

## CORRECTED PROOF

## Short Communication

## Establishing the *Aedes* watch out network, the first island-wide mosquito citizen-science initiative in Cyprus within the framework of the Mosquitoes Without Borders project

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## OPEN ACCESS

### Abstract

Recent outbreaks of Zika, chikungunya and dengue fever worldwide highlight the importance of understanding the spread of pathogen-carrying mosquitoes. Citizen or community science initiatives can contribute towards early warning rapid response systems and complement at spatial and temporal scales traditional mosquito surveillance which often relies on limited resources. Herein, we provide information regarding a first attempt of involving citizens in mosquito monitoring on the island of Cyprus. During the 2018–2019 season, an island wide network of citizen scientists was formed as part of The Three Mosquiteers initiative and the Mosquitoes Without Borders project that aims at educating and engaging citizens of all ages regarding mosquitoes. The new network was named *Aedes* Watch Out and it aims to provide information on island wide mosquito presence overcoming jurisdictional barriers and cost constraints. *Aedes* Watch Out aims to serve as an early warning information source about the non-native Asian tiger mosquito (*Aedes albopictus*) arrival to Cyprus, complementing current capacities and any work that the authorities undertake. The initial outcomes of the project demonstrate that even a small number of dedicated citizen scientists can generate important information and greatly facilitate experts in entomology and public health.

**Key words:** *Aedes albopictus*, *Aedes cretinus*, *Culex pipiens*, early warning, rapid response, invasive

### Introduction

According to the World Health Organization (WHO), there are over 500 million cases of mosquito-borne illnesses such as Zika, yellow fever, chikungunya, dengue fever, malaria, and West Nile each year (WHO 2017). Being proactive about the management of these diseases is the best approach. Acquiring information on the presence, abundance, and distribution of mosquito vectors, including information on adult and larval

life stages and breeding sites is essential (Takken and van den Berg 2019; Jourdain et al. 2019). Traditional monitoring methods cannot always deliver information on the desired scale or the required resolutions and often fail to engage or educate the public (Tyson et al. 2018). Citizen or community science is a process where the public actively contributes to scientific research. Participants, the citizen scientists, can collect information and help researchers, government officials, and the public understand and manage risks (Silvertown 2009). The role of community science in entomology is pivotal for the collection of large-scale and long-term data sets, instrumental in underpinning our knowledge of the status and trends of many insect groups, as well as guiding management decisions, whether for the conservation of native species, or the control of invasive species (Gardiner and Roy 2022).

Invasive alien species introduced intentionally or unintentionally by humans to a new location can cause environmental changes and negatively impact biodiversity and good quality of life in adjacent communities (Pejchar and Mooney 2009). Invasive insect vectors such as the *Aedes* mosquito species are a major global concern as they are responsible for the transmission of pathogens that can affect human health (Martinou and Roy 2018). *Aedes albopictus*, also known as the Asian tiger mosquito, is one of the most invasive and widely recognised mosquito species, and it is a potential vector of at least 22 arboviruses, including Zika, dengue and chikungunya (Gratz 2004). It breeds in man-made containers, thrives in urban areas, and has spread from the western Pacific and Southeast Asia to Europe, Africa, the Middle East and the Americas over the past three decades. It is currently spreading in Europe including the Mediterranean region and countries like Albania, France (including Corsica), Greece (including Crete), Italy (including Sardinia, Sicily, Lampedusa, and other islands), Malta, San Marino, Spain, Turkey and Vatican City (ECDC 2016).

In Cyprus, *A. albopictus* has not been reported but surveillance is limited both spatially and temporally. An intensive surveillance programme is run at the Sovereign Base Areas of the island which includes the Akrotiri peninsula, RAF airport, port of Limassol, Dekheleia, and Episkopi. However, no regular surveillance programme for *Aedes* spp. takes place on the rest of the island, at points of entry such as ports, airports, marinas and other locations that the tiger mosquito could establish, if introduced and not detected early. Martinou and Roy (2018) summarize the on-island strengths and weaknesses of integrated mosquito management. Some of the strengths are the collaborative efforts between different public health authorities on island, horizon scanning exercises that have taken place predicting invasive species including invasive mosquito species likely to arrive within the next 10 years (Peyton et al. 2019, 2020), and the existence of a code of practice with particular focus on wetland mosquito species (Martinou et al. 2020). Some of the weaknesses include the lack of communication between urban

development planners and public health authorities as well as limitations in coverage of the current surveillance system. Other impediments are the lack of a policy agreement for mosquito management under different scenarios and the absence of an evaluation scheme that can provide an insight on the effectiveness of the implemented mosquito programme and the success of the collaborative efforts (Martinou and Roy 2018).

In Europe, traditional Asian tiger mosquito surveillance generally involves active approaches such as trapping by the public health authorities using devices such as ovitraps or BG sentinel traps (Biogents®) (Bellini et al. 2020). Ovitraps are small black containers of water with ovipositional substrates where females can lay their eggs in the field. BG sentinel traps work with attractants or lures with or without CO<sub>2</sub> and attract female mosquitoes. Personnel of the public health authorities set the traps at points of entry (such as ports or airports) or other locations where *Aedes* spp. have established and check them at regular intervals. The specimens then need to be carried back to the laboratory for morphological and/or molecular identification. In countries like Spain, where invasion by the tiger mosquito is fast-moving, initial detections at new sites come mostly from the public (Palmer et al. 2017). Through a Spanish citizen science initiative, the Mosquito Alert, contributions by members of the public are made towards the early warning and rapid response systems for *Aedes* spp. Such initiatives can complement traditional mosquito surveillance undertaken by the public health services which can be limited by jurisdictional boundaries and cost constraints (Bartumeus et al. 2018).

The Asian tiger mosquito has a distinctive black and white appearance and aggressive bite and thus is difficult to miss. However, in Cyprus and Greece, there is a native species with close resemblance to the tiger mosquito, *Aedes cretinus* (Martinou et al. 2016, 2021). Martinou et al. 2016 highlight the importance of public engagement to understand the distribution of the native species which is also an aggressive biter. Citizens could easily spot and record black and white mosquitoes, but records should be validated by an experienced entomologist as the two species are very similar in morphology.

Globally and across Europe, there are many citizen science programmes for mosquito surveillance where the public can participate and contribute to scientific research. Some of these programmes such as Mosquito Alert (Spain), Muggenradar (the Netherlands) and Zanzamapp (Italy) mostly focus on invasive mosquitoes, while others like the Mückenatlas (Germany) focus on native and non-native species (Pernat et al. 2021) or on breeding sites e.g. the GLOBE Mosquito Habitat Mapper by NASA (Amos et al. 2020). Citizen science programmes for mosquito recordings have proved useful even in remote locations such as the Solomon Islands in the Pacific region (Amos et al. 2020; Craig et al. 2021).

During the 2018–2019 season, as part of the Three Mosquiteers initiative and the Mosquitoes Without Borders project, we initiated a pilot study in Cyprus to establish an island-wide network of citizen scientists trained to collect mosquito specimens and record breeding sites and led a citizen science monitoring programme for the early detection of *A. albopictus* and other *Aedes* invasive mosquitoes.

## Materials and methods

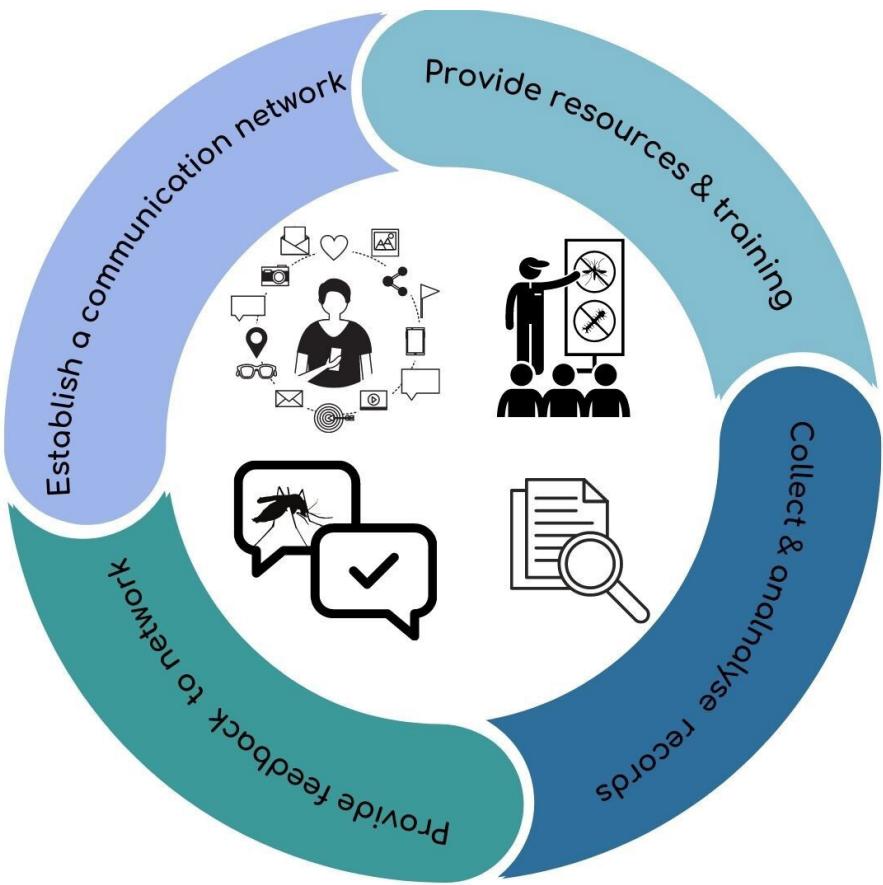
Fifteen citizens were asked if they were interested in recording mosquitoes and more specifically, *Aedes* invasive mosquitoes, facilitating the work of scientists in locating mosquitoes and mosquito breeding sites early. The citizens were also asked if they were willing to monitor for mosquitoes by placing trapping devices at their premises (gardens). Ten citizens who agreed to place traps were selected based on the proximity of their premises to a possible point of entry for invasive mosquitoes. Initially, training was provided to the citizens regarding the life cycle of mosquitoes, invasive mosquito species and their morphological characteristics and on how to set trapping devices such as BG-sentinel traps with BG-lure for the survey.

The *Aedes* Watch Out Network was formed as part of The Three Mosquiteers initiative (<https://scistarter.org/the-three-mosquiteers>) and the Mosquitoes Without Borders project which aim at educating and engaging citizens of all ages regarding mosquitoes. A mobile messaging platform, WhatsApp (MetaPlatforms, Inc., Menlo Park, CA) was used. WhatsApp messages were used to share information about when the traps should be set and collected, and to explain the procedures that needed to be applied for the preparation of the collected mosquito specimens for future morphological identification in the laboratory. Members of the network could also upload pictures of mosquitoes or “mosquito looking insects” observed at their premises and receive feedback from the researchers. Figure 1 summarises this process. Trapping was standardised and took place over the peak mosquito season from the beginning of May until June 2019. Traps operated every two weeks for 24 hours.

In addition to the monitoring of adult mosquito species, members of the *Aedes* Watch OutNetwork also indicated possible mosquito breeding sites. Seventeen of these mosquito breeding sites in 13 locations were visited by the experts on the 8<sup>th</sup> and 10<sup>th</sup> of April 2019. In total, 37 samples were collected. For each sample, 3 dips were undertaken by a standard 350 ml dipper (Bioquip®) and 1 litre of water was collected. Information regarding breeding sites were provided either by citizens who were concerned about mosquitoes or by naturalists and wildlife photographers who enjoy natural sites and engage in bird watching and trekking.

## Results

No invasive *Aedes* species such as *Aedes albopictus* or *Aedes aegypti* were detected. Twelve species of mosquitoes (Table 1) were collected by either

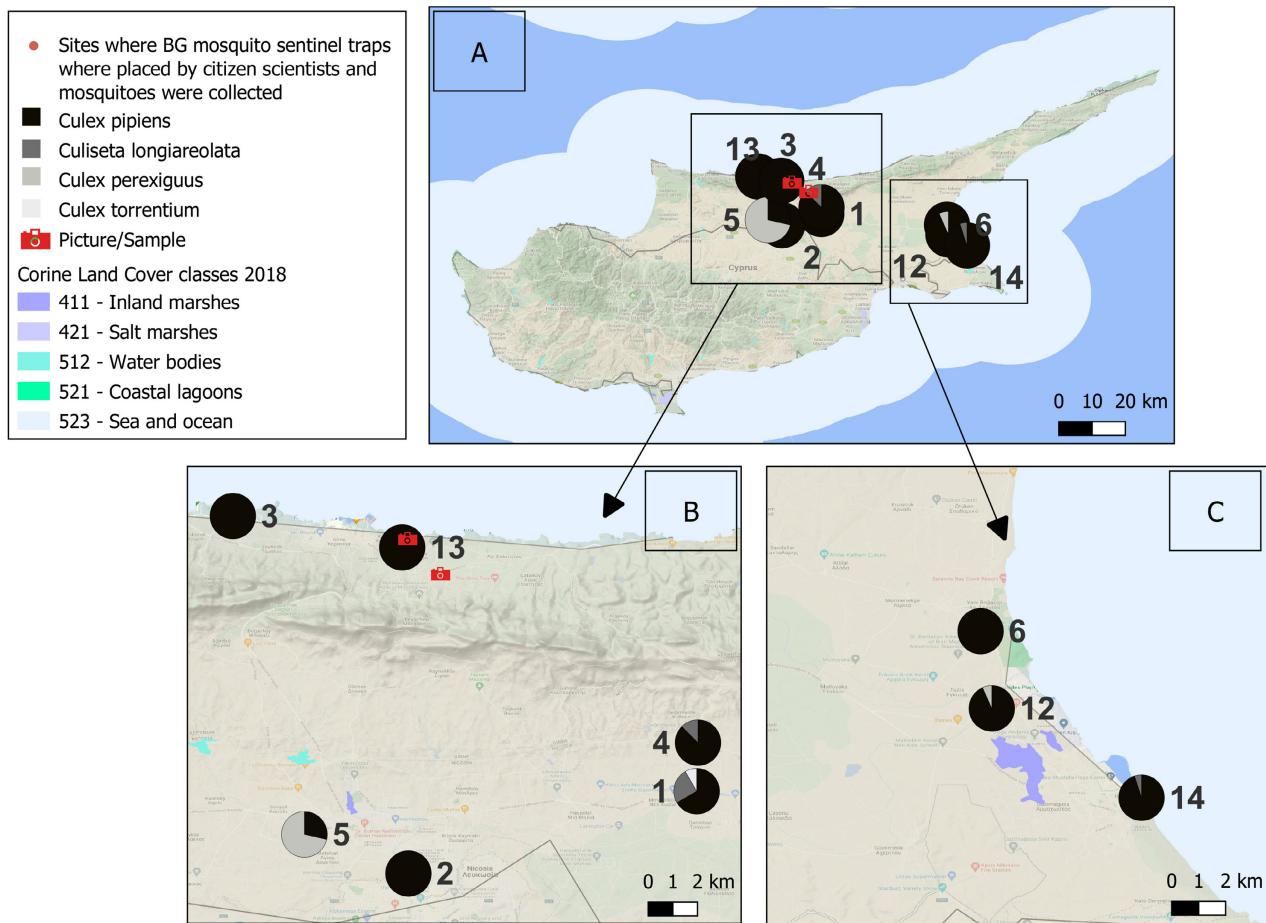


**Figure 1.** An infographic summarizing the process of creating and running the *Aedes* Watch Out network with the help of the volunteer citizen science recorders. A communication network was established, training and resources (traps) were provided to the members of the network. Researchers collected the results/specimens for their analyses and provided feedback to the citizen scientists.

**Table 1.** Species collected either by larval dipping or with BG sentinel traps (\*except *A. cretinus* which were photographed and caught while trying to feed or resting on a wall).

	Species	Larval stage (Dipping)	Adult stage (BG Sentinel)
1	<i>Culex mimeticus</i>	x	
2	<i>Culex perexiguus</i>	x	x
3	<i>Culex pipiens</i>	x	x
4	<i>Culex territans</i>	x	
5	<i>Culex torrentium</i>	x	x
6	<i>Culiseta annulata</i>	x	
7	<i>Culiseta longiareolata</i>	x	x
8	<i>Ochlerotatus</i> or <i>Aedes detritus</i>	x	
9	<i>Culex theileri</i>	x	
10	<i>Ochlerotatus</i> or <i>Aedes caspius</i>	x	
11	<i>Aedes phoeniciae</i>	x	
12	<i>Aedes cretinus</i> *		x

larval dipping or by the BG sentinel traps that the *Aedes* watch out network members had placed in their gardens. The common house mosquito *Culex pipiens* was collected most often. A total of 109 adult female mosquitoes were identified to species level and recorded. Figure 2 shows the overall adult mosquito catches for the two-month period.

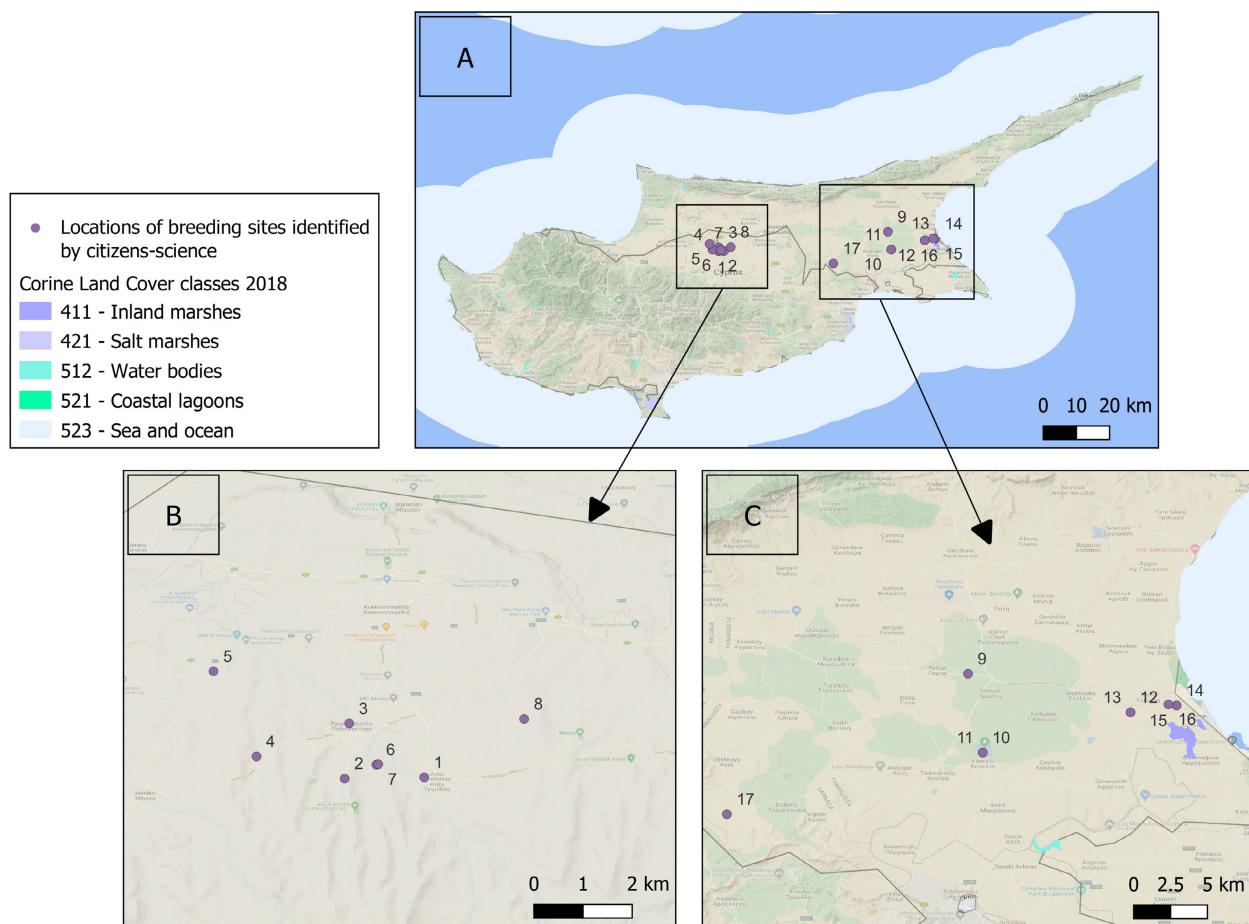


**Figure 2.** Sites where BG mosquito sentinel traps were placed by citizen scientists. Mosquitoes were collected during the peak mosquito period beginning of May 2019 to end of June 2019. Pie graphs show the relative proportions of mosquito species caught at each site. Each pie graph has a unique number which was given to each of the citizen-scientists. At sites 13 and 15 photographic records and specimens of *A. cretinus* were collected by citizen scientists.

Larval dipping was undertaken by both experienced and less experienced members of the research team; therefore, we did not attempt a quantitative analysis of the results and only provide qualitative results presence/absence data, i.e., the list of species found in Table 1 as well as the locations of the breeding sites in Figure 3. Latitude and longitude data are provided for the locations of the traps and the breeding sites as Supplementary material in Table S1 and Table S2 respectively.

## Discussion

The results of the *Aedes Watch Out* network showed that West Nile Virus (WNV) vectors (Rizzoli et al. 2015) such as *Culex pipiens*, *Culex perexiguus* (Orshan et al. 2008; Benbetka et al. 2018) and *Culex torrentium* (Vilibic-Cavlek et al. 2019) are common throughout the area of the survey. WNV circulation in Cyprus as well as evidence of pathogenicity among Cypriot patients is known (Paphitou et al. 2016; Billiou et al. 2019; Pallari et al. 2021), therefore, managing mosquito vectors (monitoring and control) and studying of arboviral infections in Cyprus should be strengthened as these pathogens are potential causes of severe neurological diseases (Paphitou et al.



**Figure 3.** Locations of breeding sites identified by citizen scientists. Larval sampling was undertaken by the team of experts at these locations during 2 days in April 2019.

2016 and Billiou et al. 2019). The *Aedes* Watch Out network also confirmed that *A. cretinus*, the native mosquito species that closely resembles *A. albopictus* has a much wider distribution on island than previously thought (Martinou et al. 2016, 2021).

Many of the breeding sites indicated by the members of the *Aedes* Watch Out network were in marshy areas that are heavily urbanised and had been flooded due to heavy rains. It is common for urban planning to not adequately consider mosquito borne diseases and mosquito breeding sites during changing land use for urban development and town planning even though mosquito-borne diseases and mosquito control can incur considerable cost for both individuals and government (Dwyer et al. 2016). Mosquito production should be seriously considered in Cyprus within wetland zones that are currently of great interest for urban development (Martinou et al. 2020).

Even though our project ran for one season (during the peak season for mosquitoes) and not for the whole breeding season, it provided valuable results. Although *Anopheles* spp. were not collected during our study, possibly due to our sampling methods that were mostly targeted towards *Aedes* spp., previous studies have shown mosquitoes of that genus are also present in Cyprus (Martinou et al. 2016), and three locally acquired cases of *P. vivax* malaria were recorded in August 2017 (ECDC 2017).

The potential of citizen science to inform invasive non-native species strategies and management has been widely demonstrated (Roy et al. 2015; Palmer et al. 2017). While it is recognised that some taxa and environments present challenges for citizen science, there are many ways in which these can be overcome, particularly through combining professional and volunteer surveillance approaches (Pocock et al. 2017; Craig et al. 2021). Provided that a system for taxonomic identification of citizen records by experts can be set up, citizen science could generate large datasets in an affordable manner that could not otherwise be collected during mosquito control programmes (Sousa et al. 2022). Authorities could instead concentrate their resources and efforts on mosquito hotspots (Kampen et al. 2015; Martinou et al. 2020), e.g., within wetlands where larval densities are high or at points of entry such as ports, airports, and marinas where invasive non-native species could be introduced, become established, and expand their range. Costs related to running a citizen science scheme and developing a suitable application and platform for data recording, validation and management should be considered (Martinou et al. 2020).

Citizen scientists can be recruited for fixed point trapping mosquito surveillance (Sousa et al. 2022) like in our case. Surveillance data collected by citizens can give valuable information on species richness and mosquito species composition for the locations where the traps are set. Citizen science mosquito surveillance is less expensive than professional programmes (Sousa et al. 2022) thus, widespread surveillance by citizen scientists may substantially reduce the costs associated with field work in surveillance programmes undertaken by the authorities. However, for this to succeed coordination and continuous engagement of stakeholders and support for the citizen scientists is essential. Citizen science is a novel solution in addition to the traditional methods for tracking disease-carrying mosquitoes which are hitting budget constraints as the scales over which they must be implemented grow exponentially but requires new models of innovation in the public health sector (Bartumeus et al. 2018).

Citizen science promotes public engagement and awareness on issues related to public and environmental health, in addition to making direct contributions to research and environmental monitoring (Den Broeder et al. 2018). Researchers greatly benefit from this engagement with the public and can maximize the amount of data that can be collected. We conclude that citizen science networks like the *Aedes* Watch Out Network can provide reliable and sustainable solutions to challenges related to widespread environmental monitoring and are unique opportunities for public engagement with science. In the future, engaging citizens through a mosquito recording app such as Mosquito Alert (Palmer et al. 2017) or the Globe Observer Mosquito Habitat Mapper (Amos et al. 2020) would allow us to expand the *Aedes* Watch Out Network and contribute our results to the wider scientific community on-island and internationally.

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## Authors' contribution

Angeliki F. Martinou: conceptualization and supervision, formal analysis, data acquisition; Angeliki F Martinou, Ioanna Angelidou and Kardelen Yetismis: Data curation; Kardelen Yetismis, Ioanna Angelidou, Angeliki F. Martinou, Kamil Erguler, Songül Yetismis: Investigation, methodology; Kardelen Yetismis, James Fawcett, Edmund Foroma and Nicolas Jarraud: Project administration and communication; Angeliki F. Martinou led the writing; all authors contributed to reviewing and editing.

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#### Supplementary material

The following supplementary material is available for this article:

**Table S1.** Locations where BG-sentinel mosquito traps were placed. Coordinates are given as the centroids of the nearest 5 km × 5 km grid including the trap.

**Table S2.** Breeding sites and number of samples collected per breeding sites and coordinates.