



# *Aedes koreicus*—a new member of the genus *Aedes* establishing in Germany?

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## Abstract

*Aedes koreicus*, a mosquito species originating from Japan, China, Korea, and parts of Russia, has been sporadically found in Europe since 2008. It is suspected to be a vector of a variety of viruses and nematodes. In Germany, one individual was found in 2015 in the city of Augsburg, situated in the federal state of Bavaria. Based on morphological and molecular species identification, this study reports a new finding of *Ae. koreicus*, about 370 km northwest from Augsburg. The sampling point is located in the city of Wiesbaden, in the federal state of Hesse, where four individuals were found over a period of 2 months in 2017. The re-finding of the species in the same location in May and July 2018 suggests that (a) the species was able to reproduce and overwinter at this site, and (b) spreading of non-native mosquito species is an ongoing process in Germany, which requires close monitoring.

**Keywords** Non-indigenous mosquitoes · *Aedes koreicus* · Establishment

## Background and findings

Various non-native *Aedes* (*Ae.*) mosquito species have been found in Europe over the last decade (e.g., Medlock et al. 2015). While *Ae. albopictus* (Asian tiger mosquito) is considered to be invasive in all parts of the Mediterranean region and *Ae. japonicus* (Asian bush mosquito) is now widely distributed and firmly established in large parts of Central Europe, another member of the genus, *Ae. koreicus*, has only recently been reported from several countries of Central Europe (ECDC 2018).

Both *Ae. japonicus* and *Ae. koreicus* originate from Japan, Korea, China, and Russia and show adaptations to temperate

climates, e.g., they can produce cold- and drought-resistant eggs (Knight 1968; Tanaka et al. 1979; Kampen et al. 2017). Various studies suggest that these adaptations might have played a role for their spread into new geographic regions (Versteirt et al. 2012; Kaufman and Fonseca 2014), with successful development in natural as well as artificial breeding sites (Andreadis et al. 2001; Versteirt et al. 2012). In 2008, *Ae. koreicus* was found in Belgium (Versteirt et al. 2012), which was the first record of this species in Europe.

According to the European Centre for Disease Prevention and Control (ECDC), *Ae. koreicus* is currently considered an established species in Belgium, Switzerland, Italy, and Hungary and is reported as an introduced species in Germany, Southeast Russia, and Slovenia (Kampen et al. 2017; ECDC 2018: [https://ecdc.europa.eu/sites/portal/files/images/Aedes\\_koreicus\\_distribution\\_June\\_2018.png](https://ecdc.europa.eu/sites/portal/files/images/Aedes_koreicus_distribution_June_2018.png)). The first occurrence of this species in Germany was noticed in 2015 near Augsburg, in the federal state of Bavaria (Werner et al. 2016, Fig. 1). As for *Ae. japonicus*, international trade might be the main pathway of introductions for *Ae. koreicus* specimens to regions beyond the native range (Versteirt et al. 2012). However, while *Ae. japonicus* has been well studied, information about the biology and ecology of its close relative *Ae. koreicus* is rare (Versteirt et al. 2012; ECDC 2014). Findings of *Ae. koreicus* from Northeast Italy suggest that similar habitats (breeding sites, altitude level, temperature

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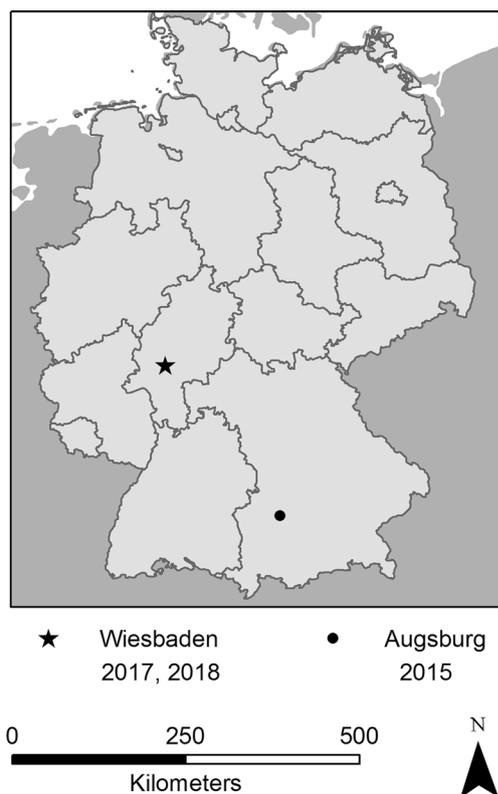
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**Fig. 1** Map of Germany with the occurrence records of *Aedes koreicus* from 2015 (black dot; Werner et al. 2016) and our sampling point of this species in the city of Wiesbaden in 2017 and 2018 (black star)

ranges) might be used in the introduced range as in its native range in South Korea (Montarsi et al. 2013).

The introduction of non-native species is not only of concern due to their possible negative impacts on native ecosystems, but also due to their role as potential vectors for disease agents. *Aedes koreicus* tends to bite during the day, and its non-specific host preference (biting humans as well as animals) is suggestive for being a potential bridge vector (Tanaka et al. 1979; Turell et al. 2005). Although knowledge on the vector potential of *Ae. koreicus* is generally very limited, the species is known to transmit the Japanese encephalitis virus (JEV) and to act as a competent vector of the filarial nematodes *Brugia malayi* and *Dirofilaria immitis* (Feng 1930; Miles 1964; KCDC 2007; Montarsi et al. 2015). Recently, Ciocchetta et al. (2018) reported a vector potential for chikungunya virus (strain ‘La Reunion’) under laboratory conditions.

In our study, mosquitoes were collected from April to October 2017 using BG-Sentinel™ traps (Biogents AG, Regensburg, Germany) with CO<sub>2</sub> and Biogents® BG-Lure as attractants. All sampled specimens were morphologically identified using identification keys of Tanaka et al. (1979) and Becker et al. (2010). Individuals belonging to species complexes, e.g., *Culex pipiens*-complex or specimens which could not be morphologically identified due to missing or damaged

morphological characters, were additionally identified using *cox1* (cytochrome-c-oxidase subunit 1) as a barcoding marker (Kumar et al. 2007).

The specific BG-Sentinel trap at the location in Wiesbaden (federal state of Hesse, Germany, coordinates: Fig. 1, 50.0826; 8.2876) was placed in a backyard, next to rain barrels filled with water all year round. Based on their morphology, four individuals from this sampling site (collected between August 8 and October 16) were pre-identified as *Ae. cf. japonicus*. However, the subsequent molecular identification protocol according to Werblow et al. (2015) of three specimens suggested *Ae. koreicus* with a 99.6% identity when compared to an individual sequence from Belgium (GenBank accession: KJ486602). The nucleotide sequences of the three genetically verified specimens were deposited in the Genbank database under accession numbers MH001388 – MH001390. Based on the major distinguishing morphological characters between *Ae. japonicus* and *Ae. koreicus* (reviewed in Werner et al. 2016), the morphological re-examination of the remaining fourth individual confirmed the species *Ae. koreicus* at this location. As the identification of the individuals did not take place before winter 2017/2018, a further inspection of the sampling location and its surrounding areas did not occur in 2017.

In late May 2018, however, we checked the sampling location in Wiesbaden again for *Ae. koreicus*. Larvae and pupae were collected from the rain barrels and raised to adult stage in the laboratory. After morphological analysis, 17 individuals were identified as *Ae. koreicus*. To verify the morphological identification, three specimens were genetically identified with the same result. Based on these findings, we deposited a BG-Sentinel trap (running every 2 weeks for 24 h) next to the rain barrels. We re-visited the sampling site on July 12 and collected larvae and pupae from the rain barrels again. Out of these newly collected specimens, another nine individuals were morphologically identified as *Ae. koreicus* after the adults had hatched in the laboratory. All samples from the BG-Sentinel trap were negative for *Ae. koreicus*. An inspection of potential breeding sites in surrounding backyards as well as in plant selling centers about 400 m away did not lead to further findings of the species.

## Discussion and conclusion

The new finding site of individuals of the non-native mosquito species *Ae. koreicus* in Germany is situated in the city of Wiesbaden (Fig. 1) which is about 370 km northwest from Augsburg, where the first record of *Ae. koreicus* in Germany had been reported in 2015 (Werner et al. 2016). All specimens ( $n = 4$ ) sampled in 2017 were collected between August 8 and October 16, one individual each in weeks 32, 34, 38, and 41. These findings might be a first evidence for a stable

**Table 1** Examples of preferred climatic data in native and non-native regions of *Aedes koreicus* based on the literature

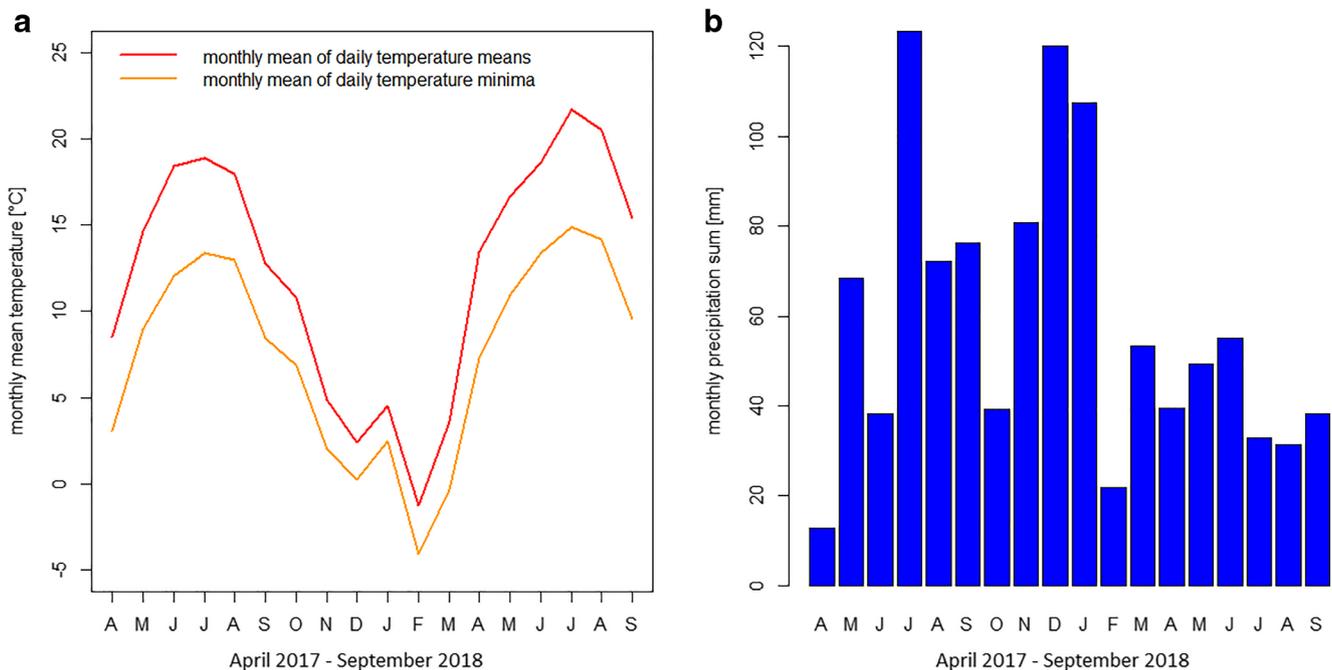
	Annual mean temperatures (°C)	Monthly mean temperatures (°C)	Mean min temperatures	Annual mean precipitation (mm)	References
South Korea (native range)		12.2–14.3	6.0–9.0	1000	Montarsi et al. 2013
Belgium	9–11			800	Versteirt et al. 2012
Northeastern Italy		10.9/10.8 (Apr. 2012/Oct. 2012)	4.9/6.2 (Apr. 2012/Oct. 2012)	1.500 (2012)	Montarsi et al. 2013
Germany (2012–2017)	9–11 (2012–2017)	8.5–10.8–13.4 (Apr. 17–Oct. 17–Apr. 18)	3.1–6.9–7.3 (Apr. 17–Oct. 17–Apr. 18)	511–805 (2012–2017)	DWD Climate Data Center (CDC) for Germany, 2018; station Wiesbaden-Auringen

population of *Ae. koreicus* (able to reproduce and overwinter) existing at this location, supported by the repeated finding of the species at the same spot in May and July 2018.

A comparison with other studies, e.g., Capelli et al. (2011), Versteirt et al. (2012), or Kurucz et al. (2016), shows that a further spread and establishment of *Ae. koreicus* to temperate zones of Europe is conceivable. In Belgium and in northeastern Italy, the species was found in regions where the climate as well as habitat conditions are similar to those in their native range. Additionally, different studies suggest that the species is able to survive European winters, as larvae were found in early spring at the same place (or nearby) as in the previous year (Versteirt et al. 2012; Montarsi et al. 2013). One strategy allowing the survival of the species is the production of cold-resistant eggs, with larval hatching at the time of snowmelt (e.g., Capelli et al. 2011). Another benefit for the establishment

in new regions might be the adaptation of *Ae. koreicus* to urban environments where the species finds numerous artificial and natural breeding sites as well as possible hosts for their blood meal (Montarsi et al. 2013; Kurucz et al. 2016).

The new sampling point of the species in Wiesbaden shares characteristics with other occurrence points, such as landscape structure and climatic factors (Versteirt et al. 2012; Montarsi et al. 2013). In Table 1 and Fig. 2, the climatic conditions from the DWD-station (Deutscher Wetterdienst) in Wiesbaden–Auringen about 6 km away from our sampling location are shown. A comparison of these data with available climatic data, e.g., temperature (annual mean, monthly mean, and mean minimum), from the species' native range and non-native sampling points (Table 1) shows that the localities have similar climatic conditions within the reported activity range of *Ae. koreicus* (April to October, e.g., Montarsi et al. 2013).



**Fig. 2** Climatic conditions during the period April 2017–September 2018 in Wiesbaden-Auringen (about 6 km from the sampling point). **a** Monthly mean of daily mean temperature (red) and daily minimal temperature

(orange) in 2 m height (°C). **b** Monthly sum of precipitation height (mm). Data provided by the Deutscher Wetter Dienst (DWD Climate Data Center for Germany, version v007, 2018)

However, data show that the annual precipitation for the recorded sampling sites in Belgium (800 mm, Versteirt et al. 2012) and Germany (500–800 mm) is below the native range (about 1000 mm). Medlock et al. (2006) assume an annual precipitation of about 500 mm necessary to fill typical used container breeding sites of *Ae. koreicus* with enough water. Therefore, annual rainfall does not seem to be the main limiting factor for breeding success, especially since these typically used artificial breeding habitats are usually filled with water independent of the precipitation (e.g., cemetery vases, flower coasters) or the water remains in the container over a longer period of time (e.g., rain barrels).

Unfortunately, it was not possible to clarify the potential way of introduction to Wiesbaden. However, our findings confirm that spreading of non-native mosquito species is still an ongoing process in Germany that needs further surveillance and monitoring, especially in the case of non-native species with no or little information on their ecology and vector potential. As *Ae. koreicus* is currently only found in a spatially restricted area, eradication options should be considered.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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