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Malaria risk in the highlands of western Kenya: an entomological perspective

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Abstract

Epidemics of malaria seem to occur more frequently in the highlands of eastern Africa. In western Kenya, for example, epidemics have spread from 3 to 15 districts. There is an increasing debate on the possible causes of this phenomenon, but detailed field studies are lacking to test a number of basic hypotheses. In this chapter, we review some of the results from a comparative field study on malaria risk in a highland and a lowland area in western Kenya. Questions that will be addressed in this chapter are: under which conditions may malaria epidemics occur in highland areas and to what extent is the situation in western Kenya comparable to other highland areas in the region?

Keywords: *Anopheles gambiae*; *Anopheles arabiensis*; malaria risk; Kenya; environmental change; highlands

Introduction

The intimate relationships between parasites or viruses, and their vectors, hosts and natural environment make this ecological web extremely sensitive to disturbances. Therefore, environmental and socio-economic changes, such as global warming, deforestation, commercial development and construction of water-control systems, are expected to exert a huge impact on the transmission of viral and parasitic diseases, such as Rift Valley fever, yellow fever, schistosomiasis, filariasis and malaria (Githeko et al. 2000; Martens, Slooff and Jackson 1997; Martens 1998; Patz and Reisen 2001; Patz et al. 2000). The diseases may spread to areas where they did not occur before or the current situation may aggravate in areas where the disease is already endemic.

Theoretically, one infective mosquito bite is enough to acquire an episode of malaria. Clinical symptoms may range from mild, such as fever, abdominal pains, nausea and vomiting, to severe and life-threatening, such as anaemia, renal disfunction and cerebral malaria (Warrell 1993). However, not everybody who gets an infection becomes seriously ill or dies, because this depends on the degree of immunity of the individual. A substantial level of immunity to malaria may already be acquired after one or two infective bites. The antigenic variation of *P. falciparum* (i.e.

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the variation in antigens expressed at the surface of the infected red blood cell) is thought to play an important role in this (Day and Marsh 1991; Gupta et al. 1999; Roberts et al. 1993). During their first 3 to 6 months of life, infants have a protective immunity through antibodies they obtained from their mother. After this period, they will build up protective immunity, if regularly infected, and around their fourth year of life the severity of malaria attacks begins to decline. As evidenced from field studies, death among adults is rare in high-transmission areas, but the level of immunity may rapidly decrease when moving outside these areas (Marsh 1993).

From this follows that children up to the fifth year of life are at high risk of dying from malaria (if not appropriately treated). Also pregnant women deserve special attention, since malaria infection during pregnancy may lead to low birth weight of the infant, either through prematurity or intra-uterine growth retardation. Low birth weight, on its turn, may lead to infant mortality (Steketee et al. 2001). Furthermore, people living in areas where transmission is low or absent, such as the cool highland areas or areas at the northern and southern fringes of current malaria distribution, are also at high risk of getting severe malaria once infected.

Epidemic malaria

Historically, outbreaks of malaria have occurred in areas of unstable malaria transmission when environmental conditions were favourable (Garnham 1945; 1948). However, there is evidence that the number of outbreaks has increased during the past decades. In eastern Africa, many countries have suffered from serious epidemics with a high number of deaths (Malakooti, Biomndo and Shanks 1998; Etchegorry et al. 2001; Bonora et al. 2001; Lindblade et al. 1999). In western Kenya, malaria epidemics have spread from 3 to 15 districts during the past 13 years, often with devastating effects (Githeko and Ndegwa 2001). Some of these epidemics have been associated with extreme weather events, such as the El Niño Southern Oscillation event in 1997-1998, which caused heavy rainfall and flooding in eastern Africa (WMO 1999). Curiously, the same climatic event in Tanzania was associated with lower malaria incidence (Lindsay et al. 2000), suggesting that no clear-cut answer exists to what the effects of these extreme weather events are on malaria transmission.

Next to analysing single malaria outbreaks, researchers have attempted to relate historical patterns of malaria incidence to environmental changes. Increased malaria incidence over the past 30 years in the highland tea estates of western Kenya could not be explained by increased temperatures or a changed climate in general (Shanks et al. 2000; 2002). Similar observations were made for other East-African countries (Hay et al. 2002a), although a re-analysis of climatic data did show a warming trend for the same countries (Patz et al. 2002). This has led to a debate on the potential causes of malaria resurgence in eastern Africa, with global warming on the one hand and non-climatic events, such as the emergence of chloroquine resistance during the 1980s, on the other (Hay et al. 2002b; Patz et al. 2002). Although climatic changes may not be evident from the recent past, a warming climate in the near future, as predicted by various climate-change scenarios (IMAGE team 2001), may have severe consequences for malaria transmission.

With the advancement of satellite imagery and Geographical Information Systems (GIS), researchers have been able to integrate the different entomological, epidemiological and socio-economic components of malaria risk in 'easy-to-handle' data sets and 'easy-to-interpret' figures (see, e.g., MARA/ARMA 2002). This has resulted in a variety of models to forecast malaria outbreaks (so-called early-warning

systems (Thomson and Connor 2001), study malaria transmission patterns and assess malaria risk in relation to climate change (Table 1).

Table 1. Examples of models developed to predict malaria epidemics and assess malaria risk in relation to environmental change. Input data and output parameters are given together with the area for which they were developed

Input	Output	Area	Goal	Reference
Rainfall and maximum temperature	Epidemic risk	Kenya	Early warning	Githeko and Ndegwa (2001)
Malaria vector density	Epidemic risk	Uganda	Early warning	Lindblade, Walker and Wilson (2000)
Number of presumptive malaria cases	Epidemic risk	Madagascar	Early warning	Albonico et al. (1999)
Normalized Difference Vegetation Index (NDVI)	Malaria seasonality	Kenya	Predicting malaria transmission seasonality	Hay, Snow and Rogers (1998)
Rainfall and temperature	Distribution of *An. gambiae s.s.* and *An. arabiensis*	Africa	Facilitating species-specific vector-control activities	Lindsay, Parson and Thomas (1998)
Temperature, NDVI, cold-cloud duration and elevation	Distribution of 5 sibling species of the *An. gambiae* complex	Africa	Forecasting malaria	Rogers et al. (2002)
Rainfall and temperature	Distribution of malaria transmission	Africa	Providing basis for predicting impact of climate change	Craig, Snow and Le Sueur (1999)
Rainfall, temperature and population data	Distribution of population exposed	Africa	Providing risk map for malaria mortality	Snow et al. (1999)[1]
Temperature and rainfall	Potential malaria risk	World	Assessing malaria risk in relation to climate change	Martens et al. (1995)

[1] Based on the model of Craig, Snow and Le Sueur (1999)

Most of these models have been developed to investigate malaria risk on the continental scale of Africa. Logically, these models are too crude to assess malaria risk on local and regional scales. They have rarely been validated with real data and make many assumptions and generalizations on malaria transmission. For example, the vector of malaria is often modelled as a generic species, whereas many differences exist in the transmission capability of the main malaria vectors. In addition, most models only consider the effects of ecological variables on the adult stage, while effects on the larval stages are often neglected. Furthermore, it is still unknown which ecological variables are responsible for the temporal and spatial dynamics in species

abundance and how this affects malaria risk. Besides, it is not clear how malaria transmission is maintained in highland areas or how epidemics may occur here.

Vector biology and malaria risk on a local scale

A means of understanding the effects of environmental factors on malaria vector biology and malaria risk is to study these on different spatial and temporal scales. This is schematically presented in Figure 1. A comparative field study was undertaken in western Kenya to investigate vector population dynamics in relation to malaria risk (Koenraadt 2003). *Anopheles arabiensis* Patton and *Anopheles gambiae s.s.* Giles, both members of the *Anopheles gambiae* complex, and *Anopheles funestus* Giles are the main vectors involved in malaria transmission in this area. In addition, western Kenya is of particular interest, since on a relatively small spatial scale there is considerable variation in altitude, climatological conditions and land-use patterns. As a consequence, the epidemiological situation of malaria varies as well (Figure 2). Here, we briefly summarize some of the most important findings of this study for our understanding on malaria transmission in highland areas.
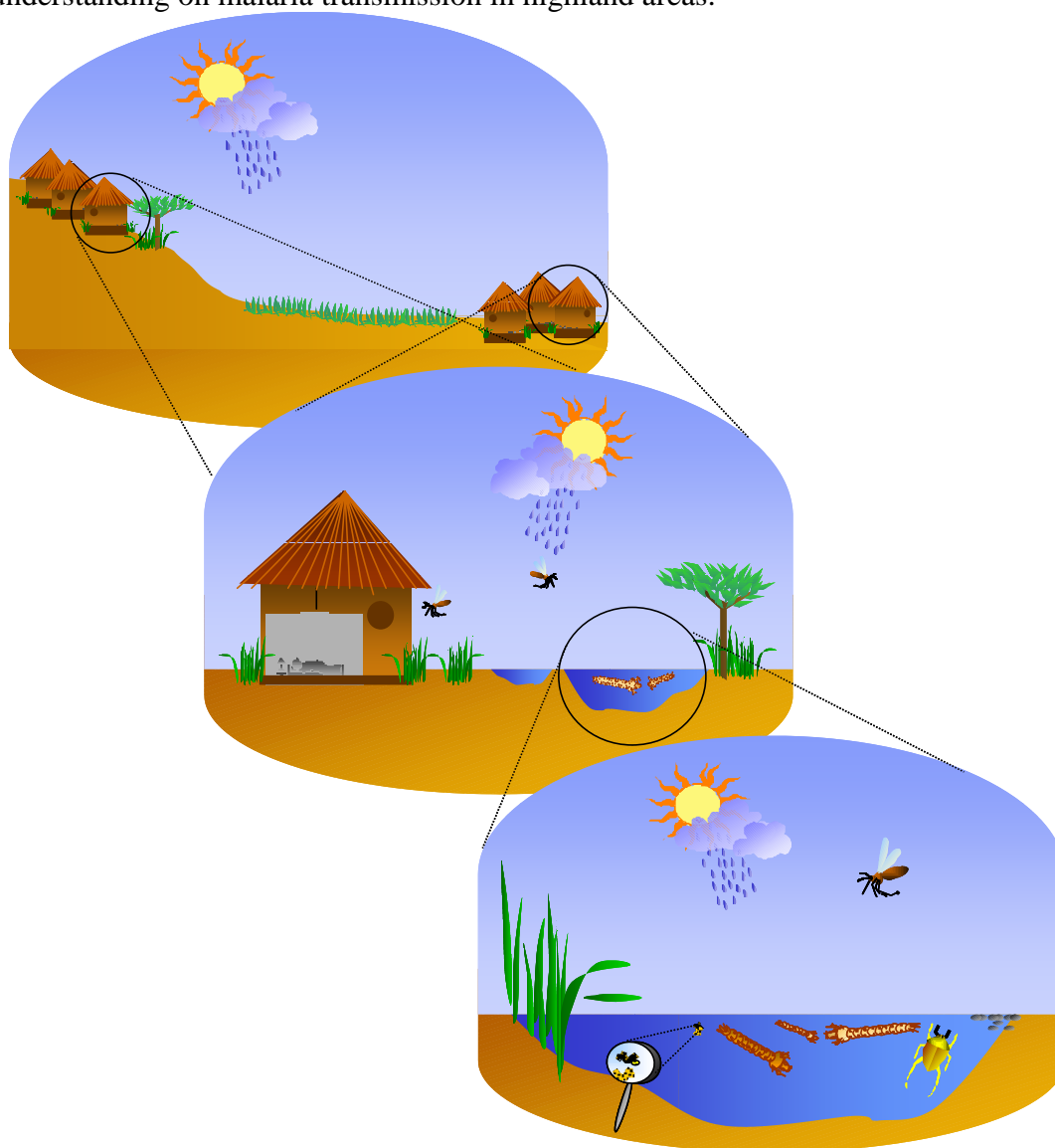

Figure 1. Schematic representation of the different scales when investigating the effect of environmental factors on vector biology and malaria risk
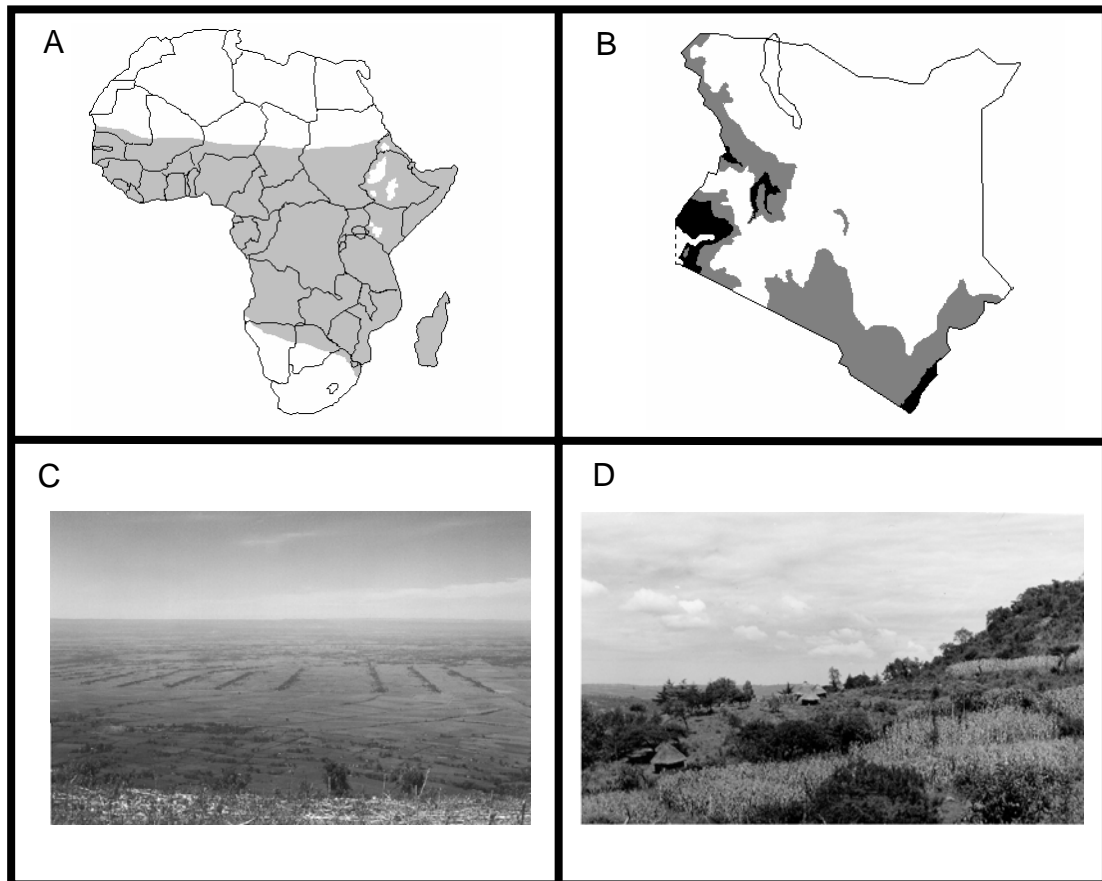
Figure 2. (A) Malaria distribution over Africa (drawn after WHO 1997); (B) epidemiological situation of malaria in Kenya. Black areas: endemic malaria; grey areas: epidemic malaria; white areas: no malaria (drawn after MARA/ARMA 2002); (C) picture of lowland area in western Kenya (approximately 1200 m altitude), characterized by the flat terrain and surrounded by large sugarcane plantations; (D) picture of highland area in western Kenya, 40 km south-east of the lowland area, characterized by a hilly landscape with mixed agriculture (approximately 1600 m altitude).

A striking result was that, despite the near absence of malaria vectors (5 malaria vectors were collected in 200 light-trap and 190 resting-catch collections spread over two years), malaria was transmitted throughout a two-year study period in a highland area of western Kenya (at 1600 m altitude). Malaria prevalence was relatively low, with a two year average of 10% among school children in the age of 5 - 10 years (minimum 0% and maximum 17% prevalence). Larval habitats of *An. gambiae s.l.* were present in the highland area, although their number was rather limited compared to a lowland area 40 km to the northwest (at 1200 m altitude). For example, only 7 *An. gambiae s.l.* breeding habitats were identified during a 4-month study within an area of approximately 4 km^2, whereas on a 1.7-km dirt road in a lowland area more than 100 *An. gambiae s.l.* breeding habitats could be identified on a single sampling occasion (Koenraadt, Githeko and Takken 2004). Interestingly, three of the seven identified breeding sites in the highland area were the result of human conduct: larvae were found in sites that were the result of leaking taps or in sites that were regularly filled by people for domestic purposes or to provide drinking water for cattle. All *An. gambiae s.l.* larvae were found in the presence of larvae of *An. christyi* Newstead & Carter. To what extent this association affected vector dynamics in the area, remains

unclear. Experimental studies showed that larvae of *An. gambiae s.s.* and *An. arabiensis* did not survive the cool environmental temperatures in the highland area, whereas adults of both species (placed in cages) survived inside local houses in the same area (Koenraadt 2003). These studies also showed that adults of *An. gambiae s.s.* survived longer than *An. arabiensis* in the highland area, whereas the reverse was true for the lowland area. In addition, larvae of *An. arabiensis* developed faster to the pupal stage than *An. gambiae s.s.* in the lowland area, consistent with earlier findings under laboratory conditions (Schneider, Takken and McCall 2000). The combined experimental and field observations suggested that the contribution of a locally breeding vector population to malaria transmission in the highland area was negligible. More likely, the few infections among school children were caused by infected mosquitoes that immigrated from areas where environmental conditions are more favourable. Since children rarely moved out of the study area, we ruled out the possibility that their infections were obtained through visits to lower areas. Population-genetic studies on vectors collected in highland areas and in the nearby lowland areas may give more insight in the degree of gene flow and thus the amount of genetic divergence between highland and lowland mosquitoes (Wang, Kafatos and Zheng 1999; Lehmann et al. 1997, Lanzaro pers. comm.).

It should be emphasized that the transmission process described above may not be valid for all highland areas in eastern Africa. Local variation may arise as a result of differences in (i) geography, e.g. highland areas may be surrounded by steep escarpments or valley bottoms, and (ii) land cover/land use: suitability of the environment for mosquito survival and dispersal will differ between, for example, relatively bare highland areas, areas surrounded by marshes and areas with large-scale agriculture. Several studies have focussed on malaria transmission in high-altitude areas in Kenya, Tanzania and Uganda, and the role of vectors therein. However, these studies were limited to collections of the adult stages (Bødker 2000; Lindblade et al. 1999; 2000; Minakawa et al. 2002; Shililu et al. 1998). Therefore, most of these studies could not confirm the true existence of transmission by a local population or transmission by a population which immigrated from an adjacent area.

The insights obtained on malaria transmission in a highland area, allow us to speculate in more detail on the potential impact of environmental change on malaria risk. An increase in temperature in the near future, either as a result of global warming or land-use changes affecting microclimate, may enhance larval survival. As a result, local vector populations may establish in sufficient numbers to cause epidemics. This is supported by observations of Garnham (1945), who speculated that epidemics occurring at high altitudes may result from temporarily favourable climatic conditions that allow breeding of *An. gambiae*. On a larger time scale, it may be the more efficient vector *An. gambiae s.s.* settling first in highland areas, because this species survives better than *An. arabiensis* under present highland conditions.

Temperature and vector density have been used to develop early warning systems based on data from past epidemics (Githeko and Ndegwa 2001; Lindblade, Walker and Wilson 2000). Our results demonstrate that monitoring the larval stages may provide an additional means to assess the likelihood of outbreaks of malaria. For example, a warning based on increased environmental temperatures may be more confident if it is associated with high densities of local breeding sites in which larvae survive.

Final remarks

From our studies it became clear that many biological processes underlying the rise and fall of malaria vector populations are still poorly understood. Besides the mentioned differences in larval development and adult survival in response to different environmental conditions, other factors, such as competition among *An. gambiae s.l.* larvae occupying a site (Koenraadt and Takken 2003) and larval behaviour in response to drought (Koenraadt et al. 2003) may also play an important role in determining the size and species composition of vector populations. Although the evidence seems to point towards the establishment of vector populations in a highland area from nearby lower areas when environmental conditions are suitable, the degree of immigration remains to be studied. Finally, the phenomena observed in the highland area in western Kenya need to be evaluated for other areas in eastern Africa. Only then, local malaria risk models can be reliably upscaled to the regional and continental scale.

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