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Climate change and malaria risk

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Abstract
The biological activity and geographic distribution of the malarial parasite and its vector are sensitive to climate influences, especially temperature and precipitation. In this paper the effects of an increase in temperature on the epidemic potential of malaria are explored. Assessment of the potential impact of global climate change on malaria risk suggests a widespread increases of risk due to an expansion of areas suitable for malaria transmission. The health impact will be most pronounced in populations living in the less economically-developed temperate areas in which endemicity is low or absent.

1. THE ISSUE

The occurrence of vector-borne diseases ranges from the tropics and subtropics to the temperate climate zones. With a few exceptions, vector-borne diseases do not occur in the cold climates of the world. In Table 1 some of the world's most important vector-borne diseases are listed.

Table 1: Global status of the major vector-borne diseases in 1990.[1]

disease	vector	populations at risk (millions)	prevalence of infection (millions)
malaria	mosquito	2200	270
schistosomiasis	snail	600	200
lymphatic filariasis	mosquito	900	90.2
onchocerciasis	blackfly	90	17.8

The extent to which vector-borne disease transmission occurs in a specific area is determined by two factors: first, the presence of (an abundance of) vectors capable of transmitting the disease, and second the presence of the relevant parasite. Any factor influencing these two determinants hence influences disease transmission. Direct effects of the anticipated changes in global and regional temperature, precipitation, humidity and wind patterns resulting from anthropogenic climate change are the factors which have an impact on the vectors' reproduction habits and on their longevity, and are thus associated with changes in annual vector density. In general, the rate of development of a parasite accelerates as the temperature rises. An increase in temperature may therefore result in the completion of the life cycle of a parasite in areas in which previous temperatures were too low for the parasite to reach maturity. Indirect effects of climate change include changes in vegetation and agricultural practices which are mainly caused by temperature changes and trends in rainfall patterns. Another indirect effect of climate change is associated with the rise in sea level and the resulting coastal flooding. The proliferation of brackish water lagunae influences the availability of habitat and either encourages or discourages vector species depending on whether they prefer brackish water. Generally speaking, drought and desertification, including a migration or extension of global desert belts, could be expected to decrease vector-borne disease transmission. It is thus evident that major changes in the incidence of vector-borne diseases associated with a climate change might be expected, and that the manifestation of these changes is closely related to socio-economic development and the provision of health services.

2. MALARIA: A GLOBAL PROBLEM

One of the world's most important vector-borne diseases is malaria, and there are few infectious diseases which have as great an impact on the social and economic development of societies. Out of a world population of approximately 5,300 million people in 1990, some 2,200 million are regarded as being at risk of contracting malaria. Roughly 270 million people are actually infected with the malaria parasite. At present, the distribution of malaria is mainly restricted to the tropics and sub-tropics, although before the Second World War malaria was a common disease in many temperate areas of the world. Malaria eradication campaigns and socio-economic development caused malaria to disappear from areas in which it had previously been endemic, although mosquito densities still allow transmission in these areas.[2] The incidence of malaria is determined by various factors: the abundance of *Anopheline* species, the propensity of the mosquitoes to bite human beings, the longevity of the mosquitoes and the rate at which the *Plasmodium* parasite in the mosquito develops.

3. TEMPERATURE AND EPIDEMIC POTENTIAL

A unit of measurement which encapsulates many of the important processes in the transmission of infectious diseases is the basic reproduction rate (R_0), defined as the average number of secondary infections produced when a single infected individual is introduced into a potential host population in which each member is susceptible.[3] The basic reproduction rate allows us to calculate the critical density threshold of host populations necessary to maintain parasite transmission. The critical density for malaria transmission can be expressed as:

$$\frac{N_2}{N_1} = k_1 * \frac{-\log(p)}{a^2 p^n} \quad (1)$$

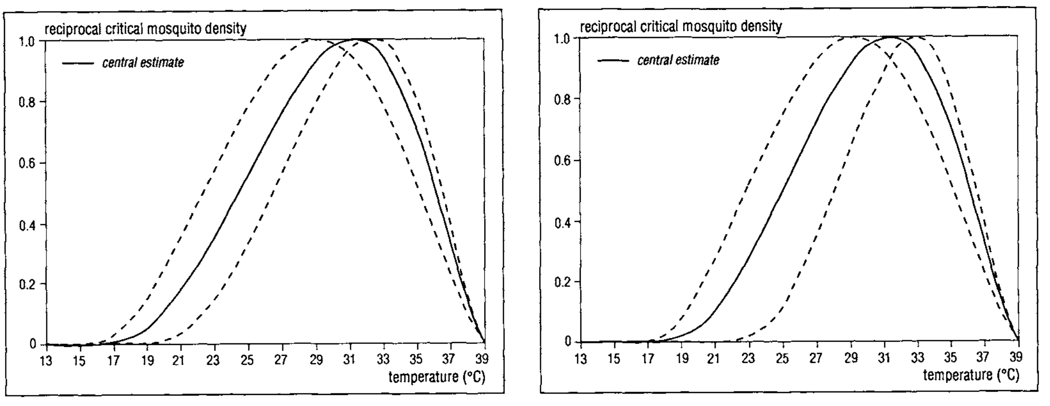
where N_2/N_1 is the number of malarial mosquitoes (N_2) per human (N_1); p the survival probability of the mosquito; a the frequency of taking human blood meals; n the incubation period of the parasite in the vector. The term k_1 is a constant, incorporating variables assumed to be temperature independent (including the efficiency with which an infective mosquito infects a susceptible human and an infected human infects a susceptible mosquito, the number of blood meals a mosquito takes from man, and the recovery rate in man). The epidemic potential of malaria is defined as the reciprocal of the host density threshold. This epidemic potential can be used as a comparative index in estimating the effect on the risk of malaria represented by a change in ambient temperature. In Table 2, a number of temperatures which are critical to malarial transmission are set out.

Table 2: Crucial temperatures in malarial transmission.

	extrinsic incubation cycle Plasmodium species		digestion of blood-meal Anopheline species		
	vivax	*falciparum*	*maculipennis*	*culicifacies*	*stephensi*
degree-days (°C day)	105	111	36.5	29.7	43.4
threshold temperature (°C)	14.5-15	16-19	9.9	12.6	8.9

The most direct effect of temperature is on n. The incubation period of the parasite in the malarial mosquito must have elapsed before the infected vector can transmit the parasite. The relation between ambient temperature and latent period is calculated using a temperature sum as described by MacDonald.[4] The frequency of feeding depends mainly on the rapidity with which a blood meal is digested, which increases as temperature rises, and can be calculated by means of a thermal temperature sum.[5] The female mosquito has to live long enough for the parasite to complete its development if transmission is to occur. Between certain temperature thresholds, the longevity of a mosquito decreases with rising temperature. The optimal temperature for mosquito survival lies in the 20-25°C range. Temperatures in excess of these will increase mortality and there is a threshold temperature above which death is inevitable. By the same token, there is a minimum temperature below which the mosquito cannot become active. Relying upon data reported by Boyd[6] and Horsfall[7], we assume a daily survival probability of 0.82, 0.90 and 0.04 at temperatures of 9°, 20° and 40°C, respectively.

The epidemic potential is most sensitive to changes in host mortality rates and development time of the parasite. In Figure 1 the influence of increasing temperature on the epidemic potential and the effects of different values of mosquito longevity and minimum temperature requirements for parasite development on the epidemic potential are illustrated.



A B

Figure 1:
Epidemic potential (valued as 1 as a maximum) for A) *P. vivax* (left-hand curve $p(20°C) = 0.8$ and $Tmin = 14.5°C$; central estimate $p(20°C) = 0.9$ and $Tmin = 14.5°C$; right-hand curve $p(20°C) = 0.95$ and $Tmin = 15°C$), B) *P. falciparum* (left-hand curve $p(20°C) = 0.8$ and $Tmin = 16°C$; central estimate $p(20°C) = 0.9$ and $Tmin = 16°C$; right hand curve $p(20°C) = 0.95$ and $Tmin = 19°C$).

A high epidemic potential indicates that despite a smaller vector population, or alternatively, a less potent vector population, a given degree of endemicity may be maintained. As temperature increases, epidemic malarial potential increases until a maximum is reached. At high temperatures, the accelerated development of the parasite and the increased biting rate can no longer compensate for the decreasing mean life expectancy among the mosquitoes. The distributions shown in Figure 1 indicate that, in temperate climates, small increases in temperature can result in large increases in epidemic potential, irrespective of the values chosen for the survival probability or minimum temperatures assumed for parasite development. The effect of an increase in temperature will be more pronounced on the epidemic potential of less potent mosquito populations. It should be noted that, although the maximum values for epidemic potential are found in the ranges 29-33°C for malaria, the actual transmission intensity also depends on vector abundance. The optimal temperature for the rapid expansion of a population of malarial mosquitoes is found to lie in the range 20-30°C.[8] Therefore, within this range, an increase in mosquito numbers may cause an additional increase of the epidemic potential.

4. MALARIA RISK DUE TO CLIMATE CHANGE

The concept of the basic reproduction rate, discussed in the previous section, is used in an integrated linked-system model to study the effects of projected changes in temperature and precipitation on malaria epidemic potential next century.[9] Here, some major conclusions of this study are presented.

With a global mean temperature increase of approximately 3°C, the simulation runs on the model show a projected worldwide increase in transmission potential of the mosquito population and an extension of the areas conducive for malaria transmission. The risk of introduction of malaria transmission in non-malarious areas, including large parts of Australia, the United States, and Southern and Central Europe, associated with imported cases of malaria is a real one, since the former breeding sites of several *Anopheles* species are still available. Given the fact that in the most developed countries, effective control measures are economically feasible, it is not to be expected that human-induced climate changes would lead to a return of a state of endemicity in these areas. A different situation can be expected in currently endemic areas and areas bordering on them, especially in the subtropics. In the highly endemic malarious areas of tropical Africa, the malaria prevalence may increase. In the malarious areas of lower endemicity, however, the prevalence of infection is far more sensitive to climate changes. Therefore, a human induced climate change may have profound effects on numbers of people suffering from malaria in such areas.

In this study, the *direct* effects of a changing temperature and precipitation on malaria transmission were considered. Additional research on the biological, ecological and socio-economic factors important in malaria transmission will be required for a more complete analysis of the impact of a human-induced climate change on this vector-borne disease.

5. REFERENCES

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