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MINIREVIEW

Records of *Aedes* (*Stegomyia*) *cretinus* in Greece before and after the invasion of *Aedes* (*Stegomyia*) *albopictus* (Diptera: Culicidae)

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Abstract. This manuscript compiles all the available information on the presence of the native mosquito species *Aedes cretinus* in Greece, before and after the invasion of *Aedes albopictus.* Mosquito survey data particularly from the Region of Attica, as well as other areas in Greece indicate *Ae. cretinus* has become scarce since the invasion of *Ae. albopictus,* which is now widespread. This mini review on *Ae. cretinus* occurrence in Greece over the years indicates a marked decline in its populations that seems to be related to the prevalence of the invasive mosquito *Ae. albopictus,* and a need for more comprehensive entomological surveys in areas where these species co-occur.

BIOLOGY AND ECOLOGY OF *AEDES CRETINUS*

Aedes (*Stegomyia*) *cretinus* (Edwards, 1921) is a black-white striped, tree-hole mosquito that bites aggressively during the daytime (Samanidou & Koliopoulos, 1988). It is native to Greece (Samanidou et al., 2005) with limited distribution across the world including Georgia (Mattingly, 1954; Gutsevich et al., 1974), Turkey (Lane, 1982; Alten et al., 2000; Caglar et al., 2003) and Cyprus (Lane, 1982; Martinou et al., 2016). Little is known about its biology and its ability to transmit pathogens is unknown (Becker et al., 2010). *Aedes cretinus* belongs to the same subgenus *Stegomyia* as the invasive mosquito species *Aedes* (*Stegomyia*) *albopictus* Skuse (1894) (Darsie, 1999) and both species share many behavioural and morphological traits (Samanidou et al., 2005; Patsoula et al., 2006) (Fig. 1). *Aedes cretinus* is reported to be an anthropophilic mosquito that bites and rests outside buildings, i.e., an exophagic and exophilic species (Samanidou & Koliopoulos, 1998; Alten et al., 2000; Caglar et al., 2003). In Greece, it has been found primarily in sparsely or densely vegetated and wooded locations in urban and peri-urban residential areas, as well as in rural areas, breeding in small natural or man-made breeding sites, such as, tree-holes, ground pools, flowerpots and dishes, barrels, road drains and used tyres (Samanidou, 1998; Samanidou & Koliopoulos, 1998; Koliopoulos, 2011; Giatropoulos et al., 2012a). *Aedes cretinus* larvae have been collected from tree-holes, potholes and small hollows in forests and open fields in Turkey (Alten et al., 2000; Caglar et al., 2003) and from tree-holes in forests in Cyprus (Martinou et al., 2016).

AEDES CRETINUS IN GREECE BEFORE *AEDES ALBOPICTUS* INVASION

First records of *Ae. cretinus* in Greece date back to 1921 from Macedonia and the island of Crete (Edwards, 1921; Lane, 1982; Samanidou, 1998) (Table 1). Edwards (1921) described *Ae. cretinus* for the first time based on two female specimens collected in Crete, one of them from Amari in Rethymno, and named it after the location where it was first collected (Crete = Creta in Latin) (Snow, 2001). He called it the "Mediterranean representative" of *Ae. albopictus* due to its morphological resemblance to this species (Samanidou, 1998), long before the invasion of *Ae. albopictus* in Europe, in Albania, in 1979 (Adhami & Reiter, 1998). Almost 70 years after it was first recorded in Greece, low populations of *Ae. cretinus* were reported in 1992–1997 in vegetated suburbs of Athens in the northern part of Attica Region where it was reported biting ag-

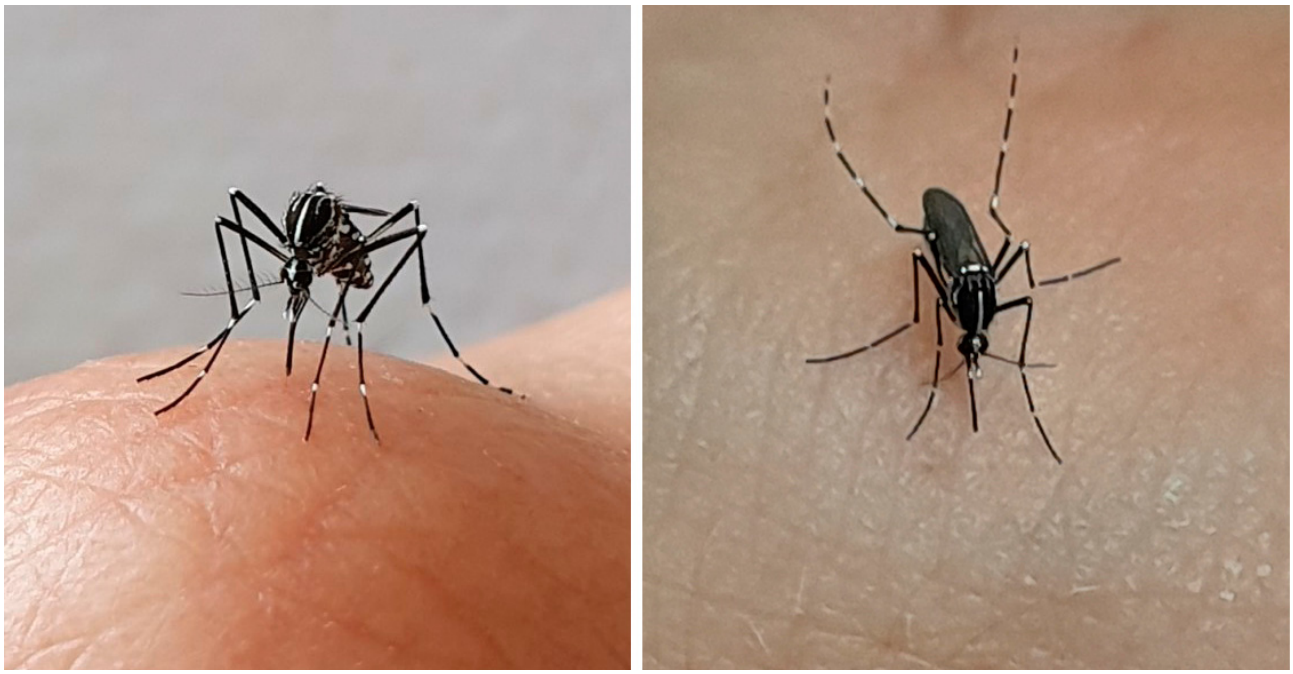

Fig. 1. Females of *Aedes cretinus* (left) and *Aedes albopictus* (right).

gressively humans during daytime, from spring to autumn (Samanidou, 1998; Samanidou & Koliopoulos, 1988). In 1994, *Ae. cretinus* larvae were collected from tree holes in a city park in Fodele, a small town located in the Regional Unit of Heraklion on Crete (Taafe Gaunt et al., 2004). Subsequently, its presence was confirmed in the Region of Attica in 2000–2002 by a 3-year mosquito survey using oviposition traps, human landing collections of adults and larval samplings (Koliopoulos, 2011).

AEDES CRETINUS IN GREECE AFTER *AEDES ALBOPICTUS* INVASION

Aedes albopictus was recorded for the first time in Greece in 2003–2004, in the northwestern part of the country (Corfu and Igoumenitsa) (Samanidou-Voyadjoglou et al., 2005; Patsoula et al., 2006). Patsoula et al., (2006) using molecular techniques and morphology-based identification keys, identified *Ae. cretinus* collected as resting adults during 2004–2005 in the Municipalities of Pallini and Kifissia located in Northeastern and Northern Attica, respectively, in Municipality of Athens, and on the islands of Evia (Central Greece) and Crete (South Greece). A few years later, in 2008, *Ae. albopictus* was first recorded in the Municipality of Athens (location Rizoupoli) in Attica Region (Koliopoulos et al., 2008; Giatropoulos et al., 2012a) (Table 1). A field survey by Giatropoulos et al. (2012a) in the following two years (2009–2010) using oviposition traps in the greater Athens urban area of Attica revealed that *Ae. albopictus* was the dominant container breeding mosquito dispersed throughout the area studied displaying high oviposition activity and a trend to expand its range. This study also revealed the presence of the native mosquito *Ae. cretinus* in much lower population densities that were restricted to vegetated areas where both species co-occurred. Later, Kioulos et al. (2014) reported the presence of *Ae. cretinus* in Attica from mosquito females caught during a two-year (2007–2008) mosquito larval sampling survey conducted in vegetated streamside locations in urban and peri-urban areas in which the larvae and nymphs of this species were not recorded.

Aedes albopictus, known as the Asian tiger mosquito, is considered the most invasive mosquito species worldwide and is of great medical importance as it transmits several human diseases including dengue, chikungunya and Zika viruses (Medlock et al., 2012; Bonizzoni et al., 2013). The introduction of *Ae. albopictus* in Athens, Attica, and its high activity raised public awareness triggering people to collect "tiger-like" mosquitos and send them to Benaki Phytopathological Institute (BPI) for identification. Mosquito samples collected by the public from 2009 to 2011 revealed the presence of *Ae. albopictus* in many areas of Attica Region and in many parts of the country, and that *Ae. cretinus* occurred mainly in central and northern areas of Attica, was widespread on Crete, and was present in a few areas in the Macedonia and Peloponnese Regions (Giatropoulos et al., 2012b).

A review by Badieritakis et al. (2018) of the invasion history of *Ae. albopictus* in Greece based on information provided by pest control companies and/or citizens, official samples sent to BPI and the National School of Public Health (NSPH), and mosquito surveys carried out by the BPI, reported the dispersal of the Asian tiger mosquito almost all over the country until 2016 and no records of *Ae. cretinus* during 2014–2016. After *Ae. albopictus* was first recorded in Greece it spread slowly up to 2010 and then rapidly spread throughout almost the whole of the country by 2016 (e.g., in the Regions of Central Macedonia, Peloponnese and Attica) according to Badieritakis et al. (2018). Wide-spread distribution of *Ae. albopictus* in Greece, including Attica, until 2019 was reported by Kolimenakis

Table 1. Literature and other data on the presence of *Aedes cretinus* in Greece.

Year	Location	Collection method	Reference
1921	Crete (Rethymno), Macedonia	Not specified	Edwards, 1921 Samanidou, 1998
1992	Attica	Larval samplings	Samanidou, 1998
1994	Crete (Fodele, Herakleion)	Larval samplings	Taafe Gaunt et al., 2004
1994–1997	Attica	Not specified	Samanidou & Koliopoulos, 1988
1997	Attica	Specimens (adults) collected by citizens	Samanidou, 1998
2000–2002	Attica	Oviposition traps, Human landing collections, Larval samplings	Koliopoulos, 2011
2004–2005	Attica, Evia, Crete	Capture of resting adults	Patsoula et al., 2006
2007–2008	Attica	Human landing collections	Kioulos et al., 2014
2009–2010	Attica	Oviposition traps	Giatropoulos et al., 2012a
2009–2011	Attica, Crete (Chania, Rethymno, Heraklion, Lasithi), Macedonia (Halkidiki, Pieria), Peloponnese (Argolida)	Specimens (adults) collected by citizens	Giatropoulos et al., 2012b
2017–2018	Crete (Rethymno)	Specimens (adults) collected by citizens	Lytra et al., 2018
2018	Leros	Oviposition traps	Lytra et al., 2018
2018	Crete (Chania)	Not specified	Balaska et al., 2020
2018–2020	Crete (Chania, Rethymno)	CDC trap (with light and CO_2)	Fotakis et al., 2022
2021	Attica (Melissia and Afidnes)	Human landing collections	New data[1]
2023	Attica (Vravrona)	Human landing collections	New data[2]
2023	Preveza	Information from citizens	New data[3]

[1]Under the frame of the project "A systematic surveillance of vector mosquitoes for the control of mosquito-borne diseases in the Region of Attica". [2]Under the frame of the IAEA TC project RER/5/022 "Establishing Genetic Control Programs for *Aedes* Invasive Mosquitoes". [3]Under the frame of the project "Mosquito Alert" in Greece, https://mosquitoalert.conops.gr and http://www.mosquitoalert.com/en/.

et al. (2019). Entomological surveys implemented under the framework of LIFE CONOPS project (www.conops.gr, coordinated by BPI) from 2014 to 2018 for the detection of invasive mosquito species in Greece, using surveillance methods appropriate for the collection of *Stegomyia* species (e.g., BG-sentinel adult traps and oviposition traps), revealed the presence of *Ae. cretinus* only on two islands, namely Crete (Regional Unit of Rethymno) based on adult mosquitoes collected by citizens in 2017–2018 and Leros based on a few eggs collected occasionally from oviposition traps in 2018 (Lytra et al., 2018). A two-year (2017–2018) survey of mosquito adults caught using BG-sentinel traps in urban and wetland areas in eastern and southern parts of the Attica Region reported that *Ae. albopictus* and *Cx. pipiens* s.l. were by far the most abundant species and no *Ae. cretinus* (Beleri et al., 2021). An entomological survey in 2017–2019 in urban and peri-urban localities in Greece in the Regional Units of Thessaloniki and Rodopi (northern Greece), Region of Attica and Regional Unit of Argolida (central Greece), the Municipalities of Patras and Kalamata (western Greece) and the islands of Chios (north-eastern Aegean Islands complex), Kefalonia (Ionian islands complex) and Crete (Chania, Rethymno and Heraklion – southern Greece) revealed the dominant presence of *Ae. albopictus* over other *Aedes* container breeding species and confirmed its widespread distribution in the country, whereas *Ae. cretinus* was detected only in Chania, Crete, in 2018 at very low population densities (Balaska et al., 2020). After the invasion of *Ae. albopictus* in Crete (Chania) in 2014 (Patsoula et al., 2017), a mosquito oviposition surveillance network was established in 2017 in rural and agricultural areas in Chania, which ran for 2 years (Stefopoulou et al., 2022). This reported the wide establishment of *Ae. albopictus* and absence of *Ae. cretinus*, indicating an adverse effect of the invasion of *Ae. albopictus* on the population of the local species *Ae. cretinus* (Stefopoulou et al., 2022). Fotakis et al. (2022), reported that a mosquito survey program using CDC light traps baited with dry ice in urban, peri-urban and rural areas in Crete in 2018–2020 revealed that *Ae. albopictus* was the dominant species in the genus *Aedes* (>86% of *Aedes* specimens collected) in all Regional Units of the island, while *Ae. cretinus* only occurred in low numbers in Chania and Rethymno Regional Units (13.5% and 2.2% of specimens of *Aedes* collected, respectively). It is note-worthy that, *Ae. cretinus* was also reported in the Regional Unit of Preveza (Western Greece) in 2023, by the Mosquito Alert application (https://mosquitoalert.conops.gr, new data, Table 1). This citizen science tool, introduced for the first time in Greece (http://www.mosquitoalert.com/en/), has not only proven valuable in providing early warnings for new invasive mosquito species, but also for documenting the presence of less common species, such as *Ae. cretinus*.

AEDES CRETINUS IN ATTICA, GREECE, BASED ON EXTENSIVE MOSQUITO SURVEYS

Fig. 2 presents records of *Ae. cretinus* in Municipalities in the Attica Region from 1992 (first record in Attica) until 2008 when *Ae. albopictus* was first detected in Attica, during the three-year period shortly after *Ae. albopictus* was first recorded (2009–2011) and from 2012 until 2023. In 2000, a network of 75 oviposition traps was set by Koliopoulos (2011), in 17 Municipalities (out of total 66) in the central, eastern, western, northern and southern parts of Attica Region, in sparsely or densely vegetated and wooded locations in urban and peri-urban residential areas as well as in a wetland and a rural area. These ovitraps were monitored weekly for three years until 2002 and the result

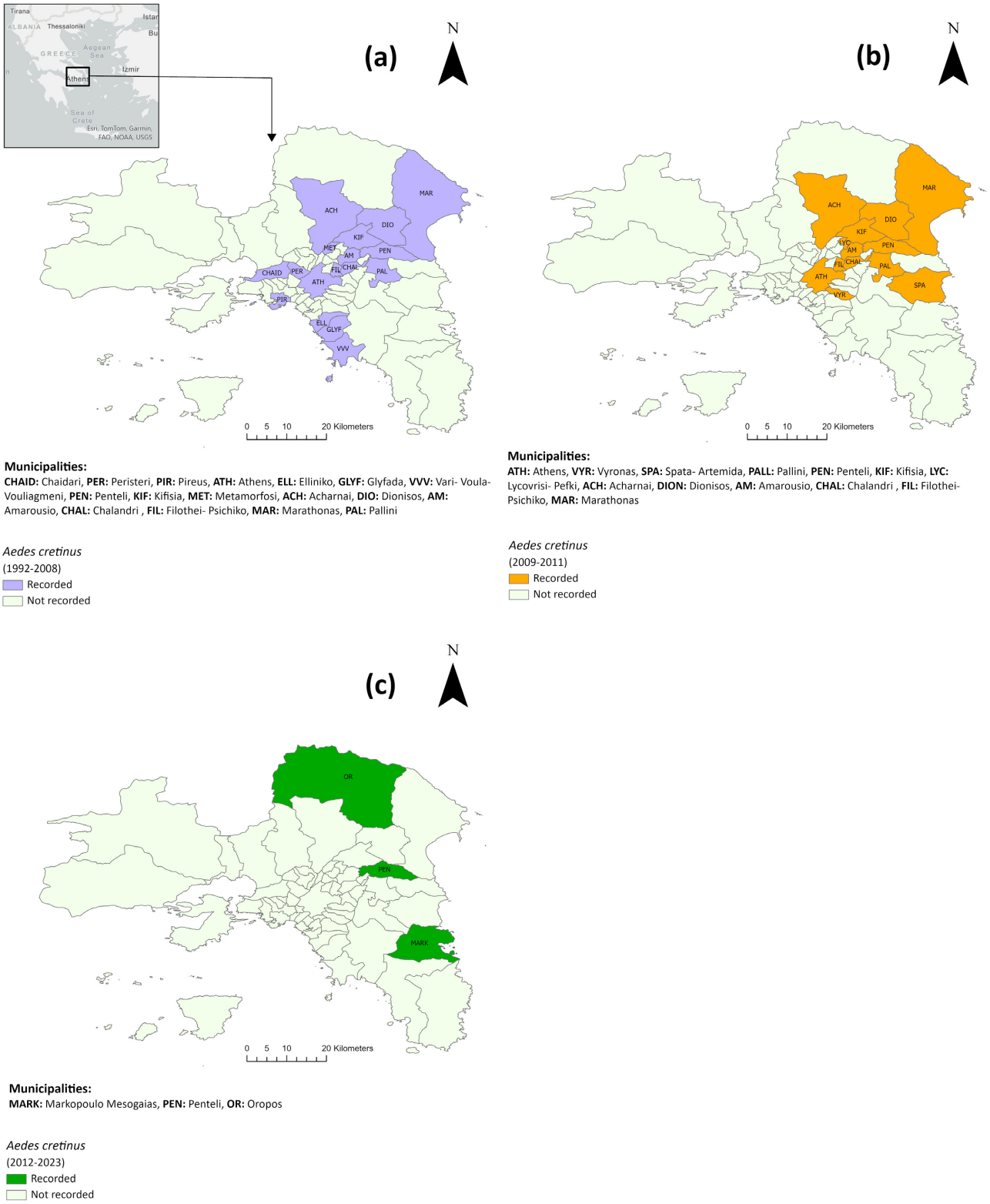

Fig. 2. Records of *Ae. cretinus* in Municipalities of the Attica Region before and after *Ae. albopictus* was first detected in Attica in 2008: (a) for 1992 when *Ae. cretinus* was first recorded in Attica, until 2008, (b) for 2009 to 2011, and (c) for 2012 to 2023.

indicated that *Ae. cretinus* was widespread every year in the areas studied, particularly residential areas. It was the only container breeding *Aedes* mosquito caught in the traps and performed continuous oviposition activity from March to December which was particularly high from July to September (>100 eggs/trap/week, in some cases). In this study, *Ae. cretinus* larvae were collected from small natural or man-made breeding sites such as tree-holes, ground pools, flowerpots, dishes, barrels, road drains and used tyres located in mainly sparsely or densely vegetated and wooded locations in urban and peri-urban residential areas in Attica Region. In these areas, *Ae. cretinus* adults were collected

with human landing method mainly in gardens, close to streams and in cemeteries. Interestingly, soon after *Ae. albopictus* was first recorded in Attica (2008) *Ae. cretinus* was not recorded by Giatropoulos et al. (2012a) during 2009–2010 in areas in the central, northern and western parts of Attica Region such as, the Municipalities of Athens, Amarousion and Metamorfosis, respectively, where Koliopoulos et al. (2011) recorded high *Ae. cretinus* oviposition activity almost 10 years previously. It is note-worthy that *Ae. cretinus* was reported as scarce and occurring only in vegetated areas in Attica in the field study by Giatropoulos et al. (2012a), where almost all of the obtained adults (99.3%) from collected mosquito eggs were identified as *Ae. albopictus,* and a negligible percentage (0.7%) belonged to *Ae. cretinus*. Nevertheless, based on the adult mosquito specimens collected by citizens, *Ae. cretinus* was present in many areas of Attica Region during 2009–2011 (Giatropoulos et al., 2012b) (Table 1, Fig. 2).

A few years later, *Ae. cretinus* was not reported from a mosquito trapping network of the LIFE CONOPS project using BG-sentinel adult traps and oviposition traps set almost throughout the whole of the Attica Region during 2014–2018 (Badieritakis et al., 2018; Lytra et al., 2018). Over the last 4 years (2020–2023), an extensive mosquito surveillance network, using oviposition traps, BG-sentinel adult traps and human landing counts was established in almost all of the Municipalities in Attica Region under the frame of mosquito surveillance programs coordinated by BPI. This mosquito surveillance network confirmed the wide distribution of *Ae. albopictus*, and the scarce occurrence of *Ae. cretinus* based on a pool of eggs collected in Afidnes (location in Municipality of Oropos in East Attica) and few adults collected with human landing collection method in Melissia (location in the Municipality of Penteli in Northeast Attica) in 2021 and Vravrona (location in the Municipality of Markopoulo Mesogaias in East Attica) in 2023 (new data, Table 1). To the best of our knowledge, these are the first reports of *Ae. cretinus* in Attica since it was last recorded in 2011, almost 10 years ago, by Giatropoulos et al. (2012b) (Table 1, Fig. 2). Hence, the absence of *Ae. cretinus* in Attica during the 2010s, followed *Ae. albopictus* invasion and spread. Notably, the decade of 2011–2021 is characterized by more intense mosquito surveys for *Aedes* container-breeding mosquitoes in the Attica Region and other parts of Greece due to *Ae. albopictus* invasion showing its wide dispersal across the country and the Attica Region including the Municipality of Athens (Badieritakis et al., 2018; Lytra et al., 2018; Balaska et al., 2020; Beleri et al., 2021). The comparative maps in Fig. 2 indicate that, *Ae. cretinus* records in the Attica Region gradually decreased after the invasion of *Ae. albopictus*. The limited presence of *Ae. cretinus* after the rapid spread of *Ae. albopictus* that occurred particularly in Attica was probably due to competition between these species. The competitive advantage of *Ae. albopictus* over *Ae. cretinus* was evidenced in the laboratory by cross mating and larval competition studies (Giatropoulos et al., 2015, 2022). Competitive interactions between the two species is also likely to have occurred in other areas of Greece, like Chania, where both species co-occur and shortly after the invasion of *Ae. albopictus, Ae. cretinus* is scarcely found (Balaska et al., 2020; Fotakis et al., 2022; Stefopoulou et al., 2022). It is note-worthy that the phenomenon of competitive displacement due to interspecific competition is already known and well-studied between the invasive mosquitoes *Ae. albopictus* and *Ae. aegypti* which is another member of the subgenus *Stegomyia* (Estrada-Franco & Craig, 1995; O'Meara et al., 1995; Jouliano, 1998, 2009; Lounibos, 2007; Tripet et al., 2011; Bargielowski et al., 2013).

Overall, based on published and new mosquito survey data for Greece and particularly that for the Attica Region before and after *Ae. albopictus* invasion, it is evident that *Ae. cretinus* is hardly found following the invasion of *Ae. albopictus* which is widely spreading at the same time. Interspecific competition between these species may account for the current limited presence of *Ae. cretinus* in areas where these closely related species may have co-occurred. Hence, continuous entomological surveys are considered necessary to monitor the presence of *Ae. cretinus* in Attica and other areas in Greece since its existence seems to be endangered by competition from *Ae. albopictus.* The extensive mosquito trapping surveys reported herein, considering also those coordinated by BPI, were carried out in sparsely or densely vegetated and wooded locations in urban and peri-urban residential areas, as well as rural areas. However, further mosquito surveillance data in Greece should be collected from areas close to and in forests (woodlands) which are favourable habitats of *Ae. cretinus* and this information would be useful for ascertaining its distribution status.

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