Deforestation

Forests are disappearing at an alarming rate in Thailand. Forest cover has dropped from a little over 50% of the total land area of the country in 1960 to about 18% in 1990 (Ganjanapan, 2000). A great loss of forest cover was caused by concessions provided by logging companies that made it easier for villagers to clear forested areas to produce cash crops. In addition, an increase in the amount of land for resettlement projects has significantly altered the environment in several areas. Due to the extent of deforestation, the Royal Forest Department has begun to pay more attention to the conservation of the forests. Many areas are now protected – these include national parks, wildlife sanctuaries, and watershed areas.

Bionomics

There are a number of biological, physical, and chemical factors that must be considered when conducting surveys for both adult and immature mosquitoes. Although there are numerous unique factors that can influence the collection of specific species, some of the common factors to be considered when conducting mosquito surveillance are discussed below.

a. Factors affecting mosquito distribution

The following factors commonly affect adult mosquito distribution:

- Association with specific biogeographical regions
- Terrain
- Seasonality
- Elevation
- Temperature
- Abundance and types of vegetation
- Daily activity/feeding patterns (diurnal or nocturnal)
- Blood host abundance
- Host specificity or the use of certain specific collection methods
- Abundance of and proximity to larval habitats

The following factors commonly affect larval mosquito distribution:

- Association with specific biogeographical regions
- Terrain
- Elevation

- Shade
- Water permanency
- Water condition (putrid, fresh, brackish, polluted, turbidity, *etc*)
- Water movement
- Water temperature
- Aquatic vegetation (emergent, submerged, floating, algae, *etc*)
- Type of water source (artificial container, natural container, *etc*)
- Influence of animals (crabholes, buffalo wallows, footprints, *etc*)

b. Adult behavior

There are many aspects of mosquito behavior to be considered when studying and collecting adults. Knowledge of the natural host of species is very important. Some mosquitoes feed only on birds, mammals, amphibians or reptiles, while others will feed across the range of these hosts. Unfortunately, the feeding behavior and host preferences of many mosquito species is not known, primarily because they have never been (or are rarely) collected as adults. Females of most species require a blood meal to produce eggs, while others can produce at least one batch of eggs without a blood meal, and a few never require a blood meal. The ability to oviposit viable eggs without a blood meal is called autogeny, and is apparently more common in species residing in desert or semi-desert regions, probably an adaptation to less frequent mosquito-host contact. Most mosquitoes in the wet tropics and subtropics are anautogenous and require a blood meal for egg development and deposition. Other important adult mosquito behavioral traits include:

Female horizontal dispersal. Female mosquitoes have species-specific flight ranges. Some species will only fly short distances from their larval habitats and shaded areas (usually container-breeding *Aedes* and *Ochlerotatus*, or deep forest species), whereas others (many *Anopheles* and *Culex* species) will fly several kilometers from their immature habitats to find a blood source. When collecting adult mosquitoes for the detection of pathogens *(eg, Plasmodium* sporozoites or dengue virus infections), it is normally advisable to collect near the source of the blood-meal rather than adjacent to the larval habitats, because females in these latter areas are more likely to be freshly hatched and unexposed to pathogens. This is normally more important with *Anopheles* and *Culex* mosquitoes than with *Aedes* species. Horizontal dispersal via transportation by humans is also very important in the continuing spread of many species (Belkin, 1962). Although most human-assisted horizontal dispersal of mosquitoes involves the transport of eggs

or immature stages, many adults are also transported to other areas within a country, to other countries, or even to other continents by means of cars and/or air and ship transport.

Female vertical dispersal. Female mosquitoes have species-specific vertical dispersal patterns. Many species will selectively feed on hosts located at certain heights above the ground or will lay their eggs in certain vertically placed habitats. Knowledge of vertical preferences can often help in determining whether a given species is likely to serve as a vector of bird or mammal (zoonotic) pathogens to humans.

Female biting patterns (diurnal, crepuscular, and/or nocturnal behavior). Mosquitoes vary greatly in their daily activity. A number of species are primarily diurnal (*eg, Aedes* sp); however, most mosquitoes in Thailand are most active during the crepuscular and nocturnal periods. Certain species have distinct feeding/activity periodicity; for example, some species primarily bite in the early evening (*ie, Anopheles maculatus*), whereas others have a peak biting period after midnight. Many day-biting species preferentially feed during the early morning or late afternoon hours when outside, but will bite all day indoors. Other species may only feed during the crepuscular periods (evening and morning).

c. Larval habitats

The importance of the larval habitat cannot be over-emphasized. Although the term 'larval habitat' is widely used, a more accurate description is the 'oviposition site', as the actual site of larval development that results from habitat selection made by the gravid female. Many species of mosquitoes are 'generalists' in their selection of habitats, whereas others are 'specialists'. The former may distribute their eggs in a wide variety of habitats, while the latter will utilize only one to several unique habitats for oviposition. Surveillance for species with unique larval habitats is dependent upon a clear knowledge of the specific habitat. Mosquitoes that are 'generalists' nearly always include the species that function as vectors of human pathogens, whereas the 'specialists' are usually less common species that rarely or infrequently come into contact with humans. The latter species are those that are most affected by human alterations of the environment, and are usually the first to disappear from an area after logging, cultivation, or development. The 'generalists' are species that are able to survive in a wide range of habitats and are very abundant over wide areas. These are the species that have been or are becoming major threats to human health through their rapid transport around the world, *eg, Anopheles*

gambiae Giles*, Aedes aegypti* L.*, Ae. albopictus* (Skuse)*, Ochlerotatus japonicus* (Theobald), *Culex pipiens* L., and *Culex quinquefasciatus* Say.

There are several basic categories of habitats that female mosquitoes use for oviposition. These can be divided into container habitats and ground water habitats. Container habitats consist of either natural containers (such as rock pools, treeholes, holes in stumps, plant axils, plant flowers, shelf fungi, fallen leaves, various natural bamboo habitats, coconut husks and shells, beetle and woodpecker holes in trees, *etc*) or artificial containers (such as tires, bottles, buckets, earthen water storage jars, barrels, cans, cups, plastic containers, man made bamboo cups, concrete pools and water storage tanks, *etc*). Ground water habitats include streams, rivers and lakes, fresh and saltwater crabholes, ground pools, freshwater marshes and swamps, salt marsh habitats, and numerous others to include footprints, wheel ruts, *etc.* These different habitats can hold permanent, semi-permanent, or temporary water.

A list of the different types of larval habitats associated with each genus and subgenus of Culicidae that occur in Thailand is presented in Table 4 (modified from Rattanarithikul, 1982). Certain species in a given genus or subgenus of Thailand mosquitoes may occur in container habitats, whereas other species in that genus or subgenus may occur in ground water habitats. This overlapping of the two basic habitat types within a given genus or subgenus is common, but caution must be used in interpreting habitats recorded on collection records. For example, flooding streams can suck crab-hole species out of their specific habitat so that they are collected down-stream in a completely unnatural habitat, and larvae can be flushed out of container habitats and end up in ground water habitats. Genera and subgenera of Thai mosquitoes that have species overlapping in these two basic immature habitats include *Anopheles*, *Aedes* (*Diceromyia* and *Stegomyia), Armigeres, Culex (Culex, Culiciomyia,* and *Eumelanomyia), Ochlerotatus (Finlaya), Toxorhynchites, Uranotaenia,* and *Verrallina*.

Natural container habitats are most common in forested or recently forested areas of Thailand. However, other areas where natural containers are commonly found include regions where trees have been cut and logs/stumps are still numerous, and on islands or coastal areas with numerous coconut palm trees that produce numerous natural containers in the form of palm fronds, coconut shells, coconut husks, and even beetle holes in the coconut palm tree. Attempts to control mosquito in the latter areas must target both natural and artificial containers. Other natural containers that commonly produce mosquito in Thailand include: (i) a variety of bamboo-associated habitats (such as bamboo

stumps, split bamboo poles, and bamboo internodes); (ii) tree holes, root holes, holes in stumps, hollow logs, and woodpecker holes; (iii) plant leaf axils on banana, *Pandanus* spp, *Nipa* spp, pineapple, elephant ear plants (*Alocasia, Colocasia*, *etc*), and Bird of Paradise flower plants; (iv) highly specialized plant containers such as pitcher plants (*Nepenthes* spp), ginger flowers, and shelf fungi on trees; and, (v) rock pools (freshwater and saltwater), deep and narrow rock holes, and rock pools deep inside caves. Species of the following genera and subgenera occupy one or more of these types of containers, and are found in various subregions of Thailand: *Aedes (Aedimorphus, Alanstonea, Bothaella, Christophersiomyia, Diceromyia, Edwardsaedes, Fredwardsius, Isoaedes, Lorrainea, Paraedes Scutomyia, Stegomyia), Anopheles (Anopheles, Cellia), Armigeres (Armigeres, Leicesteria), Ayurakitia, Culex (Culex, Culiciomyia, Eumelanomyia, Lophoceraomyia, Oculeomyia), Lutzia (Metalutzia), Heizmannia (Heizmannia, Mattinglyia), Malaya, Mimomyia (Etorleptiomyia, Ingramia, Mimomyia), Ochlerotatus (Bruceharrionius, Finlaya, Kenknightia, Mucidus, Ochlerotatus), Orthopodomyia, Topomyia (Topomyia, Suaymyia), Toxorhynchites (Toxorhynchites), Tripteroides (Rachionotomyia, Tripteroides), Udaya, Uranotaenia (Pseudoficalbia, Uranotaenia), Verrallina (Neomacleaya)* and *Zeugnomyia.*

Artificial container habitats are an indication of human activity and human modification of the environment. Obviously, such habitats are most common in and around villages, towns, and cities. However, artificial containers can be found in deep forests where inhabitants use cut bamboo joints to carry water, in canoes and boats along rivers, and in discarded cans, bottles and other trash. In Thailand, one of the most common artificial containers is the 'Ong' jar (clay earthern jars of various sizes) that were originally used for storage of water. Although they are still used for this purpose in more rural areas and towns and in the poorer areas of larger cities, many are used only for decorative purposes in the larger cities. These jars are a key habitat for *Aedes aegypti* and *Aedes albopictus*, the primary vectors of dengue and dengue hemorrhagic fever (DHF). An efficient, sustained effort to eliminate water in these jars would vastly reduce the incidence of dengue in Thailand. Some artificial containers are so large that they attract species of genera that normally use permanent ground water habitats. Such is the case with the genus *Anopheles*. Several species of this genus have been collected from large water jars, however, this is not the normal habitat for these species (except for *Anopheles stephensi* Liston in the western and northern subregions of Thailand). Other genera and subgenera that commonly occur in artificial containers include: *Aedes (Diceromyia, Stegomyia), Armigeres (Armigeres), Culex (Culex, Culiciomyia, Eumelanomyia, Lophoceraomyia), Lutzia (Metalutzia), Ochlerotatus (Finlaya), Toxorhynchites, Uranotaenia*

(Pseudoficalbia, Uranotaenia), and *Verrallina (Neomacleaya).*

Ground water habitats are by far the most common and extensive oviposition habitats for female mosquitoes in Thailand. During the wet monsoon season these habitats are found everywhere and produce significant numbers of both diurnal and nocturnal mosquitoes. Included in this category are some unique and infrequently encountered habitats, such as animal footprints, fresh- and salt-water crab holes, and sapphire mining holes or pits. Other common sites include: (i) ditches, springs, canals, ponds, lakes, marshes, swamps, rivers, and streams that contain permanent water; (ii) seeps, rice fields, ditches, marshes, and swamps that have semi-permanent water; and, (iii) numerous ground pools of various sizes that have temporary water. Additional common habitats are tidal sand pools and mangrove swamps, that have brackish water. Genera and subgenera that most commonly utilize these habitats are: *Aedeomyia (Aedeomyia), Aedes (Aedimorphus, Cancraedes, Edwardsaedes, Fredwardsius, Lorrainea, Neomelaniconion, Paraedes), Anopheles (Anopheles, Cellia), Coquillettidia (Coquillettidia), Culex (Culex, Culiciomyia, Eumelanomyia, Lophoceraomyia, Oculeomyia), Lutzia (Metalutzia), Ficalbia, Hodgesia, Heizmannia (Heizmannia), Mansonia (Mansonioides), Mimomyia (Etorleptiomyia, Mimomyia), Ochlerotatus (Finlaya, Mucidus, Ochlerotatus, Rhinoskusea), Uranotaenia (Pseudoficalbia, Uranotaenia),* and *Verrallina (Harbachius, Neomacleaya, Verrallina).*

Mosquito distribution

A majority of species of the genera and subgenera of mosquitoes found in Thailand are dispersed in their respective habitats throughout the country. These include: *Anopheles (Anopheles, Cellia), Aedeomyia (Aedeomyia), Aedes (Aedimorphus Diccromyia, Edwardsaedes, Fredwardsius, Neomelaniconion, Paraedes, Scutomyia, Stegomyia), Armigeres (Armigeres, Leicesteria), Heizmannia (Heizmannia), Ochlerotatus (Finlaya, Kenknightia), Verrallina (Neomacleaya), Culex (Culex, Culiciomyia, Eumelanomyia, Lophoceraomyia, Oculeomyia), Lutzia (Metalutzia), Ficalbia, Mimomyia (Etorleptiomyia, Mimomyia), Hodgesia, Coquillettidia (Coquillettidia), Mansonia (Mansonioides), Orthopodomyia, Malaya, Tripteroides (Tripteroides, Rachionotomyia), Uranotaenia (Pseudoficalbia, Uranotaenia),* and *Toxorhynchites (Toxorhynchites).* Other genera and subgenera that are confined by their oviposition habitats to specific regions of the country. For ease of interpretation, the spatial distribution of mosquito taxa has been transferred from a biogeographical reference map (Lekagul and Mc Neely, 1988) onto a map that demarcates political regional and provincial boundaries (Fig 2).