

Original article (Orijinal araştırma)

Status of the invasive mosquito species *Aedes aegypti* (L., 1762) and *Aedes albopictus* (Skuse, 1895) (Diptera: Culicidae) in Turkey¹

İşgalci sivrisinek türleri *Aedes aegypti* (L., 1762) ve *Aedes albopictus* (Skuse, 1895) (Diptera: Culicidae)'un Türkiye'deki durumları

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Abstract

Aedes aegypti (L., 1762) and *Aedes albopictus* (Skuse, 1895) (Diptera: Culicidae) are important vectors of arboviruses. In Turkey, *Ae. albopictus* eggs were detected in the Thrace area of northwestern Turkey for the first time in 2011. In 2015, studies revealed the spread of *Ae. albopictus* and the first detection of *Ae. aegypti* within northeastern Turkey was reported. This paper reports the results of a survey of the presence and distribution of *Ae. albopictus* and *Ae. aegypti* in Turkey conducted over 5 years. As of 2019, monitoring studies were conducted on the presence of *Ae. albopictus* and *Ae. aegypti* in five geographical regions (Black Sea, Central Anatolia, Marmara, Mediterranean and Aegean Regions). A comprehensive range of potential larval habitats, such as tires, artificial containers, cemeteries, water bottles and natural breeding habitats, were assessed. In addition, standard ovitraps and adults' traps were used in some localities. This study showed that *Ae. albopictus*, in particular, expanded its distribution each year and has the potential to extend its range throughout Turkey over the next few years. In Turkey, the distribution of *Ae. aegypti* is currently limited to northeastern Turkey. Future work focused on determining more effective surveillance and control studies is discussed.

Keywords: *Aedes aegypti*, *Aedes albopictus*, breeding habitats, mosquito ecology, vector control

Öz

Aedes aegypti (L., 1762) ve *Aedes albopictus* (Skuse, 1895) (Diptera: Culicidae) birçok arbovirüsü taşıyan çok önemli vektörlerdir. Türkiye'de *Ae. albopictus* yumurtaları ilk defa 2011 yılında Türkiye'nin kuzeybatısında bulunan Trakya'da tespit edilmiştir. 2015 yılında ise yapılan çalışmalarla, *Ae. albopictus*'un yayılımını genişlettiği ortaya çıkarılmış ve *Ae. aegypti* türü de Türkiye'nin kuzeydoğusunda ilk defa tespit edilmiştir. Bu çalışma *Ae. albopictus* ve *Ae. aegypti*'nin Türkiye'de 5 yıl boyunca yayılım ve dağılımlarına dair bulgular veren ilk çalışmadır. 2019 yılı itibarıyla *Ae. albopictus* ve *Ae. aegypti*'nin varlığını tespit etmek için 5 coğrafi bölgede (Karadeniz, İç Anadolu, Marmara, Akdeniz ve Ege Bölgeleri) çalışmalar yapılmıştır. Çalışmada lastikler, yapay konteynerler, mezarlıklar, su şişeleri ve doğal üreme habitatları gibi tüm potansiyel larva üreme alanları kontrol edilmiştir. Ayrıca bazı alanlarda ovitrap ve ergin tuzakları da kullanılarak örneklemeler yapılmıştır. Sonuçlar, *Ae. albopictus*'un her yıl yayılımını arttırdığını ve gelecek yıllarda tüm Türkiye'de yayılma potansiyeli taşıdığını göstermiştir. *Aedes aegypti*'nin yayılımı ise şimdilik sadece kuzeydoğu ile sınırlı kalmıştır. Gelecekte yapılabilecek daha efektif süveyans ve kontrol çalışmaları da tartışılmıştır.

Anahtar sözcükler: *Aedes aegypti*, *Aedes albopictus*, üreme alanları, sivrisinek ekolojisi, vektör kontrolü

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Introduction

The yellow fever mosquito, *Aedes aegypti* (L., 1762) (Diptera: Culicidae), originated in Africa where a domestic form arose through a single sub speciation event and spread throughout the rest of the subtropical world via human movement and trade. While it established throughout southern Europe during from the late eighteenth to the mid twentieth centuries, the mosquito inexplicably disappeared from the Mediterranean, Black Sea and Macaronesian biogeographical regions (Canary Islands, Madeira and the Azores) (Schaffner & Mathis, 2014). *Aedes aegypti* has since colonized Madeira (Almeida et al., 2007), reappeared in Georgia and southern Russia (Krasnodar Krai and Abkhazia) (Yunicheva et al., 2008) and has been reported in the Netherlands (Scholte et al., 2010) and Turkey (Akıner et al., 2016).

The Asian tiger mosquito, *Aedes albopictus* (Skuse, 1895) (Diptera: Culicidae) has a widespread distribution that includes both temperate and tropical climates. However, the mosquito is native to subtropical and tropical parts of Southeast Asia, and has spread to many regions including Africa, Europe, the Middle East and America due to international human travel and the transportation of used tires (Knudsen, 1995; Mitchell, 1995). *Aedes albopictus* has been reported in over 20 European countries and is considered the most settled invasive mosquito species in Europe (Medlock et al., 2015).

Aedes aegypti and *Ae. albopictus* are vectors of several important arboviruses. *Aedes aegypti* is known to be an efficient vector of several arboviruses including chikungunya virus (CHIKV), yellow fever virus (YFV), Zika virus (ZIKV) and dengue virus (DENV). *Ae. albopictus* has a wide host range, and provides important bridge vectors for zoonotic pathogen spread between humans and other hosts. Additionally, studies performed on *Ae. albopictus* specimens collected from several locations in Black Sea region of Turkey during 2016-2017 revealed the presence of West Nile virus (WNV), *Aedes flavivirus* (AEFV) and cell fusing agent virus (CFAV) within the species (Akıner et al., 2019).

Aedes albopictus eggs were detected for the first time in 2011 in the Thrace area of northwestern Turkey by Oter et al. (2013). Additional monitoring was conducted in northeastern Turkey and Georgia in September 2015 to get information about the dispersion of these invasive *Aedes* species (Akıner et al., 2016). Knowledge regarding the ecological and behavioral attitudes of mosquito populations is important for enhancing our understanding of the transmission dynamics of mosquito-borne diseases and for developing more efficient vector control programs. Studies of these two invasive species have increased worldwide. Here, we present the results of five years of surveillance of the presence and spread of *Ae. albopictus* and *Ae. aegypti* and assess their ecological adaptability in Turkey. Additionally, we discuss the future direction of research and promising control strategies with the potential to be employed throughout the country to minimize harmful effects of the vector of humans.

Material and Methods

Aedes aegypti and *Ae. albopictus* were monitored throughout 2016 and 2017 along the entire Black Sea coastline, which includes Black Sea and Marmara Regions (Figure 1). The Black Sea has a temperate, oceanic climate, warm-wet summers and cool to cold-wet winters (Sensoy et al., 2008). The coast areas of the Black Sea Region have the greatest annual rainfall, receiving 2,200 mm rainfall annually (Sensoy et al., 2008). The Marmara Region and Istanbul have transitional climates, with warm, hot and moderately dry summers and cool to cold, rainy winters (Sensoy et al., 2008). However, in the winter temperatures can drop below zero. The Black Sea Region, in particular, has large tire dumps that provide ideal breeding sites for *Aedes* species. Additionally, tires ideal for providing breeding sites for these invasive species have been used as building materials to make handmade elevators that are used to carry tea leaves from hills and for garden beds within yards. Finally, in order to determine potential spread of the two species to other major touristic localities, such as in Antalya, Ankara and Izmir, surveillance studies were expanded to the Central Anatolia, Mediterranean and Aegean Regions in 2018 and 2019 (Figure 1). Central Anatolia has a semiarid

continental climate with hot, dry summers and cold, snowy winters whereas the Mediterranean and Aegean Regions have hot, dry summers and mild, rainy winters. Additionally, depending on the precise location considered, precipitation varies from 580 to 1,300 mm annually in Mediterranean and Aegean Regions (Sensoy et al., 2008).

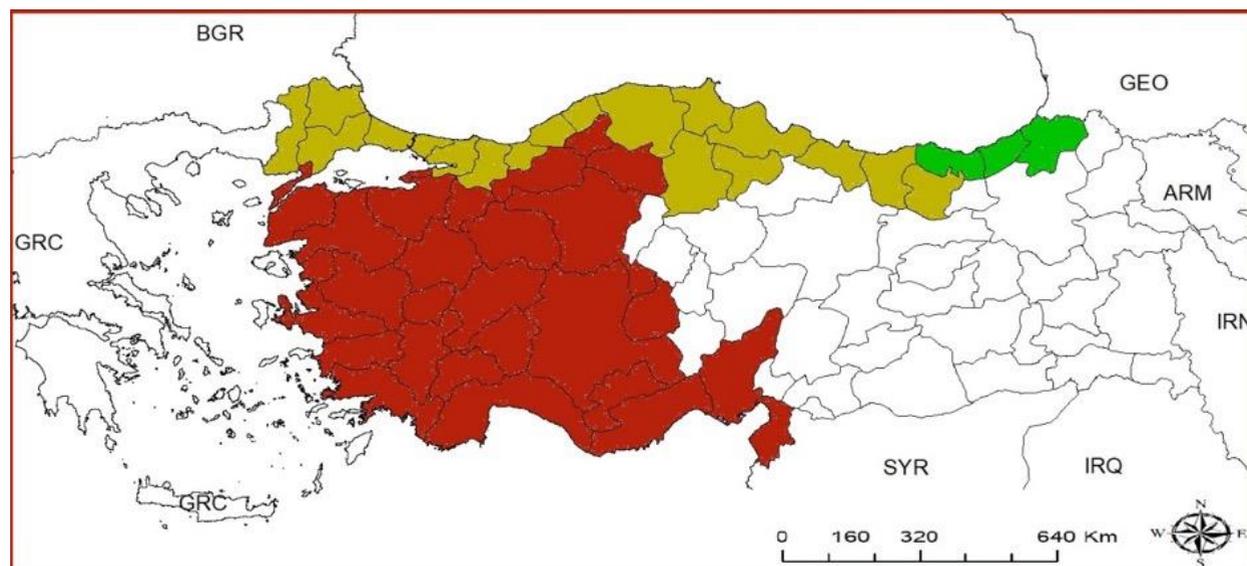


Figure 1. 2015-2019 surveillance area. Green: 2015 surveillance area (East Black Sea Region); Yellow: 2015-2016-2017 surveillance area (West Black Sea and Marmara Regions); Red: 2015-2016-2017-2018 and 2019 surveillance area: (Aegean, Mediterranean and Central Anatolia Regions). ARM: Armenia; BGR: Bulgaria; GE: Georgia; GRC: Greece; IRQ: Iraq; IRN: Iran.

A comprehensive range of larval habitats, such as tires, artificial containers, cemeteries, water bottles and natural breeding habitats, were examined and larvae were collected using a dipper or pipette. In addition, adults were collected using human landing catch (HLC) and BG-Sentinel™ traps in some localities. HLC included two adults with mosquitoes collected after landing on their exposed legs with a Hepa Filter Mouth Aspirator. Collections were performed for 10 min on one day per month from May to October 2017 to 2019. The BG sentinel traps (with BG-Lure) were placed on the ground with the trap mouth opening positioned 40 cm above the ground. The traps were operated for 24-h once a week from May to October 2017 to 2019. In addition, ovitrap surveillance was conducted 5 days per month from May to November 2017 to 2019. Black plastic cups (1 L) filled with water were used as ovitraps. The ovitraps were lined with a strip of filter paper along the water margin where female *Aedes* species could lay their eggs. All collected ovitraps were brought back to laboratory and allowed to develop to adults under standard laboratory conditions at 25°C and 65 ± 20% RH. The HLC, BG-Sentinel™ traps and ovitraps sampling locations and coordinates are given in Tables 1 and 2. Sampling was performed on private land after obtaining permission of the owners. Sampling locations were georeferenced using GPS and the type of containers from which the species were collected were recorded. The morphological identification of species was performed microscopically and selected samples were confirmed molecularly. Morphological identification of larvae and females was performed using the interactive CD of Schaffner et al. (2001). Molecular confirmation was obtained by the amplification of the cytochrome c oxidase I (COI) gene using LCO1490 and HCO2198 primers (Folmer et al., 1994). Twenty females *Ae. albopictus* and four females *Ae. aegypti* from different sampling locations were used for molecular confirmation.

Results

Aedes aegypti and *Aedes albopictus* distribution

In total, 33,580 larval stages of *Ae. albopictus* and *Ae. aegypti* were collected over the 5 years. The COI barcoding was used for confirmation of species identification and the maximum likelihood method, based on a general time reversible model, was used to infer the evolutionary history (Nei & Kumar, 2000). The tree with the highest log likelihood (-1090) is shown in Figure 2. The percentage of trees in which the associated taxa clustered together is shown next to the branches. A maximum composite likelihood approach was used with performing the BioNJ method to obtain initial trees for the heuristic search. Modeling the evolutionary rate differences between sites [(4 categories (+G, parameter = 0.802))] were performed with a distinct gamma distribution. The rate variation model allowed for some sites to be evolutionarily invariable ([+I], 33.1% sites). The tree is drawn to scale, with branch lengths as the number of substitutions per site. The analysis involved 28 nucleotide sequences. Codon positions included were the first, second, third and noncoding positions. There was a total of 599 positions in the final dataset. Evolutionary analyses were conducted in MEGA7 (Kumar et al., 2015).

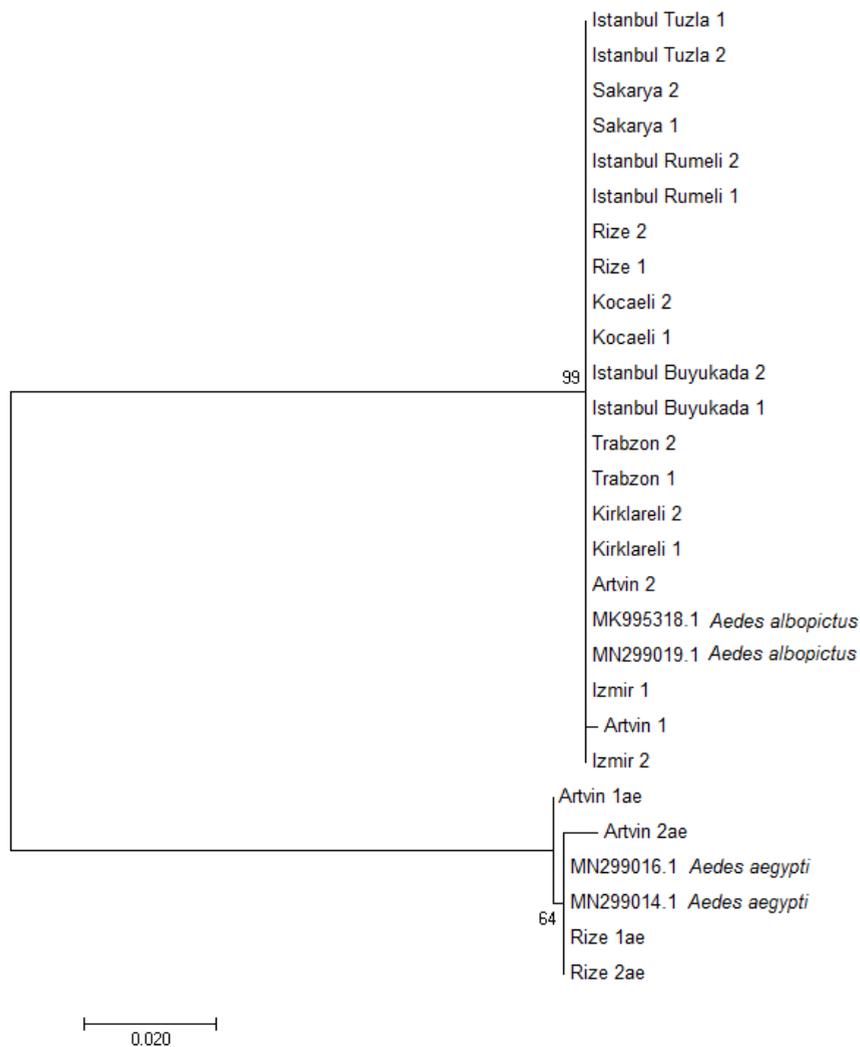


Figure 2. Molecular phylogenetic analysis by maximum likelihood method. The sequences obtained in mosquito species in this study are given with the name of sampling locations and numbers. Reference sequences are shown with GenBank accession number and species.

The distribution of *Ae. albopictus* and *Ae. aegypti* in northeastern Turkey in 2015 are shown in Figure 3. *Aedes albopictus* was found in 21 (34%) out of 62 monitored areas, *Ae. aegypti* was found 8 (13%) and both *Ae. albopictus* and *Ae. aegypti* were identified in three sites (5%). In all locations in which both species were identified, *Ae. albopictus* was the most abundant.



Figure 3. Distribution of *Aedes albopictus* and *Aedes aegypti* in northeastern Turkey in 2015. Blue triangles; monitored sampling sites, yellow circles; positive sampling sites for *Ae. albopictus* and green circles; positive sampling sites for *Ae. aegypti*.

The distribution of *Ae. albopictus* and *Ae. aegypti* in 2016 and 2017 are shown in Figures 4 and 5, respectively. In 2016, *Ae. albopictus* was found in 53 (33.8%) and *Ae. aegypti* was found in 21 (13.4%) sites monitored and the both species were identified in 4 (2.5%) of the 157 total sites monitored. In 2017, *Ae. albopictus* was found in 208 (51.2%) and *Ae. aegypti* in 29 (7.1%) monitored sites and both species were identified from 28 (6.9%) of 406 monitored sites.

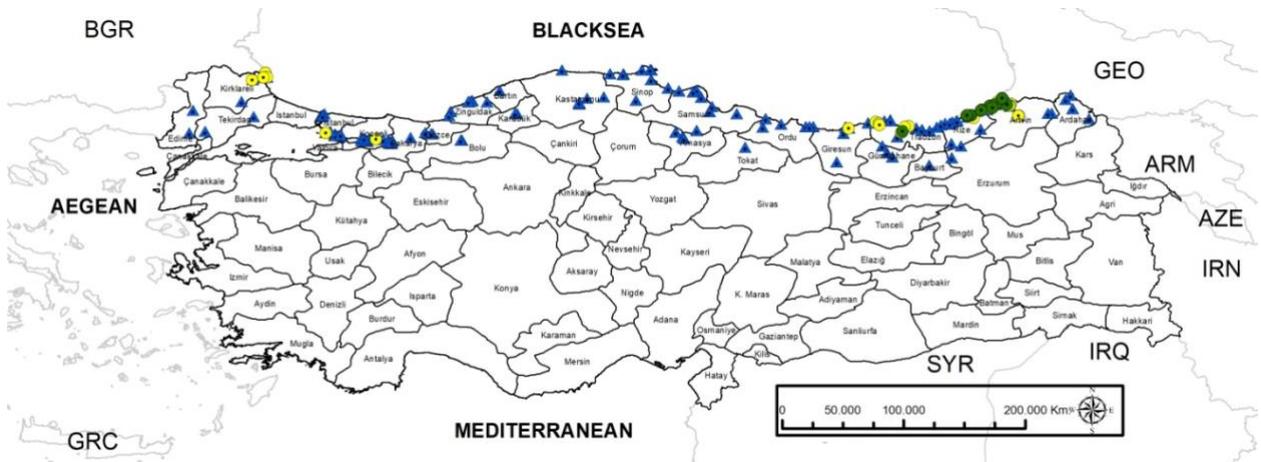


Figure 4. Distribution of *Aedes albopictus* and *Aedes aegypti* in northeastern Turkey in 2016. Blue triangles; monitored sampling sites, yellow circles; positive sampling sites for *Ae. albopictus* and green circles; positive sampling sites for *Ae. aegypti*.

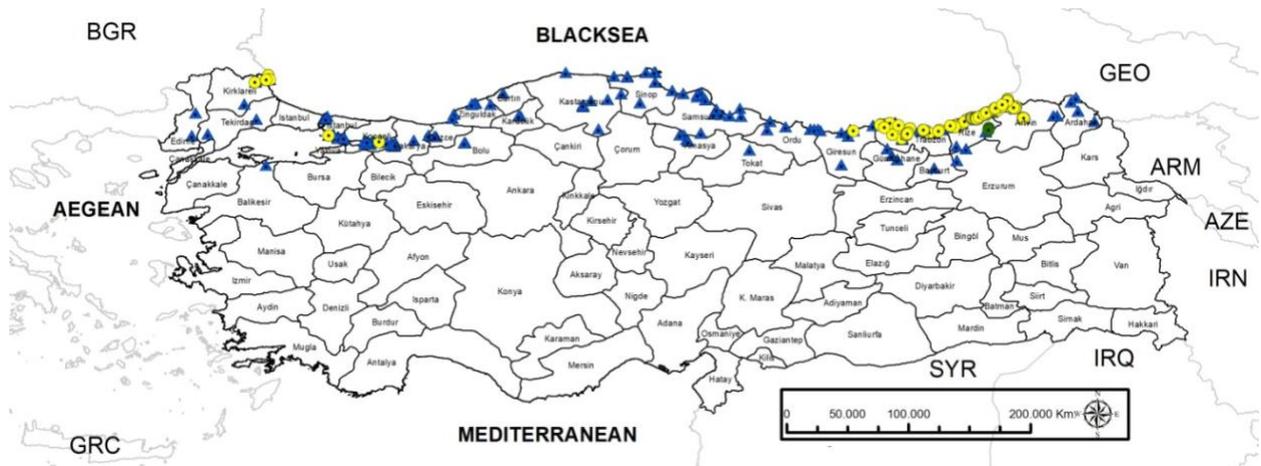


Figure 5. Distribution of *Aedes albopictus* and *Aedes aegypti* in northeastern Turkey in 2017. Blue triangles; monitored sampling sites, yellow circles; positive sampling sites for *Ae. albopictus* and green circles; positive sampling sites for *Ae. aegypti*.

In 2018 and 2019, mosquito sampling areas were expanded, and surveillance also included Central Anatolia, Aegean and Mediterranean Regions. *Aedes albopictus* was identified in three geographical regions (Black Sea, Marmara and Aegean) whereas *Ae. aegypti* was only found in northeastern Turkey. The distributions of *Ae. albopictus* and *Ae. aegypti* in 2018 and 2019 are shown in Figures 6 and 7, respectively. In 2018, *Ae. albopictus* was found in 234 (36.9%) and both *Ae. albopictus* and *Ae. aegypti* were found together in 7 (1.1%) of 635 monitored sites. In 2019, *Ae. albopictus* was found in 457 (65.3%) and both *Ae. albopictus* and *Ae. aegypti* were found together in 9 (1.3%) of 700 monitored areas.

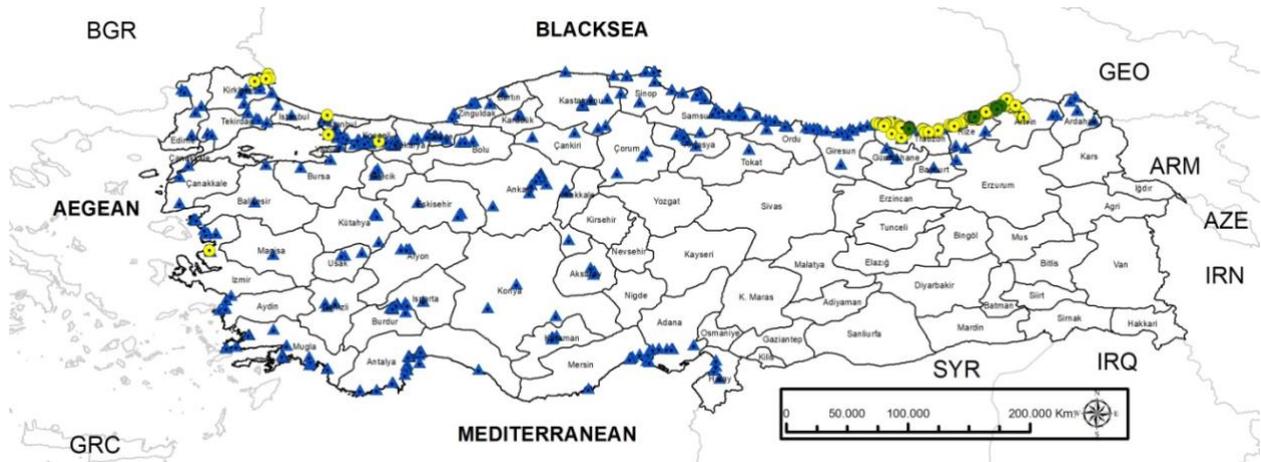


Figure 6. Distribution of *Aedes albopictus* and *Aedes aegypti* in northeastern Turkey in 2018. Blue triangles; monitored sampling sites, yellow circles; positive sampling sites for *Ae. albopictus* and green circles; positive sampling sites for *Ae. aegypti*.

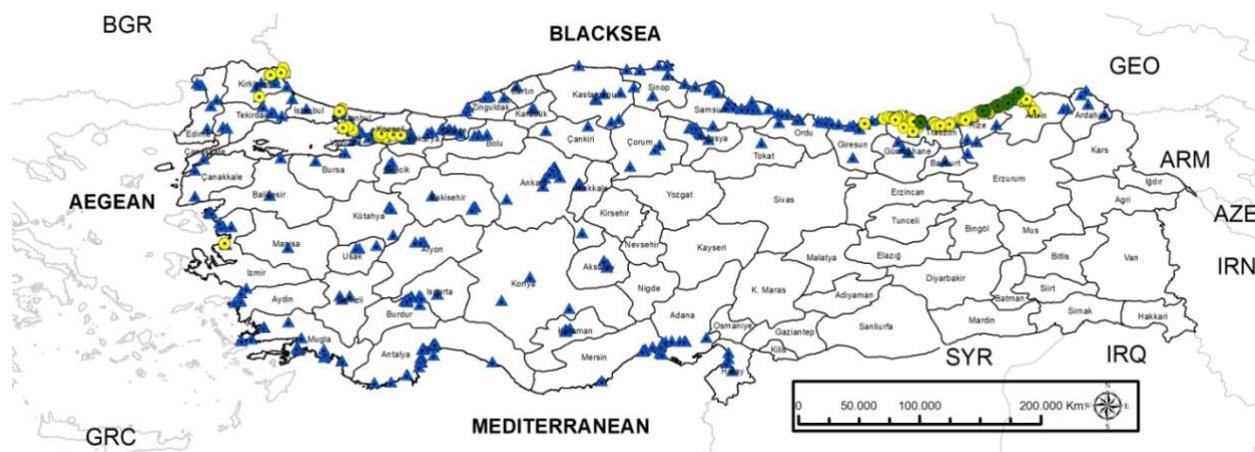


Figure 7. Distribution of *Aedes albopictus* and *Aedes aegypti* in northeastern Turkey in 2019. Blue triangles; monitored sampling sites, yellow circles; positive sampling sites for *Ae. albopictus* and green circles; positive sampling sites for *Ae. aegypti*.

Adult collection was standardized in some localities during 2017 to 2019 and number of adults were collected using HLC, BG-Sentinel™ and also number of eggs collected using ovitraps and number of adults emerged from eggs are given in Tables 1 and 2.

Table 1. Human landing catch, BG-Sentinel™ traps and ovitraps sampling locations and coordinates for *Aedes albopictus* and number of adults emerged from eggs

Sampling Sites	Coordinates	2017		2018		2019	
		OVI (eggs)	HLC	OVI (eggs)	HLC	OVI (eggs)	HLC
Hopa Automobile Industrial Estate (BSR)	41°25'42" N 41°26'00" E	2511	511	2390	501	4410	340
Arhavi (BSR)	41°21'01" N 41°17'54" E	3386	219	3253	183	4830	127
Fındıklı (BSR)	41°16'34" N 41°08'49" E	2836	110	2703	75	7223	70
Hamidiye (BSR)	41°10'37" N 40°57'14" E	1661	141	1559	82	2984	93
Sürmene (BSR)	40°54'44" N 40°06'53" E	1256	196	1162	155	1366	161
Trabzon Automobile Industrial Estate (BSR)	40°59'53" N 39°45'13" E	1740	120	1662	88	2016	104
İstanbul Kartal (MR)	40°56'07" N 29°10'46" E	5150	226	4828	181	4672	176
İstanbul Rumeli Kavağı (MR)	41°11'05" N 29°03'38" E	5487	253	5320	213	4909	215
Kırklareli Beğendik (MR)	41°57'35" N 28°01'12" E	5125	172	4918	151	5248	154
İzmir Aliağa (AR)	38°48'03" N 27°03'19" E	4843	176	4661	161	4515	158
Total		33995	2124	32456	1790	42173	1598
Number of adults emerged from eggs		30935 (90.9%)		29632 (91.3%)		38124 (90.3%)	

HLC, human landing catch; OVI, ovitrap; BSR, Black Sea Region; and MR, Marmara Region.

Table 2. Human landing catch, BG-Sentinel™ traps and ovitraps sampling locations and coordinates for *Aedes aegypti* and number of adults emerged from eggs

Sampling Sites	Coordinates	2017			2018			2019		
		OVI (eggs)	HLC	BG	OVI (eggs)	HLC	BG	OVI (eggs)	HLC	BG
Hopa Automobile Industrial Estate (BSR)	41°25'42" N 41°26'00" E	2511	511		2390	501		4410	340	
Arhavi (BSR)	41°21'01" N 41°17'54" E	3386	219		3253	183		4830	127	
Fındıklı (BSR)	41°16'34" N 41°08'49" E	1226	38	12	848	24	9	1040	32	17
Pazar (BSR)	41°10'50" N 40°52'56" E	1223	50	16	1020	37	22	1065	42	22
Total		4335	168	57	2932	111	50	3637	138	66
Number of adults emerged from eggs		3641 (84%)			2500 (85.2%)			3033 (83.4%)		

†HLC, human landing catch; OVI, ovitrap; BG, BG-Sentinel trap; BSR, Black Sea Region; and MR, Marmara Region.

Larval habitats assessed at each location

By 2019, a total of 700 potential breeding sites has been examined throughout four geographical regions spanning Turkey. Of these, 466 (66.6%) were determined to be infested with immature *Aedes* spp. *Aedes albopictus* and *Ae. aegypti* were found in association with several other mosquito species. These include *Anopheles plumbeus* Stephens 1828, *Anopheles claviger* (Meigen, 1804), *Culex territans* Walker 1856, *Culex pipiens* Linnaeus 1758 and *Aedes geniculatus* (Olivier, 1791). These positive breeding sites were distributed into four groups, as follows: used tires, natural areas and mixed breeding sites such as discarded water bottles, flower pots, drainage pipes and closets. Used tires were the abundant potential breeding site studied (88.6%), followed by mixed breeding sites (7.7%) and natural breeding sites (3.6%) (Table 3). Photos of breeding site types are given in Figure 8.

Table 3. Larval breeding containers and their characteristic

Region	Discarded tires	Natural	Mixed	Total
Black Sea	391 (83.9%)	15 (3.2%) (temporary breeding habitats)	13 (2.8%) discarded containers 5 (1.2%) (flower pots) 2 (0.4%) (thrown closets) 5 (1.1%) (water bottles) 2 (0.4%) (drainage pipes)	433 (92.9%)
Marmara	22 (4.7%)	2 (0.4%) (tree holes)	4 (0.9%) (discarded containers) 2 (0.4%) (drainage pipes) 2 (0.4%) (water bottles)	32 (6.7%)
Mediterranean	0	0	0	0
Aegean	0	0	1 (0.2%) (water bottle)	1 (0.2%)
Total	413 (88.6%)	17 (3.6%)	36 (7.7%)	466 (100%)



Figure 8. Representative examples of breeding habitats for *Aedes* mosquitos. Breeding site types including temporary (natural) breeding habitats (a), discarded tires (b-d) and mixed breeding habitats (e-h).

Discussion

This is the first study that has performed the widespread profiling of the geographical distribution and prevalence of *Ae. albopictus* and *Ae. aegypti* mosquitoes in Turkey since both species were reported in 2011 and 2015, respectively. The study revealed that the most infested areas are settlements, permanent populations of the species were detected for the first time (northeastern Turkey) and *Ae. albopictus* has been identified in several areas where it was not determined to be present previously. However, the distribution of *Ae. aegypti* in Turkey remains limited to northeastern Turkey.

Our study reveals the coexistence of *Ae. albopictus* and *Ae. aegypti* within the same larval sites. However, a decrease in the distribution of *Ae. aegypti* was observed after 2017. It seems the species has become scarce within areas where it previously had been detected. The distribution of *Ae. albopictus* is much wider than that of *Ae. aegypti*. Although environmental factors such as vegetation and climate may be responsible for observed differences between the prevalence of the two species, difference may also be a result of competition between the species. While the coexistence of the two species has been documented within the same larval developmental areas (Braks et al., 2003; Simard et al., 2005; Chen et al., 2006), a competitive advantage for *Ae. albopictus* over *Ae. aegypti* has been suggested in several studies (O'Meara et al., 1995; Barrera, 1996; Daugherty et al., 2000; Juliano et al., 2002, 2004; Lounibos et al., 2002). *Aedes albopictus* appears to have a great degree of environmental plasticity, which facilitates the adaptation of the species to different environments (Hawley, 1998). Kobayashi et al. (2002) showed that *Ae. albopictus* can synthesize large amounts of lipids, which provides substantial yolk resources to the eggs in diapause which facilitated the enhanced adaptation of the species to cooler climates than *Ae. aegypti* and increased the capacity of *Ae. albopictus* to distribute throughout both temperate and tropical regions. Also, Otero et al. (2006) showed that *Ae. aegypti* eggs have elevated mortality rates when exposed to frost during intense winters. However, while both species have desiccant-resistant eggs, *Ae. aegypti* is more tolerant to elevated temperatures than *Ae. albopictus*, and thus, *Ae. aegypti* is more capable of living within hot and dry environments than *Ae. albopictus*, if breeding sites are available (Sota, 1993; Juliano et al., 2004).

In the present study, used tires, in particular, were identified as sites associated with high detection rates for invasive *Aedes* larvae. This is consistent with studies conducted in other countries, including India (Singh & Rahman, 2013; Vijayakumar et al., 2014) Mexico (Lloyd et al., 1992) and Africa (Simard et al., 2005; Kamgang et al., 2010; Ngoagouni et al., 2015). This might be due to the fact that discarded tires are often stored for long periods, which makes them suitable breeding containers for larvae that are not often disturbed (Snr et al., 2011). Also, the attraction of *Ae. albopictus* and *Ae. aegypti* to tires may be associated with the similarity of tires to natural breeding habitats, such as natural tree holes (Tedjou et al., 2019). Both sites share similar characteristics including dark color and dark interior, and both provide suitable resting and oviposition sites. Laboratory-based studies on the oviposition of *Ae. albopictus* have also revealed that the species is attracted to black colored jars (Yap et al., 1995). Also, the attachment of eggs to the tires is important for the protection of *Aedes* population during the mosquito off season. However, the results showed that both species have the capacity to adapt to different breeding habitats such as discarded tanks, flower pots and water bottles, which is similar to reports of mosquito habits observed in other countries (Eritja et al., 2005; Seidahmed & Eltahir, 2016; Mathias et al., 2017; Stefopoulou et al., 2018). In this present study, tire dumps and used tires were mainly targeted for sampling to increase the possibility that immature stages of the species would be found. Also, no biotic/abiotic factors that may have affected the oviposition preferences of vector species such as water quality, vegetation and microbiota were not examined. Nonetheless, it remains important to focus on the common occurrence of huge tire dumps throughout the Black Sea Region and the presence of discarded tires that are used in tea leaf elevators of the eastern Black Sea Region (Figure 8d). This observation may be useful for raising awareness of the larval habitats of these vector species and for fighting arboviral diseases. Despite the limitations of the study, it represents the first report to characterize the presence of *Aedes* mosquitoes and their preferred breeding habitats in Turkey and to provide baseline data regarding the presence and distribution of the invasive mosquitoes in Turkey.

Aedes albopictus and *Ae. aegypti* are known to transmit ZIKV, CHICKV, YFV, all four DENV serotypes and are also potential vectors for Venezuelan equine encephalitis virus, Eastern equine encephalitis virus, Mayaro virus, Potosi virus, Cache Valley virus and La Crosse virus (Fontenille et al., 1997; Gratz, 2004; Turell et al., 2005; Long et al., 2011; da Moura et al., 2015; Seixas et al., 2018). Studies also have demonstrated the independent replication and dissemination of DENV and CHIKV when *Ae. aegypti* and *Ae. albopictus* were coinfecting with the arboviruses (Vazeille et al., 2010; Nuckols et al., 2015). Also, it is known that *Ae. albopictus* is able to transmit at least 22 arboviruses, including Rift Valley fever, Japanese encephalitis, WNV, and Sindbis viruses (Mitchell, 1995; Schaffner & Mathis, 2014; Medlock et al., 2015; Xia et al., 2018). Laboratory-based studies have revealed the potential of the species to transmit other arboviruses such as Oropouche, Trivittatus viruses and San Angelo virus (Moore & Mitchell, 1997). In tropical and subtropical countries, the epidemiology of arboviruses, such as CHICKV, ZIKV and DENV, are very different than in Europe due to the existence of the sylvatic cycle between wild animals and mosquitoes that facilitates year-round viral circulation in tropical/subtropical climates (Diallo et al., 1999). Due to the lack of this sylvatic cycle, local transmission throughout European countries only occurs when a competent vector becomes infectious after feeding an imported human case. This occurred throughout chikungunya fever spread in Italy in 2007, West Nile fever outbreaks in Romania and Greece in 2010 and regional dengue fever transmission that occurred in France and Croatia in 2010 (Hubálek & Halouzka, 1999; Lanciotti et al., 1999; Tsai et al., 1998; Papa et al., 2011; Lwande et al., 2015). Additionally, a study performed on *Ae. albopictus* and *Ae. aegypti* specimens collected from varied locations throughout the Black Sea Region of Turkey throughout 2016-2017 possessed WNV, CFAV and AEFV (Akıner et al., 2019). While there has been reports about imported DENV, CHIKV and ZIKV cases (Yağcı Çağlayık et al., 2012; Sezen et al., 2018) and serologically confirmed sporadic exposure to DENV (Ergünay et al., 2010), there is no information about the local transmission of ZIKV, DENV, YFV or CHIKV in humans in Turkey.

Over the past 30 years, the global geographical distribution of *Ae. albopictus* and *Ae. aegypti* has greatly expanded, and the effect of climate change on the range of the species has been shown (Romi et al., 1999; Benedict et al., 2007). Temperature can affect mosquito development and infection rates and may allow vector species to develop pathogens increasingly rapidly, which may facilitate their spread to new areas (Chaves & Koenraadt, 2010; Patz et al., 2003). Other effects of climate change, such as enhanced insecticide resistance, population density, sociodemographic factors, lifestyle, intensive agriculture, improper water storage and used tire trading, have the potential to affect the spread and expansion of vectors and pathogens (Gratz, 2004). The control of *Ae. albopictus* and *Ae. aegypti* is difficult and could require a combination of different vector control strategies including chemical, biological and genetic methods, along with public education strategies that involve informing individuals about health risks associated with the species and strategies that involve the cleaning or removal of possible larval habitats (O'Meara et al., 1995; Abramides et al., 2011). It has previously been shown that artificial containers on private land make up the majority of reproductive sites for *Aedes* larvae and the reduction of larval breeding habitats by removing water containers may be the most effective *Ae. albopictus* control method (Bartlett-Healy et al., 2012). The temporary suppression of immature *Ae. albopictus* by reducing larval sources was first reported in the USA (Ali & Nayar, 1997). The phenomenon was also reported in Spain (Abramides et al., 2011) New Jersey (Fonseca et al., 2013) and Grand Cayman Island (Wheeler et al., 2009). Involving the communities in *Aedes* mosquito control using different public awareness campaigns involving various communication channels, such as the internet and media, should be combined with the application of larvicides and adulticides.

In conclusion, our results show that *Ae. albopictus*, in particular, has expanded its distribution each year, and has the potential to extend its range throughout Turkey in the next few years. Observed increases in both mosquito distribution as well as detection of imported virus cases have the potential to produce a worrying scenario in the future. Unfortunately, there is no current national strategy for reducing populations and the dispersal of these invasive species in Turkey. Therefore, we strongly recommend the implementation of appropriate control strategies, which should be managed by local, regional and central governments. In Turkey, especially in the eastern Black Sea Region, numerous and large tire dumps currently serve as principal *Aedes* larval habitats, and urgent solutions are needed to mandate the removal/recycle of tires. In addition, tourism is very important in the Black Sea Region. Future arbovirus circulation may be enhanced due to the fact that the majority of tourists that come to the region are of Arabian origin, and the Arabian Peninsula contains large numbers of some arboviruses. In this sense, cooperation between the government, researchers, local administrations and policymakers is necessary for the standardization of invasive *Aedes* surveillance, for performing integrated control studies (public awareness, chemical, biological and genetic methods) and for funding countrywide control strategies.

References

- Abramides, G. C., D. Roiz, R. Guitart, S. Quintana, I. Guerreroe & N. Giménez, 2011. Effectiveness of a multiple intervention strategy for the control of the tiger mosquito (*Aedes albopictus*) in Spain. *Transactions of the Royal Society of Tropical Medicine & Hygiene*, 105 (5): 281-288.
- Akiner, M. M., B. Demirci, G. Babuadze, V. Robert & F. Schaffner, 2016. Spread of the invasive mosquitoes *Aedes aegypti* and *Aedes albopictus* in the Black Sea region increases risk of chikungunya, dengue, and Zika outbreaks in Europe. *PLoS Neglected Tropical Diseases*, 10 (4): e0004664.
- Akiner, M. M., M. Öztürk, A. B. Başer, F. Günay, S. Hacıoglu & A. Brinkmann, 2019. Arboviral screening of invasive *Aedes* species in northeastern Turkey: West Nile virus circulation and detection of insect-only viruses. *PLoS Neglected Tropical Diseases*, 13 (5): e0007334.
- Ali, A. & J. K. Nayar, 1997. Invasion, spread, and vector potential of *Aedes albopictus* in the USA and its control possibilities. *Medical Entomology and Zoology*, 48 (1): 1-9.
- Almeida, A. P., Y. M. Goncalves, M. T. Novo, C. A. Sousa, M. Melim & A. J. Gracio, 2007. Vector monitoring of *Aedes aegypti* in the Autonomous Region of Madeira, Portugal. *Eurosurveillance*, 12 (11): E0711156.

- Barrera, R., 1996. Competition and resistance to starvation in larvae of container-inhabiting *Aedes* mosquitoes. *Ecological Entomology*, 21 (2): 112-127.
- Bartlett-Healy, K., I. Unlu, P. Obenauer, T. Hughes, S. Healy, T. Crepeau, A. Faraji, B. Kesavaraju, D. Fonseca, G. Schoeler, R. Gaugler & D. Strickman, 2012. Larval Mosquito Habitat Utilization and Community Dynamics of *Aedes albopictus* and *Aedes japonicus* (Diptera: Culicidae). *Journal of Medical Entomology*, 49 (4): 813-24.
- Benedict, M. Q., R. S. Levine, W. A. Hawley & L. P. Lounibos, 2007. Spread of the tiger: Global risk of invasion by the mosquito *Aedes albopictus*. *Vector-Borne and Zoonotic Diseases*, 7 (1): 76-85.
- Braks, M. A., N. A. Honorio, R. Lourenco-De-Oliveira, S. A. Juliano & L. P. Lounibos, 2003. Convergent habitat segregation of *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae) in southeastern Brazil and Florida. *Journal of Medical Entomology*, 40 (6): 785-794.
- Chaves, L. & C. Koenraadt, 2010. Climate change and highland malaria: Fresh air for a hot debate. *The Quarterly Review of Biology*, 85 (1): 27-55.
- Chen, C. D., W. A. Nazni, H. L. Lee, B. Seleena, S. Mohd Masri, Y. F. Chiang & M. Sofian-Azirun, 2006. Mixed breeding of *Aedes aegypti* (L.) and *Aedes albopictus* Skuse in four dengue endemic areas in Kuala Lumpur and Selangor. *Tropical Biomedicine*, 23 (2): 224-227.
- da Moura, A. J., M. A. de Melo Santos, C. M. Oliveira, D. R. Guedes, D. de Carvalho-Leandro, M. L. da Cruz Brito, L. F. Gomez & C. F. Ayres, 2015. Vector competence of the *Aedes aegypti* population from Santiago Island, Cape Verde, to different serotypes of dengue virus. *Parasite and Vectors*, 8: 114.
- Daugherty, M. P., B. W. Alto & S. A. Juliano, 2000. Invertebrate carcasses as a resource for competing *Aedes albopictus* and *Aedes aegypti* (Diptera: Culicidae). *Journal of Medical Entomology*, 37 (3): 364-372.
- Diallo, M., J. Thonnon, M. Traore-Lamizana & D. Fontenille, 1999. Vectors of chikungunya virus in Senegal: Current data and transmission cycles. *American Journal of Tropical Medicine and Hygiene*, 60 (2): 281-286.
- Ergünay, K., M. B. Saygan, S. Aydoğan, N. Litzba, M. Niedrig, A. Pinar & D. Us, 2010. Investigation of dengue virus and yellow fever virus seropositivities in blood donors from Central/Northern Anatolia. *Mikrobiyoloji Bülteni*, 44 (3): 415-424.
- Eritja, R., R. Escosa, J. Lucientes, E. Marques, D. Roiz & S. Ruiz, 2005. Worldwide invasion of vector mosquitoes: Present European distribution and challenges for Spain. *Biological Invasions*, 7: 87-97.
- Fonseca, D. M., I. Unlu, T. Crepeau, A. Farajollahi, S. P. Healy, K. Bartlett-Healy, D. Strickman, R. Gaugler, G. Hamilton, D. Kline & G. G. 2013. ClarkArea-wide management of *Aedes albopictus*. Part 2: gauging the efficacy of traditional integrated pest control measures against urban container mosquitoes. *Pest Management Science*, 69 (12): 1351-1361.
- Fontenille, D., M. Diallo, M. Mondo, M. Ndiaye & J. Thonnon, 1997. First evidence of natural vertical transmission of yellow fever virus in *Aedes aegypti*, its epidemic vector. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 91 (5): 533-535.
- Gratz, N. G., 2004. Critical review of the vector status of *Aedes albopictus*. *Medical and Veterinary Entomology*, 18 (3): 215-227.
- Hawley, W. A., 1998. The biology of *Aedes albopictus*. *Journal of the American Mosquito Control Association Supplement*, 1 (1): 1-39.
- Hubálek, Z. & J. Halouzka, 1999. West Nile fever-a reemerging mosquito-borne viral disease in Europe. *Emerging Infectious Diseases*, 5 (5): 643-650.
- Juliano, S. A., L. P. Lounibos & G. F. O'Meara, 2004. A field test for competitive effects of *Aedes albopictus* on *Aedes aegypti* in south Florida: differences between sites of coexistence and exclusion? *Oecologia*, 139 (4): 583-593.
- Juliano, S. A., G. F. O'Meara, J. R. Morrill & M. M. Cutwa, 2002. Desiccation and thermal tolerance of eggs and the coexistence of competing mosquitoes. *Oecologia*, 130 (3): 458-469.
- Kamgang, B., J. Y. Happi, P. Boisier, F. Njiokou, J. P. Herve, F. Simard & C. Paupy, 2010. Geographic and ecological distribution of the dengue and chikungunya virus vectors *Aedes aegypti* and *Aedes albopictus* in three major Cameroonian towns. *Medical and Veterinary Entomology*, 24 (2): 132-141.
- Knudsen, A. B., 1995. Global distribution and continuing spread of *Aedes albopictus*. *Parassitologia*, 37 (2-3): 91-97.
- Kobayashi, M., N. Nihei & T. Kurihara. 2002. Analysis of northern distribution of *Aedes albopictus* (Diptera: Culicidae) in Japan by geographical information system. *Journal of Medical Entomology*, 39 (1): 4-11.

- Kumar, S., G. Stecher & K. Tamura, 2015. MEGA7: Molecular Evolutionary Genetics Analysis version 7.0 for bigger datasets.
- Lanciotti, R., J. T. Roehrig, V. Deubel, J. Smith, M. Parker, K. Steele, B. Crise, K. E. Volpe, M. B. Crabtree, J. H. Scherret, R. A. Hall, J. S. MacKenzie, C. B. Cropp, B. Panigrahy, E. Ostlund, B. Schmitt, M. Malkinson, C. Banet, J. Weissman, N. Komar, H. M. Savage, W. Stone, T. McNamara & D. J. Gubler, 1999. Origin of the West Nile virus responsible for an outbreak of encephalitis in the northeastern United States. *Science*, 286 (5448): 2333-2337.
- Lloyd, L. S., P. Winch, J. Ortega-Canto & C. Kendall, 1992. Results of a community-based *Aedes aegypti* control program in Merida, Yucatan, Mexico. *The American Journal of Tropical Medicine and Hygiene*, 46 (6): 635-642.
- Long, K. C., S. A. Ziegler, S. Thangamani, N. L. Hausser, T. J. Kochel, S. Higgs & R. B. Tesh. 2011. Experimental transmission of Mayaro virus by *Aedes aegypti*. *The American Journal of Tropical Medicine and Hygiene*, 85 (4): 750-757.
- Lounibos, L. P, S. Saurez, Z. Menedez, N. Nishimura, R. L. Escher, S. M. O'Connell & J. R. Rey. 2002. Does temperature affect the outcome of larval competition between *Aedes aegypti* and *Aedes albopictus*? *Journal of Vector Ecology*, 27 (1): 86-95.
- Lwande, O. W., G. Mosomtai & S. Symekher, 2015. West Nile virus, a reemerging virus. *Precision Medicine*, 2 (1): e604.
- Mathias, L., V. Baraka, A. Philbert, E. Innocent, F. Francis, G. Nkwengulila & E. J. Kweka, 2017. Habitat productivity and pyrethroid susceptibility status of *Aedes aegypti* mosquitoes in Dar es Salaam, Tanzania. *Infectious Diseases of Poverty*, 6 (102): 1-10.
- Medlock, J. M, K. M Hansford, V. Versteirt, B. Cull, H. Kampen, D. Fontenille, G. Hendrickx, H. Zeller, W. Van Bortel & F. Schaffner, 2015. An entomological review of invasive mosquitoes in Europe. *Bulletin of Entomological Research*, 105 (6): 637-663.
- Mitchell, C., 1995. Geographic spread of *Aedes albopictus* and potential for involvement in arbovirus cycles in the Mediterranean basin. *Journal of Vector Ecology*, 20 (1): 44-58.
- Moore, C. G. & C. J. Mitchell, 1997. *Aedes albopictus* in the United States: Ten-year presence and public health implications. *Emerging Infectious Diseases*, 3 (3): 329-334.
- Nei, M. & S. Kumar, 2000. *Molecular Evolution and Phylogenetics*. Oxford University Press, New York. 333 pp.
- Ngoagouni, C., B. Kamgang, E. Nakoune, C. Paupy & M. Kazanji, 2015. Invasion of *Aedes albopictus* (Diptera: Culicidae) into central Africa: what consequences for emerging diseases? *Parasite and Vectors*, 8 (191): 1-7.
- Nuckols, J., Y.-J. Huang, S. Higgs & A. Miller, 2015. Evaluation of simultaneous transmission of chikungunya virus and dengue virus type 2 in infected *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae). *Journal of Medical Entomology*, 52 (3): 447-451.
- O'Meara, G. F., L. F. Evans, A. D. Gettman & J. P. Cuda, 1995. Spread of *Aedes albopictus* and decline of *Ae. aegypti* (Diptera: Culicidae) in Florida. *Journal of Medical Entomology*, 32 (4): 554-562.
- Oter, K., F. Gunay, E. Tuzer, Y. M. Linton, R. Bellini & B. Alten. 2013. First record of *Stegomyia albopicta* in Turkey determined by active ovitrap surveillance and DNA barcoding. *Vector Borne and Zoonotic Diseases*, 13 (10): 753-761.
- Otero, M., H. G. Solari & N. Schweigmann, 2006. A stochastic population dynamics model for *Aedes aegypti*: Formulation and application to a city with temperate climate. *The Bulletin of Mathematical Biology*, 68 (8): 1945-1974.
- Papa, A., K. Xanthopoulou, S. Gewehr & S. Mourelatos, 2011. Detection of West Nile virus lineage 2 in mosquitoes during a human outbreak in Greece. *Clinical Microbiology and Infection*, 17 (8): 1176-1180.
- Patz J. A., A. K. Githeko, J. P. McCarty, S. Hussain, U. Confalonieri & N. de Wet, 2003. "Climate Change and Infectious Diseases, 103-132". In: *Climate Change and Human Health: Risks and Responses* (Eds. A. J. McMichael, D. H. Campbell-Lendrum, C. F. Corvalán, K. L. Ebi, A. K. Githeko, J. D. Scheraga & A. Woodward). World Health Organization, Geneva, Switzerland, 322 pp.
- Romi, R., M. Di Luca & G. Marjori, 1999. Current status of *Aedes albopictus* and *Aedes atropalpus* in Italy. *Journal of the American Mosquito Control Association*, 15 (3): 425-427.
- Schaffner, F., A. Guy, G. Bernard, H. Jean-Paul, A. Rhaïem & J. Brunhes. 2001. Les moustiques d'Europe: Logiciel d'identification et d'enseignement = The Mosquitoes of Europe: an Identification and Training Programme. Paris (FRA); Montpellier: IRD; EID, 1 CD ROM (Didactiques). ISBN 2-7099-1485-9.

- Schaffner, F. & A. Mathis, 2014. Dengue and dengue vectors in the WHO European region: past, present, and scenarios for the future. *Journal of the American Mosquito Control Association*, 14 (12): 1271-1280.
- Scholte, E., W. Den Hartog, M. Dik, B. Schoelitsz, M. Brooks & F. Schaffner, 2010. Introduction and control of three invasive mosquito species in the Netherlands. *Euro Surveillance*, 15 (45): 19710.
- Seidahmed, O. M. E. & E. A. B. Eltahir, 2016. A sequence of flushing and drying of breeding habitats of *Aedes aegypti* (L.) prior to the low dengue season in Singapore. *PLoS Neglected Tropical Diseases* 10 (7): e0004842-e0004813.
- Seixas, G., H. Jupille, P. S. Yen, B. Viveiros, A. B. Failloux & C. A., 2018. Sousa Potential of *Aedes aegypti* populations in Madeira Island to transmit dengue and chikungunya viruses. *Parasite and Vectors*, 11 (509): 1-8.
- Sensoy, S., M. Demircan, U. Ulupinar & I. Balta. 2008. Climate of Turkey. (Web page: <http://www.mgm.gov.tr/files/en-US/climateofturkey.pdf>) (Date accessed: 31.12. 2012).
- Sezen, A. L., M. Yıldırım, M. N. Kültür, F. Pehlivanoğlu & D. Menemenlioğlu. 2018. Cases of Zika virus infection in Turkey: newly married couple returning from Cuba. *Mikrobiyoloji Bülteni*, 52 (3): 308-315.
- Simard, F., E. Nchoutpouen, J. C. Toto & D. Fontenille, 2005. Geographic distribution and breeding site preference of *Aedes albopictus* and *Aedes aegypti* (Diptera: Culicidae) in Cameroon, Central Africa. *Journal of Medical Entomology*, 42 (2): 726-731.
- Singh, S. & A. Rahman, 2013. Contribution of *Aedes aegypti* breeding by different income group communities of Dehradun city, Uttarakhand, India. *Biological Forum International Journal*, 5 (1): 96-99.
- Snr, S., Y. Norma-Rashid & M. Sofian-Azirun, 2011. Mosquitoes larval breeding habitat in urban and suburban areas, Peninsular Malaysia. *World Academy of Science, Engineering & Technology*, 58: 569-573.
- Sota, T., 1993. Response to selection for desiccation resistance in *Aedes albopictus* eggs (Diptera: Culicidae). *Applied Entomology and Zoology*, 28 (2): 161-168.
- Stefopoulou, A., G. Balatsos, A. Petraki, S. L. LaDeau, D. Papachristos & A. Michaelakis, 2018. Reducing *Aedes albopictus* breeding sites through education: A study in urban area. *Plos One*, 13 (11): e0202451.
- Tedjou, A. N., B. Kamgang, A. P. Yougang, F. Njiokou & C. S. Wondji, 2019. Update on the geographical distribution and prevalence of *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae), two major arbovirus vectors in Cameroon. *PLOS Neglected Tropical Diseases*, 13 (3): e0007137.
- Tsai, T. F., F. Popovici, C. Cernescu, G. L. Campbell & N. I. Nedelcu, 1998. West Nile encephalitis epidemic in southeastern Romania. *Lancet*, 352 (9130): 767-771.
- Turell, M. J., D. J. Dohm, M. R. Sardelis, M. L. Oguinn, T. G. Andreadis & J. A. Blow, 2005. An update on the potential of north American mosquitoes (Diptera: Culicidae) to transmit West Nile Virus. *Journal of Medical Entomology*, 42 (1): 57-62.
- Vazeille, M., L. Mousson, E. Martin & A-B. Failloux, 2010. Orally co-Infected *Aedes albopictus* from La Reunion Island, Indian Ocean, can deliver both dengue and chikungunya infectious viral particles in their saliva. *PLOS Neglected Tropical Diseases*, 4 (6): e706.
- Vijayakumar, K., T. K. Sudheesh Kumar, Z. T. Nujum, F. Umarul & A. Kuriakose, 2014. A study on container breeding mosquitoes with special reference to *Aedes (Stegomyia) aegypti* and *Aedes albopictus* in Thiruvananthapuram district, India. *Journal of Vector Borne Diseases*, 51 (1): 27-32.
- Wheeler, A. S, W. D. Petrie & D. Malone, 2009. Reintroduction of *Aedes aegypti* into Grand Cayman. *Journal of the American Mosquito Control Association*, 25 (3): 260-264.
- Xia, H., Y. Wang, E. Atoni, B. Zhang & Z. Yuan, 2018. Mosquito-Associated Viruses in China. *Virologica Sinica*, 33 (1): 5-20.
- Yağcı Çağlayık, D., Y. Uyar, G. Korukluoğlu, M. Ertek & S. Unal, 2012. An imported Chikungunya fever case from New Delhi, India to Ankara, Turkey: the first imported case of Turkey and review of the literature. *Mikrobiyoloji Bülteni*, 46 (1): 122-128.
- Yap, H. H., C. Y. Lee, N. L. Chong, A. E. S. Foo & M. P. Lim, 1995. Oviposition site preference of *Aedes albopictus* in the laboratory. *Journal of the American Mosquito Control Association*, 11 (1): 128-132.
- Yunicheva, Y. U., T. E. Ryabova, N. Y. Markovich, O. V. Bezzhonova, L. A. Ganushkina & V. B. Semenov, 2008. First evidence on the presence of breeding populations of the *Aedes aegypti* L. mosquito in Greater Sochi and various cities of Abkhazia. *Meditinskaya Parazitologiya i Parazitarnye Bolezni*, 3: 40-43.