

Will malaria return to Europe under the greenhouse effect?

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Abstract

Malaria risk is determined by environmental and socio-economic factors. The predicted climate change under the greenhouse effect is likely to affect the epidemic potential of malaria due to a change in vector mosquito phenology and distribution. This effect was simulated using a computer model incorporating mosquito life stages and parasite infections in the mosquito and human host. It was found that both air and water temperature are the most important factors determining mosquito phenology and density. A temperature rise of +4°C shows major changes in mosquito distributions and densities at a worldwide scale, but more so in temperature regions than near the equator. The European situation was taken as an example to study epidemic potential under climate change. Malaria risk, in particular that of *Plasmodium vivax*, would increase under climate change. There is little risk for transmission of *P. falciparum* in currently temperate areas because the local anophelines are refractory to this parasite. In areas adjacent to malaria endemic regions, however, climate change may cause a dramatic shift in *P. falciparum* risk.

1. INTRODUCTION

The predicted climate change as a result of the greenhouse effect is expected to cause major shifts in the distribution and epidemiological risk of vector-borne diseases (1), of which malaria is undoubtedly the most important. At present, some 400 million new cases of malaria appear each year with an estimated one million deaths (2). The world distribution of malaria is to a large extent determined by the geographical distribution of the anopheline vectors. In temperate regions malaria was eradicated due to a judicious use of control methods, which was made possible because of the absence of transmission in the winter months (3). Malaria eradication has failed in the tropics because of technical failures and inadequacies, environmental factors, and low level of socio-economic development. It is feared that under the predicted climate change the risk of malaria might return to areas where it was formerly endemic, as well as to areas adjacent to currently endemic regions. In the present study we investigated the risk of malaria transmission in Europe under climate change, using a simulation model for mosquito population dynamics and vectorial capacity.

2. THE MODEL

A weather driven, stochastic life-table simulation model (MOSQSIM) was developed to simulate the phenology and population dynamics of mosquito species. The core of the program is the so-called fractional boxcar train. This numerical scheme simulates the development cycle of an entire population during one or more stages. Both development rate as well as dispersion of development rate can be changed during the simulation (4). The model calculates the development of the mosquito population with a daily output of all life stages. Water temperature, affecting development of the aquatic mosquito stages, is calculated via an energy exchange model. Malaria transmission is simulated by allowing fractions of mosquitoes to feed on malaria infectious hosts.

2.1 Meteorology

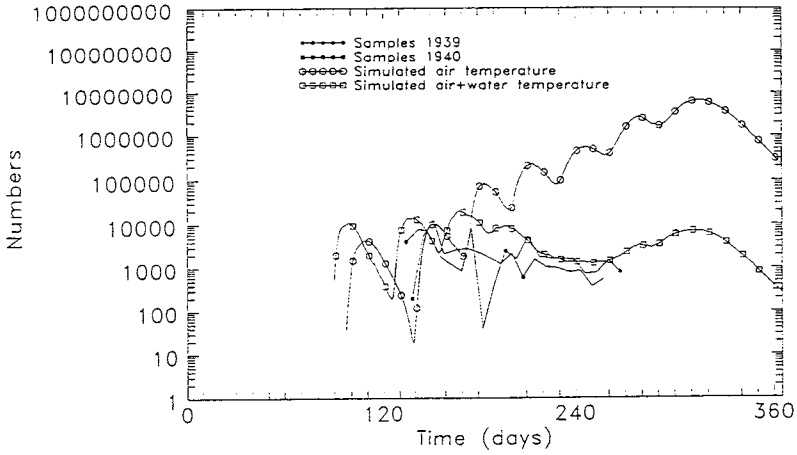
Daily weather data on temperature, humidity and sunshine duration used for case studies were obtained from routine meteorological measurements for locations studied. Monthly averaged minimum, maximum and mean temperature, mean relative humidity, wind speed and sunshine duration were derived from a global climatological database (5). The database is used to define the various climate scenarios due to the greenhouse effect.

Temperatures during the day have been simulated using the maximum and minimum air temperature. The temperature in the aquatic habitat is determined by the meteorological conditions (temperature, humidity, radiation, wind) and the characteristics of the habitat itself (depth, horizontal water flow, radiation absorption, vegetation). Estimated surface water temperatures were calculated using a mathematical model based on a model described by Losordo and Piedrahita (6). This model calculates temperature variation and thermal stratification in shallow aquaculture ponds.

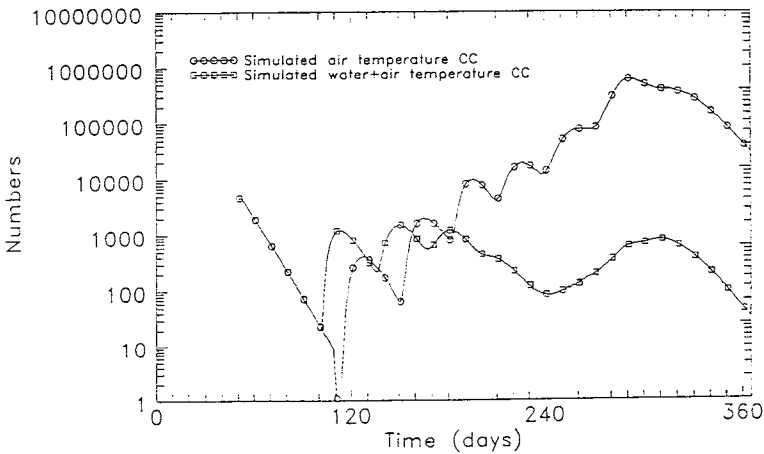
3. RESULTS

3.1 Case study

From a sensitivity analysis it was found that the temperature of the aquatic habitat plays an important role in larval development and survival. As far as we have been able to ascertain, only one reliable data set of both aquatic and terrestrial stages is available, namely from Aguas de Moura in Portugal (7). The larval and pupal countings reported by these authors were used to verify model computations for *An.*



Aguas de Moura: Larval stage IV



Aguas de Moura: Adults

Fig. 1 - Comparison of simulated and field collected data in Aguas de Moura, Portugal, of (A) larval populations of *Anopheles atroparvus* and of adult populations. Simulations are shown for air temperature only and air and water temperature combined.

atroparvus. Mean monthly maximum temperatures, minimum temperatures and relative humidities for Aguas de Moura during the period 1937-1940 were derived from (8). The simulations have the same pattern as the observations (Fig. 1). After two generations the number of emerging adults starts to decrease due to an increased mortality of the aquatic stages. At the same time adult mortality increases due to higher vapour pressure deficits. At the end of August the number of female adults reaches a minimum value and starts to increase again till November. A first peak of adults in May-June and a second peak in September-November was typical for southern Europe.

3.2 Distribution of malaria vectors in Europe

The distribution limits of the various species of the *An. maculipennis* complex are determined by environmental conditions. Mortality is closely related to aquatic and ambient temperatures. The model parameters found in literature have been used to calculate the population dynamics of members of the *An. maculipennis* complex over Europe using climate data. Incorporation of the water surface model (see above) enabled us to simulate the distribution of the various species. Results from simulations, using the weather data of the various stations in the Müller climate-database, predicted where in Europe malaria was endemic. The model had a good fit with historic data from malaria endemic areas in Europe. Based on these simulations it is possible to use the MOSQSIM model to predict the effect of climate change on malaria.

3.3 European distribution *An. atroparvus*

An. atroparvus is the most widespread malaria vector in Europe. Under increasing temperatures (+4°C), the model predicts an increase in adult mosquito densities in northern Europe but a decrease in southern Europe. At the southern distribution limit of *An. atroparvus* the number of adults sharply decreased. The highest densities were calculated for central Europe. Under increasing temperatures the model predicts an 100 fold or more increase in infectious mosquito densities in central Europe but a decrease in south-eastern Europe.

3.4 Epidemic potential

A comparative index to estimate malaria risk was derived from the vectorial capacity and is expressed as epidemic potential. This is defined as the reciprocal of the critical density threshold of mosquitoes resulting in more than one new potentially infective contact per infectious person per unit time. Simulated global changes of yearly mean epidemic potential for *Plasmodium falciparum* caused by a temperature increase of 4°C show a projected worldwide increase and an extension of the areas conducive for malaria transmission as climate changes. The highest changes are seen at the northern and southern distribution limits of *P. falciparum* and at higher altitudes within malarious areas (9). Particularly in temperate zones where malaria was once widespread, epidemic potential is likely to increase due to an increase of

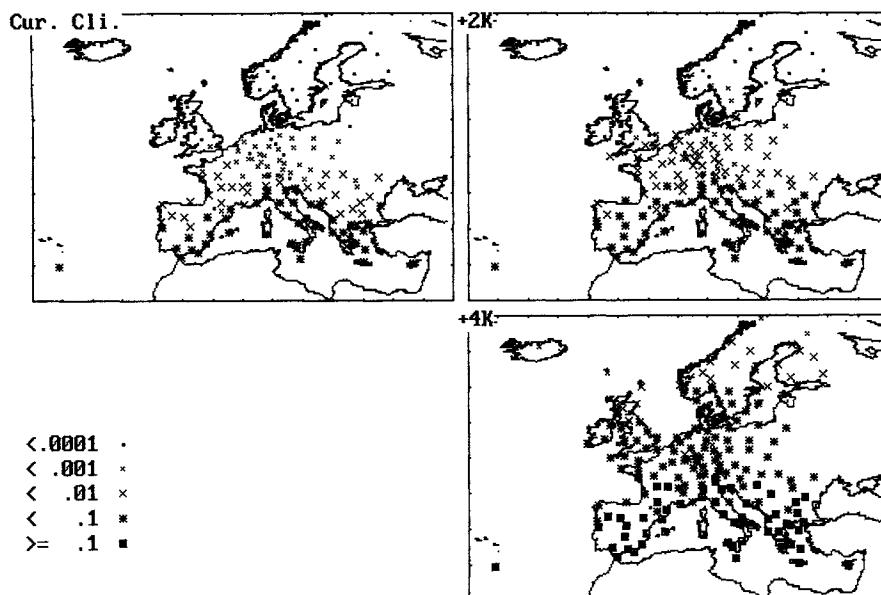


Fig. 2 - The impact of a temperature increase on the simulated epidemic potential of *P. vivax* malaria in Europe for September. Cur.Cli. = Current Climate; +2K = temperature increase of 2°C; +4K = temperature increase of 4°C.

parasite development rate in the mosquito, mosquito longevity and biting rate. This concerns large parts of the world including Europe, the Asiatic part of Russia and the continental USA. In these regions potential malaria transmission will largely be due to *P. vivax* because many anopheline species of these regions are refractory to *P. falciparum*. The model predicts that under a temperature rise of +4°C, epidemic potential of *P. vivax* malaria increases 10 fold in southern Europe and 100 fold further north (Fig. 2).

4. DISCUSSION

In the present study it is shown that the population dynamics and distribution of European malaria vectors can be simulated accurately provided the models incorporate environmental data from a large number of geographical locations. The significant difference between surface water temperature and ambient temperature as derived from this study, shows that the impact of climate change can affect insect populations in two ways. First, higher temperatures may cause increased mortality of aquatic stages in species adapted to the Mediterranean climate and second, higher temperatures lead to accelerated development and extra generations in the more northern vector species without the observed mortality in the aquatic stages. The study clearly

shows that the winter temperatures in Europe were the limiting factors for malaria transmission of the past. Under the predicted climate change, with higher annual temperatures, there will probably be a shift of anopheline distribution in Europe, with the southern species moving further north, and the northern species extending their phenological duration and density. For these reasons the risk of malaria transmission will increase provided infectious individuals are present in the human population.

Endemic malaria has been eradicated from Europe since the nineteen seventies, and in the absence of a *Plasmodium* reservoir, we do not expect a return to a state of endemic malaria due to an increasing potential transmission intensity caused by climate change. The high level of socio-economic development in Europe, in particular the health care system and current animal husbandry, will prevent a reintroduction of endemic malaria. However, large numbers of imported cases of malaria are being registered in Europe each year due to the increased travel to and from endemic countries. Therefore, with the densities and distribution of European anopheline species increasing, there is an increased risk of incidental *P. vivax* cases, especially in those areas in south-eastern Europe where socio-economic conditions have deteriorated.

The present study focused on the impact of climate change on malaria vectors in Europe. Preliminary investigations on a global level demonstrated that the models can be used to predict malaria risk and vector distribution on a larger scale (9; 10). Such studies will be especially useful to assess the risk of malaria (and other vector borne diseases) under climate change in areas that are bordering endemic regions and to predict the potential shift in transmission risk in endemic areas. Such studies are needed in order to prepare for the consequences of climate change at the socio-economic level, particularly in developing countries.

5. REFERENCES

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