ECOLOGICAL DIVERSITY OF AQUATIC INSECTS WITH EMPHASIS ON MOSQUITO OF QATAR AND PERCEPTION AS WELL AS AWARENESS LEVEL AMONG QATARI TOWARD MOSQUITO-BORNE DISEASE

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by

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"Praise be to God, the do we worship and thin aid we seek"

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KEPELBAGAIAN EKOLOGI SERANGGA AKUATIK DENGAN PENGKHUSUSAN KE ATAS NYAMUK QATAR DAN PERSEPSI SERTA PERINGKAT KESEDARAN DALAM KALANGAN BANGSA QATAR TERHADAP PENYAKIT BAWAAN NYAMUK

ABSTRAK

Satu tinjauan keatas larval nyamuk telah dilakukan di Qatar dari Oktober 2013 hingga Mei 2015 untuk mengkaji komposisi larva nyamuk, taburan dan mencirikan habitat larva nyamuk. Teknik pencedukan standard telah digunakan untuk menyampel larva nyamuk dari habitat pembiakkan yang berbeza, manakala serangga akuatik telah disampel dengan menggunakan teknik pencedukan dan pengheretan. Tahap pengetahuan dan kesedaran di kalangan orang Qatar terhadap nyamuk dan penyakit bawaan nyamuk telah disiasat diantara September dan December 2013 melalui pengedaran kertas soal selidik. Enam spesies daripada 3 genus telah dijumpai; *Anopheles stephensi*, *Culex pipiens*, *Culex quinquefasciatus*, *Culex mattinglyi*, *Ochleratus dorsalis* dan *Ochleratus caspius*. *Culex mattinglyi* ialah pertama kali dijumpai di Qatar, manakala *Oc. dorsalis* pertama kali dicamkan diperingkat larva. Kelimpahan larva nyamuk adalah tinggi pada musim sejuk dan rendah pada musim panas, manakala diversiti maksimum (H=1.03) larva nyamuk pada musim daun gugur dan diversiti minimum (H= 0.77) pada musim panas. Tiga musim; luruh, sejuk dan bunga adalah paling sesuai kerana suhu udara yang sederhana dan kurang penyejatan. Untuk tempat pembiakan, diversiti maksimum (H=0.95) di kawasan bandar dan diversiti minimum di kawasan perindustrian. Pembolehubah persekitaran telah direkodkan termasuk lindungan, kekeruhan, vegetasi, alga, pemangsa, suhu air, kemasinan, oksigen terlarut dan pH pada setiap habitat pembiakan. Kawasan bandar mempunyai tempat pembiakan yang paling tinggi disebabkan oleh aktiviti manusia

manakala tempat semula jadi terendah. Kolam air minuman adalah tempat pembiakan larva nyamuk yang paling produktif. *Anopheles stephensi* berkait negatif dengan kedalaman air dan vegetasi manakala berkait positif dengan habitat yang besar dan teduh (P<0.05). *Culex pipiens* berasosiasi positif dengan kekeruhan dan pH air (P < 0.05), tetapi berkait secara negatif dengan vegetasi dan saiz habitat (P<0.05). *Culex quinquefasciatus* berkait secara negatif dengan oksigen terlarut, suhu air, kemasinan (P < 0.05) dan terdapat di habitat yang besar. Satu kajian ke atas komposisi dan kelimpahan serangga akuatik dilakukan setiap bulan dari Oktober 2013 hingga Mei 2015. Enam order serangga akuatik ditemui: Diptera merupakan yang paling banyak dan telah diwakili oleh 5 famili; Chironomidae (3 genera-*Chironomus, Polypedium, Cricotopus*), Ephydridae (1 genus, *Ephydra*), Psychodidae, Syrphidae (1 genus, *Eristalis*) dan Tabanidae. Hemiptera diwakili oleh 3 famili; Corixidae (1 genus, *Sigara*), Notonectidae (1 genus *Anisops*), dan Veliidae (1 genus, *Microvelia*). Odonata diwakili oleh satu family; Libellulidae (*Orthetrum sabina*). Tiga order hanya diwakili satu famili; Coleoptera (Dytiscidae), Trichoptera (Philopotamidae) dan Ephemeroptera (Baetidae). Kepelbagaian biologi (Biodiversiti) adalah tinggi pada kolam banjir najis (0.75). Nilai Indeks Margalef kurang dari 1 disemua habitat yang dikaji. Tahap pengetahuan dan kesedaran penduduk Qatar terhadap nyamuk dan penyakit bawaan nyamuk telah dikaji di antara bulan September hingga Disember 2013. Sebanyak 876 respondan telah menjawab soal selidik, kebanyakannya oleh penduduk Qatar yang berumur diantara 31-40 tahun dan berpendidikan universiti. Umumnya, respondan mempunyai pengetahuan yang baik tentang perlindungan peribadi tetapi hampir setengah mempunyai kurang pengetahuan tentang nyamuk vektor dan penyakit bawaan nyamuk. Umumnya, kajian ini menyediakan data asas untuk kajian di masa hadapan mengenai nyamuk dan fauna serangga akuatik yang lain untuk pengurusan vektor yang berkesan.

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ABSTRACT

A mosquito larval survey was conducted in Qatar from October 2013 to May 2015 to study the larval composition, distribution and larval habitats. Standard dipping technique was used to sample mosquito larvae from different breeding habitats, while aquatic insects were sampled using dipping and dragging techinques. Knowledge and awareness level among people of Qatar towards mosquitoes and mosquito-borne diseases were investigated between September and December 2013 through distributing a paper questionnaire. Six species representing three genera were recognized, namely, *Anopheles stephensi*, *Culex pipiens*, *Culex quinquef*asciatus, *Culex mattinglyi*. *Ochlerotatus dorsalis* and *Ochlerotatus caspius*. *Culex mattinglyi* is a first record in Qatar, and *Oc. dorsalis* is the first identified in the larval stage. Mosquito larvae were most abundant in the winter and low in the summer, while the maximum (H= 1.03), and minimum (H= 0.77) diversity was found in fall and summer respectively. The three seasons; fall, winter and spring are the most preferable seasons due to moderate s air temperature and low evapouration. Maximum diversity (H= 0.95) was found in the urban area and minimum diversity (H= 0.26) in the industrial area. Environmental variables were recorded at each habitat including shade, turbidity, vegetation, algae, predators, water temperature, salinity, dissolved oxygen and pH. Majority of breeding habitats were found in urban areas due to human activities and minority in the natural areas. Drinking water pools were the most productive habitats for mosquito larvae. *Anopheles stephensi* has a negative association with water depth and vegetation and positive association with large and shaded habitats (P < 0.05). *Culex pipiens* was positively associated with turbidity and water pH (P < 0.0.5), but negatively associated with vegetation and habitat size (P < 0.05). *Culex quinquefasciatus* was negatively associated with dissolved oxygen, water temperature, salinity (P < 0.05). A survey on the composition and abundance of aquatic insects was conducted on monthly basis from October 2013 to May 2015. Six orders of aquatic insects were found; Diptera was the most abundant and was represented by five families; Chironomidae (three genera; *Chironomus*, *Polypedium*, *Cricotopus*), Ephydridae (one genus, *Ephydra*), Psychodidae, Syrphidae (one genus, *Eristalis*), and Tabanidae. Hemiptera was represented by three families; Corixidae (one genus, *Sigara*), Notonectidae (one genus, *Anisops*), and Veliidae (one genus, *Microvelia*). Odonata was represented by one family; Libelullidae (*Orthetrum sabina*). Three orders were represented by one family each; Coleoptera (Dytiscidae), Trichoptera (Philopotamidae), and Ephemeroptera (Baetidae). Biodiversity was high in flooded sewage pools (0.75). The value of Margalef's index was less than 1 at all investigated habitats. A total of 876 respondents completed the questionnaire, comprising mostly of Qatari, aged between 31-40 years old, and university educated. Generally, the respondents had poor knowledge on their personal protection, mosquito vectors and mosquito-borne diseases. In general, this study provides a baseline data for further studies on mosquito and other aquatic insect fauna for effective vector management.

CHAPTER 1

INTRODUCTION

1.1 Background

Mosquitoes have the ability to carry and spread diseases to human and cause millions of deaths every year in the world (WHO 2015). Despite 50 years of malaria control efforts, malaria remains a main global public health problem in 100 malarious countries and 2.4 billion people are at risk with over 2 million deaths per year, mainly children in Africa. Dengue virus is transmitted by *Aedes* mosquitoes; *Ae. aegypti* (Linnaeus 1762) and *Ae. albopictus* (Skuse 1895), which recently are distributed across all continents. Over 50 years, dengue has become a growing public health problem (Kraemer et al 2015). In the past 30 years, the worldwide incidence of dengue has risen 30-fold increase, and more countries are reporting their first outbreak of the disease (WHO 2015). Conservation of natural resources and biodiversity has become an urgent issue in recent years for attaining an environmentally sustainable future. Biodiversity loss in freshwater ecosystems is an increasing phenomena, mainly due to human activities (Abell 2002). Biodiversity is fundamental to the future sustainability of the world's natural resources.

Qatar is responsible for conservation and proper management of its native flora and fauna, especially for endemic species, unique to the country. Such commitment is part of Qatar National Vision 2030 "Management of the environment such that there is harmony between economic growth, social development, and environmental protection". Studying diversity of mosquitoes and other aquatic insects, particularly those that transmit diseases are in a line with the Qatar's vision on biodiversity.

In the past few decades, expansion of urbanization in Qatar has affected the insect fauna, particularly mosquitoes and other aquatic insects. Development in most parts of the State with favorable climatic conditions for mosquitoes and other aquatic insects survival, as led to the creation of more permanent as well as temporary breeding sites. Unfortunately, knowledge of freshwater fauna in Qatar is extremely limited with scanty information available on aquatic insects. Development in rapid transport system, tourism, trade links, and human-environmental changes are expected to affect the species composition of mosquitoes in Qatar.

In 2007, WHO classified Qatar as malaria free country (WHO 2007). Subsequently, Khan et al. (2009) confirmed these reports, with no other report of mosquito-borne disease. However, further studies are required in this area to provide and confirm such information especially since the vector exist.

Harbach (1985), reported finding two *Anopheles* and one *Culex* species in Qatar; *An. multicolor* (Cambouliu 1902), *An. stephensi* (Liston 1901) and *Cx. quinquefasciatus* (Say 1823). Later on, Glick (1992) reported the presence of two *Anopheles* species in Qatar; *An. multicolor* and *An. sergentii* (Theobald 1907). Mikhail et al. (2009), identified the geographical distribution of some adult mosquitoes in the country. In the last two years, there have been only three studies on the mosquitoes of Qatar, including the larvae and adult survey in Alkhor district by Kardousha (2015, 2016) and in Alrayyan by Ahmed (2015). There is very little information on the ecology of the larvae and their habitats. Ecological data, such as species composition, larval habitats, geographical and seasonal distribution, play an important role in integrated vector management.

There is no ecological study on the inventory and classification of the mosquito-borne diseases or other aquatic insects, their abundance, geographical distribution and seasonal activity in Qatar. Recent outbreaks of mosquito-borne diseases in the world and in adjacent countries, show the need for better knowledge of the taxonomic and functional biodiversity of both native and invasive vector species. To assess the distribution of mosquitoes and their epidemiological importance in Qatar, this study was conducted from 2013-2015.

1.2 Objectives

Specifically, the study aims to:

1- Determine the mosquito species composition, seasonal abundance, and geographical distribution,
2- Identify mosquito larval habitats in Qatar,
3- Establish the aquatic insects' fauna of Qatar, and,
4- Determine the level of knowledge, attitude and practices of the population on mosquitoes as disease vectors.

CHAPTER 2

LITERATURE REVIEW

2.1 Qatar

The combination of many environmental factors such as drought and salinity, and high evapo-transpiration, irradiance and temperature do not allow many plants to grow and survive in this region (Yasseen 2011). The vegetation of Qatar is composed of a permanent framework of perennials, the interspaces of which may be occupied by ephemerals after rains depending on the amount and distribution of rainfall (Abulfatih et al. 2001). Thus, such climatic factors combined with many environmental factors, such as type of landscape, scanty of vegetation and limited water sources could have great impact on the biodiversity of flora and fauna (Yasseen and Al-Thani 2013). Information on the occurrence and distribution of desert animals in Qatar is limited. A small number of wild animals have been recorded including insects species (Walker and Pittaway 1987), some butterflies (Pittaway 1980), and a list of 170 insect species which were collected from desert localities, farms and house gardens was reported by Abdu and Shaumar (1985) and Abushama (1997) where recorded a number of desert arthropods in Qatar. Sharaf et al. (2015) studied the biodiversity of invertebrates in Qatar.

During recent years, a surge of 2.5 million in Qatar's population was observed in 2016 as compared to 1.7 and 2.3 million in 2010 and 2014 respectively. The majority (92%) reside in Doha, the capital. Temporary residence and foreign workers make up almost 90% of the population, with the Indians being the largest community numbering around 545,000, followed by Nepalis, Filipinos, Egyptians, Bangladeshis, Sri Lankans and Pakistanis.

The country has the third-largest reserves of liquefied gas in the world and after oil exports increased in 1950s, employment opportunities attracted Arabs from other Gulf States and foreigers (mostly Indians) to Qatar. Foreign workers represented 94.2% of the total economically active population in Qatar in 2010 (Bel-Air 2014). As the economy is growing fast in Qatar, demand for foreign workers is expected to increase in the coming years. There are an estimated 1.2 million expatriates in the country, mostly working in the construction sector.

Qatar has become an important international center for various activities, political, sports, social, etc., which requires tremendous expansion in the infrastructure of various aspects of the civil life (Richer 2008). Due to population growth, economic development, rapid urbanization, large scale industrialization and environmental concerns of water stress, has emerged as a real threat. Enormous activities of constructions, a rapid disappearing of many coastal and inland habitats in Qatar would put wildlife, environment, and biodiversity in the country at real risk.

Scarcity of water resources is the main problem facing Qatar, as is the case in many countries in arid zones. There is no permanent surface water in Qatar and the search for groundwater has been practiced since early days. Since oil production began on a commercial scale in 1949, the social-economic changes resulted in a great need for water.

Continued population and economic growth raise concerns about water security. Qatar has experienced rapid economic growth due to the discovery of fuel oil and natural gas. The natural renewable water resources such as rainfall and groundwater are scarce (Darwish and Mohtar 2012). There are two main basins of groundwater in Qatar: the northern groundwater (NGW) and the southern groundwater (SGW); and three secondary basins Abu Samra, Doha, and the Aruma deep groundwater in the south of the country. The NGW basin is the most important GW source. It covers about 19% of the total land area and at 10-40 m below ground. The salinity of this basin varies from 500 to 3000 mg/l and increases towards the sea reaching 10,000 mg/l. The SGW basin extends to about half of the land area. The water levels are mostly at least 30 m below the surface and water salinity is relatively high, which is not suitable for agriculture (3000-6000ppm) (Abu Sukar et al. 2007; Darwish and Mohtar 2012). A very small amount of groundwater is treated to become potable water and is distributed to consumers. The municipal potable water mainly contains 99% desalted seawater and 1% groundwater. Most desalted water in Qatar is produced predominantly using desalting system. On the other hand, sewage network covers about 68% of all over Qatar’s building and 95% of Doha building (Darwish and Mohtar 2012). Treated wastewater is used to irrigate the ornamental trees found in the streets and public parks, while crop farms mainly depend on well water. The main source of water supply in Qatar is the desalination plants in Ras Abu Aboud and Ras Abu Fontas (IHW 1982). The first desalination plant in Qatar was commissioned in 1953 and the largest desalination facility is located in Ras Abu Fontas, in southern Doha, which meets most of the civilian sector’s demands. Other desalination plants are mainly used to supply water to the industrial sector in Dukhan, Ras Laffan, Mesaieed, Umm Bab, remote outskirts of Abu Samra, and the Ashamal Military Camp

(Darwish and Mohtar 2012). Overexploitation of groundwater can lead to intrusion of seawater and deep saline groundwater into freshwater aquifers and thus increase the salinity and concentration of dissolved substances. High concentrations of salinity and dissolved substances can make the water unsuitable for drinking water and agriculture purposes (MDPS 2013).

In Qatar, the urban wastewater is collected by sewerage and by tankers. Wastewater is connected to sewerage and treated in Urban Wastewater Treatment Plant "UWWTPs". Agriculture has become the most important user of treated wastewater (37% in 2013), followed by the government (16% used for irrigation of greenspaces). About 23% of the wastewater is used for deep injection into aquifers and about the same amount of treated wastewater is discharged to an open lagoon without further use (MDPS 2013).

2.2 Mosquito-borne diseases

Malaria is a major public health concern throughout the world caused by protozoan parasites of the genus *Plasmodium* and transmitted from person to person by female *Anopheles* mosquitoes. Five plasmodia species, namely: *Plasmodium falciparum* (Welch), *P. vivax* (Grassi), *P. ovale* (Stephens), *P. malaria* (Grassi) and *P. knowlesi* (Knowles) cause human malaria (Caraballo et al. 2014). Malaria is endemic in 108 countries around the world and cause death mostly among children under 5 years old. In the Arabian Peninsula and its neighbouring countries, malaria in people is the most common vector-borne disease in Yemen (Al-Taiar et al. 2006; Al-Mekhlafi et al. 2011), in Iran (Hanafi-Bojd et al. 2011a), in Iraq (Korzeniewski 2006), and in Saudi Arabia (Abdoon and Alshahrani 2003). Risk of imported malaria in the Arabian

Peninsula countries, such as Oman (Ganguly et al. 2009; WHO 2015), United Arab Emirates (Nilles et al. 2014), Kuwait (Iqbal et al. 2003), Bahrain (Ismaeel et al. 2004) and in Qatar (Al-Kuwari 2009; Khan et al. 2009) remains high due to the large number of immigrant workers from malaria-endemic countries.

West Nile virus (WNV) is a zoonotic virus, which causes neurological disease in both humans and horses was reported in Yemen (Qassem and Jaawal 2014), and has also been detected in Saudi Arabia (Al-Ghamdi 2014). Rift Valley fever virus (RVFV) is a member of the virus family Bunyaviridae. It is an important veterinary pathogen in Africa causing abortions and deaths in young animals, primarily goats and sheep. In 2000, an outbreak of Rift Valley fever was reported along the southwestern border of Saudi Arabia and Yemen (Miller et al. 2002).

Dengue is a vector-borne disease belonging to the genus *Flavivirus*, family Flaviviridae. It is transmitted by *Aedes* mosquitoes, *Aedes aegypyti* being the most important and primary domestic vector of urban dengue (Gubler 1998). The disease is endemic in more than 100 countries and around 2500 million people are at risk (WHO 2002; Knowlton et al. 2009). Epidemics of dengue fever has been reported from the Arabian Peninsula since the late 19th century, affecting many major cities such as Aden, Jeddah, Makkah, and Madinah (Gubler 1998). It is endemic in Makkah (Shahina et al. 2009) and in Jeddah (Ayyub et al. 2006; Jamjoom et al. 2016), which are the main entry points for the pilgrimage to Makkah and Madinah. Dengue fever and dengue hemorrhagic fever is a notifiable disease in Oman (Mohammed et al. 2010). Multiple dengue outbreaks have been reported in Yemen in recent years (Qassem and Jaawal 2014; Alyousefi et al. 2016)

2.3 Taxonomy of mosquitoes

Mosquitoes belong to the phylum Arthropoda, class Insecta, order Diptera. Many studies deal with the systematic taxonomy of mosquitoes such as Stojanovich and Scott (1966) who published a key based on adult females and fourth larval stage in Vietnam. Darsie and Ward (1981) published an illustrated keys to adult females and fourth-instar larvae of mosquitoes of North America and North of Mexico. Morphological keys to adult mosquitoes and fourth-instar larvae in Egypt, Iran and Saudi Arabid were published by entomologists including Glick (1992), Azari-Hamidian and Harbach (2009), and Al Ahmad (2011).

Mosquitoes are classified into two subfamilies, 11 tribes, 39 genera and 135 subgenera. Recentlkky, Harbach (2007) presented a classification of mosquitoes, which includes two subfamilies, 11 tribes, 111 genera, and 3528 species in the world fauna. *Ochlerotatus* was elevated to the rank genera from a subgenera level, which is considered as a most important change. In Iran, Azari-Hamidian and Harbach (2009) provided an illustrated key based on larvae and adult females of the genus *Ochlerotatus*.

2.3.1 *Anopheles* mosquito

The genus *Anopheles* includes seven subgenera and at least 465 species (Harbach 2007). Glick (1992) published an illustrated key to the female *Anopheles* of Southwestern Asia and Egypt, representing 39 species, three subspecies and two subgenera (*Anopheles* and *Cellia*). Azari-Hamidian and Harbach (2009) provided a key to 23 species of the genus *Anopheles* based on the fourth-instar larvae and adult females with taxonomic notes on the morphological variation of some species. Recently, Al Ahmad (2011) published a key based on 33 mosquito species belonging to nine genera recorded from Saudi Arabia using morphological characters of the fourth-instar larvae. Eleven of these species belong to the genus *Anopheles*. Further, two more *Anopheles* species were added to the fauna of Saudi Arabia; *An. culicifacies* (Giles 1901) and *An. subpictus* (Grassi 1899).

2.3.2 *Culex* mosquito

Thirty-four species of *Culex* belonging to seven subgenera; *Barraudius*, *Culex*, *Culiciomyia*, *Lasiosiphon*, *Lutzia*, *Maillotia*, and *Neoculex* were identified in southwestern Asia and Egypt (Harbach 1985). Harbach (1985, 1988) published a pictorial key to the genera mosquitoes, subgenerus of *Culex* and *Culex* species occurring in southwestern Asia and Egypt.

Azari-Hamidian and Harbach (2009) provided a key with morphological variations to the genus *Culex* based on the larvae and adult females of Iran. Al Ahmad (2011) provided a key to the identification of fourth-instar larvae, of 13 species belong to the genus *Culex* in Saudi Arabia. *Culex arbieeni* (Salem 1938), *Cx. simpsoni* (Theobald 1905) and *Cx. univittatus* (Theobald 1901) are the new species record for Saudi Arabia.

2.3.3 *Aedes* mosquito

In Iran, Azari-Hamidian and Harbach (2009) provided a key to the *Aedes* genus based on the larval and adult morphological variations. Al Ahmad (2011) identified fourth-instar larvae of Saudi Arabian mosquitos and described two species of the genus *Ochlerotatus*. In addtion, he identified the *Aedes* mosquito population in the western region of Saudi Arabia, especially in and around Jeddah based on morphological characteristics of the adult female four new species were described.

2.3.4 Mosquito morphology

The morphological description of mosquito females and their larvae were used in the keys for identification. The body of the adult female is divided into three principle regions: head, thorax, and abdomen. The characters of the head which are used in identification such as the shape of proboscis, scales on proboscies, length of palp, scales of palp, scales on antennal pedicel, length of antennae and flagellomere, width of frons, interocular setae and scales on dorsum of head. The thorax is divided into three segments: prothorax, mesothorax, and metathorax. There are some characters that are used in identification such as the size and scales of the anterpronota (AP), scutum (Scu) setae, size and colour, scutellum (Stm), which in the subfamily Anophelinae, is arcuate and bears an even row of seta while in the subfamily Culicinae, is trilobite with a group of setae on each lobe. The two functional wings their, scales, cells, and veins provide many useful key characters. Also, scale patterns of the abdomen and leg segments are used as key characters. The fourth instar mosquito larval body is divided into the head, thorax and abdomen. The head capsule is completely sclerotized while the thorax and abdomen are largely membranous. The larval body is covered with setae and various kinds of spicles. The organization and nomenclature of these structures are very important for larval identification (Figure 2.1) (Darsie and Ward 1981, 2005).

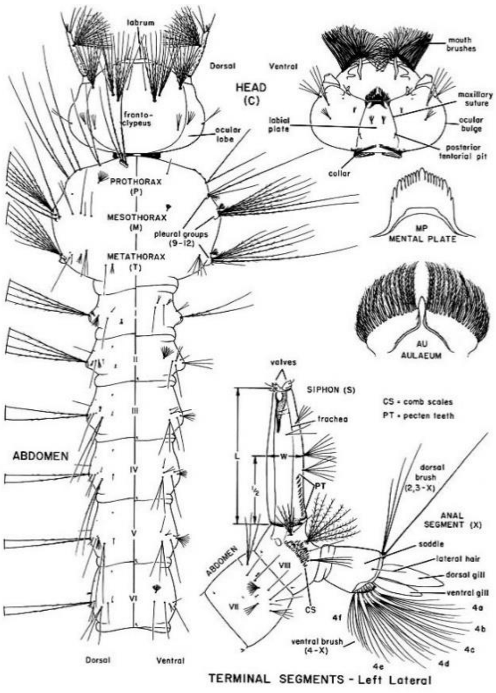

Figure 2.1 Fourth stage of larval mosquito after Belikn (1962).

2.3.4(a) Distinguishing Anophelines from Culicines

Family Culicidae is divided into two distinct subfamilies; Anophelinae and Culicinae. The two subfamilies can be distinguished through morphological features. Anopelinae adults are distiguished by the long palps of both sexes, which are approximately the same length as the proboscis (Becker et al. 2010; Stajanovich and Scott 1966; Darsie and Ward 1981). In males, the two apical segments of the palps are swollen and laterally flattened (Becker et al. 2010). Most adult Anophelinae has wings with distinct spots. The scutellum of anopheline females is evenly rounded and uniformly setose (Figure 2.2) (Becker et al. 2010; Stajanovich and Scott 1966; Darsie and Ward 1981). Usually adult anophelines have longer legs than culicines and can be identified by their resting position at 30-40° angle to the surface (Becker et al. 2010). The larvae have no visible respiratory siphon and seta1 of most abdominal segments is usually of the palmate type (Becker et al. 2010; Stajanovich and Scott. 1966; Darsie and Ward 1981). At the sides of the anterior margin of the thorax are two lobes. These reversible organs (notched organs) can be retracted and together with palmate setae on the abdominal segments, support the body when standing on a horizontal position at the surface film. The larvae of anophelines have the ability to rotate their head 180^{o} towards both sides while resting under the water surface in a horizontal position and feeding on particles from the surface film (Becker et al. 2010).

Figure 2.2 Lateral view of head and Posterior dorsal view of thorax of *Anopheles*. Scutellum (Stm), maxillary palpus (MPlp), proboscis (P) after Darsie and Ward (1981).

In the subfamily Culicinae, adults of both sexes have palps shorter than the proboscis. The head capsule is more or less squared or rounded and the antennae are of variable length (Becker et al. 2010). The scutellum of the adult is trilobed (Becker et al. 2010; Stajanovich and Scott 1966; Darsie and Ward 1981), and the seta are arranged in three sets in the lobes (Figure 2.3) except in Toxorhynchitini, which have an evenly rounded scutellum. The wings are broader than those of Anophelinae and have the cross veins r-m and m-cu well expressed. The legs are often scaled in a characteristic pattern. Abdominal terga and sterna are densely covered with scales. The larvae of Culicinae have a siphon (Becker et al. 2010; Stajanovich and Scott 1966; Darsie and Ward 1982).

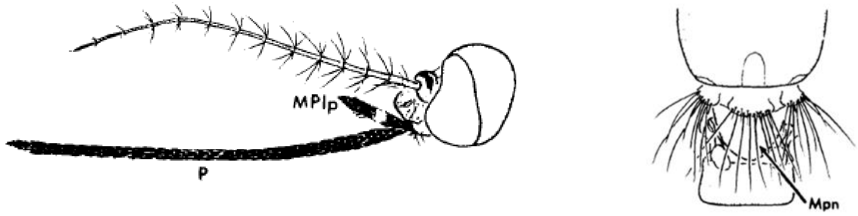

Figure 2.3 Lateral view of head and Posterior dorsal view of thorax of Culicine. Mesopostnotum (Mpn), maxillary palpus (MPlp), proboscis (P) after Darsie and Ward (1981).

2.4 Biology of mosquito

Mosquitoes have a holometabolous type of development; having four distinct stages in their life cycle; egg, larva, pupa and adult. The female adult lays eggs up to several hundred, either singly (*Aedes*, *Anopheles*) or in cluster (*Culex*, *Culiseta*) (Rueda 2008). Larvae and pupae are entirely aquatic. Larvae undergo shedding of the skin four times before pupation. Pupae do not feed and live for 1-3 days before adults emergence (Rueda 2008) (Figure 2.4).

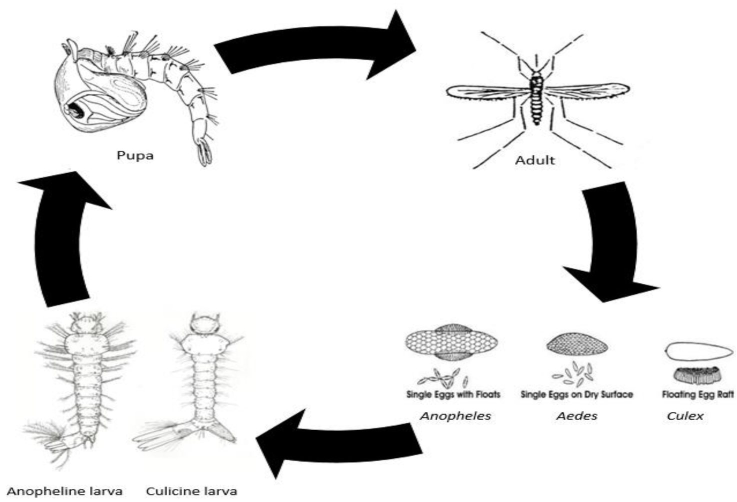

Figure 2.4 Mosquito life cycle after Rueda et al. (2008).

2.4.1 *Anopheles* life cycle

Anopheles females lay several hundreds of single eggs at a time on the surface of water or while hovering above it (Rueda 2008; Becker et al. 2010). Anopheline larvae possess a spiracular lobe at the VIII abdominal segment and lie horizontally at the water surface. Larvae of *Anopheles* can be found in association with other mosquito species in fresh-or-brackish-water marshes, mangrove swamps, grassy ditches, edges of streams as well as in small temporary water collections (Becker et al. 2010). The larvae sheds their cuticle four times at intervals, before reaching to the pupal stage. Under optimum conditions, development of pupa is complete, and it shed its skin and the adult emerges.

2.4.2 *Culex* life cycle

Culex females stand on the water surface with the hind-legs in a V-shaped position (Becker et al. 2010) and lay their eggs which are usually brown, upright on the water surface and placed together to form an egg raft which can comprise of up to about 300 eggs (Rueda et al. 2008; Becker et al. 2010, Service 2012). *Culex* eggs hatch within 2-3 days in the tropics, but in cooler temperateure countries they may not hatch until after 7-14 days, or longer, but they can not survive desiccation (Service 2012). *Culex pipiens* (Linnaeus 1758) females prefer to lay their eggs in a habitat rich with organic material. *Culex* eggs are non-dormant and hatch after a short time when the embryonic development is completed. *Culex pipiens* eggs hatch one day after the eggs had been laid at 30°C and the larvae can develop in a wide range of temperatures from 10 to 30°C (Becker et al. 2010). *Culex quinquefasciatus* requires a few days to develop from egg to adult between temperatures of 15-27°C (Rueda et al. 2008).

The larvae are filter feeders, and possess a siphon at the VIII abdominal segment and usually hang head downwards from the water surface where resting. Larvae molt four times at intervals, before reaching the pupal stage. When development of the pupa is complete, it shed its skin, and the adult emerges.

2.4.3 *Aedes* life cycle

Adult females lay single to several hundred eggs on the surface of the water (Rueda et al. 2008; Becker et al. 2010). *Aedes* eggs are usually black, more or less ovoid in shape and can withstand desiccation (Service 2012). The species have a variety of breeding habitats, such as tree holes during the dry season, in moist soil (e.g. *Ochlerotatus caspius* (Pallas 1771)) or in artificial breeding sites (Becker et al. 2010). *Aedes* spread to new geographical areas due to fact that most *Aedes* lay dormant eggs and dormant viable eggs are dispersed via transportation and stored used tires (Rueda et al. 2008). The embryonic development usually takes a longer time of 3-4 days at 20-25 °C and high water temperature stimulates larval development in usually 6-7 days at 30 °C before the pupation (Becker et al. 2010). Most *Aedes*/*Ochlerotatus* larvae hang head downwards from the water surface when at rest and collect their food by scraping or shredding microorganisms, algae, and protozon from the surface of submerged substance. The duration of the pupal stage may be reduced or extended, at higher or lower temperatures respectively (Becker et al. 2010).

2.5 Mosquito 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 such as ponds, streams, ditches, swamps, marshes, temporary and permanent pools, rook holes, tree holes, crab holes, lake margins, plant containers (leaves, fruits, husks, tree holes, bamboo nodes), artificial containers (tires, tin cans, flower vases, bird feeders), and other habitats (Rueda 2008; Rueda et al. 2010; Service 2012). Knowledge of larval habitats is important in determining vector control, as well as for disease prevention purposes. Knowledge of performance breeding site and oviposition of adult females and ecological data such as larval habitats, species composition, and active season, play an important role in the vector control management of mosquitoes (Azari-Hamidian 2011; Banafshi et al. 2013). A number of environmental factors effect the presence and density of Culicidae larvae have been investigated by many. The most practical way to reduce a local population of pestiferous mosquitoes is to eliminate their habitats as much as possible (Rueda 2008).

Curtis (1994) reported that *Cx. quinquefasciatus* is anthropophilic and feeds on birds as an alternative. It is found in urbanized area all over the tropic or subtropics and breed in wet pit latrines, incompletely sealed cesspits or open drains. *Aedes aegypti* is localized around its domestic breeding sites such as jars and discarded tires. *Anopheles gambiae* (Giles 1902) is adapted to breed in a site created by human or animal activities such as foot or hoof prints in marshy or irrigated land and *An. dirus* (Peyton and Harrison 1979) can breed in small forest pools.

A study was conducted in the Gambia by Fillinger et al. (2009) on the characteristics of larval habitats and most densely populated areas by anopheline larvae to estimate the numbers of adults produced in different habitats. They performed a case-control design using area samplers and emergence traps. The authors reported that *Anopheles* larvae have a variety of breeding habitats and the presence of malaria vectors larvae, which was positively associated with emergent vegetation and algae, their density decreases with increasing size of habitats, vegetation cover shading the habitats, presence of tidal water and when water depth is more than 50 cm and conductivity is above 2000 uS/cm. Whereas, pH, turbidity and oxygen saturation were not associated with larval density. A negative correlation was also found in the case of malaria vectors in the Gambia, wherein the conductivity above 2000 uS/cm led to significant reductions in the larvae density.

Minakawa et al. (1999) conducted a study in Kenya to characterize mosquito larval habitats and analyzed spatial heterogeneity of mosquito species during the dry season. They reported that anopheline larvae prefer open sun-lit waters. Water temperature of small sun-lit pools often reaches close to 40 °C and that might be an important factor to accelerate larval development and allow more microorganisms to grow which provide food sources for mosquito larvae. *Anopheles gambiae* s.l. is tolerant to relatively high water temperatures. Moreover, anopheline larvae were not found in shaded habitats, such as water tanks without soil substrates. Soil may provide nutrients for the enrichment of bacteria that serve as a food source for larvae, and possibly are oviposition attractant. Impoinvil et al. (2008) studied the abundance of *Anopheles* and culicines in different breeding sites of urban environment in Kenya. The authors observed that *Anopheles* mosquitoes particularly, *An. gambiae* was capable of colonizing urban water bodies. *Anopheles* and culicine immatures were found to have an aggregated distribution within different water body types, and lower interspecific mean crowding for *Anopheles* immatures compared to culicines in the same body type. In addition, they observed that *Anopheles* immatures tend to exist in the rain-dependent habitats, while culicines mostly occupy habitats resulting from drainage and sewage systems.

Mwangangia et al. (2009) studied the mosquito aquatic habitats to determine their seasonal distribution and composition in Kenya. They used a cross-sectional survey of mosquito habitats and detected anopheline larvae prefered temporary small pools and puddles where warm temperatures accelerate their larval-pupal development. *Culex* breed in a wide range of habitat. *Culex quinquefasciates* were found in all habitats investigated (puddles, tyres, temporary pools and reservoir tanks), and preferred to breed in habitats rich with organic material. The anopheline and culicine larvae coexisted in most habitats, while *Aedes aegypti* were only found in reservoir tanks.

In Ethiopia, Tadesse et al. (2011) reported that *Anopheles* showed a positive association with water transparency. *Anopheles* and *Culex* larvae were positively associated with dissolved oxygen and pH of more than 7, but both were not associated with water temperatures. Vegetation was also an important predictor of the presence of *Anopheles* and *Culex* larvae.

Gopalakrishnan et al. (2013) conducted a study to investigate the composition of disease vectors especially *Aedes* spp. and the physicochemical properties of natural and man-made water-holding containers. The study was conducted in India during four seasons; pre-monsoon, monsoon, post-monsoon and winter. They found that the predominant species was *Ae. albopictus.* Apart from *Aedes* mosquitoes, *Cx. quinquefasciatus* and *Armigeres subalbatus* were found to be widely distributed in the water-holding containers. They reported that larval density has a positive correlation with pH ranging from 6.72 to 7.63 and a negative correlation was observed with conductivity in the range of 162.9-616.9 µS/cm and salinity in the range of 0.09 to 0.39 ppt. The authors suggested that road transport perhaps was a reason for *Ae. aegypti* geographical spread and finding in semi-urban areas with close proximity to roads and vehicle garages.

Hanafi-Bojd et al. (2012) conducted a study to determine some ecological parameters of the anopheline species, physiochemical characteristics of their breeding places, and mapping the potential mosquito larval habitat in southern Iran. Eight anopheline species were found are five of them have been reported as malaria vectors. Dominant species was *An. culicifacies*, which is the main malaria vector in that region and was found in breeding habitats with relatively high salinity. *Anopheles stephensi* was also found breeding in a wide range of urban and rural habitats, utilizing all sources of water bodies, and was found in water with high salinity, sometimes reaching or even exceeding that of seawater. It was the species that was found in full sunlight water bodies with sandy beds. Azari-Hamidian (2011) focused on studying the larval habitats of *Anopheles* species, such as water temperature, in Guilan Province in Iran. Furthermore, Banafshi et al. (2013) studied the fauna and some aspects of the ecology of *Anopheles* and culicine larvae in Iran and reported that all collected larvae were found in natural habitats (river edges or ground pools) and no larvae were found in shaded habitats. The most interesting finding in this study is that the most prevalent collected species often occupied their habitat alone.

Abdullah and Merdan (1995) studied the composition and distribution of mosquito larvae in southwestern Saudi Arabia, focusing on the main features of species taxonomy and their habitat description. Sampling was performed in three different ecological region starting from sea level, moderately elevated to highest altitude using larval net. They detected nine species belonging to four genera; *Anopheles* (4 species), *Culex* (3 species), *Aedes* (1 species) and *Culiseta* (1 species). Among the *Anopheles* species, *An. arabiensis* (Patton 1905) was the most dominant and it is considered as a malaria vector in that region. Generally, they found that anopheline species prefer to breed in spring clean running shady shallow water. This breeding site is associated with algae or short herbs with salinity ranging from 0.3 -4 gm Cl^-/L, except for *An. multicolor* (Cambouliu 1902) which preferred higher salinity level (11.0- 25.0 gm Cl-/l); the pH ranged between 6.5- 8.0. *Culex pipiens* was the most dominant among the culicine species and they suggested that it might be due to its wide range of suitabile breeding sites, variable extremes of temperature, different altitudes, in wide range of salinity (0.3-2 gm Cl-/l) and pH 6.0-8.0. Meanwhile, *Cx. quinquefasciatus* was limited to coastal area in almost all months of the year and found breeding in a relatively high salinity area (2.0 -5.3 mg Cl-/l), a wide range of temperature (8- 28 °C) and pH range from 6.5 - 8.0. Generally, culicine species prefered to breed in shaded, vegetated habitats, having stagnant deep and shallow water. No significant was association found between prevalence of culicine species and turbidity, water depth and temperature. *Ochlerotatus caspius* larvae were found almost throughout the year in a wide range of breeding sites close to human inhabitants such as sewage, high salinity water with rotting organic materials. Alahmed (2012) recognized that *Culex* species larvae were the most abundant and where collected from a wide variety of breeding habitats in the eastern region of Saudi Arabia. The author detected that *Culex* species can exploit a wide variety of aquatic habitats due to their ability to tolerate highly polluted aquatic habitats and relatively saline water. In addition, presence or absences of shade, vegetation, degree of water motion and turbidity can play an important role in determining the suitability of various types of aquatic habitats for mosquitoes. Al-Thabiany et al. (2012) investigated the prevalence of container breeding mosquitoes, providing information on seasonal distribution and relative abundance of potential vector population in Makkah City. Mosquito larvae were more abundant during the cool rainy season due to the abundance of breeding habitats.

There is no in-depth study on mosquitoes of Qatar. Diversity and distribution of mosquitoes (Diptera: Culicidae) in Qatar has been investigated by extremely limited investigators. Mosquitoes were mentioned in a few studies that were focused on the insects of Qatar. Abdu and Shaumar (1985) found *Cx. molestus* and *Theobaldia* sp. in Alshahaniyah. Abushama (1997) studied the density and diversity of the desert arthropods of Qatar. Where by in this study *Culex pipiens* larvae from a temporary rain swamp/pool. Abushama (2006) found few mosquitos in a residence backyard in Doha city without identifying the species (Tables 2.1 and 2.2). Mikhail et al. (2009) studied the mosquito fauna in Qatar, in terms of composition, densities and vector-borne diseases. Larval surveys were conducted in different geographical areas and different habitats including; seepages, drains, wells, cesspits by dipping and netting. Six species belonging to three genera were collected; *Culex* was the dominant followed by *Anopheles* and *Ochlerotatus*. The six species collected were *Cx. pipiens*, *Cx. univittatus* (Theobald 1901). *Cx. pusillus* (Macquart 1850), *Oc. caspius, An. multicolor* and *An. stephensi* (Liston 1901). *Culex. pipiens* and *Cx. univettatus* were mainly present in Alrayyan, Doha, Alkhor and Althekira. *Culex pipiens* had the highest density in all municipalities. *Culex pusillus* was found in Doha and Aldaayan while *Oc. caspies* was found in Aldaayan and Alshamal. *Anopheles multicolor* and *An. stephensi* were mainly present in Alshamal and present in low density in Alrayyan

(Ain Khalid location) (Tables 2.1 and 2.2). Recently, Kardousha (2015) identified 10 species of mosquito larvae collected from Alkhor municipality in the northeastern of Qatar. These species belonged to three genera, *Culex* (eight species), *Anopheles* (one species), and *Ochlerotatus* (one species). The species encountered were *Culex pipiens molestus*, *Cx. univittatus*, *Cx. pusillus*, *Cx. quinquefasciatus*, *Cx. tritaeniorhynchus* (Giles 1901), *Cx. laticinctus* (Edwards 1913), *Cx. sitiens* (Wiedemann 1828), *Cx. perexiguus* (Theobald 1903), *An. stephensi*, and *Oc. caspius* (Tables 2.1 and 2.2). Ahmed (2015) identified species belonging to three genera in Alrayyan municipality; *Anopheles* (one species): *An. stephensi*, *Culex* (three pecies): *Cx. vagans* (Wiedemann 1828), *Cx. mimeticus* (Noe 1899), *Cx. bitaeniorhynchus*, and *Coquillettidia* (one specise) (Tables 2.1 and 2.2). Only two species were collected at the larval stage, while the rest were collected as adults by using light traps. *Anopheles stephensi* larvae were collected from a bucket filled with fresh water in partially shaded area with a pH ranging from 7.88 - 8.14. *Culex vagans* larvae were collected from construction water tank, leaking sewer water, and sewage swamp. The pH ranged from 6.2 - 7.88. Kardousha (2016a) using CDC gravid traps collected and identified six species belonging to three genera, *Culex* (three species), *Ochlerotatus* (two species) and *Anopheles* (one species), namely; *Cx. pipien molestus, Cx. quinquefasciatus, Cx. tritaeniorhynchus*, *Oc. caspius*, *Oc. dorsalis* and *An. stephensi* (Tables 2.1 and 2.2).

Table 2.1 Summary of history of mosquitoes reported from Qatar.

Genus/ Species	Site	Stage	Habitat	Author
Culex pipiens	Alkaraana	larvae	Treated sewage swamp	Abushama (1997)
	Alkhor, Nuaija, Doha, Alrayyan, Messaied, Aldaayen, Alshamal, Alshahaniya	Larvae		Mikhail et al. (2009)
	Alkhor, Althkhira, Ras Lafan, Alghuwiriya, Smaisma	Larvae & adults		Kardousha (2015; 2016)
				Walker and Pittaway (1987)
Cx. quinquefasciatus,				Harbach (1985)
	Alkhor, Althkhira, Ras Lafan, Alghuwiriya, Smaisma	Larvae & adults		Kardousha (2015; 2016a)
Cx. univittatus	Alkhor, Doha, Alrayyan, Alshahaniya, Mesaieed	Larvae		Mikhail et al. (2009)
	Alkhor, Althkhira, Ras Lafan, Alghuwiriya, Smaisma			Kardousha (2015)
Cx. pusillus	Doha, Aldaayen	Larvae		Mikhail et al. (2009)
	Alkhor, Althkhira, Ras Lafan			Kardousha (2015)
Cx. tritaeniorhynchus	Alkhor, Alghuwiriya, Smaisma	Larvae & adult		Kardousha (2015; 2016)
Cx. laticinctus	Alkhor, Althkhira, Alghuwiriya, Smaisma	Larvae		Kardousha (2015)
Cx. sitiens	Alkhor, Althkhira			
Cx. perexiguus	Alkhor, Althkhira, Ras Lafan, Alghuwiriya			
Cx. bitaeniorhynchus	Doha, Dukhan	Adults		Ahmed (2015)
Cx. vagans	Muaither, Alkaraana, Alshahaniya, Rawdat Rashed	Larvae & adults	Water tank, leaking sewage, sewer sewage swamp	
Cx. mimeticus	Dukhan	Adults		
Cx. molestus	Alshahaniya			Abdu and Shaumar (1985)
Anopheles spp				Walker and Pittaway (1987)
An. sergentii		Adult female		Glick (1992)
An. multicolor		Adult female		Glick (1992)
	Alrayyan, Alshamal	Larvae		Mikhail et al. (2009)
An. stephensi	Alrayyan	Larvae		Mikhail et al. (2009)
	Alkhor, Ras Laffan, Alghuwairiya, Smaisma	Larvae & adults		Kardousha (2015; 2016)
	Rawdat Rashed	Larvae	Artificial water container	Ahmed (2015)
Oc. caspius	Aldaayen, Alshamal	Larvae		Mikhail et al. (2009)
	Alkhor, Althikhera	Larvae & adults		Kardousha (2015; 2016a)
Oc. dorsalis	Alkhor	Adults		Kardousha (2016a)
Theobaidia sp.	Alshahaniya			Abdu and Shaumar (1985)
Coquillettidia		Adult		Ahmed (2015)