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ORIGINAL PAPER

Influence of climate change on mosquito development and mosquito-borne diseases in Europe

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Abstract Mass occurrence of mosquitoes can have an immense impact on the quality of life in areas such as the Upper Rhine Valley. Therefore, biological and environmental measures are applied to prevent mass development in many regions of Europe. Despite successful prevention measures, the risk of contracting mosquito-borne viral diseases, such as West Nile fever, should be discounted in Central Europe. The transport of mosquitoes (e.g., through tire trade or within containers) into Germany has to be prevented. Individuals (tourists and immigrants) infected with imported vector-borne pathogens and parasites must be diagnosed and treated immediately. Mosquitoes and mosquito-borne diseases know no borders, and their spread is also a consequence of high mobility and globalization. Therefore, mosquito control requires international cooperation. People's increased mobility and international trade play a more important role in the dissemination of the vectors and their pathogens/parasites than increasing temperatures.

Introduction

Scientists and the public are concerned on the increasing risk of vector-borne diseases in Europe, including Central Europe, both from a medical and epidemiological point of view. Changing climate conditions make diseases, which have already been eradicated, or newly appearing diseases a threat to human health. It is necessary to inform the public of the potential risks of introduced or newly occurring infectious diseases or vector organisms on the base of realistic assessments in order to prevent a sensitive public from overreacting due to panic mongering. Usually, malaria is mentioned in the media when climatic changes and the resulting epidemic threats are considered. Although malaria is still the most important vector-borne disease in the tropics, it can be clearly stated that a revival of a malaria epidemic in Germany is very unlikely as long as high general hygienic and medical standards are maintained.

More than 300 million people are infected with the malaria parasite worldwide, which is transmitted solely by anopheline mosquitoes. The World Health Organization (WHO) estimates that more than 3 million people (approximately one person every 30 s) die each year from this vector-borne disease (WHO 1997). Dengue viruses are transmitted through mosquito bites, primarily from the yellow fever mosquito *Aedes aegypti*. More than 2 billion people, mostly in rapidly growing megacities in the tropics, live with the risk of contracting dengue fever or even the often-lethal dengue hemorrhagic fever. Due to inadequate provision of tap water in these regions, water is saved in containers, thereby creating ideal breeding grounds for *Ae. aegypti*. No other animal on the planet has such a decisively negative impact on the fate of mankind as vector-competent mosquitoes.

This article will explore whether mosquito-borne diseases in Germany could become more relevant within the context of climate change. In this context, the introduction of (tropical) mosquitoes or parasites, international trade, and changes in lifestyle habits, such as increased mobility, have to be considered. This risk analysis will also highlight

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the interaction between the vectors (mosquitoes) and the etiologic agents (pathogens or parasites). In order to do so, the following aspects should be taken into account:

(a) The direct interaction between mosquitoes and the etiologic agents

Transmission through vectors can, as a general rule, only be successful if the pathogen/parasite is able to replicate itself in the mosquito. This can be illustrated with the following two examples. First, mosquitoes are not appropriate vectors for human immunodeficiency virus (HIV), since HIV cannot proliferate in the mosquito and penetrate into their salivary glands. Second, among the malaria fever mosquitoes (anopheline mosquitoes), there are many examples within closely related mosquito species; some of these species are capable of transmitting malaria, while others show no or low vector capacity. Apparently, pathogen/parasite and vector (mosquito) either adapted to each other during the course of evolution, resulting in coexistence, or the pathogen/parasite was repelled.

(b) Climatic and ecological factors

Climatic and ecological factors determine whether, in a given region, the pathogens/parasites or vectors can exist and multiply successfully. The malaria parasite can only develop in the mosquito if temperatures are sufficiently high. Introduced mosquitoes require certain climatic conditions to successfully reproduce. Therefore, it has to be examined whether climate change can lead to the spread of tropical diseases and their vectors to Europe and Germany, respectively.

(c) The availability of etiologic agents and vectors

The life cycle of parasites/pathogens can only be completed if the disease-causing agent and the vector exist in the same area. If either the pathogen/parasite or the vector has been successfully eradicated in a region, the life cycle is interrupted. However, due to people's increased mobility and worldwide trade, pathogens and mosquito vectors can be transported from continent to continent within a few hours. Each year, approximately 1,000 people living in Germany are infected with malaria parasites while traveling in the tropics (Löscher 1998). In addition, infected mosquitoes can be carried to Europe, e.g., on airplanes and ships, causing people who have never been in the tropics to contract tropical diseases, especially malaria, dengue, and chikungunya fever, after being bitten by these transported mosquitoes. The question then arises as to whether indigenous mosquitoes are also capable of transmitting the disease after biting an infected person. In other words, what is the vector competence of indigenous mosquitoes for imported pathogens?

In the following, these issues will be addressed using concrete examples, and the necessity of finding answers or adequate solutions to the problem of mosquito-borne diseases will be highlighted.

What impact do environmental changes have on malaria?

Human malaria is caused by four species of *Plasmodium*: *Plasmodium falciparum* (causes malignant tertian malaria, malaria tropica), *Plasmodium vivax* and *Plasmodium ovale* (benign tertian malaria, malaria tertiana, fever attack each third day), and *Plasmodium malariae* (cause malaria quartana, fever attack each fourth day). Their vectors are exclusively specific anopheline mosquitoes.

In order to determine what will be the effect climate change, one must analyze the life cycle of the vector, the anopheline mosquito, and that of the *Plasmodium* parasite. When an infected *Anopheles* female bites a human, the infectious agents, the sporozoites, are injected into the human with the insect's saliva. Once inside, they travel through the blood stream to the liver cells and undergo multiplication (exerythrocytic schizogony) in order to invade erythrocytes, where they multiply further (erythrocytic schizogony) to produce merozoites (Becker et al. 2003). Whenever the merozoites break out of the red blood cells, they cause an attack of fever (with *P. vivax* always after 48 h, the "3-day fever"). Within the erythrocytes, in addition to merozoites, male and female gametes are produced. These gametes cannot develop further in humans, but must be ingested with a blood meal by an *Anopheles* female to transform into the sexual forms of the parasite in the mosquito gut. Fertilization of the oocyte also takes place in the gut (resulting in the motile ookinete). The ookinetes penetrate through the wall of the gut and form oocysts in the outer gut epithelium. Within the oocysts, sporogony results in the formation of the infectious sporozoites, which migrate to the salivary glands. The *Anopheles* female can then bite and infect another human, thereby transmitting the disease. The cycle from being bitten by an infected mosquito to the development of the gametes lasts approximately 2 weeks in humans (*P. falciparum*, 9–14 days; *P. vivax*, 12–17 days).

The effect of temperature on the development of *Plasmodium* in the *Anopheles* mosquitoes

Since mosquitoes are poikilothermal, the development of the parasites in the mosquito is dependent on the outside temperature. The minimal temperature at which the development of the parasites can be completed (summer isotherm) is 16.5°C for *P. falciparum* and 14.5°C for *P. vivax*. Higher temperatures accelerate their development (Fig. 1).

Parasite species	No. of days for parasitic development in mosquitoes				
Temperature	16	18	20	25	28
P. falciparum	-	-	23	11	8
P. vivax	55	29	16	10	7

Fig. 1 Average duration of sporogony of *Plasmodium falciparum* and *P. vivax* (modified from WHO Manual on Practical Entomology in Malaria, Part II, 1975)

The higher the temperature, the faster the sporozoites are formed, and the faster the life cycle is completed. Therefore, the risk of being infected with malaria increases with increasing temperatures. However, there is also a correlation between the longevity of the mosquito and temperature; mosquitoes live longer at lower temperatures than at higher temperatures. At extreme temperatures, the mosquitoes and the parasites can die. Due to this, there is an optimal temperature range for the transmission of *Plasmodium* (22–28°C for *P. vivax* and *Anopheles messeae*, and 26–32°C for *P. falciparum* and *Anopheles gambiae*).

The effect of temperature on mosquito development

In addition to an adequate supply of water, temperature plays a decisive role in mosquito development. Temperature, above all else, influences the progression of generations and the size of the vector population.

The effect of temperature on the development of mosquitoes can be determined by the following equations (these equations can also give approximate information about the temperature-dependent development of the *Plasmodium* in the mosquito).

The average accumulated temperature required for development is constant for each species and equals the product of the development period (D) and the difference between test temperature (t) and the threshold temperature at which the development rate is zero (t_0). The thermal constant is calculated using the following equation:

$$K = \text{Thermal constant} = D \times (t - t_0)$$

This equation describes a hyperbola.

The temperature threshold (t_0) is calculated according to the following equation (Tischler 1984):

$$t_0 = t_1 - \frac{D_2 \cdot (t_2 - t_1)}{D_1 - D_2}$$

D_1 Development period at low temperature (t_1)
D_2 Development period at high temperature (t_2)

After determining the threshold temperature, the experimentally measured values can be used in the above equations to calculate the thermal constant for each experimental temperature, which, under ideal conditions, should be the same for all temperatures.

The following results were obtained for one of the potentially most important vector for autochthonous malaria in southern Germany, *Anopheles messeae* (Fig. 2).

An increase in temperature accelerates not only the development of mosquitoes in their breeding sites but also other phases of the life cycle, such as the frequency of blood meals, the duration of the gonotrophic cycle (time from a blood meal to the final development of eggs), and their longevity. A reduction in the duration of the gonotrophic cycle increases the frequency of blood meals and, therefore, also the probability of transmitting disease agents such as malaria (Dhiman et al. 2008; Snow 2008).

Malaria assessment—the situation in Germany

Even as recently as 80 years ago, endemic malaria episodes were not uncommon in Europe. Napoleon probably lost more soldiers in the Upper Rhine Valley in Germany to malaria than to bullets from his opponents. In northern Germany, it was impossible to colonize the marshes due to the threat of malaria.

In Germany, there are six *Anopheles* species that can transmit malaria and listed here together with their preferred breeding biotops:

Anopheles maculipennis s.s.—densely vegetated shallow water; occasionally also containers such as rain barrels

Anopheles messeae—densely vegetated shallow water; seldom in containers

Temperature (°C)	15	20	25
Days	34,87	25,47	19,75
Thermal constant	455,4	459,99	455,44

Fig. 2 Duration of the larval and pupal development of *Anopheles messeae* at various temperatures and resulting thermal constant (t_0=1.94°C)

Anopheles atroparvus—mostly brackish water bodies, marshes along coastlines (these three species belong to the *An. maculipennis* complex).

Anopheles algeriensis—mostly shaded permanent water bodies, tolerates also brackish water (species is rare and is not important as vector)

Anopheles claviger—mostly in shaded plant-rich bodies of water, can appear early in the year in cool temperatures

Anopheles plumbeus—tree hole breeder, increasingly appears in underground septic tanks or other artifical water containers contaminated with organic substances

It is highly likely that in Germany, these species exclusively transmitted *P. vivax*, the cause of malaria tertiana. It is worth noting that people in Europe died of malaria tertiana by the thousands. Today, in the tropics, a *P. vivax* infection only rarely results in death. Lethal cases can be attributed almost exclusively to *P. falciparum*. Therefore, one can conclude that the virulence of *P. vivax* has declined over the course of evolution. It is of advantage for a parasite not to cause its host's death, as is primarily the case today with *P. falciparum*, but rather to keep the host as a continuous source of infection. Even the development of hypnozoites, the latent form of *P. vivax* in the human liver, serves as an adaptation of the parasite to the temperate climate in Europe. As hypnozoites, the parasite can live through times of the year, including winter, when conditions for development in the vectors are unfavorable.

In Germany, there have not been any large malaria epidemics since the end of the nineteenth century. Outbreaks of malaria occurred only concurrently with the postwar confusion after WWI and WWII. However, these cases of malaria infection were predominantly brought in by the soldiers.

What are the causes of the decline of malaria in Europe?

The following are the causes of the decline:

(a) First of all, the appearance of quinine as a treatment for malaria and the consistent treatment of malaria patients led to a continual reduction in the numbers of infected people. This in turn led to a drastic decrease in the probability of a mosquito taking up the parasite through human blood meals.

(b) Ground water levels have steadily become lower through the canalization of rivers. A reduction in malaria infection was achieved in Europe through hydraulic engineering measures before the developmental cycle of the disease-causing agent was known. Laveran and Ross discovered this at the end of the nineteenth century.

(c) Lifestyle changes have resulted in humans coming into contact less and less with *Anopheles* mosquitoes. For example, stables and living quarters, once together in one complex, are now separate. The female *An. maculipennis* s.s. and *An. messeae* are mainly zoophilic, meaning they prefer large mammals as hosts for their blood meals, such as cows and horses. Only when in close contact do they bite humans, thereby acting as vectors.

(d) Central Europe is a borderline for malaria parasites, climatically speaking; this is one reason why eradication was possible. Today, all of the malaria vector-competent mosquitoes are still present in Germany; however, indigenous malaria has disappeared in Central Europe, excluding single conjectural cases. This is also the case in Southern Europe, even with its more favorable climate.

What effect does climate change have on the transmission of malaria parasites?

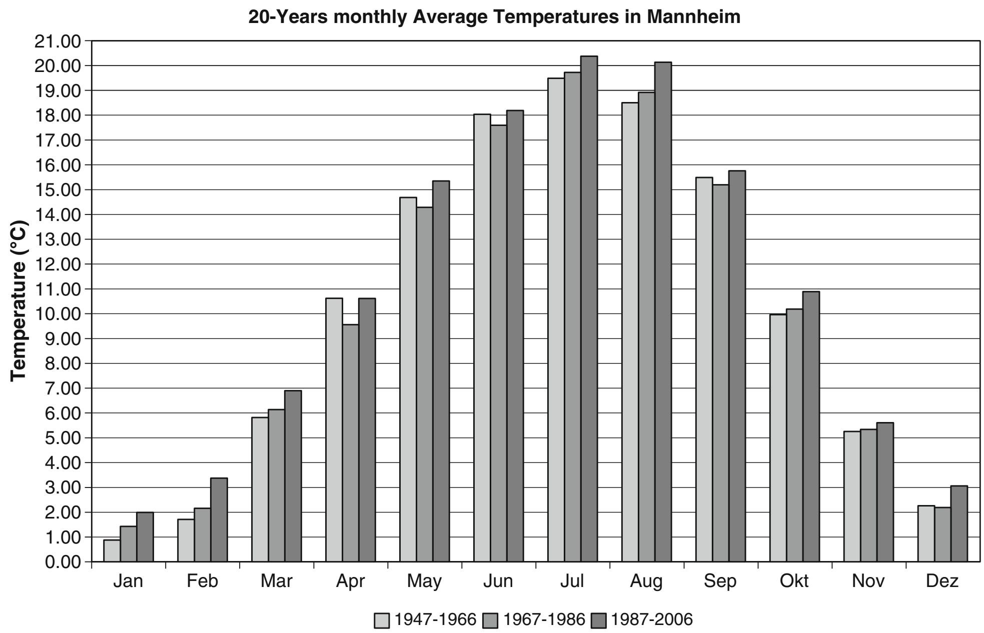
As described above, environmental conditions have a significant effect on the development of the mosquito vectors and on the parasites themselves. Aside from appropriate breeding sites for the mosquitoes, precipitation (rain), and a relative humidity higher than 60%, temperature especially affects the transmission of the parasites. Therefore, as the temperatures in Germany rise, so does the concern regarding the reoccurrence of malaria. This concern was also expressed in the recent Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC 2007). Global temperatures are predicted to increase by 1.8°C to 4°C by the year 2100, which could be associated with a considerable increase in the number of vector-borne diseases.

In order to evaluate the change in temperature that has taken place in Germany so far, the average monthly temperatures from the last 60 years in Southwest Germany (Mannheim's weather station) were examined. Three time periods were compared: (a) 1947–1966, (b) 1967–1986, and (c) 1987–2006 (Fig. 3).

Temperatures have risen continually in the last years to approximately the same degree in both the summer months as in the winter months. Since temperatures have begun to be recorded, the warmest years have been within the last 10 years. On average, the increase in temperature is approximately 1.2°C (from 1977 to 2006). During the same period, the increase in the summer months was 1.4°C (Figs. 4 and 5).

A temperature elevation of 1.6°C would signify an acceleration of *An. messeae* development of 2.3 days. This means that both the gonotrophic cycle would be shortened and the number of *An. messeae* generations would increase.

Fig. 3 Twenty-year average temperatures in Mannheim



Can autochthonous malaria emerge in Germany again?

Even though the malaria parasites were eradicated in Central Europe, they are now being imported into Europe from the tropics more often. Tourists, above all others, are responsible for the transport of the parasites. Approximately 10,000 malaria cases per year are registered in Europe and more than 1,000 cases per year in Germany (Löscher 1998). Most of the tourists are infected with the dangerous *P. falciparum*. Since they are generally treated quickly, the parasites are not transmitted further. In Europe, rarely the infection is lethal. Infected mosquitoes can also be imported from the tropics in airplanes, causing the so-called airport malaria in people who have never visited the tropics. The question remains as to whether these imported malaria cases could become a threat to the populace.

Are our mosquitoes able to transmit the tropical malaria parasites?

As a general rule, there must have been co-adaptation between the vector and the parasite in the course of evolution to enable them to synergize. In the past few years, British scientists from the London School of Tropical Medicine and Hygiene have demonstrated that *P. falciparum* can multiply in *An. plumbeus*, an *Anopheles* species native to Germany (Marchant et al. 1998).

This observation is significant in Germany. The fever mosquito *An. plumbeus* normally lays its eggs in tree holes, where the larvae and pupae develop. In rural areas of Germany, especially in the south, the behavior of these mosquitoes has changed dramatically—they have started using abandoned cesspools (liquid manure tanks) as

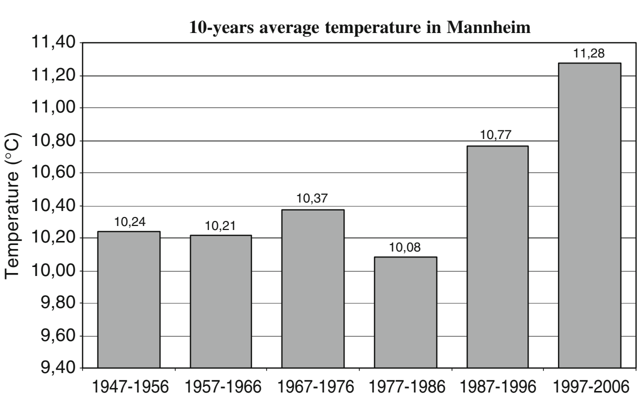


Fig. 4 Ten-year average temperatures in Mannheim

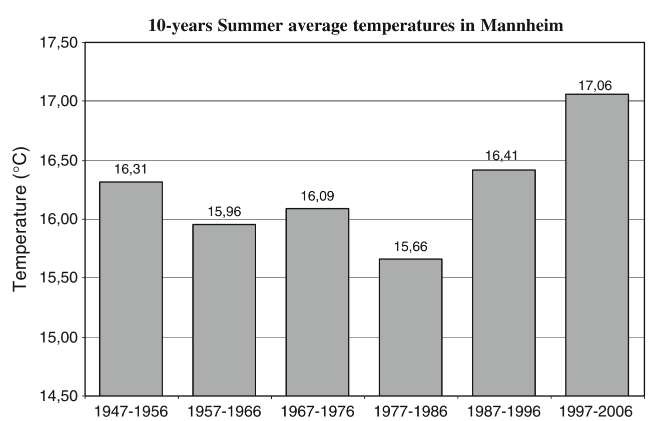


Fig. 5 Ten-year summer average temperatures in Mannheim

breeding sites in areas were cattle are no longer reared. While only a few mosquitoes can breed in natural tree holes, the cesspools represent huge artificial "tree holes" in which millions of mosquito larvae can develop. Disturbances from these mosquitoes in residential areas have been reported more frequently in the last 10 years. Females are not only anthropophilic blood feeders, but they also exist in the immediate surroundings of human dwellings.

In the past few years, our research group has examined the degree to which these and other indigenous *Anopheles* mosquitoes can, under favorable conditions, transmit imported malaria parasites. For the first time, we demonstrated that not only oocysts but also sporozoites (which traveled to the salivary glands) could develop in a female *An. plumbeus*, which had ingested blood infected with *P. falciparum*. Therefore, *An. plumbeus* could potentially transmit the causing agent of the deadly Malaria tropica (Kotter 2005).

Measures to reduce the risk of malaria

The German Mosquito Control Association/KABS (Kommunale Aktionsgemeinschaft zur Bekämpfung der Schnakenplage e.V.) surveys *An. plumbeus* mass breeding sites within its geographical domain and beyond, supported by the communities. The breeding sites are administered in a geographical information system program. Furthermore, tablets containing the biological agent of *Bacillus thuringiensis israelensis* (Culinex/Vectobac DT tablets) are supplied to treat cesspools and water containers. Several million tablets are used each year, thereby greatly reducing the density of the mosquitoes in urban areas. On request, KABS employees also take targeted measures against *An. plumbeus*. Due to its bothersome habit of biting during the day, the population has a heightened interest in its control.

Through the wide use of the *B. thuringiensis israelensis* tablets, the *Anopheles* population is also being greatly reduced to ensure that there is a concurrent reduction in the risk of malaria.

Conclusion Warmer temperatures in Germany of a few degrees will not necessarily lead to malaria epidemics. However, they favorite the development of mosquitoes and have a strong impact on the control operations (Fig. 6). Malaria infection has been on the decline for various reasons. *An. maculipennis* s.l. numbers have been reduced through the elimination of its breeding sites. Improved health and sanitation and the prompt treatment of people infected with malaria parasites all act to disrupt the infection cycle. Despite this, the risk of isolated autochthonous malaria cases in Germany has increased. Major changes in agricultural practices especially increase this risk. In the past, due to high levels of organic waste, cesspools were not appropriate breeding sites for *An. plumbeus*. However, through the abandonment of the use of cesspools and the installation of cisterns in which only lightly contaminated rainwater is collected, mass breeding areas for *An. plumbeus* were produced. This is illustrated by the types of complaints that KABS increasingly has to respond to. *An. plumbeus* must be considered a potential risk factor not only because its population size is increasing but also because it is a suitable vector for *P. falciparum* and *P. vivax*. It is anthropophilic and is often present in considerable numbers in rural residential areas.

The changes in agricultural practices have a greater effect on the risk of malaria than an elevation in temperature of approximately 2°C. It should also be taken into consideration that there are already significantly higher temperatures in Southern Europe, where there have not yet been any malaria epidemics.

Do arboviruses pose a danger to the inhabitants of Germany?

It is likely that arboviruses, e.g., viruses transmitted by mosquitoes, pose a much greater threat to the German population than indigenous malaria. The so-called Tahyna virus has been known for decades; it is present in rabbits, for example, and can be transmitted to humans to cause a type of summer influenza with mild symptoms (headache, low fever). In the Upper Rhine Valley, antibodies for this virus were detected in many people even 20 years ago, indicating a relatively high infection rate. In the last decades, the infection rate has steadily decreased, probably due to mosquito eradication campaigns or/and a reduction in animal reservoirs. Therefore, the Tahyna virus no longer poses a threat to humans in Germany, even though in the USA, a closely related species can cause grave diseases (encephalitis) with subsequent loss of life.

West Nile virus Much more of a danger is the so-called West Nile virus. This virus was discovered in Uganda in 1937 (West Nile region). It circulates predominantly in wild birds, which become infected in their wintering grounds in Africa. The pathogen can then be imported to Europe with migrating birds (similar to the transport of certain influenza viruses); this occurred in Romania in 1996 and 1997. The virus was first spread through the bird population by ornithophilic mosquitoes (feed on birds), such as the house mosquito *Culex pipiens pipiens*. If the viremia in the bird population is high, the virus can be transmitted to humans by mosquitoes. In 1996 and 1997, approximately 400 people in the vicinity of Bucharest were infected, and 31 people died, 17 in 1996 and 14 in 1997.

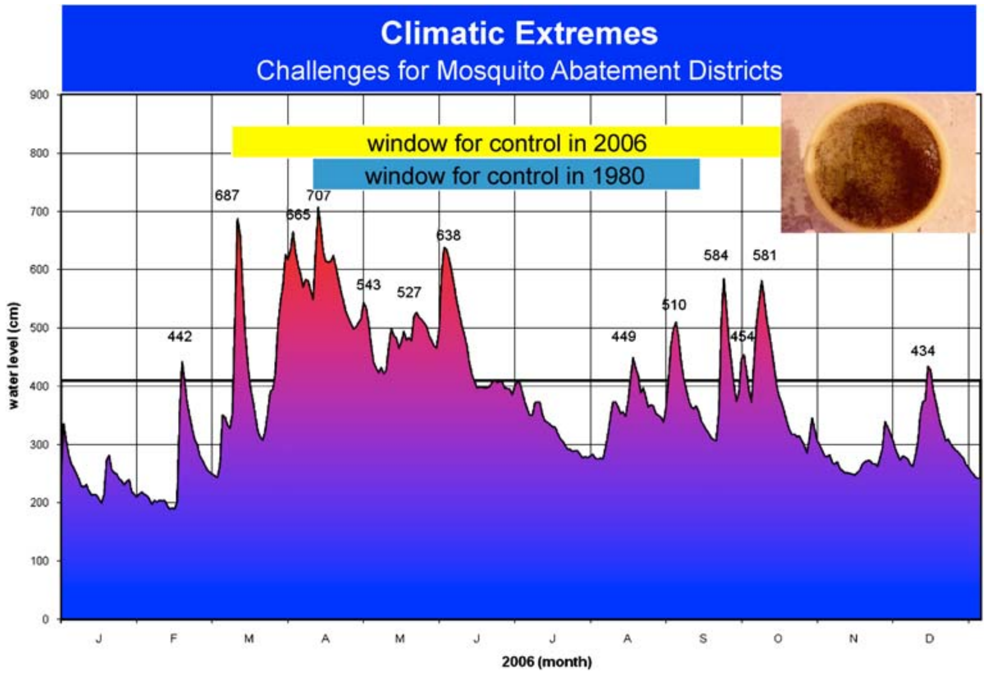


Fig. 6 Climate Extremes and influence on mosquito development and control. In the Upper Rhine Valley, due to elevated temperatures and local, often heavy precipitation, the time period during which mosquito control measures are taken has widened significantly. In the 1980s, control measures began in mid-April and now are begun already in March. Earlier, the campaigns ended in mid-September but, in the past few years, have continued into October. With the change in climate with higher temperatures and strongly fluctuating rainfall, the sequence of eradication campaigns has increased heavily, with an accompanying rise in the cost of the campaigns

The expansion of the range of this virus was first limited to Africa, Asia, Southern France, Eastern Europe, Romania, and Israel. In 1999, the first viral infections were recorded in New York, USA. Within a short amount of time, the virus spread over the whole North American continent. In 2003, almost all of the states in the USA were affected, and nearly 10,000 people were infected, of which 264 died (CDC 2003). Initially, the extensive use of insecticides prevented the epidemic from spreading further.

Dengue fever This was a serious threat to people living in Southern Europe only 80 years ago. One of the largest dengue epidemics occurred in Greece, as more than 1 million people in 1927 and 1928 became infected. More than 1,000 people died of the disease (Halstead and Papaevangelou 1980). Today, dengue and dengue hemorrhagic fever represent the most important arbovirus infection in the tropics worldwide, of which mostly children die. The main vectors are *Ae. aegypti* (Yellow fever mosquito, new species name: *Stegomyia aegypti*) and *Aedes albopictus* (new species name: *Stegomyia albopicta*), the Asian tiger mosquito. Dengue epidemics cannot be excluded wherever *Ae. albopictus* can reproduce and a virus reservoir is present.

It is most likely that dengue will not become a problem in Germany, since the climate is not optimal for the pathogen. However, an increase in temperature and the increased mobility of the population significantly promote the incidence of a virus epidemic.

Chikungunya virus Chikungunya virus epidemics have recently drawn a great amount of attention after there were sudden outbreaks in 2005 in Réunion, when more than 300,000 people were infected, and again in the past 2 years in India, when more than 2 million people were infected with the Chikungunya virus. In 2007 (July to October), the first epidemic of this tropical disease broke out in Italy. One person traveling from India (Kerala) to Italy developed symptoms of Chikungunya fever at the end of June. Subsequently, there were approximately 250 cases of Chikungunya fever in Ravenna Province. The disease symptoms include high fever, limb/muscle and joint pain ("Chikungunya" comes from Suaheli, meaning "that which bends up," referring to the severe joint pain). Most of the time, the disease is relatively harmless, and hemorrhage seldom occurs. However, older people above all others are in danger of dying from this viral infection. In the Ravenna region, an 83-year old man died of this disease. Due to this, it is required to report cases when hemorrhage occurs. In addition, the laboratories have to report these cases according to the European "prevention of infection regulations" (ECDC 2008).

Chikungunya virus was detected in *Ae. albopictus* females, indicating that the newly introduced pathogens that led to this epidemic were transmitted by the tiger mosquitoes, which had spread to Italy in previous years. The degree to which indigenous mosquitoes (other than the newcomer tiger mosquito) can act as vectors for the Chikungunya virus and whether the viruses can be passed on by transovarian transmission during egg development are now being examined.

Currently, there is no vaccination for Chikungunya fever; the only protection is to avoid being bitten by mosquitoes.

Expansion of *Ae. albopictus*

The Asian tiger mosquito, *Ae. albopictus*, originates from Southeast Asia, where its developmental stages (egg, larvae, and pupae) occur e.g. in water-filled coconut shells or bamboo stumps. Only later it adapted to artificial containers. They can now be found in containers such as water barrels, car tires or other places where small pools of water may collect. This mosquito is characterized by its black coloring with white stripes on the legs, thorax, and abdomen that lend it a “tiger-like” appearance. These exotic mosquitoes have undergone an astonishing expansion of their range within the last decades. Since 1979, *Ae. albopictus* can be found in Africa, the Americas and Europe, and more recently also in the Pacific region. It is expected to spread worldwide to tropical and subtropical regions and occasionally to regions with moderate climates. Increasing international trade and people’s mobility support the spread of the mosquito. The international used tire trade has facilitated its spread over large distances and between continents. Females lay their eggs inside moist tires; when rain water collects in the tires, the larvae hatch at favorable temperatures of over 10°C. With high summer temperatures, they can develop within 1 week from egg to adult. Due to its ability to colonize a wide range of natural and artificial breeding places, the resistance of its eggs to desiccation and cold (diapausing larvae in eggs), and the relative lack of preference concerning its host type (humans, dogs, cats, rodents, amphibians, birds, and reptiles), this species has been able to rapidly build populations in newly colonized geographic regions. Once established, national trade and traffic lead to rapid distribution within the geographic zone.

In Europe, *Ae. albopictus* was first reported in Albania in 1979 and the second time in Italy in 1990, where it was introduced through the import of used tires from the USA to the port town of Genoa. Within the following years, this species was rapidly dispersed to other regions of Italy and has been reported in France, Montenegro, Bosnia-Herzegovina, Belgium, Switzerland, The Netherlands, Greece, Slovenija, Croatia, and Spain. In September 2007, *Ae. albopictus* was discovered in the Upper Rhine valley of Germany, thus being present in 13 European countries (Pluskota et al. 2008a).

Surveillance and control activities for *Ae. albopictus*

In cooperation with the University of Heidelberg, KABS has comprehensively analyzed the potential for this mosquito to spread in Germany based on climatic modeling (Pluskota et al. 2008b). This model is mainly based on the 18+°C isotherms of the three warmest summer months (June to August), the −3°C isotherms of the coldest month (January), and an annual precipitation of 500 mm. Drawing on additional climatic variables, areas of potential expansion can be divided into different groups with different levels of risk (Fig. 7). For the determination of the reproduction period, the number of days of frost during the overwintering period and the seasonal emergence of the apple tree blossoms (which differs by region) are taken into account. Whereas mean temperatures reflect macroclimate conditions, phenological data such as the commencement of apple tree flowering take all relevant micro-, meso-, and macroclimatic factors into account.

Mathematic modeling also suggests that the permanent establishment of *Ae. albopictus* within the Upper Rhine lowlands is possible given the current favorable climatic conditions (Pluskota et al. 2008b). With increasing temperatures, this mosquito could also establish itself in other parts of Germany.

In 2005, KABS initiated a project to react to the increasing chance of the introduction and the establishment *Ae. albopictus* in Germany. The primary goals of the project are to analyze the possible paths of introduction into Germany, to identify potential colonization sites, and to regularly monitor known “hot spots” in order to initiate appropriate control measures once these mosquitoes are reported.

From the beginning of May to the end of September of each year, these known “hot-spots” are monitored by using ovitraps (egg deposition traps), which are examined for eggs and larvae every 14 days. In addition, in the areas surrounding the traps, promising woodlands are checked for mosquitoes using the human bait method (a test person exposes his body to attract mosquitoes). Deposited eggs are preliminarily identified in the lab using a microscope, subsequently hatched and the larvae reared to the imago stage. Identification keys from Becker et al. (2003) are used to conclusively determine the species.

The primary mode of dispersal of *Ae. albopictus* through human activity has been by transport of the desiccation-resistant eggs with cargo that previously contained water. The most significant cargo of this type is the tires that have been stored outdoors. Therefore, companies processing or trading used tires are likely to introduce *Ae. albopictus* and are given high priority in the monitoring process.

Due to high humidity and cool air temperature, freight containers offer conditions suitable for the transport of living insects. Therefore, container terminals are also under observation.

The rest stops and parking lots on the German highway A5 have a high potential for serving as passage ways of introduction and, therefore, are the focus of the monitoring program. Highway A5 runs north–south through the entire Upper Rhine valley and is one of the most important

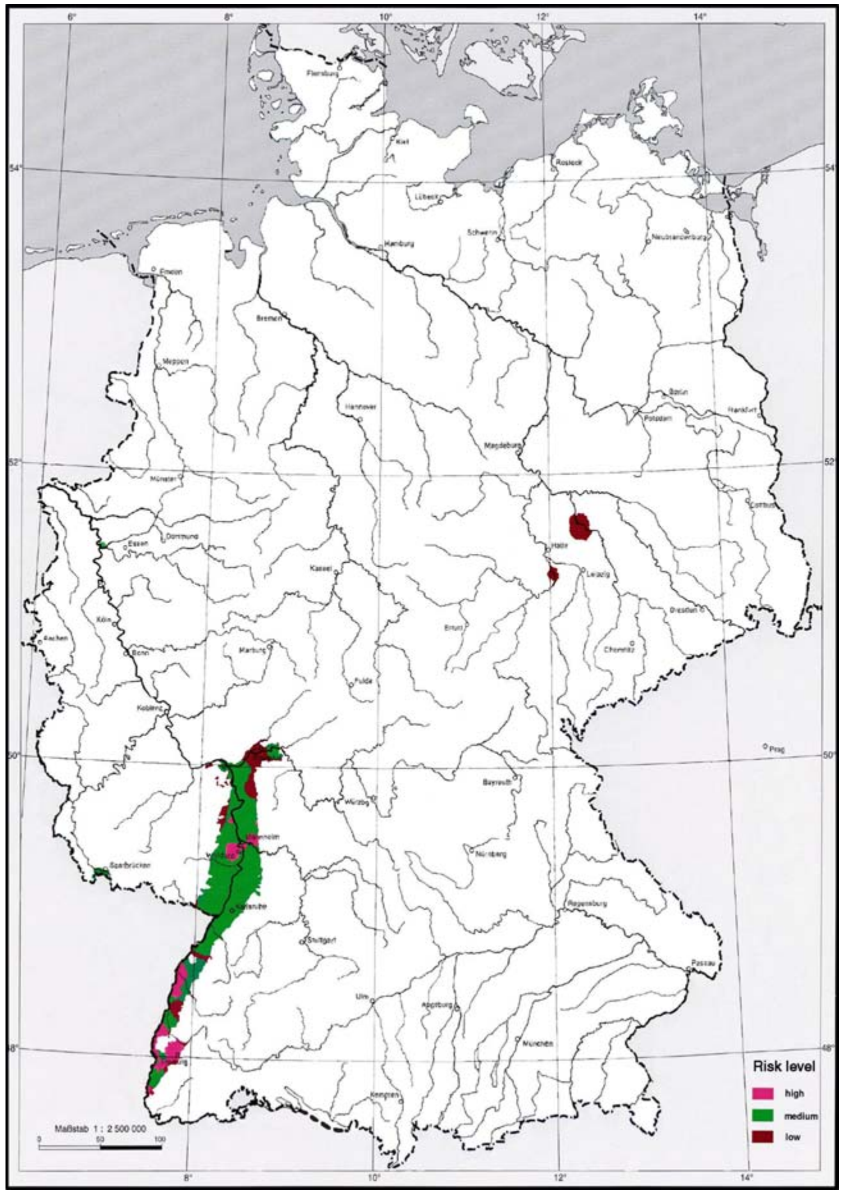


Fig. 7 Potential distribution areas of *Aedes albopictus* in Germany distinguished into different risk levels (Pluskota et al. 2008a, b)

continuous north–south freight lines in Europe, running from Scandinavia to the Mediterranean.

Within the monitoring program, so far, four species of the mosquito family Culicidae have been collected in the ovitraps. Most of the mosquitoes collected were the indigenous species *Ae. geniculatus* and *An. plumbeus* of the tree hole breeding (dendrolimnobiontic) type. *Cx. pipiens pipiens* was also collected in some cases. During trap inspection in September 2007, five *Ae. albopictus* eggs were found on the egg deposition substrate in one of the traps in the southern part of the German highway A5. After flooding the eggs several times with drying phases in between and keeping them at 25°C, two of the eggs hatched. Both hatched larvae developed into flying insects and were identified as *Ae. albopictus*, thereby providing the first evidence of this species in Germany. The female that laid the eggs in Germany most likely came from northern Italy.

Particularly at the end of vacation times in Germany, Scandinavia, and Benelux, a large number of tourists drive back from Italy on German highway A5. *Ae. albopictus* females are most likely attracted to the campers and caravans by human olfactory signals. Since caravans are commonly unoccupied while on the road, mosquitoes can be transported to distant places without being detected and killed in cars and truck cabins. In addition, females could have had blood meals in their place of origin (e.g., Italy) and then rested in dark areas of the caravan during oogenesis. After arriving in Germany, they could have left the caravan to deposit their eggs (Pluskota et al. 2008a).

Control measures for the next years

Monitoring program

In the coming years, the scope of the program of monitoring the spread of *Ae. albopictus* in Germany will be expanded. In particular, the number of surveillance traps will be increased on positive sites, and potential breeding sites (e.g., tree holes and artificial sites) will be mapped and checked for larvae every 2 weeks.

Public relations measures such as an info-homepage (www.kabsev.de) and info-brochures as well as press releases will and have in the past activated community participation. Precise physical descriptions of *Ae. albopictus* have been placed on the homepage. Due to this, mosquitoes (and other insects) are regularly sent to KABS for identification. The participation of the public can ensure a useful record of the incidence of *Ae. albopictus.*

Control measures

(a) Culinex/Vectobac DT-Bti-tablets are being available across Germany to control container-breeding mosquitoes. These tablets have been used in the KABS area for more than 15 years, thereby minimizing the risk of establishment of new container-breeding mosquitoes. Since some years, Bti-tablets are also used in Italy against *Ae. albopictus*.

(b) The public is being called upon to eliminate unnecessary potential breeding sites, such as car tires, cans, and the like. Other man-made pools of water, such as rain barrels, are treated with Bti-tablets.

(c) With each occurrence of *Ae. albopictus* females, pyrethroid insecticides should be sprayed, which are relatively nontoxic to humans. Since their use would also be limited to local areas when fish habitats are absent, they are also ecologically justifiable.

(d) National and international cooperation should be increased to confront the *Ae. albopictus* phenomenon. Close collaboration with other European working groups and organizations, such as the European Mosquito Control Association and the European Centre for Disease Prevention and Control, are called for.

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