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FRESHWATER ANIMAL DIVERSITY ASSESSMENT

Global diversity of mosquitoes (Insecta: Diptera: Culicidae) in freshwater

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Abstract Mosquitoes that inhabit freshwater habitats play an important role in the ecological food chain, and many of them are vicious biters and transmitters of human and animal diseases. Relevant information about mosquitoes from various regions of the world are noted, including their morphology, taxonomy, habitats, species diversity, distribution, endemicity, phylogeny, and medical importance.

Keywords Mosquitoes · Culicidae · Diptera · Freshwater · Diversity

Introduction

Mosquitoes are important groups of arthropods that inhabit freshwater habitats. Their role in the ecological food chain is well recognized by many aquatic ecologists. They are prominent bloodsuckers that annoy man, mammals, birds and other animals including reptiles, amphibians, and fish. They are probably the most notoriously undesirable arthropods, with respect to their ability to transmit pathogens causing human malaria, dengue, filariasis, viral encephalitides, and other deadly diseases. They are also known for being irritating biting pests. Sometimes, their nuisance bites are so severe that they make outdoor activities almost impossible in many parts of the world. Many large coastal areas are made unbearable by salt marsh mosquitoes, and the real estate development and the tourism industry are also seriously affected. More than a hundred species of mosquitoes are capable of transmitting various diseases to humans and other animals. *Anopheles* mosquitoes, for example, solely transmit malaria. It is undoubtedly the most serious arthropod vector-borne disease affecting humans. About 90% of all malaria deaths in the world occur in Africa, south of the Sahara. This is because the majority of infections in Africa are caused by *Plasmodium falciparum*, the most dangerous of the four human malaria parasites. It is also due to the fact that efficient malaria vectors (e.g., *Anopheles gambiae* Giles) are widespread in Africa and are very difficult to control. In many parts of the world, the indirect effect of malaria and mosquito-borne diseases in lowered vitality and susceptibility to other non-vector-borne diseases accounted for more deaths as well as reduced production following work losses.

This chapter presents the current information on the morphology, taxonomy, habitats, species diversity, phylogeny, distribution, endemicity, and medical importance of the various groups of mosquitoes

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Freshwater Animal Diversity Assessment

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worldwide. It is not the intention of this work to comprehensively review all major topics mentioned above. Selected references are included, and should be consulted for further reading.

General morphology

Mosquitoes, like any arthropods, are bilaterally symmetrical. The adult mosquito (Fig. 1A) is covered with an exoskeleton, and its body is divided into three principal regions: the head, thorax, and abdomen. The head is ovoid in shape, with large compound eyes. It bears five appendages, which consist of two antennae, two maxillary palpi and the proboscis. The thorax, the body region between the head and abdomen, is composed of three segments, the prothorax, mesothorax, and metathorax. Each segment has a pair of jointed legs; in addition, the mesothorax has a pair of functional wings, and the metathorax, a pair of wings represented by knobbed structures called halteres. The abdomen is composed of 10 segments, of which the three terminal segments are specialized for reproduction and excretion. Apparently, the mosquito adults resemble Chironomidae, Dixidae, Chaoboridae, and other Nematocera, which like mosquitoes have aquatic immature stages. Mosquitoes, however, are distinguished from such similar looking dipterous flies by the presence of scales on the wing veins and wing margins, and by their forwardly projecting long proboscis that is adapted for piercing and sucking. In contrast to an adult, the larva (Fig. 1B) is largely composed of soft, membranous tissues in the thorax and abdomen, and hardened, sclerotized plates in the

Fig. 1 (**A**) Mosquito adult female, *Anopheles sinensis*, lateral view. (**B**) Mosquito larvae, *An. sinensis*, dorsal view. (**C**) Mosquito habitat, creek. (**D**) Mosquito habitat, irrigation ditch

head. This allows for the swimming movements and doubling of the body when cleaning the mouth or palatal brushes.

Detailed morphological descriptions and glossaries of the adult, pupa, larva, and egg of mosquitoes are found in several publications (e.g., Harbach & Knight 1980, 1981; Darsie & Ward 2005). Most taxonomic keys to identify mosquitoes are based on morphological characters (e.g., Belkin 1962; Harrison & Scanlon 1975; Huang 1977; Rueda et al. 1997; Rueda 2004; Rattanarithikul et al. 2005). For additional list of identification keys and references, you may visit the WRBU website, http://wrbu.org/.

Biology

Mosquitoes have a holometabolous type of development; that is, having four distinct stages in their life cycle: egg, larva, pupa, and adult. Larvae and pupae of mosquitoes require an environment with standing or flowing water for proper development. The female adult lays either single eggs (e.g., *Aedes, Anopheles*) or in clusters (e.g., *Culex, Culiseta*), up to several hundred at a time, on the surface of the water, on the upper surface of floating vegetation, along the margins of quiet water pools, on the walls of artificial containers or in moist habitat subject to flooding. The larvae (called *wrigglers*) undergo shedding (or *molting*) of the skin (or *exuviae*) four times before becoming pupa. Larvae of most species usually filter out and feed on organic matter and other microorganisms, in the water for about 1–3 weeks or longer depending on the water temperature. Larvae of mosquito predators (e.g., *Toxorhychites*, *Lutzia*) feed on larvae of other mosquitoes. In some predatory species, the first instar is a filter feeder, and the predaceous feeding structures are not developed until the second instar. The pupae (called *tumblers*), or resting stage, appear after the fourth larval molt. Unlike larvae, pupae do not feed, and live for 1–3 days before becoming adults. Only adult female mosquitoes bite humans and animals. Male mosquitoes feed primarily on flower nectars, while the females require the blood meal to produce viable eggs. Some species (*anthropophilous*) prefer to feed on man, while others (*zoophilous*) feed in nature on animals (including mammals and birds) other than humans. Females of *Toxorhynchites* and other mosquitoes do not feed on blood. There are some species that readily feed on fish exposed to air, reptiles, amphibians, and insect larvae (Harris et al. 1969; Harwood & James 1979). Some autogenous females can also produce viable eggs, even without blood meal. Females typically feed every 3–5 days, and in a single feeding a female usually engorges more than its own weight of blood. Some species of mosquitoes (e.g., *Anopheles*) prefer to feed at dusk, twilight or nighttime, while others bite mostly during the daytime (e.g., *Aedes*). Other species exhibit seasonal switching of hosts that provides a mechanism for transmitting diseases from animals to humans (called *zoonotic disease transmission*). Diapause (i.e., hibernation, aestivation, over wintering) occurs in various life stages, e.g. as eggs in *Psorophora* and most *Aedes*; as larvae in *Coquillettidia*, some *Culiseta, Mansonia, Orthopodomyia, Toxorhynchites, Wyeomyia*, some *Aedes*; as adults, often fertilized females, in *Uranotaenia*, most Culex, some *Anopheles* and other *Culiseta*; and as either eggs or larvae in *Culiseta morsitans* (Theobald) (Stojanovitch & Scott 1997).

The stimuli or factors that attract mosquitoes to a human or animal host are complex and are not fully understood. Mosquitoes, like other biting arthropods, use visual, thermal, and olfactory stimuli to locate a host. Olfactory cues may be the most important as a mosquito nears the host but visual stimuli seem important for in flight orientation, particularly over wide ranges. For daytime biters, movement of the host may initiate orientation toward that person or animal. Out of more than 300 compounds that are released from the human body as by-products of metabolism, more than 100 volatile compounds can be detected from human breath. Carbon dioxide is released primarily from the breath and the skin, and can be detected by mosquitoes. Carbon dioxide and octenol are common attractants that are used in monitoring and surveillance of mosquitoes in their habitats (Rueda et al. 2001). The antennae of mosquitoes have chemoreceptors that are stimulated by lactic acid, but can be inhibited by repellents. Repellents (e.g., deet or *N,N*-diethyl-3-methyl-benzamide) are effective personal protective measures against biting insects to reduce or prevent transmission of vector-borne diseases (Rueda et al. 1998).

Habitats

Mosquitoes have diverse habitats that allow them to colonize different kinds of environments. The immature stages of mosquitoes are found in a variety of aquatic habitats (Table 1, Fig. 1C, D), e.g., ponds, streams, ditches, swamps, marshes, temporary and permanent pools, rock holes, tree holes, crab holes, lake margins, plant containers (leaves, fruits, husks, tree holes, bamboo nodes), artificial containers (tires,

Table 1 Common habitats of the mosquito larvae

Habitats*	Examples of mosquitoes	Remarks
1. Flowing streams	*Culex fuscocephala, gelidus;* *Anopheles kochi; An. spp.*	Include creeks, drainage and irrigation ditches
2. Ponded streams	*An. kochi; Cx. annulus, bitaeniorhynchus;* *Lutzia fuscanus*	Include flooded stream beds, Chlorophyta-rich habitats, polluted ponds
3. Lake edges	*An. farauti, maculipennis* *An. quadrimaculatus, pseudopunctipennis* *Cx. annulirostris, squamosus*	Margins of lakes
4. Swamps and marshes	*An. farauti, gambiae, kochi, punctulatus* *An. sinensis; An. spp.* *Cx. annulus, bitaeniorhynchus, gelidus, sitiens* *Cx. tritaeniorhynchus; Lutzia fuscanus*	Include coastal marshes, mangrove swamps, irrigated fields
5. Shallow permanent ponds	*Aedes longirostris, An. kochi, sinensis* *Cx. gelidus, tritaeniorhynchus* *Mansonia uniformis, Mimomyia chamberlaini*	Include fishponds, duckweed ponds
6. Shallow temporary pools	*Ae. communis, excrucians, hexodontus, impiger* *An. dirus*	Include snowmelt pools
7. Intermittent ephemeral puddles	*An. gambiae, kochi, punctulatus* *Cx. annulus, fuscocephala, tritaeniorhynchus*	Common in road construction sites resulting from rainy season downpours
8. Natural containers (plant origin)	*Aedes (Aedimorphus, Finlaya, Stegomyia,) spp.,* *Anopheles spp., Armigeres spp., Culex spp.,* *Ficalbia spp., Haemagogus sp., Orthopodomyia spp.* *Sabethes spp., Toxorhynchites spp., Tripteroides spp.* *Uranotaenia spp., Wyeomyia spp.*	Include tree holes, internodes, leaf axils, flower bracts, fronds, nuts, pods, pitchers [Graminae(bamboo), Pandanaceae (screwpines), Palmae (palms), Agavaceae (Dracaena), Araceae (taro), Musaceae (banana, abaca), Bromeliaceae (bromeliads, pineapples), Cytanaceae (rafflesias), Nepenthaceae (climbing pitcher plants), Sarraceniaceae (terrestial pitcher plants)]
9. Natural containers (animal and other origins)	*Aedes (Cancraedes, Geoskusea, Levua, Lorrainea)* *Ae. (Rhinoskusea, Skusea, Stegomyia) spp.* *Anopheles spp., Culex spp., Culiseta spp.* *Deinocerites spp., Eretmapodites spp.* *Uranotaenia spp.*	Include shells of snails, clams, arboreal ant nests, crab holes
10. Artificial containers	*Aedes spp., Culex spp., Toxorhynchites spp.*	Include tires, cans, flower vases, bottles, tanks, troughs, drums, gutters, etc.

* Adapted from Laird (1988) and other references

tin cans, flower vases, bird feeders), and other habitats (Laird 1988; Rueda et al. 2005, 2006). The enormous importance of diverse habitats on the increasing populations of mosquitoes has been well recognized by aquatic ecologists and public health personnel. Furthermore, knowledge of larval habitats is important in determining vector control, as well as for disease prevention purposes. It is extremely necessary in designing effective vector control programs. The most practical way to reduce a local population of pestiferous mosquitoes is to eliminate their habitats as much as possible, particularly sources of standing water, such as old discarded tires, clogged gutters, stumped tree holes, etc. Larval habitats that are not possibly eliminated can be modified (e.g., cleaning clogged ditches, open water management in salt marshes). Appropriate methods can be applied such as using biological control agents (predatory fish, microbials), selected insecticides for permanent habitats (ponds, lakes), or other environmental modification techniques to control breeding of mosquitoes.

Table 2 Number of genera by subfamily/tribe in each zoogeographical region

Subfamily/Tribe	Number of genera[a]						
	PA	NA	NT	AT	OL	AU	World
Subfamily Anophelinae	1	1	2	1	2	2	3
Subfamily Culicinae	18	12	22	14	23	20	39
Tribe Aedeomyiini	0	0	1	1	1	1	1
Tribe Aedini	5	4	3	2	8	5	12
Tribe Culicini	2	2	3	1	1	1	4
Tribe Culisetini	1	1	1	1	1	1	1
Tribe Ficalbiini	2	0	0	2	2	2	2
Tribe Hodgesiini	0	0	0	1	1	1	1
Tribe Mansoniini	2	1	2	2	2	2	2
Tribe Orthopodomyiini	1	1	1	1	1	1	1
Tribe Sabethini	3	1	9	1	4	4	13
Tribe Toxorhynchitini	1	1	1	1	1	1	1
Tribe Uranotaeniini	1	1	1	1	1	1	1
Total	19	13	24	15	25	22	42

PA, Palaeractic; NA, Nearctic; NT, Neotropical; AT, Afrotropical; OL, Oriental; AU, Australasian (including South Pacific Islands)

[a] Based on multiple searches of the Walter Reed Biosystematics Unit web site in December 2005

Species diversity

Mosquitoes belong to the family Culicidae, order Diptera, class Insecta (Hexapoda), phylum Arthropoda. There are two recognized subfamilies, the Anophelinae and Culicinae. Subfamily Culicinae has 11 tribes: Aedeomyiini (*Aedeomyia*), Aedini (*Aedes, Armigeres, Ayurakitia, Eretmapodites, Haemagogus, Heizmannia, Opifex, Psorophora, Tanakius, Udaya, Verrallina, Zeugnomyia*), Culicini (*Culex, Deinocerites, Galindomyia, Lutzia*), Culisetini (*Culiseta*), Ficalbiini (*Ficalbia, Mimomyia*), Hodgesiini (*Hodgesia*), Mansoniini (*Coquillettidia, Mansonia*), Orthopodomyiini (*Orthopodomyia*), Sabethini (*Isostomyia, Johnbelkinia, Limatus, Malaya, Maorigoeldia, Onirion, Runchomyia, Sabethes, Shannoniana, Topomyia, Trichoprosopon, Tripteroides, Wyeomyia*), Toxorhynchitini (*Toxorhynchites*), and Uranotaeniini (*Uranotaenia*). There are about 3,500 species and subspecies, under 140 subgenera in 42 genera of mosquitoes worldwide (Walter Reed Biosystematics Unit 2001). In Culicinae, tribe Sabethini (13) has the greatest number of genera, followed by Aedini (12) and Culicini (4). Tribes Ficalbiini and Mansoniini each have two genera, and the remaining tribes each with one genus. The Oriental region (OL, 25) has the greatest number of genera, followed by the Neotropical region (NT, 24), and the Australasian region (22) (Table 2, Fig. 2).

The diversity of the mosquito species varies among different geographical regions of the world. The greatest diversity of mosquito species is found in the NT (31% of total known species; 1069/3492), followed by the Oriental (30%), Afrotropical (22%), and Australasian (22%) regions. The Nearctic region (5%) has the lowest species diversity (Table 3, Fig. 2). In the NT, the greatest number of species in Culicinae is found under tribe Culicini, followed by Aedini and Sabethini. Only one species in Aedeomyiini is known, but none of Ficalbiini and Hodgesiini from the NT. In the OL, Aedini has the greatest number of species, followed by Culicini and Sabethini. Orthopodomyiini, Hodgesiini, Culisetini, and Aedeomyiini have lower number of species in the OL. In the Afrotropical, Palearctic, Nearctic, and Australasian region, Aedini and Culicini have the greatest number of species. Aedomyiini and Orthopodomyiini have the lowest number of species in the

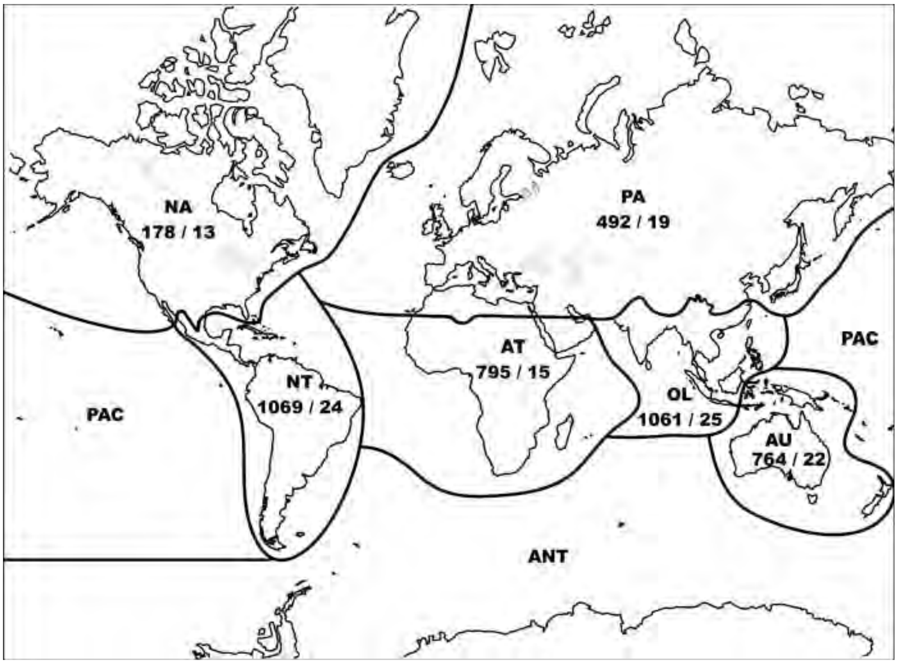

Fig. 2 Number of species and genera in each zoogeographical region (from Tables 2 and 3). PA, Palaearctic; NA, Nearctic; NT, Neotropical; AT, Afrotropical; OL, Oriental; AU, Australasian region including South Pacific Islands (PAC: Pacific Oceanic Islands; ANT: Antarctic)

Table 3 Number of species by subfamily/tribe in each zoogeographical region

Subfamily/tribe	Number of species[a]						
	PA	NA	NT	AT	OL	AU	World
Subfamily Anophelinae	94	21	125	148	168	95	489
Subfamily Culicinae	398	157	944	647	893	669	3003
Tribe Aedeomyiini	0	0	1	3	1	2	6
Tribe Aedini	217	96	258	300	407	302	1262
Tribe Culicini	96	35	360	169	185	155	813
Tribe Culisetini	16	8	8	7	4	15	40
Tribe Ficalbiini	8	0	0	34	15	13	53
Tribe Hodgesiini	0	0	0	4	6	5	11
Tribe Mansoniini	7	2	27	26	18	26	81
Tribe Orthopodomyiini	3	3	7	7	7	1	25
Tribe Sabethini	19	4	223	6	135	89	409
Tribe Toxorhynchitini	10	5	24	22	35	15	88
Tribe Uranotaeniini	22	4	36	69	80	46	215
Total	492	178	1069	795	1061	764	3492

PA, Palaeractic; NA, Nearctic; NT, Neotropical; AT, Afrotropical; OL, Oriental; AU, Australasian (including South Pacific Islands)

[a] Based on multiple searches of the Walter Reed Biosystematics Unit web site in December 2005

Afrotropical and Australasian regions. In the Nearctic region, Mansoniini has the lowest number of species, and none is known of Aedeomyiini, Ficalbiini, and Hodgesini. In the Palearctic region, Orthopodomyiini has the lowest number of species, but none is known of Aedeomyiini and Hodgesiini.

Although mosquito taxonomists use new methods of computerized and molecular analyses and new data sets to address the phylogeny and classification of mosquitoes, many problems arise to change the classification and nomenclature. Due to the importance of mosquitoes in disease transmission, many technical issues need to be resolved to facilitate communication and information exchange among public health practitioners, medical entomologists, parasitologists, epidemiologists, ecologists, and other interested groups. In this article, the taxonomic classification of the family Culicidae as given by Knight & Stone (1977) is followed. Mosquitoes are documented in world catalogs (Knight & Stone 1977 and its three supplements) that are updated regularly (Walter Reed Biosystematics Unit 2001).

Phylogeny

The classification of mosquitoes, Family Culicidae, consists of two subfamilies, the Anophelinae and

Culicinae (Harbach & Kitching 1998, 2005). Subfamily Anophelinae has three genera: *Anopheles* Meigen (cosmopolitan in distribution), *Bironella* Theobald (Australasian), and *Chagasia* Cruz (Neotropical). Subfamily Culicinae has 39 genera (Table 2). Phylogenetic analysis is needed within the family Culicidae. Detailed observations still need to be made that many hypotheses of relationship must be regarded only as a stimulus for further investigation. The phylogeny of anopheline mosquitoes has been examined using morphological characters (Sallum et al. 2000; Harbach & Kitching 1998, 2005) and nuclear, ribosomal and mitochondrial DNA sequences (Krzywinski et al. 2001a, b, Sallum et al. 2002). Based on cladistic analysis of morphological data (Harbach & Kitching 1998), Anophelinae is a monophyletic clade comprised of *Chagasia* in a sister-group relationship to *Bironella* and *Anopheles*. However, separate analyses based on both morphological and molecular data (Sallum et al. 2000, 2002, respectively) suggest that subgenus *Anopheles* is a paraphyletic assemblage relative to *Bironella*. Recent study (Harbach & Kitching 2005) based on morphological data analysis using implied weighting supported the monophyly of Anophelinae, the basal position of *Chagasia*, the monophyly of subgenera *Cellia, Kertezia* and *Nyssorhynchus*, and the sister relationship of *Kertezia* and *Nyssorhynchus*. *Bironella, Lophopodomyia*, and *Stethomyia* are firmly nested within subgenus *Anopheles*.

Mosquito taxon sampling and under representation of the species and groups in the analyses of morphological and molecular data clearly affect the outcome of a phylogenetic reconstruction. In addition, the sequence-based phylogenies are heavily compromised by the selection of DNA fragments, interpretations of gene structure and homology, alignment and sequencing error and choice of phylogenetic method (Harbach & Kitching 2005). Due to the medical importance of *Anopheles* in malaria transmission, many taxonomists, medical entomologists, mosquito control specialists and preventive medicine personnel are very likely to prefer the practice of recognizing subgenera rather than raising those groups to numerous genera.

The phylogeny of tribe Aedini is still not stabilized, despite recent attempts by Reinert et al. (2004). In their cladistic analysis, they used the morphological characters of less than 10% (119/1239) of the species in the tribe Aedini. They tried to translate the results of their cladistic analysis directly into a reclassification of genera. They proposed an elevation of 32 subgenera to generic status, even though most of these genera are poorly defined and difficult or impossible to identify, which results in too much confusion (Savage 2005).

Some fossil mosquitoes have been traced back to the Eocene period (38–54 million years before the present, BP). Most fossil discoveries of mosquitoes have been from the Oligocene period (26–38 million years BP) (Lutz 1985) by which time genera *Aedes, Culex*, and probably *Mansonia*, can be recognized. Although Bode (1953) described new genera and species from immature forms as possibly belonging to the Culicidae, they are difficult to ascertain or confirm. Those interested in the phylogeny and paleontology of mosquitoes should consult Edwards (1923), Christophers (1933), Statz (1944), Wood & Borkent (1989), Harbach & Kitching (1998), and Poinar et al. (2000).

Distribution and endemicity

Mosquitoes have an almost world wide distribution, being found throughout the tropics and temperate regions. They are absent only from a few islands and Antarctica. They can thrive in a variety of habitats with fresh water, brackish water, or any water (clear, turbid or polluted) except in marine habitats with high-salt concentration. Although there are about 3,500 known species and subspecies, there are probably more than 1,000 species that have yet to be found and described. The biodiversity of mosquitoes is very evident, with many genera having worldwide distribution and some genera with limited or endemic distribution. For example, the genera, i.e., *Anopheles, Aedes, Coquillettidia, Culex, Culiseta, Lutzia, Orthopodomyia, Toxorhynchites*, and *Uranotaenia*, have at least one species found in all five regions of the world. About 36% of the 42 known genera are endemic in four regions. In the NT, there are nine endemic genera (*Chagasia, Galindomyia, Isostomyia, Johnbelkinia, Limatus, Onirion, Sabethes, Shannoniana*, and *Trichoprosopon*); in the OL, three endemic genera (*Ayurakitia, Udaya*, and *Zeugnomyia*); in the Australasian region, including South Pacific Islands (AU), two endemic genera

(*Maorigoeldia* and *Opifex*); and in the Afrotropical or Ethiopian region (ET), one endemic genus (*Eretmapodites*). There are 47 species under uncertain subgenera in four genera, namely *Aedes* (1 species in uncertain genus in AU), *Culex* (7 species in NT, 1 in AU), *Wyeomyia* (37 species in NT), and *Culiseta* (1 species in AU). The NT has 58% and 57% of the 81 known subgenera and 42 genera, respectively, worldwide; Nearctic region, 23% and 31%; OL, 52% and 60%; Afrotropical region, 33% and 38%; Australasian region (including South Pacific Islands), 53% and 55%; and Palearctic region, 39% and 45%.

In all five regions, subfamily Culicinae (81–88%) has greater number of species than subfamily Anophelinae. In the subfamily Culicinae, tribe Aedini (46–61%) has the greatest number of species in all regions, except in the NT. Species in all 10 tribes of the subfamily Culicinae are found in the Australasian, Oriental, and Afrotropical regions. Species of tribe Hodgesiini have not been reported from the Nearctic, Palearctic, and NTs, while species of the tribe Aedeomyiini have not been reported from the Palearctic region. Many countries or island groups in the Oriental, Australasian, and NTs have endemic species of mosquitoes. For example, about 40% of the mosquito fauna in the Philippines are found only in that country, and such endemicity is conspicuous especially for the genera *Tripteroides*, *Zeugnomyia*, and *Aedes* (*Finlaya*) and *Armigeres* (*Armigeres*) (Tsukamoto et al. 1985). In the South Pacific Islands, about 84% of the indigenous species are endemic to the islands (Belkin 1962). The endemism of the mosquito fauna in the South Pacific Islands and other parts of the Australasian region, for example, is not confined to the specific level. In addition to two endemic genera (*Opifex*, *Maorigoeldia*), there are several endemic species groups in *Uranotaenia*, *Culex*, *Coquillettidia*, *Aedes,* and *Tripteroides* from this region. Belkin (1962) compared the mosquito fauna of the South Pacific Islands with the other regions of the world. He noted that there are some affinities of South Pacific fauna with the Oriental, Nearctic, Palaearctic and Afrotropical regions, and parts of the NT (South Chile areas). Due to the relatively poor knowledge of numerous mosquito groups, it is very difficult to ascertain the exact affinities of mosquito fauna from various regions. An updated list of endemic species for each country and the general distribution record of each species can be found in the online systematic catalog of Culicidae (Walter Reed Biosystematics Unit 2001).

Human related issues

Medical importance

Many members of the mosquito genera such as *Anopheles, Aedes, Culex,* and *Mansonia* commonly bite humans and animals, and are involved in the transmission of infectious diseases as principal, secondary or bridge vectors. They are a nuisance to humans and other animals. Cutaneous responses to mosquito bites range from common localized wheal- and -flare reactions to delayed bite papules, and anaphylaxis. Bite reactions are the result of sensitization to mosquito salivary antigens, which lead to the formation of specific IgE and IgG antibodies. In extreme cases, severe itching can lead to secondary infection through scratching of the skin. In heavily infested areas, particularly during peak season, they cause annoyance to humans, and can affect the agriculture and tourism industry along coastal areas. These mosquitoes might also be important in the epidemiology of various pathogenic organisms in those areas.

Mosquitoes are important vectors of organisms causing diseases to humans and animals, particularly malaria (plasmodia, i.e., *P falciparum, Plasmodium vivax, Plasmodium malariae, Plasmodium ovale*), lymphatic filariases (filarial worms, i.e., *Wuchereria, Brugia*), arboviral encephalitides (viruses, i.e., dengue, yellow fever, West Nile, Japanese, Eastern Equine, others) (Harwood & James 1979; Peters 1992; Service 1993; Centers for Disease Control and Prevention 2005). Malaria is a very serious disease, affecting about 40% of the world's population, mostly in the tropical and subtropical areas of the world. Despite the heavy use of pesticides to control *Anopheles* vectors of malaria during the 20th century, more than 1 million deaths and over 300 acute malaria cases are still reported annually in the world, with greatest number of deaths occurring in Africa (World Health Organization 2005). Antimalarial drugs have been available for more than 50 years, but effective vaccines are still needed to help boost the campaign against the malarial disease. Important malaria vectors are found in various regions of the world such as NT (*e.g.*, *An. albimanus, An. albitarsis, An. darlingi, An. aquasalis, An. pseudopunctipennis*), Afrotropical region (*An. gambiae, An. funestus, An. arabiensis*), OL (*An. dirus, An. minimus, An. flavirostris*), Palearctic region (*An. lesteri, An. sinensis*), and Australasian region (*An. farauti, An. punctulatus, An. koliensis*) (Peters 1992).

Dengue is another serious arboviral disease of Asia, South and Central America, and Africa. Although it has a low mortality, it has very debilitating symptoms. *Aedes aegypti* and *Ae. albopictus* are the common vectors of dengue. They can easily adapt and proliferate in new areas, resulting in the wide spread of dengue worldwide. For example, in 2003, Brazil reported more than 350,000 human cases and 42 deaths. In 2004, Indonesia had a dengue outbreak that caused more than 54,000 cases and over 600 deaths, while Venezuela reported 11,600 cases. Yellow fever is another important disease in Africa and South and Central America, with about 200,000 cases and 30,000 deaths in 33 countries every year. It is transmitted primarily by *Ae. aegypti*. Most countries have strict regulations and requirements for yellow fever vaccination prior to entering the country that may help in minimizing disease infections among tourists or travelers. West Nile virus (WNV) has spread from its origin in Africa (Uganda) in 1937 into Europe and west and central parts of Asia. In 1999, it first appeared in North America (New York) with 62 cases and 7 human deaths. It is widespread in the United States, Canada, Mexico, and the Caribbean Islands. In the United States, more than 43 species of mosquitoes have tested positive for WNV. *Culex pipiens* complex is the most common mosquito group associated with human and horse infections. Furthermore, significant population growth, demographic movement to urban residential area, and an increase in tourism-based facilities are deemed major factors involved in mosquito-borne disease resurgence in many parts of the world.

Food chain

Many people think that mosquitoes would be one of the last groups of wildlife that they would consider saving. Mosquitoes can be unbearable, biting viciously in forest shades or near salt-water mangroves, especially during the rainy season. Even though mosquitoes are annoying to most people, they play an important role in the food chain, particularly in the everglades and other freshwater habitats. For instance, mosquito larvae are usually at the base of the food chain. In freshwater areas, they are a primary source of food for small fish such as the mosquito fish (*Gambusia*), which in turn are food for medium size fish such as the blue gill and brim. These fish are food for still larger fish, such as large mouth and garfish. The bass and the gar are a food source for the alligator, birds, and humans. Wading birds (i.e., egrets, spoon bills, and wood storks) also benefit from the mosquito food chain. As the mosquito ponds dry up between rains, the mosquito fish and killifish become trapped by the thousands. Wading birds congregate at the receding ponds and feed on concentrated, readily available fish. Furthermore, without mosquito larvae, local fishermen and fish sportsmen in many coastal areas would have less fish to catch (U.S. Department of the Interior 2005).

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