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Field Studies on Mosquitoes (Diptera: Culicidae) in the Western Coast of Saudi Arabia: Influence of Temperature, pH and Salinity of the Breeding Water on Larval Abundance

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ABSTRACT

The knowledge of the characteristics of the breeding habitats and the environmental factors affecting mosquito abundance can help in designing optimal vector control strategies, for this, mosquito larvae were biweekly surveyed for two years in six localities representing the western coast of Saudi Arabia. Temperature, pH and salinity of the breeding water were measured to examine the effect of such factors on larval density. *Cx. quinquefasciatus, Cx. theileri*, *Cx. pipiens* and *Cs. longiareolata* had wider temperature ranges (15 to 33 ºC) than *Cx. tritaeniorynchus*, *St. aegypti*, *An. multicolor*, *Cx. perexiguus*, *Cx. sitiens* and *An. d'thali* (17 to 33) and *Cx. torrentium* (26 ºC). *St. aegypti*, *Cx. pipiens,* Cx. *quinquefasciatus* and *Cs. longiareolata* breed in either acidic or alkaline water (pH: 4.2 to 9.5) while the rest of species breed entirely in alkaline water (pH: 7.0 to 9.6). *St. aegypti*, *Cx. tritaeniorynchus*, *Cx. quinquefasciatus*, *Cx. theileri* and *Cs. longiareolata* had wider salinity ranges (154 to 1990 ppm) than the other species (611 to 1972 ppm), i.e., all species breed in fresh / brackish water. Multiple Regression analysis indicated that densities (No larvae / 10 dips): (1) of the tested species: *Cx. pipiens*, *Cx. quinquefasciatus* ($P<0.05$), *Cx. tritaeniorynchus* ($P<0.01$), Cx. *theileri*, *Cx. sitiens*, *An. multicolor*, *St. aegypti* and Cs. *longiareolata* were directly related to temperature (b = 0.32 to 6.15), (2) of *Cx. pipiens*, *Cx. theileri*, *Cx. sitiens*, *An. multicolor* and *St. aegypti* were indirectly related to pH (b = -0.13 to -74.57), while those of the other species were directly related to pH (b = 2.44 to 23.60) and (3) of *Cx. quinquefasciatus*, *Cx. theileri* and *St. aegypti* were indirectly related to salinity (*b* = -0.002 to -0.017), while those of the other species were directly related to salinity (*b* = 0.002 to 0.074).

INTRODUCTION

The Western part of the Kingdom of Saudi Arabia “16° and 33° N, 34° and 56° E” (Wikipedia: https://en.wikipedia.org/wiki/KSA) includes the west coast, north of Asir. It contains a mountain chain (with peaks
rising to 3,000 meters, running south to north and decreasing gradually in elevation as it moves northward) and the coastal plain bordering the Red Sea. It also includes the most cosmopolitan city of Jeddah which is the main port for thousands of pilgrims as the first step on their trip to Holy Cities of Mecca (to the east) and Al Madinah (to the north).

In the mountains above Mecca and Jeddah is the town of Taif. Its elevation gives it a climate far cooler and pleasanter than either Jeddah or Mecca and without the uncomfortable humidity of the former cities. The coastal area of the Western Region is notorious for its humidity, with summer temperatures rising to above 40ºC. Three regions representing this part: (1) The Mecca Region (Makkah) “21°25′N 39°49′E” is the most populous region in Saudi Arabia, (2) The Al Madinah Region “25°0′N 39°30” is located along the Red Sea coast. and (3) Tabouk (Tabuk) Region “28°0′N 37°0′E” is located along the north-west coast of the country, facing Egypt across the Red Sea.

Fifty three mosquito species belonging to 11 genera: *Anopheles, Culex*, *Lutzia*, *Ochlerotatus*, *Stegomyia, Aedes* , *Aedimorphus*, *Fredwardsius*, *Culiseta*, *Uranotaenia* and *Orthopodomyia* are indigenous in the Kingdom, of which 35 species: 14 *Anopheles*, 14 *Culex*, 2 *Ochlerotatus* and 1 species each of *Lutzia, Stegomyia, Aedimorphus, Culiseta* and *Uranotaenia* are present in the western part of the Kingdom (Al Ali et al., 2008; Al Ghamdi et al., 2008; Alahmed et al., 2009; Kheir et al., 2010; Al Ahmad et al., 2011; Khater et al., 2013; Alikhan et al., 2014; Mahyoub et al., 2015; Hassan et al., in prep).

Several mosquito species of the western part are implicated as vectors of diseases either in this part or in the other parts of the Kingdom: *Cx. pipiens* may act as a potential vector of bancroftian filariasis (Omar, 1996) and a vector of West Nile Virus (Al-Ali et al., 2008). *Cx. tritaeniorhynchus* and *Am. v. arabiensis* are the main proven vectors of Rift Valley Fever virus (Jupp et al., 2002; Miller et al., 2002). Sindbis virus was isolated from *Cx. univittatus* (*Cx. perexiguus*) in the Eastern Region (Wills et al., 1985). *Ae. aegypti* (*St. aegypti*) is the primary vector of Dengue fever (El-Badry and Al-Ali, 2010). *An. arabiensis, An. stephensi, An. sergentii* and *An. fluviatilis* act as the malaria vectors (Daggy, 1959; Al- Seghayer et al., 1999; Abdoon and Alshahrani, 2003).

To control mosquitoes, a good knowledge and understanding of the relevant biology and ecology of the target species is of paramount importance (Seghal and Pillai, 1970; Gimnig et al., 2001). The knowledge of the ecological characteristics of the breeding habitats and the environmental factors affecting mosquito abundance can help in designing optimal vector control strategies (Overgaard et al., 2001). Moreover, understanding climatic factors (temperature, relative humidity and rainfall) influencing adults and larvae is the first step to control over mosquito vector distribution and abundance (Jemal and Al-Thukair, 2016).

Generally, mosquitoes breed in a wide range of habitats with different types of waters. The physical and chemical nature of the water probably determines the selection of the breeding sites (Seghal and Pillai, 1970). It was reported (Piyaratnea et al., 2005) that breeding water quality is an important determinant of whether female mosquitoes will lay their eggs, and whether the resulting immature stages will successfully complete their development to the adult stage.

There are no available studies on physical and chemical factors mainly temperature, pH and salinity relative to mosquito breeding in Saudi Arabia except that of Al-Ahmed et al. (2010) who suggested that the salt content and pH have no significant effects on the larval distribution of different species in Najran and of Jemal and Al-Thukair (2016) who examined the relationship between larval / adult mosquito abundance and climatic factors (temperature, relative humidity and rainfall) in the Eastern Province. So that, this study was undertaken to examine the ranges of temperature, pH and salinity of mosquito larval habitats and relation of such factors with the occurrence and abundance of a particular mosquito species in six localities representing the western coast of Saudi Arabia.

MATERIALS AND METHODS

The Study Area

The study was carried out in four sea ports (Jeddah: 21°32′36″N 39°10′22″E, Yanbu: 24°05′N 38°00′E, Duba: 27°20′57.3″N 35°41′46.2″E and Haql: 29°17′N 34°56′E) and 2 cities (Taif: 21°26′N 40°21′E and Mecca: 21°30′N 41°0′E) representing the 3 regions of the western part of the Kingdom namely Mecca, Al Madinah and Tabouk (Fig 1). In each locality, certain sites were selected for sampling mosquitoes. Each site was biweekly surveyed during the period from January 2013 to December 2014.

Fig. 1: surveyed localities

Mosquito Sampling

The larvae were sampled in the water bodies by dipping using a plastic dipper, 125 mm in diameter with a 90 cm aluminum telescoping handle. Three samples of 10 dips (a survey unit, SU) per breeding site were taken. Collected larvae were placed in labeled plastic bags (Nasco whirl pack 4002 filline U.S.A) and transported to the laboratory in a picnic ice box containing cold water to prevent overheating. At the laboratory, 3rd and 4th larval instars were killed with hot water and preserved in labeled specimen tubes containing 70% ethyl alcohol to be ready for identification. Collected larvae were identified according to keys of Mattingly and Knight (1956) and Al Ahmad et al. (2011). Along with larval collection, the water temperature, pH and salinity (ppm) were measured in situ using pH/EC/TDS/Temperature meters (Model Hi 98130, Hanna instruments Co. USA).

Data Analysis

The compiled ranges of water temperature, pH and salinity of the different breeding habitats were calculated for each larval species in all studied localities. Multiple Regression analysis was used to examine the relation of larval density (No / SU) with the temperature, pH and salinity of the breeding water. The regression equations were in the form of Larval density= a + b_1 temperature + b_2 pH + b_3 salinity where a = constant (intercept), b_1-b_3 are the slopes (regression coefficients). The slopes were tested for deviation from 0 by t-test. The PAST (PAleontological Statistics Version 2.08, Hammer et al., 2001) computerized software was used for statistical analysis.

RESULTS AND DISCUSSION

Ranges of the Breeding Water Temperature, pH and Salinity

Mosquitoes breed in a wide range of habitats with different types of waters that are known to be specific for certain species. The prevailing physicochemical parameters in these habitats are important factors for survival and development of mosquitoes (Oyewole et al., 2009) and probably determine the selection of the breeding sites
(Seghal and Pillai, 1970). Moreover, It was reported that the breeding water quality is an important determinant of whether female mosquito will lay their eggs, and whether the resulting immatures will successfully complete their development to the adult stage (Piyaratnea et al., 2005). Mosquito immatures are poikilothermic and therefore, their activity depends to a large extent on the temperature of the water they inhabit. Besides nutrition, temperature is the main factor that affects the development and growth of mosquito larvae (White,

1974). In general, an increase in water temperature will result in faster development of aquatic stages, but will decrease the size of the emerging adults (Bayoh and Lindsay, 2003), decrease larval survival and at higher temperatures fewer adults are produced due to increased mortality (Bayoh and Lindsay, 2004).

In the present study (Figure 2), *Cx. quinquefasciatus* (15 to 33 ºC), *Cx. theileri* (15 to 31 ºC), *Cx .pipiens* (15 to 29 ºC) and *Cs. longiareolata* (15 to 29 ºC) had wider temperature ranges than those for *Cx tritaeniorynchus* (17 to 31 ºC), *St. aegypti* (17 to 33 ºC), *An. multicolor* (18 to 28 ºC), *Cx. perexiguus* (20 to 26 ºC), *Cx. sitiens* (22 to 33 ºC) and *An. d'thali* (28 to 33 ºC). *Cx. torrentium* collected only from water had temperature of 26ºC. In general, a compiled temperature range of 15 to 33 ºC (mean 24.0 ºC) was observed for the eleven reported species altogether. More or less similar range of 16.4 to 27.7 ºC was found suitable for production and survival of larvae (*Culex, Aedes* and *Anopheles* genera) in the Eastern Province, Saudi Arabia and in the summer season, the average temperature in this area became greater than 35 ºC which is unsuitable for larval growth (Jemal and Al-Thukair, 2016). Different temperature ranges were reported in several Egyptian Governorates such as 21 to 29 ºC (Kenawy et al., 1998), 18 to 30 ºC (Abdel-Hamid et al., 2009), 23 to 28 ºC (Abdel-Hamid et al., 2011a), 22 to 28 ºC (Abdel-Hamid et al., 2011c) and 17 to 30ºC (Kenawy et al., 2013). Moreover, WHO (1975) stated that the average optimum temperature for development of most mosquito species is around 25-27°C.

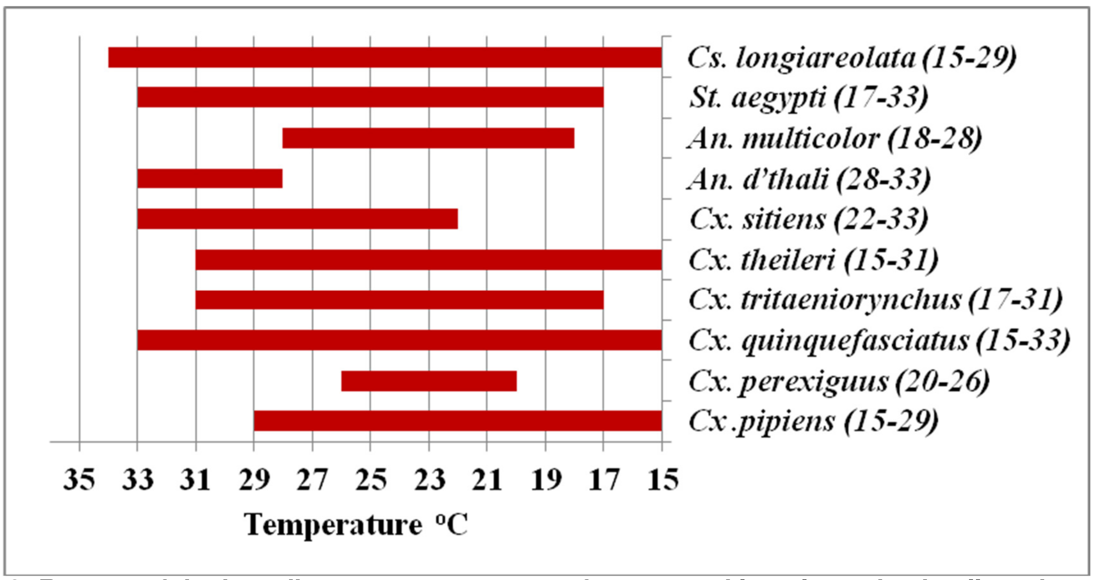

Fig. 2: Ranges of the breeding water temperature for reported larval species in all study areas

MacGregor (1927) recorded acidophile and alkalinophile mosquito larval species. For the reported species, the observed pH ranges (Figure 3) indicate that *St. aegypti* (4.2 to 9.3), *Cx. pipiens* (4.5 to 9.1), *Cx. quinquefasciatus* (5.0 to 9.5) and *Cs. longiareolata* (5.0 to 8.8) breed in either acidic or alkaline water (overall range: 4.2 to 9.5). The observed acidic to alkaline range is similar to 6.4-9.0 observed by Gad and Salit (1972) in the Red Sea, Egypt and 5.0-8.7 for *Cx. pipiens*, *Cx. perexiguus* and *Oc. caspius* in Cairo (Kenwy et al., 2013). While *Cx. sitiens* (7.0 to 9.5), *Cx. tritaeniorynchus* (7.3 to 9.1), *An. multicolor* (7.5 to 9.6), *An. d'thali* (7.5 to 8.6), *Cx. theileri* (8.0 to 9.6) and *Cx. perexiguus* (8.1 to 8.8) breed entirely in alkaline water (overall range: 7.0 to 9.6). *Cx. torrentium* collected only from water had pH of 8.5. Although some breeding was observed in acidic water however, most of larval breeding was in alkaline water in agreement with the observations of Kirkpatrick (1925), kenawy and El Said (1990), Kenawy et al. (1998) and Abdel-Hamid et al. (2013) who indicated that mosquito breeding water in several Egyptian Governorates was mostly alkaline (>7).

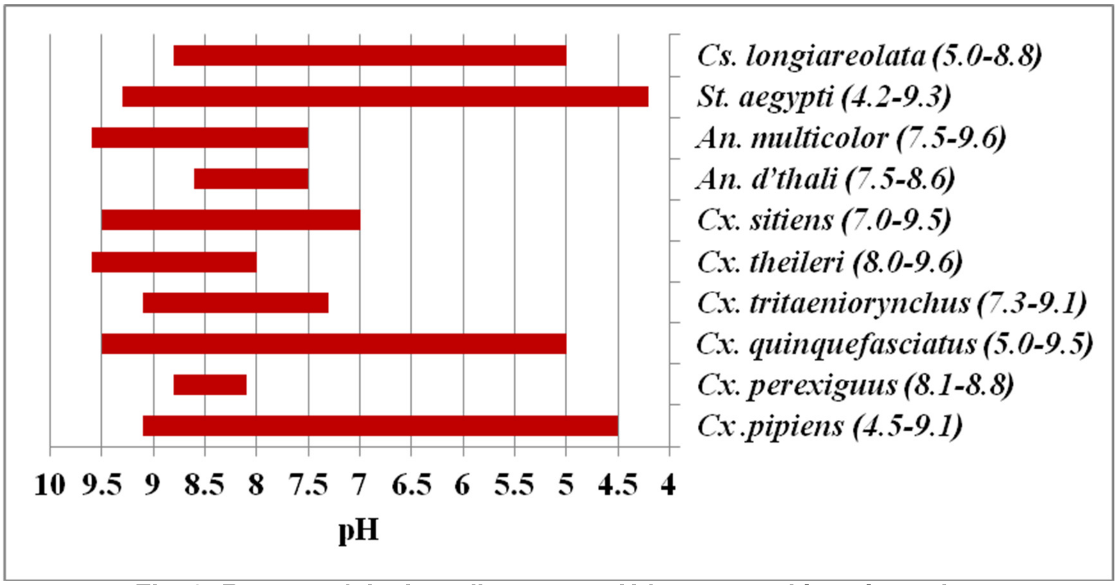

Fig. 3: Ranges of the breeding water pH for reported larval species in all study areas

For the breeding water salinity, no available data for Saudi Arabian mosquitoes as do for other countries. Based on water salinity, Kirkpatrick (1925) classified mosquito fauna of Egypt to purely fresh water breeders, purely salt water and more or less indifferent. In the present study, the eleven larval species generally have a salinity range of 154 to 1990 ppm (*ca.* 0.02 to 0.20%) indicating that these species breed in fresh / brackish water in agreement with the observation of Abdel-Hamid et al. (2011b) for *Cx. pipiens* and *Cx. perexiguus* in El-Ismailia and Kenawy et al. (2013) for five species (*Cx. pipiens, Cx. perexiguus, Cx. pusillus, Oc. caspius,* and *Cs. longiareolata*) in Cairo, Egypt. The observed salinity ranges for the reported species (Figure 4) indicate that: *St. aegypti* (154 to 1690 ppm), *Cx. tritaeniorynchus* (210-1866 ppm), *Cx. quinquefasciatus* (340 to 1752 ppm), *Cx. theileri* (340 to 1990 ppm) and *Cs. longiareolata* (360 to 1620 ppm) had wider ranges than *Cx. pipiens* (611 to 1972 ppm), *Cx. perexiguus* (676 to 1227 ppm), *Cx. sitiens* (700 to 1500 ppm), *An. d'thali* (710 to 840 ppm), and *An. multicolor* (962 to 1830 ppm). *Cx. torrentium* collected only from water had salinity of 907 ppm.

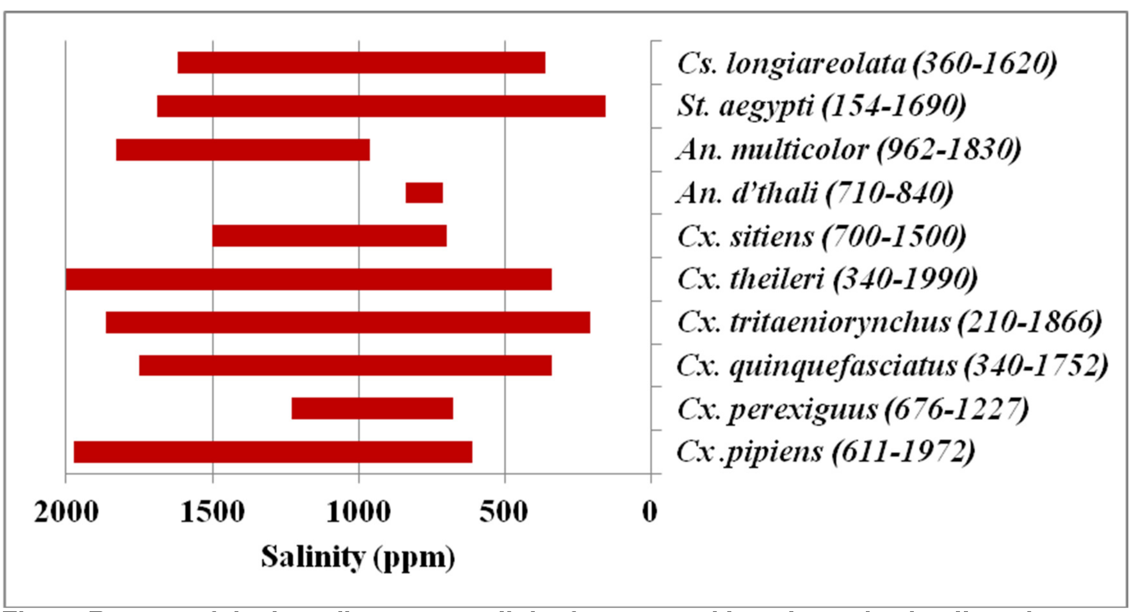

Fig. 4: Ranges of the breeding water salinity for reported larval species in all study areas

Influence of the Breeding Water Temperature, pH and Salinity on Larval Density

Multiple Regression analysis was used to examine the relation of larval density (No / SU) with the temperature, pH and salinity of the breeding water. Results (Table 1) indicate that:

Table 1: Multiple regression analysis for the effect of temperature, pH and salinity on larval densities of the reported mosquito species.

Species	The slope (regression coefficient, b)		
	Temperature	pH	Salinity
Cx .pipiens	1.959	-0.133	0.040
Cx. quinquefasciatus	2.641*	2.442**	-0.017
Cx. tritaeniorynchus	4.241**	23.600**	0.016
Cx. theileri	1.236	-18.059	-0.002
Cx. sitiens	6.151	-74.570**	0.074
An. multicolor	0.516	-3.167	0.013
St. aegypti	1.045	-4.016	-0.009
Cs. longiareolata	0.323	3.503	0.002

***P<0.05, **P<0.01 (t- test)**

(1) Densities of all species were directly related to temperature i.e., increase as temperature increases. With the exception of *Cx. quinquefasciatus* (b = 2.64, P<0.05) and *Cx. tritaeniorynchus* (b = 4.24, P<0.01), the b values (0.32 to 6.15) of the other species (*Cx. pipiens*, Cx. *theileri*, *Cx. sitiens*, *An. multicolor*, *St. aegypti* and *Cs. longiareolata*) were insignificantly different (P>0.05). However, in the Eastern Province, Jemal and Al-Thukair (2016) observed that mosquito larval abundance has a negative correlation with temperature (mean correlation coefficient = -0.773 for the whole Province: -0.075 to -0.941 for the 8 study sites). The authors indicated that regression model of the 3 climatic factors (temperature, relative humidity and rainfall) accounted for 64.3% (R= 0.643) of the variance in larval abundance and the remaining 35.7% attributed to other factors such as the presence of vegetation, waste materials and water reservoirs such as ditches.

(2) Larval densities of *Cx. pipiens*, *Cx. theileri*, *Cx. sitiens*, *An. multicolor* and *St. aegypti* were indirectly related to pH (b = -0.13 to -74.57), while those of *Cx. quinquefasciatus*, *Cx. tritaeniorynchus* and *Cs. longiareolata* were directly related to pH (b = 2.44 to 23.60) and (3) Larval densities of *Cx. quinquefasciatus*, *Cx. theileri* and *St. aegypti* were indirectly related to salinity (b = -0.002 to -0.017), while those of *Cx. pipiens*, *Cx. tritaeniorynchus*, *Cx. sitiens*, *An. multicolor* and *Cs. longiareolata* were directly related to salinity (b = 0.002 to 0.074). No comparable study for Saudi mosquitoes except that of Al-Ahmed et al. (2010) which suggested that the salt content and pH have no significant effects on the larval distribution of the different species in Najran. However, several studies in Egypt and other countries support the present findings. Kenawy et al. (1996) in El Sharkia Governorate, Egypt reported that densities of *Cx. antennatus* and *Cx. perexiguus* significantly (P<0.05) increased as a linear function of pH and temperature of the breeding water. Kenawy et al. (1998) in El Sharkia rice fields, Egypt observed that the relation of larval densities of *Cx. antennatus* and *Cx. perexiguus* were positive with pH and negative with temperature. Sunish and Reuben (2002) investigated the relationship of 13 abiotic variables with the abundance of *Cx. vishnui* immatures in rice fields in south India and indicated a positive relation with water temperature. Abdel-Hamid et al. (2011a) in El Menoufia Governorate, Egypt found that the total larval density of *Cx. pipiens, Cx. antennatus* and *Cx. perexiguus* decreased as both temp and pH increased (P>0.05). Abdel-Hamid et al. (2009, 2011b, 2013) in 3 Egyptian Governorates indicated that the overall larval density of *Cx. pipiens, Cx. antennatus* and *Cx perexiguus* increases as temperature increase (P<0.05) while it decreases (P>0.05) as pH increase. Kenawy et al. (2013) indicated that densities of both *Cx. pipiens* and *Cx. perexiguus* in Cairo had positive relation with temperature and pH (P>0.05) and negative relation with salinity (P<0.05). Kadhem et al. (2014) showed that *Aedes caspius* had insignificant positive correlation with pH and temperature, *Culex pipiens* had insignificant negative correlation with pH and temperatureand *Culiseta longiareolata* had significant negative correlation with pH (P<0.05) and temperature (P<0.01).

CONCLUSION

The obtained different ranges of temperature, pH and salinity and relations of such factors with the abundance of the reported larval species may be of help in designing and implementing control program based on environmental manipulation or modifying habitat characteristics that will be effective in controlling targeted mosquito species specially disease vectors.

COMPETING INTERESTS: The authors declare that there is no conflict of interests.

AUTHORS' CONTRIBUTIONS:

MIH: Participated in preparation of draft article and approved final Ms.
HAA: Carried out field studies.
MS: Participated in preparation of draft article and approved final Ms
MAK: Partly participated in field studies, carried out statistical analysis and prepared the draft and final Ms.

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