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Effects of environmental change on malaria in the Amazon region of Brazil

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Abstract

Malaria is endemic in Brazil, affecting mostly the Amazon states. Whereas 50 years ago good progress was made towards its control, since the opening up of the Amazon region for forestry, agriculture and livestock activities, the disease has rapidly increased in incidence, peaking to >500,000 cases annually in the 1990s. Rondônia state was particularly hard hit, with thousands of new immigrants suffering malaria attacks. It is argued that the environmental change caused by deforestation has favoured the main malaria vector *Anopheles darlingi*, creating numerous sunlit larval habitats and bringing potential blood hosts in the vicinity of the mosquitoes. The creation of malaria clinics and strengthened control programmes has reduced the malaria situation, but risk is still high, particularly in rural and peri-urban areas where humans and mosquitoes are in close contact. The continuing environmental change, caused mainly by deforestation, is likely to favour the malaria situation in Brazil as it creates new malarial habitats and affects large numbers of non-immune settlers who are attracted to the Amazon region.
Keywords: malaria; *Anopheles darlingi*; Amazon; risk; deforestation; environmental change

Introduction

Recent publications about climate change as a result of anthropogenic activities predict a warming of the earth from 2.5 to 4 ^{o}C in the next century and dramatic variations in the intensities of precipitation with large differences between geographic areas (Watson, Zinyowera and Moss 1998). Apart from creating numerous effects on the environment, these changes are likely to affect human health as well. It has been suggested that vector-borne diseases may be one of the major health impact factors that will be affected (Patz and Balbus 1996; McMichael and Beaglehole 2000; Haines and Patz 2004). Among these, malaria has been singled out as a particularly vulnerable target, as both vectors (mosquitoes of the genus *Anopheles*) and parasites may be affected, and also because thousands of people are currently living in areas where the malaria vectors are present but the parasites are absent or circumstances are

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unsuitable for parasite development (Martens et al. 1999). Current epidemiological models predict malaria risk based on generalized climate data, using average annual temperatures and rainfall, with little regard for local variation. As the climate changes will affect regions differently, it is of critical importance to be able to study the effects of the changes on local malaria risk, taking into consideration the topography, land use, habitat structure and demography of each area. Other changes may also affect malaria risk, such as rapid changes in land use, deforestation, urbanization and human migration. As the predicted climate change may affect these entities differently, the study of environmental change and malaria becomes complex and challenging.

Malaria in Brazil is currently confined mostly to the tropical regions of the country, with the Amazon basin as the endemic region. Major threats to the Amazonian environment have taken place in the last 35 years, chiefly because of the large-scale deforestation of primary rainforest in connection with road construction and agricultural development (Cruz Marques 1987; Skole and Tucker 1993; Camargo et al. 1994; Cardille and Foley 2003; Souza et al. 2003). Indeed, the destruction of the rainforest has grown into a global debate as this is considered one of the contributions to climate change (Laurance 2000). These developments are still continuing at a rate of 2.4 million hectares of forest per year, in spite of scientific consensus that urgent measures are required to stop or reverse these developments for the principle reason that rainforests are critical sources of biodiversity and climate stability, and essential as carbon sinks (Laurance et al. 2001; 2004).

It has often been assumed that the disappearance of the rainforest would be accompanied at least by beneficial effects on vector-borne diseases, as the habitat of the vectors would be destroyed, and with this the transmission of infectious diseases would be reduced or even eliminated. However, recent studies have shown that this scenario is untrue, and surprising increases in the incidence of vector-borne diseases such as leishmaniasis, Chagas and malaria have been recorded following the disappearance of the rainforest. Notorious is the rise of malaria in Rondônia State, Brazil, where between 1970 and 1990 the annual incidence of malaria increased from 10,000 to >250,000 per year (Kingman 1989). Indeed, this situation has become a classic example of vector-borne disease risk and environmental change. However, it should be noted that this increase was accompanied by a huge influx of immigrants from elsewhere, which may have exacerbated the situation.

The present study was undertaken to examine whether climate change would similarly contribute to malaria risk in the Brazilian Amazon basin, and which other human activities might indirectly cause increased risk for malaria infections. To this, we assessed the current situation of malaria in Brazil and the effects of climate change on malaria with emphasis on the Amazon rainforest as baseline information for the elucidation of factors that now and in the future might determine malaria risk in this area. Potential mitigating factors to reverse the emergence of risk factors are discussed.

Malaria in Brazil

Historically, malaria was endemic in much of Brazil, from the tropical Amazon region to the southern coastal regions as far south as São Paulo. Both *Plasmodium vivax* and *P. falciparum* occurred, with the former more prevalent than the latter. Numerous mosquito vector species are present in the country, with *Anopheles darlingi* and *An. nunetzovari* being the most important species in the rainforest, and *An. aquasalis* the vector in coastal regions. Locally, other species can also be involved in malaria transmission (Deane 1986; Rosa-Freitas et al. 1998). As malaria control has been highly effective in the southern and eastern regions of Brazil, today the disease is restricted mostly to the Amazon region, with *An. darlingi* as the main vector.

In the 1940s, all Brazilian regions were affected by malaria with the occurrence of millions of cases per year. Social changes and development, coupled with the intense work of the Malaria Eradication Campaign, led to a relative control of the disease, lowering the annual records to less than 100,000 cases, spatially restricted to the states of the Amazon Region.

The Amazon Legal Region is made up of the states Acre, Amapa, Amazonas, Maranhao, Mato Grosso, Para, Rondônia, Roraima and Tocantins. The risk of acquiring malaria is not uniform in the region. The Annual Parasite Index (API) is used to measure the malaria risk, which is given by the number of positive blood smears per 1000 persons at risk. According to this index, endemic areas are classified as high, medium and low transmission risk (Figure 1, see Colour pages elsewhere in this book).

After 1970, Amazon development projects with highways opening, hydroelectric dams, expansion of mining activities, logging and rural settlements, stimulated intense population migration and anthropogenic environmental changes. This process resulted in the dispersion of malaria throughout the region, with a significant increase in the number of cases to an average of 520,000 cases per year during the 1990s (Figure 2). A steep rise in the malaria trend was observed in 1999/2000 when the number of cases was above 600,000 and the average API achieved 30 (Figure 3). This rise led the Brazilian Ministry of Health in July 2000 to conceive and implement, with Amazon states and 254 counties, the Plan of Intensification of Malaria Control Actions (PIACM). The main goal was to achieve a 50% reduction of malaria cases by December 2001. The strategy was focused on political mobilization, capacity building in local health systems, early diagnosis and treatment, health education, social mobilization and intersectorial actions. With a budget of US$ 50.2 millions the PIACM was able to decentralize diagnosis and treatment to states and counties, integrating community health agents and health family teams. This initiative provided easiest and quick access of Amazon populations to prompt health care. Vector control activities were expanded with more field personnel, new vehicles and spray equipment. This made it possible to increase coverage of indoor residual insecticide spraying and spatial treatments to interrupt outbreaks. Draining and other environmental measures were applied in urban areas, such as Manaus and Porto Velho, to eliminate breeding sites. Another important initiative in March 2001 was the development of a protocol with the National Institute of Land Reform and Colonization (INCRA) to submit new settlements to extensive evaluation by the Ministry of Health to prevent malaria outbreaks. The National Environmental Council (CONAMA) issued a resolution in August 2001 establishing that the environmental license for developments in endemic regions requires evaluation of the health authorities regarding malaria prevention.

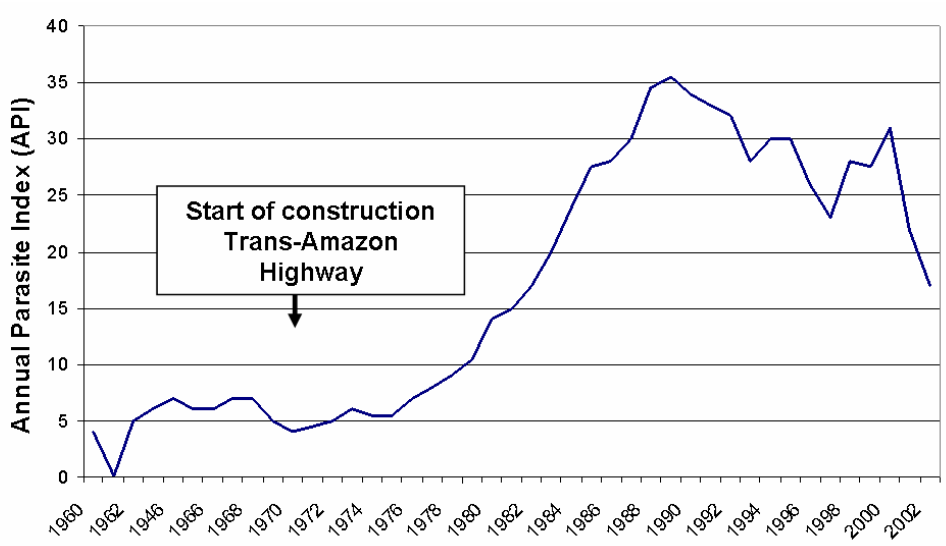

Figure 2. Annual Parasite Index, Amazonia, Brazil between 1960 and 2002 (source: PNCM 2003)

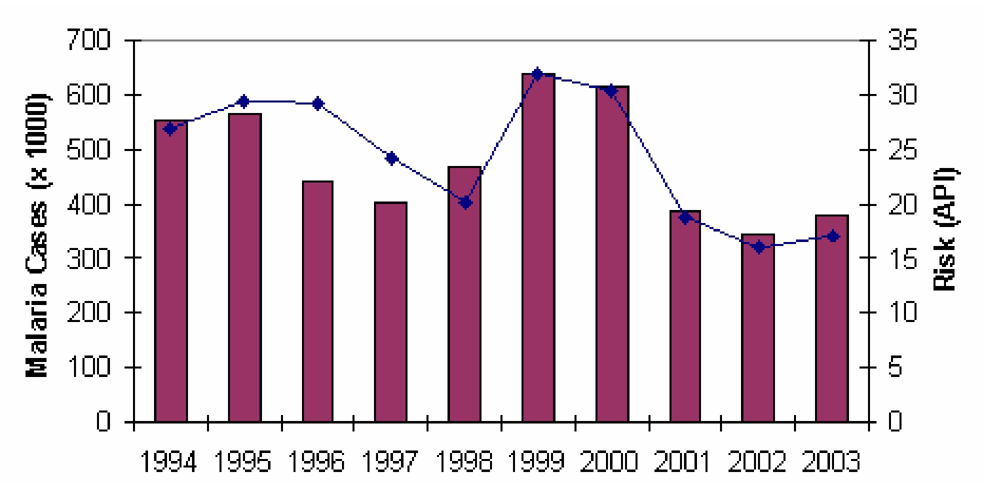

Figure 3. Malaria incidence and risk (expressed as Annual Parasite Index) in Brazilian Amazonia between 1994 and 2003.

Bars: the number of malaria cases; Line: the Annual Parasite Index per 1000 inhabitants

The impact of the actions developed by the PIACM was observed by the end of the year 2001, with a reduction of 38.9% in the overall number of cases and 41.1% in the API (Figure 2). The number of hospitalizations and deaths was reduced significantly by 69.2% and 36.5%, respectively (PNCM 2003). In spite of the increased control of malaria, transmission levels still remained high after 2001. The results differ significantly among states (data not shown). While Amazon and Acre achieved more than 60% reduction, Rondônia and Amapa obtained reductions of 9% and 15%, respectively. In 98 counties (38% of 254 in total) the malaria risk is considered high (API>50), with half of them showing an API >100. The proportion of malaria caused by *Plasmodium falciparum*, which causes the most serious clinical complications and high death rates, remains above 20% of the total, and is increasing in eight of the nine states (Table 1).

Table 1. Relative changes in all-cause malaria incidence (expressed as API) and *P. falciparum* rate in the Amazon region, Brazil, between the first quarters of 2003 and 2004

	2003			2004			Relative changes 2003/2004	
State Name	No. of cases	*P.falc + (Pf+Pv)*	*%P.f*	No. of cases	*P.falc + (Pf+Pv)*	*% Pf*	Relative change in API	Relative change in *Pf* ratio
AC	1,449	449	31.0	786	267	34.0	-47.0	9.6
AM	17,714	1,524	8.6	20,824	3,295	15.8	14.9	83.9
AP	1,789	735	41.1	3,202	1,605	50.1	73.1	22.0
MA	1,188	215	18.1	713	198	27.8	-40.7	53.5
MT	946	119	12.6	573	69	12.0	-40.5	-4.3
PA	19,396	5,184	26.7	9,976	2,845	28.5	-49.5	6.7
RO	10,102	3,306	32.7	16,546	5,635	34.1	61.1	4.1
RR	1,015	187	18.4	2,700	284	10.5	158.5	42.9
TO	230	42	18.3	106	29	27.4	-54.8	49.8
AMAZôNIA	53,829	11,761	21.8	55,426	14,227	25.7	1.2	17.5

AC = Acre; AM = Amazonas; AP = Amapa; MA = Maranhao; MT = Mato Grosso; PA = Para; RO = Rondônia; RR = Roraima; TO = Tocantins
API = Annual Parasite Index = number of positive blood smears per 1000 inhabitants
P.falc + (Pf+Pv) = all cases of *P. falciparum* and mixed infections

The malaria control activities, guidelines and financial support are now organized in the National Malaria Control Programme (PNCM 2003) from the Ministry of Health. The programme was formulated to sustain the advances obtained with the PIACM, and to improve the results in some areas and activities. The major objectives are (i) to achieve a reduction in incidence, mortality and severe-and-complicated malaria; (ii) to eliminate transmission in the urban areas from capital cities; (iii) to keep areas where transmission has been interrupted free from malaria.

Environmental changes in Brazil affecting malaria

The epidemiology of malaria is much determined by climate, vector habitat, susceptibility of the human population and vector and parasite behaviour, amongst other things. The major vector in Brazil, *Anopheles darlingi*, is widely distributed in Central and South America (Manguin et al. 1999), determined by a suitable habitat and the availability of blood hosts. In much of the Amazon region the habitat for *An. darlingi* is optimal, with the mosquito profiting from the destruction of rainforests (Cruz Marques 1987). Thus, as an apparent paradox, the environmental change witnessed in the Amazon region does not lead to the disappearance of malaria vectors; on the contrary. Recent figures demonstrate the high incidence of the disease in Brazil (Figure 3), and nearly all of these cases originate in (former) rainforest zones. It should be mentioned here that some indigenous populations of the Amazon region experience a high parasite rate, but it is not well known to what extent they suffer from malaria morbidity and mortality (De Arruda et al. 1996; 1998; Perez Mato 1998; Camargo, Alves and Pereira da Silva 1999). It is assumed that here, too, *An. darlingi* is the principal vector. This anopheline species benefits much from the reported deforestation by rapidly expanding its population in sunlit areas, where numerous newly created water bodies provide adequate larval habitats. As the biting habits of

An. darlingi include humans, the presence of new settlements, anopheline vectors and malaria parasites combined is sufficient to maintain the parasite transmission cycle and a high malaria incidence.

Case study: malaria in Rondônia

Rondônia state is located in the southwestern Amazon region, bordering with Bolivia. The state is bisected by the Madeira river, which runs from the eastern slopes of the Andes and merges with the Amazon river near Manaus. The general topography is flat country, with an average elevation of 300 m above sea level. The climate is characterized as tropical, with a long rainy season from January till May. However, some rainfall is recorded during other months of the year as well. Up to the 1960s, Rondônia was covered with near-complete lowland rainforest and sparsely populated. This situation changed when construction began of the Amazon highway (road BR364), which runs from the southern state border north to the capital city of Porto Velho, and then continues west to Acre state and beyond into Peru (Figure 4). Road BR364 is an all-weather road covered with tarmac, and serves mainly as a transport line for goods entering or leaving Rondônia. From Porto Velho road BR319 runs north to Manaus, but this road it not surfaced and rarely used. Most goods arriving in Porto Velho with destination Manaus are transported by ship across the Madeira river. In the 1960s Porto Velho had the character of a frontier town, serving transport companies and settlers from the north of the state. Gold was found in the Madeira river, and gold mining became a major economic activity in the 1980s, attracting thousands of settlers. From 1970 onwards, the Federal Government of Brazil initiated a development plan for Rondônia, encouraging landless people from the southern states to settle in Rondônia to become farmers. Settlers were given a piece of land that had been cleared of forest. Thus began one of the largest deforestation programmes witnessed. Originally, the activities began in the southern parts of the state. By the 1980s, the town of Ariquemes became the centre of this development, with large-scale logging and deforestation. This can be seen from a series of Landsat images taken in 1976, 1986 and 1992 (Figure 5, see Colour pages elsewhere in this book). Most activities occurred on both sides of BR364, with roads being built perpendicular to the highway, providing a fishbone structure when viewed from the air. New immigrants settled along these new roads to grow commercial crops such as fruit, maize, cotton and rice. The land they occupied had been clear-cut, with the timber being processed in Ariquemes and other commercial centres. As the land became rapidly exhausted by the crop farming, settlers switched to beef production or sold their land. Today many of these original farms are no longer used for crop production, most having turned over into rangeland (Browder, Pedlowski and Summers 2004; Guild, Cohen and Kauffman 2004).

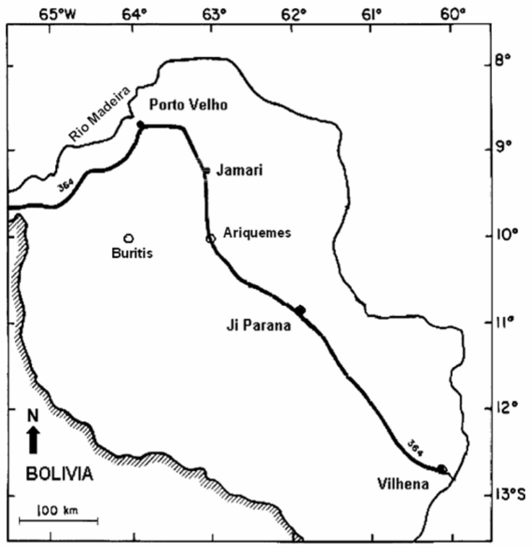

Figure 4. Map of Rondônia, Brazil, showing the position of highway BR364, along which much of the deforestation occurred (for details see Figure 5, see Colour pages elsewhere in this book). Source: Guild, Cohen and Kauffman (2004)

By the year 2000, these developments had reached Porto Velho in the north, and extending westwards along the BR364 all the way to Acre state. Within a 50-km radius from the highways, deforestation was dominant, while further away primary rainforest could still be found. However, even there land-use changes are occurring rapidly. In 2001 the authors witnessed the development of Buritis, a new town situated 100 km northwest of Ariquemes and accessible only by newly constructed roads. On either side of these roads, clear-cut deforestation was ongoing, with new farms being established (W. Takken and F. dos Santos, personal observation).

What are the consequences of these developments for malaria? The main malaria vector in Rondônia is *An. darlingi*, with other anopheline species present, but these are of little epidemiological significance (De Oliveira-Ferreira et al. 1990). As mentioned above, *An. darlingi* is the natural malaria vector in lowland rainforests of South America. The species breeds in large pools of stagnant water, mainly along the edges, as well as in slow-moving streams. As the species is heliophilic, larvae thrive in sunlit pools. The methods of deforestation in Rondônia, aided by road construction, have caused the creation of thousands of small dams, increasing the larval habitats of *An. darlingi*. Because this was followed by human settlement and often also by the introduction of livestock such as cattle and horses, new blood sources for the mosquitoes were introduced as well. *An. darlingi* benefited from these developments by expanding its population size. Several studies have demonstrated an increased risk in malaria associated with the forest industry in Rondônia, and the inhabitants of towns are frequently affected by the diseases (Camargo et al. 1994; 1996; 1999; Lima et al. 1996) (Figure 6). Even at the suburban areas of the capital city Porto Velho, malaria is frequently contracted, presumably because of vector mosquitoes breeding in man-made pools and forest islands. It has been observed that after an initial surge in malaria incidence following forest clearance and the arrival of new settlers, the malaria incidence is reduced and becomes stable. In addition, malaria diagnosis and treatment are freely available from government clinics, and patients can be rapidly identified and treated. In spite of these excellent public-health measures, in Rondônia malaria remains present and continues to pose a major public-health threat. It is important to realize that the low level of infection risk does not allow for the development of immunity, and this is one of the main reasons for the continuous malaria incidence at all ages. Forest workers are most affected, but also others who venture into the forests.

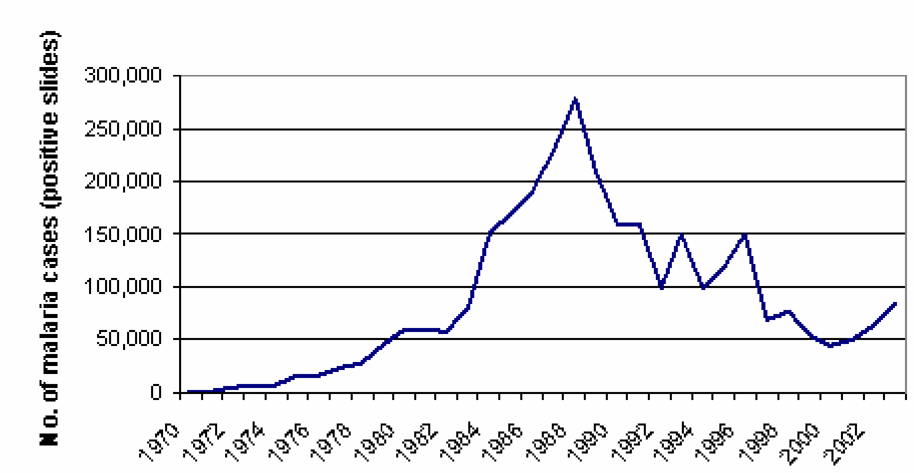

Figure 6. Malaria incidence as measured by number of positive blood slides in Rondônia between 1970 and 2004

Malaria risk under climate change in the Brazilian Amazon forest

As malaria incidence and prevalence is likely to change under climate change (see above) and current indications are that malaria remains one of the main diseases affecting public health in the Brazilian Amazon region (PNCM 2003), we may consider the implications of the predicted changes for malaria in the region. Past and current deforestation has caused considerable environmental changes, but the effects of these on malaria are that the disease has become firmly associated with peri-urban settlements and rural development. The predicted increase in mean temperature, resulting from greenhouse-gas emissions, is unlikely to affect the biology of the mosquito vectors, although higher maximum temperatures may be detrimental to larval and adult-mosquito survival (Clements 1992). Increased precipitation will result in filling up of water reservoirs, but since the annual rainfall is already high in the entire region, it remains to be seen to what extent extra rainfall enhances mosquito breeding. Human behaviour may lead to seeking more escape from the heat, by retiring indoors with air-conditioning. However, this is unlikely to be the case among the relatively poor sections of the Amazon population. The central question will be how current measures to restrict deforestation and protect natural ecosystems will be affected by climate change (Laurance 1998). Successful environmental protection is likely to favour the natural mosquito habitats and, hence, an important determinant of malaria. Unlike other regions, where malaria is seasonal or epidemic in some years, the Amazon region exhibits a continuous transmission. For these reasons the predicted changes are unlikely to affect malaria risk, and the latter is much more affected by environmental change associated with deforestation and urbanization.

Discussion

The data presented show that malaria is present throughout the Amazon region of Brazil, and that anthropogenic activities of the past 40 years have caused large increases in disease incidence both in rural and peri-urban areas. In spite of a high level of public-health care through clinics and free treatment programmes, malaria maintains a presence of significance. For these reasons, the National Malaria Control Programme received fresh inputs in 2001 and has been successful in reducing the incidence of malaria in many areas. Without this programme, the disease is likely to increase again. The environmental conditions appear highly suitable for the continuing transmission of the disease, even in areas with a relatively low human population density. Ongoing deforestation will favour malaria in other areas, affecting the health of new settlers. We predict that the main vector, *An. darlingi*, will be little affected by climate change, as this mosquito can adapt to varying environmental conditions. Higher temperatures may cause a reduction in parasite incubation time, but this is unlikely to affect the transmission rate of the parasite. Therefore, the main determinants of malaria in the Amazon region will be little affected by the predicted change. By contrast, further east and south, in areas of Brazil where malaria has previously been eradicated, climate change may favour an environmental change suitable for renewed malaria transmission. The consequences of these changes should be studied with renewed malaria risk strategies (Van Lieshout elsewhere in this volume).

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