Migration, Urbanization and Malaria: A Comparative Analysis of Dar es Salaam, Tanzania and Machadinho, Rondônia, Brazil

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Introduction

The relationship between population movement and the spread of diseases is no novelty. Hippocrates (about 460 BC – about 377 BC) considered the appearance of a *stranger* in a place as one of the issues to be addressed in order to investigate medicine properly ("Airs, Waters, and Places", 400BC). The progressive improvement in transportation over the centuries, both in quality and in travel speed, facilitated the exchange of diseases. The contact between the Roman and Chinese empires, the Crusades (11^{th} – 13^{th} century), the voyages of discovery during the 15^{th} and 16^{th} century, the contact between Europeans and Americans, and slave trade resulted in major epidemics. Many plague outbreaks have occurred since ancient times, but invariably diseases were spread by travelers and merchants (Scott and Duncan, 2001). Native Americans lacked immunity to diseases such as smallpox, measles, whooping cough, typhoid, diphtheria, influenza, malaria, yellow fever, onchocerciasis, tuberculosis, etc. In many areas the population was decimated (Bruce-Chwatt, 1988; Meade and Earickson, 2000; Prothero, 2001). Throughout history, deaths caused by tuberculosis usually occurred in cities with high population density (Cliff, Haggett and Smallman-Raynor, 1998). The adoption of disease quarantine is one of the oldest methods of limiting the spread of diseases. Historical records show that quarantine dates back to 1377, when it was used to prevent the spread of plague (Meade and Earickson, 2000). Finally, the spread of vectors that transmit diseases is also believed to have been facilitated by increased levels of travel and trade (Litsios, 2001).

The importance of population movements has also been recognized by the International Organization for Migration (http://www.iom.int/), which considered this phenomenon to be one of the most important determinants of global health (Prothero, 2001). The recent diffusion of Severe Acute Respiratory Syndrome – SARS, an atypical pneumonia of unknown etiology, is the latest example of the spread of a disease due to population movements. It is believed that the disease started in China, and in only six months it has already spread to 28 countries in all continents (mainly due to air travel), has infected 4,836 people, and has taken 293 lives[1].

Population movements vary in motivation and type. They can be voluntary, driven by tourism, regional trade, search for better economic conditions, and education. They can also be forced, caused by war, famine, drought, flooding, land expropriation, and major environmental catastrophes. Irrespective of the type and motive of the movement, migrants can become active

[1] Numbers updated as of April 26, 2003 (http://www.who.int/csr/sars/en/).

transmitters or passive acquirers of certain diseases, depending on their levels of immunity, origin, and destination (Prothero, 1994; Martens and Hall, 2000; Robert et al., 2003).

Some population movements have significant implications for malaria transmission. Refugees constitute an important group of forced migrants, and malaria has been identified as the most frequent cause of mortality and morbidity in many refugee camps: Cambodians in Thailand, Mozambicans in Malawi, and Ethiopians in eastern Sudan (Martens and Hall, 2000; Bloland and Williams, 2003). In Tanzania, an outbreak in a refugee camp with 22,000 Burundians in 1997 caused approximately 18-20 deaths per week, mostly children under 5 years of age. (Crowe, 1997). Refugees usually live in lowland areas, under extremely poor conditions, lacking sanitation, clean water, and basic health care (Keely, Reed and Waldman, 2001). Considering only the forced movements that took place inside countries in 1996, Africa accounted for half of the those people (Fischhoff, 2002). In 2000, approximately 9% of all migrants worldwide were refugees, amounting to 16 million people (UN, 2002).

Migration for the purpose of settlement in new areas is another major factor associated with malaria transmission, especially in the case of settlement in tropical forest areas. Major environmental transformations take place during occupation, fostering the proliferation of mosquito breeding sites, and resulting in major malaria outbreaks. Migrants are most likely to lack immunity against the disease, as well as the appropriate knowledge of the transmission process. It is important to emphasize, however, that undisturbed forests do not pose serious risk for malaria transmission (Hirsch, 1883).

Out of 20 countries that present high risk of malaria transmission, 16 consider human mobility as the major cause for the persistence of the disease. Seasonal migration of workers has been associated with epidemics in Kenya (Bloland and Williams, 2003). Furthermore, population movement also impacts on the extent of drug resistance. Migrants that move from areas where resistant strains of the parasite have been identified will introduce the strain into areas where resistance hasn't been acquired yet (Meade and Earickson, 2000).

Urbanization is one of the processes dramatically impacted by migration[2]. In Africa, the percentage of urban population was 14.7% in 1950, but is expected to reach 40% in 2005 (UN, 2003). A large fraction of the most recent growth is attributable to population movements.

[2] It is important to emphasize that there is not a unique definition of 'urban' or the process of 'urbanization'. Urban areas grow, function, and look different between and within countries (Phillips, 1993).

Migrants (mostly coming from rural areas) are likely to live under poor conditions, becoming exposed to different diseases. Rural practices are brought to the city, such as growing of crops and raising livestock. Some agricultural practices facilitate the spread of vector-borne diseases. Also, the presence of cattle in marshy areas results in the creation of hoof prints that potentially offer ideal conditions for mosquito breeding.

These two issues, opening of new areas for human settlement and urbanization, will be addressed in this paper in the context of the Brazilian Amazon and Africa, respectively. For the former we chose an area in the Northwestern portion of the Amazon, located in the State of Rondônia, named Machadinho. For the latter we selected the urban area of Dar es Salaam, Tanzania. Our objective is to characterize and compare the interrelationships between migration, urbanization, and malaria risk in two different cultural and environmental settings. We review and point out some of the key lessons from past malaria campaigns, indicating some of the crucial steps necessary to implement effective control in each setting.

1. Migration, urbanization and malaria

An interesting hypothesis, hotly debated in the current literature (Hughes and Verra, 2001; Volkman et al., 2001; Mu et al., 2002) is that when Africans experienced a dramatic change in their environmental and behavioral practices 10,000 years ago, shifting from hunter-gatherers to farmers, malaria started to infect humans (Cliff, Haggett and Smallman-Raynor, 1998). Most recently, migration is believed to have initiated malaria transmission in African highlands. A study in Kenya shows that malaria cases were first registered upon the returning of soldiers from World War I between 1918 and 1919. One quarter of the indigenous population was infected (Lindsay and Martens, 1998). In Brazil, malaria transmission reached its lowest level in 1970, but increase more than ten fold in one decade as a result of the massive migratory movement of non-immune people, mainly from the South of the country, to the Amazon. Later, in the mid 1980's, return migration from the Amazon initiated malaria outbreaks in the South of Brazil (Monte-Mór, 1997).

Major urban centers, experiencing rapid and unplanned population growth due to intense migratory movements, face serious problems with sanitation, overcrowding, poor housing, pollution, lack of food, and inadequate water. This combination of conditions is conducive to transmission of vector-borne diseases (malaria, dengue, filariasis) and tuberculosis. The latter has become extremely serious in many Asian and African cities (Meade and Earickson, 2000), as well as cities in the US, mainly among migrants, who account for approximately 46% of all tuberculosis cases (CDC, 2001). Major health problems have been reported in places such as Bangkok, Lima, and Bombay (Harpham, Lusty and Vaughan, 1988).

Specifically related to urban malaria in Africa, some of the pioneering and most comprehensive studies were done in Brazzaville, Congo, during the 1980's (Trape, 1987b; Trape, 1987a; Trape et al., 1987; Trape and Zoulani, 1987b; Trape and Zoulani, 1987a). Primary breeding sites were identified, and detailed entomological and parasitological data were collected. Virtually all breeding sites in the rural villages near Brazzaville originated from man-made environmental transformations. In urban areas, the number of sources for mosquito breeding were scarcer, and vector density was found to be dramatically smaller even a few hundred meters from these sources.

These examples illustrate the impacts of migration and urbanization on health. However, these impacts vary in magnitude and direction according to the environmental and cultural context in which they take place. City planning that took account of the ecological features of malaria risk could, in principle, substantially reduce the transmission problem. However, such coordinated planning has occurred very infrequently in African urban development. One notable exception is the malaria control that has been incorporated in multiple instances over the past 100 years in Dar es Salaam, Tanzania (Schilling, 1910b; Clyde, 1967; Beck, 1977).

2. Urban expansion: Dar es Salaam, Tanzania

During the African colonization by Europeans, small trading centers were established along the coast. Although some centers eventually collapsed, others flourished and became major cities, such as Dakar (Senegal), Abidjan (Ivory Coast), Lagos and Port Harcourt (Nigeria), Mombassa (Kenya), Takoradi and Tema (Ghana), and Dar es Salaam (Tanzania) (Thomas, 1970). The latter became the most densely populated area in Tanzania, and the city with the most rapid population growth in east Africa. The latest Population and Housing Census reveals that Dar es Salaam moved from 356 thousand inhabitants in 1967 to 2.5 million in 2002. Since 1965, it is estimated that approximately 69% of the population growth was caused by rural-urban migration (Sommers, 2001). Population density in 2002 is 1,793 people per km^2, by far the largest human agglomeration in the country (Mwanza ranks second in Tanzania, but with only 150 people per km^2)[3].

2.1.Pattern of urban expansion in Dar es Salaam

According to the city administrative specification, Dar es Salaam has an area of 1,393km^2, although most of that area is not urbanized. Based on work done by Briggs and Mwamfupe (2000) and by Mike Shand (http://mshand.geog.gla.ac.uk/DAR/tanzania.htm), we estimate that the urban area in Dar es Salaam was approximately 25 km^2 in 1945, 40 km^2 in 1967, 93km^2 in 1978, 259km^2 in 1992, and 418km^2 in 1998[4]. Recent estimates presented by Masanja (2002) show that the built-up area in 2001 was on the order of approximately 572 km^2. The intense urban development that took place after 1978 was not homogeneous across the city. It was driven by two main features: (i) the hydrological characteristics of Dar es Salaam, and (ii) the available public transportation system (Briggs and Mwamfupe, 2000).

Dar es Salaam has a complex creek system, with Msimbazi Creek and Mzinga Creek playing an important role in the spatial expansion of urbanization. Most of the development was concentrated north of the creeks, while expansion to the south was constrained mainly by Mzinga Creek (Briggs and Mwamfupe, 2000). The marshy characteristic of the soil near the creeks left many areas unsuitable for housing construction, unless drainage was put in place.

The transportation system limited the expansion of urbanization even more. Until the late 1980s, the transportation network was precarious, and private vehicle ownership was limited. People needed to live in areas where access to and from the main city centre would be guaranteed by public transportation. As a result, urban expansion took place basically along the major roads. During the 1990s, the transportation system was dramatically improved, and different types of vehicles became available for the population**.** Access was provided not only to major roads, but also to feeder and dirt roads. Consequently, urban expansion started to become more intense in interstitial areas between the main roads (Briggs and Mwamfupe, 2000).

Another important feature of the urbanization process in Dar es Salaam is the role played by agriculture in both the urban and peri-urban zones. Dar es Salaam experienced the fastest population growth in Tanzania (4.8% between 1978 and 1988, and 4.3% between 1988 and

[3] For more information regarding the results of the 2002 Census in Tanzania check http://www.tanzania.go.tz/census/tables.htm.

2002), mainly due to rural-urban migration, but also due to population movements from Rwanda, Burundi, Zaire and Mozambique (Briggs, 1991). Such rapid growth fostered a serious economic crisis during the 1980s. Urban agriculture assured the availability of food. Some families owned land both in the peri-urban area and the city center. Some household members worked at farming activities, while others kept their jobs in the urban centre. Most new migrants, however, established residency in the peri-urban area, heavily engaging in agricultural production (Briggs, 1991; Briggs and Mwamfupe, 2000). At present, urban agriculture in Dar es Salaam includes crop production and the raising of livestock. The rationale for this contemporary activity goes well beyond subsistence and extends to cash crops and meat production (Mlozi, 1997).

2.2.Malaria in Dar es Salaam

Dar es Salaam has a hot and humid tropical climate with two rainy seasons – a long one observed during the months of March and April, and a short one occurring in November and December. A theoretical model based on climate conditions (rainfall and temperature) characterizes Dar es Salaam as an area with endemic and perennial malaria, with transmission occurring during the whole year (MARA/ARMA, 2002).

Plasmodium Falciparum is the most common malaria parasite, accounting for 90% of all cases. *Anopheles Gambiae* and *Anopheles Funestus* are the main vectors of malaria in Dar es Salaam. The former prefers small collections of clean and fresh water, although some subspecies can breed in salty water. The latter favors permanent water, especially near inland marshes. Different types of breeding sites are found in urban areas of Dar es Salaam, and they are the result of the physical characteristics of the area (presence of creeks) and of the activities undertaken by the population (such as agriculture). They include *matuta* (raised planting beds), salt pans, paddy fields, sand pits, seepage, swamps, mangrove swamps, pits for house construction, roadside puddles, and marshes. Each type presents distinct conditions conducive to high larval density, demanding specific interventions for control. Compared to rural areas, the number of mosquito breeding sites in urban places is reduced because, pools of stagnant water become polluted, cemented, or are replaced by construction with concrete(Yamagata, 1996a; Robert et al., 2003).

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[4] We digitized the maps publicly available at http://mshand.geog.gla.ac.uk/DAR/tanzania.htm in order to obtain these estimates.

Malaria is the leading cause of outpatients in hospitals and clinics, deaths of hospitalized people, and admissions of children under 5. It is considered the major cause for the decrease in learning capacity of people between the ages of 5 and 25, and for the loss of economic productivity of those between 15 and 55. The disease represents one of the most important obstacles to economic development and investment in Tanzania (MOH, 2002).

Malaria in the built up areas of Dar es Salaam is less intense than in peri-urban and rural areas. It is considered to be residual malaria from rural areas linked to the focal breeding sites distributed around the city. During the late 1980s, parasite rates among school children ranged between 2% and 10% in the urban areas, while in the peri-urban and rural areas these figures were in the order of 40% and 70%, respectively (Yamagata, 1996a). Additionally, rates are higher in the south portion (below Mzinga Creek), which is less urbanized when compared with the north area of the city, as mentioned before.

It is important to emphasize that the role played by urbanization on malaria transmission is twofold. On the one hand, it reduces the number of places that could potentially become anopheles-breeding sites, since standing water tends to be more polluted and there is considerable building construction and pavement of roads. On the other hand, the initial process of urban expansion is accompanied by an increase in malaria rates in the periphery of the city. This is driven by the establishment of new shanty town zones with open sand pits and burrows, and by the dangerous encounter at the 'urban fringe' of a population with low malaria immunity coming into contact with parasite carriers migrating from rural areas (Yamagata, 1996c; Cox, Mouchet and Bradley, 2002). Furthermore, intense urbanization is likely to reduce the individual human exposure, given the very high population density in cities. A dense population also has a major impact on the spatial distribution of mosquitoes. Since they do not have to fly too far to find a source of blood, they tend to be very localized, contributing to the development of pockets of malaria transmission in town (Trape et al., 1992).

This impact of urbanization was also stressed in an evaluation of vector control programs implemented in Dar es Salaam between 1954 and 1971. Results show that the density of female anopheles had a significant annual reduction of 0.06 females per room during the period (the number for the first and last three years of the considered time period were 1.070 and 0.015, respectively – a reduction of 98.6%). It would be erroneous to attribute that decline solely to the interventions for malaria control, since similar declines were observed in untreated areas at the periphery of Dar es Salaam (in the case of *A. Gambiae* the density declined from 24.5 females per room in 1955 to 1.72 in 1971). Instead, urbanization must be regarded as part of a package of interventions, since it brings dramatic changes in the environment, resulting in the reduction of potential breeding sites for anopheles (Bang, Mrope and Sabuni, 1977).

2.3.Malaria control

The history of malaria control in Dar es Salaam dates back to the 19th century, when the area was under German possession. Over the years, interventions included the use of quinine to treat all infected people and for individual prophylaxis, and environmental management, mainly direct soil work for larval control (Schilling, 1910a; Beck, 1977; Kilama, 1991). In 1913, the German ordinance for mosquito extermination was set forth. It authorized legal sanction for the destruction of ponds, vessels, tins, etc. Interventions included oiling water accumulations for larval control, spraying houses for adult mosquito control, and drain construction. By the time World War I began, mosquito population densities in Dar es Salaam had been reduced by 90%.

During and soon after World War I, malaria control was taken over by the British government, through the Royal Army Medical Corps. Interventions were heavily concentrated on drainage work, straightening of streams (to increase the flow of water), oiling of puddles, cleaning the banks of drains in order to facilitate the flow of predatory fish, and surveillance of livestock so that they would be kept far from streams and swamps. Livestock surveillance led to the prevention of hoof prints in places that could offer conditions for mosquito breeding (Yamagata, 1996a).

Larvicidal air spraying was first tried in 1945, and DDT was used for residual spraying in houses in 1946 (Clyde, 1962). After World War II, chloroquine was introduced and used as the only drug for malaria treatment. This positive innovation in treatment had the unfortunate negative consequence of diverting attention away from other interventions that had been part of previous integrated (multi-intervention) programs (Kilama, 1994).

During the 1960s environmental management strategies in Dar es Salaam (and other major cities in Tanzania) were based on drainage work. This contributed to a reduction in larvae of both *anopheles* and *culex* mosquitoes. In 1961, with the advent of independence, prisons, aerodromes, and major development projects, such as mining and agricultural estates, were all under effective vector control. There was also careful control at the Ukonga Airport in Dar es Salaam, covering a perimeter of over one mile. Interventions were heavily based on environmental management including drainage, filling, and other engineering works. Community health education was also a concern at that time, and was intensified in 1964. In the 1960s, malaria transmission in urban areas was considered to be of limited magnitude (Tanganyika, 1966; Kilama, 1994).

In June 1971, a field experiment showed that an integrated approach for vector control, including environmental management, chemical interventions, and health education was more likely to last longer than chemical use alone. The integrated program benefited from the fact that local labor costs were low. An evaluation after 13 months revealed that the density of mosquitoes was reduced in all areas, but more significantly in the trial area. The resting density (female mosquitoes per room) of anopheles was 128.9 in the comparison area, but only 3.5 in the trial area (Bang, Sabuni and Tonn, 1975).

In 1972, adverse economic conditions and a policy of decentralization, resulted in the deterioration of the health system, and chemotherapy was the only anti-malaria effort still in place. As a result, the annual number of *anopheles* collected in Dar es Salaam, which averaged less than 500 during 1967 and 1971, increased more than 10 times by the early 1980s (Kilama and Kihamia, 1991). In 1983, the Ministry of Health of Tanzania promoted a reformulation of malaria control policies, placing emphasis on a combination of interventions, including vector control, chemotherapy, monitoring of drug resistance, and personnel development (Yamagata, 1996a).

In 1988, the Government of Japan (through the Japan International Cooperation Agency (JICA)) launched the Urban Malaria Control Project (UMCP). Between 1988 and 1996, JICA coordinated a detailed set of operations, heavily concentrated on vector control. It clearly established environmental management as especially efficacious. Particular advantage accrued from the elaborate drainage network that had been put in place during the German and British colonial periods. Maintenance of the drainage system was often inadequate as a result of financial constraints in Tanzania. However, cleaning and rehabilitation of drains as part of UMCP was a critical ingredient in the reduction of larval density attained from 1988 thru 1996 (Yamagata, 1996b; Yamagata, 1996c).

Most recently, the Ministry of Health of Tanzania launched the National Malaria Medium Term Strategic Plan (MTSP), aiming at reducing mortality and morbidity due to malaria by 25% as of 2006 and by 50% by the year 2010. The core of interventions includes early detection and prompt treatment of the disease, and the adoption of selected preventive measures. Drug resistance is a major issue in the provision of a proper malaria treatment. The average rate of Chloroquine treatment failure is 52%, but it can be as high as 72%. In Dar es Salaam, failure rates were on the order of 43% in 1997 (MOH, 2002). Indeed, such high failure rates culminated in a decision by the Health Ministry to abolish Chloroquine as the first line drug for malaria treatment in 2002 (IDRC/MOH, 2002). Selected preventive measures are heavily concentrated on the use of insecticide treated bed nets (ITNs), although environmental management measures are also planned (MOH, 2002).

3. New settlement areas: Machadinho, Rondônia, Brazil

According to the last Brazilian Census 21.1 million people were living in the Amazon in the year 2000, or 12.4% of the population of the country. In 1872, the population of the Amazon was approximately 752 thousand (only 393 thousand if the Northeastern State of Maranhão is not considered). By 1980, the population size had reached 11 million. The changes in the Amazonian population over the past 150 years were not uniformly distributed over time. In fact, over the past five centuries the area registered huge population increases and decreases, all driven by economic opportunities. During the past 40 years, however, occupation of the Amazon became the main goal. New settlements areas were opened as a government effort to promote occupation and integration of the area with the rest of the country. The rivers, which were the traditional routes of transportation, gave way to highways used by a massive migratory flux, marking the opening of a new frontier in Brazil.

3.1.Frontier expansion in the Amazon

Traditionally, road construction has been the major tool for promoting rural development (Chomitz and Gray, 1996). In the context of the Amazon, the benefits of the road can become residual when compared to the delicate issues it raises. Without an organized and effective plan of occupation, the opening of roads is synonymous with deforestation, substantial migration, pressure on natural resources, disease outbreaks, and poverty.

Between 1970 and 1980 the net migration in the legal Amazon was on the order of 1.1 million people (Wood and Wilson, 1984), resulting in severe changes in the socioeconomic, ecological, and demographic characteristics of the area. After unsuccessful attempts to settle people along the Transamazon Highway during the 1970s, the government decided to focus on the Northwestern part of the Amazon, especially in the State of Rondônia. Until 1983, one third of all settlement projects in the Amazon were located in that State. While the annual growth rate of the population of the whole country was 2.48% between 1970 and 1980, Rondônia registered an astonishing yearly growth rate of 16.03%. Migration during the mid-1980s was intensified, and the State received 151.6 thousand new migrants in 1985, and 165.9 thousand in 1986 (Perdigão and Bassegio, 1992). This migration process was not associated with an increase in the wealth of the region, since migrants were basically poor people, suffering the effects of the droughts in the Northeast, and the intense mechanization and land speculation in the South of the country. They were attracted by cheap land and by the illusion that the Amazon had fertile soils for agriculture (Moran, 1981; Martine, 1990). As a consequence, the area registered significant increases in deforestation. It also saw very rapid development of new urban centers and suffered multiple malaria outbreaks.

Deforestation in Rondônia increased dramatically after 1970. While in 1975 only 0.3% of the State forest cover had been cleared (Mahar, 1989), by 1996 this number jumped to 22% (Arcanjo et al., 1997), with most of the clearing concentrated along the Cuiabá-Porto Velho Highway (BR-364). According to satellite image analysis, deforestation in Rondônia increased from 8,000 Km^2 in 1980 to 28,000 km^2 in 1985, and 41,000 km^2 in 1987 (Pedlowski, 1998). Considering a buffer zone of 50 Km on each side of BR-364, estimates show that 33% of the forest along the highway was cleared by 1991 (Nepstad et al., 2000). That impact was considered by the National Aeronautics and Space Administration (NASA) as one of the most dramatic man-made transformations of the earth visible with satellite images (Caufield, 1996).

New urban areas flourished in the Amazon after the 1970s. In 1950, only 24% of the population of the legal Amazon was living in urban areas, while in 2000 this number jumped to 70%, and the rural population actually experienced a reduction in absolute numbers. Following the frontier expansion, urban agglomerations prospered in areas that concentrated the infrastructure and services provided to new settlement areas (Monte-Mór, 1997). In some cases (such as Machadinho, as we will detail later) the growth was so fast and significant that new municipalities were created.. Rondônia had only two municipalities prior to 1970. However, the intense occupation of the State that started during the 1980s led to an increase to 23 municipalities by 1991 and 52 in 2000 (IBGE, 2000).

Malaria outbreaks resulted from a combination of factors that included man-made transformations to the environment, lack of acquired immunity among most of the settlers, precarious habitat conditions that offered no protection against mosquitoes, and lack of adequate knowledge of the disease. Malaria was a primary reason for a considerable turnover of settlers (Sawyer and Sawyer, 1987). Martine (1990) highlights the fact that, in the early 1970s, some settlers would exchange their plots for medical treatment; a practice that made some of the first physicians that came to Rondônia large landowners. Moreover, when migrants did not succeed in obtaining land, they returned to their place of origin or kept moving to alternative locations. This contributed to the spread of the disease to other areas in Rondônia and in the country[5]. In 1986, Rondônia was considered the 'capital' of malaria in Brazil, containing 43% of all cases registered in the nation (50% in 1988), and 46% of all cases in the Amazon.

Prior to the post-1970 Amazon frontier expansion, malaria was under control in Brazil. After more than a decade of successful malaria eradication campaigns (following WHO directions), malaria reached its lowest level in Brazil in 1970 when slightly more than 52,000 cases were registered in the country. At that time, the Amazon contained 60.6% of the national cases. Following the opening of roads, a disorganized occupation, associated with disturbance of the natural environment and with a lack of infrastructure, resulted in severe malaria epidemics. There was an increase in malaria cases during the 1970s, with a dramatic increase during the 1980s. A peak of 558 thousand cases was attained in 1989.

An unfortunate aspect of the fact that many settlement projects were starting during the 1980s was that this coincided with one of the most difficult periods in Brazil's economic history. Many economists referred to the 1980s as the 'lost decade'. Annual inflation was 110% in 1980, jumping to 1,783% in 1989. The country was facing one of the most serious economic recessions and fiscal crises. All social indicators deteriorated during this period, including those related to basic health (Silva, 1992). At present, virtually all malaria cases occur in the Amazon (99.7%), approximately 60% are registered in settlement areas, and 12% in urban settings.

3.2.Malaria in new settlement areas

Tropical rain forests assure good conditions for the proliferation of insects. *Anopheles Darlingi* is the main vector of malaria in the Brazilian Amazon. It is a species that can maintain

[5] Between 1985 and 1990, malaria cases observed in the States of Paraná (PR) and Espírito Santo (ES) were a result

endemicity even at low densities (Tadei et al., 1998). The larvae prefer deep, standing or slowly flowing, partly sunlit and clear water with pH near neutral, with aquatic plants and no decomposing organic matter (Sawyer, 1992). During the rainy season *A. Darlingi* uses pits of water, culverts, and even animal footprints as breeding sites (Deane, 1947; Consoli and Oliveira, 1998). Natural breeding places are observed in the forest fringe at the beginning and end of the rainy season. Inside the undisturbed forest, however, the ideal conditions for *A. Darlingi* are seldom found, since standing water is acidic and the partial shade favored by this species is absent. With the opening of new settlement areas, however, manmade modifications to the local environment result in a dramatic increase of *anopheles* breeding places. Among the many sites are pits left by mining; pools of stagnant water along unpaved roads, river margins, and in areas where a poor clearing resulted in irregular soils; and accumulated water due to obstruction of streams by felled trees (Marques, 1987; Sawyer and Sawyer, 1987; Coimbra Jr., 1988).

Although in the early 1930s *A. Darlingi* was primarily feeding indoors, studies in Rondônia during the 1980s found this vector feeding both indoors and outdoors, but mainly outdoors, in the vicinity of houses (Deane, 1986; Deane, 1988a; Rosa-Freitas et al., 1988; Camargo et al., 1996). Furthermore, the daily biting pattern is bimodal, with peaks in the early evening (6:00 p.m.) and at dawn (5:00 to 6:00 a.m.), exactly the hours at which workers are carrying out outdoor activities (Klein and Lima, 1990; Tadei, 1991). This U-shape behavior is totally different from what is observed anywhere else in the world, where the distribution is typically unimodal – inverse U-shaped (Sawyer, 1992). This is a major constraint for the adoption of traditional measures of malaria control, such as DDT spraying inside houses.

The complex Amazon frontier transmission pattern calls for a distinctive definition. Sawyer (1988) proposed the concept of frontier malaria to mean that most or all of the following conditions are observed: high vector density, intense human exposure to vectors, outdoor transmission, low immunity of the exposed population, limited knowledge of the disease, high morbidity and relatively low mortality, high proportion of *P. Falciparum* malaria, difficulty of conventional control measures to succeed, weak institutional presence in the area, little sense of community, high population mobility, and political marginality of the local people.. This concept highlights the role played by a multitude of factors, other than just epidemiological and entomological issues, in malaria transmission.

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of a process of return migration from Rondônia.

Malaria in new settlement areas in the Amazon evolves through time in a very special way. Sawyer and Sawyer (1992) proposed a model of malaria transition as a 3-stage process, evolving over a period of approximately 15 years. The first phase (epidemic) starts with the occupation of an area, and spreads over the first three years of the settlement process. It is characterized by a fast and dramatic rise in the Annual Parasite Index – API[6] up to around 3,000 per 1,000 people. During this phase, the total cleared area is still low; the quality of the house is poor; man-made transformations favor the proliferation of mosquito breeding sites; and settlers do not have the appropriate knowledge to protect themselves against malaria. The second phase (transition) lasts for about five years. It is characterized by significant decreases in the API. Cleared area increases, profits from the agricultural production allow the improvement of housing and personal care, and knowledge about malaria becomes more widespread. The third and last phase (endemic) starts approximately eight years after the inception of the settlement project, and registers much lower infection rates. Settlers are likely to be well established in their plots, producing different crops, living in better houses, and able to protect themselves against malaria in much better ways than at the time of the initial occupation. Local infrastructure should also have improved, facilitating the search for health care, the storage and transportation of commodities, and also the organization of community groups. Moreover, as the area develops, pollution of mosquito breeding places contributes to a decrease in the risk of malaria transmission (Sawyer and Sawyer, 1992).

3.3. Machadinho settlement project

The Machadinho settlement project is located in the municipality of Machadinho D'Oeste, in the northeastern portion of Rondônia State. Altitude is between 100 and 200 meters, and a dense network of streams drains the area. The climate is hot with a very short dry season (during the months of June, July, and August). Quiet or stagnant pools of water are observed at the beginning and end of the rainy season. Average annual temperatures are above 25^{o}C, reaching an average monthly maximum above 32^{o}C from July to October. Relative humidity is usually above 80%. All these conditions are favorable to a high density of *A. Darlingi* mosquitoes (Sawyer and Sawyer, 1987).

[6] The Annual Parasite Index (API) relates the number of positive blood slides to the total population, and is usually expressed per 1,000 people.

Machadinho was part of the Northwest Region Integrated Development Program – POLONOROESTE, a project co-sponsored by the Brazilian federal government and the World Bank. The area of the project was primarily jungle before the settlement started, sparsely populated by rubber tappers. There were no disturbances to the environment; no malaria was officially registered in the area, although rubber tappers most likely had malaria at low symptomatic levels. The interaction between the incoming population, the local environment, and the rubber tappers should solely determine malaria transmission in the area.

Machadinho was the first colonization project that incorporated, in its design, a whole plan of action to prevent the most harmful consequences of frontier expansion observed in previous settlement projects, including malaria outbreaks. It was started in late 1984 with the hope that it would be a model of successful colonization in the Amazon. However, it turned out to be an example of how the lack of multidisciplinary coordination can result in a major social, environmental and health problem. One of the most dramatic experiences in Machadinho was the outbreak of malaria that occurred as soon as the area was occupied. In 1985, the API reached 3,400 positive slides per thousand people, with 65.7% of the settlers having at least one episode of malaria. This number jumped to 90.1% in the next year. Also in 1986, 55.9% of people had malaria episodes in more than five months of the year, and almost 40% of malaria cases registered in Rondônia were observed in Machadinho (Sawyer and Sawyer, 1987; Sydenstricker, 1992). In 1987, the situation was so critical that an internal World Bank report even suggested an eventual evacuation of the area (BENFAM, 1987).

By 1995, some major factors had changed. The quality of roads had improved, new community groups (unions, churches, etc) and neighborhood networks were established, and there was greater land clearance accompanied by improved housing. As a result, the level of malaria transmission was much lower than in the initial three years (as proposed in the theoretical model of malaria transition in settlement areas). A very important aspect is that malaria transmission is highly focal during all phases of the settlement process, although the locations of the foci change over time (Castro, 2002). This pattern is driven by an intricate combination of environmental, social, behavioral, and economic factors that make malaria control very difficult.

Most recent data include the municipality of Machadinho D'Oeste as an area of high malaria risk (FUNASA, 2000a). In 1996 it registered an API equal to 316.3 per 1,000 people, ranking 10th place among all municipalities in Rondônia State. In 1999, the API was 252.4 per 1,000, ranking 7th place. One year later Machadinho moved to 5th place in the ranking of municipalities with the highest API, 594.5 per 1,000 people. The increase between 1999 and 2000 was a consequence of four new colonization projects opened in Machadinho D'Oeste during that period, with a repetition of the earlier malaria experience in the area.

3.4.Malaria control

The history of malaria control initiatives in Brazil started at the beginning of the 20th century with the remarkable work of Oswaldo Cruz, Carlos Chagas, Afranio Peixoto, Arthur Neiva, and Alcides Godoy, among others (Deane, 1988b). The early programs were coordinated with the construction of railways, water supply systems, and other public works. Major efforts were concentrated in the Amazon in 1942, when the increased demand for rubber during World War II called for measures to improve the health of rubber gatherers. Despite the great success after the introduction of DDT in the mid-1940s, malaria in the Amazon was very difficult to control, especially because of the favorable conditions that the forest naturally offered to the breeding of mosquitoes. Moreover, DDT spraying was basically concentrated in the capitals and major cities in the Amazon, leaving most of the area without control. In 1962, DDT spraying in the Amazon was intensified, and a much larger coverage achieved by 1968 (Coimbra, 1987).

The most remarkable event in malaria control in Brazil was the eradication of *Anopheles Gambiae*, the most effective vector of malaria, from Ceará State, located in the Northeast region. This African vector was brought to Brazil by a French ship coming from Dakar, Senegal, in 1929[7]. *A. Gambiae* was responsible for one of the most severe epidemics in Latin America, and certainly the worst in the country prior to 1940. There were 150 thousand cases, and 14 thousand deaths in only 8 months between 1938-39 (Deane, 1990). A massive control program was implemented at the end of 1938, and by 1940 *A. Gambiae* had been eradicated from Brazil. Approximately 4 thousand workers were employed during 19 months of control. Strategies included monthly house spraying, early case detection and rapid treatment, spraying of cars and

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[7] One year before, Adolfo Lutz had already called attention to the fact that the increased transportation network between Brazil and the African continent could result in the importation of mosquitoes from Africa (Soper and Wilson, 1943; Deane, 1988b).

trucks leaving or entering the endemic area, elimination of breeding sites, ditching of subsurface water areas, house capture, and use of larvicides (Soper and Wilson, 1943; Deane, 1988b; Killeen et al., 2002). A similar campaign was repeated in Egypt in 1943-44, inspiring the eradication strategy that marked the WHO agenda between 1955 and 1969 (Bailey, 1982; Litsios, 1997).

Malaria eradication campaigns started in 1957, and persisted during the 1960s. The number of cases decreased dramatically, reaching a minimum level in 1970 with 52,371 cases of malaria (31,733 of them registered in the Amazon). After that, however, malaria started a dangerous increase, spatially confined to the Amazon, and driven by government-sponsored programs of colonization in the area.

Recent efforts of control have all been concentrated in the Amazon. In 1989, the Amazon Basin Malaria Control Project was launched, partially financed by the World Bank. Among the strategies adopted were vector control, epidemiological and entomological surveillance, intensification of treatment, and special attention to indigenous areas. The number of health units equipped with microscopes increased from 402 in 1992 to 1,095 in 1996. The information system was dramatically improved, and in 1993 it gathered data from 98% of the municipalities considered to have potential for high malaria risk (Akhavan et al., 1999). With better available data, the actions could be focused on areas with higher risk, promoting more cost-effective interventions for malaria control (Carter, Mendis and Roberts, 2000)[8].

Another program for malaria control started in July of 2000 – Intensification Plan of Malaria Control Activities in the Legal Amazon (PIACM). The strategies adopted included a reorganization of the health agencies at the local and state level; an increase in personnel to work on diagnosis, treatment, and DDT spraying; intensification of training activities; acquisition of vehicles, bicycles, motorcycles and boats to allow complete coverage of the population living in the municipalities selected as priorities for control; acquisition of microscopes and new equipment for in-house spraying; construction of drains where appropriate; expansion of the network of health services; development of a GIS system using malaria data; and conditioning the opening of new areas for settlement to approval by the National Health Foundation. At its

[8] Spatially targeted interventions were a significant improvement in the use of financial resources for control policies. As an example, in 1986, 60% of all malaria cases in the Amazon were concentrated in 458 municipalities, but 70% of the budget for malaria control was being spent in municipalities with only 3% of cases (Akhavan et al., 1999).

completion in December 2002, malaria cases were reduced by 39%. Major achievements facilitated this decline, such as the incorporation of more than 7,600 employees to the existing workforce; the improvement of the infrastructure through the acquisition of vehicles, boats, motorcycles, bicycles, microscopes, and computers; and the training of almost 20 thousand people in malaria control strategies (FUNASA, 2000b).

The most recent program for malaria control was launched in January of 2003 – National Program for Malaria Prevention and Control (PNCM). The goal is to reduce the number of malaria cases by 25% in one year and by 15% afterwards, and to eliminate the occurrence of malaria in urban areas of all capital cities in the Amazon by 2006. The interventions are basically a continuation of the remarkable efforts implemented by the PIACM (FUNASA, 2002).

In settlement areas, it is important to emphasize that massive migration imposes serious constraints on the adoption of malaria control strategies. First, migrants never exposed to malaria lack immunity and the appropriate knowledge to protect themselves against the disease. Second, migratory flows are, most of the time, higher than the acceptable carrying capacity of the area**.** This imposes extra pressure on the environment and on the already deficient infrastructure of the area, contributing to the aggravation of most of the problems mentioned above. Third, migrants that come to colonization areas are highly mobile, and can carry the malaria to other areas every time they move. Moreover, effective environmental management and biological control techniques are difficult to implement in the presence of unstable human migration. They have no record of successful utilization in the modern period of frontier expansion. The exceptions to this are some corporate-sponsored projects where extensive land-clearance is a malaria-protective measure (Sawyer, 1992). In summary, the combination of high human density, high vector density, and lack of immunity in colonization areas is destined to produce malaria outbreaks.

Mitigation strategies against malaria should not rely solely on traditional interventions, such as DDT spraying inside the houses and drug distribution, but focus on alternative and diversified procedures that encompass the complexity of transmission over space and time.

4. Differences and commonalities in a comparative perspective

The Tanzanian and Brazilian cases presented here differ enormously in cultural context, ecology, and the details of migration patterns. Thus, one might expect an extensive list of differences in patterns of malaria transmission, disease incidence, environmental transformation, and personal behavior. However, at a deeper level, there are remarkable similarities.

First, in both Dar es Salaam and Machadinho, urban development followed the opening of new roads. Once the governments built the main roads, dirt feeder roads proliferated, opening the way to further settlement. In both cities, easy access to city centers and more peripheral areas ensured further geographical expansion.

Second, in both Dar es Salaam and Machadinho, migration and settlement disproportionately affected poor people. The vast majority of settlers in the Amazon are landless people, and most of migrants from rural areas in Tanzania are equally poor. They move searching for better opportunities in life, but face a harsh reality: lack of adequate infrastructure, economic opportunities and food supply, poor habitat conditions, and exposure to different diseases (Taylor-Ide, Taylor and Shahi, 1997). Moreover, their behaviors also show similarities. Both in the Amazon and in Dar es Salaam it was common to find people owning houses in two locations. In the Amazon, some settlers would choose to live in the urban center of the colonization project, but keep a rural plot for farming. In Dar es Salaam, some people worked in the city, but would live in the peri-urban area and develop agricultural activities. In both cases, a pattern of intense human mobility is observed, which has important implications for malaria transmission.

Third, both settings experience dramatic environmental transformation. Human settlement in the Amazon is not restricted to areas chosen by the government. Spontaneous (and illegal) occupation takes place near roads, driven by corporate interests or by the surplus of migrants in need of land. Huge portions of the forest are cleared, overcoming any previous expectations. When trees are cut down, streams are frequently blocked, and they become exposed to sunlight. Pits are opened for mining. Troughs are created in the ground simply as a result of a poor clearing of the forest. Dirt roads lack adequate drainage, and pools of water are formed in roadside ditches. All these situations result in ideal breeding places for malaria vectors in settlement areas.

Analogously, urban expansion is frequently accompanied by dramatic changes in the local ecology. Poor migrants are likely to build up precarious houses in slums and shantytowns, without adequate sanitation. Pollution soon becomes a problem, which can affect nearby streams and rivers. Additionally, as the city expands there will be more industrial plants established in the periphery, which if not under tight control will contribute to the occurrence of high levels of air pollution. This will disproportionately affect the poor, since very often live in slums and shantytowns close to those plants (Harpham, Lusty and Vaughan, 1988).

Fourth, in both locations, the spatial distribution of malaria is very heterogeneous. In the urban context, transmission will be less intense in the most developed areas, depending also on the vector density. Transmission levels will vary based on local characteristics of both the settlers and the ecology (Trape et al., 1992; Longstreth and Kondrachine, 2002). This common feature indicates the need for spatially targeted interventions for malaria control.

4.1.Migratory patterns

The vast majority of migrants occupying new settlement areas in the Amazon are poor people attracted by government-sponsored programs of land distribution, who are willing to travel any distance, in any conditions, to guarantee a share of land for their family. The early success of the settlement efforts brought to the area a migratory flow above the sustainable carrying capacity[9]. Although the government never conducted thorough analyses to assess the carrying capacity of the settlement sites, the influx of migrants exceeded all prior expectations.

Although prevention of migration is not feasible, around 1974 and 1975 the Brazilian government installed roadblocks at the borders of the States of Rondônia and Mato Grosso, in order to impede the entrance of new migrants who arrived in huge trucks. A triage was conducted allowing only a small fraction to enter the State. Furthermore, the federal government produced and distributed a special flyer in areas that sent many migrants to Rondônia, stressing the fact that the State could not afford further settlers, that the infrastructure was deficient, and that penalties would be imposed on those making illegal land deals. None of these efforts actually stopped the migratory flow. Finally, in 1979 the government, responding to political pressure, eliminated these efforts (Veja, 1977; Martine, 1990).

The relationship between malaria transmission in Africa and population movements has been detailed in comprehensive studies (Prothero, 1965; Bruce-Chwatt, 1968; Prothero, 1989; Prothero, 2001). As Prothero (1994) states, not only population movements affect disease, but disease also has a significant impact on population movements. Rural-urban migrants often have poor houses, live in slums or illegal settlements, and are poorly paid (Hardoy and Satterthwaite,

[9] Sustainable carrying capacity is the maximum number of persons that can be supported in perpetuity on an area, with a given technology and set of consumptive habits, without causing environmental degradation (Fearnside, 1986).

1997). Their characteristics and spatial distribution in cities may explain part of the variation in malaria transmission among and within different urban locations (Robert et al., 2003).

4.2.Urbanization patterns

The present pace of global urbanization has no precedent in history. Meade and Erickson (2000) compare this process to two other major changes in human history: the flourishing of cities after the domestication of plants and animals, and the industrial revolution. It has been particularly significant in Africa, where urbanization rates shifted from 14.7% in 1950 to 34.5% in 1995 (UN, 2003). Rapid urbanization has been almost universally followed by poverty – poor housing, inadequate sanitation and water supply, scarce food supply, and spread of diseases such as dengue, typhus, malaria, filariasis, diarrhea, and hemorrhagic fever (Gratz, 1997; Martens and Hall, 2000).

In Dar es Salaam, a large amount of the urban expansion results not from natural population growth, but from rural-urban migratory movements. In many cities migrants keep their traditional rural practices, such as raising livestock (mainly chicken and cattle), farming crops, and storing water. These practices intensify and contribute to disease outbreaks, and give a new character to urban areas Knudsen and Slooff (1992) name this phenomenon 'ruralization' of cities. In the urban area of Dar es Salaam (as well as in other urban areas in Tanzania), agriculture and rearing of livestock are very common activities with significant economic returns. They are practiced not only by migrants and/or the poor, but also by a significant number of people of higher socioeconomic status. Urban agriculture is the second largest source of employment, and 74% of the farmers raise livestock. Animal dung is a major concern: in Dar es Salaam, approximately 72% of cattle dung is dumped along the roadside. Different forms of environmental degradation are observed, such as soil erosion. Crops raised in *matuta*, without adequate drainage, provide ideal conditions for mosquito breeding. All these issues bring serious health and environmental problems (Mlozi, 1997; Dongus, 2000).

In newly opened areas in the Amazon the concept of urbanization is quite different. Usually settlement areas have a main center where basic infrastructure, local government institutions, and major commerce are located. There are no industrial plants and the area is not a major trade zone. However, the capitalist forces are present in those areas. These center zones are considered as urban, although their characteristics are radically different from those of Dar es Salaam. They change from jungle to a busy city in less than five years. The area is cleared, filled with precarious houses and small businesses, and receives a massive influx of migrants that overwhelm the available services. Pressure on the environment is huge, as is the demand for infrastructure and basic services. In Machadinho, the main urban area experienced a serious outbreak of malaria in 1986 (roughly one year after the area was opened). This was aggravated by the fact that mobility was very intense, with people living in town and working on their rural plots. These characteristics result in patterns of malaria transmission that sharply distinguish urban Dar es Salaam from the early development period of urban Machadinho. However, 8+ years after the opening of the Machadinho settlement area, the urban center was quite similar to Dar es Salaam in terms of the focality of anopheles breeding sites and the low level of inner city transmission.

In summary, regardless of the type of urbanization process, if it occurs in an uncontrolled and unplanned way, it is very likely that malaria transmission will become a serious problem, more so in new settlement areas in the tropical forest than in cities where urbanization expands to the periphery.

4.3.Ecosystem transformations

Roberts, Masuoka and Au (Roberts, Masuoka and Au, 2002) propose the concept of 'regional environmental capacity' for malaria transmission, which encompass two issues: (i) capacity provided by the natural environment (climate, temperature, rainfall, humidity, etc), and (ii) capacity provided by the altered environment (man-made transformations).

In theory, the man-made transformations that take place during the urban expansion should reduce the capacity for malaria transmission. Open spaces are replaced by buildings and cemented areas, roads are paved, and standing water becomes polluted. In the beginning stages of city growth, malaria rates increase because of precarious conditions in slums, opening of pits for housing construction, improper storage of water, etc. When urban centers are consolidated, the capacity for malaria transmission should be dramatically reduced.

In the case of new settlement areas in the Amazon, although the natural environment has ideal conditions for mosquito breeding, the undisturbed forest is not ecologically compatible with *A. darlingi* breeding and biting habits. However, when the environment, potential sources of breeding sites proliferate in the forest fringe and at the margins of streams, now exposed to partial sunlight due to deforestation. As the settlement consolidates over time, the capacity for transmission is progressively reduced. McGreevy (1989) showed that prevalence rates in the

State of Rondônia were higher in newly opened areas relative to old settlements, ranging from 1-2% to 14-26%, respectively.

The timing and specific character of ecosystem transformations that occur in urban and new settlement areas can either intensify or reduce the capacity for malaria transmission. Adequate understanding of the timing, and of the different types of man-made transformations is essential for efficient, cost effective, and sustainable interventions for malaria control. Next, we address this issue into detail.

4.4.Malaria control

The challenges for malaria control in urban and new settlement areas are multifold. Although the most adequate interventions for each area are not the same, the historical efforts to control the disease in both Dar es Salaam and Machadinho yield important lessons for present campaigns.

In urban settings, such as Dar es Salaam, human and housing density is very high, and the sources of mosquito breeding are limited and most often accessible (Trape et al., 2002). In such cases, integrated vector control strategies are more cost effective than massive chemoprophylaxis or house spraying. Control programs should be heavily concentrated on environmental management. This can result in a reduction of flooding, marshy areas, and general water accumulation. Areas previously considered unsuitable for development can be reclaimed and used productively. Dar es Salaam already has a well-established drainage network, so most of the financial resources would be spent on rehabilitation and maintenance, which are less expensive than constructing new drains. Active participation of the community would reduce expenses even further (Yamagata, 1996a). If a drainage network was not already in place, the initial cost of this kind of intervention may be high. However, it will be amortized over time, since only maintenance of the drain will be necessary in the future to eliminate this habitat for mosquito breeding.

In rural settings, such as settlements in the Amazon, however, a different set of interventions is needed. Human and housing density is very low, the number of potential breeding sites is extremely large, and access to some areas is precarious. In such a scenario vector control would not be a cost effective intervention. Moreover, one of the main requirements for the success of vector control is the capacity to methodically register and access all breeding sites in the area. This is a virtually impossible task in settlement areas in the tropical forest.

Given the pattern of malaria transition over time, and the spatial heterogeneity of malaria transmission, an adequate control policy for settlement areas should include different phases (Castro, 2002). First, when a settlement project starts, health officials must have complete knowledge about the area, including eventual residents in the forest that could be carriers of the malaria parasite. Newcomers, and eventual residents, should be tested for malaria, and treated in case they are infected. The initial interventions must focus on property management, such as (i) rapid and complete clearance of forest near the house (at least 100m) immediately after people occupy their plot, and progressive elimination of forest over time, until the effects of the forest fringe as larval habitats are minimized; (ii) fully enclosed and screened housing (ideally located far from sources of water); and (iii) rapid transition from forest to cleared area to crop production.

Simultaneously, the knowledge of the settlers regarding malaria risk could be improved by massive educational campaigns. Settlers should be encouraged to have animals in their plots, providing alternative sources of blood for mosquitoes. Community participation should be promoted as early as, possible. Once the settlement is more stable, with environmental risk factors relatively under control, and with lower malaria incidence, the educational campaign should be intensified. Settlers should be encouraged to adopt personal protection measures, and to adapt their behavior to the local characteristics of the malaria vector. For example, settlers should be advised to avoid staying outside their houses at the peak hours of mosquito biting. Clothes should not be washed near rivers, and shower should be taken inside the house. Community groups, like churches, schools and unions of different workers, could address most of these issues, emphasizing the need to promote community participation in settlement areas.

4.5.Sustainable development & sustainable health

The opening of new settlements in the Amazon was proposed on the grounds of promoting the integration of the area with the rest of the country, assuming that those areas would result in sustainable agricultural production zones. Analogously, urban expansion ideally should imply sustainable development. In both scenarios, the question is: what do we mean by ‘sustainable’? A comprehensive definition is provided by James Gustave Speth (Shahi et al., 1997: 219):

> "Sustainable development is development that doesn't merely generate growth, but distributes its benefits equitably; it regenerates the environment rather than destroying it; it empowers people rather than marginalizing them; it enlarges their choices and opportunities and provides for peoples' participation in decisions affecting their lives. Sustainable human development is development that is pro-poor, pro-nature, pro-jobs and pro-women. It stresses growth but growth with employment, growth with environment, growth with empowerment, growth with equity."

Many extensions and offshoots of this definition could be given, including sustainable urban growth, sustainable agriculture production, and sustainable public health. They would simply express urban growth, agriculture production, and public health in the context of sustainable development. Virtually no African urban setting and no settlement area in the Amazon meet all the criteria that define sustainable development. However, this ideal is increasingly in the public discourse, and there is definite progress toward operationalization of the idea of sustainability.

It is important to highlight that deforestation and malaria are linked by an unavoidable tension. Once deforestation starts, malaria rates jump to dramatic levels; and one of the strategies to reduce the rates is to promote rapid clearance around inhabited areas. This issue alone would certainly require an extensive discussion, starting from the rationality of promoting settlement in the forest. This is beyond the scope of this paper. However, what needs to be emphasized is that, if the forest is to be replaced by a whole new community, a detailed set of policies should be put in place to ensure sustainable living conditions for the settlers. The lack of such policies perpetuates poverty, promotes irreversible damage to the environment, and ultimately results in dramatic social inequalities.

A similar cycle characterizes urban expansion in older cities, such as Dar es Salaam. When expansion of the city begins, malaria rates are high, progressively decreasing as the area gets more developed. Peri-urban areas have higher malaria, which will only decrease when they become part of an expanded central core of the city. However, more development is likely to encourage further migration. Without adequate planning, there will be pockets of poverty at the periphery of the city, and the people will suffer serious health problems.

5. Conclusion

The transmission of malaria is strongly influenced by population movements and by the process of urbanization. Whether malaria risk increases or decreases depends on the social, economic and behavioral characteristics of the migrants, on the type of ecological setting, on the availability of malaria vectors in the area, and on the changes people impose on the environment. Historical evidence, briefly discussed here, reveals that the onset and spread of epidemics of different diseases can be facilitated by both migration and urbanization. Most often, malaria increases in all newly opened frontiers for economic development in agriculture and mining, in those areas affected by war, lawlessness and open conflicts, and in locations that are a focal point for refugee migrations (Knudsen and Slooff, 1992).

Taken as an isolated issue, urbanization is not intrinsically a threat to human health. It is unplanned urban expansion that introduces serious challenges for the health and wellbeing of the population (Mwaluko, Lukmanji and Kasale, 1991). Poor residents of urban areas do not benefit from the positive aspects of development. Instead, they are very likely to suffer from diseases such as tuberculosis, malaria, dengue, and undernourishment, to name a few (Harpham, Lusty and Vaughan, 1988). Analogously, the natural forest is not unhealthy. It is the combination of ecological transformations and social changes that precipitate major challenges (Prothero, 2001).

The two case studies presented in this paper show that uncoordinated expansion of both cities and settlement areas often have serious implications for the health conditions of the population. Specifically in the case of malaria transmission, Dar es Salaam and Machadinho exhibit an initial increase in incidence, which tends to stabilize at lower levels over time. However, the magnitude of the malaria outbreaks, and the interventions for control that ideally should be put into place in both areas are very different.

In urban areas, characterized by high levels of development, the presence of industrial plants, extensive transportation system, and extensive built-up areas, environmental management interventions (including drainage work, but also the provision of sewage and clean water) and tight regulations against pollution would dramatically improve the overall health conditions of the population. Most importantly, those efforts must be maintained over time in order to facilitate the achievement of sustainable development. Community participation and training of people in different sectors is key to guarantee that maintenance will occur.

In settlement areas, rigorous planning should start prior to the occupation. Since the most dramatic impacts in health take place during the onset of the colonization process, any delays cost thousands of workdays, many lives, and serious damage to the local environment. If the purpose of settling people in the tropical forest is to promote sustainable agricultural production, then sustainable public health should be put into practice.

In summary, population movement is at the heart of the human condition. Continents were discovered, conquered, and occupied because people move. Transportation shifted from horses to airplanes because people move. Cultural and technological exchange is possible because people move. Diseases easily spread because people move fast and in large numbers. This is not going to change, but the negative impacts of population movements can and should be mitigated. And it is only through extensive research that facilitates the understanding of the major determinants of disease transmission in different cultural and environmental settings that this can be achieved.

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