*Russian Entomol. J. 34(3):* 408–414 

# Distribution of the invasive species *Aedes koreicus* (Edwards, 1917) on the Black Sea coast of Russia

# Распространение инвазионного вида комаров *Aedes koreicus* (Edwards, 1917) на Черноморском побережье России

**K.A. Sycheva[1,2]*, I.S. Kovalenko[3], Yu.V. Lopatina[2]**
**К.А. Сычева[1,2]*, И.С. Коваленко[3], Ю.В. Лопатина[2]**

[1] Central Research Institute of Epidemiology, Federal Service for the Oversight of Consumer Protection and Welfare (Rospotrebnadzor), Novogireevskaya ul. 3A, Moscow 111123 Russia.
[2] Department of Entomology, Faculty of Biology, Lomonosov Moscow State University, Leninskie gory 1-12, Moscow 119234 Russia.
[3] Anti-Plague Station of the Republic of Crimea, Rospotrebnadzor, Promyshlennaya ul. 42, Simferopol 295023 Russia.
[1] ФБУН ЦНИИ Эпидемиологии Роспотребнадзора, Новогиреевская улица, 3А, Москва 111123 Россия.
[2] Кафедра энтомологии,биологический факультет Московский государственный университет им. М.В. Ломоносова, Ленинские горы, д. 1, стр. 12, Москва 119234 Россия.
[3] Противочумная станция Республики Крым Роспотребнадзора, Промышленная ул., д. 42, Симферополь 295023 Россия.
* Corresponding author
Kseniia Sycheva: k.sycheva2019@gmail.com; ORCID https://orcid.org/0000-0001-9083-4137
Irina Kovalenko: krimpchs@mail.ru; ORCID https://orcid.org/0000-0003-0057-9836
Yuliya Lopatina: ylopatina@mail.ru; ORCID https://orcid.org/0000-0002-5183-2216

KEY WORDS: mosquitoes, climate zones, habitat specificity.
КЛЮЧЕВЫЕ СЛОВА: кровососущие комары, климатические зоны, биотопическая приуроченность.

ABSTRACT. The first occurrence of the invasive mosquito species *Aedes koreicus* outside the endemic area was reported in Belgium in 2008. In subsequent years, this species was recorded in several countries of central Europe. In Russia, *Ae. koreicus* was first recorded in 2013, but data on its distribution remain scanty. The aim of this study was to determine the current range and habitat preferences of *Ae. koreicus* in Krasnodar Krai and Crimea. The study is based on the materials collected in 2019–2022. The distribution of *Ae. koreicus* is located in the zone of humid subtropical climate. In Krasnodar Krai, the dispersal of *Ae. koreicus* occurred within coastal-marine terraced landscapes with humid broad-leaved forests. In Crimea, the mosquitoes dispersed in mountain meadows and steppes of summit plateaus and southern coastal sparse forests, which are characterized by Mediterranean climate. All sites where the presence of *Ae. koreicus* is confirmed in Crimea are located along a major federal highway, which allows us to assume that the spread of *Ae. koreicus* could have occurred passively by ground vehicles. The altitudinal distribution of *Ae. koreicus* ranges from 60 to 1025 m a.s.l.

РЕЗЮМЕ. Впервые инвазионный вид комаров *Aedes koreicus* был обнаружен за пределами эндемичной территории в 2008 г. в Бельгии. В последующие годы этот вид был отмечен в нескольких странах центральной Европы. На территории России *Ae. koreicus* впервые был обнаружен в 2013 г., но до сих пор сведения о его распространении ограничены. Цель работы — установить современный ареал и биотопическую приуроченность *Ae. koreicus* в Краснодарском крае и в Крыму. В основу настоящего исследования положен материал, собранный в 2019–2022 гг. Ареал *Ae. koreicus* расположен в зоне влажного субтропического климата. В Краснодарском крае расселение *Ae. koreicus* произошло в пределах прибрежно-морских террасированных ландшафтов с влажными лиственными лесами, в Крыму — в горных лугах и степях яйл, южнобережном редколесье, для которых характерен средиземноморский климат. В Крыму все места находок *Ae. koreicus* расположены вдоль крупной федеральной трассы, что позволяет предположить, что распространение *Ae. koreicus* могло происходить пассивным путем с помощью автотранспорта. Градиент высот, в пределах которых происходит развитие *Ae. koreicus,* составляет от 60 до 1025 м н.у.м.

## Introduction

*Aedes* (*Hulecoeteomyia*) *koreicus* (Edwards, 1917) is one of the least studied invasive mosquito species, probably due to its less significant medical importance com-

How to cite this article: Sycheva K.A., Kovalenko I.S., Lopatina Yu.V. 2025. Distribution of invasive species *Aedes koreicus* (Edwards, 1917) on the Black Sea coast of Russia // Russian Entomol. J. Vol.34. No.3. P.408–414. doi: 10.15298/rusentj.34.3.11

pared to other invasive species of this genus. In the 1960s, it was shown that *Ae. koreicus* could be a specific vector of the Japanese encephalitis virus in the endemic territory [Shestakov, Mikheeva, 1966; Miles, 1964]. However, later studies have not confirmed this assumption: no infected individuals of *Ae. koreicus* have been found in Asia, where cases of human infection with the Japanese encephalitis virus are regularly recorded [Tolsá-García *et al*., 2023; Levesque *et al*., 2024]. It has been proved that *Ae. koreicus* can be an intermediate host and vector of helminths, *Dirofilaria immitis* (Onchocercidae) [Montarsi *et al*., 2015] and *Brugia malayi* (Onchocercidae) [KCDC, 2017]. Under certain conditions, *Ae. koreicus* can transmit the Chikungunya and Zika fever viruses, but only as a secondary vector [Jansen *et al*., 2021, 2022].

Active development of international trade and tourism and global climate change leads to the introduction of invasive animal and plant species into new territories [Jasjukevich *et al*., 2017; Crystal-Ornelas, Lockwood, 2020]. Among invasive species of mosquitoes, the genus *Aedes*, including *Ae. koreicus*, have been the most successful invaders in Europe [Roiz *et al*., 2024].

The endemic range of *Ae. koreicus* includes China, Japan, South Korea, and the Russian Far East (Primorsky Krai) [Gutsevich *et al*., 1970]. *Ae. koreicus* inhabits mainly forested areas, but also occurs in urbanized habitats [Tanaka *et al*., 1979]. Information on the biology of this species in the endemic area is poor, and the species is known to be rare throughout its range [Wang *et al*., 2012]. *Ae. koreicus* larvae develop in both permanent and temporary water sources. Immature stages of mosquitoes within the endemic area were found both in natural water sources of various origins and in artificial water containers, such as garden barrels, plastic containers, jerry cans, etc. In natural conditions, immature stages of *Ae. koreicus* takes place in tree hollows filled with water and in cut bamboo, less often in puddles, pits, fallen tree leaves and stone crevices. Rarely, *Ae. koreicus* larvae are found in larger water bodies (e.g. irrigation canals, small ponds) [Ho, 1931; Rueda, 2006; Waseem *et al*., 2012].

*Ae. koreicus* was first found outside its original range in 2008 in Belgium [Versteirt *et al*., 2012; Deblauwe *et al*., 2022], after which the species spread to other European countries over the next 17 years. In 2011, *Ae. koreicus* was first detected in Italy [Capelli *et al*., 2011], in 2013 in Switzerland and Slovenia [Suter *et al*., 2015; Kalan *et al*., 2017], in 2015 in Germany [Steinbrink *et al*., 2019], in 2016 in Hungary [Kurucz *et al*., 2016], in 2018 in Austria [Fuehrer *et al*., 2020]. In 2021, the Netherlands and the Czech Republic (single finding of *Ae. koreicus*) joined the list of the mentioned countries [Teekema *et al*., 2022; Vojtíšek *et al*., 2022]. The dispersal of *Ae. koreicus* continues at present, although its spread to new territories is much slower in comparison with the other invasive species *Ae. albopictus*.

Despite the introduction of *Ae. koreicus* into several European countries, its range has remained restricted and disjunctive [Liu *et al*., 2023].

The mosquitoes were collected mainly in urbanized areas and rarely in natural habitats, in particular in broad-leaved forests [Versteirt *et al*., 2012]. Breeding sites of *Ae. koreicus* are public parks, private gardens, and cemeteries [Capelli *et al*., 2011]. Typically, immature stages of mosquitoes develop in shaded habitats, rarely larvae were found in water containers in direct sunlight [Versteirt *et al*., 2012; Waseem *et al*., 2012; Montarsi *et al*., 2014]. In Europe, immature stages of mosquitoes are most often develop in tires, old plastic parts of equipment, rusty cans, flower pots, water catchment tanks, i.e. in artificial water containers [Ciocchetta *et al*., 2017].

There is no unanimous agreement among experts regarding how *Ae. koreicus* initially spread to Europe. It is most commonly thought that the spread of *Ae. koreicus* is due to globalization processes and international trade, as well as with the transport of used tires and with decorative dracaena (*Dracaena sanderiana*) [Tatem *et al*., 2006]. The same route of dispersal has been shown previously for another invasive mosquito species *Ae. albopictus* [Lwande *et al*., 2020].

In Russia, during the monitoring of invasive mosquito species, the presence of *Ae. koreicus* was detected for the first time in 2013 in the Mamaika microdistrict of Sochi [Bezzhonova *et al*., 2014]. Then in 2016 that species was found in Sevastopol [Ganushkina *et al*., 2020], in 2018 in Simferopol [Kovalenko, Tikhonov, 2019], and in 2022 in the Republic of Adygea, the city of Maykop [Borodai *et al*., 2024]. All finds of *Ae. koreicus* in Russia were made in urbanized habitats.

The appearance of *Ae. koreicus* in Europe became the reason for its active study in the places of introduction, especially in Italy, where this species has widely spread [Negri *et al*., 2021]. In Russia, information on the range of *Ae. koreicus* is fragmentary and is represented by only a few publications [Patraman, Ganushkina, 2014; Kovalenko, Tikhonov, 2019; Fedorova *et al*., 2018; Ganushkina *et al*., 2020]. Thus, the aim of this study was to investigate the range and biotopic distribution of *Ae. koreicus* on the Black Sea coast of Russia (Krasnodar Krai, Crimea).

## Material and Methods

Material was collected in 2019–2022 in Krasnodar Krai and the Crimean Peninsula. In 2019, 2020, 2022, mosquitoes were captured in July and in late August to early September. In 2021, mosquitoes were collected in July and in September. Adult *Ae. koreicus* mosquitoes were collected in the field during their seasonal abundance peaks. A total of 23 geographic locations were examined in 2019, 30 in 2020, 47 in 2021, and 10 in 2022. Collection was conducted at 14 geographic locations for two or more seasons. A total of 73 locations were examined (Fig. 1).

The main collection sites for adult and mosquitoes larvae were urban biotopes (cemeteries, railway and highway stations, park areas, embankments, etc.). In addition, mosquitoes were collected in several natural biotopes.

All possible breeding sites, such as catch basins, man-made containers and natural mosquito larval habitats were checked. Larvae were collected using a standard dipper. The collected larvae of younger instars were reared to instar IV, and the collected pupaewere reared to adults [Schaffner *et al*., 2012].

Adults were collected using Lovkom-01 (Russia) traps baited with dry $CO_2$ and octenol. Lovkom-1 were set during twilight from 18:00–19:00 to 7:00–8:00 hours. Adults trying to land on the personnel were also collected with a Krishtal trap was carried out mainly during morning and afternoon hours for 10 minutes. A minimum of three repetitions were conducted at every location. The specimens were morphologically identified [Gutsevich *et al*., 1970]. A list of mosquito collection sites where *Ae. koreicus* was detected is given in Table 1.

## Results

A total of 73 sites in Krasnodar Krai and the Crimean Peninsula were surveyed for the presence of *Ae. koreicus*, 29 sites studied for several years. The presence of *Ae. koreicus* mosquitoes was confirmed at 17 sites (17/73, 23.3%) (Table 1).

The range of altitudes where *Ae. koreicus* was detected varied from 60 m a.s.l. (mainly flat part of Krasnodar Krai) to 1025 m a.s.l. (Chatyrdag Plateau).

In Krasnodar Krai, adults of *Ae. koreicus* were captured in biotopes with antropogenic load: in some cemeteries and in a recreational forest area. In Crimea, *Ae. koreicus* was also found primarily in the forest zone, in cemeteries, and, moreover, in habitats with low anthropogenic load: mountain forest zone, mountain meadows and steppes of yailas (mountain plateaus).

In the Krasnodar Krai, *Ae. koreicus* inhabits subtropical zones, particularly coastal-marine terraced landscapes with humid broad-leaved forests. According to meteorological records, these subtropical areas receive an average annual rainfall of 1400–1800 mm and experience 263 frost-free days per year [Nagalevsky, Mishchenko, 1996; Nagalevsky, 2013]. The coastal mean annual temperature ranges between +14° and +16 °C [Mokievsky *et al*., 2019].

The northernmost boundary of the Caucasus Mountains lies in the central part of the Krasnodar Krai, close to Anapa. In this area, their elevation ranges from 150 to 200 m a.s.l., while near Sochi, they rise to heights of up to 2000 m a.s.l. This mountain range acts as a natural barrier, blocking air currents from both the north and the south. As a result, most of the precipitation from the sea falls along the coast, creating a subtropical climate in the region.

In the Crimean Peninsula, *Ae. koreicus* was detected in habitats within the South Coast sub-Mediterranean zone. This region features a terraced lowland with a highly dissected relief, shaped by deep river valleys, gullies, and ravines (Fig. 2). The area also includes yay-

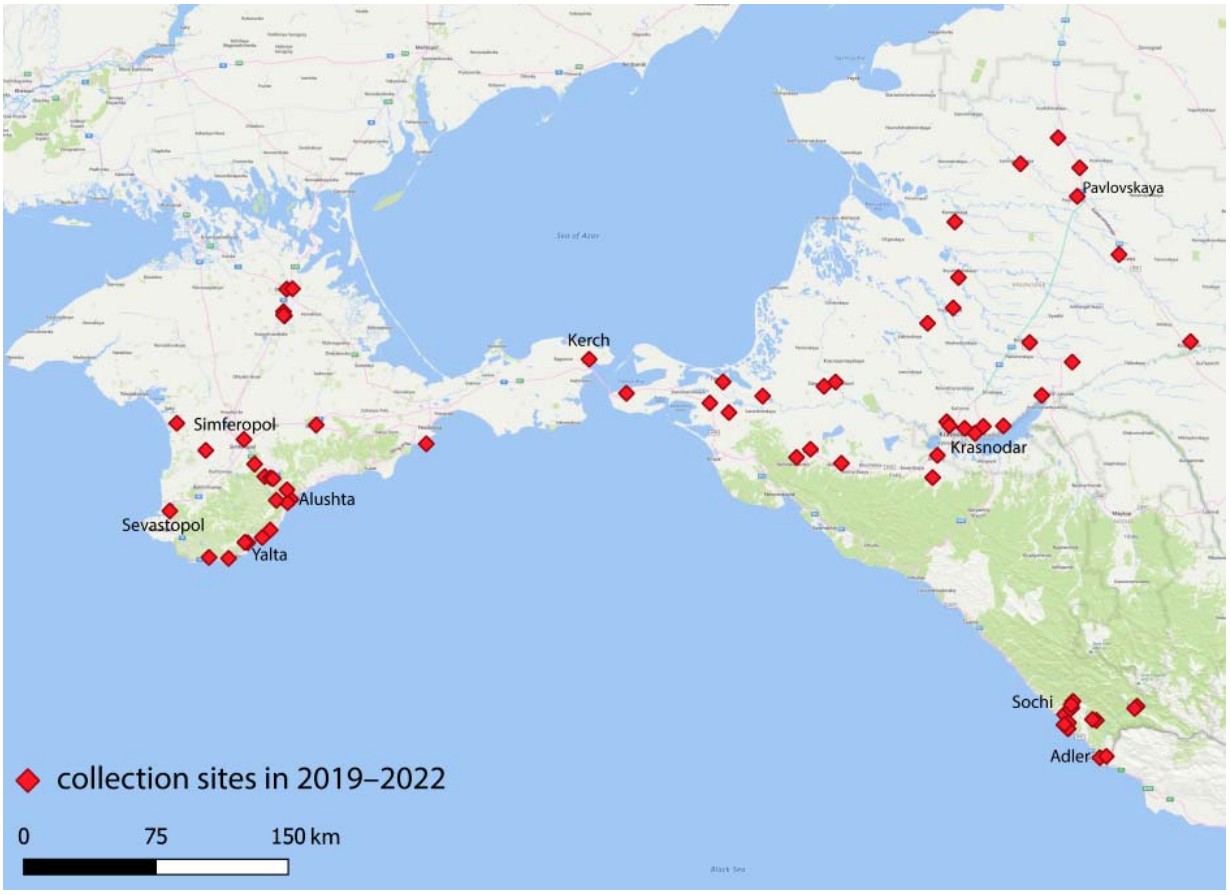


**Fig 1.** Collection sites of bloodsucking mosquitoes in 2019–2022
**Рис. 1.** Места сбора кровососущих комаров в 2019–2022 гг.

**Table 1.** Positive sites of adults and/or larvae of *Aedes koreicus*.
**Таблица 1.** Места находок имаго и/или личинок *Aedes koreicus*.

| Location | Coordinates (N, E) | Altitude, m a.s.l. | Year |
|---|---|---|---|
| **Krasnodar Krai** | | | |
| Adler, Susdalskaya ul. (cemetery) | 43.4279°, 39.9587° | 64 | 2021 |
| Sochi, Agurskiye Waterfalls | 43.5546°, 39.8226° | 202 | 2022 |
| Plastunka village, Leselidze ul. | 43.6905°, 39.7620° | 73 | 2021 |
| Plastunka village, cemetery | 43.6894°, 39.7632° | 126 | 2022 |
| Plastunka village, Dzhaparidze ul. | 43.6688°, 39.7549° | 96 | 2022 |
| Sochi, Dagomisskaya ul. (cemetery) | 43.6013°, 39.7445° | 85 | 2021, 2022 |
| Razbityi Kotel village, Orekhovskiy Waterfalls | 43.7071°, 39.7746° | 134 | 2021 |
| Russkaya Mamayka village | 43.6420°, 39.7160° | 181 | 2021 |
| Vorontsovka village, Tsarskiye Vorota | 43.6176°, 39.9080° | 223 | 2021 |
| Vorontsovka village, Vorontsovskiye Caves | 43.6129°, 39.9341° | 524 | 2021 |
| Sochi, Novaya Matsesta | 43.5557°, 39.7969° | 65 | 2022 |
| **Crimean Peninsula** | | | |
| Yalta, Bakuninsky proesd (cemetery) | 44.4856°, 34.1323° | 226 | 2021 |
| Vynogradnoe village (cemetery) | 44.4878°, 34.1129° | 297 | 2021 |
| Simferopol, Kuibisheva ul. (cemetery) | 44.9876°, 34.1069° | 268 | 2021 |
| Mramornoe village | 44.8079°, 34.2491° | 616 | 2021 |
| Chatyrdag plateau | 44.8019°, 34.2894° | 945 | 2021 |
| Nikita village, Botanical garden | 44.5114°, 34.2326° | 187 | 2021 |

las with meadow and forest landscapes, which are influenced by a Mediterranean-type climate. The climate is characterized by hot, dry summers and moderately warm winters, with an average annual temperature of +11° to +14° and annual precipitation exceeding 1000 mm. The number of frost-free days per year exceeds 210 [Mokievsky *et al*., 2019]. The Crimean Mountains, located in the southeastern part of the peninsula, consist of three parallel ridges stretching 150–180 km in length and about 12 km in width. The elevation of the mountains ranges from 150 to 1500 m a.s.l. and, similar to the Caucasus Mountains, they act as a barrier to air masses moving from the north, separating the southern coast of Crimea (SCC) from the rest of the peninsula's lowland areas. The southern macroslope and the SCC exhibit features of a subtropical climate [Podgorodetsky, 1988; Razumeyko, 2010].

According to the modern Köppen-Geiger classification [Kottek *et al*., 2006], the areas where *Ae. koreicus* was found belong to climate zone Cfa, where C indicates temperate, f stands for no dry season, and a denotes hot summers (Fig. 3). This zone extends as a narrow strip along the coasts of Abkhazia and Russia up to the city of Tuapse [Beck *et al*., 2018].

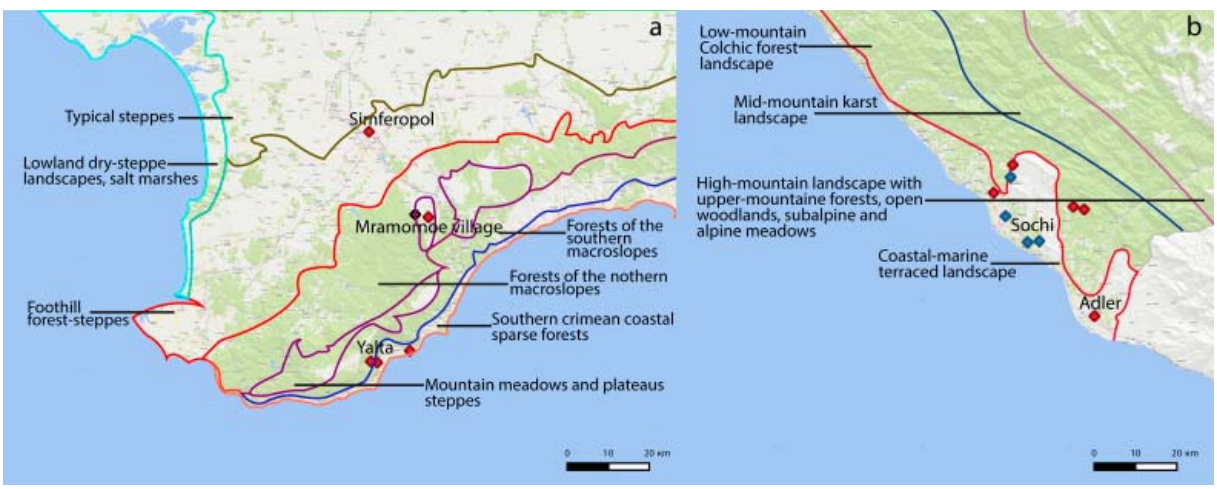


**Fig 2**. Landscapes where *Ae. koreicus* was recorded: a — Krasnodar Krai, b — Crimea; red diamond — detection of *Ae. koreicus* in 2021, blue diamond — detection of *Ae. koreicus* in 2022.
**Рис 2.** Ландшафты, где был обнаружен *Ae. koreicus:* a — Краснодарский край, b — Крым; красный ромб — обнаружение *Ae. koreicus* в 2021 г., синий ромб — обнаружение *Ae. koreicus* в 2022 г.


**Fig 3.** Sites of *Ae. koreicus* findings (marked in black) according to the Köppen-Geiger climate classification: BSk — Cold semi-arid climate, Cfa — Humid subtropical climate, Dfa — Hot-summer humid continental climate, Dfb — Warm-summer humid continental climate, Dfc — Subarctic climate.
**Рис 3.** Места находок *Ae. koreicus* (показано черным цветом) в соответствии с классификацией Коппен-Гейгера: BSk — холодный полузасушливый климат; Cfa — влажный субтропический климат; Dfa — жаркий летний влажный континентальный климат; Dfb — теплый летний влажный континентальный климат; Dfc — субарктический климат.

## Discussion

Prior to this study, records of *Ae. koreicus* distribution in the Russian Federation were scarce. Before 2019, this mosquito species had only been detected in Sochi, Krasnodar Krai [Fedorova *et al*., 2018] and in Sevastopol and Simferopol, Crimea [Kovalenko, Tikhonov, 2019]. Later, *Ae. koreicus* was first recorded in Maykop, Republic of Adygea [Borodai *et al*., 2024]. All findings were exclusively in urbanized biotopes. No dedicated studies on *Ae. koreicus* distribution in southern European Russia had been conducted.

We detected *Ae. koreicus* in 2021–2022 at 17 locations in Greater Sochi, as well as in Yalta and Simferopol, Crimea, although it was absent from our 2019–2020 collections (Table 1). Our data show that range of *Ae. koreicus* in Krasnodar Krai is currently limited to Greater Sochi, bounded by 39°42'57.6"E (west), 43°42'25.6"N (north), and 39°57'31.3"E (east). In Crimea, we identified three clusters of findings: 1) Yalta, Vinogradnoe settlement, and Nikita settlement; 2) Mramornoe village and Chatyrdag; 3) Simferopol. All locations lie along the E-105 federal highway, suggesting passive vehicle-mediated dispersal, as previously shown for the invasive *Ae. albopictus* [Eritja *et al*., 2017]. The northernmost and westernmost Crimean record was Simferopol (44°59'15.4"N, 34°06'24.8"E). The biotopes where *Ae. koreicus* was recorded in Simferopol are located in an anthropogenic zone, meaning that landscape features have minimal influence on the mosquito population distribution.

Distances between Crimean clusters exceeded tens of kilometers (Yalta–Mramornoe village: 33 km; Mramornoe–Simferopol: 21.2 km). Given that mosquitoes typically disperse actively within ~1 km (most frequently 500–750 m) [Vavassori *et al*., 2019], Crimea may host three separate *Ae. koreicus* populations, although though this requires verification.

In Krasnodar Krai, *Ae. koreicus* remains confined to Greater Sochi, spreading slower than *Ae. albopictus*. Sochi lies in a humid subtropical climate (Cfa), matching the range of *Ae. koreicus* is located in the European territory. In Europe, this invader also occupies Cwa (monsoon-influenced humid subtropical) and Dfb (warm-summer humid continental) zones. Its native range includes Dwb (monsoon-influenced warm-summer humid continental), Dwa (monsoon hot-summer

humid continental), and Dfb zones (Koppen-Geiger climate map: https://koppen.earth/). European and native climate zones only partially overlap. Considering climate dependencies, *Ae. koreicus* will likely expand further into Dfb zones in Europe. Despite differing climate classifications, the Far East's monsoon conditions resemble subtropical climates, potentially explaining establishment of the *Ae. koreicus* in humid subtropical zones of Krasnodar Krai, Crimea, and Central Europe.

For invasive mosquitoes, winter temperatures (killing overwintering stages) and low precipitation (reducing adult survival and larval habitats) typically limit distribution [Fedorova *et al*., 2018]. Laboratory studies show *Ae. koreicus* develops optimally at 13–28 °C, crucial for predicting range shifts under climate change [Marini *et al*., 2019].

Landscape type and altitudinal zonation also constrain invasive mosquitoes. *Ae. koreicus* occurs up to 1250 m a.s.l., unlike *Ae. albopictus* (rare above 600 m a.s.l.) [Montarsi *et al*., 2014]. Limiting factors remain poorly understood. Crimean findings across diverse landscapes (Fig. 2) suggest *Ae. koreicus* could expand into Krasnodar's low-mountain forest and mid-mountain karst landscapes with oak-beech forests (per Nagalevsky, Mishchenko [1966]). These landscapes lie within the potentially suitable Dfb zone. Crimean records up to 1025 m a.s.l. support possible altitudinal expansion in Krasnodar Krai.

## Conclusion

In the south of Russia, *Ae. koreicus* is distributed in a mosaic manner: it was found in 17 out of the 73 surveyed geographical locations, for the first time in the foothills of the Crimean Mountains. The distribution of *Ae. koreicus* on the Crimean peninsula seems to occur along the main highways. In Krasnodar Krai and Crimea this species is mainly distributed in the zone of humid subtropical climate in a wide altitudinal range (60–1025 m a.s.l.). Mathematical modeling and additional research are needed to confirm the hypotheses about the further distribution of *Ae. koreicus*.

**Competing interests.** The authors declare no competing interests.

**Acknowledgments**. The authors are deeply grateful to M.V. Fedorova for her support in fieldwork coordination and valuable advice. We also extend our gratitude to all colleagues who assisted in sample collection. The reported study was carried out as part of the Scientific Projects of the State Order of the Government of Russian Federation to Lomonosov Moscow State University No. 121032300064-0.

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