Occurrence of *Aedes cretinus* in Cyprus based on information collected by citizen scientists

A.F. Martinou^{1,2*} , J. Fawcett³, M. Georgiou¹, I. Angelidou⁴, M. Philippou¹ and F. Schaffner⁵

¹Joint Services Health Unit, British Forces Cyprus BFPO 57, RAF Akrotiri, Cyprus; ²Care-C, Athalassa Campus, 20 Konstantinou Kavafi Street, 2121 Aglantzia, Nicosia, Cyprus; ³SO1 EH POL, Army Health, Army Headquarters, IDL 6, Zone 1, Ground Floor, Blenheim Building, Marlborough Lines, Monxton Road, Andover Hants SP11 8HT, S4B, United Kingdom; ⁴Enalia Physis, Acropoleos 2, Aglantzia, 2101, Cyprus; ⁵Francis Schaffner Consultancy, Lörracherstrasse 50, 4125 Riehen, Switzerland; a.martinou@cyi.ac.cy

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Abstract

The current study presents a success story where through a small network of citizen scientists original information regarding the occurrence of *Aedes cretinus* was received, suggesting the absence of invasive *Aedes* species on the island of Cyprus. Citizen science records show that *Ae. cretinus* most likely has an island wide spatial distribution while its seasonal activity is limited to the spring and summer months. Data collected by citizen scientists under ‘The Three Mosquiteers’ citizen science initiative, provided more records than any efforts from the authorities in the last 73 years. The future success and the longevity of this initiative will be strongly dependent on the in-depth engagement and collaboration between local experts in entomology and citizen scientists.

Keywords: mosquito surveillance, The Three Mosquiteers project, non-native mosquito, invasive mosquito, *Aedes albopictus*

1. Introduction

Surveillance is an essential component of any integrated mosquito management programme designed for native and non-native mosquitoes in natural, protected areas or urban settings (Martinou *et al.*, 2020; Osorio *et al.*, 2014). Understanding the distribution, abundance and seasonality of mosquitoes at the local scale is necessary for any risk assessment to be possible (Schaffner *et al.*, 2013). Mosquito surveillance is usually undertaken by skilled operators, experts in medical entomology, public health authorities or researchers and it requires a significant amount of expertise and resources in terms of personnel, equipment, and time (ECDC, 2012, 2014; Martinou *et al.*, 2020; Wint *et al.*, 2020).

The public can also contribute towards recording mosquitoes through citizen or community science projects where non-experts get involved in scientific research (Pataki *et al.*, 2021; Tweddle *et al.*, 2012). Citizen science can enhance and facilitate mosquito surveillance undertaken by authorities

at the local level, ensuring better geographic coverage at a finer scale, providing essential information on mosquito diversity, distribution and habitat preferences (Braz-Sousa *et al.* 2020; Palmer *et al.*, 2017; Pernat *et al.*, 2020; Tyson *et al.*, 2018). Citizen scientists, guided by experts and provided with mosquito identification keys, can contribute to mosquito recording by either collecting mosquito specimens and submitting them to the experts or by using mobile application technologies for photorecordings. The active involvement of citizen scientists can enable data collection, overcoming accessibility or transboundary limitations due to political or financial reasons (Martinou and Roy, 2018; Pernat *et al.*, 2020). Citizen science projects can contribute towards early warning rapid response systems for non-native mosquitoes informing the authorities and the public (Cardoso *et al.*, 2014).

In Cyprus, so far, there are no records of non-native mosquitoes such as *Aedes (Stegomyia) albopictus* (Skuse, 1895) (Martinou *et al.*, 2016) and the only record for *Aedes*

(*Stegomyia*) *aegypti* (Linnaeus, 1762) dates before 1934 (Aziz, 1934). However, horizon scanning exercises predict that both species are likely to arrive and establish on the island (Peyton *et al.*, 2019, 2020). Non-native invasive mosquitoes such as *Ae. aegypti* or *Ae. albopictus* have characteristic, recognisable, ‘black and white’ patterns which allow a preliminary identification by citizen scientists and subsequent validation by experts. In Cyprus and parts of the Mediterranean region there is also one native species *Aedes* (*Stegomyia*) *cretinus* Edwards 1921 that strongly resembles *Ae. albopictus* (Martinou *et al.*, 2016; Robert *et al.*, 2019). Both *Ae. cretinus* and *Ae. albopictus* have a median longitudinal stripe on their scutum (thorax) and two sub-median narrow lines. However, *Ae. albopictus* harbours short sub-median lines while *Ae. cretinus* shows longer lines that extend forward to the scutum (Gunay *et al.*, 2018). Apart from this difference the two species are morphologically identical. *Ae. cretinus* has been found in mainland Greece and the island of Crete, Cyprus, Georgia and Turkey (Alten *et al.*, 2000; Edwards, 1921; Giatropoulos *et al.*, 2012; Lane, 1982; Martinou *et al.*, 2016; Samanidou, 1998). In Cyprus, the species was first recorded in 1949 in Nicosia (Lane, 1982) but it was not listed among the mosquito species for Cyprus (Hadjivassilis, 2000; Violaris *et al.*, 2009). Since then, it was reported, 66 years later, in 2015 by Martinou *et al.* (2016).

A long-term surveillance scheme for native or non-native mosquitoes is still lacking for the largest part of the island of Cyprus as well as for potential points of entry for non-native species such as ports, airports and marinas. Any monitoring is not island wide and relies on short term efforts, except for the UK Sovereign Base Areas where there is a long-term surveillance scheme that covers the RAF airport and the Limassol port (Martinou and Roy, 2018).

The current study aims at presenting a new approach as to mosquito monitoring in Cyprus, through citizen science. Targeting the native *Ae. cretinus* that strongly resembles the non-native *Ae. albopictus*, will increase awareness regarding non-native mosquitoes. It could help towards the timely detection and recording of non-native mosquitoes before they manage to establish. Herein, we present the first results collected through a small network of citizen scientists with original information on the occurrence of *Ae. cretinus* which is also suggesting the absence of invasive non-native *Aedes* species on the island of Cyprus.

2. Materials and methods

In 2015, the Joint Services Health Unit (JSHU), British Forces Cyprus, raised two questions: (1) whether *Aedes* invasive non-native mosquitoes were present on the island of Cyprus; as there was no island wide surveillance programme undertaken by the authorities, it was impossible to know; (2) whether citizens could help the authorities find out what

is the case for invasive non-native mosquitoes by trying to detect non-native mosquitoes and by providing mosquito occurrence records. JSHU initiated a campaign about invasive non-native mosquitoes such as *Ae. albopictus* and *Ae. aegypti* so that citizens would be able to detect, identify and record them if they were introduced on the island.

In order to help the campaign and find citizens who were willing to share information, short films, newspaper articles and informative educational material (<https://alien-csi.eu/dissemination-materials>) were produced, addressed both to adults, and children. Scientific workshops and science fairs took place through ‘The Three Mosquiteers’ pilot project (<https://scistarter.org/the-three-mosquiteers>; Tyson *et al.*, 2018). Social media and questionnaire-based surveys were also employed through which citizens were asked to report mosquito nuisance and whether they have seen ‘black and white’ mosquitoes.

Citizens were informed about the native mosquito *Ae. cretinus* through social networks or during presentations and received entomological keys and photographs for all three species: the native *Ae. cretinus* and two non-native species, *Ae. albopictus* and *Ae. aegypti* (ECDC, 2012; Gunay *et al.*, 2018). An example of an *Ae. cretinus* specimen used can be viewed in Figure 1. The citizens were given detailed guidance regarding what should be included in the submitted records, for example good photorecordings of the scutum are essential to be able to distinguish *Ae. cretinus* from *Ae. albopictus*.

Informed citizens started collecting records and either share photorecordings for ‘black and white’ mosquitoes via email or the social media (<https://www.facebook.com/>

Figure 1. A photo of an *Aedes cretinus* female that was used to inform the citizen scientists via social media about this native species (photo credit: Marios Philippou, JSHU).

the three mosquitoes) or sent specimens to the Laboratory of Vector Ecology and Applied Entomology, JSHU for expert identification by one or more medical entomologists. Once the experts identified the records, they provided feedback to the citizen scientists either via email or the social media. Targeted visits were also organised by JSHU experts at locations where citizen scientists reported nuisance due to 'black and white' mosquitoes.

3. Results

The first two records (mosquito specimens) for 'black and white' mosquitoes from citizen scientists arrived in June 2015 from Agia Mavri, Koilani, Limassol region and from Avdellero, Larnaca region (Martinou *et al.*, 2016). Island wide efforts to inform the public were intensified in the following years and started being more fruitful in spring 2018 when photorecordings of 'black and white' mosquitoes made by citizen scientists were received via social media or email.

Between 2018 and 2020 a total of thirty-nine records of 'black and white' mosquitoes were received. None of the records included non-native mosquitoes such as *Ae. albopictus*. All the records were made during the spring and summer months which leads us to believe that *Ae. cretinus* has a seasonal distribution, unlike other mosquito species present on the island e.g. the common house mosquito (*Culex pipiens* s.l.) or the salt marsh mosquito (*Ae. detritus*). Depending on rainfall, the latter are present all year long (Martinou, unpublished data). Twenty of the submitted records were photorecordings or specimens of *Ae. cretinus* submitted by citizen scientists that were validated by experts (Figure 2).

Figure 2. A photorecording by one of our citizen scientists taken in Tala, Paphos 06/06/2020 (photo credit: Dave Walker).

Specimen collections were also made by a team of experts during onsite visits based on nuisance reports due to 'black and white' mosquitoes provided by citizen scientists. Verification was undertaken by one or more entomologists who examined the photorecordings or the specimens morphologically. Five records remained unverified as the citizen scientists were unable to photograph or collect the specimens. These unverified records are also included in Figure 3 and Table 1 as the citizen scientists who provided the information were experienced in identifying or collecting *Ae. cretinus*.

Another five records (habitat) were considered as suitable habitats for *Ae. cretinus* (as nuisance reports were provided for these locations) even though no *Ae. cretinus* specimens were collected at the time of the onsite visits by the experts (Figure 3; Table 1).

The previous three records presented by Martinou *et al.* (2016) are also included on Figure 3 (older records). There was only one record of another native mosquito species collected by a citizen scientist, which was a specimen of *Culiseta longiareolata* collected in Pareklissia, Limassol, on the 26th of April 2020. During the onsite visits, the other mosquito species collected were *Culex hortensis*, *Anopheles claviger* and *Cu. longiareolata* (Table 2), while other encountered species were larvae of the Chironomidae family and copepods such as *Megacyclops* spp.

4. Discussion

Aedes cretinus was difficult to be located by public health authorities due to the lack of an island wide mosquito surveillance scheme and the species' habitat preferences i.e. a dendrolimnic species breeding in tree holes (Gutsevich *et al.*, 1974; Martinou and Roy, 2018). Public engagement proved very important on this occasion in contributing knowledge for a rarely collected and poorly documented mosquito species for Cyprus and the wider Mediterranean region. The records presented herein show that *Ae. cretinus*, most likely has an island wide distribution, that it is present at a wide range of altitudes and it has a strong preference for habitats with shaded streams and deciduous vegetation (Figure 4).

Understanding the current distribution of *Ae. cretinus* is important as it is an aggressive anthropophilic daytime biter (Darsie, 1999; Samanidou-Voyadjoglou and Koliopoulos, 1998) and it can cause a great amount of nuisance at the locations where it is present. Furthermore, it belongs to the subgenus *Stegomyia* which contains many vector species such as *Ae. albopictus* and *Ae. aegypti*. Collecting occurrence data and mapping its spatiotemporal distribution could also be indicative of the areas with most nuisance for local residents and tourists. Our study also shows that *Ae. cretinus* is associated with *An. claviger*, an historical

Figure 3. Records of *Aedes cretinus* based on information provided by citizen scientists. Verified records are those that experts checked specimens or photorecordings. Unverified records are observations made by experienced citizen scientists who were unable to collect the mosquito specimen. Habitat stands for areas that were characterised as suitable for *Ae. cretinus* during the onsite visits by the experts. Older records date before 2018 (Martinou *et al.*, 2016).

malaria vector in the Eastern Mediterranean region, it will be good to investigate further any interactions of *Ae. cretinus* with other mosquito species (Becker *et al.*, 2010). More studies are needed as currently very little is known about the biology of *Ae. cretinus* (Becker *et al.*, 2010; Lane, 1982) and its vector potential remains unknown (Martinou *et al.*, 2016; Schaffner and Mathis, 2014).

The last few years citizen science projects have become important for monitoring vector-borne diseases and the surveillance of species of medical importance such as mosquitoes (Ashepet *et al.*, 2020; Bartumeus *et al.*, 2018; Braz-Sousa *et al.*, 2020; Pernat, 2020; Tyson *et al.*, 2018; Walther and Kampen, 2017), kissing bugs (Triatominae) (Curtis-Robles *et al.*, 2015) and ticks (Porter *et al.*, 2019). Citizen science efforts can complement the work undertaken by public health authorities in order to predict or manage the risk of vector-borne diseases. During the 'Mückenatlas' project, a citizen science initiative for recording mosquitoes in Germany, it was shown that mosquito monitoring by citizen scientists better detected invasive species by collecting information regarding mosquitoes from private premises that professionals usually could not access (Pernat *et al.*, 2020).

Unlike its counterparts, Mückenatlas and Mosquito Alert (in Germany and Spain, respectively) The Three Mosquiteers is still a small network at an embryonic pilot stage. However, even though the size of the network is small, the occurrence data are very valuable as prior to the

network *Ae. cretinus* had only been recorded three times in 73 years on the island. Current occurrence data help us understand better the spatiotemporal distribution of *Ae. cretinus* in Cyprus. One of the advantages of the small size of the network is that it enables good communication and feedback between citizen scientists and professional entomologists which will hopefully set the foundations for a strong vector citizen science community on island.

Citizen science projects can last far longer than any individual effort and cover far more ground. Therefore, they are particularly effective in mapping the spatial distributions of species, their declines or increases given that the target species can be easily identified (Adler *et al.*, 2020). Citizen science records can inform us about key dispersal mechanisms, changes in species distribution as a result of climate change, the spread of biological invasions at scales not attainable through more traditional methods and for tracking infectious disease at different spatial and temporal scales (Adler *et al.*, 2020; Groom *et al.*, 2019). Even when citizen science studies are not maintained continuously over long periods of time, linking studies to historical amateur naturalist datasets can offer valuable information, enable comparisons and create studies that encompass decades or centuries worth of data (Science Communication Unit, 2013). These historical data provide a foundation for assessing species richness and occurrence across a landscape and for measuring the conservation status of rare and elusive species (Adler *et al.*, 2020). Citizen science on islands like Cyprus, without a long

Table 1. *Aedes cretinus* records collected by citizen scientists (CS) or the Joint Services Health Unit team of experts (JSHU) after receiving reports regarding nuisance by 'black and white' mosquitoes.

Date	District	Grid north	Grid east	Altitude (m)	Recorder	<i>Ae. cretinus</i>	Record
18/06/2018	Paphos	35.04116	32.41833	0	CS1	1♀	unverified
30/06/2020	Nicosia	34.93316	32.74857	620	CS1	1♀	unverified
01/05/2018	Kyrenia	35.31521	33.20263	268	CS10	1♀	unverified
05/05/2020	Paphos	34.89431	32.32858	200	CS11	1♀	verified
06/05/2020	Paphos	34.89431	32.32858	200	CS11	1♀	verified
21/06/2020	Nicosia	34.96443	32.82964	1,100	CS12	1♀	verified
19/07/2020	Limassol	34.81337	32.86643	800	CS13	1♀	verified
23/09/2018	Paphos	34.86144	32.71989	615	CS2	1♀	verified
14/05/2019	Kyrenia	35.30333	33.32758	220	CS3	1♀	verified
14/05/2019	Kyrenia	35.31087	33.39529	954	CS3	1♀	verified
11/07/2020	Nicosia	34.98952	32.90166	700	CS3	1♀	unverified
20/06/2019	Paphos	34.84704	32.43548	500	CS4	3♀	verified
06/06/2020	Paphos	34.84704	32.43548	500	CS4	1♀	verified
20/06/2019	Paphos	34.79353	32.45357	0	CS5	1♀	verified
30/06/2019	Limassol	34.79491	32.93551	550	CS6	1♀	unverified
03/05/2020	Kyrenia	35.33442	33.13234	0	CS7	1♀	verified
03/05/2020	Paphos	35.02552	32.40936	40	CS8	1♀	verified
03/05/2020	Kyrenia	35.31778	33.19434	663	CS9	1♀	verified
05/05/2020	Kyrenia	35.31778	33.19434	12	CS9	1♀	verified
19/06/2018	Limassol	34.50401	32.5208	900	JSHU	23♀	verified
20/06/2018	Limassol	34.84083	32.98237	240	JSHU	2♀	verified
20/06/2018	Limassol	34.89471	33.00304	820	JSHU	0	habitat suitability
27/06/2018	Limassol	34.50401	32.5208	900	JSHU	35♀;1♂	verified
27/06/2018	Limassol	34.79752	32.83887	640	JSHU	0	verified
09/07/2018	Limassol	34.50401	32.5208	900	JSHU	2♀	verified
09/07/2018	Limassol	34.86173	32.71777	1,200	JSHU	0	none
24/04/2019	Episkopi	34.67094	32.81695	0	JSHU	1♀	verified
20/05/2019	Limassol	34.50401	32.5208	900	JSHU	1♀	verified
20/05/2019	Limassol	34.51337	32.5229	900	JSHU	1♀	verified
20/05/2019	Limassol	34.51337	32.5229	900	JSHU	1♀	verified
20/05/2019	Limassol	34.50401	32.5208	900	JSHU	1♀	verified
20/05/2019	Limassol	34.78391	32.7998	640	JSHU	0	habitat suitability
20/05/2019	Limassol	34.90297	32.8677	1,330	JSHU	0	habitat suitability
30/06/2019	Limassol	34.51337	32.5229	900	JSHU	3♀	verified
08/07/2019	Limassol	34.51337	32.5229	900	JSHU	10♀	verified
29/07/2019	Limassol	34.51337	32.5229	900	JSHU	0	habitat suitability
15/06/2020	Limassol	34.51337	32.5229	900	JSHU	3♀	verified
07/07/2020	Limassol	34.51337	32.5229	900	JSHU	1♀	verified

Table 2. *Aedes cretinus* and other species collected during the on-site visits.

Date	District	Grid north	Grid east	<i>Ae. cretinus</i> ♀	Other mosquito species	Other species
27/06/2018	Limassol	34.50400	32.52080	35♀; 1♂	<i>Culiseta longiareolata</i>	<i>Chironomus</i> spp.; <i>Megacyclops</i> spp.
09/07/2018	Limassol	34.50400	32.52080	2♀	<i>Anopheles claviger</i>	
20/05/2019	Limassol	34.50400	32.52080	1♀	<i>An. claviger</i>	
20/05/2019	Limassol	34.51337	32.52290	1♀	<i>An. claviger</i>	
20/05/2019	Limassol	34.51337	32.52290	1♀	<i>Cu. longiareolata</i>	<i>Chironomus</i> spp.; <i>Megacyclops</i> spp.
20/05/2019	Limassol	34.50400	32.52080	1♀	<i>Culex hortensis</i>

Figure 4. Typical habitat of *Aedes cretinus* in the Limassol District (photo credit: A.F. Martinou, JSHU).

tradition in recording schemes can be challenging, even more so when the project focuses on nuisance species or vectors of disease. For such a citizen science initiative to be successful, continuous communication and exchange of information is required between the experts and the citizen scientists who participate. In the future we hope to attract more citizen scientists towards The Three Mosquiteers initiative by also promoting and adopting the European Mosquito Alert app that was recently released in many European languages through the AIM-COST network (www.aedescost.eu). As we hope to expand The Three Mosquiteers network, adopting an app such as Mosquito Alert will offer advantages by providing island wide coverage at finer scales and by providing feedback to the

citizen scientists in a timely manner. Extra effort should be placed from the experts and the authorities into turning the information collected by The Three Mosquiteers network into management actions for the verified records of mosquito presence and nuisance, as this is expected by the citizen scientists (Ashepet *et al.*, 2020). Training of public health workers island wide on surveillance techniques such as larval dipping in tree holes in order to monitor for *Ae. cretinus* and treating or managing tree holes where citizen scientists indicate that *Ae. cretinus* breeds or causes nuisance should be considered. The longevity of The Three Mosquiteers network, the quality of information and its success will be strongly dependent on the deep engagement between experts and citizen scientists.

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Conflict of interest

The authors declare no conflict of interest.

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