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A survey of Culicidae (Insecta Diptera) in some habitats in Souk-Ahras province (Northeast Algeria)

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ABSTRACT A survey of immature Culicidae was conducted in diverse habitats of Souk-Ahras province (Northeast Algeria) between December 2018 and November 2019. Altogether, 12,861 specimens were collected and identified. Nineteen species of mosquitoes, belonging to two main subfamilies viz. Culicinae (accounts for 84.21 %) and Anophelinae (as 15.79 %), under 5 genera (*Culex, Culiseta, Anopheles, Aedes* and *Uranotaenia*). Among identified species, six were mentioned for the first time in the province of Souk-Ahras. The predominant species of the total mosquito fauna was *Cx. pipiens* L. with an abundance rate of 69.63 %. Two habitats were characterized by the highest prevalence of 11 species, Taoura (with 1 spp. Anophelinae, 10 spp. Culicinae) and Sedrata (with 11 spp. of Culicinae). However, Souk-Ahras site contained the largest abundance (41.20 %) belonging to 6 species. In addition, the spatial distribution of mosquitoes according to climatic factors (temperature, rainfall, humidity) was discussed. Data supported by some ecological indices of composition and structure revealed that the diversity level in Souk-Ahras province was between medium and very low compared to a scale varied between 0 and 1 (global Simpson index 0.50). The most diversified site in species was Taoura with the highest Shannon index value (2.11). Since vectors occurrence is constantly changing, it will be suggested that mosquito control should be intensified within other potential breeding sites in northeastern Algeria.

KEY WORDS Biodiversity; Climate; Distribution; Mosquito; Systematic.

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INTRODUCTION

Due to their epidemiological impacts in viral infections, several mosquito species are among the world's most major arboviral vectors (Tandina et al., 2018; Jones et al., 2020), such as Chikungunya (Prudhomme et al., 2019) and Zika (Kauffman & Kramer, 2017). Understanding ecology, trophic preferences, and spatiotemporal distribution of these insects seems critical to implementing effective control programs. Because they are confined in water, it is more practical to control the mosquito's larvae with different ecofriendly insecticides like insect growth disruptors (Hamaidia K. & Soltani 2014; Hamaidia K. et al., 2018; Hamaidia K. & Soltani, 2019) or biopesticides (Dris et al., 2017a, 2017b; Djeghader et al., 2018; Bouzidi et al., 2020).

In addition to the influence of spatio-temporal patterns on the presence of species and their larval development, altitude also plays an important role (Zimmerman, 2019). Environmental changes, trade, and tourism caused several mosquito-borne disease outbreaks which required strengthening vector management programs (Karungu et al., 2019). In the same region, climate change could cause fluctuations in species composition leading changes in dynamics transmission of mosquito-borne diseases (Afrane et al., 2012). There are positive correlations between rainfall and annual abundances in *Culex pipiens* and Ochlerotatus detritus (Roiz et al., 2014), while the presence of Cx. quinquefasciatus relies on humidity (Asigau & Parker, 2018). Temperature and rainfall were highly correlated with the abundance of mosquitoes as well (Simon-Oke & Olofintoye, 2015; Hamaidia K. et al., 2016). A series of predictions between climate conditions, local vector dynamics and spatiotemporal dynamics of dengue has been reported (Li et al., 2019). *Aedes albopictus* abundance was highest in forest edge habitats, while *Culex* mosquitoes were found in human settlements (Brown et al., 2018). Outside of climatic factors, house age was found to be coherently associated with Ae. aegypti abundance; older houses had more mosquito eggs (Walker et al., 2011). Also, land cover influenced mosquito distribution, as *Cx. tarsalis* and *Ae. vexans* were positively correlated with grass/hay and wetlands respectively (Chuang et al., 2011). However, biodiversity analysis indicated that species diversity in rural, urban and uninhabited areas was similar (Khoobdel et al., 2019). New progress requires as much attention to mosquito ecology as to their molecular biology (Godfray, 2013).

Climate change has become a top threat to biodiversity from genes over species to biome level (Sintayehu, 2018). Since aquatic landscapes are particularly vulnerable (Pletterbauer et al., 2018), it is predicted that climate change will affect the mosquitoes' distribution (Reinhold et al., 2018), and consequently will impact vector-borne diseases and health (Fouque & Reeder, 2019; Pathak et al., 2019).

Although several studies have been carried out over the past two decades on the biodiversity of mosquito-fauna in Algeria (Messai et al., 2010; Bouabida et al., 2012; Lounaci et al., 2014; Benhissen et al., 2014; Merabti et al., 2017), there is always a lack in our knowledge of the culicidian fauna in Souk-Ahras province. Only three surveys were accomplished (Hamaidia K. et al., 2016; Benmalek et al., 2018; Hamaidia H. & Bershi, 2018). In addition, some vector species have been reported in Algeria (Larfi et al., 2014; Benallal et al., 2019).

Therefore, the present study aims to update the inventoried list of Culicidae family in five habitats in Souk-Ahras region (Northeast Algeria) and provides insights into its composition and highlights, by several ecological indices, some of climate variables (temperature, rainfall and humidity) involved in its fluctuation. Data obtained permit us to enhance sustained mosquito control and management strategies.

MATERIAL AND METHODS

Study area

Souk-Ahras province, located in the far Northeast Algeria (Fig. 1), is characterized by a multitude of landscapes. The climatic conditions characterizing this region were predominantly distinguished by a sub-humid climate (warm summer and cold winter), with average annual temperature between 5.5 °C and 26.8 °C and an annual rainfall of 0 to 330.3 mm. The study area comprised five sampling sites. In total, 19 immature mosquitos' biotopes have been selected on the basis of their accessibility and the presence of mosquito immature instars; Souk-Ahras, Zarouria, Mechroha, Sedrata and Taoura communes at an altitude of 653, 743, 769, 811, 839 m, respectively. This mountainous region is known for its agricultural landscapes, its dense forest cover and several rivers flowing through it.

The larval breeding sites of Sedrata, 36°7'44"N 7°31'41"E, were located in Oued Krab containing aquatic vegetation, near to human habitations and dumps, placed 6-8 km from a wastewater treatment plant. The site of Taoura, 36°10'3"N 8°2'25"E, is a permanent lake near a forest cover. Breeding sites of Souk-Ahras commune, 36°17'11"N 7°57'4"E, were situated in Oued Medjerda that flows through it. For Mechroha, 36°21'30"N 7°50'21"E, different habitats were prospected: rural (less profound with dense vegetation) and artificial larval habitats (without vegetation and clean water). Zarouria, 36°13'42"N 7°57'22"E, habitats were located in Oued Hamam Tessa (poor vegetation, rural zone, pollution, agricultural lands).

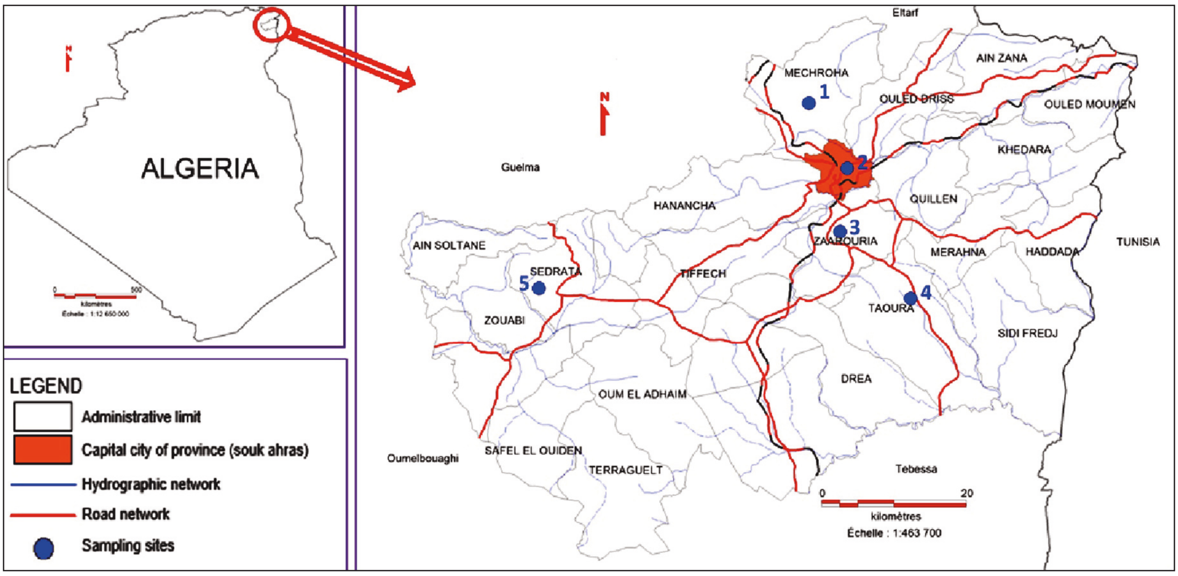

Figure 1. Sampling sites of immature mosquitoes in Souk-Ahras province (1: Mechroha; 2: Souk-Ahras; 3: Zarouria; 4: Taoura and 5: Sedrata).

Mosquito sampling, rearing and identification

Over 12 months (from December 2018 to November 2019) immature mosquitoes from each larval breeding site of the study region were sampled bi-monthly using "dipping" technique with a metal dipper (300 ml). Ten dips were taken from each. Samples were brought back alive to the laboratory of Sciences and Technical Water and Environment, Mohamed Cherif Messaadia University (Souk-Ahras, Algeria). Larvae were sorted by station and date and stored in labeled tubes containing 70% ethanol until their identification. Rearing of collected pupae was carried out in cubic cages covered with net at 25 ± 2°C until adult emergence. Culicidae larvae and laboratory-reared adults were frozen at -18°C for 20 min. External morphology-based identification to species of specimens was made according to the software of Brunhes et al. (1999).

Data analysis

To express the Culicidae fauna diversity in Souk-Ahras province, different statistical tools, graphs and indices were used in the present study to assess the alpha diversity between five contrasting habitats. The species richness (S) and the number of individuals (Abundance A) of each species present were recorded in the study sites. All analyses were performed using R, version 3.6.1 (R Core Team 2019; Ihaka & Gentleman, 1996) for MacOS (http://cran.r-project.org). Graphs (Barplots, Corrplots, Cleveland plots, Pie Donut plots and two y scales plots) and ecological indices (Shannon-Weaver diversity index H', Simpson's index D, Piélou's evenness index J' and Sørensen similarity index) were obtained by using the following R packages : '*ggplot2*' (Wickham, 2016), '*ggcorrplot*' (Kassambara, 2019) , '*webr*' (Moon 2020) and '*EcoIndR*' (Guisande et al., 2017). Furthermore, to investigate a possible association between species abundances and three measured climatic parameters (mean temperature, average rainfall and average humidity), we calculated Spearman's rank correlation with a significance level of $\alpha = 0.05$ using 'Hmisc' R package (Harrell, 2020).

RESULTS

Inventoried species

Following our survey covering five simple sites in Souk-Ahras province, a total of 12,861 specimens of mosquitoes (Diptera Culicidae) were collected and identified (Table 1; Fig. 2). Data recorded 19 mosquito species belonging to 2 subfamilies Culicinae (84 %) and Anophelinae (16 %), divided into 5 genera: *Culex, Culiseta, Anopheles, Aedes* and *Uranotaenia* (Fig. 3) as follows: *Cx. pipiens* (Linnaeus, 1758), *Cx. hortensis* (Ficalbi, 1889), *Cx. theileri* (Theobald, 1903), *Cx. simpsoni* (Theobald, 1905), *Cx. antennatus* (Becker, 1903), *Cx. martini* (Medschid, 1930), *Cx. adairi* (Kirkpatrick, 1926), *Cx. territans* (Walker, 1856), *Cx. arbieeni* (Salem, 1938), *Cx. quinquefasciatus* (Say, 1823), *Cx. laticinctus* (Edwards, 1913), *Cs. morsitans* (Theobald, 1901), *Cs. annulata* (Schrank, 1776), *Cs. longiareolata* (Macquart, 1828), *An. labranchiae* (Falleroni, 1926), *An. claviger* (Meigen, 1804), *An. marteri* (Senevet et Prannelle, 1927), *Ae. flavescens* (Mueller, 1764) and *Ur. unguiculata* (Edwards, 1913). The most dominant genus was *Culex* (89.78 %) of the total inventoried fauna with 11 spp., with abundance of *Cx. pipiens* (69.63 %). The other genera *Culiseta, Aedes, Uranotaenia* and *Anopheles* were the least prevalent (9.02 %, 0.27 %, 0.19 % and 0.73 %, respectively).

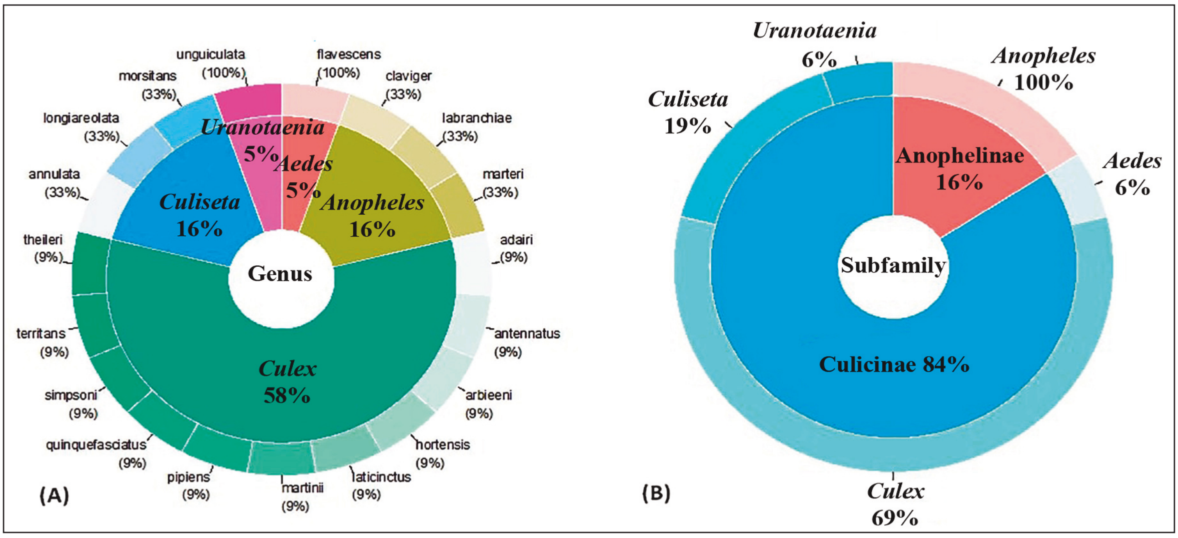

Figure 2. Ratios recorded between the different genera (A) and between the different subfamilies (B) of Culicidae fauna in Souk-Ahras province.

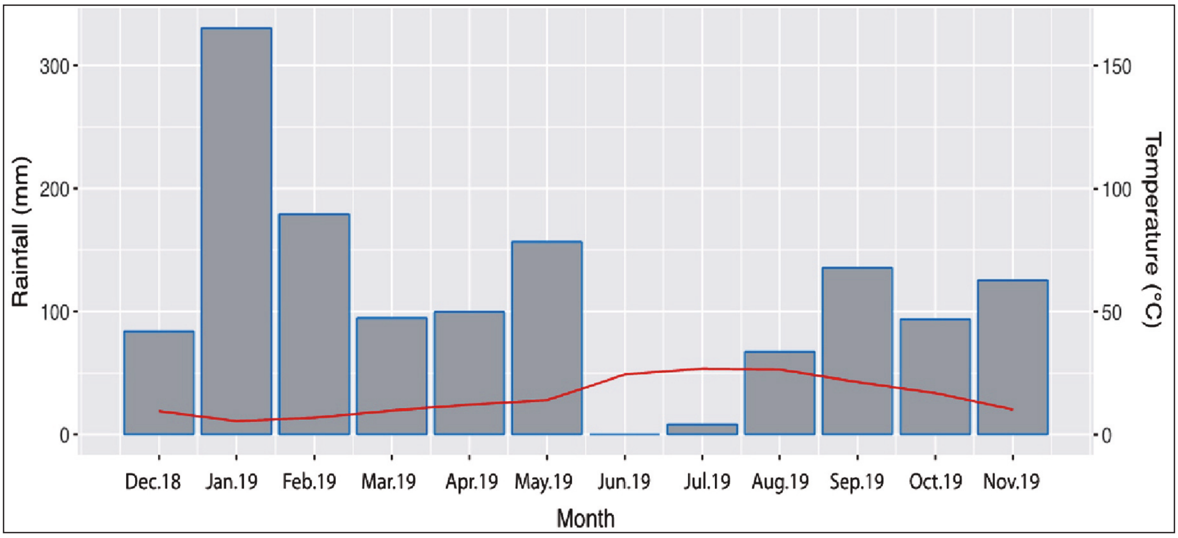

Figure 3. Monthly variation of rainfall (mm; barplot) and temperature (°C; solid line) in Souk-Ahras province during the studied period (December 2018 to November 2019).

Seasonal fluctuation of abundances

Three ecological factors (mean temperature, average rainfall and average humidity) were considered of all sites. During December 2018 to November 2019 period, the average maximum and minimum temperatures were 26.8 °C and 5.5 °C in July and January, respectively. As shown in Fig. 3, two wet periods were noted; between December 2018 and March 2019, then from September to November, separated with a long dry season from May to September 2019.

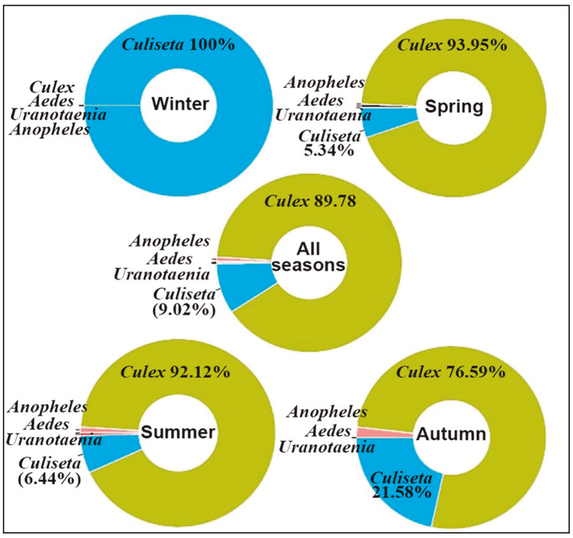

Figure 4. Seasonal genera composition of collected mosquitoes in Souk-Ahras province during December 2018 - November 2019 period.

The collected data revealed that the highest numbers of mosquitoes (overall abundances) were collected in summer (6,042) and spring (4,942 specimens), while the lowest ones were found in both autumn (1,747 specimens) and winter (130 specimens). According to figure 4, the genus *Culex* predominated the following seasons: spring, summer and autumn with 93.95, 92.12 and 76.59 % rates respectively. In contrast, winter season was dominated only by the *Culiseta* genus.

Variation in overall abundances (A) of mosquitoes depending to temperature is provided in figure 5. During cold rainy season, mosquito overall abundance was significantly reduced because of the destruction of some breeding sites by precipitations or the instability of others. Major fluctuations between the overall abundances of different taxa were observed in this study. *Cs. longiareolata* was collected from prospected habitats all over the year (four seasons). *Cx. pipiens* and *Cx. theileri* were found during spring, summer and autumn seasons because larval and adult populations have seasonal fluctuations and that overwintering females enter hibernacula in autumn and survived to emerge in the spring after complete hibernation (Simsek, 2004; Andreadis et al., 2010). For *Cx. hortensis*, it was harvested only during two seasons (spring and summer). Dynamics of *Cx. hortensis* populations followed a classic ther-

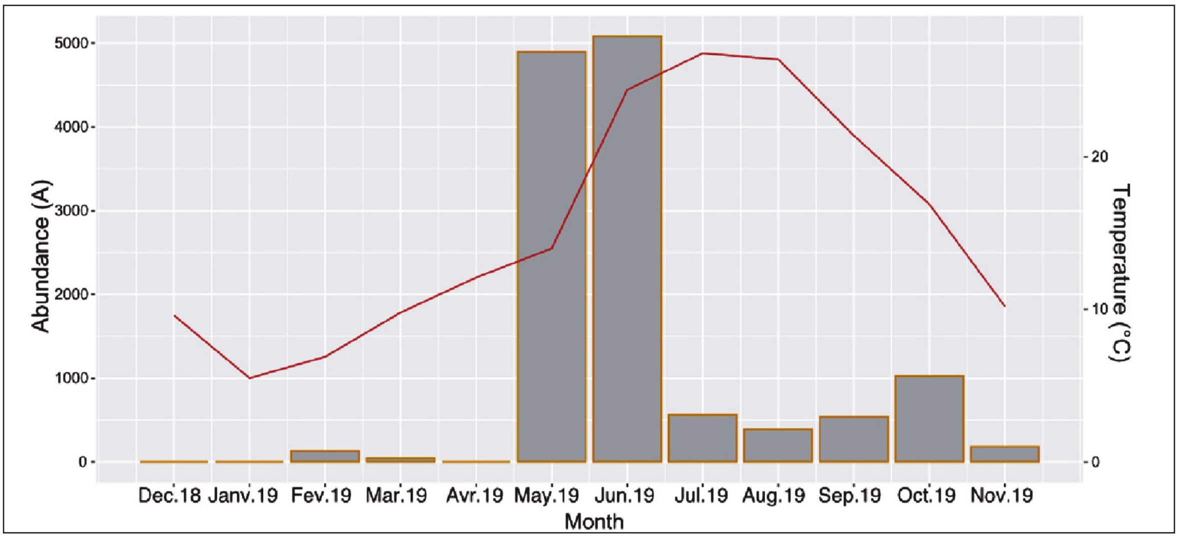

Figure 5. Monthly variations of mosquitoes overall abundances (barplot) in relation with mean temperature changes (solid line) in Souk-Ahras province during the studied period (December 2018 to November 2019).

mophilic trend (Lounaci et al., 2016); three spring species (viz. *Cx. simpsoni, Cx. antennatus* and *Cx. territans*) and one summer species (*Cx. laticinctus*) were found in our study sites. The statistical analyses revealed firstly, that temperature and rainfall were negatively correlated (r = - 0.68; p = 0.015), while humidity had positive and negative correlations respectively with rainfall (r = 0.70; p = 0.011) and temperature (r = -0.84; p = 0.007) (Fig. 6). These correlations could facilitate the explanation of the climatic changes in Souk-Ahras province. Secondly, we noticed also that the overall abundance of species was highly correlated with temperature (r = 0.73; p = 0.008) and relative humidity (r = -0.69; p = 0.010), but no significant correlation was found between overall abundances and rainfall (p > 0.05).

Mosquito taxa and ecological indices

In different ways the indices describe taxa richness and the distribution of individuals among taxa. The greatest number of mosquitoes was collected from Souk-Ahras (5,299 specimens) although it only presents 6 species (Fig. 7). From a richness point of view (Figs. 7, 8), Taoura and Sedrata sampling sites presented the highest number of species (S = 11). The highest Shannon's index value was recorded in Taoura (H′ = 2.11), which indicated that it is the most diversified site in our study; while the lowest value was recorded in Zarouria (H′ = 0.53) due its low richness (S = 3). For the Pielou's evenness index, our results showed in general a relative medium equitability between the observed taxa in their habitats. Moreover, the higher value was obtained in Mechroha (J′ = 0.63). Despite the weak sample size in Zarouria site, it showed with Sedrata site similar values of this index, J′ = 0.34 and J′ = 0.33, respectively. With regard to the Simpson's index, it showed that the diversity of all our sites was slightly variable with medium diversity level (D = 0.50).

Species / habitats	Souk-Ahras	Taoura	Sedrata	Mechroha	Zarouria	Total / Species
Culex pipiens	3,880	1,598	2,481	766	231	8,956
Culex theileri	0	258	194	35	0	487
Culex simpsoni	0	313	3	0	0	316
Culex hortensis	469	380	12	10	0	871
Culex antennatus	12	0	315	0	0	327
Culex martinii	0	0	43	0	0	43
Culex adairi	0	0	4	0	0	4
Culex territans	54	15	0	242	0	311
Culex arbieeni	1	58	0	0	0	59
Culex quinquefasciatus	0	12	0	0	0	12
Culex laticinctus	0	161	0	0	0	161
Culiseta morsitans	0	0	7	0	0	7
Culiseta annulata	0	13	5	0	0	18
Culiseta longiareolata	883	6	0	239	7	1135
Aedes flavescens	0	0	35	0	0	35
Uranotaenia unguiculata	0	0	25	0	0	25
Anopheles marteri	0	62	0	0	0	62
Anopheles claviger	0	0	0	15	0	15
Anopheles labranchiae	0	0	0	0	17	17
Total	5,299	2,876	3,124	1,307	255	**12,861**

Table 1. List of mosquito species collected from Souk-Ahras province and their abundances (December 2018 - November 2019).

According to Sørensen similarity index values, the similarity in species between the five prospected sites was medium (0.67 > B > 0.44). It was found that Souk-Ahras and Mechroha were the most similar habitats in species (B = 0.67). Taoura presented the same rate of common species with both Souk-Ahras and Mechroha (B = 0.59); while it presented less common species with Sedrata (B = 0.45).

DISCUSSION

Among the Culicidae family, two sub-families have particular medical interest: Anophelinae, with the most important genus, *Anopheles*; and Culicinae, mainly with *Aedes* and *Culex*. Adults of *Anopheles* and *Culex* spp. exhibited nocturnal or crepuscular biting activity but some species are diurnal (*Aedes* spp.) (Berenger & Parola, 2017; Foster & Walker, 2019). Also, it is important to consider indigenous species as potential vectors for emerging arboviruses (Prudhomme et al., 2019). Results from mosquito survey's studies carried out in different Algerian areas, in terms of recorded species, are summarized in Table 2.

The focus of this study was to describe the mosquito assemblages (species richness and abundance) in Souk-Ahras province. Nineteen mosquito species were identified, between which *Culex* species have been reported in all prospected breeding sites. It might be attributed to the investigation of many polluted breeding sites which could have provided favorable environment for the proliferation of *Culex* species (Farjana et al., 2015).

The densities of mosquitoes and their diversity at species- and population-level are seasonally dependent because of the abiotic factors such as temperature, rainfall and moisture influence (Reinhold et al., 2018). The egg hatching, larval and pupal development (Saari et al., 2019) and the life span of the adult's effective transmission capacity of parasites (Bogitsh et al., 2019) depended on the temperature. It was reported that mosquito species were spreading northwards as a consequence of climate warming (Tippelt et al., 2017). Thus, geographic distributions of previously tropical mosquito species may change (Waldock et al., 2013). Previously in Algeria, it has been reported infected cases with West Nile virus (Lafri et al., 2017; Larfi et al., 2019). *Aedes albopictus,* an invasive mosquito species responsible for transmission

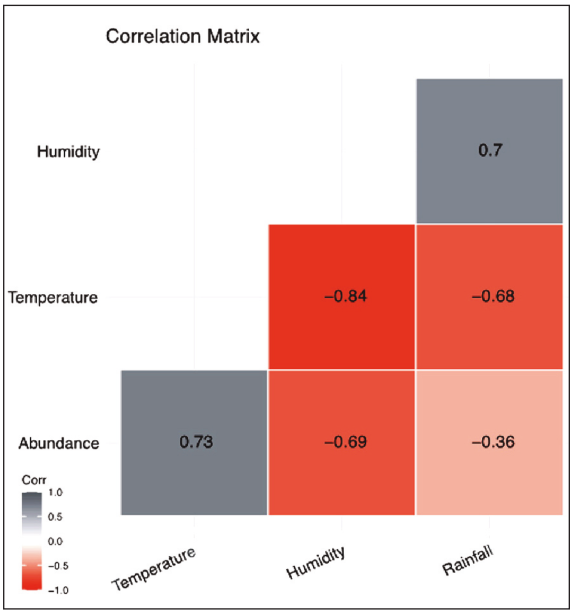

Figure 6. Graphical display of the correlation matrix using the 'corrplot' package of R; Spearman's rank correlations between three climatic variables (temperature, rainfall and humidity) and overall abundances of species (n = 12).

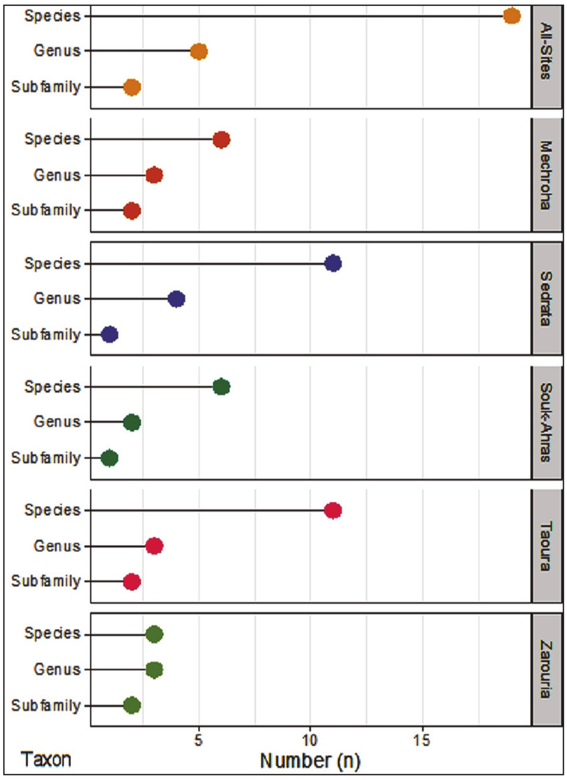

Figure 7. Taxa recorded within mosquitoes populations in different habitats from Souk-Ahras province the studied period (December 2018 to November 2019).

of chikungunya virus, has been first recorded during July 2016 in Algiers (Benallal et al., 2019). Due to distinct ecological preferences between populations (Asha & Aneesh, 2014), their response to climate fluctuations differed for survival. Mosquitoes adopt several forms of survival face of adverse conditions. Depending on the species, eggs or larvae can survive over winter and do not continue development (Saari et al., 2019). For example, the populations of mosquito inhabiting contrasted ecological areas used different aestivation strategies (Hidalgo et al., 2016).

During the past two decades, only three works focused on mosquitoes biodiversity in Souk-Ahras region (Hamaidia H. & Bershi, 2018; Hamaidia K. et al., 2016; Benmalek et al., 2018) with 13 common species have been identified: *Cx. pipiens, Cx. hortensis, Cx. theileri, Cx. quinquefasciatus, Cx. arbieeni, Cx. simpsoni, Cx. antennatus, Cx. martini, Cx. laticinctus, Cs. morsitans, Cs. longiareolata, Cs. annulata* and *An. labranchiae.*

The present results revealed a medium level of Culicidae fauna diversity in Souk-Ahras province because of dominance of *Cx. pipiens* due to its high ecological and physiological plasticity (Amara Korba et al., 2016; Tabbabi et al., 2018). This species was the most reported in several Algerian surveys (Messai et al., 2010; Benhissen et al., 2014; Hamaidia K. et al., 2016). Unlike larvae of *Culex* species, that breed profusely in polluted environments, *Aedes* and *Anopheles* mosquitoes prefer clean ground pools (Farjana et al., 2015) and unpolluted sites that contain sunny fresh water with slow current without raised vegetation (Tandina et al., 2018) respectively. Furthermore, urbanization is one of the drivers causing a significant depletion of the breeding sites of *Anopheles* species which decreases their density in favor of *Culex* species, better suited to this kind of lodgings (Tabbabi et al., 2017). *Culiseta* species were considered as mosquito fauna of the more humid and cold climate areas (Trájer & Padisák, 2019).

Some mosquitoes were innately adapted to distinct ecological exigencies and associated with particular host species. Such relations need to be expected in field-based studies, because variability in climatic factors is the most important driver of mosquito species redistribution (Hertig, 2019; Messina et al., 2019). During our survey, 6 new species were recorded in Souk-Ahras province, viz. *Cx. territans, Ae. flavescens, Ur. unguiculata, An. claviger, Cx. adairi* and *An. marteri*.

All specimens of *Cx. territans* were collected in early May from three sites (Souk-Ahras, Taoura and Mechroha at an altitude of 653, 839 and 769 m re-

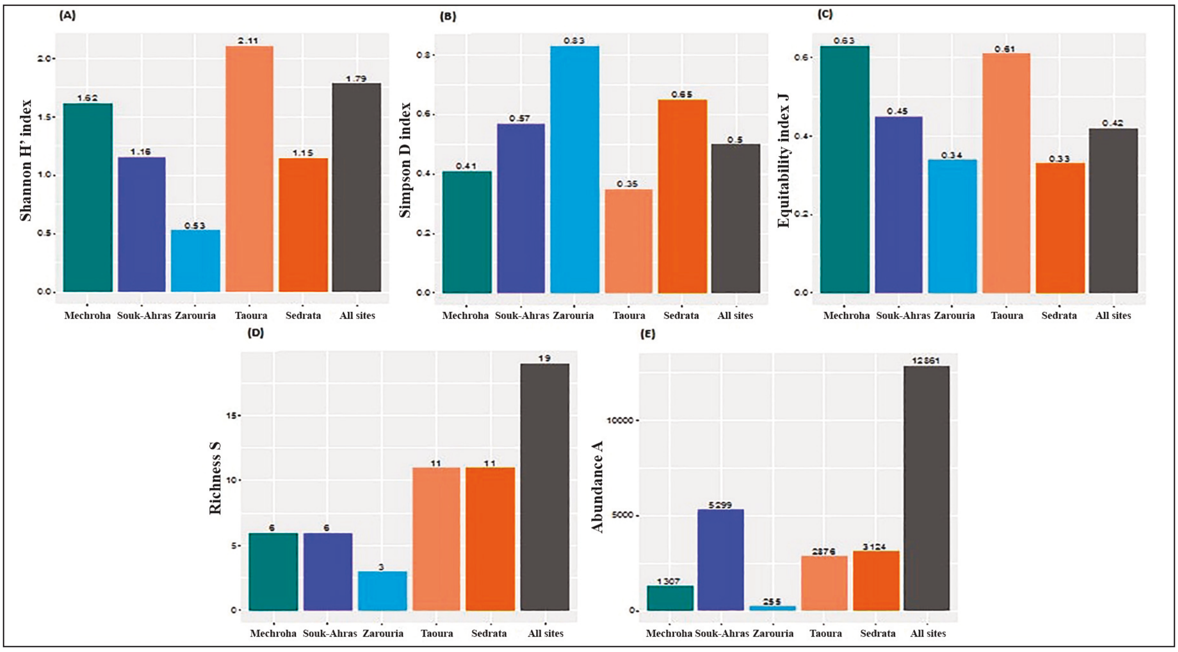

Figure 8. The ecological indices of composition and structure calculated for each sampling site in the Souk-Ahras province.

Region	Species/Genus	Species	Reference
Mila	8 *Culex* 1 *Culiseta* 2 *Anopheles* 1 *Uranotaenia*	**12 spp.** - *Cx. pipiens, Cx. modestus, Cx. theileri, Cx. hortensis, Cx. antennatus, Cx. laticinctus, Cx. deserticola,, Cx. sp, C. longiareolata, An. labranchiae, An. pharoensis, U. unguiculata*	Messai et al., 2010
Tébessa	5 *Culex* 3 *Culiseta* 1 *Ochlerotatus*	**9 spp.** - *Cx. pipiens, Cx. theileri, Cx. hortensis, Cx. perexiguus, Cx. laticinctus, Oc. caspius, Cs. longiareolata, Cs. annulata, Cs. subochrea*	Bouabida et al., 2012
Reghaïa	8 *Culex* 1 *Aedes* 1 *Culiseta* 1 *Anopheles* 1 *Uranotaenia*	**12 spp.** - *Cx. mimeticus, Cx. perexiguus, Cx. pipiens, Cx. theileri, Cx. modestus, Cx. hortensis,Cx. impudicus, Cx. territans, Ae. caspius, Cs. longiareolata, An.labranchiae, Uranotaenia unguiculata*	Lounaci et al., 2014
Biskra	7 *Culex* 2 *Aedes* 1 *Culiseta* 1 *Anopheles*	**11 spp.** - *Cx. pipiens,Cx. theileri, Cx. deserticola, Cx. modestus, Cx. torrentium, Cx. pusillus, Cx. antennatus, Cs. longiareolata, Ae. caspius, Ae. vexans, An. multicolor*	Benhissen et al., 2014
15 departments in Algeria	1 *Uranotaenia* 1 *Aedimorphus* 1 *Aedes* 5 *Ochlerotatus* 5 *Culex* 2 *Culiseta* 2 *Anopheles*	**17 spp.** - *Aedes albopictus, Aedimorphus vexans, Anopheles labranchiae, An. multicolor, Culex deserticola, Cx. hortensis, Cx. pipiens, Cx. territans, Cx. theileri, Culiseta litorea, C. longiareolata, Ochlerotatus coluzzii, O. detritus, O. dorsalis, O. flavescens, O. geniculatus, Ur. unguiculata*	Larfi et al., 2014
Tizi-Ouzou	1 *Anopheles* 4 *Culex* 1 *Culiseta* 2 *Aedes*	**8 spp.** - *An. labranchiae, Cx. hortensis, Cx. impudicus, Cx. theileri, Cx. perexiguus, Cs. longiareolata, Ae. caspius, Ae. vexans*	Lounaci et al., 2016
Souk-Ahras	7 *Culex* 3 *Aedes* 3 *Culiseta* 2 *Anopheles* 1 *Orthopodomyia*	**16 spp.** - *Cx. pipiens, Cx. theileri, Cx. modestus, Cx. simpsoni, Cx. quinquefasciatus, Cx. hortensis, Cx. arbieeni, Ae. punctur, Ae. quasirusticus, Ae. pulcritarsis, Cs. longiareolata, Cs. fumipennis, Culiseta sp1, Or. pulcripalpis, An. algeriensis, An. labranchiae*	Hamaidia K. et al., 2016
Souk-Ahras (Taoura)	8 *Culex* 3 *Culiseta* 3 *Anopheles*	**14 spp.** - *Cx. pipiens, Cx. theileri, Cx. laticinctus, Cx. antennatus, Cx. hortensis, Cx. perexiguus, Cx. mimeticus, Cx. impudicus, Cs. longiareolata, Cs. subochrea, Cs. annulata, An. labranchiae, An. petragnani, An. rufipes broussesi*	Hamaidia H. & Bershi, 2018
Souk-Ahras (Taoura)	12 *Culex* 3 *Culiseta* 2 *Anopheles* 1 *Aedes*	**18 spp.** - *Cx. deserticola, Cx. univittatus, Cx. torrentium, Cx. peregxiguus, Cx. impudicus, Cx. mimeticus, Cx. martini, Cx. pipiens, Cx. theileri, Cx. brumpti, Cx. mauritanicus, Cx. modestus, Cs. morsitans, Cs. subochrea, Cs. annulata, An. coustani, An. hyrcanus, Ae. pilatus*	Benmalek et al., 2018

Table 2. Mosquito systematic inventories in different Algerian biotopes.

spectively) inhabited by frogs. Each mosquito species required a specific group of hosts for their blood feeding (Bingham et al., 2013). Females of *Cx. territans* have a preference for amphibian bloodmeals. Therefore, larvae were temporally and spatially synchronized with these hosts. It was reported that the first larvae harvest of this species were collected on May (Bartlett-Healy et al., 2008). Larfi et al., (2014) noted the first record of *Cx. territans* in Algeria, at an altitude of 1,750 m.

Aedes flavescens and *Cx. adairi* larvae were harvested both in Sedrata site near to human habitations. This breeding site was sunny and stagnant craters formed on the edge of Oued Krab after its overflow on May. This coincided with the decrease in rainfall and the gradual increase in temperature. Larvae of *Ae. flavescens* were frequently occurring in stagnant, temporary, sunny habitats and without trees and shrubs as holes and marshes around rivers with feeding preference on the mammals then birds and reptile

(Moradi-Asl et al., 2019). *Cx. adairi* is thermophilic species with a restricted distribution (temporary rain-pools) and shorter period of occurrence (April and May only) (Dimentman & Margalitj, 1981).

As for *Ur. unguiculata*, larvae were collected in June at one locality situated in Oued Krab containing aquatic vegetation in Sedrata site only. This collection period is characterized by an increase in temperature without rainfall. This mosquito species is thermophilic and widespread throughout the Mediterranean (Kurucz et al., 2017; Tippelt et al., 2017). Immature instars preferred ground waters with vegetation, and mostly in suburban or rural areas around cities. Females targeted amphibians and reptiles species (Kurucz et al., 2017; Camp et al., 2018).

Larvae of *An. claviger* were sampled at one locality in Mechroha during autumn season (October and November), which coincided with the overwintering period. Immature instars occurred in rural with dense vegetation and less profound breeding site. The population of this species overwintered from October to April as larvae. *An. claviger* was bivoltine (May and September) with fewer eggs in the second generation (Service, 1973).

Sixty-two immature mosquitoes of *An. marteri* species were collected from only one breeding locality in Taoura site in June. It is a permanent lake near a forest cover with altitude of 839 m which conferred favorable humidity. *An. marteri* was confined to the humid bioclimatic stage (Tabbabi et al., 2017). This zoophilic species was recorded in mountainous regions near the source of river at 812 m altitude (Bueno-Marí & Jiménez-Peydró, 2010). It was found to breed mainly in permanent or temporary sunny current clear waters (Kassiri & Amani, 2012).

Climate change and biodiversity has been correlated. Likewise, a climatic change affects habitats of several species which disrupts their adaptation ability, resulting in a significant loss in biodiversity. Recent study revealed that *Cx. quinquefasciatus* abundance was associated with the environmental variables and suggested that these conditions during overwintering might be the key for West Nile virus amplification during summer outbreaks (Poh et al., 2019). Also, it was demonstrated that both immature and adult population dynamics of *An. arabiensis* was influenced by the climatic factors (Abiodun et al., 2016). Here, the link between climatic factors and mosquito diversity was evaluated over 12 months (December 2018 - November 2019). The abundance of mosquito's species was affected by the combination of temperature and rainfall which were negatively correlated. Globally, we found that mosquito abundances were greatest in just three months (from May to July) during which a gradual increase in temperature coincided with moderate precipitation, which significantly increased the humidity. Li et al. (2019) have shown that spatiotemporal vector dynamics could be predicted by climate conditions.

It has been reported also that temperature and rainfall were highly correlated with the mosquito abundance (Simon-Oke & Olofintoye, 2015). Temperature influences ideal vector competence, viz. biting rate, parasite transmission and adult survivorship (Shapiro et al., 2017). However, immature mosquitoes were more sensitive than adults (Abiodun et al., 2016). So, increasing environmental temperature could decline the success of emergence and adult longevity, immature duration and survivorship (Christiansen-Jucht et al., 2014; Ukubuiwe et al., 2018).

On the other hand, climatic conditions governed natural vegetation dynamics (Al Balasmeh & Karmaker, 2020) as suitable resting environments for adult mosquitoes from desiccating conditions with more available hosts which enhance their longevity (Arum et al., 2016). Also, warmer environmental temperatures lead to longer breeding seasons (Ryan et al., 2019). Throughout the present study period, the lowest larval abundances were observed during the coldest months. Unlike a moderate rainfall rate that could create new breeding sites through overflowing, excessive rainfall could eliminate habitats as already observed (Hamaidia K. et al., 2016). Temperature in the current week and rainfall 2–3 weeks before sampling had positive influences on mosquito abundance (Chuang et al., 2011).

Considering Shannon's diversity H′ index, Taoura and Sedrata were the most diversified geographic site in species (S = 11), and Zarouria was the least one with the lowest species richness (S = 3). Concerning Simpson's diversity D index, it showed that the diversity of these different sites was slightly variable between them. In general, the ecological indices revealed a medium diversity level of Culicidae fauna in Souk-Ahras province (global D = 0.50, global H′ = 1.79 with E = 0.42 which means that the relative abundances of the species diverge away from evenness).

CONCLUSIONS

Controlling immature mosquito instars can play a relevant contribution in vector control programs. In the scope of our survey, among 19 inventoried species, 6 are recorded for the first time in Souk-Ahras province which could pose a major concern. Recently, vector competence of *Ur. unguiculata* of a novel genetic lineage of West Nile virus (Kurucz et al., 2017; Camp et al., 2018) and *Dirofilaria repens* (Tippelt et al., 2017) was reported. Composition changes in mosquito population were revealed which could be due to climate change or/and inspection of more breeding sites Souk-Ahras. Lastly, assessment of further regular surveys is an urgent task to prepare and to respond better to potential risks of future likely vector borne diseases emergence.

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