REVIEW ARTICLE

Annals of Agricultural and Environmental Medicine 2025, Vol 32, No 2, 167–172
www.aaem.pl

Invasive and native mosquitoes in Europe, including Poland, as vectors transmitting pathogens – implications for wellbeing of Armed Forces

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A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

Komar K, Gaździński S, Borecka A, Maculewicz E. Invasive and native mosquitoes in Europe, including Poland, as vectors transmitting pathogens – implications for wellbeing of Armed Forces. Ann Agric Environ Med. 2025; 32(2): 167–172. doi: 10.26444/aaem/193428

Abstract

Introduction and Objective. Mosquitoes play a crucial role as vectors transmitting various pathogens, including parasites and viruses, which cause serious diseases worldwide, such as malaria, dengua or West Nile virus. Both invasive and native species are capable of spreading tropical diseases, which endanger troops stationing in areas rich in mosquitos. The aim of the review is to analyze current knowledge about the distribution of mosquito species in Europe, including Poland, and the factors influencing their presence.
Review Methods. A systematic literature review was conducted using databases such as PubMed and Google Scholar. The search included key words related to mosquitoes, vector-borne diseases, and climate change. Data were supplemented with information from the websites of the World Health Organization (WHO) and European Centre for Disease Prevention and Control (ECDC).
Brief description of the state of knowledge. Invasive mosquitoes, such as Aedes albopictus, have been spreading in Europe since the 1990s. Rising temperatures and global movement of people and goods are the main driving forces of this phenomenon. Even native European mosquito species, like Culex spp., are able to transmit tropical diseases. The European Mosquito Control Association is developing mosquito control programmes but they are not sufficiently implemented.
Summary. Mosquitoes transmit various viral and parasitic diseases. The presence of invasive exotic mosquitoes in Europe is linked to developments in transportation and climate change. Rising temperatures enable mosquitoes to adapt to new regions previously free of them. This issue requires effective protective measures and competent personnel to implement vector control methods.

Key words
climate change, transmission, invasive species, pathogenicity, mosquito

INTRODUCTION

A vector refers to any organism, whether vertebrate or invertebrate, that acts as a transporter of an infectious agent from one species to another [1]. Important vectors of diseases on an epidemiological scale include ticks, mosquitoes, flies, fleas, lice, mites, and midges. Diseases spread by these vectors contribute to more than 17% of infections worldwide [2]. Close to half of the world's human population are consistently at risk of contracting diseases transmitted by vectors [3]. The impact of tick-borne pathogens on health-risks in soldiers has been recently described by the authors [4].

Mosquitoes play an important role as carriers of some of the most deadly diseases caused by pathogens from the group of parasites and viruses around the world. An excellent example is the transmission of the protozoan Plasmodium spp., which causes malaria. This disease alone accounts for an estimated 219 million cases globally each year, leading to over 400,000 fatalities [5]. Mosquitoes are also capable of transmitting larger forms of parasites, e.g. larvae of nematodes, e.g. *Wuchereria bancrofti*, *Brugia malayi* and *Brugia timori*, causing lymphatic Filariasis – a tropical disease affecting over 50 million people [6]. In addition, mosquitoes can transmit various species of viruses, e.g. Zika virus, West Nile virus, yellow fever virus, Rift Valley virus, Mayaro virus, Sindbis virus, and various types of encephalitis, such as equine encephalitis, La Crosse encephalitis, California encephalitis and Japanese encephalitis [7]. Dengue presents another significant case, with its viruses spread by *Aedes* spp. Mosquitoes, placing 3.9 billion individuals in over 128 countries at risk of infection [8]. In Poland, mosquito studies have shown the presence of 47 species in 223 identified areas [9], of which 40% of documente mosquito species d have the ability to transmit pathogens dangerous to human health. They may carry arboviruses or parasites.

A recent study has revealed that native mosquitoes possess the capability to transmit non-native diseases, such as the West Nile virus [10]. However, all reported cases of mosquito-borne diseases in Poland thus far have been imported. Specifically, in 2023, there were 43 cases of malaria, 67 cases of dengue, and 5 cases of chikungunya [11]. National Institute of Public Health – National Institute of Hygiene collected data on these

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Received: 02.07.2024; accepted: 16.09.2024; first published: 18.10.2024

infections, divided into Polish provinces (Tab. 1), and in 2023, the highest number of infections was recorded in the Mazovian province – 19, followed by Pomorania – 18, and Silesia – 18. These data also show an increasing trend in infections compared to, e.g. 2022, when there were only 50 cases.

To make things worse, invasive *Aedes* mosquitoes have established themselves in Europe [12]. Climate change and the global movement of people and goods are the primary drivers behind this phenomenon [13]. Mosquitoes have the ability to migrate to different regions across the globe, facilitating the transmission of diverse diseases [14]. Even worse, native European *Culex* spp. have been shown able to spread tropical diseases [15].

The question of specific mosquito-borne diseases and their impact on members of armed forces in Europe and in Poland has addressed previously [16], but beyond the scope of this review. However, to date, the mechanisms by which invasive and native vectors spread these pathogens have not been addressed.

Table 1. number of cases of individual diseases by province

VOIVODESHIP	DISEASE		
	Malaria	*Dengue*	*Chikungunya*
Dolnośląskie	2	7	-
Kujawsko-pomorskie	1	-	-
Lubelskie	2	2	-
Lubuskie	1	2	2
Łódzkie	3	4	-
Małopolskie	4	5	-
Mazowieckie	5	14	-
Opolskie	4	-	-
Podkarpackie	3	1	-
Podlaskie	1	-	-
Pomorskie	5	12	1
Śląskie	7	11	-
Świętokrzyskie	-	2	-
Warmińsko-mazurskie	1	1	-
Wielkopolskie	4	4	2
Zachodniopomorskie	-	3	-

Source: Data from the Department of Epidemiology of Infections Diseases and Surveillance of the National Institute of Public Health and the Department for Prevention and Control of Infectiona and Infectious Diseases in Humans of the Central Statistical Office. Table compiled from data on website: http://wwwold.pzh.gov.pl/oldpage/epimeld/index_p.html

OBJECTIVE

The aim of this review is to analyze the current knowledge on the distribution of mosquito species in Europe, including Poland, the factors influencing their presence, as well as the diseases transmitted by them, which pose a great threat to human health and life. Epidemic mosquito threats to members of the armed forces on peacekeeping missions outside Europe also beyond the scope of this review.

MATERIALS AND METHOD

To comprehensively identify, collect and analyze all available data, a systematic literature review was conducted via databases such as PubMed or Google Scholar and other subject-specific databases. Searches were performed using the predefined key words 'mosquito' and 'vector diseases' or 'climate' or 'species'. The filters applied were not limited to range of publication date, language or study type. A review of 135 articles was conducted, from which the 50 most recent and most relevant works related to the topic of the article were selected for the review (maximum number of allowed references). The obtained information was augmented by publicly available information provided by organizations such as the WHO (World Health Organization) and ECDC (European Centre for Disease Prevention and Control).

Current situation in Europe and Poland. In Central Europe, three *Culex* taxa are identified as the most common mosquito species: *Culex torrentium*, and the two ecologically distinct forms of *Culex pipiens s.s.—Culex pipiens* form *pipiens* (Cx. p. pipiens) and *Culex pipiens* form *molestus* (*Cx. p. molestus*) [17]. In temperate Europe, both ornithophilic mosquito species, *Culex pipiens s.l.* (L.) and *Culex torrentium*, co-exist sympatrically. *Culex pipiens s.l.* (L.) is recognized as the most widespread mosquito species with a Holarctic distribution (inhabiting non-tropical parts of all continents) [18].

Besides native mosquitos, Europe frequently encounters the introduction of various exotic mosquito species. Over the past few decades, numerous mosquito species, particularly *Aedes albopictus* (Asian tiger mosquito), have spread rapidly beyond their tropical habitats and established themselves in temperate regions [19]; In 2009, *Aedes albopictus* was recognized among the top 100 invasive species by the Invasive Species Specialist Group and is widely regarded as the most invasive mosquito species globally [12]. Invasive mosquitoes are recognized by their ability to colonize new territories (Tab. 2). Since the 1990s, an increase has been noted in the spread of invasive mosquitoes in Europe [20] where, in 1979, the tiger mosquito was first recorded in Albania, and in 1990 in Italy [12]. Since then, it has been reported in over 20 European countries, including Malta, Spain, Switzerland, the Netherlands, Vatican City, Greece, France, Croatia, Bosnia and Herzegovina, Serbia, Slovenia, Montenegro, and Belgium. It has not yet been found in Poland [21], but it should be added that no surveillance for this invasive mosquito species has been conducted on most of the territory of Poland [19]. However, it is present in Slovakia, the Czech Republic, and Germany[10, 22]. The latest report from 2020 year mentions the detection of this mosquito in Austria [23]. The European Centre for Disease Prevention and Control (ECDC) monitors the Asian tiger mosquito in Europe, with inspections carried out in January and August 2019. Since the last update in January 2019, 262 new tiger mosquito detection reports have been recorded [24].

In addition to the tiger mosquito, two other exotic mosquitoes have appeared in Europe: the Japanese bush mosquito (*Aedes japonicus*), and the Korean bush mosquito (*Aedes koreicus*). The remarkable invasive potential of these *Aedes* species is attributed to various biological characteristics, particularly their ability to produce drought-resistant eggs and lay dormant eggs during hibernation. Consequently, the spread of these exotic mosquito species at continental, national, and regional levels is influenced by diverse patterns of human mobility dynamics [19]. Some of these invasive species are capable of transmitting the chikungunya or dengue virus, leading to reports of indigenous clinical cases of these viruses in several European countries in recent years [25].

Besides the mentioned types of mosquitoes, it is also worth noting the presence of Aedes aegypti in Europe. It is also a vector of diseases such as dengue, chikungunya, Zika virus and Yellow Fever virus. It prefers mammalian blood, especially human blood. Due to its preferences, Ae. aegypti mosquitoes can be found near human dwellings. The threat it poses stems from the fact that it feeds on multiple hosts during one gonotrophic cycle which significantly increases the risk of disease transmission for which Ae. aegypti is a vector. In 2012 in Madeira (Portugal), Europe had already experienced a dengue epidemic related to Ae. aegypti, which is a prime example of why Europe should not underestimate this mosquito, and perhaps also consider its monitoring [12].

European native mosquito species are believed to have a low or negligible vector capacity for these viruses. Nevertheless, recent research has shown that indigenous *Culex* species in Europe may indeed transmit Usutu virus (USUV) and West Nile virus (WNV) [19].

In Poland, 47 mosquito species have been identified so far [9]. A recent study by Vogels et al. demonstrated that Polish domestic mosquitoes are capable of transmitting tropical diseases [15]. The transmission rates of West Nile virus (WNV) have been assessed in four European mosquito species: *Aedes albopictus*, *Ochlerotatus detritus*, *Culex modestus*, and *Culex pipiens*. Notably, *Aedes albopictus*, despite being invasive, has not yet been identified in Poland, and both *Ochlerotatus detritus* and *Culex modestus* are not prevalent. Conversely, *Culex pipiens* is abundant across the entire country and often appears in large numbers [10].

Table 2. Diseases transmitted by invasive mosquitoes and their presence by country

MOSQUITO SPECIES	*DISEASE*	*CURRENT KNOWN DISTRIBUTION*
Aedes albopictus	Dengua Chikungunya Zika virus Yellow Fever virus [7]	Albania, Austria, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, France (including Corsica), Georgia, Germany, Greece, Hungary, Italy (including Sardinia, Sicily, Lampedusa, and other islands), Liechtenstein, Malta, Monaco, Montenegro, the Netherlands, Portugal, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye, Vatican City
Aedes aegypti	Dengua Chikungunya Zika virus Yellow Fever virus [7]	Azerbaijan, Cyprus, Continental Portugal and Azores, Georgia, the Netherlands, Türkiye, Russia
Aedes japonicus	West Nile virus Chikungunya Dengue [7]	Austria, Belgium, Croatia, Czech Republic, Italy, France, Germany, Hungary, the Netherlands, **Poland (first observed in 2023),** Russia, Switzerland, Slovenia, Slovakia, Spain
Aedes koreicus	Chikungunya Zika virus [7]	Belgium, Czech Republic, Germany, Hungary, Italy, Russia, Switzerland, Slovenia

Source: European Centre for Disease Prevention and Control and European Food Safety Authority. Mosquito maps [Internet]. https://ecdc.europa.eu/en/disease-vectors/surveillance-and-disease-data/mosquito-maps; Stockholm: ECDC; Available from: July 2024

Outbreaks of mosquito-borne diseases in Europe and Poland. Over the last two decades, vector invasion has led to an increase in the number of mosquito-borne virus outbreaks across Europe. For example, dengue outbreaks have been reported in Spain in 2018 and France between 2013–2015 and in 2018 [26]. The largest West Nile virus outbreak was reported in 2018 with 1584 locally acquired infections, mainly in South and East European countries [27].

Currently, there are no native mosquito-borne diseases in Poland; however, historically, Poland struggled with domestic malaria. The country has been officially declared free from domestic malaria since 1963, although local transmission continued until 1957 [28]. Nowadays, all cases of malaria recorded in Poland have been imported by travellers from various climatic regions [28]. Similarly, the number of imported dengue cases is increasing in Poland due to the rising number of travellers to tropical areas [29]. Before the COVID-19 pandemic, Poland reported approximately 30–50 new cases of dengue annually, all as imported infections [30].

Polish tourists returning from trips to tropical countries mainly present to the doctor with fever. Between 2007–2011, fever occurred in 23.3% of 42,173 tourists returning from tropical countries. The three main causes of fever in these patients were malaria (29%), dengue (15%), and typhoid fever. Fever caused by the chikungunya virus accounted for 1.67% of infections [30]. These data are especially worrisome, as most mosquito-borne diseases lack effective vaccines, and anti-malarial drugs are encountering resistance challenges [31].

Despite the fact that Poland is a malaria-free country, it is worth noting the increase in cases among people who have not traveled. Such cases have occurred in Greece, Spain, and Italy. All were classified as introduced malaria, meaning a mosquito infected locally by a person with imported, airport, or hospital-acquired malaria [32]. It would be worth considering the possibility of such a scenario for viruses transmitted by mosquitoes as well.

Impact of transport on spread of mosquitoes. Aircraft play a significant role in the spread of mosquitoes; however, on national and regional scales, transport via cars and trains are the most crucial modes of dispersal. Given the relatively limited flight range of invasive species, the active dispersal of these mosquito species likely plays a minor role on the local scale [19].

Global air travel is closely associated with the intercontinental spread of vectors and vector-borne diseases. The spread between continents is mainly due to the transport of eggs attached to various goods, such as plants (e.g., lucky bamboo) and tyres, carried as ship freight, which is also highly significant [19]. Female mosquitoes lay their eggs in a variety of container habitats with the eggs deposited above the waterline, and are resistant to the drying- out of water for long periods time. Containers like tyres and those containing aquatic plants are then exported to new geographic areas. Subsequent inundation by water facilitates egg hatching, leading to new populations in suitable local climates. Undoubtedly, their success in colonizing new areas is due to their ability to adapt to different climates through the production of cold-resistant eggs, with temperate strains surviving cold winters in northern latitudes. Like many invasive mosquito species, their preference for container habitats (e.g., tyres and vases) in domestic settings has increased their potential for contact with humans [12]. Additionally, luggage on aircraft has occasionally been suspected of containing infected *Anopheles* mosquitoes from endemic areas into Europe [33].

Impact of climate changes on the spread of mosquitoes and mosquito-borne diseases. During the summer months in Europe (July – September), mosquitoes regularly increase their activity. Research conducted in both northern and southern Europe clearly shows the peak abundance of various mosquito species during this period. It is also when the highest level of autochthonous virus transmission occurs, along with reports of diseases spreading to new areas. Conversely, the winter months (December – February) generally lead to a reduction in their activity [34].

Mosquitoes, in addition to having dietary preferences, some favouring human blood (anthropophilic) while others prefer animal blood (zoophilic) [35], are also ectothermic organisms. This limited ability to regulate their own body temperature makes them highly sensitive to temperature changes throughout all stages of their life cycle [36]. Climate change has led to temperature increases in Europe, especially at higher latitudes, as well as changes in rainfall patterns. This makes some areas more susceptible to drought, increases climate variability, and causes the occurrence of more extreme weather events (severe storms, extreme heat waves, intense rainfall (>5 cm/day), etc.) [37].

Temperature changes can also restrict the spread of disease vectors. For instance, Aedes aegypti, the host for yellow fever and dengue fever viruses [37], is well adapted to living near humans in rural and urban areas, where it breeds by laying eggs in containers, pots, or tyres [38]. Laboratory experiments have demonstrated that *A. aegypti* larvae perish when the water temperature exceeds 34 °C; adults begin dying off when the air temperature surpasses 40 °C [39]. As global warming persists, disease hosts like *A. aegypti* may vanish from certain regions where temperatures exceed their thresholds [40]. Nevertheless, mosquitoes have devised survival strategies. *A. aegypti*, for example, has been observed seeking refuge from scorching summer temperatures reaching 40 °C in Jalore Town, Rajasthan, India, by utilizing household containers or underground concrete water tanks. Similarly, field observations have documented live *A. aegypti* larvae in frozen water [39]. Similarly, malaria transmitted by *Anopheles* mosquitoes predominantly thrives when temperatures surpass 16 °C. A decrease in temperature below this threshold would prove advantageous for malaria control [40]. The development of the malaria parasite is halted when temperatures exceed 33–39 °C. Rising temperatures can influence the reproduction and extrinsic incubation period (EIP) of pathogens, for instance, the EIP for *P. falciparum* decreases from 26 days at 20 °C to 13 days at 25 °C [39].

Similarly, mosquito-borne diseases like dengue, malaria, and West Nile fever represent dynamic systems characterized by complex ecological interactions influenced by local environmental conditions. The transmission rates, range, distribution, and seasonality of their causative agents are significantly impacted by environmental changes. Climatic factors, such as air temperature, precipitation, and relative humidity, can influence the suitability of habitats, distribution, biology, abundance of mosquito vectors transmitting these agents, as well as their host-seeking activity and biting behaviour. Furthermore, the duration of the extrinsic incubation period (EIP) is strongly temperature-dependent [41].

Dynamic models predict that the warming associated with the doubling of carbon dioxide in the atmosphere will increase the transmission capacity of mosquitoes approximately 100 times in temperate (climate) zones, and the area capable of sustaining transmission will expand from containing 45% of the world's population to 60%, although recent statistical models forecast smaller changes. It should be noted that all these analyses are based on average temperatures, rather than the more rapid changes in minimum temperatures observed, which may therefore underestimate biological responses [37].

Changes in humidity levels impact many disease hosts. Relative humidity influences malaria transmission by affecting the activity and survival of mosquitoes. If the average monthly relative humidity falls below 60%, the lifespan of the malaria vector mosquito becomes too short to effectively transmit malaria [39]. When periods of high humidity and warm weather are interrupted by dry spells, mosquitoes carrying the West Nile virus and Lyme disease may migrate into unconventional areas, such as Canada and Scandinavia [42].

On the other hand, low humidity can have a negative impact on the survival of certain diseases. Low humidity and drought are either direct consequences of global warming or result from excessive forest and farmland development, or simply due to inadequate water retention infrastructure [43]. For instance, the adult survival of *A. aegypti* may decrease, thus potentially reducing dengue transmission [39].

Wind also has a dual impact on disease vectors/hosts and can influence both negatively and positively the malaria cycle. Strong winds can reduce the biting opportunities of mosquitoes, but can also increase their flight distance. During the monsoon season, wind can alter the spatial distribution of mosquitoes [39].

To sum up, these climate changes can result in the emergence of diseases imported from tropical regions and/or the re-emergence of diseases considered extinct in given geographical region. In other words, climate changes may lead to increase in incidence and geographic expansion of well-known diseases that were successfully controlled in the past. Firstly, they can prompt the migration of vectors and vector-borne pathogens towards higher latitudes as the climate warms in temperate zones, therefore becoming more conducive to these species. These changes can also give rise to the emergence of new genotypes of vector-borne pathogens as a result of changes in the dynamics of animal hosts and vectors prompted by these changes [44].

Mosqutio control in Europe. The establishment of the European Mosquito Control Association in 2000 provided a platform for extensive knowledge exchange in effective mosquito control, aimed at addressing mosquito-related issues across Europe [19]. mosquito control programmes are customized to local conditions and national/regional regulations, incorporating all appropriate available monitoring and control tools [45]. Typically, such a programme includes the following components:

a) physical control – environmental management (e.g., reduction of breeding sites) and sanitation (modification of breeding sites, e.g., by covering containers), application of surface layers of chemical and biological agents that impede the development of pupae and late larvae, and reduction of human-vector contact, e.g., through the use of mosquito nets;
b) chemical control – spraying with adulticides and larvicides with minimal environmental side-effects, such as insect growth regulators;

c) biological control – aside from fish and invertebrates (e.g., copepods), microbial control agents, such as products based on *Bacillus thuringiensis israelensis* (Bti) and *Lysinibacillus sphaericus*, are the primary biological control tools used in Europe;
d) genetic control – insect sterilization techniques based on irradiation (SIT) against the tiger mosquito have are already been successfully implemented.

Unfortunately, preventive measures across Europe remain insufficient; for instance, there are deficiencies in entomological research, legal support, surveillance capacity, and inconsistencies in entomological and epidemiological surveillance systems, all of which highlight gaps in the European response [27].

The CDC reports that since 2019, one billion genetically modified mosquitoes have been released in certain parts of Brazil, Cayman Islands, Panama and India. These mosquitoes have a self-limiting gene that prevents the offspring of female mosquitoes from reaching adulthood. These mosquitoes are used for vector-borne disease control. Most importantly, they are safe for humans and animals [46].

Risk to soldiers. Soldiers serving in the armed forces may be at increased risk of contracting diseases transmitted by mosquitoes due to the nature of their field assignments. This is especially true for soldiers of Polish Armed Forces who serve in areas rich in marsh and swamps, as at the eastern border with Belarus. Unfortunately, to date, no study has tackled this problem. Most data has been collected for the US Army. Over the course of 5 years, a study was conducted on active duty and reserve members across the branches of the United States military – Army, Navy, Air Force, and Marine Corps deployed around the world. The study identified a total of 709 confirmed cases, 196 probable cases, and 163 suspected cases of vector-borne diseases among the personnel. Active members represented 86% of confirmed cases, 84% of probable cases, and 83% of suspected cases. Among the 709 confirmed cases, the majority (94%) were linked to diagnoses of Lyme disease (n=311), malaria (n=172), Zika virus infection (n=80), Rocky Mountain spotted fever (n=54), and dengue (n=51) [47]. Another study reported that during a 13-year study involving the US military, including active-duty and former members stationed in diverse global locations, Lyme disease was the prevailing illness across all formations. Nonetheless, within the United States European Command, malaria ranked as the most prevalent, succeeded by Lyme disease and dengue [48].

Currently, there is no significant occurrence of vector-borne diseases observed among Polish soldiers engaged in military operations. However, neglecting preventive measures such as vaccinations or the use of pharmacological agents markedly raises the likelihood of importing infections into the home country [49]. In Poland, it is necessary to consider the threat to soldiers due to their training locations which are usually forested. The potential exposure to mosquito-borne diseases in these locations can be inferred from studies on foresters in the Świętokrzyskie and Podlaskie provinces. Out of 52 foresters tested in the Świętokrzyskie Province, one tested positive for West Nile Virus IgG antibodies. In the Podlaskie Province, out of 42 foresters tested, four had positive results for West Nile Virus IgG antibodies [50].

Preventive countermeasures and unit protection measures are used to reduce soldiers' exposure to mosquito-borne diseases. Preventive measures include proper use (manner of wearing) of uniforms, application of repellent to exposed skin, use of repellents such as permethrin to impregnate uniforms, and the use of mosquito nets, curtains, tents, and insecticide-treated nets. Collective protection measures, on the other hand, include site selection for military bases, environmental management, spraying in spaces that may provide habitats for mosquitos, and indoor spraying. In a combat environment, personal countermeasures are often the last line of protection for soldiers. To be effective, collective protection measures require knowledge of the entomological situation regarding mosquitoes, and the presence of appropriate personnel competent to implement the chosen vector control methods [16].

CONCLUSIONS

An important aspect enabling the survival of exotic mosquitoes in Europe is climate change affecting the continent. Rising temperatures allow mosquitoes to adapt to new geographic locations that were previously unsuitable for them; additionally, native mosquitoes are able to transmit tropical disease. The public should be made more aware of the dangers posed by mosquitoes and how to protect themselves against them. Workers in areas prone to mosquito colonization should be equipped with personal protective measures, such as uniforms and repellents for use on exposed skin. Measures should also be taken to manage areas prone to mosquito habitats, and in line with the European Mosquito Control Association, implement protective actions including biological, physical, chemical, and genetic methods.

Acknowledgement
The research was funded in 2021–2025 by the Ministry of Health in Warsaw, Poland, as part of the National Health Programme under Agreement No. 364/2021/DA of 29 November 2021.

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