some kind in colleges and universities.

There are three standard references containing keys to mosquitoes of California;

- Bohart RM, Washino RK. 1978. Mosquitoes of California, 3rd Ed. University of California Press, Berkeley. 235 p.

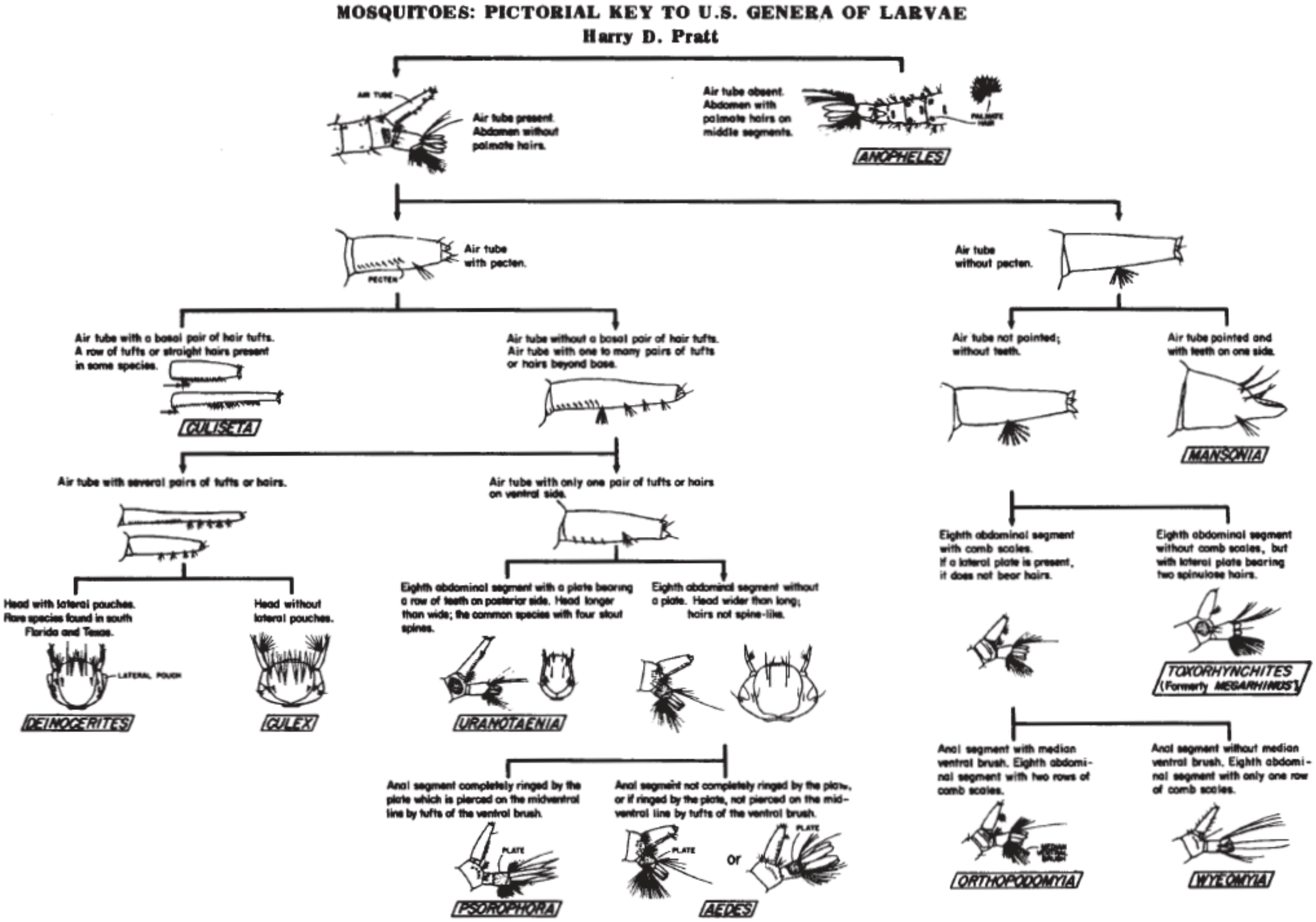


Fig. 4.5 Key to genera of mosquito larvae

- Meyer RP, Durso S. 1998. Identification of the mosquitoes of California. Mosquito and Vector Control Association of California, Sacramento. 80 p.
- Darsie RF, Jr, Ward RA. 2005. Identification and geographical distribution of the mosquitoes of North America, north of Mexico. 2nd Ed. University Press of Florida, Gainesville. 384 p.

The second and third references include drawings to illustrate each key couplet. The first reference uses many illustrations, and includes extensive biological and public health information on each species.

It is beyond the scope of this manual to provide a complete description of all the mosquito species that are found in California. Those interested in detailed descriptions of all the species as well as keys to their identification should consult the book written by Meyer and Durso referenced above.

The most important species from the standpoint of public health, and the ones most likely to be encountered by insecticide applicators are discussed in the following paragraphs.

The distribution of the majority of mosquito species of California, by county, are contained in Tables 4.1 and 4.2.

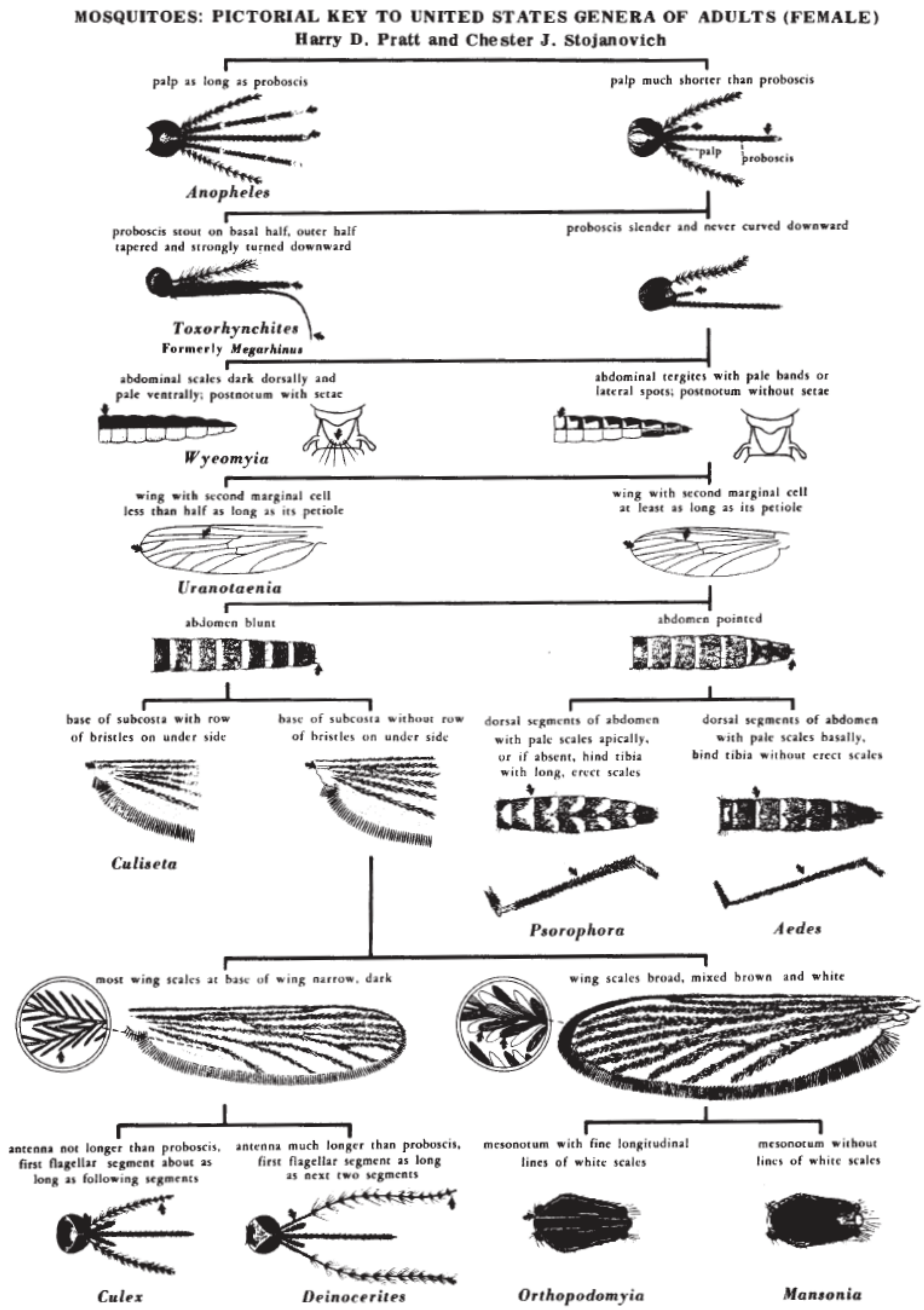


Fig. 4.3 Key to genera of adult female mosquitoes

IMPORTANT CALIFORNIA SPECIES OF MOSQUITOES

The following 22 species have been selected for presentation here because they represent those most likely to be encountered by control technicians. Some of the species were chosen because they are important in transmitting mosquito-borne disease agents to humans and other vertebrates. Others are serious pests of humans and may be responsible for non-infectious diseases (e.g., hyperallergic reactions). A few species are included because they have unusual and interesting life history and habitat associations. A county by county distribution of all the species of mosquitoes are shown in Tables 4.1 and 4.2 at the end of this chapter.

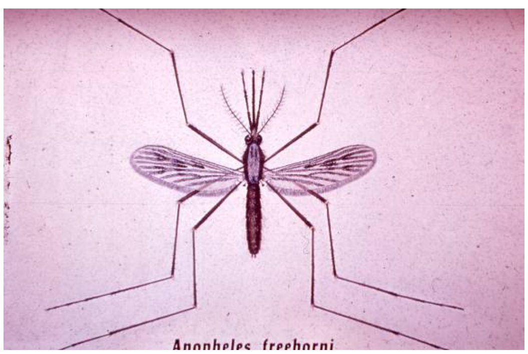


Fig. 4.6 Anopheles freeborni, the western malaria mosquito

Anopheles freeborni Aitken

Identification: *Anopheles freeborni* (the western malaria mosquito) adults are medium-sized, slender, brown mosquitoes with palpi and tarsi without bands of pale scales (Fig. 4.6). As members of the *Anopheles maculipennis* complex, they are easily separated from other California *Anopheles* by the presence of four dark scale patches on each wing and the fringe of the wing completely dark-scaled. Recent cytogenetic studies have separated southern coastal populations of *An. freeborni* into a separate, but morphologically identical species, *Anopheles hermsi.*

Anopheles freeborni larvae are typical *Anopheles* larvae in lacking air siphons and lying horizontally at the water surface when at rest. Distinguishing *An. freeborni* larvae from other California *Anopheles* larvae is difficult and relies primarily upon body hairs and the pattern of spots on the head.

Distribution: *Anopheles freeborni* has been collected from below sea level near the Salton Sea to elevations above 6,000 feet in the Sierra Nevadas and Cascades. Although found throughout the state, the largest populations occur in rice-producing areas of the Sacramento Valley. Because of the uncertainty of the ranges of *An. freeborni* and the closely related *An. hermsi*, and accurate description of the geographical range of either is difficult.

Ecology: Females of this species survive the winter in an inseminated, non-gravid, un-blood fed state. Diapausing females may move many miles to seek overwintering shelters in buildings, culverts, cellars or other protected places. On warm days in January or February, the females will leave their shelters to find blood meal sources. Blood meal sources are deer, sheep, horses, dogs and humans.

Spring rain pools, river seepage areas, marshes, swamps, semipermanent or permanent ponds in irrigated pastures, rice fields and drainage ditches are among the most common larval habitats.

Eggs, as with all anophelines, have characteristic floats extending from the sides. They are laid separately on the water surface. The time required for the egg to hatch is affected by temperature, but usually occurs in 2-4 days.

Larvae lie horizontally just below the surface of the water and feed by filtering suspended matter carried to the mouth by spiral currents created by the action of their oral brushes. The larval stage lasts about 15 days, depending upon the temperature and the quality of the larval nutrition. The pupal stage lasts about three days. The total developmental time from egg to adult is 20 or more days.

Importance: *Anopheles freeborni* is an efficient malaria vector and before World War II was responsible for the transmission of this parasite throughout much of northern California and the Central Valley. Since that time, it has been responsible for several locally-transmitted outbreaks in the northern part of the state. It readily enters homes and animal shelters to bite at dawn and dusk. This species is a significant pest during mid-summer and early fall in the rice-producing areas of the Sacramento and Shasta Valleys.

Anopheles hermsi Barr and Guptavanji

Identification: *Anopheles hermsi* is a recently described species of the *Anopheles maculipennis* complex. Information on the bionomics of this southern California Species is limited and must be presumed to be similar to that of *An. freeborni*. The three members of this complex in California are *An. freeborni*, *An. occidentalis* and *An. hermsi*. All three of these three species are dark-legged, dark-palpi anophelines. Adults of *An. occidentalis* can be distinguished from the other two by having pale golden fringe on the tips of the wings. The other two species have dark scales on the fringe of the wings and are indistinguishable on the basis of morphology. Currently, separation of *An. freeborni* and *An. hermsi* is based on examination of stained microscope preparations of their sex chromosomes, and their geographic distribution.

Distribution: In southern California, *An. hermsi* and An. freeborni appear to have separate and distinct distributions with *An. hermsi* occurring south and west of the Tehachapi Mountains and Coastal Ranges and *An. freeborni* occurring to the north and east of these ranges. In general, *Anopheles hermsi* appears limited to the coastal areas south of San Luis Obispo County. However, isolated populations of this species have been found in counties north of this point. This species has occasionally been called the "southern California malaria mosquito".

Ecology: *Anopheles hermsi* larvae have been collected in a variety of habitats including matted cattail stands, matted root systems of willow trees, river margins and the edges of canyon streams or pools. Larvae rarely are collected from habitats typically associated with *Anopheles* breeding (e.g., sunlit pools with heavy algal mats).

In San Diego County, *An. hermsi* occurs in low numbers throughout the year with peak populations in June and July. Females bite in shaded situations beginning about ½ hour before sunset and continuing thereafter for 1-2 hours. A second peak of biting activity begins about one-half hour before sunrise and continues until shortly after sunrise. *Anopheles hermsi* is an aggressive, flighty biter and will attempt to feed on a number of different hosts in order to obtain a blood meal. Females have been known to feed on chickens, goats, cattle, dogs and humans.

Importance: In recent years, *An. hermsi* has been implicated as the vector in locally-transmitted human malaria outbreaks in San Diego County.

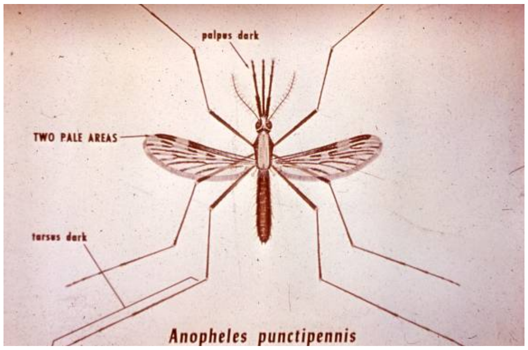


Fig. 4.7 Anopheles punctipennis, the woodland malaria mosquito

***Anopheles punctipennis* (Say)**

Identification: *Anopheles punctipennis* (the woodland malaria mosquito) adults are medium-sized, brown mosquitoes with dark palpi, a wide grey longitudinal stripe on the mesonotum and two pale spots on the forward wring margin (Fig. 4.7).

Distinguishing *An. punctipennis* larvae from other California *Anopheles* larvae requires microscopic examination of the placement and branching of body hairs on the 4th and 5th abdominal segments. The pattern of dark bands on the head also is distinctive.

Distribution: *Anopheles punctipennis* is the most abundant anopheline in the Sierra Nevada foothills and Coastal Ranges, where it is common and widespread. Isolated colonies sometimes are found on the floor of the Central Valley. It occurs abundantly below 4,000 feet and has been recorded as far south as Orange County along the coast and in the Tehachapi Mountains.

Ecology: Larvae inhabit shaded grassy pools in cool wooded areas along intermittent creeks and permanent rivers. Adult females survive winters in diapause. Females are aggressive day and dusk feeders, but will seldom enter enclosed buildings to feed. Animals other than humans are the principal hosts but this mosquito bites humans frequently enough to be regarded as a porch biter and outdoor recreational pest.

Importance: This species is susceptible to laboratory infection with human malaria parasites. In California, *An. punctipennis* was a significant cause of malaria in the early 1900s in Placer County. Problems with this species led to one of the first mosquito abatement programs in the state. It also was probably the vector responsible for the Lake Vera outbreak of malaria at a Girl Scout camp near Nevada City in the 1950s.

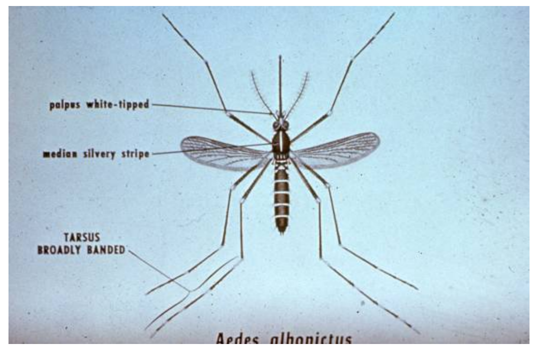


Fig. 4.8 Aedes albopictus, the Asian tiger mosquito

***Aedes albopictus* (Skuse)**

Identification: The most notable characteristic of the species is a narrow stripe of white scales on the scutum, hence the name "tiger mosquito" (Fig. 4.8). The last segment of the hind tarsi are entirely white scaled. Fourth-stage larvae of this resemble those of *Aedes aegypti,* but the comb scales have a fringe of fine spicules, whereas *Ae. aegypti* comb scales have strong spines.

Distribution: **T**his species occurs throughout the southeastern USA. It has invaded California in the past, but currently is not present.

Ecology: Larvae of this species are found in a variety of artificial containers holding water such as tires, tin cans, tubs, and bird baths. Larvae can also develop in water held by living plants and plant parts (phytotelmata).

Importance: This species currently does not occur in California, but it has invaded several times in recent years. The climate of California may not permit permanent residence of the species, but future invasions are possible, and mosquito technicians should be alert to its occurrence. Where this species does occur in the USA it is a persistent day-biting pest, and a potential vector of several human pathogens.

Aedes bicristatus Thurman & Walker

Identification: Adults have unbanded tarsi, maxillary palpi have intermixed dark and pale scales, abdomen with complete basal bands of pale scales. Larvae have head hairs 5 and 6 two-branched, and an anal saddle incomplete.

Distribution: This species is found in most localities in California with oak forests, primarily in the Coast Range and Sierra Nevada foothills. It may be found at elevations as high as 6,000 ft.

Ecology: This species is one of the earliest *Aedes* to appear as an adult in California. The larvae can be found in shallow pools containing green algae, especially in vernal pools and roadside ditches. The substrate of these pools is almost always oak leaves.

Importance: The females of this species are not aggressive human biters. The species is included here because of its unusual larval habitat and because of its relationship to a species of public health importance that occurs in the midwestern USA, *Aedes* (*Rusticoides) provocans*. This species is a probably vector of Jamestown Canyon virus to vertebrates in New York state. There are only nine species in the subgenus *Rusticoides* in the world, only two in the USA. *Ae. bicristatus* is the only representative of this subgenus in California.

Aedes dorsalis (Meigen)

Identification: *Aedes dorsalis* females are medium-sized, whitish to tawny-yellow mosquitoes, superficially resembling *Aedes melanimon.* However, these species are separable by the color of the scales on the anal wing vein; most of the anal wing vein scales are light in *Ae. dorsalis* and dark in *Ae. melanimon.*

Aedes dorsalis larvae may occur with *Ae. melanimon* (inland) or *Ae. squamiger* (coastal) larvae throughout most of their range. Fourth-stage larvae of *Ae. dorsalis* can be distinguished from. *Ae. melanimon* by the much longer dorso-median hairs of the mesothorax (which are nearly as long as the antennae in *Ae. dorsalis*) and from *Ae. squamiger* by the shorter lateral hair of the anal segment (which is shorter than the saddle in *Ae. dorsalis*).

Distribution: *Aedes dorsalis* generally is associated with tidal coastal marshes and with alkaline marshes or irrigated pastures inland. In California, it occurs abundantly along the coast, in the northeastern counties, on the eastern slope of the Sierra Nevada, in the Owens Valley and along the Colorado River. Small populations are located sporadically within the Coachella, Imperial and Central Valleys. There have been unsuccessful attempts to separate the coastal and inland populations into separate species based on differing body color, but apparently there is just a single, very adaptable species in California.

Ecology: Adult *Ae. dorsalis* begin to appear on the tidal marshes in late spring, usually after the annual emergence of *Ae. squamiger*. Mating occurs during the first few days after emergence.

Females often will disperse inland many miles from the tidal marshes to feed in pastures, woodlands or urban areas.

However, they must return to the marshes to oviposit. Laid singly, eggs are deposited in batches of up to 130 eggs.

Under ideal conditions, some *Ae. dorsalis* females may live as long as two months. Feeding primarily on large mammals such as horses and cattle, females readily take human blood when available and occasionally will feed on birds. Biting occurs most often during the daylight hours and at dusk with some blood feeding continuing into the night.

Eggs of many *Aedes* species will not hatch until they have been exposed to very cold temperatures for periods as long as 6 months or more. This exposure is called **conditioning**. Once conditioned, eggs may hatch immediately when flooded, however, hatching may be blocked by low temperatures. Studies of coastal populations indicate that gradually decreasing temperatures cause the eggs to become dormant, whereas gradually increasing temperatures cause them to regain the ability to hatch when flooded. Thus, fall weather arrests hatching and causes the species to overwinter as diapausing eggs, which do not hatch until temperatures rise in the spring. *Aedes dorsalis* can pass form egg to biting adult in less than two weeks with the potential of producing 8-12 generations year.

Aedes dorsalis larvae are very tolerant of high salinity and the pupae can survive 48 hours after being stranded when a source is drained or dries prematurely.

Importance: *Aedes dorsalis* is a major pest species both immediately surrounding its larval breeding source and, after periods of dispersal migrations, for quite some distances away. In addition, there is some evidence that *Ae. dorsalis* is involved as a secondary vector for **WEE** and CE in the Central Valley.

Aedes hexodontus Dyar

Identification: This species is a typical dark-legged snow pool *Aedes*. All of these species are easily identified as larvae, but very difficult to identify as adults. Larvae are readily identified by the presence of (usually) six thorn-like comb scales. No other snow pool species in California has scales like these.

Distribution: Occurs in mountainous areas in California, typically at elevations above 6,000 ft. They are especially common near mountain passes in the Sierra Nevada and Cascade Range, but also occur in the Trinity Alps and at the highest elevations of the Coast Range.

Ecology: This species has a single generation per year (**univoltine**). Eggs are deposited in late spring and summer in moist depressions that will fill with snow the following winter. The eggs are conditioned to hatch by the winter temperatures beneath the snow. The eggs hatch later in the spring than those of *Aedes tahoensis*, a related dark-legged *Aedes* that occupy the same larval habitats. After emergence, the females mate and aggressively seek a blood meal from any available large mammal (including humans). After females have digested the blood meal and a batch of eggs has developed, the female returns and lays eggs at a location near the same snow pool from which they emerged.

Importance: The Jamestown Canyon virus (JC) has been isolated from males and females reared from naturally-infected larvae many times, and this species is probably an important enzootic vector for this virus. In addition, this species is one of several that are the scourge of hunters, fishermen, forest rangers, campers, and other people exposed to them in the spring. About 30% of this group was found to have antibodies against JC in a serosurvey conducted several years ago.

Aedes melanimon Dyar

Identification: Female *Ae. melanimon* vary from brown to tan and have a predominantly dark-scaled abdomen with narrow basal bands of white scales across the top of each abdominal segment and a whitish stripe along the midline of each segment. Their dark tarsi have white bands overlapping the joints. *Aedes nigromaculis* is similarly marked, but its tarsal bands are restricted to the basal side of the joints. *Aedes dorsalis* markings are almost identical with those of *Ae. melanimon,* but the two species differ in general color (usually paler in *Ae. dorsalis* and darker in *Ae. melanimon*) and other subtle characters.

Distribution: *Aedes melanimon* is primarily an inland mosquito occurring in most of the major inland valleys of California from Orange and Riverside Counties northward through the Central and Sacramento Valleys.

Ecology: This species is often found in association with *Ae. nigromaculis* in irrigated pastures and alfalfa fields. It also occurs in many types of intermittently irrigated or flooded vegetated areas. Although *Ae. melanimon* larvae can tolerate slightly higher salinity levels than *Ae. nigromaculis,* both of these species are much less salinity tolerant than *Ae. dorsalis.* *Aedes melanimon* also are common in duck hunting club ponds and wildlife areas flooded in late summer and early fall.

Females are active biters at dusk with rabbits and cattle serving as the primary blood sources although they will readily feed on humans. They fly considerable distances and, when assisted by prevailing winds, can move ten or more miles from a breeding source.

In hot weather, the larvae develop rapidly and can reach the pupal stage in three days. Like *Ae. dorsalis,* pupae can survive being stranded for two days on damp soil. Optimally, adults may emerge as soon as five days after the eggs hatch.

Importance: *Aedes melanimon* is not only a major pest in localized areas near its larval breeding sources, but it has been implicated as an enzootic vector of WEE and an endemic vector of CE in the Central Valley. The original isolation of CE was from *Aedes melanimon*, and almost all subsequent isolations of this virus have been from this same species.

Aedes nigromaculis (Ludlow)

Identification: *Aedes nigromaculis* (the irrigated pasture mosquito) adults usually are medium-sized, but in the Central Valley rapid growth at high temperatures or larval crowding may result in the production of small individuals. Females have a line of yellowish-white scales extending down the center of the upper surface of the black-scaled abdomen. A white ring may be present on the proboscis and the basal portions of the tarsal segments are white-banded.

Distribution: This widely distributed species has been reported from 49 of the 58 California counties. It has been collected from sea level to 6,000 feet in elevation. *Aedes nigromaculis* were first discovered in California in 1937 and within a few years had rapidly spread throughout the state.

Ecology: *Aedes nigromaculis* larvae are associated with irrigated pastures and alfalfa fields. A brood is usually produced with each irrigation at intervals ranging from 10–16 days. In California, the irrigation season usually extends from March to November with peak *Ae. nigromaculis* populations occurring in July and August.

The Central Valley is the major *Ae. nigromaculis* producing region in California. *Aedes nigromaculis* larvae are found most frequently in fields with lower alkalinity and salinity than one would typically associate with *Ae. melanimon* or *Ae. dorsalis.* It occasionally occurs in waters producing *Ae. melanimon* or *Culex tarsalis.*

During midsummer, larvae may grow rapidly and pupate in three days. The pupal stage lasts 1–2 days. Since the pupae can survive on damp, shaded substrates three days of standing water is sufficient to support adult emergence.

The eggs are laid in damp areas subject to later inundation. Each *Ae. nigromaculis* female lays 100–150 eggs per batch with the first batch deposited 4–5 days after the female emerges. Due to the female's short life span (average 10–14 days and maximum 20 days), only 1–2 batches of eggs are deposited by each female before she dies. A majority, but not all of the eggs hatch with each irrigation. As temperatures drop in the fall, the eggs become dormant for the winter. In this state of dormancy (diapause) the eggs will not hatch until soil and water temperatures reach 64-70°F (18-21°C) in the spring.

Aedes nigromaculis blood feed predominately on cattle and readily attack humans. Females are most active at dusk, but also will attack during the day. Normally, the adults remain near the larval site, but under favorable conditions, females are capable of dispersing over 20 miles to obtain a blood meal.

Importance: This mosquito is one of the most pestiferous *Aedes* in the Central Valley, second only to *Ae. melanimon.* Large populations may be produced, resulting in serious economic loss and considerable annoyance to domestic animals and humans.

Aedes sierrensis (Ludlow)

Identification: *Aedes sierrensis* (the western tree hole mosquito) adults are brightly marked with white scales which contrast with the generally dark body. The tarsi have white bands overlapping the joints, the proboscis is unbanded and the tips of the palpi are white-scaled.

Aedes sierrensis larvae usually have very long anal papillae (gills). The often occur in the same habitat as another mosquito, *Orthopodomyia signifera*. Larvae of *Aedes sierrensis* have pecten teeth, whereas *Or. signifera* larvae lack them.

Distribution: Although *Aedes sierrensis* is found widespread throughout California from near sea level to elevations above 9,000 feet, this species is most prevalent in the moist woodland coastal and Sierra Nevada foothill communities of northern California. Where it occurs in southern California, *Ae. sierrensis* is associated with coastal riparian and montane environments.

Ecology: Adults emerge and are most abundant in the early spring, but some emergence may occur in the summer and fall depending on the occurrence of rainfall, the amount of light reaching the tree holes and temperature. This species overwinters in the larval or egg stage. Adults have a limited flight range and generally are found close to breeding sites Females are not attracted to traps using light as an attractant, and specialized traps such as the Fay trap are required to sample adults.

Female *Ae. sierrensis* blood feed predominately on small and large mammals, including humans. Field studies repeatedly indicate small woodland mammals (rodents) as the primary sources of blood meals. *Ae. sierrensis* has a peak of feeding activity at dusk, but also bites during the day and night.

The immature stages are found mainly in rot holes in trees. They have been found in more than 20 species of trees having cavities with external openings as small as

½ inch. They are taken infrequently in old tires, water barrels, tubs and other receptacles containing leaf litter.

Eggs are laid scattered in batches of 50–150, usually in moist places inside a tree hole. They will not hatch for 12 days or more after being laid. Some eggs survive for long periods between floodings.

The larval stage may last from 10 days to several months depending on environmental conditions. The pupal stage lasts four days or longer.

Importance: *Aedes sierrensis* can be a very annoying pest when humans invade its environment. It is most troublesome in wooded recreational and suburban areas. Although not presently considered a vector of human disease, several field and laboratory studies implicate *Ae. sierrensis* as the most important vector of dog heartworm in the coastal and foothill communities of northern California.

Aedes squamiger (Coquillett)

Identification: Adult *Aedes squamiger* (the California salt marsh mosquito) are medium-sized, dark mosquitoes easily distinguished from other California *Aedes* by their characteristic broad wing scales.

The larvae of *Ae. squamiger* superficially resemble the larvae of other *Aedes* such as *Ae. dorsalis, Ae. melanimon* and *Ae. washinoi,* but can be distinguished from these by the length of the lateral hair of the anal segment and short anal papillae. Short anal papillae are typical of mosquito larvae that are adapted to saline environments.

Distribution: This univoltine (one generation per year) species is closely associated with tidal and reclaimed marshes of the Pacific Coast from Baja California to Bodega Bay. This species is closely related to snow pool *Aedes* found in the Sierra Nevada, and probably is a relict species stranded at the end of the ice age.

Ecology: Adults appear on the marshes beginning in February or March. Before mating, both males and females move into wooded areas near the marshes for 4–7 days before the female is ready to blood feed. In favorable late spring weather, females disperse from salt marsh breeding sites over great distances in search of blood meals. After blood feeding, female *Ae. squamiger* return to the salt marshes to lay their eggs.

Aedes squamiger eggs will not hatch immediately after they are laid, even if flooded by summer tides. Rather, they must pass through a period of conditioning, and hatching will occur with the first rains of winter (frequently in December) when source temperatures are below 40°F. As with other salt marsh-breeding larvae, *Ae. squamiger* larvae are very tolerant of high salinity.

Importance: On a localized and seasonal basis, *Ae. squamiger* is considered a major pest species with the females readily attacking humans during daylight hours and at dusk.

Recently, a member of the California serogroup of viruses was isolated from *Ae. squamiger* and named Morro Bay virus. However, this virus has yet to be associated with disease in humans.

Aedes taeniorhynchus (Wiedemann)

Identification: *Aedes taeniorhynchus* (the black salt marsh mosquito) adults are medium-sized to small mosquitoes distinguished from other *Aedes* by a white median band on the proboscis, white-tipped palpi and basal white bands on the hind tarsal segments that slightly overlap the joints.

Fourth-stage larvae have more than nine comb scales, siphon with pecten teeth evenly spaced, siphon tufts inserted beyond the pecten and anal segments completely ringed by the saddle.

Distribution: *Aedes taeniorhynchus* occurs in California in coastal saline waters from Santa Barbara County to San Diego County and inland alkaline waters in the deserts of eastern Imperial and Riverside Counties along the Colorado River.

Ecology: *Aedes taeniorhynchus* is a multivoltine species. In San Diego County, it breeds in high tide pools, primarily those supporting growth of pickleweed (*Salicornia ambigua*). Females lay about 100 eggs scattered in damp places subject to flooding from tides (coastal) or rainfall (inland). After seven days of conditioning, about 95% of the eggs are capable of hatching when flooded. Some eggs do not hatch when flooded for the first time, a result from the slow hatch response of a few eggs in nearly all batches and from the deeper diapause requirements of eggs laid by some females.

Larval development occurs best at temperatures of 72–93°F (22–34°C) and can be accelerated by increasing food supplies, lowering larval densities and maintaining moderate salinity levels, although they are tolerant of high salinity levels.

Females mate when they are 30–40 hours old and avidly blood feed on cattle and occasionally humans.

Importance: Although several arboviruses have been isolated from *Ae. taeniorhynchus,* including eastern equine encephalomyelitis (EEE) and Venezuelan equine encephalomyelitis (VEE), there is no evidence that this species transmits human disease pathogens in California. This species can become a localized and seasonal pest near or around coastal salt marshes or inland alkaline areas in the desert.

Aedes tahoensis Dyar

Identification: This species was previously known as *Aedes communis* (DeGeer). Population genetic studies of the *Ae communis* complex of species in North America showed that only *Ae. tahoensis*, previously considered a synonym of *Ae, communis,* occurs in California. This species is another dark-legged snow pool *Aedes.* Identification of larvae is fairly easy; identification of adults is very difficult.

Among snow pool-breeding larvae, *Ae. tahoensis* are characterized and separable by a pecten row with 14–21 evenly spaced spines, a comb with many scales in a large triangular patch, broadly incomplete saddle without small spicules along its apical portion and head hairs 5 and 6 with one branch each. *Ae. tahoensis* larvae are difficult to differentiate from those of *Ae. sticticus*, a species that was once common along river flood plains in northern California, but is rarely collected now.

Distribution: *Aedes tahoensis* is common along the crest of the Sierra Nevada at elevations above 4,500 feet from Inyo and Tulare Counties northward to Tehama and Lassen Counties.

Ecology: This univoltine spring species occurs in shaded, temporary snow-melt pools with clear margins and a bottom of pine needles. Larvae are found in the same habitats as *Ae. hexodontus*, but earlier in the year. *Ae. tahoensis* is often the earliest mosquito to emerge in the spring at high elevations.

Females are persistent, vicious dusk biters of large mammals, including humans, but adults of this species rarely stray far from the larval development site, so that chances of being attacked by females seeking a blood meal falls off quickly as you move away from the depressions in the mountains where snow pools form.

Importance: *Aedes tahoensis* often reaches numbers sufficient for it to be considered a localized pest species in mountain communities. Jamestown Canyon virus, a member of the California serogroup, has been isolated repeatedly from this species in California. It is probably the most important enzootic vector of the virus in California. Although this virus has been shown to cause a severe and sometimes fatal human disease in the midwestern United States, it has yet to be associated with human disease in California.

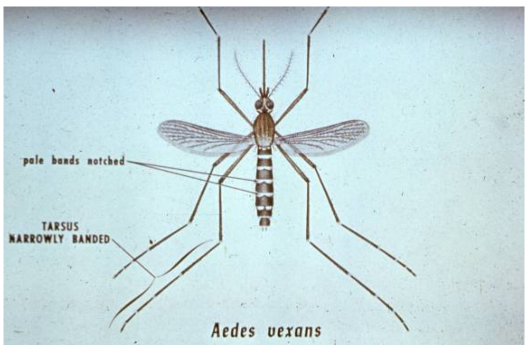


Fig. 4.9 Aedes vexans, the inland floodwater mosquito

Aedes vexans (Meigen)

Identification: *Aedes vexans* (the inland floodwater mosquito) adults are medium-sized, brownish mosquitoes which are easily distinguished from other California *Aedes* by the indented (scalloped) transverse white basal abdominal bands, narrow white basal rings on the hind tarsi and dark wing scales (Fig. 4.9).

Fourth-stage larvae are characterized by 3- or 5-branched upper frontal head hairs, double- or triple-branched lower frontal head hairs, fewer than 20 comb scales and siphon tufts inserted beyond the irregular row of pecten.

Distribution: Widely distributed throughout the USA, *Ae. vexans* occurs in 33 of the 58 California counties. It does not occur in the coastal and high mountain counties.

Ecology: *Aedes vexans* is a multivoltine species which typically breeds in woodland watercourses, but occasionally breeds in open pastures. Females lay 100–180 eggs scattered in moist places left by receding or overflow pools. Shaded soil with a covering of leafy vegetation provides a particularly favorable oviposition site.

Egg hatch is regulated by air temperature and humidity, water temperature, water oxygen content and depth of the eggs in the soil or litter. Hatching of eggs is stimulated by a decrease in oxygen content of the water. The hatching of eggs in a staggered pattern (installment hatching), a phenomenon commonly observed with *Ae. vexans*, may result from variations in age and parentage of the eggs present in a given area as well as from environmental conditions to which the eggs were exposed prior to flooding.

Aedes vexans larvae develop best at temperatures of 50–86°F (10–30°C), taking 46 and 8 days at these respective temperatures. They achieve optimal development at a constant temperature of 77°F (25 °C), requiring a minimum of 7 days to pupation. Low and high lethal temperatures determined in the laboratory are 40° and 100°F (4° and 38°C). In the field, the pupal stage of *Ae. vexans* lasts 35 hours at 84°F (29°C).

Adults mate within two days after emergence and may disperse up to 10 miles in search of nectar or a blood meal. Females are vicious day and night biters, taking blood from large mammals including humans. Birds are occasionally attacked as well.

Importance: Several arboviruses have been isolated from *Ae. vexans* in nature, including WEE and EEE. In California, this mosquito is not considered to be a vector of human disease, but may play a lesser role in the transmission of dog heartworm.

Aedes washinoi Lanzaro and Eldridge

Identification: Recently described as a new species in the *Aedes increpitus* complex, adult *Ae. washinoi* are morphologically inseparable from the other adult members of this complex, *Aedes increpitus* Dyar and *Aedes clivis* Lanzaro and Eldridge. Females of these species have tarsi with broad basal bands of white scales on most joints, dark-scaled wings with a few pale scales concentrated on the anterior veins and a dark-scaled abdomen with the top of each segment transversed by a complete basal band of pale scales.

Aedes washinoi larvae are inseparable from *Ae. increpitus* larvae and have prominent spicules along the apical portion of the incomplete anal saddle, 16–24 evenly spaced pecten spines on the siphon, a comb with more than twenty scales, head hair 5 with 1 and rarely 2 branches and head hair 6 with 1 branch. The last character separates *Ae. washinoi* larvae from *Ae. clivis* larvae which occasionally have head hair 6 with 2 branches.

Distribution: *Aedes washinoi* is common along coastal California at sea level, ranging eastward as far as the Sierra Nevada and Cascade Range foothills in some areas. *Ae. increpitus* probably does not occur in California, except possibly in the far northeastern corner of the state.

Ecology: This species is generally a univoltine late winter and early spring species throughout most of its range, but possibly may be multivoltine at lower elevations. Larval sources include various types of freshwater ground pools, especially in riverine habitats. The larvae are found in many habitats in northern California occupied by *Ae. sticticus* in earlier years.

Females are active day biters, do not fly much more than ½ mile from larval sources and will readily attack humans.

Importance: *Aedes washinoi* occasionally reaches numbers sufficient for it to be considered a localized pest species. Recently, a member of the California serogroup of arboviruses was isolated from this species, but the species does not appear to be an important arbovirus vector.

Culex erythrothorax Dyar

Identification: *Culex erythrothorax* (the tule mosquito) adults are medium-sized mosquitoes with a dark-scaled proboscis and palpi. The back and sides of the thorax are reddish-orange, wing scales are dark brown and legs are medium brown, giving it a bronze-like appearance. This mosquito may be confused with *Culex pipiens* and *Culex quinquefasciatus* but differs by the reddish thorax and yellowish abdominal bands (white bands in Cx. pipiens and *Cx. quinquefasciatus*).

Culex erythrothorax larvae appear similar to those of *Cx. pipiens* and *Cx. quinquefasciatus* with the one- or two-branched lateral hairs on abdominal segments III and IV, but differ by having a much longer siphon index (6–7 in *Cx. erythrothorax* and 4–5 in *Cx. pipiens* and *Cx. quinquefasciatus*).

Distribution: This species occurs in 36 of 58 California counties, mainly in the foothill, coastal and southeastern desert areas.

Ecology: Larvae have been collected year-round in ponds, lakes, marshes and streams where there is shallow water that supports extensive tule or cattail growth. This is one of the few *Culex* species which overwinter as a 4th-stage larva. Sampling *Cx. erythrothorax* larvae is extremely difficult using the standard 1-pint dipper. Disproportionately large numbers of adults often are trapped in typical tule/cattail habitats where attempts to sample larvae result in only a few individuals per dip.

Females usually remain close to the wetland habitat and utilize a broad range of blood sources, including birds and humans. Peak landing and biting activity occurs one to two hours after sunset. However, this species will readily attack and feed during daylight hours in shaded, wind-protected areas.

Importance: Despite isolations of several arboviruses (e.g., WEE and SLE) from *Cx. erythrothorax,* this species does not experimentally transmit these viruses by bite. Locally, *Cx. erythrothorax* can become a major pest to humans and other vertebrates that reside near their tule/ cattail breeding habitats.

Culex pipiens Linnaeus

Identification: This species is indistinguishable from *Culex quinquefasciatus* (Say) using morphological characters except those of the male genitalia. Adults and larvae of the two species can be distinguished using various biochemical procedures. Some non-taxonomists consider the two species to be subspecies (*Cx. pipiens pipiens* and *Cx. pipiens quinquefasciatus*). However, the latest taxonomic treatment of the subgenus *Culex*, to which they both belong, recognize them as distinct species, and until another authoritative taxonomic treatment is published, that is how they must remain according to the International Code of Zoological Nomenclature. The two species occur in temperate regions worldwide, with *Cx. pipiens* (the northern house mosquito) occurring in regions farthest from the equator and *Cx. quinquefasciatus* (the southern house mosquito) occurring in a band closer to the equator.). The former species undergoes a physiological diapause, the latter does not. In California (and elsewhere), there is a zone where hybrids exist in nature. However, this situation is not unique to these two species.

Adult *Culex pipiens* are medium-sized brown mosquitoes with dark-scaled unbanded legs and an unbanded proboscis. Larvae have head hairs 5 and 6 usually with five or more branches and a moderately long siphon tube bearing four tufts with the subapical tuft out of line.

Distribution: *Culex pipiens* is widely distributed throughout the state north of the Tehachapi Range. Hybrids occur in central California (between approximately 5° to either side of 39°N latitude). Populations of this complex north of this will be nearly all *Cx. pipiens*.

Ecology: Diapausing *Cx. pipiens* overwinter as inseminated females. Males do not survive winters. Almost all females enter diapause as a result of exposure of mature larvae and pupae to shortened day-lengths. Diapausing females usually do not take blood meals, and the few that do will not develop eggs. Usually the breeding source is in or near the area from which complaints are received.

Larval sources generally are in permanent or semipermanent, foul or polluted waters. Typical sources include artificial containers, fish ponds, cesspools, septic tanks, catch basins, waste treatment ponds, dairy drains, log ponds and improperly maintained swimming pools.

Eggs are deposited on the surface of the water in rafts containing 120–200 eggs. Hatching usually occurs in 1–2 days with larval development requiring 4–6 days. Pupal development is quick, requiring only 1–2 days.

Mating occurs 1–2 days after emergence with a blood meal usually necessary for eggs to be developed. *Culex pipiens* is known to have autogenous populations, but no autogenous *Cx. quinquefasciatus* populations have been found.

Birds are the principal blood meal source for this species. However, they will attack humans and invade homes to annoy the occupants. Females feed mainly in the evening and at night, spending the daylight hours resting in cool, humid, dark places.

Importance: *Culex pipiens* has been found infected with encephalitis viruses (e.g., SLE, **WNV**, and WEE) in California, but its role in the natural transmission of these diseases is considered to be secondary to that of *Culex tarsalis*. *Culex pipiens* is predominantly a bird-feeder, but will feed on humans at times. *Culex pipiens* is also a likely vector of dog heartworm.

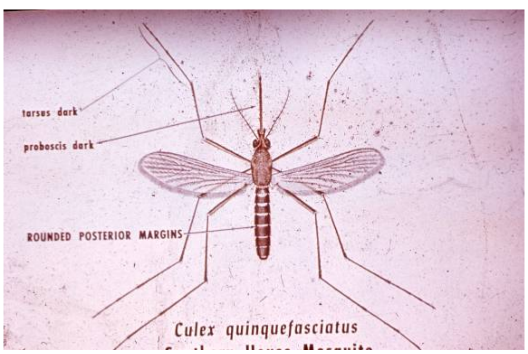


Fig. 4.10 Culex quinquefasciatus, the southern house mosquito.

Culex quinquefasciatus Say

Identification: This species is indistinguishable from *Culex pipiens* using morphological characters except those of the male genitalia (Fig. 4.10). Adults and larvae of the two species can be distinguished using various biochemical procedures. Some non-taxonomists consider the two species to be subspecies (*Cx. pipiens pipiens* and *Cx. pipiens quinquefasciatus*). However, the latest taxonomic treatment of the subgenus *Culex*, to which they both belong, recognize them as distinct species, and until another authoritative taxonomic treatment is published, that is how they must remain according to the International Code of Zoological Nomenclature. The two species occur in temperate regions worldwide, with *Cx. pipiens* (the northern house mosquito) occurring in regions farthest from the equator and *Cx. quinquefasciatus* (the southern house mosquito) occurring in a band to either side of the equator.). The former species undergoes a physiological diapause, the latter does not. In California (and elsewhere), there is a zone where hybrids exist in nature. However, this situation is not unique to these two species.

Adult *Culex quinquefasciatus* are medium-sized brown mosquitoes with dark-scaled unbanded legs and an unhanded proboscis. Larvae have head hairs 5 and 6 usually with five or more branches and a moderately long siphon tube bearing four tufts with the subapical tuft out of line.

Distribution: *Culex quinquefasciatus* is widely distributed throughout the state south of the Tehachapi Range. Hybrids occur in central California (between approximately 5° to either side of 39°N latitude). Populations of this complex to the south of this will be nearly all *Cx. quinquefasciatus*.

Ecology: *Culex quinquefasciatus* do not survive winters as diapausing females, which may be one reason they do not occur in the cold climates occupied by *Cx. pipiens.* However, females do spend periods of cold weather in a short inactive state.

Larval sources generally are in permanent or semipermanent, foul or polluted waters. Typical sources include artificial containers, fish ponds, cesspools, septic tanks, catch basins, waste treatment ponds, dairy drains, and improperly maintained swimming pools.

Eggs are deposited on the surface of the water in rafts containing 120–200 eggs. Hatching usually occurs in 1–2 days with larval development requiring 4–6 days. Pupal development is quick, requiring only 1–2 days.

Mating occurs 1–2 days after emergence with a blood meal usually necessary for eggs to be developed. *Culex pipiens* is known to have autogenous populations, but no autogenous *Cx. quinquefasciatus* populations have been found.

Birds are the principal blood meal source for *Cx. quinquefasciatus*. However, females will readily attack humans and invade homes to annoy the occupants if circumstances permit. Females feed mainly in the evening and at night, spending the daylight hours resting in cool, humid, dark places.

Importance: *Culex quinquefasciatus* has been found infected with encephalitis viruses (e.g., SLE, WEE, and WNV in California, but its role in the natural transmission of these viruses is considered to be secondary to that of *Culex tarsalis* in rural situations. However, in urban environments, *Culex quinquefasciatus* may be the primary WNV vector. *Culex quinquefasciatus* is also a probable vector of dog heartworm.

However, there is growing evidence that *Cx. quinquefasciatus* may play either a primary or a secondary role in the transmission of SLE in the urbanized areas of southern California. This species can transmit filarial worms responsible for dog heartworm and the viruses causing avian pox. In some tropical areas of the world *Cx. quinquefasciatus* is an important vector of filarial worms causing human filariasis.

Culex stigmatosoma Dyar

Identification: *Culex stigmatosoma* (the banded foul water mosquito) has undergone several name changes over the years. The original name, *Cx. stigmatosoma,* was changed to *Culex peus* for a while, but subsequently back to *Cx. stigmatosoma.*

Morphologically, this medium-sized mosquito is very similar to *Cx. tarsalis,* possessing pale bands that overlap the tarsal joints and a pale median band on the proboscis. Unlike *Cx. tarsalis*, the hind femur and tibia do not have a narrow line of white scales. Also, the black scales on the underside of the abdomen form oval or round spots instead of the pattern of V's exhibited by *Cx. tarsalis.*

Culex stigmatosoma larvae are separated from *Cx. tarsalis* larvae by the out of line multi-branched subapical hair tuft on the siphon and the enlarged setae along the dorsal crest of the anal saddle. Both of these characters also separate this species from *Cx. pipiens* and *Cx. quinquefasciatus*

Distribution: *Culex stigmatosoma* is abundant throughout most of California, with the exception of the crest of the Sierra Nevadas.

Ecology: *Culex stigmatosoma* breeds in a variety of natural and man-made sources, particularly in highly polluted water sources such as dairy waste water lagoons, log milling ponds and sewage treatment ponds.

In warmer parts of the state, adults and larvae can be collected throughout the year. In cooler areas, the adult females overwinter in protected locations such as animal burrows in diapause. Peak adult activity occurs during the summer months.

Females often fly far from larval sources and rarely attack humans. Instead, they feed predominately on birds. Eggs are deposited on the water surface in rafts consisting of approximately 250 eggs each. Under optimum conditions, one generation can complete development in 7–15 days.

Importance: Because *Cx. stigmatosoma* feeds almost exclusively on birds and rarely bites humans, it probably is not involved in the transmission of human disease pathogens. However, recent studies indicate that *Cx. stigmatosoma* may play a role in the secondary

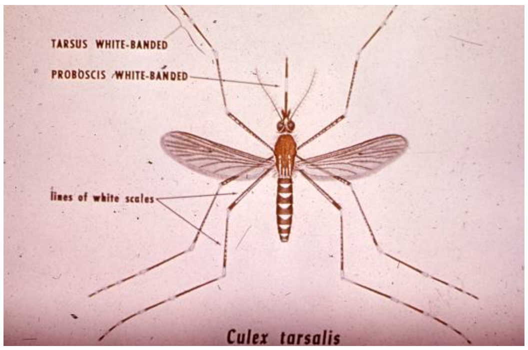


Fig. 4.11 Culex tarsalis, the western encephalitis mosquito

amplification and transmission of SLE in wild bird populations.

Culex tarsalis Coquillett

Identification: *Culex tarsalis* (the western encephalitis mosquito) adults are medium-sized, brownish mosquitoes with a median white band on the proboscis, white bands overlapping the tarsal joints and narrow lines or dotted rows of white scales on the outer surface of the hind femur and tibia (Fig. 4.11). The underside of the female's abdomen is pale-scaled with an inverted V-shaped pattern of dark scales on each segment.

Larvae of *Cx. tarsalis* are separated from other *Culex* larvae by triple-branched lateral hairs on abdominal segments III and IV and all siphon tufts being aligned along the siphon's posterior margin.

Distribution: This species occurs throughout California, having been recorded from all 58 counties over a wide range of elevations.

Ecology: *Culex tarsalis* colonizes a wide variety of aquatic sources ranging from clean to highly polluted waters and is also able to tolerate fairly high salinity levels. It is associated with floodwater, rain pools, irrigation waters, ornamental ponds and dairy drains. However, throughout its range, *Cx. tarsalis* is most commonly associated with agricultural sources. During years of extensive rainfall and surplus irrigation water, this species may become very abundant, increasing the likelihood of encephalitis transmission to humans.

Populations overwinter in cooler areas of the state as inseminated, diapausing females in protected places such as burrows, rock fissures, rock piles, caves, culverts and pipelines. In southern California all stages may be found throughout the year with two peaks of production usually observed; the first in April or May and the second in October or November. In the Central Valley, there is usually a single peak of production in early summer.

The adult life span varies with the time of the year or temperature with the physiological state of the mosquitoes being shortened in the summer months due to the increased rate of egg production, flight activity and general metabolic activity.

Autogenous populations have been found, but are probably not involved in the transmission of encephalitis. Host-seeking *Cx. tarsalis* females show a preference toward birds, but also will take blood from cattle, horses and humans, often flying considerable distances (up to 16 miles with estimates indicating they can fly 20–25 miles if assisted by winds) to do so. This is important in the distribution and transmission of encephalitis viruses. *Culex tarsalis* are highly attracted to $C0_2$-

baited traps and both males and females are attracted to light traps.

Eggs are laid in rafts which float on the water surface for 2–3 days before hatching. Under favorable conditions, larvae mature in 5–8 days and the pupal stage requires 2–3 days.

Importance: In the fall, *Cx. tarsalis* occasionally becomes numerous enough to be considered a localized pest. However, its greatest importance is as a primary vector of SLE, WEE, and WNV.

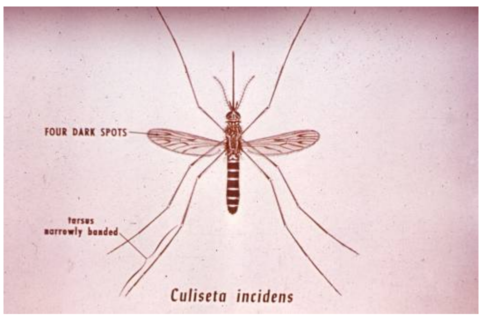


Fig. 4.12 Culiseta incidens, the cool weather mosquito

Culiseta incidens (Thomson)

Identification: *Culiseta incidens* (the cool-weather mosquito) adults are large mosquitoes with narrow white bands on the tarsi and dark-scaled patches on the wings (Fig. 4.12).

Distribution: *Culiseta incidens* is found throughout California, most commonly along the coastal, foothill and mountain regions up to 9,500 feet. It occurs sporadically in the Central Valley and drier parts of southern California.

Ecology: *Culiseta incidens* generally is associated with cool weather. Where summers are hot and winters cold, this species breeds mainly during the fall, winter and spring while aestivating during the summer.

The immature stages are found in clean water with some degree of shading. They also are found in natural depressions and artificial habitats filled with rain or melted snow, including watering troughs, hoof prints, ground pools, rock pools and log ponds.

The eggs are laid in rafts of 150–200 eggs on the surface of standing water. Eggs normally will hatch in 2–3 days with the larval stage lasting about 10 days or longer depending on the water temperature. The pupal stage requires four or more days to complete.

Importance: Female *Cs. incidens* are pests to humans in some areas, however, they feed mostly on large mammals such as livestock, and are not considered vectors of human diseases.

Culiseta inornata (Williston)

Identification: *Culiseta inornata* (the large winter mosquito) females are easily recognized by their large size and generally light brown to rusty appearance. They have no conspicuous scale patches on their wings and the tarsi are unbanded.

Distribution: *Culiseta inornata* is widely distributed in California and has been recorded from almost every county over a wide range of elevations.

Ecology: *Culiseta inornata* is a cool-weather mosquito. In the warmer southern part of its range it is most prevalent in the spring and fall and may occasionally appear in lesser numbers through the winter. It aestivates during the summer in protected areas such as animal burrows, road culverts and abandoned buildings. In the northern part of its range and in the Sierras of California this species breeds in the spring, summer and fall, and diapauses during the winter. The adults are strongly attracted to light and usually are the first species in the spring and the last in the fall to be sampled by light traps.

The immature stages occur in sunlit sources, but may be found in sources shaded from direct sunlight. Larvae are tolerant of moderate organic pollution and considerable levels of salinity and alkalinity. They may occasionally breed in containers.

Eggs are laid on the surface of standing water in rafts usually containing 150–200 eggs. Depending upon temperature, the eggs usually hatch in 2–3 days, with the larval stage requiring 1–2 weeks or longer. Completion of the pupal stage requires two or more days.

Females feed most frequently on livestock at dusk. Where large populations exist, economic losses through annoyance to livestock can occur.

Importance: This species may feed on humans but the degree of nuisance varies geographically *Cs. inornata* is not considered a vector of human disease in California, although it has been found naturally infected with JC, a California serogroup virus.

Psorophora columbiae (Dyar and Knab)

Adult *Ps. columbiae* are medium-sized to large mosquitoes. Females have a pointed abdomen, a median white band on the first segment of the hind tarsi, and wings speckled with dark and light scales in no definite pattern. *Psorophora* and *Aedes* females appear similar.

Fourth-stage larvae have inflated siphons with a single pair of tufts inserted on the outer third of the siphon and the anal saddle completely surrounds the anal segment.

Distribution: This species is restricted to the arid regions of eastern San Bernardino, Riverside and Imperial Counties of southern California.

Ecology: *Psorophora columbiae* breeds in irrigated fields, pastures and date groves. Females lay about 100 eggs scattered on moist places on the soil, particularly where there is a growth of grass. Preflooding temperature is the primary factor controlling egg hatch. In the spring as mean weekly air temperatures increase to 60°F, some eggs hatch when flooded. During the late summer, higher temperatures result in an increased hatch with a near complete hatch occurring at or slightly above 90°F. (32°C). In autumn, decreasing temperatures and day length induce diapause. The overwintering eggs will not hatch until diapause is terminated by warming water temperatures in the late spring.

Adult *Ps. columbiae* are found from April to November with peak abundances occurring in August and early September. Adults are most numerous where both livestock and irrigation water are present. The females are fierce day or night biters, feeding primarily on cattle and horses but dogs, pigs, rabbits and humans also are attacked.

During the summer, *Ps. columbiae* develops to the adult stage in four days after flooding with the egg to egg cycle being completed in a minimum of 11 days; well within the usual 10–14 day irrigation pattern in the southeastern desert areas.

Importance: In California, this species is thought to have little vector potential for the transmission of human diseases. However, it is a major pest species in the southeastern desert agricultural areas where alfalfa and dates are grown.

REGION	COUNTY	Aedes																							
		bicristatus	campestris	cataphylla	deserticola	dorsalis	fitchii	flavescens	hemiteleus	hexodontus	increpitus complex	melanimon	nigromaculis	niphadopsis	pullatus	purpureipes	schizopinax	sierrensis	squamiger	sticticus	taeniorhynchus	tahoensis	thelcter	ventrovittis	vexans
COASTAL	Del Norte					X			X									X							
	Humboldt	X				X	X											X							X
	Mendocino	X				X							X					X							X
	Sonoma	X				X						X	X					X	X						
	Lake	X					X					X	X					X							X
	Napa	X				X							X					X	X						
	Marin	X				X							X					X	X						
	Solano					X						X	X					X	X						X
	San Francisco																	X							
	Alameda					X							X					X	X						X
	Contra Costa					X						X	X					X	X						X
	Santa Clara					X							X					X	X						
	San Mateo	X				X												X	X						
	San Benito												X					X	X						
	Santa Cruz					X												X	X						
	Monterey					X							X					X	X						
CASCADES AND EASTERN SIERRA	Siskiyou		X	X		X	X		X	X	X	X	X	X				X							X
	Trinity	X					X			X	X		X					X							
	Shasta			X		X	X	X	X	X	X	X	X					X		X		X		X	X
	Modoc		X	X		X	X	X	X	X	X	X	X	X			X	X						X	X
	Lassen		X	X		X	X	X	X	X	X	X	X	X			X					X		X	X
	Plumas		X	X		X	X		X	X	X	X	X	X			X	X				X		X	X
	Sierra			X			X		X	X	X						X	X				X		X	
	Alpine			X		X	X		X	X	X				X		X	X				X		X	
	Mono			X		X	X		X	X	X		X		X		X					X		X	X
	Inyo			X		X				X	X	X	X		X		X					X		X	X
CENTRAL VALLEY AND WESTERN SIERRA	Tehama			X			X		X	X	X	X	X					X		X		X			X
	Butte										X	X	X					X				X			X
	Glenn											X	X					X							X
	Colusa					X					X	X	X					X		X					X
	Sutter					X					X	X	X					X		X					X
	Yuba										X	X	X					X		X					X
	Yolo										X	X	X					X		X					X
	Sacramento					X					X	X	X					X		X					X
	San Joaquin	X				X					X	X	X					X		X					X
	Stanislaus					X					X	X	X					X		X					X
	Merced					X					X	X	X					X		X					X
	Madera									X	X	X	X					X		X		X		X	X
	Fresno			X			X		X	X	X	X	X		X			X				X		X	X
	Kings											X	X					X							X
	Tulare			X						X	X	X	X		X			X				X		X	X
	Kern					X				X		X	X					X							X
	Nevada			X			X		X	X			X				X	X				X		X	
	Placer	X		X			X		X	X		X	X				X	X				X		X	X
	El Dorado	X		X			X		X	X		X	X				X	X				X		X	X
	Amador	X		X		X	X		X	X		X	X					X				X		X	X
	Calaveras	X				X				X			X					X				X		X	
	Tuolumne			X			X			X	X				X			X		X		X		X	X
	Mariposa			X			X		X	X	X							X				X		X	
SOUTHERN CALIFORNIA	San Luis Obispo					X					X		X					X	X						
	Santa Barbara					X					X	X	X					X	X		X				
	Ventura					X					X							X	X		X				
	Los Angeles				X	X					X		X					X	X		X				
	Orange										X	X	X					X	X		X				
	San Diego				X	X					X		X					X	X		X				
	San Bernardino				X	X					X	X	X			X		X							X
	Riverside				X	X					X	X	X			X		X	X		X		X		X
	Imperial					X							X			X					X		X		X

REGION	COUNTY	Anopheles					Culex												Culiseta				Others				
		franciscanus	freeborni	hermsi	occidentalis	punctipennis	anips	apicalis	boharti	erraticus	erythrothorax	pipiens/quinque	reevesi	restuans	stigmatosoma	tarsalis	territans	thriambus	impatiens	incidens	inornata	particeps	Cq. perturbans	Or. signifera	Ps. columbiae	Ps. signipennis	Ur. anydor
COASTAL	Del Norte	X	X		X	X		X	X		X	X			X	X	X			X	X	X	X				
	Humboldt	X	X		X	X		X	X		X	X			X	X	X			X	X	X	X				
	Mendocino	X	X		X	X		X	X		X	X			X	X		X		X	X	X	X	X			
	Sonoma	X	X		X	X		X	X		X	X			X	X		X		X	X	X		X			
	Lake	X	X			X		X	X		X	X			X	X	X			X	X	X	X	X			
	Napa	X	X		X	X		X	X		X	X			X	X		X		X	X	X					
	Marin	X	X		X	X		X	X		X	X	X		X	X		X		X	X	X					
	Solano	X	X			X		X	X		X	X			X	X				X	X	X					
	San Francisco				X							X			X	X				X	X	X					
	Alameda	X	X		X	X		X	X		X	X			X	X				X	X	X					
	Contra Costa	X	X		X	X		X	X		X	X			X	X		X		X	X	X		X			
	Santa Clara	X	X		X	X		X	X		X	X			X	X				X	X	X		X			
	San Mateo	X	X	X	X	X		X	X		X	X	X		X	X				X	X	X		X			
	San Benito	X	X		X			X	X			X			X	X				X	X						
	Santa Cruz	X	X		X	X		X	X		X	X	X	X	X	X	X			X	X	X					
	Monterey	X	X		X	X		X	X		X	X	X	X	X	X		X		X	X	X					
CASCADES AND EASTERN SIERRA	Siskiyou	X	X			X									X	X	X			X	X	X	X				
	Trinity	X	X			X		X	X						X	X	X			X	X	X	X				
	Shasta	X	X			X		X	X		X	X	X		X	X	X	X	X	X	X	X	X	X			
	Modoc					X										X				X	X						
	Lassen	X	X			X									X	X				X	X						
	Plumas	X	X			X		X							X	X	X		X	X	X		X				
	Sierra							X							X	X	X		X	X	X						
	Alpine	X	X					X								X			X	X	X						
	Mono														X	X			X	X	X						
	Inyo	X	X			X					X	X			X	X			X	X	X	X		X			X
CENTRAL VALLEY AND WESTERN SIERRA	Tehama	X	X			X		X	X		X	X			X	X	X	X		X	X	X		X			
	Butte	X	X			X		X	X		X	X			X	X	X	X		X	X	X	X	X			
	Glenn	X	X					X	X		X	X			X	X		X		X	X						
	Colusa	X	X			X					X	X			X	X				X	X						
	Sutter	X	X			X		X			X	X			X	X				X	X			X			
	Yuba	X	X			X		X	X		X	X			X	X	X	X		X	X	X	X	X			
	Yolo	X	X			X			X		X	X		X	X	X		X		X	X	X		X			
	Sacramento	X	X			X		X	X		X	X			X	X		X		X	X	X	X	X			
	San Joaquin	X	X			X		X			X	X			X	X		X		X	X	X	X	X			
	Stanislaus	X	X			X		X			X	X			X	X		X		X	X	X	X	X			
	Merced	X	X			X		X	X		X	X			X	X		X		X	X	X	X	X			
	Madera	X	X			X					X	X			X	X		X		X	X						
	Fresno	X	X			X		X			X	X		X	X	X		X		X	X	X	X	X			
	Kings	X	X			X						X			X	X				X	X			X			
	Tulare	X	X			X		X	X			X			X	X		X		X	X	X		X			
	Kern	X	X			X		X	X		X	X		X	X	X		X		X	X	X	X	X			
	Nevada	X	X			X		X	X		X	X			X	X	X	X		X	X						
	Placer	X	X			X		X	X		X	X			X	X	X	X		X	X	X	X				
	El Dorado	X	X			X		X				X			X	X	X	X	X	X	X	X					
	Amador	X	X			X		X	X			X			X	X				X	X			X			
	Calaveras	X	X			X		X	X		X				X	X				X	X	X	X	X			
	Tuolumne	X	X			X		X	X						X	X		X	X	X	X						
	Mariposa	X	X	X		X		X	X			X			X	X	X	X	X	X							
SOUTHERN CALIFORNIA	San Luis Obispo	X	X	X	X			X	X		X	X	X	X	X	X		X		X	X	X					
	Santa Barbara	X	X	X	X	X		X	X		X	X		X	X	X		X		X	X	X					
	Ventura	X	X	X				X	X		X	X		X	X	X		X		X	X	X					
	Los Angeles	X	X	X				X	X		X	X		X	X	X		X		X	X	X		X			
	Orange	X	X	X				X			X	X		X	X	X		X		X	X	X					
	San Diego	X	X	X			X	X	X		X	X		X	X	X		X		X	X	X		X			X
	San Bernardino	X	X	X		X		X			X	X		X	X	X				X	X	X		X	X	X	X
	Riverside	X	X	X				X			X	X		X	X	X		X		X	X	X		X	X	X	
	Imperial	X	X							X	X	X			X	X				X	X	X			X	X	

Chapter 5

PRINCIPLES OF MOSQUITO CONTROL

The primary objective of mosquito control is the protection of people from the discomfort and diseases resulting from mosquito bites. The most serious of these diseases are those caused by mosquito-borne human pathogens. Mosquito control is accomplished through direct or indirect human intervention to eliminate or reduce the size of mosquito populations in a given area. This chapter summarizes the strategies that are used alone or in combination to accomplish modern mosquito control.

INTEGRATED PEST MANAGEMENT IN MOSQUITO CONTROL

Mosquito abundance is regulated in nature by a variety of natural factors that influence survival and mortality. However, natural mortality factors are sometimes insufficient to reduce mosquito numbers below levels which prevent attacks against humans or the transmission of human disease pathogens. In these instances, intervention is required to reduce mosquito numbers to tolerable levels. These levels of toleration vary from person to person according to age, sex, life style expectations, and other factors. Some people may object to just one or two biting female mosquitoes, while others may be indifferent to relatively large numbers. One of the reasons for this is that large differences in attractiveness for mosquitoes occur among individuals. In spite of years of studies attempting to discover the reasons for this, the basis for differences of attractiveness of people for mosquitoes remains a mystery. Moreover, the exact mechanisms by which certain repellents, such as those containing DEET, protect people from mosquito bites remain unknown.

Effective and long lasting control can be accomplished by scientifically planned management and control strategies that are applied in a timely manner to achieve significant reductions in mosquito populations. These strategies fall into several different categories. **Chemical control** is the application of insecticides to adult or larval habitats of mosquitoes. Generally, chemical control of larvae is usually preferred because the chemicals can be applied in a highly directed manner, with few effects to non-**target organisms**. Control of adults by chemicals applied from either ground- or aerial-based equipment is usually reserved for emergency situations.

Physical control is a second method of reducing mosquito populations. Physical control means the modification and management of the environment of mosquitoes. Most of these methods involve water management, and are done cooperatively with other agencies charged with protection and management of lake, ponds, rivers, streams, marshes, and swamps. Some people use the term natural control for this approach to stress the value of maximizing the effects of natural regulatory mechanisms in controlling mosquitoes.

Personal protective measures are the things individuals can do for themselves and their families to protect them from mosquito bites. The use of mosquito repellents, the wearing of clothing that minimizes the amount of skin exposed to mosquitoes, and avoidance of situations (e.g., being out-of-doors at dusk) are all examples of personal protective measures. If similar methods are applied by a mosquito abatement agency (establishment of treated barriers, selective vegetation removal, etc.) then the term **area protective measures** is used.

There is a philosophy that holds that all these methods should be used in concert for the most ecologically sound method of mosquito control. This philosophy is called integrated pest management (IPM). IPM was first developed as a comprehensive control strategy for agricultural pests, but is now meant to include **vectors** such as mosquitoes as well. Some people favor using the term integrated vector management (IVM) for the application of the comprehensive application of methods to mosquitoes and other vectors.

NATURAL REGULATORY MECHANISMS

Mosquitoes have the capacity to produce abundant populations explosively when favorable environmental conditions prevail. They can complete several generations rapidly with each new one potentially as large as or larger than the preceding one. This exponential population growth can theoretically continue until the sky becomes literally filled with mosquitoes. However, this never occurs in nature, because mosquitoes, like all other forms of life, are subject to natural regulatory processes that prevent over-population. These processes are referred to collectively as natural regulatory mechanisms or limiting factors. Exclusive of human intervention, interactions of various limiting or regulatory factors determine the eventual abundance of mosquitoes over time and space.

Limiting factors can be subdivided into two groups: biological and physical. Biological limiting factors are those that are caused by the presence of other life forms (e.g., pathogens, parasites or predators) that either directly or indirectly impact mosquito survival and mortality.

Non-biological limiting factors include a variety of physical properties of the environment (e.g., temperature) that directly or indirectly influence mosquito survival and mortality. Together, survival and mortality are the limiting factors that regulate the numbers of mosquitoes present in the environment at a given time in the absence of human intervention (chemical control, physical control, etc.).

The most obvious physical limiting factor for mosquito population sizes is the presence or absence of water. In a drought year there will be fewer mosquitoes present than in a wet year. No mosquito abatement agency can take credit for the former, nor should any be blamed for the former.

It may seem that a discussion of natural regulatory mechanisms is pointless, since these seem to be out of any human control. Actually, at least two reasons to understand natural regulatory mechanisms come to mind. First, understanding of these mechanisms may help anticipate mosquito problems in advance. Long-term weather forecasts of conditions favorable to mosquito breeding for an area may alert a mosquito control agency and depending on the nature of the problem help it prepare the necessary plans for intervention. A second reason to understand natural mortality and survival is that various management options can change these factors. For example, improper water management may reduce mosquito predators in a drainage pond to the point where mosquito breeding may occur unchecked.

BIOLOGICAL LIMITING FACTORS

Biological factors important in the regulation of mosquito populations are those sources of mortality created by either competition from other organisms or the presence of pathogens, parasites, predators or toxic plants. It is beyond the scope of this manual to provide a detailed account of the wide variety of mortality factors created by the presence, absence and interaction of other organisms. However, mosquito control technicians should be aware of the fundamental biological factors directly influencing mosquito survival in both the immature and adult stages.

Both terrestrial and aquatic vegetation are important to mosquito survival and mortality. Adult mosquitoes use terrestrial plants for resting and protection from lethal high temperatures. Mosquito larvae use submergent and emergent vegetation to avoid predation.

Many mosquitoes use vegetation directly as sites for oviposition and larval development. *Aedes sierrensis* uses tree holes for this purpose. Many tropical species of mosquitoes use floating vegetation in still-running streams and ponds for oviposition and larval development. Others use bamboo, leaf axils, coconut husks, and other living and non-living plant parts for the same purpose.

PHYSICAL LIMITING FACTORS

Physical factors include weather and climate, all the characteristics of naturally occurring water (temperature, salinity, dissolved oxygen, pH, movement, etc.), air temperature, snow pack, presence of rock holes along stream banks, and various soil characteristics.

TYPES OF MOSQUITO CONTROL

The term mosquito control as used here is meant to include the various types of interventions used by mosquito abatement agencies and the various ways people protect themselves and their families from mosquitoes. Mosquito control methods are usually separated into chemical control, physical control, and biological control. Area control measures cut across all three of these and also are performed by mosquito abatement agencies. The category of personal protective measures usually does not involve any the methods used by mosquito abatement agencies

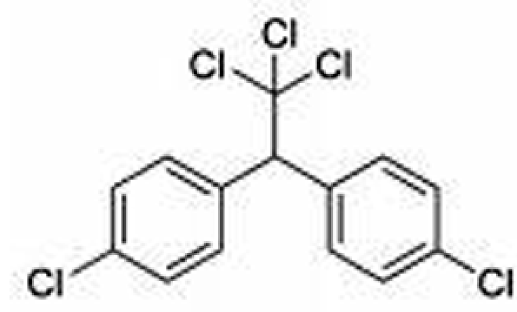


Fig. 5.1 The DDT molecule

CHEMICAL CONTROL

Chemical control is the use of insecticides and herbicides to control mosquitoes. Insecticides kill mosquito adults and larvae, depending upon how and where they are applied, and herbicides are used to control weeds in aquatic habitats that encourage mosquito breeding. The chemical control of mosquitoes is covered in Chapter 6 of this manual. Safe and effective use of insecticides requires extensive knowledge of their selection, mixing, and application. Protection of the public and people who work with insecticides from their potential toxic effects also must be fully understood by mosquito technicians. There are many federal and state regulations governing the safe use of pesticides and their proper disposal. Mosquito technicians are also expected to know these.

PHYSICAL CONTROL

Physical control is the alteration and management of large and small areas of the environment in a way that results in a lowering of mosquito population sizes. Physical control is often applied in salt marshes, agricultural fields, and in the design and construction of structures used for water management. Physical control measures are covered in Chapter 7.

Fig. 5.2 Modern marsh management control using Thiokel ® ditching equipment.

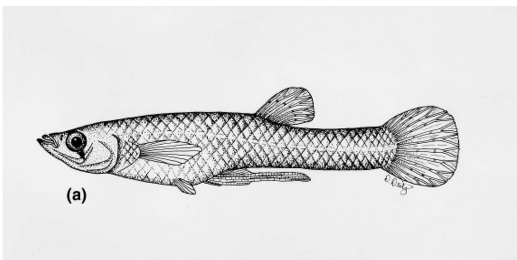


Fig. 5.3 Mosquitofish, Gambusia affinis male

Biological Control

Biological control (BC) is the use of natural enemies to manage mosquito populations. There are several types of biological control including the direct introduction of parasites, pathogens and predators to target mosquitoes. There is some overlap between management of environments where mosquitoes are present in ways that permit natural biological regulatory mechanisms to be maximally effective and the broad definition of biological control. However, it is far more important to adopt sound practices that tend to result in lower-sized mosquito populations than it is to worry about the classification of the practices. Biological control is the subject of Chapter 8.

Area Protective Measures

Area protective measures do just what they sound like. They protect large numbers of people in a given area. One way to think about the distinction between mosquito control and area protective measures is that the former is aimed at the direct reduction of mosquito populations, the latter at the protection of people from mosquitoes.

The promotion of personal protective measures thorough mailings, websites, TV spots, and other media is an example of area protection. The publication of pamphlets for area-wide distribution warning of the dangers from poorly maintained swimming pools is another. Screening of public buildings is another form of area protection.

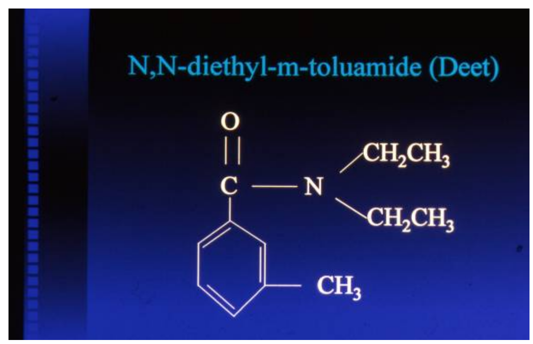


Fig. 5.4 Chemical formula for DEET, a common mosquito repellent

Personal Protective Measures

In many instances, the use of personal protective measures is the most effective form of freedom from annoyance and diseases caused by mosquitoes known.

There are many sources of information on this subject, and nearly every mosquito abatement district in California, as well as the California Department of Public Health, provides detailed information in free pamphlets. A partial list of things people can and should do to protect themselves from mosquitoes includes:

- Different mosquito species bite at different times of the day or night, and vary in their seasonality. Some bite during the day, others near dusk and dawn, and still others at night. Some mosquito species are active in the summer and fall, others in the winter and spring. Know when the mosquitoes in your area are active seasonally and at what time of day they are out seeking blood meals.
- When adult mosquitoes are present and active, avoid outdoor activity (miniature golf, sitting outside on a lawn swing, etc,).
- If you must be outdoors during the time mosquitoes are biting, minimize the amount of skin that you expose to mosquitoes. Wear long sleeved shirts or blouses, and trousers or slacks with legs that reach to the shoes.
- If mosquito biting is likely to be especially heavy, apply a mosquito repellent to exposed skin areas. Use an EPA-registered insect repellent that contains DEET (N, N-diethyl-meta-toluamide) (Fig. 5.4), picaridin or oil of lemon eucalyptus. New effective materials are coming on the market every year.
- In the early spring, before adult mosquitoes are present, check and repair window and door screens. If doors or windows lack screens, install them.
- If you are a camper, consider sleeping under a bed net during mosquito season, or use a tent with full netting.
- If mosquitoes are exceptionally active during camping trips (e.g., late spring at high elevations in the Sierra Nevada) spray repellents on your clothing and netting. Repellents containing permethrin or other synthetic pyrethroids can be used for this, but this class of chemicals should not be applied directly to the skin.
- Inspect your yard for sources of standing water. Do not permit water to remain for periods longer than a few days in bird baths, fountains, areas around broken sprinklers, etc.
- If you have ornamental ponds without fish in them, get some mosquitofish from your local mosquito abatement district and place them in the pond.

Table 5.1 summarizes the various factors that affect the size of mosquito populations, and strategies for reducing them and protecting people from annoyance and diseases from mosquitoes.

Table 5.1. Summary of Natural Mosquito Population Limiting Factors and Mosquito Abatement Strategies

NATURAL POPULATION LIMITING FACTORS	
Biological limiting factors	Pathogens, Parasitism, Predation, Toxic plants, Competition, Resource (food) availability
Physical limiting factors	Adults - Air temperature, Relative humidity, Protective shelter Immatures - Water temperature, Dissolved salts/pollutants, Currents
CHEMICAL CONTROL METHODS	
Adulticides	Organophosphates, Pyrethrum, Synthetic pyrethroids
Larvicides	Pyrethrum, Microbials, Biochemicals, Petroleum oils
PHYSICAL CONTROL METHODS	
Aquatic habitats	Water management, Vegetation management, Physical design
Terrestrial habitats	Field grading, Effective building codes, air conditioning
BIOLOGICAL CONTROL METHODS	
Releases of agents	Pathogens, Parasites, Predators
Conservation of agents	Proper water management, use of selective insecticides
AREA PROTECTIVE MEASURES	
Public relations	Literature, public education, mosquito-proofing of public buildings
Area control	Mosquito barrier treatments
PERSONAL PROTECTIVE MEASURES	
Personal measures	Repellents, protective clothing, staying indoors
Home control	Draining of water, use of mosquitofish

Chapter 6

CHEMICAL CONTROL OF MOSQUITOES

PRINCIPLES OF INSECTICIDE USAGE

Insecticides are necessarily toxic to living organisms. Some affect only animals, others only plants and some to both. Some are lethal to mosquitoes, but nearly harmless to warm-blooded animals. Nevertheless, insecticides, as with nearly all substances one encounters in life, are toxic to people if the dose and exposure are high enough.

Insecticides must be used by trained personnel and after careful planning. They must also be used in conformance with instructions for use printed on insecticide labels. Only by reading, understanding, and following label instructions can there be assurance the material being used will control the target pest without causing significant harm to the applicator, non-**target organisms**, and the environment. General rules for the use of insecticides to control mosquitoes include:

- Use insecticides as a last resort to complement biological, physical or natural controls.
- Apply insecticides in a manner that minimizes harm to non-target organisms.
- Use insecticides to treat specific sites where mosquitoes that are causing annoyance or creating a public health problem are being produced.
- Apply insecticides selectively to the proper life stage of the mosquito (e.g., egg, larva, pupa, or adult).
- Apply insecticides in a manner that will minimize personal hazard to the applicator and other persons in the vicinity.
- Apply insecticides in accordance with federal and state laws and regulations, and in compliance with the insecticide label.

ADVANTAGES AND DISADVANTAGES OF CHEMICAL CONTROL

In spite of the many changes relating to insecticide use seen over the past half-century, insecticides remain an essential part of the arsenal available for the control of public health pests. The modern arsenal includes other control approaches, such as ecologically-sound habitat management, use of biological control agents, and the use of modern **vector** surveillance methods to assess presence and size of infestations. However, it seems unlikely that effective vector abatement will be possible in the foreseeable future without the use of insecticides.

Despite their role in the protection of people from mosquitoes, insecticide use is not without some risks. Insecticides, if used improperly, can have toxic consequences for people and pets, harm agricultural commodities, or disrupt aquatic and terrestrial wildlife. This is why applicators of public health insecticides must read, understand, and follow exactly the directions on insecticide labels before application.

INSECTICIDES USED FOR MOSQUITO CONTROL AND PREVENTION OF MOSQUITO BITES

INSECTICIDES

Larvicides

Insecticides designed to be applied directly to the aquatic habitats of immature mosquitoes are called larvicides (Fig. 6.1). The use of larvicides has several advantages over insecticides that target adult mosquitoes. Larvicides kill mosquitoes before they develop to the stage where female mosquitoes can suck the blood of humans and other animals, and thus transmit disease organisms. Larvicides are easy to apply in a way that makes direct contact with mosquito larvae. On the other hand, there are many restrictions placed by the US Environmental Protection Agency (EPA) on what materials can be applied directly to water. Still not resolved is whether or not mosquito larviciding

Fig. 6.1 Spraying insecticides for control of mosquito larvae

comes under the Federal Clean Water Act under the jurisdiction the US Army Corps of Engineers.

Generally, only three types of materials are available as larvicides in California: biorational insecticides, larviciding oils, and monomolecular films (these categories will be discussed below)

ADULTICIDES

When the abundance of adult female mosquitoes becomes so high that human discomfort becomes an issue in a large number of people, application of insecticides designed to kill adult mosquitoes often becomes the preferred alternative to larvicides. When outbreaks of human diseases caused by mosquito-borne pathogens occur, adulticides are the only choice.

HERBICIDES

Mosquito control technicians frequently use herbicides to kill plants, or inhibit their growth when the plants either contribute to mosquito production, or prevent technicians from being able to control mosquitoes efficiently. Herbicides have been used in association with mosquito abatement operations for many years. In the early 1900s organic materials such as iron sulfate, copper nitrate, and sulfuric acid were used. In the 1940s, 2,4-D, a synthetic organic chemical, was developed as a selective herbicide. Since that time, hundreds of herbicides have been synthesized.

REPELLENTS

Repellents are chemicals used to protect humans, livestock, or pets from bloodsucking mosquitoes. The most widely used chemical in repellent formulations is ***N*,*N*-Diethyl-*meta*-toluamide**, or **DEET**. In recent years a variety of formulations have been developed to minimize DEET's unpleasant characteristics when used as a skin repellent, and also to lengthen the duration of its effectiveness. Since the end of the 20th century, several repellents with an entirely new chemical basis have been released, some rivaling the effectiveness of DEET.

ATTRACTANTS

Substances that attract immature and adult mosquitoes have several purposes. Traps used for capture of adult female mosquitoes for testing for presence of **virus** usually contain an attractant — carbon dioxide in the form of dry ice in battery-powered, light weight traps, or hay infusion in traps designed to capture gravid females (female mosquitoes with fully-developed eggs). They are also used in large suction traps designed to lower population levels of female mosquitoes. However, the effectiveness of these traps is questionable.

CLASSES OF INSECTICIDES USED IN MOSQUITO CONTROL

Organochlorines (=chlorinated hydrocarbons)

Organochlorines are one of the first groups of insecticides synthesized, and include the well-known insecticide DDT. Although DDT is still used for mosquito control in many tropical areas of the world, especially for malaria control, DDT's registration for nearly all uses was suspended by EPA many years ago, and consequently, it is no longer used for mosquito control in the United States. Most other organochlorines used for mosquito control, including chlordane, dieldrin, and lindane, have met similar fates.

Organophosphates (OP)

Although a few OP formulations remain available for mosquito control, use has dramatically decreased because of resistance to OPs, the potential for non-target effects, and the development of replacement products. Members of this group contain phosphorous in their molecules. Products currently labeled for mosquito control include temephos (Abate®), naled (Dibrom®), malathion, and chlorpyrifos. Organophosphates are considered by most to pose a greater human health risk for insecticide applicators than other families of insecticides.

Carbamates

Chemicals in this class are chemically similar in structure to organophosphates, but whereas OPs are derivatives of phosphoric acid, carbamates are derivatives of carbamic acid. There are no insecticides in this group used for mosquito control in California, but there are some herbicides containing carbamates.

Pyrethrum

Insecticides in this group are natural organic products derived from plants in the genus *Chrysanthemum*. There are about 30 species in the genus, most of which use the generic name as their common name. The insecticide is produced by grinding of the flowers, thus releasing the active component of the insecticide, called **pyrethrin**. Sometimes you will see these insecticides referred to as pyrethrins.

Insecticides containing pyrethrin are neurotoxic to nearly all insects. They are harmful to fish, but are far less toxic to mammals and birds than many synthetic insecticides and are non-persistent, breaking down easily on exposure to sunlight. They are considered to be amongst the safest insecticides for use around food.

Pyrethrin-containing insecticides are used widely in California for adult mosquito control. Pyrethrins are usually mixed with PBO (piperonyl butoxide), which acts as a **synergist**. Synergists are materials that are not necessarily pesticidal by themselves but have the effect of increasing the toxicity of insecticides with which they are mixed. Without PBO, treated insects would be knocked down, but would eventually recover.

Pyrethroids

There is a very large group of insecticides that have synthetically-produced active ingredients chemically similar to pyrethrin. Because of this similarity, they are called pyrethroids (pyrethin-like). As with pyrethrin, pyrethroids are not persistent. Many insecticides containing pyrethroids are used for adult mosquito control. At rates applied for this purpose, they break down quickly in sunlight, and are rarely present after just a few days. The mode of action of pyrethroids is the same as that of pyrethrin. Most pyrethroids are also synergized with PBO. Several generations of pyrethroids have been produced, with the latest formulations being effective at extremely small doses. These new compounds do not break down as readily in sunlight as do pyrethrin, and in some cases pyrethroid synergists do not markedly improve their effectiveness.

Pyrethrin and pyrethroids are now among the most common public health insecticides used in California, especially for the control of adult mosquitoes. Their use now far outstrips that of conventional synthetic insecticides such as organochlorines and organophosphates.

Biorational Insecticides (=Biorationals or Bioinsecticides)

Biorational insecticides are pesticides that are considered relatively non-toxic to humans and are also environmentally safe. The EPA defines biorationals as "certain types of insecticides derived from such natural materials as animals, plants, bacteria, and certain minerals." Most insecticide specialists interpret the word "derived" broadly, and include synthetic insecticides that resemble natural substances. There is no single or legally clear definition for this group of insecticides. Biorationals can be separated into two groups: (1) biochemical (hormones, enzymes, pheromones, and natural insect and plant regulators) and (2) microbial (viruses, bacteria, fungi, protozoa, and nematodes.

The action of biochemical biorationals is based on the interruption of natural growth processes of mosquitoes. They are not particularly selective among invertebrate species, but generally have extremely low toxicity for vertebrates, including people. Insect growth regulators (IGRs), chitin inhibitors, plant growth regulators, and chromosterilants are included in this group. For mosquito control, the use of methoprene (an insect growth regulator) far outweighs all other uses. For many years after their introduction, IGRs were considered immune to the development of resistance by target pests However, resistance has now been detected against some mosquito species in specific locations in California and elsewhere.

Microbial insecticides kill mosquitoes either by toxins released by microbial organisms, or by infection by the organisms. Two common insecticides that fit within this group include the bacterial toxin produced by Bti, and the live bacteria, *Bacillus sphaericus* (Bs). Products containing both of these bacteria are used against mosquito larvae, with Bti being effective in killing black fly larvae as well (Fig. 6.2). Most microbial insecticides are more selective than biochemical insecticides.

Fig. 6.2 Spraying BTI on an Oregon log pond

MATERIALS APPLIED TO WATER SURFACES

Petroleum Oils

These products are refined from crude oil and in vector control are used both as carriers for insecticides, and more directly when mixed with a surfactant and applied to the water surface as a suffocating agent against mosquito larvae and pupae.

Alcohols

This is a newer group of materials for application to bodies of water for control of mosquito larvae. (e.g., Agnique®) These materials are used in the form of a monomolecular film, and act by reducing surface tension of the water, eventually leading to the drowning of mosquito larvae or pupae.

Water surface control insecticides have several advantages over conventional insecticides. Oils and alcohols will kill mosquito pupae as well as larvae, and because there action is more physical than biochemical, they do not lead to development of insecticide resistance. The disadvantage of these products is they kill non-target organisms that either breath at the water surface (e.g., small aquatic beetles), or that depend on surface tension of the water (e.g., water striders).

Herbicides

Herbicides are used in mosquito control to clear various types of mosquito aquatic habitats of weeds that provide favorable conditions for larval development. Mosquito control technicians should take special care in mixing and applying herbicides, and in learning the proper safety precautions needed for their use. Herbicide mixing, storage, and application can pose significant occupational health risks. Also, herbicides often present greater long term environmental risks than other insecticides, particularly to groundwater. Herbicides can create significant economic damage to croplands in agricultural areas.

Herbicides can be separated into **organic** or **inorganic** materials. Organic herbicides have a carbon based molecular structure and usually act by altering the normal growth pattern of the plant. Organic herbicides may be further divided into two major groups—the petroleum oils and the synthetic organic herbicides. The petroleum oils, refined from crude oil, can be used as either herbicides or insecticides. When formulated as herbicides, they usually are applied without dilution. Synthetic organic herbicides are artificially created in laboratories, and are made up of carbon, hydrogen, often nitrogen, and other elements. Included among the common synthetic organic herbicides are 2,4-D, and glyphosate.

Inorganic herbicides are often in the form of a salt, or contain a metal that is toxic to plants, often preventing proper uptake of water or inhibiting movement of material across cell walls. Inorganic herbicides are chemical compounds which do not have a carbon structure. The inorganics include such common materials as salt, copper sulfate, sulfuric acid, and sodium chlorate. These herbicides are extremely persistent and have caused serious soil pollution problems in some areas. Many are restricted materials.

Some of the major types of herbicides used in mosquito control operations include phenoxies, triazines, thiocarbamates, ureas, benzoics, acetanilides, sulfonylureas, and imidazolinones. Information on herbicides, their mode of action, and their uses in mosquito control are covered in considerable detail in the training manual “The safe and effective use of insecticides”.

FORMULATIONS OF INSECTICIDES USED FOR MOSQUITO CONTROL

Insecticides are nearly always applied in formulations containing other materials. This is true by almost all types of insecticides. Unformulated insecticides are referred to as technical grade, and these are used only by toxicologists and other insecticide chemists or biologists conducting tests on insecticide resistance or susceptibility to target and non-target organisms. Technical grade insecticides are either formulated by manufacturers or by commercial insecticide distributors. All formulations sold in the USA must be labeled with complete instructions and restrictions for use.

Formulations are nearly always the form in which insecticides are obtained by mosquito control specialists, and it is the formulation that must be registered, have an EPA registration number, a label, and a Material Safety Data Sheet. The formulation of any insecticide is identified by a letter or letter combination on the label.

Formulations may undergo a final dilution with water or other diluent after being added to a spray tank or similar device. This is not considered formulation, and this final form is usually called the tank mix.

Some of the most commonly used formulations are:

Emulsifiable Concentrates (EC)

These chemicals consist of concentrated oil solutions of technical grade insecticides combined with an emulsifier added to permit further mixing with water. Emulsifiers are detergent-like materials that allow the suspension of very small oil droplets in water to form an **emulsion**. Emulsifiable concentrates are used widely in mosquito control operations, with final water dilutions typically being made in spray tanks. Tank mixes are usually milky in appearance. ECs are losing popularity somewhat with the rise in costs of petroleum products, and new formulations using plant-derived oils are being sought. ECs can be used as both mosquito adulticides and larvicides.

Wettable Powders (WP or W)

These dispersible powders are finely ground, dry powders consisting of active insecticide ingredients mixed with other ingredients to aid in mixing and dispersion. Wettable powders are intended for mixture with a liquid, usually water, for application by spray equipment. They are generally mixed with water to form slurry before being added to the spray tank. In the tank they require continual agitation. WPs are used mostly as larvicides in mosquito abatement operations. The can be used with most spray equipment. Bti is available as a WP. WPs are harder on equipment than some other formulations, and can cause rapid wear on pumps, gaskets, and spray nozzles.

Soluble Powder (SP)

These powders are similar to wettable powders, except that the active ingredient, as well as the diluent and all formulating ingredients are completely soluble in water. Uses of soluble powders are similar to those of wettable powders. SPs are used only as mosquito larvicides.

Granules (G)

In a granulated formulation, the active ingredient is mixed with various inert clays to form particles of various sizes. Granules used in vector control operations are usually from 20–80 mesh in size. Granular formulations are intended for direct application without further dilution. Granular formulations may require specialized dispersal equipment, and may be applied from the air or on the ground.

They may also be used with small hand-cranked units, or simply scattered by hand. Granular applications of insecticides are especially useful in treating mosquito larvae in locations where heavy vegetation would otherwise prevent the insecticide from reaching the water. They are also favored in situations where drift would otherwise be a problem.

Baits

Baits are not used extensively in mosquito control. They have been tried mixed with insecticides in certain kinds of attractant traps both as a control measure and as means of estimating mosquito abundance.

Aerosols (A)

Aerosols, or "bug bombs" are pressurized cans which contain a small amount of insecticide that is driven through a small nozzle under pressure from an inert gas (called a propellant). Aerosols have been used in households to kill mosquitoes and other flying insects. The use of aerosols peaked during the 1990s when concern for propellents consisting of chlorofluorocarbons being linked to damage to the ozone layer of the earth. Since then, aerosol can uses of all kinds have dropped significantly, although substitute propellants are continually being tested as replacements for chlorofluorocarbons.

Flowables (F or L)

A flowable liquid usually is mixed with water for use in a sprayer. It forms a suspension in water which requires continual agitation. Principal uses are similar to those of emulsifiable concentrates.

Water-Soluble Concentrate (WS)

These liquid formulations form true solutions in water and require no agitation once mixed. They are used in the same way as emulsifiable concentrates.

Ultra Low Volume Concentrates (ULV)

Ultra low volume concentrates (**ULV**) are sold as active ingredients in its original liquid form, or product dissolved in a small amount of solvent. They are applied using special aerial or ground equipment that produces a fine spray at very low application rates. Their main use in public health is as mosquito adulticides. Pyrethroid insecticides are usually formulated with a synergist, typically PBO. The underlying principle of ULV is based on the discovery many years ago that a single extremely small droplet of insecticide (~10 microns) that strikes a mosquito is lethal, and that droplets of larger size are wasteful and can have undesirable environmental effects. ULV applications, when done correctly, are very effective and very safe to people and other non-target organisms.

Fogging Concentrates

Fogging concentrates combine a insecticide with a solvent, with the type of solvent depending upon the type of fogging to be done. These are formulations sold only for public health use to control flies and mosquitoes. These formulations are applied using special truck-mounted machines called foggers. Foggers are of two types: thermal foggers use flash heating of an oil solvent to produce a visible plume of vapor or smoke, and cold (ambient) foggers atomize a jet of liquid in a venturi tube under pressure from a high-velocity air stream. Cold foggers can use insecticides combined with oil, water, or emulsifying agents.

Slow Release or Controlled Release Formulations

Some insecticides can be encased (encapsulated) in an inert material for a controlled release, resulting in decreased hazard and increased likelihood of the active ingredient reaching the target organism. Sustained-release mosquito larvicides are based on this principle. The most successful mosquito control products are those that provide slow release of bioinsecticides, although some critics of this approach claim that this encourages physiological resistance on the part of the target pests.

Other Formulations

There are other formulations that could be mentioned here, some of them very important, such as the formulations for impregnating clothing, bednets, and curtains in tropical areas of the world for malaria control. There are other formulations, such as oil solutions and soluble pellets that are found mostly on hardware store shelves for home use. Novel formulations are being evaluated continually, and some of these will probably eventually be adopted for vector control use.

EQUIPMENT USED IN MOSQUITO CONTROL

UNPOWERED EQUIPMENT

Generally, unpowered equipment is suitable for relatively small insecticide applications, such as spot treatments of aquatic sites where mosquito larvae are present (Fig. 6.3). Typical unpowered equipment for liquid pesticides includes the some backpack and tank sprayers. Sometimes these types of equipment are called compression sprayers. Unpowered backpack sprayers are really just tank sprayers with straps to permit them to be carried like a backpack. These sprayers sometimes have a continuously operated pump lever to maintain pressure in the pesticide tank. Others are pumped up by hand until pressure reaches a certain point. The pesticide then can be sprayed until the pressure drops below the level where the sprayer works effectively. Then it must be re-pressurized. Pressurized tank sprayers and backpack sprayers come in sizes ranging from about 1–5 gallons. Sprayers that are not backpack types are often referred to as “hand can, or by their capacity, such as a “3-gallon sprayer.”

Fig. 6.3 A small hand insecticide sprayer

Insecticides in solid form (granules, slow release briquettes, powders, etc.) can be applied by hand, with small crank-operated spreaders, dust cans, or similar devices. Aerosol bombs are also unpowered pesticide applicators.

Small unpowered equipment is inexpensive, simple to use, and easy to clean and store. Small areas (less than an acre) can be treated by a single person in a relatively short period of time. However, calibration of small unpowered devices can be difficult, and larger-capacity liquid tank sprayers may be difficult for physically smaller technicians to handle.

ULTRA LOW VOLUME SPRAYERS (ULV)

Ultra Low Volume (ULV) sprayers are designed to apply extremely low volumes of highly concentrated insecticides in the form of very small (5–30 micron) droplets into the air (Fig. 6.4). A micron, abbreviated mμ, is equal to 1/25,000 of an inch. ULV sprayers are used primarily against adult female mosquitoes, and require the use of insecticides formulated for this purpose. These formulations are either sprayed as sold without additional dilution or diluted with light oils. Most ULV sprayers utilize a small electric pump that can be very finely adjusted. Many commercial formulations are available for ULV adult mosquito control. A typical formulation contains a small concentration of pyrethrin (5–10%) combined with a synergist such as PBO. The remainder of the insecticide usually consists of an oil of some kind. With the exception of malathion, ULV products have a low percentage of active ingredient. ULV sprayers may be mounted in trucks, amphibious vehicles, or in aircraft. They are currently the most widely used type of sprayer for adult mosquito control.

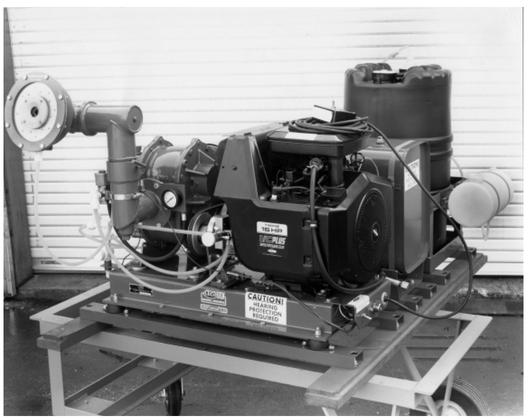


Fig. 6.4 A modern sprayer designed for ULV insecticide applications

ULV spraying is a highly effective means of adult mosquito control and a sensible alternative to the old fashioned fogging machines. The combination of extremely low volumes (less than a ½ gallon per acre) and insecticides having very low toxicity for humans and other vertebrates makes them very safe for both humans and other non-target organisms.

Effective ULV spraying requires careful attention to weather conditions. The very small droplets of concentrated insecticide tend to drift out of the target zone at high wind speeds, and generally, the higher the wind speed during application, the lower the effective swath. ULV applications are generally not effective for mosquito control at wind speeds over 10 MPH. Temperature is another important consideration because of the effect it can have on evaporation of the insecticide.

Temperature inversions occur when temperatures at ground level are lower than temperatures at higher altitudes. This is the reverse of the normal temperature situation near the surface of the earth. During inversions, cold air is trapped by the warm air above it, and there is little vertical mixing of air. Under these conditions, the very small droplets produced by ULV sprayers remain suspended in the cool air at ground level. For some agricultural applications, and for application of herbicides, spraying under these conditions is considered undesirable because the spray droplets may remain suspended in the cooler air at ground level and damage non-target organisms. However, a temperature inversion is considered desirable for ULV mosquito control applications, because at the time of spraying mosquitoes are ordinarily flying, and the risk of damage to non-target organisms is low. If there is no lateral air movement, and no temperature inversion, the very small droplets will rise with vertical air currents above the level where they will effectively kill ground-level mosquitoes.

Because of the effect of weather variation on ULV applications, calibration must be checked frequently for flow rate and droplet size.

THERMAL FOGGERS AND COLD FOGGERS

Foggers are of two types: thermal foggers use flash heating of an oil solvent to produce a visible plume of vapor or smoke, and cold (ambient) foggers atomize a jet of liquid in a venturi tube under pressure from a high-velocity air stream. Cold foggers can use insecticides combined with oil, water, or emulsifying agents. Thermal foggers (Fig. 6.5) were used extensively in mosquito control operations at one time, but they have been largely supplanted with ULV sprayers.

The design of most cold foggers have evolved into units specialized for use with ULV applications.

Fig. 6.5 A thermal fogger in operation to control adult mosquitoes

CALIBRATION OF INSECTICIDE EQUIPMENT

WHY CALIBRATE?

All insecticide labels contain information on allowable application rates. For an insecticide applicator to determine what dose is being applied, the application equipment must first be calibrated. There are many things that determine insecticide application rates. Some are related to the proper preparation of the tank mix, but many others are related to the operation and condition of the application equipment. Although power sprayers may produce consistent results when new, gradual wear of nozzles, pumps, and other components of the system will affect application rates. Further, no two pieces of equipment will behave in exactly the same way. For this reason, every time a vector control technician applies an insecticide, steps must be taken to insure that the appropriate amount of insecticide is applied. Calibration of equipment is the means by which this is achieved.

Calibration of insecticide spray equipment is a legal requirement. It is a violation of state and federal regulations to apply a insecticide in any manner other than as specified on the label. Calibration of equipment is important to the success or failure of a insecticide treatment. It is a waste of time and money to apply any insecticide in an inefficient or ineffective manner.

WHAT IS CALIBRATION?

Calibration is the preparation of insecticide spray equipment for spraying to insure that a insecticide is applied uniformly, in the desired area, and with the correct amount of active ingredient. Calibration is the only accurate way to determine that the rate of application is consistent with the label requirements. Careful preparation of tank mix and proper operation of equipment during actual applications are also important factors to an effective and legal treatment.

Inaccurate insecticide application rates, spray patterns, and droplet size can all lead to ineffective and often illegal insecticide applications. These factors can lead not only to ineffective treatments, but also significant movement from insecticides away from the target area. Studies have shown that three factors stand out in insecticide applications that do not conform to label requirements: inaccurate preparation of tank mixes, worn spray nozzles, and improper calibration of spray equipment.

The actual procedures needed to calibrate insecticide application equipment are beyond the scope of this manual. However, considerable information is available in the manual "Insecticide Application and Safety Training for Applicators of Public Health Insecticides."

RESISTANCE TO INSECTICIDES BY MOSQUITOES

Insecticide resistance is the ability of pests to avoid the lethal effects of insecticides. Certain populations of mosquitoes use one or more different physiological defense mechanisms to withstand doses of insecticides that previously were lethal to the pests. This can happen through spontaneous mutations in populations resulting in genes that confer insecticide resistance, or because a small proportion of the population carries a gene for insecticide resistance naturally. In either case, resistance develops gradually to the point where insecticide applications begin to fail after repeated exposure to the same material. This is because the individual mosquitoes in a population that carry the gene for susceptibility are killed off, and soon, a disproportionate segment of the population carrying the gene for resistance predominates. This can be an unintended effect of using to control mosquitoes, or an accidental effect stemming from agricultural use of insecticides.

The repeated exposure to treatments of the same insecticide by a population of mosquitoes that results in a change in the genetic makeup of the population is called **selection pressure**. In this case, the population is selected to favor resistant genes at the expense of susceptible genes, and the population becomes resistant to that insecticide. Because of the nature of population genetics, the population never becomes completely resistant, but the frequency of individuals have susceptible genes becomes very small.

Knowing the mechanisms of development of insecticide resistance is important to developing strategies to avoid creation of resistance in mosquito populations. The basic principle is the preservation of susceptible genes in mosquito populations, and the endeavor to do this is named **insecticide resistance management**.

Usually, when a pest population becomes resistant to one insecticide it can still be controlled by other insecticides, especially those from a different family of chemicals. Occasionally, resistance to insecticides other than the insecticide responsible for resistance may occur. This is called **cross-resistance.** Its occurrence is usually seen across chemically related insecticides where the mode of action is identical or very similar.

RECOGNIZING RESISTANCE

Not all mosquito control failures are the result of resistance. Improper control practices may be at fault. However, if the material was timed and applied properly at the recommended rate and no other important factors (such as unfavorable weather) have interfered with the insecticide application, resistance should be considered.

Early signs of resistance may sometimes be recognized in the field. These include increasing difficulty in controlling mosquitoes in a given area or increasing trouble with mosquito-borne disease. Suspected resistance should be reported to your supervisor immediately since early detection may make it possible to delay resistance by the application of counter measures.

RESISTANCE MANAGEMENT

Based on the genetic principles of development of insecticide resistance in pests, a number of principles have evolved over the years that when implemented can either delay resistance, or avoid it entirely. Some of these principles are:

- Avoid under-dosing in insecticide applications. If this is done repeatedly it encourages survival of individual pests carrying genes for resistance, especially when the effects of the gene are not absolute (protects only partially).
- Do not always treat a given population with the same insecticide. Switch to other products periodically. This is called insecticide rotation.
- Test populations of vectors for evidence of resistance, and when it is

detected switch to alternate insecticides.

- Avoid slow-release applications where pest populations are exposed for long periods of time to sub-lethal doses of one insecticide.
- Combine insecticide applications with other forms of pest management such as biological control, habitat alteration, and use of biorational insecticides. The use of biorational insecticides is not a guarantee that resistance to these products will not occur, but resistance to biorational insecticides have been far less common than to conventional insecticides.

TOXICITY OF MOSQUITO CONTROL INSECTICIDES TO WARM-BLOODED ANIMALS.

Toxicology is the science of poisons. Paracelsus, who lived from 1493 to 1541, wrote: "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy." Paracelsus was right. Few substances that can be absorbed through the skin, inhaled, or ingested are truly inert. Many substances that are harmless or even beneficial in limited quantities or with some exposure routes could be considered poison via an alternative exposure route. It has been said that there are no harmless substance only harmless ways of using substances." This is generally true and a very important concept.

Insecticides are poisons. If they were not, they could not be effective in controlling mosquitoes. However, insecticides generally are far more poisonous to mosquitoes than they are to humans or domestic animals. Insecticides vary greatly in the toxicity hazard they represent to humans and domestic animals. Generally, modern mosquito control operations emphasize the use of insecticides that are the least hazardous to non-target organisms and regulatory agencies place great stress on means of reducing human hazards to insecticides. Data from poison control centers in the USA show that deaths resulting from poisonings from insecticide exposure represent a relatively small proportion of the total number of poison-related deaths. Nevertheless, each year some insecticide-related poisonings do occur in the USA, and some have major medical consequences, including death. Because of this, it is essential that everyone involved in insecticide use understand the principles of insecticide poisoning, and the role of safe use of insecticides in avoiding poisoning incidents.

INSECTICIDE TOXICITY AND HAZARDS

In terms of insecticide safety, there is an important difference between the words "**toxicity**" and "**hazard**". Toxicity refers to inherent poisonous potency of a material. Its toxicity is evaluated in toxicology laboratories and is always expressed in quantitative terms such as LC_{50} (lethal concentration-50, the concentration at which a material will kill 50% of some reference organism.) Hazard, on the other hand, means the risk of poisoning when the material is used. Hazard, then, depends not only on the toxicity of a material, but also on the risk of toxic exposure when used. In simple terms, remember that toxicity is the capacity of a substance to produce illness or death, hazard is a function of toxicity and exposure.

TYPES OF TOXICITY

Toxic effects can range from slight **symptoms** like minor skin irritation or hay-fever like symptoms to headaches or nausea. Organophosphate insecticides and some herbicides can cause severe symptoms like convulsions, coma, possibly even death. Insecticide toxicity in humans can be classified by the nature of exposure, by the route by which exposure occurs, or by the body function or system affected. Generally, any poison is more toxic if ingested by mouth than if inhaled, and more toxic if inhaled than if by dermal (skin) exposure.

Classification by Type of Exposure

Toxicity may be divided into four types, based on the number of exposures to a poison and the time it takes for toxic symptoms to develop. The four types of toxicity based on exposure are:

- **Acute.** When a person suffers illness as the result of a single dose of a insecticide, it is referred to as an acute exposure.
- **Chronic**. When there is repeated or continuous exposure to a insecticide by a person, it is called chronic exposure.
- **Subchronic**. When there has been repeated or continuous exposure to a insecticide, but no measurable toxic affects have resulted, a person is said to have been subjected to subchronic exposure.
- **Delayed**. Delayed toxicity may occur many years after exposure to a chemical and is most often only discovered in retrospective epidemiological studies (studies done after the fact.

Classification By Route of Entry

There are four common ways in which insecticides can enter the human body: through the skin, the mouth, the lungs, and the eyes.

- **Dermal**. Absorption through the skin is the most common route by which insecticide applicators are poisoned by insecticides and other chemicals. This is called dermal exposure. Dermal absorption may occur as a result of a splash, spill, or drift when mixing, loading or disposing of insecticides.
- **Oral.** If enough insecticide gets into the mouth, it may cause serious illness, severe injury, or even death. Insecticides may be consumed through carelessness or they may be consumed by individuals who are intent on personal harm.
- **Respiratory**. Insecticides are sometimes inhaled in sufficient amounts to cause serious damage to nose, throat, and lung tissues. The hazard of respiratory exposure is great because of the potentially rapid absorption of insecticides through this route. Vapors and extremely fine particles have the greatest potential for poisoning via respiratory exposure.
- **Ocular**. Eyes are particularly absorbent, and therefore getting any insecticide in the eye presents an immediate threat of blindness, illness, or even death. Eye protection is always needed when measuring or mixing concentrated and highly toxic insecticides. Eye protection also should be used when there is a risk of exposure to dilute spray or dusts that may drift into the eyes.

MEASUREMENTS OF TOXICITY

The standard unit used to describe dosage in toxicity tests of insecticides are the LD_{50}, expressed as mg/kg of body weight. This figure refers to the number of mg of a chemical that will kill 50% of a group of test animals. It should be remembered that **the smaller the number, the more toxic the chemical tested**. A chemical with a small LD_{50} (such as 5 mg/kg) is very dangerous. A chemical with a large LD_{50} (1,000 to 5,000 mg/kg) is not very dangerous.

Another expression used in connection with toxicity testing is the lethal concentration 50, or LC_{50}. This is usually used for exposures of insecticides in the vapor state, such as fumigants.

Typical toxicity values for insecticides used in mosquito control are shown in Table 6.1. The EPA has established classes of insecticides based on their toxicity levels. These are shown in Table 6.2.

HOW INSECTICIDES AFFECT HUMANS

The exact way that insecticide poisoning can affect humans and the degree to which certain segments of the human population can be affected are not completely understood. However, the signs and symptoms of acute insecticide poisoning are well known. **Symptoms** are what a person feels and can express to others. **Signs** are things one person can observe in another person, even if that person is unconscious. Pain and nausea are symptoms. Redness of skin, swelling, and hot, dry skin are signs. You should learn and be alert to the signs and symptoms of the early stages of poisoning. If any sign of poisoning develops, you should immediately and completely remove the source of exposure. By doing so, you may prevent additional exposure and minimize injury. **Early recognition of the signs and symptoms of insecticide poisoning, and immediate and complete removal of the source of exposure may save a person's life. This is especially critical if the person is unconscious, or otherwise unable to communicate clearly.**

However, remember that the signs and symptoms of insecticide poisoning can also be caused by other factors, such as infectious diseases or exposure to other chemicals. Therefore, it cannot be assumed that because an individual is in the vicinity of insecticides or a insecticide application, the development of some signs or symptoms of poisoning are necessarily the result of insecticide exposure. Nevertheless, if any signs or symptoms appear after contact with insecticides, you should contact a physician for assistance *without delay*.

SYMPTOMS OF INSECTICIDE POISONING

Organophosphate, carbamate, and organochlorine insecticide use has dramatically declined or been eliminated in mosquito control operations in California. However, because some products with a high potential for human poisoning fall into these groups, the signs and symptoms associated with poisoning should be well known to insecticide applicators.

ORGANOPHOSPHATE INSECTICIDES

Organophosphate poisons attach themselves to a chemical in the blood that is normally present and necessary for proper nerve functioning. This chemical is the enzyme **cholinesterase**. The organophosphate insecticides bind to the enzyme and make it unavailable to the nerve connections. When cholinesterase is unable to perform its normal function, the nerves in the body fail to send messages to the muscles properly. In such cases, the muscles may receive continuous or erratic stimulation, leading to twitching, tremors, or constant contractions (tetany). If the muscle action becomes intense, the victim may suffer convulsions. In cases of severe poisoning, quick and proper medical treatment may reverse the effects of the poisoning, and the life of a person can be saved even in advanced states of poisoning.

CARBAMATE INSECTICIDES

The mode of action of carbamates is similar to that of organophosphates, and they also inhibit the enzyme cholinesterase. The signs and symptoms of carbamate poisoning are essentially the same as those caused by the organophosphates, but carbamates are broken down relatively rapidly in the human body. Consequently, the effect of carbamates on cholinesterase inhibition is relatively brief. Because of this, blood tests on cholinesterase in people suspected of insecticide poisoning may not be an accurate indication of carbamate poisoning.

BLOOD TESTS FOR OPERATORS

California regulations require medical supervision of workers whose duties expose them to insecticides known to have the potential to inhibit blood cholinesterase levels, i.e., organophosphates and carbamates. The details of this supervision are contained in Section 6728 of the Health and Safety Code. The enforcement of this program is the responsibility of the California Department of Insecticide Regulation (DPR), whose insecticide safety program is widely considered to be the best and most stringent in the nation. The details of this supervision are important, and are contained in their entirely in Appendix 1.

ORGANOCHLORINE INSECTICIDES

Most compounds in this group are no longer registered for public health uses in California. The organochlorines act on the central nervous system. Many of these compounds and their degradation products can be stored in the fatty tissues as a result of either large single doses or repeated small doses. Single large doses can cause liver and kidney damage in animals. Symptoms of organochlorine insecticide poisoning include nervousness, nausea, and diarrhea. Heavy doses may lead to convulsions or other central nervous system impairment.

BOTANICAL INSECTICIDES

Insecticides derived from plants vary greatly in their chemical structure and also in their toxicity to humans. The toxicity of these insecticides ranges from pyrethrum, which is one of the least toxic of all insecticides to mammals, to strychnine, which is one of the most toxic

PYRETHRUM

Pyrethrum is a natural botanical insecticide containing the active ingredient pyrethrin. These insecticides are among the least toxic to mammals (LD_{50} in rats about 1,500 mg/kg).

SYNTHETIC PYRETHROID INSECTICIDES

These are synthetic insecticides with chemical structures similar to pyrethrin. Because of this they are called pyrethroids, or pyrethrum-like. Pyrethroids exhibit a wide range of toxicity, from very low (permethrin, LD_{50} in rats >4,000 mg/kg) to very high (tau-fluvalenate, LD_{50} in rats 261 mg/kg). Pyrethroids used in public health applications include permethrin, resmethrin, sumithrin, cypermethrin, cyfluthrin, deltamethrin, lambda-cyhalothrin, and others. However, in aquatic environments, these materials can be considered very toxic to various components of the fauna. In EPA toxicity tests 96-hour LC_{50} values of <1 µg/liter have been found for some organisms. Resource agencies will usually use these very low values when establishing relative-risk evaluations for insecticides or other chemicals.

Chemical Class	Insecticide	LD_{50} (mg/kg)

		Oral	Dermal
Organochlorines	Methoxychlor	6,000	6,000
	DDT	118	2,510
Organophosphates	temephos (Abate)	1,000	4,000
	malathion (Cythion)	1,000	4,444
	naled (Dibrom)	250	800
	fenthion (Baytex)	245	330
	chlorpyrifos (Dursban)	82	202
	dichlorvos (DDVP, Vapona)	56	75
	parathion, methyl	24	67
	parathion, ethyl	3.6	6.8
Carbamates	carbaryl (Sevin)	500	4,000
	propoxur (Baygon)	86	2,400
Botanicals	pyrethrum	>5,000	>2,000
Biochemicals	methoprene (Altosid)	34,600	>5,000
	diflubenzuron (Dimilin)	>4,640	> 1,860
Microbials	Bti (Teknar)	30,000	-
Pyrethroids	Resmethrin (Scourge)	2,700	>2,000

Table 6.1. Toxicity of Selected Insecticides for Humans

Table 6.2. Insecticide Toxicity Categories and Acute Toxicity Values

Category	Toxicity	Signal word required on label	LD_{50} (mg/kg) Oral and Dermal; μ/I, respiratory route		
			Oral	Dermal	Respiratory
I	High	Danger	0-50	0-200	0-2,000
II	Moderate	Warning	50-500	200-2,000	2,000-20,000
III	Low	Caution	> 500	> 2,000	> 20,000

Chapter 7

PHYSICAL CONTROL OF MOSQUITOES

Some of the earliest forms of mosquito abatement were examples of physical control. For example, the methods used to control mosquitoes that transmitted yellow fever **virus** and malaria parasites in Central America during the building of the Panama Canal were physical control methods. Physical control of mosquitoes essentially is the modification of the environment in a way that reduces the number of mosquito breeding sites.

Physical control often is integrated with chemical or biological control in successful IPM programs. In some instances, physical control by itself is sufficient to effectively reduce mosquito populations. Examples of physical control measures include draining of a pond, grading of an agricultural field to eliminate pools of standing water, or conversion of a swamp to farmland. California mosquito control agencies employing earth moving equipment to eliminate troublesome mosquito sources have demonstrated that well designed projects can benefit agriculture, the environment, and mosquito control mutually. These projects may reclaim previously unused land to useful purposes, such as agricultural production or wildlife use.

Physical control may be as simple as shutting off the flow of irrigation water at the optimum time to prevent standing water. Conversely, it may be complex, requiring a detailed plan. Major projects usually involve other agencies and require activities such as aerial surveys, filling, grading, and ditching. Maintenance requirements of projects after completion can include ditch clearing, repairing water gates, or restoration of dikes.

The duties of mosquito control technicians with respect to physical control vary greatly, depending upon the capabilities of local agencies and the scope of the physical control projects. In some cases, all of the work is done by personnel of local mosquito abatement agencies, in other cases the role of agency personnel is only to cooperate and advise other agencies that do the actual work.

EXAMPLES OF PHYSICAL CONTROL MEASURES

Physical control measures used to modify mosquito producing environments have effects ranging from insignificant to substantial. Breeding places are affected in several ways:

- Agricultural fields with low spots that hold irrigation water can be leveled more accurately with inexpensive modern laser leveling systems. This prevents accumulation of irrigation pools where mosquito larvae may develop and enhances drainage of excess irrigation water.
- Marshes may be modified so that upland areas are periodically flushed with saline water, eliminating development of freshwater mosquito species.
- Artificial permanent or semipermanent bodies of water may be kept mosquito free by modifying their banks to eliminate shallow regions with emergent vegetation where mosquito larvae can avoid predators.
- Engineered stormwater structures for flood control and pollution mitigation can be designed and maintained to drain rapidly and completely to prevent mosquito production.
- Artificial structures for holding drainage water from highways may be

designed in ways to avoid holding the water for periods long enough to permit completion of mosquito development. These structures are known as "Best Management Practices (BMP)" and research for better designs has been going on for several years between the California Department of Transportation and the California Department of Public Health.

CONSTRAINTS TO PHYSICAL MOSQUITO CONTROL MEASURES

At the time the first mosquito abatement agencies were organized in the early years of the 20th century, there were few objections to the physical methods used to eliminate mosquito breeding. In California, salt marshes often were drained by filling, diking, or cutting deep drainage ditches. Even more salt marshes were lost to filling for economic developments of various types. In time, the value of salt marshes in maintaining coastal ecosystems became appreciated, and new methods of marsh management were developed that reduced problems with mosquitoes while enhancing the marsh environment.

Currently, a variety of public agencies have statutory regulatory responsibilities for water-related ecosystems such as streams, rivers, lakes, marshes, vernal pools, and even neglected stormwater storage and conveyance systems. Some of these agencies are the US Army Corps of Engineers, the US Fish and Wildlife Service, the US Environmental Protection Agency, and various state agencies. The days of local agencies taking unilateral actions involving significant bodies of water are over.

Mosquito control agencies now prepare plans in advance annually for any work planned involving mosquito control in waters under jurisdiction of the aforementioned resource agencies for their review and approval.

PHYSICAL CONTROL OF URBAN RESIDENTIAL SOURCES

Urban residential sources of mosquito breeding include ornamental ponds, neglected swimming pools and spas, runoff pools from over-irrigated landscape or leaking plumbing, clogged rain gutters, and faulty septic systems, Finding mosquito sources in residential areas requires intensive and frequent inspections. Swimming pools in unoccupied residences has become a particularly difficult problem for mosquito control programs (Fig. 7.1, 7.2). Information on occupancy from tax and other local records, and the availability of aerial maps on the Internet (e.g., Google Maps®) have been particularly helpful in finding problem swimming pools. Well planned and executed public relations programs to promote the cooperation of residents to find and help eliminate backyard breeding sources are very valuable.

Fig. 7.1 Mosquitoes in a neglected swimming pool.

Rental properties provide additional challenges, especially where remedial action may be too expensive for residents, and landlords may be located in distant jurisdictions.

Although permanent physical solutions to urban mosquito problems are expensive, difficult, and time-consuming, they must be addressed aggressively. The species of mosquitoes that often emanate from these kinds of sources are also **vectors** of serious disease organisms such as WNV and SLE.

The usual physical control methods that must be employed to solve urban residential mosquito problems involve maintenance, repair, and proper water management. The question is who will do these things and who will pay for them. This often to leads to another kind of mosquito control: legal action.

Fig. 7.2 Mosquito larvae in a chlorinator in an unmaintained swimming pool.

PHYSICAL CONTROL OF MOSQUITOES FROM COMMUNITY, COMMERCIAL, AND INDUSTRIAL SOURCES

Large industrial facilities may have various types of holding ponds and other facilities for handling of liquid waste from manufacturing or processing activities. Others may use large quantities of water for cooling that eventually end up in ponds. Diaries, wineries, and canneries all have the need to handle liquid waste in some way or another. For new construction, mosquito abatement personnel or sanitary engineers may help design and construct facilities in a way that minimizes mosquito breeding. Obsolete facilities may present serious problems with mosquitoes, and the permanent solution to these is usually closure of the facility or extensive retrofitting of liquid waste systems.

The usual involvement for mosquito abatement district personnel is to monitor and identify mosquito problems, and to advise the management on ways to eliminate the problem. Most commercial managers strive to be good public citizens, especially when their facilities are close to population centers. Large companies may even have their own vector control programs.

Publicly-owned facilities that may cause mosquito problems include gutters, catch basins, and culverts associated with public streets (Fig. 7.3), community sewage disposal facilities, and public lakes and reservoirs.

Fig. 7.3 A poorly maintained culvert under a public street

Sewage ponds (lagoons) present special problems. They are rich in organic matter, and certain species of mosquitoes (e.g., *Culex stigmatosoma*) thrive under these conditions. Some of the design features of drainage structures that tend to minimize mosquito breeding are:

- Are free of small coves
- Are large enough for wind to cause wave action
- Are deep enough to discourage growth of emergent vegetation
- Have steep inner levee faces to limit growth of shoreline vegetation

- Are not loaded with organic wastes in the form of floating solids or vegetation
- Are well maintained

Mosquitoes associated with street and road structures for the capture and conveyance of stormwater and water from melted snow traditionally have been one of the biggest challenges for local agencies. Chemical control methods are expensive, tedious, and short-lived. Over the years, city, county, and state transportation agencies have worked with public health and mosquito control agencies to design and maintain structures in ways that do not hold water long enough to result in the completion of development of mosquitoes (Fig. 7.4). Many strategies have been adopted for this, including steep channels that cause flushing of immature mosquitoes.

Fig. 7.4 An extended detention basic retrofit.

Since the early 2000's, all new construction (i.e., commercial and industrial buildings and residential housing tracts) must comply with federal and state clean water laws that mandate the proper management of stormwater and urban runoff. Proper management must include both flood protection and mitigation (i.e. removal or reduction) of solid and dissolved pollutants carried in runoff from the developed property. The result is a proliferation of dry detention basins, wet ponds, vegetated swales, and various other above and belowground devices, all with the potential to create mosquito breeding habitat. Developers may select to install any type or combination of stormwater management structures on a given property as long as they satisfy clean water goals, making mosquito control challenging.

Mosquito control programs will need to become familiar with the structure and function of different stormwater systems and forge relationships with the local planning agency to obtain details of location. Physical mosquito control methods will vary by structure. Above ground systems should be designed and maintained to drain rapidly and completely to prevent mosquito production. In those structures built with permanent water zones, physical controls should focus on minimizing suitable mosquito breeding habitat through design and routine vegetation management. In most cases, belowground structures offer no physical control solutions and must be routinely inspected and chemically treated against mosquitoes (Fig. 7.5).

Fig. 7.5 A coastal salt marsh with water flow restricted by trash.

PHYSICAL CONTROL OF MOSQUITOES IN NATURAL SOURCES

Prior to the extensive water resource projects and land developments which now characterize California, mosquito problems mainly were related to natural sources such as swamps, marshes, river flood plains, and vernal pools. These problems were addressed by ditching, draining, and filling of salt marshes, the conversion of freshwater ponds and marshes to agriculture by installation of ditches and tiling systems, and the removal of trees followed by re-grading to eliminate swamps. Vernal pools in the way of development usually were just bulldozed. In more recent years, whole-scale alteration and removal of such natural water sources has become an unacceptable solution to mosquito problems. Various local, state, and federal agencies regulate aquatic environments, and mosquito abatement agencies work with these agencies to develop balanced programs for mosquito control.

Fortunately, natural sources of water do not present as many mosquito problems as do artificial sources. This is because natural sources often contain fish and other mosquito predators, have free-flowing water not conducive to mosquito development, and often do not represent a rich source of food for mosquito larvae. However, there are notable exceptions this, such as river flood plains and flooded tree holes.

Where significant problems with mosquitoes do occur in natural wetlands, solutions are usually complicated and arrived at only after considerable coordination with the various local and regional agencies having jurisdiction of some kind. The solutions to these kinds of problems are extremely variable, and must be developed within the context of the type of wetlands involved, the agencies involved, local public attitudes, and the seriousness of the problem.

SALT MARSHES

Marshes are wetlands that are subject to frequent or continuous flooding. They are similar to swamps, but differ in that swamps are usually characterized by woody vegetation (e.g., mangrove swamps) whereas marshes typically feature grasses, rushes, reeds, typhas, sedges, and other herbaceous plants. If woody plants are present in marshes, they are usually low growing (i.e., not trees).

Salt marshes represent a special type of marsh that is found along coasts of oceans and bays in the intertidal zone between land and the sea. Salt marshes are usually associated with estuaries or bays, which in turn have shores consisting of mudflats and sandflats. Creeks and other channels may exist within the shore features.

Salt marshes represent an unusual and valuable ecosystem. Biologically, they are very productive because of the tidal surges that bring in nutrients constantly. Salt marshes are characterized by salt tolerant plants and animals. Typical plants are cordgrass, pickleweed, and saltgrass. Typical animals include mosquitoes such as *Aedes squamiger* and *Ae. dorsalis*. Because these species are aggressive human biters, salt marshes are of great concern to coastal mosquito abatement agencies. The challenge to mosquito abatement agencies is to address mosquito problems in ways that preserve the valuable characteristics of the marsh ecosystem while minimizing the production of biting mosquitoes. Fortunately, through years of research and cooperation among mosquito specialists and marsh ecologists, this goal often has been realized.

Open Circulation Marshes

It has been known for many years that ditching of salt marshes to increase tidal circulation helps reduce mosquito populations. Studies have shown that the increased tidal flushing increases fish diversity and density by improving fish access from tidal channels. This has a negative impact on mosquito populations through predation by fish, but a positive impact on other animals such as salt marsh song sparrows. Although ecologists often prefer to rely on natural marsh channels for tidal flushing, most recognize that well-planned ditching is preferable to application of insecticides for mosquito control.

Restricted Circulation Marshes

When tidewater circulation is restricted due to a low **tidal prism** (=tidal volume) ditching may not be effective in reducing larval mosquito populations. Low tidal prisms may be due to artificial marsh obstructions such as roads, berms, inoperative tidal gates, or plugged culverts, or to natural deficiencies in water courses (Fig. 7.6). In many cases, mosquito control may be achieved by removing restrictions: repairing tide gates, clearing culverts, and installing new ditches to supplement natural water courses. Installing new or larger culverts under marsh roads also may be necessary.

Fig. 7.6 An urban underground drain with extensive mosquito production.

Impoundments

Impoundments are areas in a salt marsh created by construction of earthen dikes that allow the areas to be artificially flooded during the mosquito breeding season. Most salt marsh mosquitoes will not lay their eggs upon standing water. Instead, they oviposit upon moist soil; and the eggs hatch when flooded by tides or rainfall. Thus impoundments may eliminate mosquito production from the area without having to use pesticides.

Impoundment dikes may surround an entire marsh, or may stop at the upland edge. Various water control structures are often used to manipulate water levels within impoundments, including pumps, culverts, spillways and weirs. Impoundments were once used extensively for mosquito control, but are seldom used today. The construction of dikes and the installation of maintenance structures are more expensive than managing marsh circulation, and marsh ecologists object to the significant changes in marsh flora and fauna that often accompany impounding.

Modern Marsh Management

In the late 1800s and early 1900s, thousands of acres of salt marsh in California were converted to other types of land use though draining and filling. This was before the valuable role of salt marshes in the ecosystem was appreciated. Now, the emphasis is on comprehensive management of salt marshes in ways that meet multiple goals, including mosquito abatement. Federal, state and local legislation dictates that each proposed management activity meet standards for careful engineering and biological surveys and that the impact upon the environment be assessed before projects are undertaken. Mosquito and vector control agencies should provide ample warning to regulatory agencies for projects undertaken to reduce mosquitoes to allow for review and comment of all salt marsh stakeholders.

PHYSICAL CONTROL OF MOSQUITOES FROM AGRICULTURAL SOURCES

The primary mosquito production problems of agricultural areas result during the application of irrigation water to crops and the drainage and storage of waste water. In addition to the typical agricultural mosquito sources, residential, industrial waste and natural sources may occur about farm dwellings.

Mosquito problems may arise with both large scale operations and small family farms. Generally, mosquito production in agricultural operations are most pronounced in areas where crops are irrigated. However, even in dry-farming areas, problems can be created in connection with stock ponds, waste water ponds, and other water-holding activities. Such problems may stem from faulty designs of water holding facilities, or poor maintenance of pumps, sumps, drains, and other mechanisms and structures associated with water storage.

The degree to which irrigation and drainage contribute to mosquito problems depends upon a number of factors. These factors include:

- Soil type and characteristics
- Water quality
- Ground slope
- Farm irrigation delivery and control systems
- Irrigation methods
- Soil intake rates (permeability)
- Soil compaction
- Presence of hardpan
- Type of crop
- Crop water requirements
- Management of intercrop periods
- Water table
- Subsurface and surface drainage
- Soil fertility
- Soil sealing (bacterial, sedimentation)
- Soil chemistry
- Cultivation practices
- Soil temperature ranges

Proper drainage of excess surface water is essential to the prevention of mosquito problems. Even if drainage practices are sound, it is necessary to maintain ditches and other structures for conveyance of drainage water in good order to prevent ponding sufficient to allow development of mosquitoes.

Proper drainage of surface water depends on properly terraced and graded fields. This has become easier and more efficient with the advent of laser leveling systems. Laser systems can insure adequate crop irrigation while improving drainage systems (Fig. 7.7). These systems offer not only a physical control approach to reduction of mosquitoes, but also conservation of water, increased crop yields, and saving of labor formerly needed to survey and stake fields.

Fig. 7.7 Ditch containing tail water from a tomato field.

Flooded Agricultural Crops

Rice fields and irrigated pastures are two crops that present enormous challenges to mosquito control agencies because both often involve flooding with irrigation water for long periods. Complicating the situation is the presence of emergent vegetation (the crop) and frequently, the absence of predaceous fish.

Mosquitofish may come in with the irrigation water or may be added by mosquito control agencies, but they rarely distribute to all parts of the fields unless present in large numbers. The first irrigation of the season typically results in a generation of *Aedes* mosquitoes that develops rapidly in the absence of predators. Subsequently, *Culex* and *Anopheles* mosquitoes lay eggs and replace the emerged *Aedes*. By then, predators have become established and their numbers may be sufficient to significantly reduce mosquito production.

Many physical methods have been used to reduce the numbers of mosquitoes produced in these crops. Timing of flooding is probably the most effective. Sometimes delay in flooding in just a week or so can make a profound difference in mosquito development. In the case of irrigated pastures, management to reduce the time water stands on the pasture to a point too short for mosquitoes to complete development from egg to adult is important. However, *Aedes* that hatch after the first flooding can have very short development times, and removing irrigation water before they emerge can be difficult. When large numbers of mosquitoes emerge from a flooded pasture, ranchers are often heard to remark that the pasture got away from them.

Seepages and poorly maintained field or roadside ditches associated with rice fields also may be significant producers of mosquitoes. Physical control in rice growing areas generally is limited to maintaining levees to prevent seepage pools from forming, cleaning irrigation and drainage ditches to minimize mosquito breeding habitat and maintaining weed-free fields which deny mosquitoes protective shelter.

Intermittently Irrigated Crops

Mosquito breeding in crops that are furrow or sprinkler irrigated can also produce mosquitoes. Alfalfa, cotton, corn, orchards, vineyards and date groves are among irrigated crops that frequently cause problems. Water that drains from the actual crop area to ditches (called tail water) from any irrigated crop can result in mosquito breeding if the ditch system is not maintained properly by keeping culverts in good repair and keeping weeds or excess silt out the ditches (Fig. 7.8).

Each problem must be analyzed individually before solutions can be recommended. Listed below are some recommendations employed in applicable situations to improve irrigation water management and reduce mosquito production. These have been summarized from the recommendations of the Soil Conservation Service.

- Re-grade fields to proper slopes of 0.1-0.3 foot per 100 feet and eliminate irrigation grade reversals causing water to pond.
- Continue the slope to the end of the strip by eliminating the level section at the end of the irrigation run.
- Install a drainage field ditch at the end of the field to return excess water for disposal or reuse. Provide sub-surface drainage where necessary for water table or salinity control
- Reorganize irrigation systems allowing better control of water.
- Change method of irrigation.
- Change direction of irrigation.
- Adjust delivery based on soil intake rate and length of run.
- Apply soil amendments to increase soil intake rate and permeability.
- Rotate grazing and eliminate cultivation or grazing of fields when they are wet.
- Select the proper plants for the soil.
- Follow crop rotation and conservation practices to improve soil productivity.

- Adopt conservation tillage practices.
- Change land use where indicated by technical and economic analysis.
- Rip soil to break up restrictive soil layers and improve drainage.
- Begin herbicide maintenance to reduce heavily vegetated mosquito sources.

PHYSICAL CONTROL OF MOSQUITOES IN LARGE WATER STORAGE AND CONVEYANCE STRUCTURES

Federal, state, and local agencies, public utility companies and private land developers have created a statewide system of reservoirs and distribution channels to serve the essential needs of the state. In 1993, California had 1,395 dams and reservoirs with a maximum storage capacity of more than 38 million acre feet of water, of which 80% was used for irrigation.

Reservoirs and their conveyance structures can be important sources of mosquitoes. However, large reservoirs and their associated concrete-lined ditches rarely present mosquito problems because standards of maintenance are usually very high, and the usual situations that promote mosquito breeding (clogged ditches, shorelines with emergent vegetation, etc.) usually are not present.

Older dams and reservoirs can present problems with mosquitoes because of general aging and gradual deterioration of concrete surfaces. Mosquito sources can be found around the edges of reservoirs, particularly at the upstream end, unless a provision has been made for clearing the vegetation and restoring and maintaining steeply sloping shorelines. Older dams also may have seepage areas below the dams where mosquitoes can breed.

Reservoirs are filled each winter and spring as the runoff from higher land occurs and drawn upon later during summer and autumn. The area of drawdown around the margins of the reservoir between the surface elevations of maximum and minimum storage is called the zone of fluctuation. Where low areas in this zone retain water as the surface elevation is lowered, mosquitoes can breed unless cuts are made in the low ends of the depressions to make them self-draining.

FUTURE TRENDS IN PHYSICAL CONTROL

It is safe to say that there will ever be a return to the days of wholesale destruction of wetlands in California or elsewhere. This is true of cases where the destruction was for the purpose of highway construction, creation of housing tracts, and other developments, and it is also true in the case of physical control for mosquito abatement. Federal and state laws now regulate changes that are permitted in wetlands, and even small projects require environmental impact assessments and review by a number of agencies and interested individual citizens. Failure to follow strict guidelines for permitting and review can result in severe penalties. Even when some loss of wetlands is allowed to take place, mitigation is required, often in the form of wetlands creation to offset the loss.

Another likely trend will be a continual reduction in the role of insecticides in mosquito control in wetlands. Accompanying this trend will be greater emphasis on wetlands management for mosquito abatement, which is simply modern physical control. There should be a continuation of research and development activities to enhance wetlands management. Much of this will involve improved survey and analysis of wetlands, such as the use of satellite imagery.

The same trends will probably occur in farm and ranch management in ways that minimize mosquito problems, but these trends will be in other forms. Fortunately, the same modern management practices that farmers and ranchers adopt for better yields, and reduced fuel and water consumption will result in fewer mosquito problems.

Finally, the rapid changes occurring in urban and suburban environments with regard to how stormwater and urban runoff must be managed is often unintentionally in direct conflict with the objectives of mosquito control programs. New and improved physical control measures will need to be developed for the wide variety of engineered structures. Belowground devices may pose the biggest challenge to mosquito control programs because they are often difficult to find and access, produce large numbers of *Culex pipiens* complex mosquitoes important in WNV transmission, and are usually limited to chemical treatment for control. Physical barriers may be available for some systems in the future to prevent entry of female mosquitoes.

Chapter 8

BIOLOGICAL CONTROL OF MOSQUITOES

Biological control (BC) is the use of natural enemies to manage mosquito populations. There are several types of biological control including the direct introduction of parasites, pathogens and predators to target mosquitoes. These introductions are of two types: inoculative and inundative. Inoculative releases are single, relatively small introductions of natural enemies, followed by their semi-permanent establishment in the environment. Inundative releases are multiple releases of very large numbers (often millions of individuals). In most field trials, inundative releases have been more successful than inoculative ones.

Microbial pathogens of mosquitoes include **viruses**, bacteria, fungi, protozoa, nematodes, and microsporidia. Biological mosquito control methods have almost exclusively been directed against larvae.

Another type of BC is the management of habitats where mosquitoes develop in ways that tend to conserve natural enemies. Both introductions and conservation of natural enemies have a place in mosquito control operations.

If the definition of BC is expanded to include not only microorganisms, but also their toxins, then insecticides such as *Bacillus thuringiensis israelensis* (Bti) qualify as both a BC agent and a biorational insecticide.

Two other strategies have been developed that have many similarities to BC, but do not fit the classical definition of BC because natural enemies are not involved. One set of strategies comes under the broad term autocidal methods, the other genetic manipulation. Both of these strategies have been tried against mosquitoes, so far with only partial success. Both autocidal control and genetic control strategies feature using modified organisms of a given species to control populations of the same species.

BIOLOGICAL CONTROL BY INTRODUCTION OF NATURAL ENEMIES

FISH

Fish have been used as biological control agents for mosquitoes for many years. The most commonly-used species is *Gambusia affinis* (mosquitofish). This species is the most widely distributed fish in the world. Other fishes that have been used effectively are some species of carps and minnows. Fishes in the genus *Tilapia* have been studied as potential BC agents for mosquitoes, but some species tend to disruptive in some habitats because of their invasive qualities .

Fishes in the genera *Poecilia, Fundulus, Gasterosteus,* and *Lucania* have also been used for mosquito control in various parts of the world.

Gambusia affinis is not native to California; its natural geographic distribution is the southeastern USA. Because this species cannot survive the winter in many of the colder areas of the state, it must be re-introduced to mosquito habitats annually in areas with cold winters. Some mosquito abatement districts have developed large-scale rearing facilities for mosquitofish that are released as needed (Figs. 8.1, 8.2).

Gambusia affinis has been used with great success against mosquitoes that breed in swimming pools, bird baths, and similar types of artificial water structures. Most mosquito abatement agencies in California will provide mosquitofish to the public free of charge for these kinds of uses (Fig. 8.3).

Because the mosquitofish is not native to California, their use is discouraged in some open freshwater situations because they tend to attack young individuals of native fish species. However, mosquitofish may be used in disturbed aquatic habitats for mosquito control because such habitats usually do not contain native fish.

Figs. 8.1 A laboratory facility for the rearing of mosquitofish

Proper use of mosquitofish for BC requires extensive knowledge of fish biology and local regulations concerning their transport and use. Used in appropriate habitats, they are one of the most effective biological control agents of mosquitoes known.

Fig. 8.2 An outdoor facility for the rearing of mosquitofish

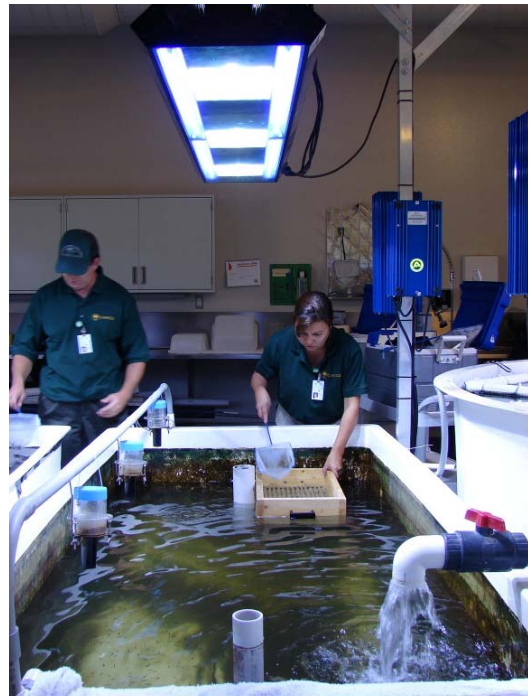


Fig. 8.3 Grading of mosquitofish in a rearing laboratory

MICROBIAL ORGANISMS FOR MOSQUITO CONTROL

Microbial insecticides are widely used for mosquito control in a wide variety of situations. In almost all instances they are used as mosquito larvicides.

Microbial organisms such *as Bacillus thuringiensis isralensis* (Bti) and *Bacillus sphaericus* (Bs) have characteristics of both microbial insecticides and BC agents. Both are available as commercial formulations and can be applied with the same spray equipment as conventional insecticides. Bti kills mosquito larvae when they ingest crystalline toxins produced by the bacteria. The toxin interferes with larval digestion. Bs also produces toxins, but mosquito larvae can suffer lethal effects from infection.

The crystalline toxins of various species of *Bacillus* have been studied extensively and new experimental strains of these bacteria have been developed to find improved performance as mosquito control agents.

Some experimental strains of Bti and Bs have been created that have more toxic crystals that the wild strains. So far, commercial preparations have relied only on the natural bacteria.

Microbial insecticides can be dispersed by hand or dispersed using any equipment designed or modified for solid products. Bti is no longer effective after the larvae become pupae, because they stop eating.

Other Organisms Tested As BC Agents Against Mosquitoes

Copepods, fungi (genus *Coelomomyces*), and *Lagenidium* have been studied extensively as possible BC agents against mosquitoes. All of these organisms have been effective in reducing larval mosquito populations in laboratory trials, and even in limited field trials. None have been accepted for wide-scale use for a variety of reasons, most of them economic. The lack of reliable and economical mass rearing methods has been the bar to wide-spread use for most of these.

Other interesting organisms that have been studied include mermethid nematodes (parasitic roundworms), planaria, and tadpole shrimp. All have shown some promise at one time or another, but all had some drawbacks preventing their adoption for wide scale use. However, some California mosquito abatement districts with well established biological control programs do have successful rearing programs for some of these agents (Figs. 8.4, 8.5, 8.6).

AUTOCIDAL CONTROL

Autocidal refers to methods by which organisms kill or otherwise harm themselves. As applied to pest control it means a method of pest control in which sterile or genetically altered insects of a given species are released to reduce the breeding success of the local insect population of the same species. This

Fig. 8.4 Infecting Cx. quinquefasciatus with parasitic nematodes

Fig. 8.5 An outdoor rearing facility for tadpole shrimp.

method gained world attention in the 1960s when scientists of the US Department of Agriculture used the method to virtually eradicate the screwworm fly from much of southern Texas.

The methods used for autocidal control involved the rearing of large numbers of male insects and their sterilization of male insects by radiation or use of chemosterilants. These male insects were introduced into natural (wild) populations using inundative releases. The sterilized males would mate with wild females, but no fertile offspring would result. Mathematical models upon which this method is based showed that over time and repeated releases the population level of the wild populations of pest insects would be suppressed to a very low level.

In the 1970s and 1980s the method was tested in several sites in Florida against anopheline **vectors** of malaria. The field trials were eventually discontinued when it became obvious that the success on screwworm flies in Texas could not be duplicated with anopheline mosquitoes in Florida. Problems were encountered with relative fitness of modified males, with mass rearing procedures, and possibly with emigration of wild males into the test areas.

Fig. 8.6 Extracting eggs of tadpole shrimp

GENETIC CONTROL

The autocidal methods used to sterilize male pest insects were not considered genetic methods because there was no change in the genetic structure of the wild pest populations involved. Consequently, there was not way lethal or otherwise harmful genes could be passed on to future generations of pests. This led to the idea of sterilizing males by genetic methods (e.g., by rearranging chromosome structure through a process called translocation). A number of these methods was developed, but none was found that improved the existing sterile male release programs.

From these early attempts, as well as a wealth of new molecular biology techniques for genetic alteration of organisms, arose a new and promising line of research to alter the genetic makeup of vectors in a variety of ways to reduce their population sizes or change their ability to transmit pathogenic microorganisms. This is presently an active and exciting area of research involving not only mosquitoes, but many other arthropod vectors as well. Significant progress has been made in development of our understanding of the genetic makeup of mosquitoes, and methods of altering this makeup. Successful large-scale programs based on these approaches are still in the future, but they hold an important promise for things to come.

Chapter 9

MOSQUITO CONTROL IN CALIFORNIA

PRINCIPAL CALIFORNIA AGENCIES INVOLVED WITH MOSQUITOES

Mosquito control in California is carried out by more than 70 local agencies, including mosquito and **vector** control districts, environmental health departments, and county health departments (Fig. 9.1). About 50 of these agencies are members of the Mosquito and Vector Control Association of California (MVCAC). The objective of MVCAC is to promote cooperation among agencies and personnel involved in mosquito control and related subjects, to stimulate improved mosquito control methods, and to disseminate information about mosquito control.

Two other state organizations cooperate closely with local agencies conducting mosquito control. The California Department of Public Health (CDPH) provides many services to local agencies and to the public in connection with mosquito problems. Some of their activities include provision of technical support to agencies on mosquito control operations, testing and certification of public health pesticide applicators, coordination of a statewide mosquito-borne arbovirus disease surveillance program, performance of epidemiological investigations of human disease cases associated with mosquitoes, and coordination and participation in a regional emergency response in conjunction with the California Office of Emergency Services.

A key instrument in the assistance provided local agencies by CDPH is the **Cooperative Agreement**. This is an agreement between CDPH and local agencies that agree to certain standards of operation whereby CDPH assumes responsibility for certain functions pertaining to the application of state laws and regulations pertaining to pesticide use for vector control by the districts. It is based on a separate document, a memorandum of understanding among CDPH, the California Department of Pesticide Regulation, and the County Agricultural Commissioners (CAC) concerning various responsibilities in meeting laws and regulations on pesticide use.

Cooperating agencies agree to calibrate pesticide application equipment, maintain records of pesticide applications, submit pesticide applications and adverse pesticide application effects reports to CAC, certify pesticide applicators, and submit to periodic inspections to insure agency activities are in compliance with state laws and regulations pertaining to pesticide use.

Fig. 9.1 Agencies providing mosquito control in California

The third state organization that participates in mosquito-oriented activities is the University of California (UC). These activities are carried out primarily by the three campuses that have strong involvement with the Agricultural Experiment Station and the Cooperative Extension Service. UC provides education in subjects related to medical entomology and vector biology, and many of these subjects have considerable content related to the biology and control of mosquitoes. Several of the campuses offer graduate degrees in entomology and related subjects. UC also has the responsibility for research and development in mosquito biology and control. UC cooperates close with CDPH and MVCAC in their research and development programs.

The commitment of the three state agencies to participate in mosquito control programs within their overall mission is a tribute to the talented and dedicated personnel who are interested in these programs and also the foresight of key individuals in fostering cooperation among the three organizations. These individuals saw this cooperation in protecting California's citizens from mosquitoes and their associated diseases as a "3-legged stool".

APPROACHES TO MOSQUITO CONTROL IN CALIFORNIA

No two states in the USA have exactly the same set of problems with mosquitoes. Consequently, no two states use the same approach to solve these problems. California is a state with enormous diversity, and this is true of mosquito problems as well. In California we have salt marshes, irrigated agriculture, heavily urbanized areas, high mountain passes with snow pools, forested areas with log ponds, oak savannahs with tree holes, and natural and artificial wetlands of various types. All of these environments support the development of mosquitoes (Figs. 9.2–9.9a, b).

The basic approach to mosquito control in California is control of mosquito larvae. This is accomplished through physical, biological, and chemical control methods. The reason for this is that larval control can be specifically targeted towards mosquitoes, whereas adult mosquito control has the potential to impact other organisms, including humans.

The chemical control of adult mosquitoes also has an important place in California programs. Where there is an eminent danger of human mosquito-borne disease cases, control of adult mosquitoes may be the only option available to a local agency. There are also times when a very large emergence of adult mosquitoes occurs near a city or town. This is usually due an unusual change in water conditions during very warm weather. Under these conditions chemical control of adults may be needed to avoid considerable public discomfort or disease.

For many years there has been an emphasis on the development of new physical and biological control technologies to supplant chemical control. Great strides have been made in this direction, but it is unlikely that chemical control will ever disappear as a significant mosquito control tool. Nevertheless, mosquito control in California now is a vastly safer and environmentally friendlier enterprise than it was 50-60 years ago. The most important improvements in mosquito control during this period include:

- The movement away from conventional persistent insecticides (organochlorines, organophosphates, carbamates) and their replacement with biorational insecticides. In California, this movement is nearly complete.
- The development of improved pesticide dispersal equipment permitting sharply targeted applications and fine control over dosage.

- The adoption of comprehensive surveillance programs for both mosquito-borne diseases and for the presence of mosquito populations.
- The development of ecologically sound water management programs, especially in valuable coastal marsh habitats.
- The creation of interagency cooperation to construct water conveyance structures in ways that minimize mosquito breeding.

THE FUTURE OF MOSQUITO CONTROL IN CALIFORNIA

It is reasonable to expect that mosquitoes will continue to present problems to people in California for as long as there are people here. It would be impossible to eradicate all 40+ species of mosquitoes from the state even if everyone considered that a worthy goal. More importantly, we will probably see periodic invasions of human disease pathogens transmitted by mosquitoes from other parts of the world, much as **WNV** came here at the end of the last century.

The emphasis on biorational insecticides to control mosquitoes will also continue. A major responsibility of mosquito technicians will continue to be to educate the public in the nature of these mosquito control products, and to help them understand the basic differences between conventional and biorational materials.

The public will demand that training and certification of pesticide applicators be not only continued, but strengthened. Because advances in mosquito control technology will continue to arrive at a brisk pace, the need for training to understand these new methods will increase. It was only 20 years ago that nobody needed to know how to use a global positioning device, or a hand-held data input device — there weren't any!

Fig. 9.2 A managed salt marsh in Massachusetts

Fig. 9.3 An irrigated pasture, Fresno County, California

Fig. 9.4 An urban mosquito problem in Orange County

Fig. 9.5 A mosquito pool resulting from melted snow

Fig. 9.6 A log pond in Oregon

Fig. 9.7 Collecting *Aedes sierrensis* larvae from a tree hole in a large oak, Lake County, California.

Fig. 9.8 A pile of discarded tires in the Central Valley of California

Fig. 9.9a Experimental flooding of Owens Lake, June 1994

Fig. 9.9b Experimental flooding of Owens Lake, June 1995

Chapter 10

SURVEILLANCE FOR MOSQUITOES AND MOSQUITO-BORNE DISEASES

SURVEILLANCE FOR MOSQUITO-BORNE DISEASES

ARBOVIRUSES

Surveillance for both human and equine diseases caused by infection with mosquito-borne arboviruses has been carried out in California for more than 80 years. Over time, surveillance has been expanded to include evidence of arboviral infection in wild and sentinel vertebrates, and in wild-caught mosquitoes. Early surveillance activities were not carried out on a statewide basis, but were done in connection with research activities carried out in various laboratories. The current surveillance program was formalized about 1979 and placed under the direction of the California Department of Public Health (CDPH). The present program is a cooperative venture of CDPH, the University of California, and the more than 60 mosquito abatement agencies. The CDPH has the responsibility for managing the program and reporting of results, and does much of the actual testing of surveillance samples. The University of California (UC) conducts research on new surveillance, testing, and reporting methodology, and the local mosquito abatement agencies collect biological samples for testing for evidence of arboviral activity.

The present surveillance plan is described fully in the document "California Mosquito-borne Virus Surveillance and Response Plan", published jointly by CDPH, the Mosquito & **Vector** Control Association of California (MVCAC), and UC. This document is revised every year. A supplement to the surveillance and response plan, entitled "Operational Plan for Emergency Response to Mosquito-borne Disease Outbreaks", describes the responsibilities of various agencies to outbreaks of human disease. Both documents are available in PDF format on the website http://westnile.ca.gov.

Before 2000, the primary focus of the surveillance program was the two most important arboviruses in the state, **WEE** and SLE. The detection of **WNV** in New York in 1999 prompted a review and expansion of surveillance guidelines in California, and consequently, when WNV arrived in California in 2003 state agencies were well-prepared for its detection and monitoring.

Elements of the arbovirus surveillance program are described below, and are listed in the order of the theoretical lead-time provided by the element before the occurrence of human disease.

Analysis of Climate Variation.

Disease ecologists have observed that various weather factors tend to presage peaks of arboviral activity in North America. However, until recently, adequate data sets for arboviral activity and sound correlations between weather factors and arboviral activity have not been available. Through the work of many agencies and individuals in California, this is changing, and we are moving closer to useful predictive models based on climate forecasts.

Mosquito Abundance

Mosquito abundance can be estimated by sampling larval and adult mosquitoes. This provides abatement agencies with information needed to guide control operations, and it also provides advance warning of high risk to arboviral activity and thus human disease outbreaks. Adult mosquito abundance is a key factor contributing to the risk of **virus** transmission.

Mosquito larvae are sampled by use of a long-handled ladle called a “dipper”. Technicians sample small bodies of water and count the number of larvae appearing in the dipper and also count the number of dips taken. Larval density is expressed as number of larvae per dip. It is difficult to derive estimates of adult mosquitoes based on estimates of larval mosquitoes for a number of reasons. High numbers of larvae do not always translate into high numbers of adult mosquitoes because of mortality factors, which are often density-dependent. This is a fancy term that means that the chances of survival of larvae to the adult stage are less when their density is high, and *vice versa*. However, routine sampling for mosquito larvae is essential in guiding control operations.

Guidelines for adult mosquito surveillance are contained in the publication “Integrated mosquito surveillance guidelines” published in 2003 by RP Myer and WK Reisen and other members of the Vector and Vector-Borne Disease Committee of MVCAC. These guidelines are also summarized in the mosquito-borne virus surveillance and response plan.

Several methods are used to estimate adult mosquito abundance. The most common and oldest method is the New Jersey light trap (Fig. 10.1). This trap requires a 110V power source, but requires little attention once it is installed. Some traps have been operated at the same location for many, years. Trapped mosquitoes are collected weekly in a killing jar of some kind.

Fig. 10.1 A New Jersey style light trap.

Fig 10.2 A carbon dioxide battery-powered adult mosquito trap.

Estimated mosquito abundance based on trap counts of mosquitoes in New Jersey style light traps are expressed as mosquitoes per trap-night. Since male mosquitoes do not come to light traps in large numbers, this is usually understood to refer to female mosquitoes. The results are usually broken down by species. Here is an example based on two species an agency might be interested in, *Cx. tarsalis* and *Ae. melanimon*. Assume 10 traps were operated for 5 nights each, and the total mosquitoes trapped was 73,234 and 23,678, respectively:

For *Cx. tarsalis*, the estimated abundance would be 73,234/10x5 = 1,465 females per trap night.

For *Ae. melanimon*, the estimated abundance would be 23,678/10x5 = 474 females per traps night.

Carbon-dioxide traps (Fig. 10.2) are used for both estimates of adult mosquito abundance and for collection of female mosquitoes for virus testing (see below). Carbon-dioxide (dry ice)-baited traps are small, light, battery powered, and portable.

Gravid females of some species of mosquitoes, notably those in the genus *Culex,* can be attracted to traps containing mixtures of oviposition stimulants (e.g., extracts of rotten hay or grass). Female mosquitoes enter these traps, and are forced into collection containers by an updraft fan (Fig. 10.3).

Fig. 10.3 The Cummings gravid trap for monitoring female Culex mosquitoes

Another method of estimating female mosquito abundance is the "resting box" (Fig. 10.4). These are usually painted dark saturated colors (e.g., red) thought to resemble dark hiding places of female mosquitoes, yet provide enough contrast with the color of the mosquitoes to permit technicians to see and removed them. Some of these boxes are very large, and technicians can walk into the boxes and remove the resting mosquitoes with a mouth aspirator.

Fig. 10.4 A "resting box" for collecting adult mosquitoes.

All of these methods, as well as still others used for special studies, have advantages and disadvantages. The pros and cons of each are discussed in Appendix A of the surveillance and response plan referenced above. Proper deployment of traps are presented in the surveillance guidelines.

Mosquito Infections

Early virus activity can be detected by testing adult female mosquitoes for viral infection. Because *Culex tarsalis* in the primary rural vector of WEE, SLE, and WNV, the arbovirus surveillance program emphasizes testing of samples of this species. Other important species that should be tested are *Culex quinquefasciatus*, *Culex pipiens*, and *Culex stigmatosoma*. Female mosquitoes are trapped by local mosquito abatement agencies for virus testing, or are trapped for both estimation of abundance and virus testing (carbon dioxide and gravid traps). Trapped mosquitoes are identified to species, counted, placed in groups (pools) of 50 females each, and frozen immediately at -80°C to preserve virus. Frozen pools are sent to the Arbovirus Research Laboratory of the Center for Vectorborne Diseases (CVEC) at UC Davis for testing to detect the presence of WNV, WEE, and SLE. Unidentified viruses that show up in mosquito pools are identified after the end of the season. This is a very important component of surveillance, because it increases vigilance for new viruses that may be imported into the state, much as WNV did earlier. Complete information on collection, processing, and shipment of mosquito pools are contained in Appendix B of the surveillance and response plan.

Avian Infections

There are three ways avian populations can be tested for evidence of arboviral infections: (1) the use of flocks of chickens maintained in cages as sentinels to detect arboviral antibodies, (2) the collection and bleeding of wild birds to detect arboviral antibodies, and (3) the testing of dead birds for virus reported by the public in connection wit the CDPH WNV Dead Bird Program.

Sentinel Chickens. In California, flocks of ten chickens are placed in locations where mosquitoes are known to be abundant, or where there is a history of arboviral activity (Fig. 10.5). In some cases, flocks have been maintained and tested in the same location for as long as 30 years. Technicians of local mosquito abatement agencies collect blood samples every two weeks by pricking the comb and allowing a drop of blood to flow on a filter paper strip. This strip is dried and mailed for testing to the Richmond laboratory of the Vector-Borne Disease Section of CDPH. Chickens that have been infected with arboviruses transmitted to them by mosquitoes will develop antibodies that can be detected by testing. These chickens are then said to have seroconverted. Mosquito-borne virus activity in the state can be tracked by following patterns of seroconversion in these chicken flocks. Complete guidelines for maintenance of flocks, bleeding of individual chickens, and testing protocols are contained in Appendix C of the surveillance and response plan.

Fig. 10.5 A sentinel cage used in arbovirus surveillance programs.

Live birds. Viral infections in wild bird populations can be monitored by capturing, bleeding, and releasing birds in traps or mist nets, and testing the blood for evidence of infection. Wild bird data can provide clues to the role of various species as hosts of arboviruses, and the presence of antibodies in wild birds may supplement evidence of viral activity obtained in other ways. Because of the expense and technical difficulty of sampling and testing of live birds for virus, this method is not widely used in California for routine arbovirus surveillance.

Dead birds. Unlike WEE and SLE, WNV in North America frequently causes death in some species of birds, especially those in the family Corvidae (crows, magpies, jays). To exploit this fact, dead bird surveillance was begun by CDPH in 2000 to provide early detection of WNV. The program is based on the reporting of dead birds by members of the public through a Dead Bird Hotline (1-877-WNV-BIRD) and via the West Nile website (http://westnile.ca.gov). Birds meeting certain criteria are necropsied by the California Animal Health and Food Safety Laboratory, and kidney snips are tested for WNV RNA (ribonucleic acid) at the Arbovirus Research Laboratory of CVEC. Oral swabs from dead crows are tested by some local agencies using rapid antigen tests. Complete information on the dead bird testing program is contained in Appendix D of the surveillance and response plan.

Tree Squirrel Infections

Tree squirrels were added to the surveillance program in 2004 based on evidence they are susceptible to fatal infections by WNV (Fig. 10.6). The West Nile Hotline accepts reports of dead squirrels from the public; the squirrels are picked up by local mosquito abatement agencies. Dead squirrels are necropsied by the California Animal Health and Food Safety Laboratory, and kidney snips are tested for WNV RNA at CVEC. Complete information on the dead tree squirrel testing program is contained in Appendix D of the surveillance and response plan.

Equine Infections

Equine disease caused by WEE and WNV is not a sensitive indicator of activity of these viruses because of the intentional or natural vaccination of horses, donkeys, and mules. If confirmed cases do occur, it is a strong indication that WEE or WNV activity has amplified to levels where human disease cases are eminent. Veterinarians are alerted annually to the possibility of disease in equines not only to WEE and WNV, but also other arboviruses that are known to exist in North America and also

Fig. 10.6 The western tree squirrel, *Sciurus griseus*.

arboviruses from outside the continent that may pose a risk should they invade California.

Human Infections

Local mosquito abatement agencies depend upon the rapid detection, confirmation, and reporting of human arbovirus cases to plan and implement emergency control activities to prevent additional clinical infections. Nevertheless, human cases are not a sensitive surveillance indicator of arboviral activity because most infected humans are asymptomatic. No human cases of western equine encephalomyelitis or St. Louis encephalitis have occurred in recent years. However, 2,320 laboratory confirmed cases of disease caused by WNV were detected between 2003 and 2007.

California regulations require physicians and clinical testing laboratories to report cases of WNV infection or positive test results to their local public health departments. The local public health departments collect detailed clinical and demographic information and provide this information to CDPH.

Specimens from presumptive encephalitis cases also may be submitted to the California Encephalitis Project, operated by the Viral and Rickettsial Disease

Laboratory Branch (VRDL) of the CDPH. VRDL offers complete diagnostic testing for most agents causing encephalitis, including arboviruses.

Appendix G of the surveillance and response plan provides a national case definition for arboviral disease.

Risk Assessment and Response Levels

The California Mosquito-borne Virus Surveillance and Response Plan contains risk assessment guidelines based on values assigned to different levels of the surveillance components described above. These levels are evaluated annually by agencies cooperating in arbovirus surveillance. Table 10.1 shows assessment values for adult *Culex tarsalis* abundance for WEE. A complete set of tables for WEE, SLE, and WNV as well as the characteristics of conditions and responses for all viruses, can be found in the surveillance and response plan. Again, the entire plan can be downloaded in PDF format from the California West Nile virus website http://westnile.ca.gov.

MALARIA

Before World War II, malaria was endemic in parts of California, especially the Central Valley. Malaria is no longer endemic here, and very few human malaria cases occur as a result of being bitten by infected anopheline mosquitoes in the state. When this does happen, such cases are called "**locally-transmitted malaria**". Nevertheless, several hundred cases of malaria are reported in California every year. Most of these are called "**imported malaria**", because the person is infected in a malarious area elsewhere in the world, and comes down with malaria after his or return to California. These cases are tracked carefully by the CDPH, and when evidence suggests that a rare instance of **imported malaria** has occurred, the cases are investigated thoroughly by epidemiologists. This type of surveillance is called **passive surveillance.**

FILARIASIS

There is no systematic surveillance for canine filariasis (dog heartworm), although researchers have done surveys for infections in dogs and other susceptible vertebrates from time to time. Some studies have been done to incriminate various mosquito species as vectors, but such studies are not done routinely in California.

There are surveillance programs in California for some tick-borne diseases such as Lyme disease. These are covered in other training manuals.

SURVEILLANCE FOR INSECTICIDE RESISTANCE BY MOSQUITOES

Although individual mosquito abatement agencies test populations of important species of mosquitoes for evidence of insecticide resistance, there is presently no statewide surveillance program for this purpose. The desirability of such a program is widely recognized, and efforts have begun to develop one. This would permit recognition of statewide patterns and has the potential of early detection of insecticide treatment failures. This would be a very valuable component of the overall surveillance programs for mosquito-borne diseases.

A surveillance program for insecticide resistance by mosquitoes will require standardization of testing methods, establishment of a central testing laboratory or training of local agency personnel for testing, a method, a means of collecting and analyzing test results on a statewide basis, and means of periodic dissemination of test summaries mosquito abatement district personnel and other public health agencies.

Table 10.1. Mosquito-borne Virus Risk Assessment for WEE based on adult *Culex tarsalis* abundance*

WEE Surveillance Factor	Assessment Value	Benchmark
Adult *Culex tarsalis* abundance Determined by trapping adults, identifying them to species, and comparing numbers to averages previously documented for an area for current time period.	**1**	*Cx. tarsalis* abundance well below average (≤50%)
	2	*Cx. tarsalis* abundance below average (51-90%)
	3	*Cx. tarsalis* abundance average (91-150%)
	4	*Cx. tarsalis* abundance above average (151-300%)
	5	*Cx. tarsalis* abundance well above average (>300%)

***For complete tables refer to California Mosquito-borne Virus Surveillance & Response Plan**

REPORTING AND DISSEMINATION OF SURVEILLANCE RESULTS

Reporting of surveillance results in California has evolved rapidly over the past decade, and the present system is probably one of the best in the nation. It is based on the use of relational databases, computerized mapping, and the World Wide Web.

The intense planning and organizational activities spurred by the invasion of the USA by WNV in 1999 provided funding for a wide variety of activities, including better and faster testing of biological specimens and the reporting of results of this testing to agencies submitting specimens and to the general public. The use of the World Wide Web has been implemented for surveillance reporting through the use of several websites supported by servers and databases of the CDPH and CVEC.

THE WEST NILE VIRUS WEBSITE ([HTTP://WESTNILE.CA.GOV](http://westnile.ca.gov)).

The West Nile virus website (Fig. 10.7) offers extensive information on West Nile and other arboviruses to the public and contributing agencies. It is used not only for supplying information, but also for the reporting of dead birds by the public. The website also provides access to important documents in PDF format, and also archival files of weekly reports of arboviral activity and mosquito abundance data going back many years.

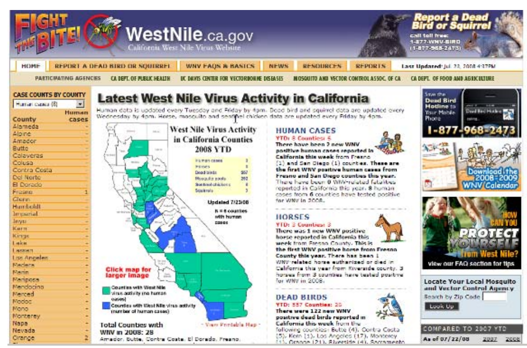


Fig. 10. 7 The West Nile virus website

CALSURV

CalSurv stands for California Vectorborne Disease Surveillance System. It is a new cooperative program of the CDPH, MVCAC, and UC. It was created to provide a platform for the aggregation of surveillance data and reporting of results for all vector-borne diseases, particularly for important diseases such as Lyme disease, Rocky Mountain spotted fever, and plague that heretofore have not had standardized surveillance systems comparable to the arbovirus disease surveillance system. CalSurv also has the responsibility of administrating the electronic surveillance data policy adopted for use by CalSurv activities. In addition to the general objectives of developing standardized methods for surveillance data gathering data and reporting, it provides an umbrella for the California Arbovirus Surveillance Gateway and the CalSurv website.

California Vectorborne Disease Surveillance Gateway (http://gateway.calsurv.org)

The California Vectorborne Disease Surveillance Gateway (Fig. 10.8) uses the World Wide Web for access to its many features by mosquito and vector control agencies in California. Due to the intended audience of this website, the services provided are available only to registered users. It does not contain any public content.

The gateway provides a complete management system for surveillance activities by local agencies. As an example, a user may register and track sentinel chicken flocks, print specimen labels, and reports, and do all the other things concerning maintenance of chicken flock data management that previously had to be done by hand. It also provides for the reporting of mosquito abundance reports and shipping of mosquito pools for testing.

Using this system, individual agencies can maintain multi-year surveillance data that can be downloaded to agency computers in bulk. It also provides for data sharing among local agencies, state entities, and federal bodies. In addition, full mapping and analytical tools for analysis of multiyear data, including the calculation of risk response levels based on the scheme described above, are provided.

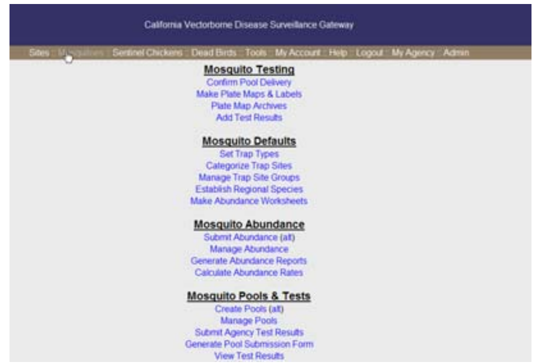


Fig. 10.8 The California Vectorborne Disease Gateway website

CalSurv (http://calsurv.org)

The CalSurv website (Fig. 10.9) is intended primarily for conveying vector-borne disease surveillance information to the general public. The website is based on a content management system, which is a system of software that allows for the assignment of content management to many specialists using access via the Internet. It is organized primarily along groups of vectors, but the menus are cross-referenced by vectors, diseases, and pathogens, making access easier for the public for specific information categories. The website includes interactive mapping for visualization of surveillance information, and even crossword puzzles that are based on questions one might encounter on an examination for certification as a public health insecticide applicator.

Fig. 10.9 The CalSurv website

Chapter 11

PUBLIC RELATIONS IN MOSQUITO CONTROL

Good public relations are an essential portion of all mosquito control programs. Mosquito control personnel must deal with people even more effectively than they deal with mosquitoes. If the public is to cooperate with and support our programs, they must understand what we are doing and why.

The more the public understands a mosquito control agency's efforts, the more cooperation and support the program will receive. This understanding obviously benefits a publicly (tax) funded agency which must enter upon private property in order to carry out its program. Furthermore, the best form of mosquito control is having the public know how not to raise mosquitoes and having them actively participating in monitoring their own properties for potential breeding sources.

Professor Herms of the University of California summed this up many years ago when he said, "The greatest public relations we can have is the involvement of people who thereafter understand and care about our work. When they see you carrying out your work and don't understand, it may be bad public relations."

TYPES OF PUBLIC RELATIONS

Public relations activities can be divided into four basic types:

- Person-to-person contacts (e.g., service requests, telephone calls and letters)
- Mass media activities (e.g., television, radio, newspapers, websites, and exhibits)
- Group contacts (e.g., presentations, tours, committee work and school visits)
- Public official contacts (e.g., local and state legislators made aware of your program)

Although the average field technician will not have the responsibilities or opportunities to engage in all types of public relations activity on a daily basis, the activities of the technician in the field are the most important part of any agency's public relations efforts. For the overall public relations program of an agency to be successful, all four types of activities must be included in an effective, well organized program. Such a program would include (1) the pursuit of good and productive relations with people impacted by mosquito control, and (2) influencing public opinion through two-way communication and acceptable performance.

To inform the general public of our mosquito program, we must make use of the mass media in every form possible to reach large numbers of people. Group contacts allow us to become more personal to the public by letting them see us on their own turf. Alternatively, they could come into our office for a tour to see just how we do things. Our local and state officials can be a great asset to us if they understand our program. They can answer the public's questions about our program or support legislation beneficial to all **vector** control programs.

Each of us becomes the face of the agency to people who know nothing else about it. If we run a red light, smile, frown, behave rudely, dress sloppily, or sound stupid, the agency is regarded to be doing just that. We are communicating something whenever someone sees us. If we endeavor to project a professional image in all encounters with the public and in the manner with which we do our duties, we may communicate a great deal more

PUBLIC RELATIONS OBJECTIVES

The objectives of all public relations programs are to organize information and make it available to the press and public in a manner that will secure their understanding and, one hopes, their approval. A successful public relations program consists of:

- Having meaningful information to present
- Presenting it effectively
- Selecting the best delivery method for the information
- Insuring receptivity by the intended user of the information

PUBLIC RELATIONS APPROACHES

When developing a public relations program, try several approaches and be sure to target all age groups. One wants to influence not only the decision makers of today, but those of the future.

It takes time and energy to create an effective program, but it can be done by either a small, one-person operation or a large fully-staffed organization. One should try to develop as many different approaches as possible and not depend on any one single program.

Consider selecting both types of media channels; controlled and uncontrolled. Controlled media channels are those in which you as the information distributor have some control over the content of messages you convey to the target audience and what messages they receive. Some such successfully used channels include:

- Websites
- Bookmarks
- Brochures
- Informational fact sheets
- Periodic newsletters
- Fair exhibits
- Presentations to students and civic groups
- Class instruction at local schools and colleges.
- Weekly informational column in newspapers.

Uncontrolled media channels such as public service announcements or press releases in local television, newspapers and radio offer the sender little or no control over the message. However, uncontrolled media channels do offer the greatest opportunity to reach the largest possible audiences with a single message.

First, select the target audience. This may be the general public or elementary school students. Next, set your objectives. An objective may be to increase community awareness or increase student knowledge of mosquito biology. Finally, tailor your information to the audience, and select the most appropriate vehicle for its presentation. Vehicles may include: slide presentations, videos, display booths, press kits, school programs, handout kits for mosquito control inspectors, press releases, and program brochures.

Consideration should be given to calling other mosquito control agencies as the plan develops. Many agencies have successful public relations programs from which one can borrow or copy. Time and money can be saved by using material from other programs and fine tuning them to meet individual needs.

THE USE OF WEBSITES FOR PUBLIC RELATIONS

There are few recent developments in public relations that have grown faster or had a greater impact than the use of websites to provide information to the public. While the growth of websites by both private and public entities has been spectacular, their quality and usefulness has been uneven in spite of the available of excellent examples of good websites and effective tools for creating websites.

The obvious penalty a mosquito abatement agency will pay for posting a sub-par website is that eventually fewer and fewer members of the public will visit the website, and then valuable funds will be wasted in creating and maintaining the site.

Some of the negative factors that result in bad websites include:

- Failure to plan the website in terms of purpose and content. This results in providing information of no interest to the public and failing to provide information that the public will be looking for.
- Confusing and non-standard structures for navigation of the website.
- Failing to fully test the site to avoid things like pages that offer no means of escape other than to exit the user's browser (this is a real killer).
- Delegation of the graphic design of a site to a person with little or no artistic talent.

There are companies that specialize in designing and maintaining websites. Although use of personal computers often fosters a "do it yourself" approach to things like website creation, the expenditure of funds for professional help in this area often is cheaper and more effective in the long run.

There are some outstanding websites available on the Internet that represent excellent sources of information in the area of vector biology and control. Providing information in this way is becoming the *de facto* standard for information exchange, and in many ways is vastly superior to mailings of pamphlets to the public, many of which find their way to the trash after a cursory inspection. On the other hand, PDF files of papers that describe mosquito abatement-related subjects are always available to anyone with a computer with a browser installed, and these files can be updated repeatedly without additional expense of re-printing and mailing.

FUTURE TRENDS IN PUBLIC RELATIONS

The need for strong public relations programs has never been more important than it is today. Gaining support for a vector control program is best accomplished by informing the public of the issues and needs of vector control.

As vector control agencies realize the increasing importance of strong public relations programs, more efforts (in the form of manpower, materials and money) are being expended towards that end. These efforts are even leading to a specialized area of control or support technician within some districts - the public relations, public education or information officer.

Just as the personal computer and related equipment have revolutionized mosquito abatement operations in many ways, so do they offer unprecedented new ways of conducting public relations activities related to mosquito abatement. The digital camera, the digital camcorder, teleconferencing systems, and content management systems for websites are just some of the developments that have become available just in the last decade. Certainly, there are more to come.

APPENDIX 1

GLOSSARY

Many of the words defined here have additional meanings. The definitions given here are related to pests, insecticides, and pest management.

A

Active ingredient — The component of a insecticide formulation that kills or controls pests. In other words, the chemical that is responsible for the toxic effect in a formulation.

Acre — Land area of 43,560 square feet; equal to an area 440 feet long by 99 feet wide; approximately equal to a square area 209 by 209 feet; or a rectangle that is 436 by 100 feet. Metric equivalent is 0.405 hectares.

Aestivation — The survival of mosquitoes during hot summer periods.

Anal papillae — The soft fleshy lobes found on the anal segment of mosquito larvae. These lobes are associated with the physiological regulation of water balance in larvae. Species adapted to saline habitats have very small papillae to avoid excess loss of water; freshwater species have large papillae to avoid excess uptake of water.

Antenna — One of the paired sense organs on the heads of insects.

Apical — Refers to the apex, or the position opposite to the base of an insect structure.

Arbovirus — Any virus that is associated with an arthropod. Most are transmitted to vertebrate animals by arthropods.

Area protective measures – Measures applied, usually by a mosquito control agency, that protect many people from mosquito attacks in a given area.

Arthropod — An animal in the Phylum Arthropoda. The name refers to the segmented legs of arthropods. The Phylum includes insects, spiders, crabs. Lobsters, ticks, mites, scorpions, centipedes, and millipedes, among others.

Autogenous — Mosquitoes that demonstrate the trait of Autogeny.

Autogeny — The production of viable eggs by mosquitoes and other blood-sucking insects without the necessity of a blood meal.

B

Bacteria — A group of single-celled microorganisms. Some are pathogens (cause disease) but most fulfill necessary functions in the environment such as breaking down complex molecules into simple ones.

Binomial nomenclature — A system for naming biological organism where each type of organism is given a name consisting of a genus and a species. Example: *Musca domestica*, the common house fly.

Biopesticides — Another term applied to biorational pesticides and insecticides.

Biorational insecticides — Insecticides derived from natural materials as animals, plants, bacteria, and certain minerals. EPA recognizes three categories of biorational insecticides: (1) microbial insecticides, (2) plant-incorporated protectants, and (3) biochemical insecticides. Biorational insecticides are subject to FIFRA regulation, Most biological control agents are not. Also called biopesticides.

Basal — Refers to the base, or the position opposite to the apex of an insect structure.

Binomial nomenclature — The system of naming of biological species where a scientific name consists of a genus and a species name (e.g., *Homo sapiens*).

Biological control — The use of natural enemies to manage pest populations, including mosquitoes. Called biocontrol, for short.

Biorational pesticides — A group of pesticides that are considered relatively non-toxic to humans and are also environmentally safe. The EPA defines biorationals as "certain types of insecticides derived from such natural materials as animals, plants, bacteria, and certain minerals."

Breeding place — A place where mosquito larvae develop. No breeding takes place there in the usual sense of the word, but the expression has been used for more then a century and is not likely to go away any time soon.

C

Calibration — The testing and adjustment of insecticide application equipment to insure a proper application rate.

California encephalitis — A disease of humans first reported in California caused by the California encephalitis virus

CE — The abbreviation for California encephalitis virus, the cause of the disease California encephalitis. CE is a member of the California Serogroup of viruses, so-named because CE was the first virus to be classified in the serogroup.

Chemical — A material with a definite chemical composition. A pure chemical substance cannot be separated into other substances by a process that does not involve a chemical reaction. The material studied by chemists.

Chemical control — The control of pests, including mosquitoes, by the use of chemicals.

Chemist — One who works with chemicals.

Cholinesterase — An enzyme present at nerve junctions in animals and necessary for proper functioning of nerve impulses.

Classification — The process of arranging a series of some kind into groups according to common characteristics. In vector control operations, insecticides, target organisms, application equipment, and laws and regulations are just some of the things that are frequently classified. In insecticide classifications the same material can often be classified into several different groups according to target species, chemical nature, manner of formulation, mode of action, and toxicity.

Common name — A well-known, simple name of a insecticide accepted by the federal and state insecticide regulation agencies.

Competitive displacement — The replacement of one population of organisms by another in a given region, usually because of superior fitness for the particular environment.

Conditioning — A phenomenon in certain *Aedes* mosquito species whereby eggs will not hatch until they have gone though several months exposure to very cold temperatures. This exposure is called conditioning.

Cooperative Agreement — A formal agreement between the California Department of Public Health and mosquito control agencies by which CDPH oversees local vector control agency activities.

Complete metamorphosis — The process of insect development which includes the egg, larva, pupa, and adult stages.

Cross immunity — The protection from infection by a pathogen resulting from vaccination or infection by a related pathogen**.**

Cross resistance — A situation where physiological resistance to an insecticide by an insect population results in resistance to a second insecticide or group of insecticides.

Cuticle — The outer covering (or skin) of an arthropod.

D

Dead-end hosts — In epidemiology, vertebrate hosts that become infected with a pathogen, but do not serve as a source of infection for any additional hosts. This is usually because the dead-end host does not circulate pathogens in the blood in sufficient concentrations to infect new vectors. **y —** In mosquito biology, the number of mosquitoes (usually adults) per unit of area. An example would be 45,000 females per acre. Usually estimated by sampling with traps or other methods.

DEET – The common name for the insect repellent *N*,*N*-Diethyl-*meta*-toluamide

Dermal — Pertaining to the skin.

Developmental transmission — A type of transmission of a pathogen by a mosquito or other vector arthropod in which the pathogen undergoes developmental changes, but does not multiply. Example: the transmission of filarial worms by mosquitoes.

Diapause — In insects, including mosquitoes, an altered physiological state in which certain activities such as bloodfeeding, ovarian development, or flying are suspended. Diapause is often triggered by shortened day-lengths or low temperatures, and terminated by lengthened day-lengths or warm temperatures.

Disease — Any departure from normal health in an organism. A vitamin deficiency is a disease. Infectious diseases are caused by infections with pathogenic microorganisms.

Diurnal — Refers to daytime.

Dorsal — Refers to the uppermost surface of an organism.

E

Ecology — The study of the relationship between a plant or animal and its surroundings.

Ecosystem — A type of biological organization made up of all the organisms in a given area.

Emulsion – A mixture of two unblendable substances. One substance (the dispersed phase) is dispersed in the other (the continuous phase). Examples of emulsions include butter and margarine, and milk and cream. Insecticide emulsions are created with an emulsifying agent.

Encephalitis — A disease characterized by inflammation of the brain.

Encephalomyelitis — A disease characterized by inflammation of the brain and the brain stem.

Endemic — Used to describe a human disease or an organism that occurs naturally in a given area.

Enzootic — Used to describe a non-human animal disease that occurs naturally in a given area

Epidemic — Used to describe a human disease outbreak resulting in an unusually large number of cases.

Epizootic — Used to describe a non-human animal disease outbreak resulting in an unusually large number of cases

Exotic — Refers to anything that is from some other place.

F

Facultative — Refers to phenomena such as diapause or autogeny where the phenomenon is variable depending upon various other factors (also see **obligatory**).

Family — A taxonomic grouping of organisms containing one or more genera.

Fauna — All the species of animals that are present in a given area, e.g., the fauna of Chile.

Flora — All the species of plants that are present in a given area, e.g. the flora of California.

G

Ganglion — A nerve mass in insects, including mosquitoes. Part of the central nervous system.

Genetic control — A modern approach to mosquito control involving altering the genetic makeup of mosquitoes to make them infertile, reduce their ability to transmit human pathogens, or otherwise reduce their potential as pests and vectors. Usually, such genetically-altered mosquitoes are released into the environment in an attempt to "drive" the altered genes into wild populations of mosquitoes.

Genus — A taxonomic grouping of organisms containing one or more species (Plural: genera).

H

Hazard — In toxicology, the risk of poisoning when a material is used. Hazard depends not only on the toxicity of a material, but also on the risk of toxic exposure when used.

Herbicide — A type of pesticide designed to kill weeds.

Hibernation — An altered state of some kind by which insects survive the winter.

Hypersensitivity — A condition in animals in which repeated exposure to foreign antigens (usually proteins) leads to a heightened and sometimes violent reactions to subsequent exposures to the same antigens.

I

IGR — Abbreviation for insect growth regulator.

Imported malaria — A case of human malaria acquired by being bitten by an infected mosquito in an area not in the same general location where symptoms occur and treatment is sought.

Impoundment — An artificial body of water created by damming or diking.

Indigenous — Refers to an organism native to an area. The opposite of exotic.

In apparent to apparent disease ratio — In epidemiology, the ratio of infections that do not produce clinical symptoms to those that do.

Infectious diseases — Diseases of animals or plants caused by infectious of pathogenic microorganisms.

Inorganic – Materials not containing carbon atoms.

Insect growth regulator — A type of biorational insecticide that kills insects by interfering with natural reproductive processes. These are usually synthetic versions of natural insect hormones, such as the juvenile hormone.

Insecticide resistance — The ability of an insect to withstand the lethal effects of an insecticide, usually by a physiological detoxification mechanism controlled by genetic mutations.

Insecticide resistance management — A combination of strategies used in insect control that tend to delay or prevent the development of resistance to certain insecticides.

Integrated Pest Management (IPM) — A system of pest control in which various strategies are used in combination.

Integrated Vector Management (IVM) – A system for control of vectors in which various strategies are used in combination. Many people understand IPM to encompass vector control and do not use the more specific expression of IVM.

J

Juvenile hormone — A naturally occurring biochemical occurring in insects that controls certain processes in metamorphosis. Synthetic versions of this biochemical are used as biorational insecticides.

K

Kingdom — In science, one of three major categories into which natural objects are classified: Animal, Plant, and Mineral. In more recent years, additional kingdoms have been created in biology to accommodate things like viruses and fungi.

L

Label — Printed material attached to or printed on a pesticide container. The content and general format of labels is regulated by the US Environmental Protection Agency.

Labeling — All the technical information provided by the manufacturer of a pesticide, including the label.

Larvae — Immature forms of invertebrate organisms. In insects, the forms that appear after hatching from eggs and before becoming a pupae.

Larvicide — A insecticide used to kill larvae, usually of insects.

LC_{50} — A toxicological term used in pesticide testing that means the concentration required to kill 50% of a group of test subjects. The lower the number, the more toxic the pesticide.

LD_{50} — A toxicological term used in pesticide testing that means the dose required to kill 50% of a group of test subjects. The lower the number, the more toxic the pesticide.

Limiting factor — A factor, either biological or non-biological, that limits the size of a population of organisms. The most common biological factors are parasites and predators, the most common non-biological factors are weather and climate.

Locally transmitted malaria — A case of human malaria acquired by being bitten by an infected mosquito in the same general location where symptoms occur and treatment is sought.

M

Malaria — A disease of humans and other animals caused by protozoan (single-celled animals) parasites transmitted by insects. Human malarial parasites are transmitted by anopheline mosquitoes. Malaria is probably the most important disease in the world. It has been called, with considerable justification, the world's number one killer.

Malpighian tubules — Organs in the abdomen of larval and adult mosquitoes associated with excretion.

Metamorphosis — Changes that an insect goes through during its life cycle. Insects with complete metamorphosis have eggs, larvae, pupae, and adults.

Multivoltine — Many generations per year. *Culex pipiens* is a mosquito that is multivoltine.

N

***N*,*N*-Diethyl-*meta*-toluamide –** The chemical name for the insect repellent commonly known as DEET**.**

Neurohormones — Hormones in insects that are secreted by special glands that are associated with the insect nervous system. Ecdysone is a neurohormones.

Nocturnal — Active during night time. The opposite of diurnal.

Non-target organism — Any organism in an environment that is not the intended target of an insecticide application.

O

Obligatory — Refers to phenomena such as diapause or autogeny where the phenomenon is established regardless of any other factors (also see **facultative**).

Oral — Pertaining to the mouth, as in oral toxicity, the toxicity of a chemical when taken by mouth.

Order — A taxonomic group of organisms containing one or more families.

Organic — Chemical substances containing carbon.

Organochlorines — A class of insecticides contains chlorine groups; includes DDT, chlordane, lindane, and dieldrin. Also called chlorinated hydrocarbons.

Organophosphates — A class of insecticides that contains phosphate groups; includes malathion, parathion, and .

Osmosis — The movement of water across semi-permeable cell membranes from areas of lower concentrations of dissolved ions to areas of higher concentrations. To visualize this, remember that water always seeks to dilute out solutions of ions. A mosquito in pure fresh water will tend towards water uptake; a mosquito in saline water will tend towards water loss.

Oviposition — The laying of eggs by an insect, including mosquitoes.

P

Palpus — In mosquitoes, one of a pair of segmented sensory appendages that arise at the base of the proboscis.

Parasite — An organism that lives on, and at the expense of another organism (called the host). The host may be harmed by the parasite, and if the host is a desirable plant or animal the parasite is also a pest. If the host is a pest, the parasite is a biological control agent.

Parasitemia — The presence of circulating parasites in the blood of a host.

Pathogen — A disease-producing microorganism.

Permeability — The characteristic of membranes and other structures that permits the passage of fluids.

Personal protective measures – The things individuals can do for themselves and their families to protect them from mosquito bites.

Petroleum oils — Insecticides refined from crude oil for use as insecticides.

Phylum — A taxonomic group of organisms containing one or more orders.

Phytotelmata – Bodies of water held by plants. Mosquito larvae often develop in such bodies, especially in the tropics.

Physical control — The management or alteration of physical features of the environment to control mosquitoes. An example is the management of salt marshes in ways that minimize mosquito breeding.

Plasmodium — The generic name for the parasite causing human malaria.

Population — A large group of organisms of the same species living in a geographic area.

Population density — The number of organisms in a population expressed as a number per unit of area. Usually estimated by sampling.

Posterior — Situated behind. The opposite of anterior.

Predator — An organism that devours another organism for food. Predators are almost always larger then their prey; parasites are usually smaller.

Prism (tidal) — The total volume of water flowing in and out of a tidal marsh by tidal action.

Proboscis — In mosquitoes, a bundle of individual structures called stylets that are bound together to form a snout. The proboscis is the structure involved in bloodfeeding.

Propagative transmission — A type of pathogen transmission by mosquitoes and other arthropod vectors in which the pathogen multiplies within the vector but does not undergo any changes in developmental form. Example: the transmission of arboviruses by mosquitoes.

Propagative-developmental transmission — A type of pathogen transmission by mosquitoes and other arthropod vectors in which the pathogen multiplies within the vector and undergoes changes in developmental forms. Example: the transmission of malarial parasites by mosquitoes.

Pupa — An insect form that occurs after the final larval stage and before appearance of the adult form in insects having complete metamorphosis (flies, beetles, butterflies and moths, wasps, etc.) Pupae are usually non-feeding, and sometimes immobile (mosquitoes are an exception).

Pyrethrin — The insecticidally-active chemical component of pyrethrum insecticides. Both the active ingredient and the insecticide are sometimes called pyrethrins. The correct usage would be to refer to the former as pyrethrin, the latter as pyrethrum.

Pyrethroids — Synthetic compounds produced for their chemical resemblance and insecticidal similarity to pyrethrin.

Q

Quinine – An anti-malarial drug prepared from the bark of the *Chinchona* tree. One of the oldest treatments for malaria known, it is still effective, especially against malarial strains resistant to other drugs.

R

Reproductive potential — The maximum reproduction possible in a population in the absence of limiting factors. Reproductive potential is never reached in mosquito populations.

Riparian — Refers to rivers, as in riparian habitat.

S

Saint Louis encephalitis — The human disease caused by infection with St. Louis encephalitis virus (SLE).

Salivarian transmission — A type of transmission of disease pathogens by insects in which pathogens are introduced into vertebrate hosts by blood-feeding insects by the injection of infected salivary fluids.

Salivary glands — A set of glands located in the thorax of larval and adult mosquitoes. These glands contain substances that aid in feeding. In adult mosquitoes the transmission of various pathogens result from injection of infected salivary fluids.

Selection pressure — In population genetics any biological or non-biological factor that tends to affect a segment of a population with a certain genetic makeup more than another segment with a different genetic makeup.

Selective — The characteristic of insecticides that are highly specific for certain organisms, and harmless to others.

Sequelae — A term used to describe a pathological situation where infections with a pathogen result in signs and symptoms occurring significantly later than the original infection**.**

Sexual dimorphism — The situation in biological organisms such as mosquitoes where there are significant differences in form between males and females.

Sibling species — Species which satisfy the definition of separate species, but are virtually indistinguishable morphologically. *Culex pipiens* and *Culex quinquefasciatus* are sibling species.

Sign — Evidence of exposure to a dangerous pesticide or other disease process in a plant or animal that is observable by a person other than the plant or animal affected. In people, signs are observable by others even if the person affected is unconscious. In other animals and in plants, only signs are available as evidence of poisoning or illness. Compare to *Symptom.*

SLE — The abbreviation for the St. Louis encephalitis virus.

Species — A group of populations of potentially interbreeding living organisms. Since passage of the endangered species act, the definition has been broadened to consider a population having some demonstrable stable difference from another population as a species in the legal sense, even if the populations are potentially interbreeding.

Spermathecae — Structures in the abdomens of female mosquitoes in which sperm is stored. Most culicines have 3 spermathecae, anophelines have but one.

Stadium — The time between two successive molts in insects.

Stage — Nearly synonymous with stadium.

Stagnant — In reference to water, non-flowing.

Surveillance — The monitoring, or close watch, over something. In mosquito control, over mosquito-borne disease cases or mosquito population sizes.

Symptom — A feeling of unhealthiness that can be expressed by a person. It may represent a warning of pesticide poisoning. Plants cannot display symptoms, and most animals cannot display them in a readily recognizable form. Reasonable people will disagree on the question of whether non-humans can show symptoms at all, and the word symptom is often misused for "sign".

Synergist – Materials that are not necessarily pesticidal by themselves but have the effect of increasing the toxicity of insecticides with which they are mixed

T

Target organism — The organism against which a control effort is directed. In this manual, a mosquito or a weed.

Tolerance — As applied to pesticides, the legal limit of the amount of pesticide that may remain in or on foods marketed in the USA. Tolerances are established by EPA, and enforced and monitored by FDA.

Toxicity — The inherent poisonous potency of a material. Toxicity is expressed in quantitative terms such as LC_{50} (lethal concentration-50, the concentration at which a material will kill 50% of some reference organism.)

Trachea — In insects, one of the major tubes that conduct air throughout the body of an insect. Plural form is “tracheae”.

Tracheole — In insects one of the fine tubules that branch off at the end of tracheae.

Transovarial transmission — The transmission of microorganisms from parent to offspring via infected eggs of an arthropod vector.

U

ULV — Ultra low volume. An application of a insecticide at a rate of less than ½ gallon per acre (5 liters per hectare). Because the volumes be sprayed are so small, extremely low doses of insecticide result, even when the insecticides are sprayed undiluted.

Univoltine — An insect that has only a single generation per year. *Aedes tahoensis* is a univoltine species.

V

Vector — A vehicle for transporting a disease-producing organism (pathogen) from one host to another. In vector ecology, the most common vectors are insects and other arthropods. Vectors can transfer pathogens from one animal to another, and from one plant to another.

Ventral — The underside of something. The opposite of dorsal.

Viremia — The presence of circulating virus in the blood of a host.

Virus — A microorganism that can grow and reproduce only in living cells of other organisms. Often, viruses cause diseases in their hosts and are then pathogens.

W

WEE — The abbreviation for western equine encephalomyelitis virus, the virus that causes the disease western equine encephalomyelitis.

West Nile fever — One of the diseases caused by WNV.

West Nile neuroinvasive disease — One of the diseases caused by WNV.

Western equine encephalomyelitis — The disease cause by WEE.

WNV — The usual abbreviations for West Nile virus.

X

Xenobiotic — Any substance foreign or strange to life, like synthetic insecticides such as DDT.

Y

Yolk — Substance within the eggs of mosquitoes providing nutritional material for development of embryos.

Z

Zoogeography — The study of the geographic distribution of animals, including mosquitoes.

APPENDIX 2

CONVERSIONS OF UNITS AND FORMULAS USED WITH INSECTICIDES

CONVERSIONS

Length

1 mile (mi) = 1.609 kilometer (km)
1 km = 0.621 mi
1 meter (m) = 1.904 yards
1 centimeter (cm) = 0.394 inches (in)
1 in = 25.4 mm
1 micron (mµ) = 0.001 mm
1 mµ = 1/25,000 in

Speeds

1 mile/hour (mph) = 1.609 kilometers/hour (km/h)
1 mph = 0.447 miles/second (mps)
1 km/hr = 0.621 mph

Area

1 acre (ac) = 0.405 hectares (ha)
1 ha = 2.471 ac
1 ac = 43,560 ft^2

Liquids

1 fluid ounce (fl oz) = 0.0296 liters (l)
1 pint (pt) = 0.473 l
1 pt = 16 fl oz
1 gallon (gal) = 3.785 l
1 gal = 128 fl oz
1 pound (lb) = 0.454 kilogram (kg)
1 liter (l) = 33.81 fl oz
1 l = 2.113 pt
1 l = 0.264 gallons (gal)

Weight

1 ounce (oz) = 0.0283 kg
1 kg = 2.205 lbs

APPLICATION RATES

1 oz/ac = 0.070 kg/ha
1 meter/sec = 2.24 mph
1 l/ha = 13.69 fl oz/ac
1 l/ha = 0.855 pts/ac
1 kg/ha = 0.898 lb/ac
1 kg/ha = 14.27 oz/ac

FORMULAS

Gallons per acre = (5,940 x gallons per minute/nozzle)/(mph x nozzle spacing)

Gallons per minute per nozzle = (gallons per acre x mph x nozzle spacing)/5,940

Ounces per minute per nozzle = (gallons per acre x mph x nozzle spacing x 32)/1,485

Mph = distance traveled (ft)/(88 x minutes)

Mph = distance traveled (ft)/(0.47 x seconds)

APPENDIX 3

ADDITIONAL INFORMATION

WRITTEN MATERIALS

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WEBSITES

Press <Ctrl> then click to go to website or cut and past addresses into your browser

California Department of Insecticide Regulation.
http://www.cdpr.ca.gov/

California Department of Public Health, Vector-Borne Disease Section
http://www.cdph.ca.gov/programs/vbds/

California Department of Toxic Substances Control Program (DTSP). A program of Cal/EPA
http://www.dtsc.ca.gov/

California Environmental Protection Agency (CAL/EPA)
http://www.calepa.ca.gov/

California Vectorborne Disease Surveillance Gateway
http://gateway.calsurv.org/

CalSurv Website
http://www.calsurv.org/

United States Environmental Protection Agency Insecticide Website:
http://www.epa.gov/insecticides

West Nile Virus Website
http://westnile.ca.gov/