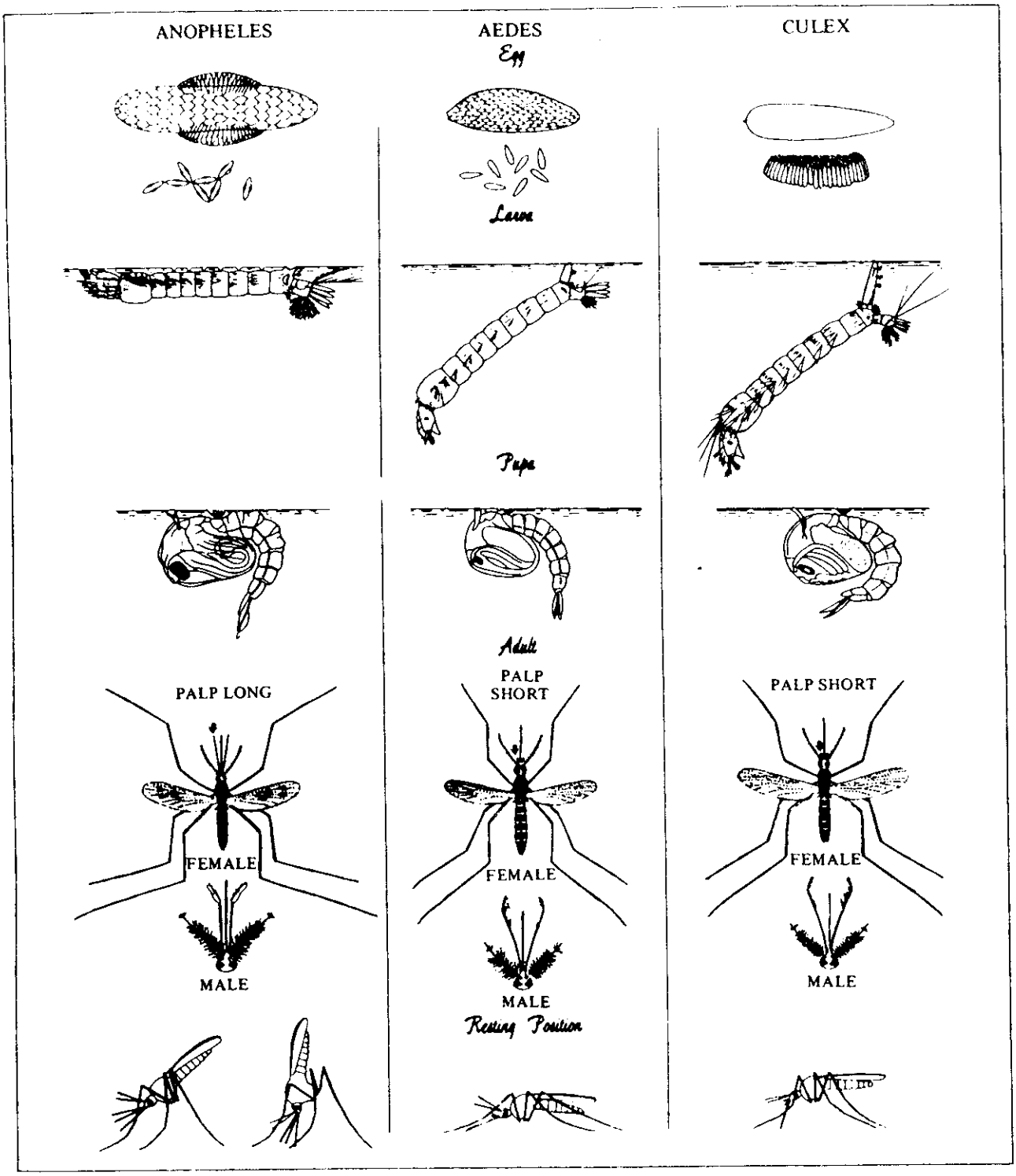

Figure 4. Characteristics of Anophelines and Culicines
(Kent S. Littig and Chester J. Stojanovich)

hatching occurs, usually after only a few days.

Eggs that are not laid on water must be placed so that the larvae can readily reach water or they must be able to survive long periods of drying until they are flooded. The eggs of *Aedes aegypti, Ae. triseriatus*, and *Orthopodomyia* are laid on the sides of containers or tree holes just above the water level. With a rise in the water, the eggs hatch. Other species of *Aedes* and all species of *Psorophora* lay their eggs on the ground where they remain until flooded. The eggs of some species can survive for 3 to 5 years if flooding does not occur. In some cases eggs hatch as soon as they are flooded; thus, there can be several generations a year. This is typical of the *Psorophora* group and of *Ae. vexans* and *Ae. sollicitans*. Eggs of some other species must be subjected to freezing before they will hatch; thus, there can be only a single generation per year. Many species of *Aedes* belong in this group; examples are *Ae. stimulans* and *Ae. abserratus*.

Larvae

The larvae of all mosquitoes live in water, permanent ponds and marshes, temporary flood waters or woodland pools, water contained in tree holes, leaves of plants, or artificial containers. Mosquitoes have adapted themselves to almost all kinds of aquatic situations except flowing streams and the open waters of large streams, lakes, and seas. Although mosquito larvae get their food from the water in which they live, they must come to the surface for air or, as in the case of *Mansonia*, or *Coquillettidia*, obtain air from the underwater portions of plants.

The larval period includes four developmental instars, or stages, which collectively require at least 4 days for completion, often one to two weeks, the time of development being controlled by such factors as water temperature and food supply. At the end of each instar the larva molts--sheds its skin. The fourth instar is the last larval stage, and the fourth molt produces the pupa.

Mosquito larvae move about in two ways, by jerks of the body and by propulsion with the mouth brushes. Movements of anopheline larvae at the surface are generally of the first type. The "crawling" movements of culicine larvae over the bottom and the slow movement at the water surface are probably due to propulsive action of the mouth brushes. Mosquito larvae assume characteristic positions in the water. Anopheline larvae lie parallel to the surface, while most other groups hang head down with only the tip of the air tube penetrating the surface film. Although larvae are heavier than water, they can rest just beneath the surface without muscular effort. Certain nonwetting structures, such as the air tube in the culicines and the spiracular plate and the palmate hairs in the anophelines, suspend the larvae from the water surface film.

Mosquito larvae are affected by light and by water conditions including temperature and movement, as well as by the dissolved gases and salts, and other living organisms present in their water habitat. Vegetation is important as protection for the larvae. Predators such as fish and insects destroy great numbers of mosquito larvae.

The three body regions, head, thorax, and abdomen are distinct (Fig. 5).

The **head** bears the antennae, eyes, and mouthparts. The antennae are located on each side toward the front. Behind the antennae near the hind margin of the head are the eyes. The mouthparts are at the underside of the head near the front. They consist of a series of brushes in addition to the grinding and grasping structures. Thus, the larva is able to strain out small aquatic organisms and particles of plant and animal material present

in the water. A few predaceous species have mouthparts adapted for grasping and swallowing their prey.

The **thorax** is broader than head or abdomen and somewhat flattened. It has several groups of hairs which are useful in identification of species.

The **abdomen** is long and subcylindrical, consisting of ten segments. The first seven segments are similar, but the eighth, ninth, and tenth are considerably modified. Anopheline larvae have float hairs, called palmate hairs, on some of the abdominal segments; culicine larvae do not have palmate hairs. The eighth segment bears the respiratory apparatus. In anophelines this consists of a spiracular plate with two spiracular openings. In culicines these openings are at the tip of a siphon, or air tube. The tenth segment is out of line with the other segments and bears two or four membranous, tapering appendages known as anal gills. These anal gills serve more for the regulation of osmotic pressure than for respiration (Fig. 5).

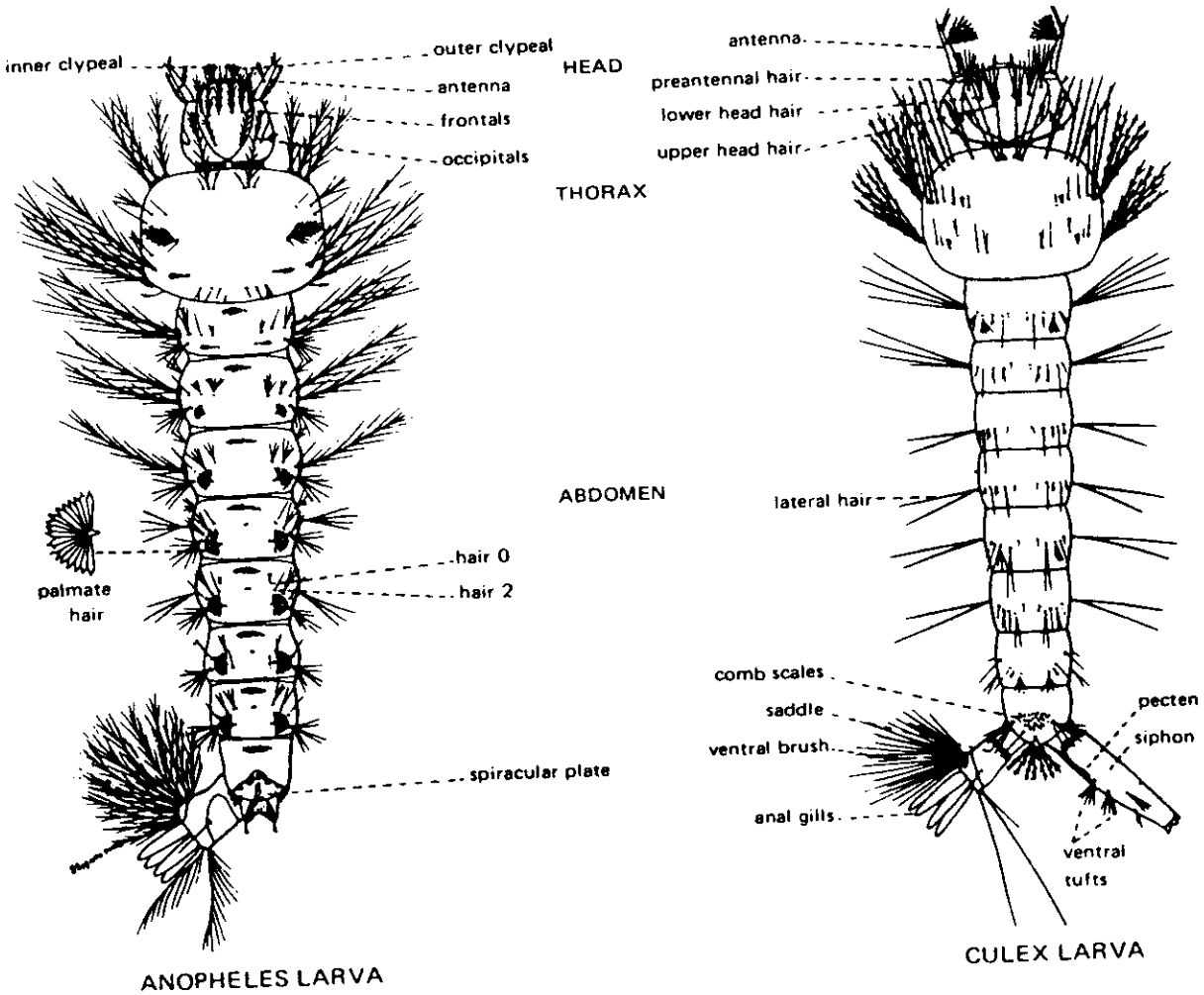

Figure 5. Fourth Stage *Anopheles* and *Culex* Larvae

Pupae

The mosquito pupa also lives in water and is very active. It does not feed, but must come to the surface for air except in the case of *Mansonia* or *Coquillettdia spp.* The pupa differs greatly from the larva in shape and appearance.

The head and thorax are greatly enlarged and enclosed in a sheath. On the upper surface is a pair of respiratory trumpets. The abdomen consists of eight freely movable segments with a pair of paddles at the tip.

Mosquito pupae are probably the most active of all insect pupae. Most species are lighter than water, their buoyancy being due to an air space between the wing cases on the underside of the combined head and thorax. By vigorous movement of the abdomen the pupae move about with considerable speed, rising directly to the surface when movement stops.

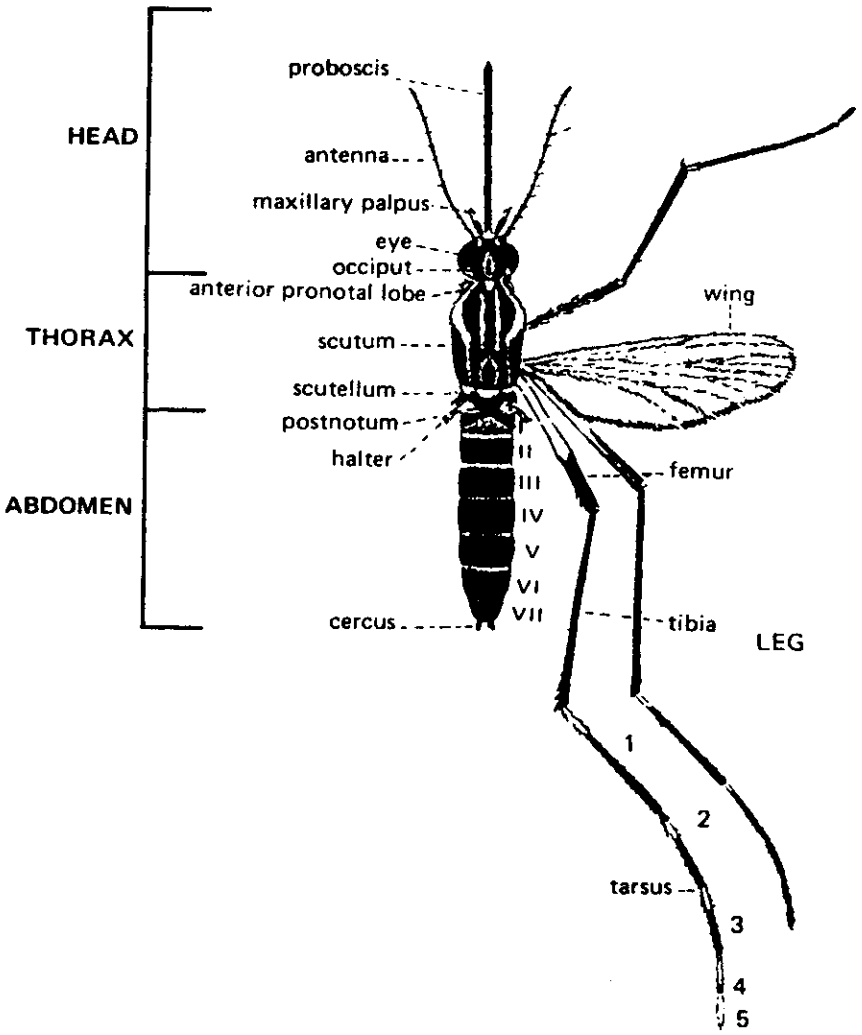

Figure 6. Diagram of Female Mosquito

The pupal stage lasts from one day to a few weeks, no species being known to pass the winter as pupae. At the end of the pupal stage, the pupal skin opens and the adult works its way out, crawls onto the surface of the water, and is soon ready to fly away.

Adults

The adult mosquito (Fig. 6) is a small fragile insect with a slender abdomen, one pair of narrow wings, and three pairs of long, slender legs. It varies in length from slightly over 1/16 inch to about 1/2 inch (2-15 mm). The three body regions, head, thorax, and abdomen are well-defined.

The head of a mosquito (Fig. 6) is almost spherical and is joined to the thorax by a narrow membranous connection. It bears a pair of large-compound eyes, a pair of antennae, a pair of palpi and a proboscis. The antennae arise on the front of the head between the eyes. They are long slender structures consisting of 15 segments only 14 of which are ordinarily visible. Each of the last 13 segments bears a whorl of hairs which are short and sparse in the females, but long and bushy in the males. The antennae are believed to serve as organs of hearing and smell. The palpi are five-segmented structures originating at the lower front margin of the head near the proboscis. In anophelines the palpi of the female are about as long as the proboscis, while those of the male are enlarged at the tip (Fig. 4). In culicines the palpi of the females are short, while those of the male are usually long, densely haired, and pointed. The proboscis projects downward and forward from the lower front margin of the head. It consists of a labium or sheath-like structure enclosing a group of six stylets. The labium serves as a protective sheath for the stylets but does not pierce the skin when the mosquito is biting. The stylets penetrate the skin of the host animal and form a small duct through which saliva is injected into the wound and a canal through which liquid food is ingested. The mouth-parts of the male are incapable of piercing the skin of humans or animals.

The **thorax,** or middle region of the body, bears the wings and legs. The upper surface of the thorax or scutum is covered with coarse hairs or scales which are variously colored. These color patterns are often useful in identification of species. The sides of the thorax may be clothed with scale patches and bear several groups of hairs or bristles, which are useful for identification. The long, slender legs arise from the lower sides of the thorax. Each leg consists of a short conical coxa, a small hinge-like trochanter, a stout femur, a long slender tibia, and a 5-segmented tarsus. The first segment of the tarsus is the longest and is often equal in length to the tibia. The fifth tarsal segment bears a pair of small claws. The legs are covered with dark or colored scales that form patterns which are often useful in separation of species. The wings are long and narrow with characteristic venation. The veins are clothed with scales, often of varying colors which may be distributed to form definite patterns, sometimes useful in identification. The hind margin of the wing also bears a close-set row of long, slender, fringe scales. Two small knobbed structures known as halteres are located behind and slightly below the wings. The halteres vibrate rapidly when the mosquito is in flight and serve as organs of equilibrium.

The elongate, nearly cylindrical **abdomen** consists of ten segments, only eight of which are readily visible. The ninth and tenth segments are greatly modified for sexual functions. North American species of *Anopheles* usually have no scales on the upper surface of the abdomen. In the culicines, the abdomen is covered with scales which often form characteristic markings. In *Aedes* and *Psorophora,* the female abdomen is tapered

apically, with the eighth segment withdrawn into the seventh (Fig. 7). In other genera in the United States the abdomen is bluntly rounded at the apex. The terminal segments of the male abdomen are greatly modified for mating and are of value in identification of the species.

HABITS OF THE ADULT MOSQUITOES

About equal numbers of male and female mosquitoes are produced. The males ordinarily emerge first, remaining near the larval habitats and mating with the females soon after their emergence. Only the females bite and most (but not all) species require a blood meal before they can lay fertile eggs. The female tends to travel greater distances and appears to live longer than the male.

Flight habits vary considerably. *Aedes aegypti,* probably the most domesticated of all mosquitoes, breeds primarily in and around human habitations and flies short distances, usually a "block" or about 200 yards. Most anophelines have a maximum flight range of about 1 mile. However, other species such as *Ae. vexans* and *Ae. sollicitans* can fly 10 to 20 miles or more.

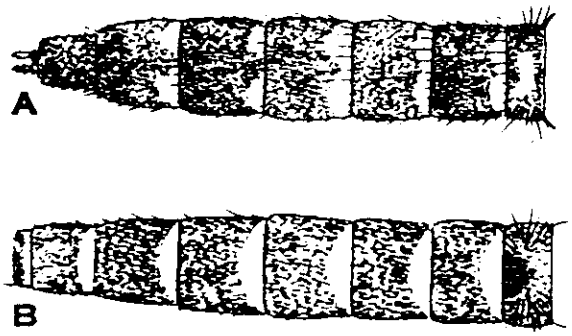

Figure 7. A. Pointed Abdomen of *Aedes*. B. Blunt Abdomen of *Culex*.

Mosquitoes also show considerable variation as to their preferred sources of blood meals. Some species by preference feed on birds or domestic animals such as cattle or horses, while others seem to prefer man. Because these preferences are not exclusive, a species will accept an alternate available host, which accounts for the transmission of encephalitis viruses from birds to humans or horses and of the yellow fever virus from monkeys to humans. A few species, which are not involved in human disease transmission, feed only on cold-blooded animals or subsist entirely on nectar or plant juices. Some mosquitoes feed entirely during the daytime while others may be active only during the evening or at night. The female mosquito requires two or more days to digest a blood meal, lay a batch of eggs, and then seek another blood meal. This cycle of feeding, laying eggs, and feeding again can be repeated many times in the life of a single female. Only one mating by the female is generally required to fertilize her lifetime egg production. The life span of adult mosquitoes is not well known. Some species apparently live one or two months during the summer. Adults that hibernate can live for six months or more.

A knowledge of the mosquito life cycle helps in understanding the epidemiology of mosquito-borne diseases. The transmission, for example, of arboviruses or the malaria parasite depends not only on an initial blood meal from an infected host and a subsequent feeding on the victim, but also requires a period of maturation of the infection in the mosquito, perhaps a week or more for the viruses and about 10 to 20 days for malaria. Once the mosquito becomes infective, she may often remain so for her lifetime, with the potential for transmitting the infection each time she feeds on a susceptible host. Thus, a knowledge of the frequency of feeding, the selection of hosts, life span, flight range, seasonal occurrence, and many other factors are important in disease epidemiology.

ECOLOGIC AND BIONOMIC TYPES OF MOSQUITO LIFE HISTORIES

For practical purposes, the numerous species of mosquitoes can be grouped on the basis of similarities in their larval habitat preferences which generally reflect other important aspects of their bionomics and ecology, e.g., oviposition habits, developmental patterns, brood patterns, seasonal density and dispersal. A convenient grouping of species includes: (1) The permanent pool group, (2) the transient water group, (3) the floodwater group, and (4) the artificial container and tree-hole group.

The Permanent Pool Group

Mosquito species belonging to this group are generally found in fresh bodies of quiet water exposed to sunlight and containing an abundance of surface vegetation and flotage at the air-water-plant interface. Typical habitats are shallow margins of ponds, lakes and smaller impoundments, the main characteristic being a degree of permanency. Such habitats are particularly suitable for *Anopheles spp.*, *Culex (Melanoconion) spp.*, *Cx. salinarius, Cx. territans, Coquillettidia spp.*, and *Mansonia spp.*

The mosquito species inhabiting permanent waters deposit their eggs on the water surface, singly in the case of *Anopheles,* and in rafts in the case of *Culex, Coquillettidia,* and *Mansonia,* with some variation in place of oviposition in the latter genus. Such sites are sheltered from wave action and are always in the presence of vegetation suitable for larval attachment or protection. Larval production is generally continuous in these species with several generations per year. Most *Anopheles* and *Culex* overwinter as adult females, but some, e.g., *Ae. walkeri,* may overwinter in the egg stage, while *Mansonia* and *Coquillettidia* overwinter as larvae attached to roots of plants. Except for *Coquillettidia* and *Mansonia,* the effective flight ranges of permanent pool species are relatively short, usually within a mile or so of the breeding area.

The Transient Water Group

The members of this group are mostly *Culiseta spp.*, some *Culex* and occasionally *Anopheles.* Their habits are similar to those in the permanent pool group, but they seem to be more often associated with pools of a temporary nature as opposed to species with an affinity for ponds and lakes. Typical sites are roadside ditches, borrow pits, canals, ground pools, clogged
streams, irrigated lands, etc. Some species associated with such habitats include *Culex pipiens quinquefasciatus, Cx. tarsalis, Cx. restuans, Culiseta inornata* and *Culiseta melanura.* If water remains sufficiently long, anophelines frequently become established in late season, particularly such species as *An. albimanus, An. punctipennis* and *An. pseudopunctipennis.*

The Floodwater Group

The floodwater species of mosquitoes of the genera *Aedes* and *Psorophora* generally deposit their eggs singly on damp soil in grassy or woodland depressions or along vegetated shorelines that are intermittently flooded. Salt-marsh mosquitoes are also included in this group. When flooded after a period of desiccation, the eggs hatch if conditions (temperature, pH, oxygen concentration, etc.) are favorable; otherwise, the eggs may remain dormant and viable on the soil until a more favorable inundation. Typically, large numbers (broods) are produced at a hatching; larval development is uniform; and adults may appear as early as six days after flooding. Some species produce a

single brood, particularly *Aedes* in northern areas, while many species of *Aedes* and *Psorophora* produce multiple broods in a given year. They overwinter in the egg stage. These species are particularly troublesome as pests and some characteristically fly long distances from larval habitats, e.g., 5-20 miles in the case of *Aedes sollicitans, Ae. dorsalis,* and *Ps. columbiae;* the woodland species such as *Ae. atlanticus/tormentor* and *Ps. ferox* tend to remain near the larval habitat. Some important vectors and pest species in this ecologic group are *Aedes sollicitans, Ae. taeniorhynchus, Ae. atlanticus/tormentor, Ae. thelcter, Ae. dorsalis, Ae. nigromaculis, Ae. vexans, Psorophora ferox* and *Ps. columbiae.*

The Artificial Container and Tree-Hole Group

Characteristic of this group are members of the genus *Aedes,* with specialized habits, the more important being *Ae. aegypti, Ae. triseriatus,* and *Ae. sierrensis.* Eggs are laid singly on the inside wall of the container, at or above the waterline, and hatch when inundated after a period of desiccation. Overwintering is in the egg stage and there are multiple broods.

Aedes aegypti and *Ae. albopictus* normally lay their eggs in artificial containers, whereas *Ae. triseriatus* and *Ae. sierrensis* females usually oviposit in natural cavities containing water, such as tree holes, but their larvae are frequently found in artificial containers with heavy sediment or decaying leaves.

This group includes not only the important *Aedes* species mentioned, but species of *Toxorhynchites* and *Orthopodomyia* as well, none of which are troublesome to man.

Although not included in this group on the basis of ecology and bionomics, females of the *Culex pipiens* complex often oviposit in artificial containers of all types, particularly those rich in organic matter.

Because of the association of artificial containers with human habitations and disease implications, *Aedes albopictus, Ae. aegypti,* and *Culex pipiens quinquefasciatus* all may become locally abundant and annoying, and are important targets of urban mosquito control campaigns.

This manual will concentrate on characterization of species which have known potential importance as disease vectors, as well as some of the more commonly found non-vector species which may occupy the same habitats and are important because of their abundance or noxious habits. However, it is not feasible to describe all mosquito species which will be encountered in vector surveillance. Identification of mosquitoes to species requires considerable knowledge of morphologic characteristics which are needed for separation of genera and species. Simple keys are appended at the end of the Manual which will assist in separating the genera found in the United States and in identifying some of the more common species. For mosquito survey and surveillance activities in any given region or locality, state or regional keys should be used, and simple keys can be devised to facilitate identification of both commonly found and target vector species. Virus associations of the mosquito species discussed have been taken from numerous sources particularly the 5 volumes, "The Arboviruses: epidemiology and ecology" edited by T. Monath (1988), Reeves (1990), Sudia *et al.* (1971), Calisher and Thompson (1983), and Tsai (1991).