Identification and characterisation of mosquitoes from different locations of Qatar in 2017–2019

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Abstract – Mosquito-borne infections have considerable consequences for public health. The mere presence of a single case of vector-borne disease (VBD) introduces a risk to the local community particularly when associated with the compatible vector, host, and suitable environmental factors. Presently, there is no well-established vector control and surveillance programme in Qatar; therefore, the likelihood of VBDs spreading is undetermined. As a result, there is a pressing need to address this gap and enable successful management of VBDs. This study presents the results of three consecutive field surveys conducted between 2017 and 2019 with the aim of defining the types and distribution of mosquitoes that are of public health importance in Qatar. The results of the adult mosquito trappings show that the southern house mosquito *Culex quinquefasciatus* is the most widespread and abundant mosquito species, followed by *Cx. perexiguus*, both species representing a risk of West Nile virus transmission. All sampling methods show that the malaria vector *Anopheles stephensi* is widespread including in urbanised areas, suggesting a risk of local malaria transmission. The wetland mosquito *Aedes caspius* is also widespread, representing a risk of Rift Valley fever virus transmission. The dengue vector *Ae. aegypti* was not detected and can be considered neither widespread nor abundant, suggesting a minimal risk for local transmission of dengue, chikungunya and Zika viruses. Interestingly, the study detected *Culiseta longiareolata* for the first time in Qatar. Regular field studies are needed to further address the knowledge gaps in terms of distribution, ecology, and biting habits of different mosquito species currently present in Qatar to accurately assess the risk of mosquito-borne diseases.

Key words: Culicidae, Distribution, Vector species, Surveillance, Qatar, Arabic Peninsula.

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Introduction

In recent years, the importance of vector-borne diseases (VBDs) has increased at the global and regional levels [29]. Several factors including the rapid growth of the human population, unprecedented urbanisation, increases in movement of humans and animals (travel and trade), and environmental challenges including climate change significantly impact the life cycle, the transmission and the geographical distribution of pathogens [17]. In non-endemic countries such as Qatar, the very first and crucial step in the prevention and control of VBDs requires the identification and appraisal of potential vector populations followed by mapping of the human and animal populations at-risk of acquiring (and transmitting) the pathogen. Currently, being a non-endemic country, the vector control and surveillance programmes were never well established in Qatar. Therefore, the Ministry of Public Health, Qatar, with technical assistance from Eastern Mediterranean Regional Office (EMRO) of the World Health Organization (WHO), have recently assessed the situation of vectors and their respective VBDs in Qatar [24, 25]. Analysis of the situation revealed a significant knowledge gap regarding the presence and distribution of mosquito species in different parts of the country, including rural-urban distribution. To address this issue, it was recommended to further strengthen Qatar’s technical capacity in the field of entomology, and in particular with emphasis on developing competencies toward vectors identification and surveillance. Subsequently, several field surveys were organised to assess the presence of key species of mosquitoes in different regions of Qatar, together with capacity-building activities.

At the time of the above-mentioned situation analysis, we conducted a literature review which included a total of nine studies, and together reported the occurrence of 20 mosquito taxa (Culicidae) in Qatar (Table 5) [25]. However, the majority of these 20 mosquito taxa were reported by a single publication. Moreover, in these cases, the authors often did not provide findings specifications, including for species described beyond their established distribution range, and thus their presence in Qatar requires further confirmation. Also, two studies reported taxa, i.e. Culiseta sp. and Coquillettidia sp., that remain yet to be identified at the species level. The literature review guided us in identifying the existing gap(s) regarding the distribution of different species of mosquito across various regions of Qatar. Furthermore, entomological reports from many neighbouring countries informed us about the presence of several mosquito species in the Middle East region (e.g. 49 species in Saudi Arabia [4]), which increases the probability of discovering other mosquito species (and sub-species) in Qatar. Therefore, we conducted field surveys to gather accurate and updated data about the presence and distribution of various mosquito species and carried out the risk assessment for mosquito-borne diseases in different regions of Qatar. Here, we report the main findings from the 3 sessions of field survey: (i) a longitudinal monitoring performed between August 2017 and August 2018; (ii) a series of samples collected during the situation analysis mission, in September 2017; and (iii) a cross-sectional study undertaken in January 2019.

Materials and methods

Study area

Qatar (24°–26° N, 50°–51° E) is a small peninsular country, located on the north-eastern coast of the Arabian Peninsula, Middle East (Fig. 1). The total area of Qatar is approximately 11,600 km² and the total population is around 2,750,000 consisting of a large number of immigrants that varies from year to year (75.5% in the year 2015) [5]. Topographically, most of Qatar consists of a flat rocky plain (the highest point is 103 m), with a small range of limestone hills in the North–West and massive sand dunes in the South. The land is comprised of urban areas at 13%, rural areas at 84.5%, and has around
5.7% (670 sq. km in 2016) of agricultural land [5]. The country is divided into eight municipalities. Qatar’s climate is classified as a hot desert (Köppen-Geiger category BWh), with an annual mean temperature of 27.1 °C and mean rainfall of 72 mm (most rainfall is between October and May) [6].

Field sampling

Session 1: Longitudinal sampling, 2017–2018

A series of repeated sampling (longitudinal) sessions were carried out to collect adult mosquito samples from across the country over a period of one year, to account for seasonal data. A total of nine locations were selected across the country to account for different environment sub-types that would influence mosquito breeding such as farms, gardening centres, and zoos (Table 1, Fig. 1).

Adult mosquitoes were collected through MozzTech Mosquito Traps (Ridpest, Malaysia) baited with Octenol and CO₂ that is produced by photocatalytic reaction of titanium dioxide exposed to black light. The traps were set for two consecutive nights each week between August 2017 and August 2018. The mosquitoes caught by this process were collected daily in the morning, and then frozen once transported to the laboratory for sorting and identification under a stereo microscope.

Session 2: Field survey, September 2017

To obtain an overview and insight about the mosquito breeding habits in Qatar, five sites previously known to local municipality’s pest control workers as common sites for mosquito breeding were inspected for three days (September 18–20, 2017) (Table 1, Fig. 1). Two strategies were used to collect larval samples: (i) using a net with a fine mesh and then transferring the samples to a 1-L white plastic tray for observation; and (ii) filling the tray by directly dipping it in water. Larvae and pupae collected using these techniques were transferred with water to a vial for transport to the laboratory. In addition, resting catches were performed by using sweep nets around vegetation, and human landing catches were performed by netting around a person. In both cases, adults were collected from the net via a mouth aspirator and brought to the laboratory.

Session 3: Cross-sectional field study, January 2019

A cross-sectional study was conducted with the aim of updating the pre-existing database of the mosquito fauna of Qatar, for species presence at as many sites as possible. A total of 18 sites were selected across the country for collecting the mosquito samples. These sites were selected to ensure rapid collection and transport of the samples to the laboratory within a one-day trip. These sites covered all possible ranges of environments, e.g. urban building areas, farms, garden centres, industrial areas, sewage lakes, wetlands, worker houses, and zoos (Table 1, Figs. 1 and 2). All the samples were collected between January 15–23, 2019. The choices of sites were guided by municipalities’ pest control workers, satellite images and/or visually along roads in the course of journeys. Larval samplings, resting catches and human landing catches were performed at...
Table 1. Location and characteristics of sampling sites [F1–F9: Longitudinal survey, session 1; Q01–Q20 Field surveys, session 2 (September 2017) and 3 (January 2019)], with sampling method, period, and number of samples analysed.

| Site ID | Municipality      | Location                     | Habitat                  | Latitude   | Longitude  | Method               | Period     | No. samples |
|---------|-------------------|------------------------------|--------------------------|------------|------------|----------------------|------------|-------------|
| F1      | Al Doha           | Widam Company                | Garden centre            | 25.235981  | 51.485530  | Adult trapping       | Aug-17 to  | 12          |
| F2      | Al Khor           | Al Sidra Farm                | Farm                     | 25.675798  | 51.307606  | Adult trapping       | Aug-18     | 12          |
| F3      | Al Khor           | Sewage Treatment Plant       | Sewage basins            | 25.661767  | 51.517150  | Adult trapping       | Aug-17     | 9           |
| F4      | Al Khor           | Umm Barkah                   | Farm                     | 25.760504  | 51.434899  | Adult trapping       | Aug-17     | 13          |
| F5      | Al Rayyan         | Al Rekkiya                   | Farm                     | 25.006483  | 51.194028  | Adult trapping       | Aug-17     | 10          |
| F6      | Al Shahaniya      | Al Dosari park and game      | Zoo                      | 25.439317  | 51.222332  | Adult trapping       | Sep 17     | 15          |
| F7      | Al Shahaniya      | Umm Weshah                   | Farm                     | 25.171333  | 51.089283  | Adult trapping       | Sep 17     | 8           |
| F8      | Al Shamal         | Al Zobara                    | Farm                     | 25.959183  | 51.072083  | Adult trapping       | Sep 17     | 9           |
| F9      | Umm Salal         | Al Siliconi                  | Farm                     | 25.465859  | 51.375235  | Adult trapping       | Sep 17     | 11          |
| Q01a    | Al Shahaniyah     | Al Dosari park and game      | Basin beside fish pond,  | 25.440457  | 51.222572  | Larval sampling      | Sep 17     | 1           |
|         |                   |                              | temporary                |            |            |                      |            |             |
| Q01b    | Al Shahaniyah     | Al Dosari park and game      | Covered cistern          | 25.440364  | 51.223533  | Larval sampling      | Jan 19     | 1           |
| Q01c    | Al Shahaniyah     | Al Dosari park and game      | Tyre (dry)               | 25.441110  | 51.222361  | Larval sampling      | Jan 19     | 1           |
| Q02     | Al Rayyan         | Abu Nakhlah, sewage lake     | Pond border with vegetation | 25.164420  | 51.377165  | Larval sampling      | Sep 17     | 1           |
| Q03     | Al Rayyan         | Abu Nakhlah, sewage lake     | Marsh border             | 25.164499  | 51.373740  | Larval sampling      | Sep 17     | 1           |
| Q04     | Al Rayyan         | Abu Nakhlah, sewage lake     | Isolated puddles outside embankment | 25.163673  | 51.379603  | Larval sampling      | Sep 17     | 1           |
| Q05     | Al Rayyan         | Abu Nakhlah, new village     | Two metallic cisterns    | 25.185860  | 51.390198  | Larval sampling      | Sep 17     | 1           |
| Q06     | Al Doha           | Nuaija                       | Container                | 25.249994  | 51.532889  | Larval sampling      | Sep 17     | 1           |
| Q07     | Al Rayyan         | Abu Hamour                   | Flooded land with vegetation | 25.209601  | 51.503795  | Larval sampling      | Sep 17     | 1           |
| Q08     | Al Doha           | Al Waab                      | Park/garden              | 25.236129  | 51.485550  | Adult trapping       | Jan 19     | 13          |
| Q09     | Al Rayyan         | Abu Sidra                    | Flooded land with vegetation | 25.235270  | 51.399403  | Larval sampling      | Jan 19     | 1           |
| Q10     | Al Rayyan         | Al Maqran                    | Wetland                  | 25.224855  | 51.371550  | Larval sampling      | Jan 19     | 1           |
| Q11     | Al Rayyan         | Abu Nakhlah, new village     | Four containers          | 25.186946  | 51.389706  | Larval sampling      | Jan 19     | 1           |
| Q12     | Al Rayyan         | Abu Nakhlah, new village     | Flooded land with vegetation | 25.183686  | 51.387945  | Larval sampling      | Jan 19     | 1           |
| Q13     | Al Doha           | West Bay                     | Two road drains          | 25.372495  | 51.522716  | Larval sampling      | Jan 19     | 1           |
| Q14a    | Umm Salal         | Al Silat Agricultural Complex | Park/garden              | 25.469579  | 51.376009  | Adult trapping       | Jan 19     | 3           |
| Q14b    | Umm Salal         | Al Silat Agricultural Complex | Artificial rock pool     | 25.469011  | 51.373434  | Larval sampling      | Jan 19     | 1           |
| Q15     | Umm Salal         | Umm Salal Ali                | Five uncovered cisterns  | 25.471937  | 51.398886  | Larval sampling      | Jan 19     | 1           |
| Q16     | Al Rayyan         | Industrial area              | Road puddles with vegetation | 25.199847  | 51.415855  | Larval sampling      | Jan 19     | 1           |
| Q17a    | Al Rayyan         | Industrial area              | One iron barrel          | 25.202058  | 51.422577  | Larval sampling      | Jan 19     | 1           |
| Q17b    | Al Rayyan         | Industrial area              | Worker house in construction | 25.202093  | 51.422830  | Resting catch        | Jan 19     | 1           |
| Q17c    | Al Rayyan         | Industrial area              | Worker house, outdoor    | 25.202546  | 51.422650  | Adult trapping       | Jan 19     | 1           |
| Q18     | Al Rayyan         | Industrial area, Labour camp | One basin/fountain and four road drains | 25.167192  | 51.489907  | Larval sampling      | Jan 19     | 1           |
| Q19     | Al Rayyan         | Industrial area              | Worker, outdoor          | 25.186026  | 51.455459  | Adult trapping       | Jan 19     | 1           |
| Q20     | Al Rayyan         | Asian town                   | Wetland                  | 25.183368  | 51.466513  | Larval sampling      | Jan 19     | 1           |
every selected site, as described for session 2. In addition, adult trapping was performed with CO2-baited traps (Fig. 2A), i.e. Heavy Duty EVS trap (BioQuip Products Inc., USA), CDC Mini Light Trap (BioQuip Products Inc., USA) and BG-Sentinel 2™ trap (Biogents, Germany). Traps were run overnight, and baited with dry ice at selected locations. Adults were collected with the trap net and brought to the laboratory, and frozen before identification.
Table 2. Relative abundance of mosquito species collected in the longitudinal adult monitoring, per site, August 2017–September 2018, according to one sample per month per site. One black dot = 1–10 individuals; Two black dots = 11–50 individuals; Three black dots = >50 individuals.

| Site ID | Aedes | Anopheles | Culex | Culex | Culex | Culiseta |
|--------|-------|-----------|-------|-------|-------|----------|
|        | caspius | stephensi | quinquefasciatus | tritaeniorhynchus | pusillus | longiareolata |
| F1     | -      | ⚫️       | ⚫️️   | -     | ⚫️️   | -        |
| F2     | ⚫️     | ⚫️️       | ⚫️️   | ⚫️️   | ⚫️     | ⚫️️      |
| F3     |       | ⚫️️       | ⚫️️   | -     | ⚫️️   | -        |
| F4     | ⚫️     | ⚫️️       | ⚫️️   | -     | ⚫️️   | -        |
| F5     | -      | ⚫️️       | ⚫️️   | -     | ⚫️️   | -        |
| F6     | ⚫️     | ⚫️️       | ⚫️️   | -     | ⚫️️   | -        |
| F7     | ⚫️     | -         | ⚫️️   | -     | ⚫️️   | -        |
| F8     | ⚫️     | -         | ⚫️️   | -     | ⚫️️   | -        |
| F9     | ⚫️     | -         | ⚫️️   | -     | ⚫️️   | -        |

**Mosquito identification**

**Morphology**

Mosquito larvae and adults (females and males) were classified as belonging to a species or, if not possible, to a group of morphologically closely related species based on standard identification keys using stereomicroscope [3, 7, 11, 12, 23]. Several subsamples of mosquito larvae and adults were preserved in ethanol (larvae and immature exuviae, male genitalia) or pinned in an insect box (adults). Molecular identification by DNA isolation and amplification of the mitochondrial cytochrome oxidase subunit I gene (COI) for Culex sp. or of the ribosomal internal transcribed spacer 2 (ITS2) for Anopheles sp. was performed on only a small fraction of total specimens, as described elsewhere [16, 26]. New sequences were deposited in GenBank with accession numbers OL653979, OL654412, OL672837, OL672843, and OL672844. In addition, a rapid polymerase chain reaction (PCR) assay that uses polymorphisms in the second intron of the acetylcholinesterase-2 (ACE2) locus was run for the identification of specimens of the Cx. pipiens complex and possible hybrids [28].

**Results**

**Longitudinal data, 2017–2018**

Thousands of mosquitoes were collected in session 1, but the presence of considerable by-catches (attracted by the black light) and the poor quality of preservation did not allow all specimens to be properly sorted and identified. However, to obtain an estimate of sampling outcomes under our time constraints, we performed subsampling and analysed one randomly chosen sample per month and per site.

We analysed 99 samples, yielding detection of seven mosquito species or groups, the most abundant being Culex quinquefasciatus species group (Cx. (Culex) pipiens (Linnaeus, 1758), Cx. (Cx.) quinquefasciatus Say, 1823, and Cx. (Cx.) perexiguus Theobald, 1903, which are almost impossible to distinguish as dried – and often damaged – adults) detected at all sites, followed by Anopheles (Cellia) stephensi Liston, 1901 collected at four sites (Table 2). No other Anopheles species was detected here. Culex quinquefasciatus gr. was highly abundant almost all over the year, whereas An. stephensi showed medium abundance in Oct–Nov and Jun–Jul (Table 3). A third species, Aedes (Ochlerotatus) caspius (Fallas, 1771), was detected at three sites only and at several periods over the year, but in small numbers. In addition, the species Culiseta (Allotheobaldia) longiareolata (Macquart, 1838) was found at three sites.

**Field studies, September 2017 and January 2019**

In sessions 2 and 3, a total of 20 sites were surveyed with 6 samples collected in 2017, and 27 in 2019 (Tables 1 and 4). This comprises 20 larval samplings, 2 adult human landing catches, 3 adult resting catches, and 8 adult trappings. Larval samplings yielded 933 larvae and 97 pupae, and entrapped adult mosquitoes accounted for 20 males and 101 females.

Seven mosquito species from four genera were observed: one Aedes, one Anopheles, four Culex, and one Culiseta (Table 5). All seven species were observed at both larval and adult (trapped or reared from immatures) stages, allowing accurate morphological identification. One specimen of An. stephensi (sample Q4b, adult female), two of Cx. perexiguus (samples Q04, adult male, and Q20, larvae) and one of Cx. (Cux.) tritaeniorhynchus Giles, 1901 (sample Q10, adult male) were submitted to molecular identification and obtained COI or ITS2 sequences were compared with vouchers deposited in GenBank. Our An. stephensi sequence showed 100% similarity with specimens from Iran and Iraq; Cx. perexiguus sequences showed 100% identity with specimens from the United Arab Emirates, while the Cx. tritaeniorhynchus sequence showed >99% similarity with specimens from India, all confirming our morphological identification. Specimens of Cx. quinquefasciatus were also submitted to molecular identification. A total of 45 specimens (adults and larvae, 1–6 specimens per sample, from all samples harbouring Cx. quinquefasciatus except Q04 and Q19) were submitted to a PCR targeting the ACE2 locus and all obtained band traces on the gel showed characteristic Cx. quinquefasciatus bands (274 bp). Preliminary genomic analysis also suggested that there is no notable trace of hybridisation with Cx. pipiens in the analysed genomes (Yuki Haba, pers. comm.). Culex quinquefasciatus was clearly the more abundant...
of the species, collected at 13 sites among 20 in total (Fig. 3), distributed in all land use categories (Fig. 4), and representing 48% of the collected individuals in total (Fig. 5). The lesser encountered species, *Cs. longiareolata*, was only found at two sites while all five remaining species were collected from five to eight different sites (Fig. 3). In terms of numbers of individuals, *Cx. perexiguus* and *Cx. (Barraudius) pusillus* Macquart, 1850 represented 20% and 18%, respectively, while the four remaining species represented less than 5%. Human landing catches revealed the occurrence of *Ae. caspius* only, while adult trappings also caught *Cx. quinquefasciatus* (88% of the caught individuals), *Cx. tritaeniorynchus* (10%) and *An. stephensi* (1%), besides *Ae. caspius* (1%) (Fig. 5). Comparing the species composition according to land use categories showed that all categories have significant mosquito diversity with at least four species among the seven found here. All species but *Cs. longiareolata* were found to occur in wetlands, and all but *Cx. pusillus* in rural habitats. Similarly to *Cx. quinquefasciatus*, *Cx. tritaeniorynchus* and *An. stephensi* were found in all land use categories (Fig. 4).

### Discussion

Highly accurate and up-to-date data about the presence and distribution of various vector species are needed by public health authorities to assess the potential threat and devise effective counter strategies for VBDs. In the present study, three field survey sessions were conducted between 2017 and 2019 with the primary aim of collecting data on geographical, topographical, and seasonal distribution of various species of mosquitoes, in different regions of Qatar.

### Field data outcomes

The samples from our entomological survey were collected from various sites to account for different factors that may influence the breeding capabilities and distribution of mosquitoes, including farms, garden centres, industrial areas, sewage lakes and sewage treatment plants, urban building areas, wetlands, worker houses, and zoos. In our survey, one or more species of mosquitoes were found at every inspected location, with the southern house mosquito species *Cx. quinquefasciatus* showing the widest geographical distribution. This is not surprising as this species is well adapted to breed in a wide range of habitats, from artificial collection of water in man-made containers to natural water bodies [7, 12]. Our overall findings were in accordance with the known preferences of the species [7, 12]. For example, the immature samples of *Cx. tritaeniorynchus* and *Cx. perexiguus* were collected more frequently from flooded land than artificial containers, while specimens of *Cx. pusillus* and *Ae. caspius* were frequently found in wetlands with brackish water. However, we were surprised to find *Cx. pusillus* in a metallic cistern filled with fresh water. The *Cs. longiareolata* samples, both adults and immatures, were collected from four different sites. This is the first time *Cs. longiareolata* specimens were detected in Qatar. Wetlands and rural habitats showed the highest mosquito fauna diversity (six species among seven) in comparison to other habitats such as agricultural land, suburban and urban habitats, which harboured at least four species. All these findings are of public health significance in terms of risk for nuisance or potential for pathogen transmission.

### Critical review of the species list

No invasive species were found during our surveys. Despite large scale inspection of many man-made containers located in both urban and suburban habitat, our surveys did not find even a single sample of *Aedes (Stegomyia) aegypti* (Linnaeus 1762), suggesting that this species is potentially uncommon in Qatar. The occurrence of the yellow fever mosquito, *Ae. aegypti*, was reported in Qatar in a single reference without providing any sampling details [2]. Nevertheless, the presence of *Ae. aegypti* in Qatar is hardly surprising, as it is reported to breed in several neighbouring countries. We need to be watchful about its possible import into Qatar by being vigilant at places of entry for goods (port, airport, road crossings).

### Table 3. Relative abundance and seasonality of mosquito species collected in the longitudinal adult monitoring, monthly, August 2017–September 2018, according to one sample per month per site. One black dot = 1–10 individuals; Two black dots = 11–50 individuals; Three black dots = >50 individuals.

| Month & Year | *Aedes caspius* | *Anopheles stephensi* | *Culex quinquefasciatus* group | *Culex tritaeniorynchus* | *Culex pusillus* | *Culiseta longiareolata* |
|--------------|----------------|-----------------------|-------------------------------|------------------------|------------------|--------------------------|
| Aug-17       |                |                       |                               |                        |                  |                           |
| Sep-17       |                |                       |                               |                        |                  |                           |
| Oct-17       |                |                       |                               |                        |                  |                           |
| Nov-17       |                |                       |                               |                        |                  |                           |
| Dec-17       |                |                       |                               |                        |                  |                           |
| Jan-18       |                |                       |                               |                        |                  |                           |
| Feb-18       |                |                       |                               |                        |                  |                           |
| Mar-18       |                |                       |                               |                        |                  |                           |
| Apr-18       |                |                       |                               |                        |                  |                           |
| May-18       |                |                       |                               |                        |                  |                           |
| Jun-18       |                |                       |                               |                        |                  |                           |
| Jul-18       |                |                       |                               |                        |                  |                           |
| Aug-18       |                |                       |                               |                        |                  |                           |
Similarly, an investigation for the possible introduction and presence of another invasive species, the Asian tiger mosquito *Ae. (Stg.) albopictus* (Skuse, 1894), which also inhabits artificial collection of water (e.g. containers) should be performed. Additionally, authorities need to be especially vigilant since this species is spreading worldwide and is even found in the Middle East (e.g. in Iran, Gulf of Oman coast; [9]). Intense international trade makes its introduction possible, and the local climate looks suitable for its establishment [10].

Two brackish-water wetland mosquitoes are reported to occur in Qatar. The first, *Aedes caspius*, looks to be widespread in the country based on our findings (Table 5). Previous studies have also reported the presence of these species in Qatar for long time. It is possible that the population of this particular

### Table 4. Mosquito species observed during our sessions 2 and 3 field surveys in Qatar, September 2017 and January 2019, per site. Within rounded parentheses: adults obtained by rearing of immatures; Within braces: number of traps. F = female; L = larva; M = male; P = pupa.

| Site ID | Date       | Method               | Numbers and stages observed | Species                      |
|---------|------------|----------------------|-----------------------------|------------------------------|
| Q01a    | 20.01.2019 | Larval sampling      | 3 L (1 F)                   | *Culex tritaeniorhynchus*    |
| Q01b    | 18.09.2017 | Larval sampling      | 20 L                        | *Anopheles stephensi*        |
|         |            |                      | 15 L                        | *Culex quinquefasciatus*     |
|         |            |                      | 25 L                        | *Culiseta longiareolata*     |
| Q01b    | 20.01.2019 | Larval sampling      | 3 L                         | *Culiseta longiareolata*     |
| Q01c    | 20.01.2019 | Resting catch        | 9 M, 4 F                    | *Culex quinquefasciatus*     |
| Q02     | 20.09.2017 | Larval sampling      | 40 L, 9 P (7 M, 10 F)       | *Culex pusillus*             |
|         |            |                      | 6 L (1 F)                   | *Culex tritaeniorhynchus*    |
| Q03     | 20.09.2017 | Resting catch + Human landing catch | 1 M, 2 F | *Aedes caspius* |
| Q03     | 17.01.2019 | Human landing catch  | 1 F                         | *Aedes caspius*              |
| Q04     | 20.09.2017 | Larval sampling      | 56 L, 12 P (23 M, 19 F)     | *Culex pusillus*             |
|         |            |                      | 2 L,1 P (1 M, 1 F)          | *Aedes caspius*              |
|         |            |                      | 12 L, 5 P (4 M, 2 F)        | *Anopheles stephensi*        |
|         |            |                      | 25 L, 10 P (6 M, 12 F)      | *Culex perexiguus*           |
|         |            |                      | 50 L, 15 P (20 M, 18 F)     | *Culex tritaeniorhynchus*    |
|         |            |                      | 1 L, 1 P (1 F)              | *Culex quinquefasciatus*     |
| Q05     | 20.09.2017 | Larval sampling      | 6 L (1 F)                   | *Culex pusillus*             |
| Q06     | 16.01.2019 | Larval sampling      | 1 L (1 F)                   | *Culex perexiguus*           |
| Q07     | 16.01.2019 | Larval sampling      | 15 L (3 M, 3 F)             | *Culex quinquefasciatus*     |
| Q08     | 17.01.2019 | Adult trapping [3]   | 1 F                         | *Anopheles stephensi*        |
|         |            |                      | 1 M, 33 F                   | *Culex tritaeniorhynchus*    |
|         |            |                      | 9 F                         | *Anopheles stephensi*        |
|         |            |                      | *Culex perexiguus*          | *Culex tritaeniorhynchus*    |
|         |            |                      | *Culex quinquefasciatus*    | *Culex perexiguus*           |
| Q09     | 17.01.2019 | Larval sampling      | 1 L                         | *Culex tritaeniorhynchus*    |
|         |            |                      | 2 L (1 M)                   | *Culex quinquefasciatus*     |
|         |            |                      | 48 L, 5 P (2 M, 5 F)        | *Aedes caspius*              |
|         |            |                      | 4 L                         | *Culex tritaeniorhynchus*    |
| Q10     | 17.01.2019 | Larval sampling      | 25 L (1 F)                  | *Aedes caspius*              |
| Q11     | 17.01.2019 | Larval sampling      | 5 L (1 M, 2 F)              | *Aedes caspius*              |
| Q12     | 17.01.2019 | Larval sampling      | 3 L (1 F)                   | *Culex tritaeniorhynchus*    |
|         |            |                      | 12 L                        | *Culex perexiguus*           |
| Q13     | 19.01.2019 | Larval sampling      | 100 L, 5 P (3 M, 2 F)       | *Culex tritaeniorhynchus*    |
| Q14a    | 21.01.2019 | Adult trapping [3]   | 180 L, 7 P (6 M, 1 F)       | *Culex quinquefasciatus*     |
| Q14b    | 21.01.2019 | Larval sampling      | 1 M, 17 F                   | *Culex quinquefasciatus*     |
|         |            |                      | 15 L, 2 P (2 F)             | *Anopheles stephensi*        |
|         |            |                      | 32 L, 2 P (1 M, 1 F)        | *Culex quinquefasciatus*     |
|         |            |                      | 25 L                        | *Culiseta longiareolata*     |
| Q15     | 21.01.2019 | Larval sampling      | 4 L                         | *Culex perexiguus*           |
| Q16     | 21.01.2019 | Larval sampling      | 35 L                        | *Culex quinquefasciatus*     |
|         |            |                      | 1 L                         | *Anopheles stephensi*        |
|         |            |                      | 1 L                         | *Culex perexiguus*           |
|         |            |                      | 18 L, 4 P (3 M, 1 F)        | *Culex quinquefasciatus*     |
| Q17a    | 21.01.2019 | Larval sampling      | 4 L                         | *Culex quinquefasciatus*     |
| Q17b    | 21.01.2019 | Resting catch        | 4 M, 6 F                    | *Culex quinquefasciatus*     |
| Q17c    | 22.01.2019 | Adult trapping [1]   | –                           | –                            |
| Q18     | 21.01.2019 | Larval sampling      | 50 L, 14 P (8 M, 6 F)       | *Culex quinquefasciatus*     |
| Q19     | 22.01.2019 | Adult trapping [1]   | 1 M                         | *Aedes caspius*              |
|         |            |                      | 2 M, 29 F                   | *Culex quinquefasciatus*     |
| Q20     | 21.01.2019 | Larval sampling      | 60 L, 2 P (2 F)             | *Culex perexiguus*           |
species may increase following rainfall or artificial accumulation of water in sewage lakes, and subsequently disperse over several kilometres and bite the human population, causing nuisance. A second species, An. (Och.) dorsalis (Meigen, 1830), which has been reported only once before [15], shares many morphological characters with Ae. caspius. This particular species if known to have a northern Holarctic distribution; however, it has never been reported from any other country in the Middle East except Iraq and Turkey [2, 22]. In addition, Ae. caspius adults show morphological variabilities, which could cause its misidentification as Ae. dorsalis [7]. Therefore, the present study recommends that the presence of Ae. dorsalis should be further studied in Qatar with sample collections, morphological observations and molecular identification.

Four Anopheles species are reported to inhabit Qatar (Table 5). The most frequently reported species, An. stephani, was also observed in our study. While the presence of An. (Cel.) culicifacies s.l. Giles, 1901 and An. (Cel.) sergentii (Theobald, 1907) are listed without any field observation data [2, 11] and therefore their presence has to be substantiated.

The mosquito species belonging to the genus Culex are the most widespread mosquitoes in Qatar. In the Middle East, the Culex pipiens complex comprises the two forms pipiens and molestus, and Cx. quinquefasciatus [13, 22]. However, distinguishing these species by morphology is a difficult task that requires meticulous specimen examination [7]. In our study, all specimens were identified as Cx. quinquefasciatus, including by molecular examination. Several articles on the Qatari fauna refer to the Cx. pipiens complex [1, 18, 19], while others mention both Cx pipiens form molestus and Cx. quinquefasciatus to occur [14, 15]. Therefore, further sampling and molecular examination is recommended to confirm the identity of the Culex pipiens complex members in Qatar.

Culex (Cux.) univittatus Theobald, 1901 and Cx. perexiguus are two other closely related species that exhibit very similar external morphology at all life stages [7]. Both species have been reported in the Arabian Peninsula [12] as well as in Qatar [14, 18]. In our study, we identified only Cx. perexiguus, confirmed by molecular identification. As for the pipiens complex, there is unclear morphological differentiation and thus further molecular examination is recommended for specimens attributed by morphology to Cx. univittatus [20]. The presence of Cx. pusillus and Cx. tritaeniorhynchus in Qatar was confirmed by our field studies, whereas five other Culex species reported in the literature were not found viz. Cx. (Oculeomyia) bitaeniorhynchus Giles, 1901, Cx. (Cax.) laticinctus Edwards, 1913, Cx. (Cax.) mimeticus Noë, 1899, Cx. (Cax.) sitiens Wiedemann, 1828, and Cx. (Cax.) vagans Wiedemann, 1828. All of them except Cx. vagans do occur in the Arabian Peninsula [2, 12, 22], but to date, there has been only a single record in the literature and thus the occurrence of these five species in Qatar remains to be confirmed.

Lastly, there is only one official record of detection of Culiseta sp. (under its synonym Theobaldia) [1] and for Coquillettidia sp. in Qatar [21]. The mention of Culiseta may refer to Cs. longiareolata that we report here for the first time, and the presence of Coquillettidia sp. has to be further investigated.

**Recommendations to further explore local mosquito fauna**

Additional and extended field surveys should be performed at regular interval to provide the most comprehensive
knowledge about the mosquito fauna in Qatar. The most comprehensive strategy would be to undertake a field survey at as many sites as possible throughout the country, covering all kinds of environments and applying various sampling and trapping methods, more intensely during the rainy season but also the rest of the year.

While city parks may not provide relevant mosquito fauna data because of their regular treatment by insecticides, wildlife conservation centres and animal holdings are important to investigate. In addition, surveys should focus on points of entry (ports, airports) as well as labour camps and industrial zones for possible alien species introductions. There are chances of discovering previously undetected mosquito species in Qatar given the existence of many other species in neighbouring countries (e.g. 36 species in Saudi Arabia [2]). However, the most pressing priority must be to design field surveys to confirm the existence of the mosquito species reported to occur in Qatar only by a single study/sample (Table 5). A quick way of achieving this could be re-analysis of the already collected specimens preferentially by a third party (providing the samples are preserved by the institutes after completion of field surveys) [13, 14, 19]. Another way of achieving this would be to sample at the same locations as mentioned by authors in those studies, possibly at the same time of the year.

Besides mapping the mosquito population in Qatar, entomological surveys should also aim to evaluate the risk of mosquito-borne pathogen transmission by collecting data on distribution, abundance, seasonality and biting behaviour of species. Such surveys may focus on (1) Anopheles species as potential vectors of malaria parasites, (2) Ae. aegypti and Ae. albopictus as potential vectors of chikungunya, dengue, and Zika viruses, (3) Ae. caspius as a potential vector of Rift Valley fever virus, and (4) Cx. pipiens complex, Cx. perexiguus, Cx. tritaeniorhynchus and Cx. univittatus as potential vectors of West Nile virus. Finally, cross-sectional and longitudinal data collections are needed to support the building of mid- and long-term surveillance and control strategies.

### Summary outcome and prospects

Our field studies have immensely extended the length, breadth, and depth of Qatar’s existing mosquito fauna database. Our field surveys were neither able to confirm nor refute the existence of Ae. aegypti in Qatar; however, given the extensive geographical coverage and length of sample collection, we can confidently say that Ae. aegypti is neither widespread nor abundant in Qatar. This suggests that there is a minimal risk for local transmission of dengue, chikungunya or Zika viruses. The malaria vector An. stephensi is widespread and common, including in urbanised areas, suggesting a risk of local transmission of malaria parasites. The wetland mosquito Ae. caspius is likewise widespread and is probably responsible for biting

| Taxon                  | First report | References for Qatar | Session 1 2017–2018 | Session 2 2017 | Session 3 2019 | Occurrence status |
|------------------------|--------------|----------------------|----------------------|----------------|----------------|------------------|
| Aedes aegypti          | 1999         | [2]                  |                      |                |                | Introduced?      |
| Aedes caspius          | 2009         | [14, 15, 18]         | ●                    | ●              | ●              | Presence to be confirmed |
| Aedes dorsalis         | 2015         | [15]                 |                      |                |                | Native           |
| Anopheles culicifacies s.l. | 1999 | [2]                  |                      |                |                | Presence to be confirmed |
| Anopheles multicolor   | 1992         | [11, 15, 18]         |                      |                |                | Native           |
| Anopheles sergentii    | 1992         | [11]                 |                      |                |                | Presence to be confirmed |
| Anopheles stephensi    | 1999         | [2, 14, 15, 18, 21]  | ●                    | ●              | ●              | Native           |
| Culex bitaeniorhynchus | 2015         | [21]                 |                      |                |                | Presence to be confirmed |
| Culex latincus         | 2015         | [14]                 |                      |                |                | Presence to be confirmed |
| Culex mimetica         | 2015         | [21]                 |                      |                |                | Presence to be confirmed |
| Culex pipiens complex  | 1985         | [1, 14, 15, 18, 19]  |                      |                |                | Native; Identity of occurring complex members to be confirmed |
| Culex perexiguus       | 2015         | [14]                 |                      | ●              | ●              | Native           |
| Culex pusillus         | 2009         | [14, 18]             | ●                    | ●              | ●              | Native           |
| Culex quinquefasciatus | 1988         | [2, 12, 14, 15, 19]  | ●                    | ●              | ●              | Native; Member of pipiens complex |
| Culex sitiens          | 2015         | [14]                 |                      | ●              | ●              | Presence to be confirmed |
| Culex tritaeniorhynchus| 2015         | [14, 15]             | ●                    | ●              | ●              | Native           |
| Culex univittatus      | 2009         | [14, 18]             |                      | ●              | ●              | Native; Identity to be confirmed by sequencing |
| Culex vagans           | 2015         | [21]                 |                      |                |                | Presence to be confirmed |
| Culiseta sp.           | 1985         | [1]                  |                      |                |                | May refer to Cs. longiareolata |
| Culiseta longiareolata | This study   |                      | ●                    | ●              | ●              | Native           |
| Coquillettidia sp.     | 2015         | [21]                 |                      |                |                | Presence to be confirmed |

1 Single record;  
2 Mentioned as pipiens complex or form molestus;  
3 As a group of three possible species, Cx. perexiguus, Cx. pipiens and Cx. quinquefasciatus.
nuisance at certain periods of the year, also representing a risk of Rift Valley fever virus transmission. Several potential vectors of West Nile virus are present in Qatar. The species *Cx. quinquefasciatus*, commonly known as the southern house mosquito, was present most abundantly and this species is mostly responsible for the indoor biting nuisance. Regular field studies are needed to further address the knowledge gaps in terms of distribution, breeding and biting preferences of different mosquito species currently present in Qatar to accurately assess the risk of mosquito-borne diseases [8, 27].

**Conflict of interest**

The authors declare that they have no competing interests.

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