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REVIEW ARTICLE

Asian tiger mosquito (*Aedes albopictus*) as a potential vector of diseases and a threat to public health in Poland

Komar tygrysi (*Aedes albopictus)* jako potencjalny wektor chorób i zagrożenie dla zdrowia publicznego w Polsce

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A – Koncepcja i projekt badania, B – Gromadzenie i/lub zestawianie danych, C – Analiza i interpretacja danych, D – Napisanie artykułu, E – Krytyczne zrecenzowanie artykułu, F – Zatwierdzenie ostatecznej wersji artykułu

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Abstract

Introduction and Objective. The *A. albopictus* mosquito, commonly known as the Asian tiger mosquito, is a vector of many infectious diseases that have been transferred from south-east Asia to many European countries. For this reason, the monitoring of this species in Europe is necessary to control its occurrence and prevent the development of mosquito-borne diseases. The aim of the study was to analyze the occurrence of the Aedes albopictus mosquito in Poland and Europe as vectors of biological factors threatening public health, based. on available literature data and reports from the European Centre for Disease Prevention and Control (ECDC), available online.

Brief description of the state of knowledge. *Aedes albopictus* is an invasive insect, native to tropical rainforests in Asia. It is capable of transmitting Viral Haemorrhagic Fevers and nematodes *Dirofilaria* spp. In the last 30 years, the mosquito has been expanding to Europe, North and South America and Asia, and monitoring by the ECDC has shown the presence of mosquitoes in more than 20 European countries. The insect can adapt to moderate climate conditions due to egg diapause, which may result in the passive settlement of new areas. A further consideration is that these invasive mosquitoes can be affected by global warming, the increasing average annual air temperatures, and thus by adjusting optimal survival conditions for *A. albopictus*.

Summary. Global expansion of *A. albopictus* in the last 30 years has caused a growing interest in the protection of public health, measures to prevent its further spread and closer monitoring. Since there are no vaccines or drugs against dengue and chikungunya viruses, the main diseases transmitted by *A. albopictus*, vector control remains the basis for the prevention and control of these diseases. It is expected that the geographical expansion of *A. albopictus* will continue.

Key words

climate change, Aedes albopictus, invasive species, disease vectors, Asian tiger mosquito

Streszczenie

Wprowadzenie i cel pracy. Komar *A. albopictus* to wektor wielu chorób zakaźnych, który został przeniesiony do wielu krajów europejskich. Z tego powodu niezbędny jest monitoring tego gatunku w Europie, aby kontrolować jego występowanie i nie dopuścić do rozwoju przenoszonych przez niego chorób. Celem pracy była analiza występowania komara *A. albopictus* w Polsce i Europie na podstawie dostępnych danych literaturowych oraz raportów ECDC. Przeprowadzenie takiej analizy jest istotne, gdyż *Aedes albopictus* jest wektorem biologicznych czynników zagrażających zdrowiu publicznemu.

Opis stanu wiedzy. *A. albopictus* to inwazyjny owad, pochodzący z tropikalnych lasów deszczowych w Azji. Jest wektorem wirusowych gorączek krwotocznych i nicieni *Dirofilaria* spp. W ciągu ostatnich 30 lat komar rozprzestrzenił się na Europę, Amerykę Północną i Południową oraz Azję. Monitoring tego gatunku prowadzony przez ECDC wykazał jego obecność w ponad 20 krajach europejskich. Owad może przystosować się do umiarkowanych warunków klimatycznych dzięki diapauzie jaj, co może skutkować biernym zasiedlaniem nowych terenów. Ocieplenie klimatu, a konkretnie wzrost średniej rocznej temperatury powietrza a tym samym wytworzenie się optymalnych warunków przeżycia dla *A. albopictus*, może mieć wpływ na dalsze rozprzestrzenianie się tych inwazyjnych komarów.

Podsumowanie. Skutkiem globalnej ekspansji *A. albopictus* w ciągu ostatnich 30 lat jest rosnące zainteresowanie ochroną zdrowia publicznego, działania zapobiegające dalszemu rozprzestrzenianiu się tego gatunku oraz ściślejsze jego monitorowanie. Ponieważ nie ma szczepionek ani leków przeciwko wirusom dengi i chikungunya, głównym chorobom przenoszonym przez *A. albopictus*, kontrola wektorów pozostaje podstawą zapobiegania i zwalczania tych chorób. Oczekuje się, że geograficzna ekspansja *A. albopictus* będzie postępować.

Słowa kluczowe

zmiany klimatu, *Aedes albopictus*, gatunek inwazyjny, wektor chorób, komar tygrysi

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INTRODUCTION AND OBJECTIVE

The Asian tiger mosquito (*Aedes albopictus*) is a species that may pose a high risk to public health in Europe. It is at the top of the list of the 100 most invasive species of the Invasive Species Specialist Group and is recognized as the dangerous species for Europe [1]. The common name 'Asian tiger mosquito' refers to the black and white stripes that cover its thorax and abdomen [2]. The mosquito is a highly invasive species and difficult to control [3, 4]. Invasive species of mosquitoes are passively introduced into to and settle in new territories, causing economic and environmental damage or diseases to humans. An increase in the number of invasive mosquitoes in Europe was observed in the late 1990s, which resulted in the tiger mosquito also constantly expanding its geographical reach [5, 6]. *A. albopictus* is most active in the early morning and late afternoon, although there are exceptions that depend on the time of year, region, and host availability [7]. *A. albopictus* feeds on the blood of both warm-blooded and cold-blooded animals. It can attack farm animals, amphibians, reptiles, and birds [8]. The mosquito prefers mammals as hosts, but while having warm-blooded animals to choose from, it first attacks humans rather than other mammals. A large number of hosts have a positive effect on its biological characteristics (e.g. fertility and survival), but also increases the risk of transmitting pathogens via the animal-animal and animal-human routes. Because of this, a large number of hosts can affect the high level of mosquito invasion.

Mosquitos are often found near trees, with its breeding places in small, limited, shady water reservoirs. Thanks to ecological plasticity, they can settle inside various objects, i.a. flower pots, beverage cans, worn tires, hatches, buckets, gutters, bathtubs, tarpaulins, pipes, gutters, sinks, crevices in trees, etc. The presence of decaying leaves can cause conditions similar to those found in the crevices of tree trunks, creating an optimal place and climate for mosquito life and reproduction. *A. albopictus* can settle in non-urbanized areas [8]. *A. albopictus* breeding sites include natural sites like bamboo trunks, bromeliads, and wood crevices [9]. Large natural water reservoirs, such as canals, marshes, lakes and rivers, are not used by these mosquito species for breeding. *A. albopictus* cannot lay eggs in brackish or salt waters [9]. Of the listed egg-laying sites, used tires are most often used by *A. albopictus* [11, 12]. This species has not been considered a public health risk because in the past the species has been judged unable to transmit pathogens to humans [13].

The aim of the study was to analyze the occurrence of the *Aedes albopictus* mosquito in Poland and Europe as vectors of biological factors threatening public health, on the basis of available literature data, and European Centre for Disease Prevention and Control (ECDC) reports available online

Occurrence. *A. albopictus* is a native species to Southeast Asia and was described for the first time by Skuse in 1894 [14]. The species gradually adapted to human-caused changes in the environment. The movement of people towards the Indo-Malay Peninsula and the islands of the Indian Ocean, including Madagascar, most likely favoured the early spread of *A. albopictus* into new areas [7]. In the 1970s, *A. albopictus* spread through the sea transport of used tires and other goods, which caused it to colonize many areas in the world [8]. The spread of *A. albopictus* has increased over the past thirty years to North, Central and South America, parts of Africa, North Australia, and many European countries [15, 16], and currently occurs on all continents except Antarctica [17, 18]. In Africa, *A. albopictus* was detected for the first time in 1989 in southern parts of the continent and subsequently found to be present in Nigeria, Cameroon, Equatorial Guinea, and Gabon [7]. In Europe, the mosquito was first registered in Albania in 1979 and then in Italy in 1990. *A. albopictus* has now been detected and registered in over 20 European countries [19], among them, Bosnia, Croatia, Herzegovina, Montenegro, Serbia and Slovenia, Belgium, France, Germany, Greece, Italy, Malta, Spain, Switzerland, San Marino, The Netherlands and Vatican City. In 2012, *A. albopictus* mosquitoes were registered for the first time in the Czech Republic, but not yet detected in Poland.

Significantly, the Asian tiger mosquito was introduced to the neighbouring countries of the Czech Republic, Slovakia, and Germany [20, 21]; in the latter country, over 25 established populations have been discovered in Baden-Württemberg, Palatine, and Hesse (southwest Germany) [22]. *A. albopictus* has been registered in several European countries since 2017, and its ability to survive the winter in these countries can contribute to its potential spread to other countries in Europe [23]. In August 2020, *A. albopictus* was recorded in Austria for the first time [24]. The years in which *A. albopictus* appeared in Europe are shown in Figure 1.

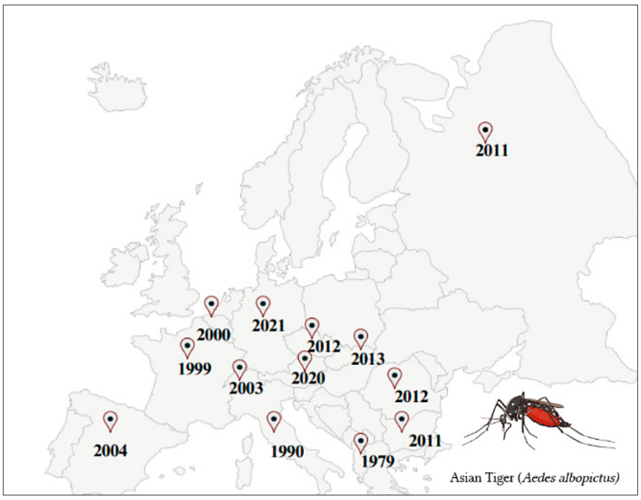

Figure 1. Years of appearance of *A. albopictus* in Europe.
Source: own elaboration in Biorender

Transmitted diseases. *A. albopictus* is capable of carrying three Flaviviruses: Dengue, West Nile Fever, and Japanese encephalitis, six Bunyaviruses: Cache Valley, Keystone, Tensaw, Potosi, Jamestown Canyon, LaCrosse, and one Alphavirus: Eastern equine encephalitis. Transmission of at least 22 arboviruses through this vector has been confirmed experimentally [14, 25, 26]. The mosquito is also a competent vector of the Ross River virus, Chikungunya virus, and Rift Valley fever viruses, and is also capable of transmitting Yellow fever virus to humans [27], and additionally known to be capable of transmitting the Dengue virus [28, 29], and all four Dengue serotypes have been isolated from *A. albopictus* [14]. Dengue virus is transmitted by *Aedes aegypti* mosquitoes or more often by *A. albopictus*, which displaces *A. aegypti* in EU Member States. Over the past 50 years, the number of cases Dengue has increased 30-fold and is still growing.

Until now, Dengue virus, a haemorrhagic fever, has not been a significant public health problem in Poland and the rest of Europe [30]. The emergence of the new *A. albopictus* vector and much warmer summers in Europe are threatening to shift the borders of dengue hemorrhagic fever even further north. Although dengue infection in Europe is rare, in September 2010, cases of infection were reported in France and Croatia. *A. albopictus* is also a vector of dirofilariasis, which are mainly canine parasites but can also be dangerous to humans [5, 31]. Nematodes *Dirofilaria immitis* and *D. repens* are, respectively, the etiological factors of heartworm disease and subcutaneous granulomas in dogs; both species can cause zoonoses: human infections can cause subcutaneous, conjunctival, and pulmonary nodules [32]. Recent data has shown the transmission of parasites by *A. albopictus* in Italy [33, 34].

History of epidemics. Outside Europe, *A. albopictus* has transmitted the Chikungunya virus, causing large-scale outbreaks in the Indian Ocean islands and South Asia since 2005. Formerly *A. albopictus* was responsible for dengue virus transmission during the epidemic on the Island of Reunion in 1977–1978, during the epidemic in Hawaii in 2001–2002, and again on the Island of Reunion (2004), in Gabon (2007) and Mauritius (2009) [5]. In 1990, the mosquitoes were discovered in Italy for the first time, probably brought from the United States in used tires [12]. In 2005–2007, after the Chikungunya epidemic in the Indian Ocean which caused millions of cases, significant morbidity, and a burden on health resources, the virus was imported in 2007 into Italy, the first European country to be affected, where it caused an indigenous outbreak. This outbreak included local transmission by the *A. albopictus* mosquito and resulted in 205 cases (one fatal), and another 129 suspected cases identified [35]. In 2010, two autochthonous Chikungunya cases were reported in France.

The increasing number of reports of tourists returning to Europe with Dengue infections, in conjunction with the spread of *A. albopictus*, have raised concerns about further epidemics and local virus transmission in Europe. This is supported by 2 cases from 2010 when *A. albopictus* was associated with Dengue infections in southern France and Croatia, all of which had been acquired locally [19]. The current risk of Dengue outbreak in Europe has emerged with the introduction of the mosquito *A. albopictus* in Mediterranean countries. Given the increasing frequency ofDdengue outbreaks worldwide and the virus-host movement, it is expected that new autochthonous cases will occur in Europe in the future.

In Catalonia (northeastern Spain), *A. albopictus* was first detected in 2004, which corresponds to the first introduction of this species to the Iberian Peninsula and Spain. Early detection of arboviruses and effective public health measures reduce the risk of wider distribution of mosquito-borne diseases (MBD) and increased impact on public health [36]. On 1 October 2019, in France, a case of locally acquired Zika disease was confirmed in a laboratory. The patient had not traveled to countries where Zika occurs endemically. On 21 October 2019, the second autochthonous case of Zika disease was reported in Hyères, France, and was probably the first described transmission of the Zika virus by the *A. albopictus* mosquito [2].

Spreading. Factors such as globalization and climate change affect the rapid expansion of the *A. albopictus* species worldwide [37]. In addition, an increase in the amount of international travel has accelerated the introduction of mosquitoes carrying viruses to new areas, and thus their further geographical expansion [24]. The flight range of an adult insect is quite short. For this reason, the colonization of new areas results from passive transport, not a flight of insects [8]. Mosquitoes and their eggs can be transmitted by trading used tires or importing the *Dracaena* spp. plant (Lucky bamboo). However, the most important impact on the long-distance relocation of *A. albopictus* in Europe in the last decade may have been the transport of ground vehicles (e.g. trucks, cars, caravans) from southern Europe.

The international transit of used tires can pose a high risk of importing the invasive mosquito into Europe. *A. albopictus* probably spread via public or private ground transport, possibly via motorways from Italy to Switzerland and Germany, from Italy to France and Spain, and possibly also to the Balkan countries (e.g. via ferry transport) [38]. Over the past few years, the incidence of Dengue and Chikungunya has increased in Europe, which is directly related to the expansion of these diseases worldwide due to the increase in international travel [7].

Adaptation to the environment and climate change. The international transport of people and goods, and climate change have influenced the spread of *A. albopictus* in Europe [38]. The mosquito produces eggs that may undergo diapause, and therefore hibernate in temperate climates, although adult forms are unable to survive in such conditions [17]. In temperate regions, diapause is a strategy designed to preserve the typical features of the species' life cycle because diapausing eggs, in addition to increased cold tolerance, exhibit high resistance to drying [39].

It is believed that climate change in Central Europe has created optimal conditions for *A. albopictus*, which may contribute to the further spread of the mosquito to northern Europe. The tropical and subtropical forests have fairly constant climatic conditions, and due to this the population of *A. albopictus* does not use wintering strategies there, whereas in Europe, *A. albopictus* is subjected to different climatic conditions. The production of eggs that undergo diapause has enabled the species to spread outside their natural range [37]. Females lay eggs resistant to drying above the water surface, e.g. in tires. Mosquito eggs inhabiting temperate regions are resistant to low temperatures compared to tropical areas [8]. *A. albopictus* tolerates lower temperatures than tropical and subtropical and hibernating [40]. At temperatures below 9°C, the mosquitos show low activity, which is why they prefer rooms due to the higher temperatures [41]. *A. albopictus* exhibit strong ecological plasticity, which allows the introduction of the species and its rapid adaptation to a very wide range of habitats with varied climatic conditions.

Although *A. albopictus* originates from Asian forests, it is now adapting to human settlements and preferentially occurs in suburban environments. The introduction of these populations was probably supported by the species' ability to adapt to site conditions, the introduction of eggs into diapause in temperate climates, the ability to reproduce in different places, and foraging on different hosts [42]. Analysis of climatological data showed that *A. albopictus* populations can continually reproduce and survive at average temperatures above 10°C in Japan and Reunion, and -5°C in the USA [36]. In temperate climates (e.g. Europe and the USA), eggs may diapause when the temperature drops below these thresholds. *A. albopictus*'s ability to survive at low temperatures is probably related to its ability to synthesize large amounts of lipids at low temperatures [43]. *A. albopictus* eggs can survive dormant (diapause) during European winters, and mosquitoes hatch when climatic conditions become optimal, leading to the formation of populations. Because eggs can survive outside a water environment, conventional measures to reduce mosquito numbers by draining water tanks may not eliminate them, and the use of additional insecticides may be required [44].

Climate change can increase the number of invasive mosquitoes and viruses transmitted by them in Europe, which can enhance the number of indigenous diseases caused by those pathogens [21]. The continental climate of Eastern Europe is characterized by a large amplitude of the annual temperature cycle, and therefore a relatively low temperature during the winter. The milder climate means that winter temperatures are usually much higher in Western Europe compared to Eastern Europe, and therefore generally more favourable to *A. albopictus* [17]. Due to the warm climate and sufficient annual rainfall occurring in the countries of Central and Eastern Europe, these territories have proved in the past to be a place suitable for mosquitoes and casual agents of the diseases transmitted by *A. albopictus* [26]. It is expected that the invasive species will continue to spread throughout Europe, and therefore remain subject to surveillance and monitoring programmes. The Asian tiger mosquito is a species adapted to higher air temperatures, therefore its spread can be strongly promoted by climate change [45].

Monitoring and control. Control of the mosquito population is carried out to reduce the occurrence of diseases affecting public health. Mosquito control is the main protection against disease transmission for the Dengue and Chikungunya diseases. To control mosquitoes, different methods are used, which are characterized by different efficiencies. For this purpose, methods of mosquito reduction, pesticide use, public education and biological control can be used, and the integration of these techniques can ensure an optimal control strategy [46]. The introduction of controls has led to the elimination of newly-created mosquito populations in some places [50]. Further surveillance of invasive mosquitoes is essential for all species on a European scale. Exchange of information between entomologists, public health specialists and people responsible for managing disease outbreaks is needed to prepare for the occurrence of vector-borne diseases [19]. This information is important for public health authorities as an aid in deciding what resources should be allocated to controlling this species [14]. The implementation of an integrated strategy to combat invasive mosquito species (IMS) should take into account the species, their ecology and the threat to public health, i.e. nuisance and disease transmission. An integrated control strategy for IMS requires coordinated involvement of local authorities and organizations of the entire society [46].

Monitoring of the Asian tiger mosquito in Europe is carried out by the European Centre for Disease Prevention and Control (ECDC), and an inspection took place in January and August 2019. Since the previous update in January 2019, 262 new mosquito detection reports have been recorded [1] (Tab. 1). In Poland, a total of 118 cases of Dengue were registered by the National Institute of Public Health between 2018 – 2022: 2022 – 23, 2021–2, 2020–9, 2019–55 and 2018 – 29, and 4 cases of chikunguny: 2019 – 2, 2022–2. These cases were reported in people who had traveled to India or Thailand [48].

In Germany, a control strategy was carried out which included 3 pillars:

1) community participation (CP), based on the elimination of breeding sites or the improvement of environmental sanitation, using effervescent tablets based on *Bacillus thuringiensis israelensis* (Bti effervescent tablets; Culinex® Tab plus);
2) door-to-door (DtD) control by trained personnel using high doses of water-dispersible granular Bti formulation (Vectobac® WG) to achieve a long-lasting lethal effect;
3) implementing a sterile insect technique (SIT) to eliminate the remaining *A. albopictus* populations [22]. The sterile insect technique (SIT) is a control strategy using radiation to create genetic mutations or chromosomal breaks that make adult insects sterile. The sterile insects are released into the wild to suppress and eventually eliminate wild pest populations [49].

Guidelines. The ECDC has developed guidelines for the surveillance of native and IMS aimed at systematizing and improving the effectiveness of surveillance throughout Europe. These guidelines recommend the implementation of an integrated control programme for invasive mosquitoes in all countries where the surveillance of MBD and the monitoring of mosquito-borne populations may indicate the risk of diseases transmitted by these vectors.

In 2011, the European Mosquito Control Association (EMCA) and the European Regional Office of the WHO developed guidelines for mosquito control, in which the WHO developed a regional framework for the surveillance and control of IMS There is currently a lack of clear recommendations and guidelines for implementing biological, chemical and environmental vector management control measures focused on IMS in Europe. The WHO recommends that European countries potentially exposed to mosquito--borne diseases should IMS develop programmes for the surveillance and control of mosquitos and their vector-borne diseases. The WHO also recommends that control measures can be managed locally and that the ultimate responsibility should rest with the national authorities of all countries. A decision by the European Union (Decision No. 1082/2013/EU) underlines the responsibility of EU Member States to establish effective surveillance, monitoring, early warning, and response measures to prevent the spread of cross-border threats. Therefore, there is a need for effective vector control measures to limit the spread of invasive mosquitoes, control their numbers and prevent disease outbreaks (ECDC, 2017).

Interest in researching the spread of invasive mosquitoes in Europe has been growing for several years because of their importance to public health. Research, including monitoring of the current spread of these species, modelling potential future spread, as well as studying the ecology of the species, is considered to be particularly important to prevent their further spread [10].

Vector-borne diseases are a specific group of infections that pose a threat to Europe and require special attention. Strengthening surveillance by IMS of *A. albopictus* is required in areas threatened by the import or spread of mosquitoes and the risk of virus transmission. This is particularly important in the context of environmental and climate change that may allow the growth of the population of vectors and virus transmission. The ECDC has identified the need for guidelines on surveillance methods that encourage EU Member States to collect relevant data on IMS on their territory. Early detection of invasive mosquitoes increases the chance for appropriate and timely remedies, thereby preventing MBD. In addition, in areas where IMS have been introduced, it is necessary to monitor their numbers and further spread to assess the risk of transmitting pathogens to humans as soon as possible. Human activity, especially the global movement of commercial goods, has led to the passive spread of species previously restricted to specific regions [23]. Some countries have not organized mosquito control, and supervisory, and control knowledge may not be available immediately; staff must be trained and equipment must be introduced. Other obstacles include legislation/regulations regarding spraying activities/product licenses and the willingness of the public to engage in control programmes. Some countries where the species is absent already have active, well-organized surveillance programmes, while other countries where invasive species have been registered have not developed these programmes [12].

Several features of this species – high ecological plasticity, various larval habitats and resistance to egg drying out – along with external factors, such as increasing tourism and global trade, can further promote their invasion [17]. Climatic conditions in Central Europe are favourable for the development of this species in the summer, and introduction should be expected in the future [50].

CONCLUSIONS

Global expansion of *A. albopictus* in the last 30 years has caused a growing interest in the protection of public health measures and closer monitoring to prevent its further spread. Since there are no vaccines or drugs against the Dengue and Chikungunya viruses, the main diseases transmitted by *A. albopictus*, vector control remains the basis for the prevention and control of these diseases. It is expected that the geographical expansion of *A. albopictus* will continue to increase. Climate change in Poland may be felt in the coming years, higher air temperatures and milder winters may facilitate the spread and multiplication of pathogenic microorganisms. Thus, it may only be a matter of time before the mosquito appears in Poland, and may even now be present, but as yet has remained detected.

Table 1. Number of new habitats compared to the previous reposting period (based on Distribution maps of invasive mosquitoes – ECDC)

Year	Number
January 2019	50
August 2019	262
May 2020	1609
September 2020	346
March 2021	5706
October 2021	4792
March 2022	885
February 2023	16545

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