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RESEARCH ARTICLE

The mosquitoes of the Balearic Islands: an inventory and a snapshot field survey

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Abstract

A snapshot field survey was conducted in the Balearic Islands (Spain) to widen knowledge about mosquito species present in the archipelago. A search for mosquito species records in published literature, local mosquito collections and unpublished grey literature was also undertaken. The main mosquito habitats (except urban habitats) on the four major islands of the archipelago (Mallorca, Menorca, Eivissa and Formentera) were visited between October and November 2019. A mosquito survey was conducted in 32 municipalities, including field collection of larvae, pupae and adults. The literature review updated the list of mosquito species in the Balearic Islands to 23 taxa (one invasive species and 22 considered native to the region). The 169 field samples collected during the snapshot identified 19 species, including three first records in the Balearic Islands (*Anopheles marteri*, *Culex mimeticus*, and *Cx. impudicus*), and also confirmed the presence of *Aedes detritus*, considered extinct until 2020. Seven species reported in the Balearics were not detected, i.e. *Ae. aegypti*, *Ae. rusticus*, *An. algeriensis*, *An. atroparvus*, *An. claviger s.s.*, *Coquillettidia richiardii*, and *Cx. hortensis*. Mosquito larvae were collected from a wide variety of natural and artificial habitats, with torrent bed pools housing the highest diversity (12 species). The most common species across a wide variety of breeding sites were *Cx. pipiens* followed by *Culiseta longiareolata* and *Cx. laticinctus*. Moreover, we provide information about the possible vector role of reported species in the Balearic Islands.

Keywords

Diptera – Culicidae – distribution – field sampling – Spain

1 Introduction

Vector-borne diseases have reemerged at the forefront in both human and animal health. Mosquitoes are among the most important vectors and the context has changed considerably since the late 1990s, with the (re-)appearance of pathogen transmission in western Europe including Spain, i.e. West Nile virus (Laycock *et al.*, 2022), malaria parasite (Velasco *et al.*, 2017) and more recently dengue virus (ECDC 2023) which was detected in Eivissa in 2022 (García-San-Miguel *et al.*, 2024). The causes behind these changes include globalisation and environmental and climate changes, which indirectly modify mosquito fauna and the range of pathogens in a given region (Franklinos *et al.*, 2019; Rocklöv and Dubrow, 2020).

Mosquito fauna in the Balearic Islands is known to comprise 17 taxa, including 13 native species, one

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introduced invasive species, and three species considered extinct, according to the most comprehensive mosquito species record for the western Palaearctic region (Robert *et al.*, 2019). When comparing the known mosquito fauna from the Balearic Islands with 14 established species, all other Western Mediterranean islands have between 2.5 and 3.3 times more recorded species (Sardinia: 35 established species; Sicily: 40 spp.; Corsica: 46 spp.; Robert *et al.*, 2019). Despite a smaller land surface compared to the latter islands, mosquito fauna can be expected to be more diverse than the level recorded in Robert *et al.* (2019). Moreover, assessing the risk that mosquito species represent to human and animal health first and foremost necessitates collecting updated distribution data for mosquito vector species.

In this sense, we performed a search for mosquito species records in published literature not included in Robert *et al.* (2019), local mosquito collections and unpublished grey literature, alongside a snapshot field survey aimed at gathering an updated picture of local mosquito fauna across all islands in the archipelago. More specifically, we aimed to (1) confirm occurrence and complete the species list and distribution data for native species, (2) investigate specific environments for other possibly present native species, e.g. *Anopheles plumbeus* in tree holes, (3) confirm the absence of species considered extinct, in particular *An. claviger sensu stricto* (*s.s.*) and *Aedes detritus sensu lato* (*s.l.*), and (4) investigate the spread of *Ae. albopictus* and check for the possible introduction of other invasive species.

2 Materials and methods

Study area

The Balearic Islands archipelago (1,176,659 inhabitants in 2022) is located in the Western Mediterranean (south-eastern Spain) and includes the islands of Mallorca (MA), Menorca (ME), Eivissa (EI), Formentera (FO), and 149 inhabited islets. Mallorca is the largest island (3,640 km^2), followed by Menorca (695 km^2), Eivissa (571 km^2) and Formentera (83 km^2) (IBESTAT, 2023). The Balearic Islands have a Mediterranean-type climate characterised by dry hot summers and wet winters (summer-dry mesothermal climate; Csa in the Köppen classification) (AEMET, 2011). The annual mean temperature is 21.8 °C and annual mean precipitation is 456 mm (AEMET, 2011).

Historical data

Historical and recent published distribution data were collected through a non-systematic search by reference tracking, targeting those not considered by Robert *et al.* (2019). Articles and grey literature documents reporting mosquito distribution data at island-level were gathered, as well as papers providing country species lists that mentioned the Balearic Islands in species distributions. In addition, accessible insect collections on the Balearic Islands were interrogated (online) or consulted to check and re-identify mosquito specimens.

Original field data

Our snapshot field study in the Balearic Islands ran from 2nd October to 17th November 2019, a rainy but still warm period of the year, following a non-systematic sampling scheme. On Mallorca, samples were taken in 20 of its 53 municipalities: Alcúdia, Algaida, Bunyola, Campos, Deià, Escorca, Esporles, Fornalutx, Inca, Llubí, Llucmajor, Manacor, Palma, Pollença, Puigpunyent, Sa Pobla, Santanyí, Selva, Sóller and Valldemossa. On Menorca, samples were taken in six of its eight municipalities: Alaior, Ciutadella, Es Castell , Ferreries, Maó and Mercadal. All five municipalities in Eivissa were investigated: Eivissa, Sant Antoni de Portmany, Sant Joan de Labritja, Sant Josep de sa Talaia and Santa Eulària del Riu. Finally, the single homonymous municipality on Formentera was also sampled (Figure 1, Supplementary Table S1). The sampling covered different environments on each of the islands, including natural, rural and peri-urban areas, in a perspective of biodiversity assessment. Urban areas were not considered a target for this study since mosquito fauna in this type of environment is well known in the Balearic Islands thanks to surveillance of invasive species (e.g. Collantes *et al.*, 2015; Barceló *et al.*, 2022). Sampling sites were selected based on expert knowledge, i.e. according to their apparent suitability for diverse mosquito species, visually in the field or based on prior diverse studies conducted in temporary ponds (Muntaner *et al.*, 2009; Pinya and Gil, 2009).

The sampling was implemented based on methods described in available guidelines (ECDC, 2012, 2014; Medlock *et al.*, 2018). Mosquitoes were collected by both larval sampling and adult trapping. Larvae and pupae were collected using different techniques according to the size of the water bodies. Immature specimens were collected from large water bodies using a large aquatic net (Bioform, Germany) with an extendable handle. In turn, a small aquarium net (Europrix, France) was used

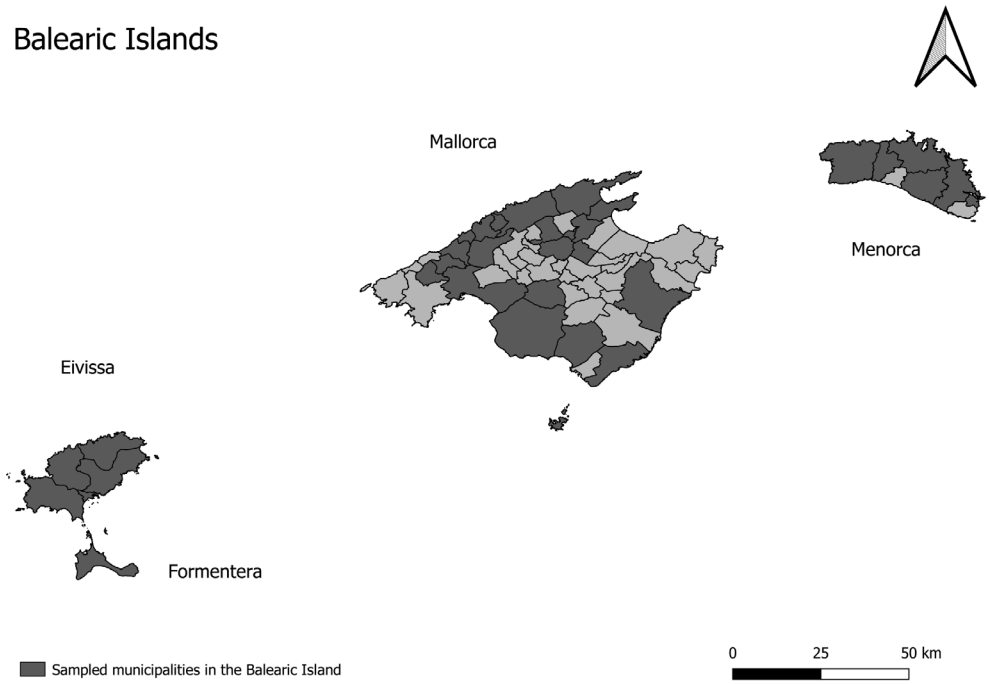

FIGURE 1 Municipalities sampled for mosquito fauna in the Balearic Islands in our snapshot field study, October-November 2019.

in small water bodies, such as puddles or artificial containers. In tree holes, either a silicone kitchen ladle, a manual rescue mucus aspirator (MedicAffaires, France) or a large cleaning pear pipette for aquariums was used, depending on the size of the opening. In all instances, the sample was observed in a 1 litre white plastic tray. Immature specimens were then transferred in water to a hermetic plastic vial for transport to the laboratory. Once there, 4th instar larvae were transferred into 70% ethanol solution, and young larvae and pupae were kept until they grew to the 4th instar or into adults. Emerged adults were transferred into a mouth aspirator and killed in a deep freezer for later identification. Some adults were dry pinned on minutia pins (mainly females) or stored in 70% ethanol solution (mainly males) and kept as a reference collection at the University of the Balearic Islands.

Mosquito adults were either collected through resting catches using a sweep net (Bioform, Germany) around vegetation, or through human landing catches sweep netting around an individual. In both instances, adults were collected from the net via a mouth aspirator and brought to the laboratory. In addition, adult trapping was performed with a Heavy-Duty EVS trap (BioQuip, Compton, CA, USA) baited with carbon dioxide released from a decommissioned fire extinguisher and equipped with a BG-CO_2 Timer® and a BG-Booster® release set (Biogents, Germany). Traps were run overnight at selected locations and under suitable weather conditions (no heavy rain or wind). Collected adults were handled as described above. Field data collection was processed using the VECMAP® software package (AVIA-GIS, Zoersel, Belgium). Mosquito specimens were identified by morphology (Becker *et al.*, 2020; Schaffner *et al.*, 2001).

3 Results

Literature data

Our literature review revealed four references containing mosquito occurrence data for the Balearic Islands that were not listed in Robert *et al.* (2019). These address six species added to the species list for the Balearic Islands (Supplementary Table S2), namely *Ae. rusticus* (Ebejer, 2003), *An. atroparvus* (Eritja *et al.*, 2002; Torres-Cañamares, 1979), *Coquillettidia richiardii*, *Culex theileri*, *Culiseta subochrea* and *Uranotaenia unguiculata* (Delgado-Serra *et al.*, 2020). The other found references provide confirmation on the occurrence of *Ae. mariae* (Bueno-Marí and Jiménez-Peydró, 2011), additional data on the introduction and spread of *Ae. albopictus* (Barceló *et al.*, 2015; Bengoa *et al.*, 2016; Miquel *et al.*, 2013) and recent faunistic data for Menorca (Bengoa *et al.*, 2020).

Field data

A total of 169 samples were collected from the Balearic Islands, including 145 larval samples, 12 human landing catches, 9 resting catches, and 3 CO_2-baited trappings (Table 1). Among these, 162 (95.9%) were positive for mosquitoes (1 CO_2-baited trapping and 6 larval samplings were negative). The samples were collected from 148 sites spread across the islands, i.e. 94 on Mallorca, 26 on Menorca, 21 on Eivissa and 7 on Formentera (Supplementary Table S1). The geographic location (coordinates) and a site description were recorded for each collected sample. Detailed information of our observations can be found in the supplementary material (Supplementary Table S3).

Our sampling yielded in a total of 6,883 specimens, of which 5,125 were larvae, 640 pupae, and 1,118 adults (583 females and 535 males; Table 2). Among the adults, almost 60% were obtained from larvae/pupae rearing.

Taxa observed on the islands with number of occurrences, October–November 2019

A total of 23 taxa are reported in the Balearic Islands according to our literature search, including three species considered extinct (*Ae. aegypti*, *Ae. detritus s.l.*, *An. claviger s.s.*, as mentioned in Robert *et al.*, 2019). Our snapshot field study observed 19 species (Table 3), including three first recordings in the Balearic Islands (*An. marteri*, *Cx. mimeticus*, and *Cx. impudicus*) and the detection of *Ae. detritus s.l.* which was considered extinct but also found in another recent study (Delgado-Serra *et al.*, 2020). Seven species reported in the literature review were not detected during the field snapshot: *Ae. aegypti*, *Ae. rusticus*, *An. algeriensis*, *An. atroparvus*, *An. claviger s.s.*, *Cq. richiardii* and *Cx. hortensis*.

4 Discussion

To our knowledge, this is the first study conducted in the Balearic Islands that aims to review all published records of mosquito species and to sample mosquito fauna in the entire archipelago in a single snapshot. Mosquito fauna in the Balearic Islands reported in the literature accounted for 23 species in this study (21 considered native, 1 invasive and 1 extinct species), while the snapshot field study detected 16 of these species and added three new records to the mosquito fauna of the Balearics, namely *An. marteri*, *Cx. mimeticus* and *Cx. impudicus*. This increases the number of occurring mosquito species in the Balearic Islands to 26.

Mallorca accounted for the higher number of species (18) followed by Menorca (12), Eivissa (9) and Formentera (6). The sampling was not intended to be systematic in the archipelago nor clustered into different ecosystems.

TABLE 1 Sampling effort of the snapshot field study in the Balearic Islands, October–November 2019.

Island	No. sites	No. samples	No. larval samples	No. human landing catches	No. resting catches	No. CO_2-baited trap-nights
Eivissa	21	24	19	2	2	1
Formentera	7	7	7	0	0	0
Mallorca	94	108	91	10	5	2
Menorca	26	30	28	0	2	0
Total	148	169	145	12	9	3

TABLE 2 Numbers of specimens collected and identified per life stages in each of the Balearic Islands, October–November 2019. Some adults were obtained from larvae/pupae rearing.

Island	No. larvae	No. pupae	No. adults
Eivissa	336	37	88
Formentera	144	28	28
Mallorca	3,155	445	844
Menorca	1,490	130	158
Total	5,125	640	1,118

TABLE 3 Mosquito taxa reported in the literature with year of first sighting, and taxa collected during our field study in the Balearic Islands, 2019.[1]

Mosquito taxa	Year of first observation from literature	Species sampled during our field study				
		Overall	EI	FO	MA	ME
Aedes (*Acartomyia*) *mariae*	1926	X	X	X	X	X
Ae. (*Aedimorphus*) *vexans*	<1930	X	–	–	X	–
Ae. (*Fredwardsius*) *vittatus*	1950	X	–	–	X[5]	–
Ae. (*Ochlerotatus*) *caspius*	1950	X	X	X	X	X
Ae. (*Och.*) *detritus s.l.*[2]	1950	X	X	X	X	X
Ae. (*Och.*) *pulcritarsis*	2006	X	–	–	X	X
Ae. (*Rusticoidus*) *rusticus*	2003[4]	–	–	–	–	–
Ae. (*Stegomyia*) *aegypti*	(<1909-≈1950)	–	–	–	–	–
Ae. (*Stg.*) *albopictus*	2012	X	X	–	X	X
Anopheles (*Anopheles*) *algeriensis*	1902	–	–	–	–	–
An. (*Ano.*) *atroparvus*	<1979	–	–	–	–	–
An. (*Ano.*) *claviger s.s.*	(1902)	–	–	–	–	–
An. (*Ano.*) *maculipennis s.l.*[2]	<1979	X	–	–	X	X
An. (*Ano.*) *marteri*	-	First	–	–	X	–
An. (*Ano.*) *petragnani*	<1979	X	–	–	X	–
Coquillettidia (*Coquillettidia*) *richiardii*	2018	–	–	–	–	–
Culex (*Culex*) *laticinctus*	1950	X	X	X	X	X
Cx. (*Cux.*) *mimeticus*	-	First	–	–	X	–
Cx. (*Cux.*) *pipiens*[3]	<1930	X	X	X	X	X
Cx. (*Cux.*) *theileri*	2018	X	–	–	X	X
Cx. (*Maillotia*) *hortensis*	<1979[4]	–	–	–	–	–
Cx. (*Neoculex*) *impudicus*	-	First	X	–	X	X
Culiseta (*Allotheobaldia*) *longiareolata*	1950	X	X	X	X	X
Cs. (*Culiseta*) *annulata*	1911	X	–	–	X	X
Cs. (*Cus.*) *subochrea*	2018	X	X	–	–	–
Uranotaenia (*Pseudoficalbia*) *unguiculata*	2018	X	–	–	X	–
No. taxa	23	19	9	6	18	12

[1]X = listed species; First = first observation for the Baleares during our study; in brackets: extinct species; EI = Eivissa: FO = Formentera; MA = Mallorca; ME = Menorca.
[2]Not identified to species level within the complex.
[3]Both *molestus* and *pipiens* forms.
[4]Doubtful records (see discussion).
[5]Collected on 4th October 2020 by one of the authors after the snapshot field study.

Therefore, the sampling effort (number of samples) in Mallorca was higher than in the rest of the archipelago due to logistical issues. With regards to administrative coverage (number of sampled municipalities per island), Formentera and Eivissa had the highest coverage (100% municipalities sampled), followed by Menorca (75%) and Mallorca (38%). In terms of ecological coverage, the major bioclimatic zones across the islands were covered in the sampling. For example, samples in Mallorca were collected from the Serra de Tramuntana mountain range, as well as from coastal and rural areas, giving an adequate representation of the major environmental units on the island.

The field survey found one species considered extinct in previous publications (Robert *et al.*, 2019), i.e. *Ae. detritus s.l.*, found to occur on all four islands. In turn, we find no trace of seven historically reported species. These include the invasive species *Ae. aegypti*, which

has been considered extinct in the Mediterranean Basin since the mid-20th century, *An. claviger s.s.*, also believed extinct (Robert *et al.*, 2019), and two species for which previous reports are deemed dubious, i.e. *Ae. rusticus* and *Cx. hortensis* (Ebejer, 2003; Torres-Cañamares, 1979). Thus, only three species reported to occur in the Balearic Islands were not detected: *An. algeriensis*, *An. atroparvus* and *Cq. richiardii*. One of these species (*An. atroparvus*) relies on molecular methods for accurate identification, which were not available to our study. The following paragraphs provide details of our findings for each species, as well as general statements on their distribution, ecology and putative vector role.

Aedes (*Acartomyia*) *mariae* (Sergent & Sergent, 1903) is member of a species complex with Mediterranean distribution, alongside *Ae.* (*Acy.*) *zammitii* (Theobald, 1903) and *Ae.* (*Acy.*) *phoeniciae* Coluzzi & Sabatini, 1968. Meanwhile, *Ae. mariae* occurs in the western Mediterranean Basin, *Ae. zammitii* is known in the central Mediterranean Basin and *Ae. phoeniciae* in the eastern Mediterranean Basin. *Aedes mariae* has been known to occur in Mallorca since the early 20th Century (Hase, 1926 in Margalef, 1949) and recent records exist (Bengoa *et al.*, 2022; Bueno-Marí and Jiménez-Peydró, 2011; Delgado-Serra *et al.*, 2020), including from Menorca. We collected the species at 13 sites across all four islands, providing the first records for both Eivissa and Formentera. Immature specimens were collected from coastal saltwater rock pools, which are the specific larval habitats for this species, together with *Cs. longiareolata* on two occasions (Figure 2C). Thus, the species may occur along all Balearic coasts where saltwater can stand in rock pools. Females can cause severe nuisance near larval habitats. Although they are not known to transmit any pathogen to mammals, they can transmit the bird malaria parasite *Plasmodium relictum* (Schaffner *et al.*, 2001).

Aedes (*Aedimorphus*) *vexans* (Meigen, 1830) has a wide Holarctic distribution. It was cited for the first time in the Balearic Islands by Gil Collado (1930) in Menorca, and a recent molecular study reported its presence in Mallorca, based on samples collected between 2010 and 2018 (Delgado-Serra *et al.*, 2020). We collected immatures of this species at 11 sites in Mallorca, including ten larval habitats formed by temporary and semi-permanent rock and ground ponds (Figure 2G), together with *Ae. caspius*, *Cx. laticinctus*, *Cx. pipiens* and *Cs. longiareolata.* One biting female was caught near to one of these habitats. Females feed on humans and cattle. The species is a proven vector of Tahyna virus (TAHv), Rift Valley fever virus (RVFv) and *Dirofilaria immitis* (dog heartworm), as well as being a potential vector for West Nile virus (WNv), Eastern equine encephalitis virus and Zika virus (ZIKv) (Becker *et al.*, 2020).

Aedes (*Fredwardsius*) *vittatus* (Bigot, 1861) has a current distribution encompassing Africa, Asia and southern European countries. The species was first reported in Mallorca by Torres-Cañamares (1951), and no additional information about its occurrence in the Balearic Islands is available. It was not collected during the snapshot period, even where the sampling was conducted in optimal habitats for the species, such as rock pools, tree holes and artificial containers. Nonetheless, it was identified in October 2020 by one of the authors from reared larvae collected in a torrent bed rock pool in the municipality of Pollença (northeast Mallorca). The species has been linked to transmission of the following viruses: Babanki, chikungunya (CHIKv), Middelburg, Semliki Forest, dengue (DENv), Saboya, Wesselsbron, yellow fever (YFv), ZIKv and Bunyamwera (reviewed by Díez-Fernández *et al.*, 2018).

Aedes (*Ochlerotatus*) *caspius* (Pallas, 1771) is found throughout the Palaearctic region, from Europe to Mongolia, north and west China, north Africa, and west and middle Asia (Becker *et al.*, 2020). It was cited for the first time in the Balearics by Torres-Cañamares (1979) in Eivissa, Mallorca and Menorca. Further studies also reported updates on this species in the Balearics: Melero-Alcíbar *et al.* (2006a), Melero-Alcíbar *et al.* (2006b), and Delgado-Serra *et al.* (2020). We found *Ae. caspius* on the same islands, as well as Formentera. Adults were collected at nine sites and immatures at a further 13, encompassing habitats such as brackish marshes, temporary and semi-permanent ponds, ditches (Figures 2E, 2F) and a torrent bed pool (i.e. a pool left by a dried-out torrent, flooded by rain and flushed by heavy rain only, with limited vegetation such as algae and a few riparian plants). *Aedes detritus s.l.*, *Ae. vexans*, *Cx. laticinctus*, *Cx. pipiens*, *Cx. theileri*, *Cs. annulata*, *Cs. longiareolata*, and *Ur. unguiculata* were also found to breed in association with *Ae. caspius* in these larval habitats. Females bite humans and other warm-blooded vertebrates (Schaffner *et al.*, 2001). The species' vector role is effective for pathogens such as WNv, TAHv and the bacterium *Francisella tularensis*. It is also considered a potential reservoir of RVFv during interepizootic periods (reviewed in Milankov *et al.*, 2009).

Aedes (*Och.*) *detritus s.s.* Haliday, 1833 and *Ae.* (*Och.*) *coluzzii* Rioux, Guilvard & Pasteur, 1998 form a Palaearctic species complex (Detritus Complex) that occurs along European coastlines and in some continental brackish water habitats (Becker *et al.*, 2020;

FIGURE 2 Examples of aquatic larval habitats found to yield mosquito species in our snapshot field study across the Balearic Islands, October – November 2019. (A) Collection site of *Anopheles marteri*, *An. petragnani* and *Culex pipiens*: an artificial container (wash house basin with spring water, site BAL066), Deià, MA, on 26/10/2019; (B) Collection site of *Aedes pulcritarsis*: a tree hole (*Quercus ilex*, site BAL079), Pollença, MA, on 01/11/2019; (C) Collection site of *Ae. mariae*: coastal rock pools (site BAL141), Sant Josep de la Talaia, EI, on 16/11/2019; (D) Collection site of *An. petragnani* and *Cx. mimeticus*: a torrent bed pool (site BAL004), Esporles, MA, on 02/10/2019; (E) Collection site of *Ae. caspius*, *Cx. pipiens*, *Culiseta longiareolata*, and *Uranotaenia unguiculata*: a ditch with isolated puddles (site BAL039), Alcúdia, MA, on 17/10/2019; (F) Collection site of *Ae. caspius*, *Ae. detritus s.l.*, *Cx. pipiens*, *Cx. theileri*, and *Cs. annulata*: a ditch (brackish water, site BAL111), Mercadal, ME, on 09/11/2019; (G) Collection site of *Ae. vexans*: temporary pond (site BAL062b), Llucmajor, MA, on 25/10/2019; (H) Collection site of *Cx. impudicus*: a semi-permanent pond (site BAL077), Lluc, MA, on 29/10/2019. Photo credits: Francis Schaffner.

Schaffner *et al.*, 2001). *Aedes detritus* was first cited by Margalef (1951) in Eivissa. Further studies reporting the occurrence of this taxon are Ebejer (2003) and Delgado-Serra *et al.* (2020). We collected larvae at nine sites across Mallorca, Menorca and Formentera, from typically described breeding sites for this species such as brackish marshes, ditches (Figure 2F), puddles, torrent bed pools and isolated ponds, together with *Ae. caspius*, *An. maculipennis s.l.*, *Cx. pipiens*, *Cx. theileri*, *Cs. annulata*, and *Cs. longiareolata.* Adults were collected by human landing catches and CO_2-baited traps at six sites in Mallorca and Eivissa near torrents and brackish marshes. Accurate differentiation between both species in the complex can only be performed by using molecular tools, i.e. the iso-enzymatic technic or the multiplex polymerase chain reaction (PCR) based on the amplification of the ribosomal internal transcribed spacer 2 (ITS2) (Brengues *et al.*, 2014; Ponçon *et al.*, 2007). Since these techniques were not accessible to our study, nor to previous studies recording the taxon, all occurrences in the Baleares refer to *Ae. detritus s.l.* to date. This taxon can generate severe nuisance where large brackish wetlands occur (Schaffner *et al.*, 2001). Females have been found naturally infected by *Dirofilaria repens* and laboratory trials have shown they are able to transmit WNv and Japanese Encephalitis virus (JEv) (Blagrove *et al.*, 2016; Schaffner *et al.*, 2001).

Aedes (*Och.*) *pulcritarsis* (Rondani, 1872) is mainly distributed throughout the Mediterranean region up to southwestern Russia and Caucasia (Becker *et al.*, 2020), although recent records are available from central European countries such as Austria (Bakran-Lebl *et al.*, 2022). *Aedes pulcritarsis* is closely related to *Ae.* (*Och.*) *asiaticus*, Edwards, 1926, previously categorised as a subspecies of *Ae. pulcritarsis* but recently raised to species level (Harbach and Wilkerson, 2023) with an Asian distribution (east of the Caspian Sea up to Pakistan). The species was cited for the first time in Eivissa by Melero-Alcíbar *et al.* (2006b) and no further record is known for this species. We collected larvae from 18 sites on both Mallorca and Menorca, exclusively from tree holes in *Quercus ilex* and *Platanus orientalis*, together with *Cx. pipiens* on a single occasion (Figure 2B). The species has not been linked to any pathogen transmission (Schaffner *et al.*, 2001).

Aedes (*Rusticoidus*) *rusticus* (Rossi, 1790) is found in Europe, north Africa and Anatolia (Becker *et al.*, 2020). There is unclear information about the first citation in the Balearics, since Ebejer (2003) cited the species in a reference collection deposited in the S'Albufera Natural Parc (Alcúdia), the main wetland area in Mallorca. However, no direct observations were reported from the survey conducted in that area in 2001 (as published in Ebejer, 2003) and the author suggested uncertain determination. The authors of the present study visited the collection and could not identify any voucher as belonging to *Ae. rusticus.* We collected samples from 15 sites in S'Albufera for the present study and no specimen of *Ae. rusticus* was detected. The species has not been linked to the transmission of any pathogen or parasite (Schaffner *et al.*, 2001).

Aedes (Stg.) *aegypti* (Linnaeus, 1762), also called the yellow fever mosquito, is an invasive species originating from Africa and currently distributed worldwide in most tropical and subtropical regions. The species was also widely distributed in the Mediterranean Basin between the 17th and mid-20th centuries, where it was responsible for several outbreaks of yellow fever and dengue (Schaffner and Mathis, 2014). There is evidence that the species was also present and common in Palma (Mallorca), and Maó (Menorca) (Arias, 1911) and outbreaks of yellow fever were reported from Palma and Maó in 1821, 1870 and 1876 (Chantemesse and Borel, 1905; Pittaluga, 1928; Hoffman, 1931). The species was not observed in Spain or the Baleares after 1953 (Eritja *et al.*, 2002) although the reasons for its disappearance remain unclear and there is concern about its possible re-establishment in the Mediterranean Basin (Wint *et al.*, 2022). *Aedes aegypti* is a major vector of YFv, DENv, CHIKv and ZIKv (Schaffner *et al.*, 2013).

Aedes (*Stegomyia*) *albopictus* (Skuse, 1894), the Asian tiger mosquito, is an invasive mosquito species that originates from Southeast Asia and is currently widespread across large areas of Africa, Europe, Australia, the Americas and the Middle East (Kraemer *et al.*, 2015). It was first detected in Spain in 2004 in Catalonia (Aranda *et al.*, 2006). The first detection in the Balearic Islands occurred in September 2012 in Mallorca following a sampling conducted after communication from a resident in the municipality of Bunyola (Barceló *et al.*, 2022; Miquel *et al.*, 2013). Two years after its detection in Mallorca, it was detected in Eivissa (Barceló *et al.*, 2015) followed by Menorca (Bengoa *et al.*, 2016). Additional studies reported presence and/or abundance data for the species across different islands (Tavecchia *et al.*, 2017; Sanz-Aguilar *et al.*, 2018). The present study recorded *Ae. albopictus* in 20 sampling sites, on the islands of Mallorca, Menorca and Eivissa. No positive samples were collected in Formentera, although direct observation by one of the authors (MAM) in December 2023 confirmed the presence of the species on the island. During the field study in 2019, the species was collected

four times in adult human landing catches and 16 times in larval samplings. Immatures were collected from artificial containers and tree holes, together with *Cx. laticinctus*, *Cx. pipiens s.l.* and *Cs. longiareolata*. *Aedes albopictus* is a vector of arboviruses, such as CHIKv, DENv and ZIKv, and parasites such as *D. immitis* (dog heartworm) (Schaffner *et al.*, 2013). *Ae. albopictus* has been shown to be a competent vector of more than 26 arboviruses in laboratory trials (Paupy *et al.*, 2009). It is also known to cause major nuisance to humans (Delatte *et al.*, 2010).

Anopheles (*Anopheles*) *algeriensis* Theobald, 1903, is distributed throughout the Mediterranean region and North Africa, western, central and eastern Europe and the Middle East (Robert *et al.*, 2019). The first citation of *Ae. algeriensis* in the Balearic Islands dates back to 1903 (Pittaluga, 1903), with a reported presence in the S'Albufera wetland. The species was reported by Ebejer (2003) in the list of Diptera from S'Albufera and it was recently recorded in a molecular analysis of mosquito specimens collected in the municipality of Palma in 2010–2011 (Delgado-Serra *et al.*, 2020). We sampled larval habitats which looked optimal for the presence of this species, such as ditches, permanent pools and brackish marshes in the same area of S'Albufera. However, no presence of the species was detected. Nevertheless, we did detect other species commonly associated with *An. algeriensis*, such as *Ur. unguiculata*. As for its vector role, *An. algeriensis* has shown to have competence for *P. falciparum* in laboratory trials (Becker *et al.*, 2020), although its role as vector in the field remains unclear (Boccolini *et al.*, 2023).

Anopheles (*Ano.*) *claviger s.s.* (Meigen, 1804) and *Anopheles* (*Ano.*) *petragnani* Del Vecchio, 1939 are two sibling species that form the Claviger Complex. While the nominotypical form *An. claviger s.s.* has been known since 1804, *An. petragnani* was described in 1939 based on tiny morphological characters of the larva and pupa. Both species occur within the Palaearctic region, although the latter is restricted to the western Mediterranean, with a few recent more northern continental records (Becker *et al.*, 2016; Schaffner *et al.*, 2023). *Anopheles claviger* was mentioned first for the Balearics (Mallorca) by Pittaluga (1903), listed by (Eritja *et al.*, 2002), but considered extinct by Robert *et al.*, (2019). *Anopheles petragnani* was reported to occur on Mallorca in 1979 (Torres-Cañamares 1979). We collected specimens from Claviger Complex at six sites, in four torrent bed pools (Figure 2D) and two artificial containers (Figure 2A). Immatures were found together with *An. marteri*, *Cx. impudicus*, *Cx. mimeticus*, *Cx. pipiens* and *Cs. annulata*. All specimens were identified by morphology as belonging to *An. petragnani*. The single report of *An. claviger* (Pittaluga 1903) was published before *An. petragnani* was described, and may therefore be understood as *An. claviger s.l.*. In addition, since only *An. petragnani* has been evidenced on Mallorca to date, we can consider the Claviger Complex to be represented in the Baleares by *An. petragnani* only. While *An. claviger s.s.* is responsible for the transmission of the human malaria parasite and several pathogens, *An. petragnani* appears solely zoophilic, and has never been implicated in pathogen transmission (Schaffner, 2002).

Anopheles (*Ano.*) *maculipennis s.l.* Meigen, 1818 and *Anopheles* (*Ano.*) *atroparvus* Van Thiel, 1927 refer to the Maculipennis Complex (= *An. maculipennis sensu lato*) and to one of its species members, respectively. The complex comprises several members that can barely be distinguished by morphology. Twelve species are currently recognised to occur in the Palaearctic region (Becker *et al.*, 2020) and several are (or have been) vectors of human malaria, with a varied role. Most of them can only be accurately identified by genetic analysis, in particular by rDNA ITS2 sequencing (Collins and Paskewitz, 1996; Linton *et al.*, 2001). Without performing this analysis, the collected specimens are better placed under the name *An. maculipennis s.l.*. In the distribution chart for Euro-Mediterranean mosquitoes, only *An. maculipennis s.l.* was mentioned to occur in the Balearics (Robert *et al.*, 2019). However, one member of the complex, namely *An. atroparvus*, was previously reported in the Balearic archipelago, as likely being present in Menorca and with a doubtful presence in Mallorca (Torres-Cañamares 1979). Later, Bengoa *et al.* (2020) reported the occurrence of *An. maculipennis* at three locations in Menorca. Our study collected specimens belonging to the complex at three locations in Menorca and one in Mallorca, providing the first evidence of its occurrence on the latter island. Larvae were found in a large ditch, temporary ponds and torrent bed pools, alongside *Ae. detritus s.l.*, *Cx. pipiens*, *Cx. theileri* and *Cs. longiareolata*. One adult was caught in a built rock cave. The genetic analysis to define complex member identity remains to be performed for these specimens. *Anopheles atroparvus* is regarded as an efficient vector of human malaria parasites, and members of the complex are also suspected to transmit viruses such as myxoma and WN (reviewed by Hernandez-Valencia *et al.*, 2023), as well as helminth worms.

Anopheles (*Ano.*) *marteri* Sénevet & Prunelle, 1927 is distributed throughout the southern Palaearctic region, mainly in mountainous regions, from Portugal to

Tajikistan. Here we report the first finding of this species in the Balearic archipelago. Larvae were found in a fountain (Figure 2A) and torrent bed pools in the Serra de Tramuntana mountain range (north Mallorca), together with *An. petragnani* and *Cx. pipiens*. Its breeding in artificial containers has never previously been described in the literature, with its usual larval habitat being rock pools and mountain streams and springs, with rocky bottoms and scarce vegetation. The species is strongly zoophilic and not known to transmit any pathogen (Becker *et al.*, 2020).

Coquillettidia (*Coquillettidia*) *richiardii* (Ficalbi, 1889) is widely distributed in the western Palaearctic region (Becker *et al.*, 2020). It was not listed as a member of the Balearic mosquito fauna until very recently, when females were reported in coastal marshes on Mallorca, without any further details (Delgado-Serra *et al.*, 2020). We did not detect the species in our snapshot. Larvae and pupae live submerged and obtain oxygen from the aerenchyma of aquatic plant roots to which they attach (Becker *et al.*, 2020). Larval habitats are fresh water permanent waterbodies rich in erect vegetation (e.g. *Phragmites*, *Typha*, *Carex*). Adults can be numerous and readily bite humans and domestic animals. The species is suggested as a vector of the Sindbis virus (SINv) and may contribute to the transmission of *Dirofilaria* nematodes and Batai virus, TAHv and WNv (Schaffner *et al.*, 2023).

Culex (*Culex*) *laticinctus* Edwards, 1913 has a distribution range that extends from the Canary Islands through Mediterranean countries to the Middle East and southwest Asia (Becker *et al.*, 2020). The species has been reported to occur in Mallorca, Menorca and Eivissa in several studies since 1951 (Bengoa *et al.*, 2020; Margalef, 1951; Melero-Alcíbar *et al.*, 2006a,b; Torres-Cañamares, 1951). We found the species at 28 sites, distributed across the four islands. We collected immatures in a large variety of larval habitats, including human-made containers, rock pools, riverbed pools, and temporary and semi-permanent ponds. They were found together with *Ae. albopictus*, *Ae. caspius*, *Ae. vexans*, *Cx. impudicus*, *Cx. pipiens*, *Cs. annulata* and *Cs. longiareolata*. We also caught adults on two occasions in a cave and in vegetation. Females look to be mainly zoophilic and have little or no medical importance (Becker *et al.*, 2020; Schaffner *et al.*, 2001).

Culex (*Cux.*) *mimeticus* Noe, 1899 is distributed throughout the southern part of the Palaearctic region and through the Oriental region (Becker *et al.*, 2020). This taxon is reported here for the first time in the Balearics. We found immatures at a single site in Mallorca on two occasions (Esporles, 02/10 and 04/11/2019, Figure 2D). Larvae and pupae were collected from a riverbed pool flooded by a spring, with almost no current, together with *An. petragnani*. The females are zoophilic but occasionally bite humans; they have been found to be naturally infected by WNv (Becker *et al.*, 2020; Schaffner *et al.*, 2001).

Culex (*Cux.*) *pipiens* Linnaeus, 1758 is widespread in the Holarctic region and found throughout Europe (Becker *et al.*, 2020). The distribution of *Cx. pipiens* in Spain has been recently revised by Gangoso *et al.* (2020). It has been known to occur in the Balearics since 1930 (Gil Collado, 1930) and was subsequently reported in many studies. This taxon represents the temperate-climate member of the Pipiens Complex. It includes both *molestus* and *pipiens* forms (or biotypes) and their hybrids, which can be sorted on behavioural observations or genetic analysis. We did not perform any molecular analysis on the specimens collected in our study. Thus, we consider the caught blood-fed specimens from a camper van and a bedroom in Mallorca (Inca and Selva) as belonging to the *molestus* form, whilst the form remains undetermined for all other collected specimens. We caught adults at seven sites by CO_2-baited traps, human landing and resting catches. We also found immatures at 73 sites located across all four islands (Figures 2A, 2E, 2F), together with one or more of the following species: *Ae. albopictus*, *Ae. caspius*, *Ae. detritus s.l.*, *Ae. pulcritarsis*, *Ae. vexans*, *An. maculipennis s.l.*, *An. marteri*, *An. petragnani*, *Cx. impudicus*, *Cx. laticinctus*, *Cx. theileri*, *Cs. annulata*, *Cs. longiareolata*, *Cs. subochrea* and *Ur. unguiculata*. Females bite a large variety of animals including humans, depending on the species form. In Europe, they may act as vectors of several arboviruses with medical and animal importance, in particular WN, SIN and Usutu viruses (Becker *et al.*, 2020).

Culex (*Cux.*) *theileri* Theobald, 1903 is distributed throughout the African and Palearctic regions, Middle East and east Oriental region (Becker *et al.*, 2020). This species was reported only recently as occurring in Mallorca (Delgado-Serra *et al.*, 2020) and its presence is confirmed in our field survey. We detected the species at two sites, one on Mallorca (Alcúdia) and one in Menorca (Mercadal). We collected immatures in two diches with vegetation (Figure 2F), together with *Ae. caspius*, *Ae. detritus s.l.*, *An. maculipennis s.l.*, *Cx. pipiens* and *Cs. annulata*. Females feed on any mammal and were found to carry canine *Dirofilaria* worms and SINv, RVFv and WNv (Becker *et al.*, 2020; Schaffner *et al.*, 2001).

Culex (*Maillotia*) *hortensis* Ficalbi, 1889 occurs in the Mediterranean region up to Central Europe, as

well as in north Africa, middle Asia and India (Becker *et al.*, 2020). It was first mentioned by Torres-Cañamares (1979) in Menorca and listed in subsequent fauna lists (Bueno-Marí *et al.*, 2012; Eritja *et al.*, 2002; Robert *et al.*, 2019), although no evidenced record exists (i.e. accurate description, specimen in collection). Larvae were possibly confused with *Cx. impudicus* which has similar morphology and develops in the same habitats. Its presence in the Balearic Islands is strongly doubtful since we inspected many suitable larval habitats such as human-made containers, rock pools and riverbed pools, without detecting the species.

Culex (*Neoculex*) *impudicus* Ficalbi, 1890 is mainly distributed in the Mediterranean region. Our field study reports this species for the first time in the Balearics. We detected the species at nine sites, five located on Mallorca (Esporles, Sóller and Lluc), one on Menorca (Ferreries) and three on Eivissa (Sant Josep de la Talaia and Santa Eulària des Riu). We collected immatures in three artificial containers, three torrent bed pools, two ponds (Figure 2H) and one spring pool, together with *An. petragnani*, *Cx. laticinctus*, *Cx. pipiens*, *Cs. annulata* and *Cs. longiareolata.* Females preferably bite amphibians and are not known to feed on humans (Becker *et al.*, 2020).

Culiseta (*Allotheobaldia*) *longiareolata* (Macquart, 1838) is distributed across Europe from Portugal to Turkey, and as far north as southern England (Becker *et al.*, 2020). The species has been reported in the Balearics by several studies since 1951 (Bengoa *et al.*, 2020; Delgado-Serra *et al.*, 2020, Margalef, 1951; Melero Alcíbar *et al.*, 2006a,b; Torres-Cañamares, 1951). We found the species at 51 sites, distributed across all four investigated islands. Larval habitats comprised various artificial containers, tree holes, coastal saltwater and inland freshwater rock pools, torrent bed pools, ditches (Figure 2E), and temporary and semi-permanent ponds. Immatures were found together with *Ae. albopictus*, *Ae. mariae*, *Ae. vexans*, *An. maculipennis s.l.*, *Cx. impudicus*, *Cx. laticinctus*, *Cx. pipiens*, *Cs. annulata*, *Cs. subochrea* and *Ur. unguiculata*. One female was also caught in a CO_2-baited trap. *Culiseta longiareolata* females mainly bite birds and are considered vectors of avian malaria parasites. They can transmit WNv in the laboratory (Schaffner *et al.*, 2001).

Culiseta (*Culiseta*) *annulata* (Schrank, 1776) is widely distributed throughout Europe up to northern Africa, Anatolia and southwest Asia (Becker *et al.*, 2020). The species was first reported in Menorca in the early 20th century (Arias, 1911; Gil Collado, 1930) and later in Mallorca (Delgado-Serra *et al.*, 2020). We collected the species at four sites in Mallorca (Escorca, Esporles, Sóller) and Menorca (Mercadal). Immatures were collected in torrent bed pools and a ditch (Figure 2F), together with *Ae. caspius*, *Ae. detritus s.l.*, *An. petragnani*, *Cx. impudicus*, *Cx. laticinctus*, *Cx. pipiens*, *Cx. theileri*, *Cs. annulata*, and *Cs. longiareolata*. Females bite mammals including humans, mainly at night and often indoors. The species is considered to be an efficient vector of avian malaria plasmodia and a potential vector of TAHv (Becker *et al.*, 2020).

Culiseta (*Cus.*) *subochrea* (Edwards, 1921) is a widespread Palaearctic species, albeit uncommon. Its distribution stretches into north Africa, the Middle East and middle Asia (Becker *et al.*, 2020). The species was only recently reported to occur in Mallorca (Delgado-Serra *et al.*, 2020) and our field study provides the first evidence of its presence in Eivissa. We collected the species at a single site (Sant Antoni de Portmany) where a single pupa was found in a temporary pond. The species was found alongside larvae of *Cx. pipiens* and *Cs. longiareolata*. Females bite mammals including humans and are not known to transmit any pathogen with importance for public health (Schaffner *et al.*, 2001).

Uranotaenia (*Pseudoficalbia*) *unguiculata* Edwards, 1913 is frequently found throughout the Mediterranean region and also occurs in middle and southwest Asia (Becker *et al.*, 2020). Like the previous species, it was only recently reported in Mallorca (Delgado-Serra *et al.*, 2020) and our field study confirms its occurrence. We collected the species at two sites on Mallorca, in a cultivated area of S'Albufera wetland (Alcúdia, Mallorca, Figure 2E). Larvae were found in a temporary pond, together with the larvae of *Ae. caspius*, *Cx. pipiens* and *Cs. longiareolata*. Females can bite amphibians and reptiles, and are not deemed to be medically important, despite having been found to be naturally infected by WNv in Central Europe (Rudolf *et al.*, 2015).

Mosquito communities according to major larval habitat types

Seven species were found in artificial containers, with *Cx. pipiens* and *Cs. longiareolata* being the most frequently collected, ahead of *Cx. laticinctus* and *Ae. albopictus* (Table 4; Figure 4A). These containers were mainly concrete basins, used tyres and fountains (Figure 3). Typical brackish marshlands were found to be mainly inhabited by known brackish water specimens, *Ae. caspius* and *Ae. detritus s.l.*, occasionally alongside *Cx. pipiens* larvae (Figure 4B). Eight species were found in ditches flooded by brackish or fresh water, with *Cx. pipiens* being the most frequently encountered (Figure 4C).

TABLE 4 Number of sites per positive larval habitat type for each mosquito species, and number of sites investigated per type in our snapshot study across the Balearic Islands, October-November 2019.

Mosquito taxa	Artificial container	Brackish marshland	Ditch	Semi-permanent pond	Temporary pond	Torrent bed pool	Coastal rock pool	Inland rock pool	Tree hole	Well	Total no. sites/sp.
Ae. (*Acy.*) *mariae*							13				13
Ae. (*Adm.*) *vexans*				1	9						10
Ae. (*Fre.*) *vittatus*						1					1
Ae. (*Och.*) *caspius*		5	2	1	4	1					13
Ae. (*Och.*) *detritus s.l.*		5	1		1	2					9
Ae. (*Och.*) *pulcritarsis*									18		18
Ae. (*Stg.*) *albopictus*	11								5		16
An. (*Ano.*) *maculipennis s.l.*			1		1	1					3
An. (*Ano.*) *marteri*	1					1					2
An. (*Ano.*) *petragnani*	2					4					6
Cx. (*Cux.*) *laticinctus*	17			1	5	1	1				25
Cx. (*Cux.*) *mimeticus*						2					2
Cx. (*Cux.*) *pipiens*	33	2	11	2	9	9	1		5	1	73
Cx. (*Cux.*) *theileri*			2								2
Cx. (*Ncx.*) *impudicus*	3			3		3					9
Cs. (*All.*) *longiareolata*	26		4	1	7	7	2	1	1		49
Cs. (*Cus.*) *annulata*			1			3					4
Cs. (*Cus.*) *subochrea*					1						1
Ur. (*Pfc.*) *unguiculata*			2								2
Total no. sites/type	46	6	11	4	17	17	15	1	24	1	142

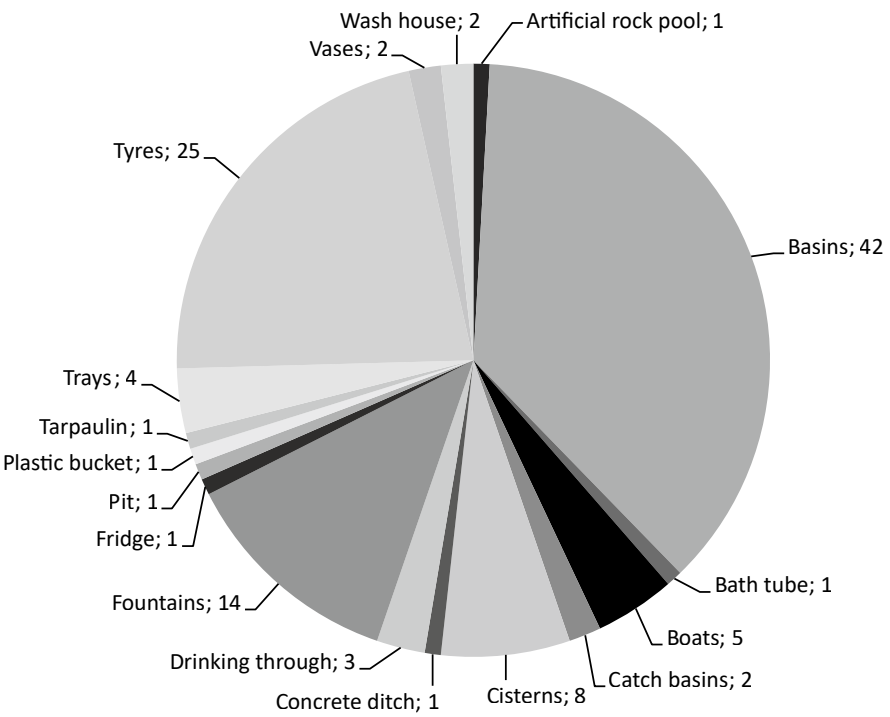

FIGURE 3 Types of artificial containers where mosquito larvae were collected in our snapshot field study across the Balearic Islands, October–November 2019.

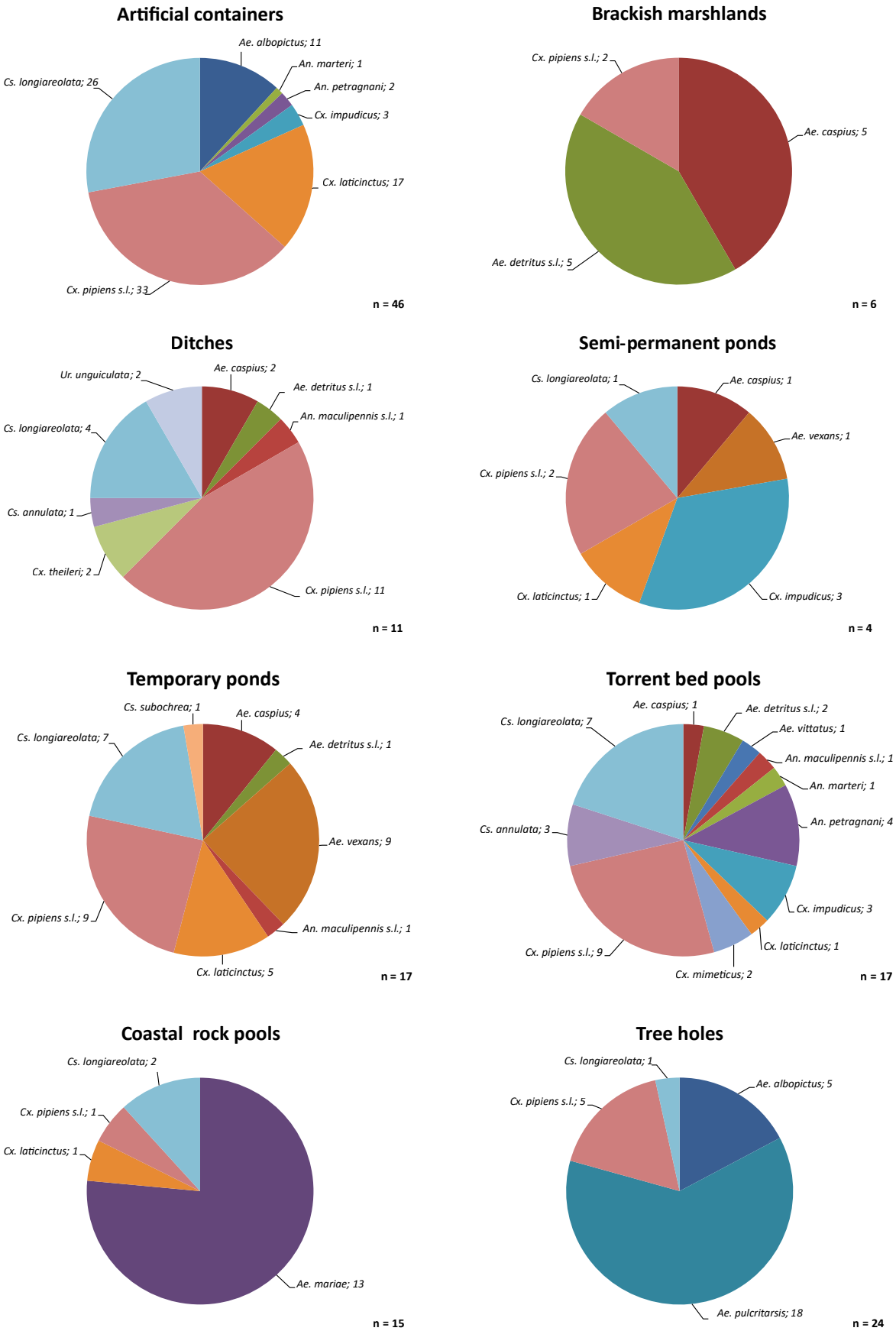

FIGURE 4 Mosquito fauna composition in the different larval habitat types inspected during our snapshot field study across the Balearic Islands, October–November 2019.

Semi-permanent ponds revealed six species, with *Cx. impudicus* and *Cx. pipiens* being the most frequently collected (Figure 4D). Temporary ponds showed more diversity, with eight species encountered (Figure 4E). Here, *Ae. vexans* was the most frequent, followed by *Cx. pipiens* and *Cs. longiareolata*. Torrent bed pools showed the highest mosquito diversity, with 12 species found (Figure 4F); *Cx. pipiens* and *Cs. longiareolata* were the most frequently collected here. In coastal rock pools, the typical saltwater rock pool species *Ae. mariae* was largely dominant (Figure 4G) and collected on one occasion alongside *Cs. longiareolata*. The latter species, *Cx. laticinctus* and *Cx. pipiens* were also found in coastal pools, which were probably at least partially flooded by rain. In inland freshwater rock pools, only *Cs. longiareolata* was collected (but in a single pool) (Table 4).

Tree holes were mostly found to be inhabited by *Ae. pulcritarsis* (Figure 4G,H), and occasionally by *Ae. albopictus* and *Cx. pipiens.* We did not detect any other tree hole breeder species found on the Spanish mainland, such as *Ae.* (*Dahliana*) *geniculatus* (Olivier, 1791), *Ae.* (*Och.*) *berlandi* Séguy, 1921, *An.* (*Ano.*) *plumbeus* Stephens, 1828 or *Orthopodomyia pulcripalpis* (Rondani, 1872). Finally, a single species, *Cx. pipiens* was collected in wells, but only one such site could be inspected (Table 4).

5 Conclusions

This first snapshot of mosquito fauna in the Balearic Islands confirmed the presence of 19 species, including three species recorded for the first time: *An. marteri*, *Cx. mimeticus* and *Cx. impudicus.* It also confirmed the presence of *Ae. detritus s.l.*, which was considered extinct but was also found in another recent study (Delgado-Serra *et al.*, 2020). When accruing outcomes from the literature review and field survey, a total of 23 mosquito taxa are reported to occur in the Balearic Islands, including one extinct species (*Ae. aegypti*) and three species for which occurrence is doubtful, namely *Ae. rusticus*, *An. claviger s.s.* and *Cx. hortensis*. *Culex pipiens* and *Cs. longiareolata* were the most widely found, in a high diversity of natural and artificial breeding. The highest diversity of mosquito fauna was found in natural environments, such as torrent bed pools and ditches, followed by artificial breeding sites such as human-made containers.

Further investigations into Balearic mosquito fauna should be performed. First, we suggest sampling habitats known to suit the three species cited above for which published records are dubious, in order to confirm their presence or absence. Following this, genetic analyses of specimens from the Maculipennis and Detritus Complexes would determine which members of these complexes occur in the Balearics. Additional species may also be discovered by thoroughly investigating wetlands, as well as areas and islets that were poorly investigated previously, if at all. Finally, regular monitoring would help to rapidly detect fauna changes due to globalisation and climate change.

Supplementary material

Supplementary material can be found online at https://doi.org/10.6084/m9.figshare.28062179

Table S1. Municipalities and numbers of samples for our snapshot field study in the Balearic Islands, per isle, October-November 2019.

Table S2. Mosquito taxa reported to occur on the Balearic Islands in the literature with references to first report, distribution data, and species checklists. X: Listed species; (X): species considered extinct; EI = Eivissa: FO = Formentera; MA = Mallorca; ME = Menorca.

Table S3. Detailed field sampling data of our snapshot mosquito field study across the Balearic Islands, October–November 2019.

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Conflict of interest

Francis Schaffner is editor-in-chief of the Journal of the European Mosquito Control Association; he had no influence in the review process and decision-making on this manuscript. The second co-author declares no conflict of interest.

Data availability

The detailed field data that support this article are accessible as supplementary material.

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