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MALARIA TRANSMISSION IN URBAN SUB-SAHARAN AFRICA

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Abstract. The rapid increase in the world's urban population has major implications for the epidemiology of malaria. A review of malaria transmission in sub-Saharan African cities shows the strong likelihood of transmission occurring within these sprawling cities, whatever the size or characteristics of their bioecologic environment. A meta-analysis of results from studies of malaria transmission in sub-Saharan Africa shows a loose linear negative relationship between mean annual entomologic inoculation rates (EIR) and the level of urbanicity. Few studies have failed to find entomologic evidence of some transmission. Our results show mean annual EIRs of 7.1 in the city centers, 45.8 in periurban areas, and 167.7 in rural areas. The impact of urbanization in reducing transmission is more marked in areas where the mean rainfall is low and seasonal. Considerable variation in the level of transmission exists among cities and within different districts in the same city. This article presents evidence from past literature to build a conceptual framework to begin to explain this heterogeneity. The potential for malaria epidemics owing to decreasing levels of natural immunity may be offset by negative impacts of urbanization on the larval ecology of anopheline mosquitoes. Malaria control in urban environments may be simpler as a result of urbanization; however, much of what we know about malaria transmission in rural environments might not hold in the urban context.

INTRODUCTION

The rapid increase in the world's urban population has major implications for the transmission and epidemiology of malaria and other vector-borne diseases.[1,2] This situation may be particularly true in sub-Saharan Africa (SSA), the most rapidly urbanizing continent,[3] with some of the highest rates of *Plasmodium falciparum* transmission. In SSA, hospitals and clinics regularly report >15% of admissions are due to malaria. Although some cases are referrals from rural areas, malaria transmission in urban and periurban settings is a significant problem.[4–6]

Despite the severity of the problem, gaps remain concerning urban malaria transmission in SSA. Several explanations exist to account for why urban areas seem to have lower malaria transmission rates compared with rural areas. One explanation is that pollution affects larval habitats, the life cycle of mosquitoes, and vectorial capacity. Other explanations include mosquito avoidance behavior by urban populations, such as screens, doors, insecticides, and bed nets. Higher human population densities may reduce biting rates, owing to the higher ratio of humans to mosquitoes. Few data are available to confirm these theories or to prioritize strategies for malaria control. Many questions remain for public health specialists hoping to regain control over malaria in urban environments.

The objectives of this article are to synthesize existing literature on malaria transmission in urban areas of SSA and to generate a conceptual framework. Following a summary of the main terms, we present a meta-analysis of entomologic inoculation rates (EIR) from urban, periurban, and rural studies. This analysis provides background to a review of the entomologic and social and behavioral literature related to urban malaria. The resulting conceptual framework illustrates factors that may explain the heterogeneity of malaria transmission within and among urban environments in SSA.

BACKGROUND

The study of malaria transmission in urban areas is not new, with significant efforts dating back to the 1930s in East Africa.[7–9] More recent measurement of urban transmission began with Krafsur,[10] followed in the 1980s by Vercruysse and Jancloes in Pikine,[11] Robert et al in Bobo-Dioulasso,[12] and Trape et al in Brazzaville.[13–15] Despite this history, considerable challenges remain. Measurement of entomologic markers in areas of low transmission is problematic. Human behaviors and socioeconomic variations interact with natural systems in heterogeneous urban populations. As such, applying relevant observational and measurable markers to differentiate levels of urbanicity is arduous at best.

The post–World War II era has been characterized by a rapid increase in the world's population, especially in tropical areas. In 2000, the population in SSA was estimated to be 784 million; by 2025, this figure is expected to be >1.2 billion.[3] Despite intriguing accounts of Africa's ancient cities, some with 40,000 inhabitants,[16–18] the continent's population remained predominantly rural until recently. In 1900, <10% of Africans lived in an urban area, and by 1950, only 15% lived in an urban area. Today, almost half of the population in SSA lives in urban or periurban areas (45% in 1999), and this proportion is expected to increase dramatically over the next 25 years. Although rapid urban growth is a relatively recent phenomenon in SSA, the cities of approximately 0.5 million population are growing faster than in any other area of the world.[19] This is an urbanization rate of 2% for the past 30 years, a doubling of the urban population every 37 years. Pollution, poor housing, lack of sanitation, unprotected water reservoirs, weak services, low productivity, and widespread economic disparity have accompanied this urbanization.[19]

Similar to most urban settlements, African cities are complex, dynamic structures. Western definitions emphasize characteristics that differentiate urban from rural areas, including land use patterns, increased density of households, differences in housing material, economic differentiation in relation to type and abundance of work, access to public transport, access to utility services, and access to social services. In many instances, urban SSA does not fit this conventional definition. Rice fields exist in the heart of Bouake,[20] and market-garden wells are common in Dakar.[21] Livestock often are herded through central business districts and are a common sight in residential, market, and commercial areas. Urban areas can encompass suburban development, affluent neighborhoods, older settlements that have become established shantytowns, business districts, and periurban slum settlements on the outskirts of towns and cities. People who settle in densely populated, undeveloped periurban areas often are met with communities already trying to overcome widespread poverty, pollution, and environmental degradation. These communities often lack the programs, personnel, and resources to combat infectious disease, a situation exacerbated by poverty, low levels of education, deteriorating infrastructure, and continued rural subsistence activity.

It is thought that about 10 anopheline species are responsible for malaria transmission in SSA. By contrast, in the urban context, there are normally 3: *Anopheles gambiae*, *Anopheles arabiensis* (both belonging to the *An. gambiae* complex), and *Anopheles funestus*. The first 2 species are the most important. *An. funestus* has not been found in most cities but was found in a district of Franceville, Gabon, and in Maputo, Mozambique.[22,23]

The value of the EIR lies in the fact that it provides an estimate of the passage of malaria parasites from infective anopheline species to human populations. It is calculated as the product of the human-biting rate (an estimation of the density of mosquitoes per person) and sporozoite index (an estimation of the proportion of vectors with sporozoites in their salivary glands). The EIR is expressed as the number of infective bites per person per year. It ranges from <1 bite per year in low-transmission areas to 2,979 infected bites per person per year in 1 sentinel house.[24] Although the EIR is a good indicator of transmission intensity in the context of high mosquito density, logistical problems exist when estimating EIR in areas of low mosquito density.[25] The determination of anopheline density at low densities can be difficult, and malaria transmission does occur below the entomologic threshold for detection.

The EIR cannot be considered an exact measure of transmission because not all bites from infected anopheline species succeed in infecting humans. In experiments, Rickman et al,[26] using persons without any antimalarial immunity and anopheline species with *P. falciparum* sporozoites in their salivary glands, showed that 1 or 2 infected bites per person infected only 5 of 10 human volunteers. This limiting factor, which is called the *infectivity success rate* (usually parameter "b" in literature), rarely is taken into account when calculating an EIR from the sporozoite index and human-biting rate. In endemic areas, the infectivity success rate ranges from 5% to 26%, with inverse variations with EIR resulting from higher protective immunity, more multiple infections, and longer episodes with parasitaemia.[24,27]

MATERIALS AND METHODS

The meta-analysis of malaria transmission began with the identification of entomologic studies that focused on malaria transmission in urban SSA and were published before 2001. Studies were evaluated for appropriate entomologic data according to the following inclusion criteria: (1) studies conducted over 12 months; (2) frequency of mosquito sampling, at least monthly throughout the year or during periods of transmission for sites with seasonal patterns of transmission; (3) standard methods, such as human-biting catches, pyrethrum catches, or light traps used for estimating biting rates; (4) dissection or enzyme-linked immunosorbent assay methods used for determining proportion of sporozoite-infected mosquitoes; and (5) studies conducted during periods when no mosquito control operations were in effect. For sites where EIR data were available for >1 year, yearly average figures were used, as provided in the articles. As far as we know, the reference set providing EIRs for urban and periurban sites in SSA is exhaustive and compares closely with another review of EIR in studies across the continent.[28] Because it was not feasible to find EIRs from matching rural sites, we selected EIRs from rural sites representative of studies from various parts of SSA, including savannas, rain forests, rice fields, various altitudes, and near large rivers and lagoons.

The EIRs reviewed were assigned a category: central urban, periurban, and rural. Categorical assignment of the respective EIRs was based on the description of the study area in the articles. Assignment in the rural category never posed a problem, whereas differentiating between central and periurban categories posed a challenge. Maps and habitat descriptions were used to differentiate between central urban and periurban when ambiguity was evident. Areas adjoining marshlands, areas adjoining rice fields, market-garden areas, or areas close to a lake were considered periurban; some central quarters of Pikine,[11,29] Bouake,[20,30] and Ouagadougou[31] were classified as periurban. Overall, 39 studies satisfied the inclusion criteria. Because several studies provided estimated EIRs from >1 site, the final data set included 90 values of EIRs distributed across 21 urban centers, 14 periurban sites, and 55 rural sites. In a separate analysis, we categorized study areas according to their ecologic niche with 33 values of EIRs in dry savannas plus Sahel versus 57 values in wet savannas plus forest zones.

RESULTS

Table 1 lists the references and the categorization of each result, and Figure 1 illustrates a summary of the EIRs across the 3 different environments. The average level of malaria transmission in urban centers, periurban areas, and rural sites differs tremendously. The arithmetic mean of annual EIRs is 7.1 in the urban centers, 45.8 in periurban areas, and 167.7 in rural areas. These values were significantly different when comparing with Mann-Whitney *U* tests between urban centers and urban peripheries ($P < 0.001$), between urban peripheries and rural areas ($P = 0.051$), between urban centers and rural areas, and between the cities (central urban plus periurban) and rural areas ($P < 0.001$). Malaria transmission is clearly and significantly of a lower magnitude in urban compared with rural environments. Periurban versus rural differences are only marginally significantly different from one another. Ranges of values were large, with minimal values of 0 in urban and periurban areas and maximal values increasing from urban to rural areas.

For most urban areas that have been studied, there is evidence of malaria transmission. Only 5 studies failed to find any entomologic evidence. Of these, 1 was from Maputo,[23] 2 were from Ouagadougou,[31] and 2 were from Dakar.[32,33] At these sites, anopheline species had low densities or low infection rates. We did not exclude the possibility, however, of

TABLE 1

Sources of data set for the annual entomologic inoculation rates (EIRs) used in the meta-analysis (total references = 39; total values = 90) and assignment in 1 of 3 categories: urban center, urban periphery, and rural area

			EIR		
Year of publication	Author(s)	Locality, country	Urban center	Urban periphery	Rural
1977	Krafsur[10]	Gambela, Western Ethiopia	11		97
1981	Vercruysse and Jancloes[11]	Pikine, Dakar, Senegal		43	
1985	Robert et al[12]	Bobo-Dioulasso area, Burkina Faso			50; 60; 55; 133
1985	Carnevale et al[61]	PK Rouge and Ndjoumouna, Congo			80; 850
1985	Vercruysse[62]	North Senegal			1; 6.5
1986	Rossi et al[31]	Ouagadougou, Burkina Faso	7; 0; 0	10; 23	92; 82; 430
1986	Robert et al[38]	Bobo-Dioulasso, Burkina Faso	0.1; 0.5	5	
1987	Trape and Zoulani[13]	Brazzaville, Congo	0.3	101	
1988	Robert et al[63]	Karangasso, Burkina Faso			244
1988	Richard et al[64]	Mayombe forest, Congo			80; 397
1990	Lindsay et al[65]	Bakau, Banjul, The Gambia		1.3	
1990	Beier et al[66]	Western Kenya			299; 237
1992	Trape et al[29]	Pikine, Dakar, Senegal	0.01	0.4	
1992	Manga et al[54]	Yaounde, Cameroon	3; 13		
1992	Fondjo et al[55]	Yaounde, Cameroon	14	30	
1992	Karch et al[67]	Kinshasa, Zaire	3	66	620
1992	Fontenille et al[68]	St Marie Island, Madagascar			100
1992	Carnevale et al[69]	Mbebe, Cameroon			182
1993	Coene[36]	Kinshasa, Zaire	30		455
1993	Smith et al[24]	Kilombero, Tanzania			329
1993	Robert et al[37]	Edea, Cameroon	4; 30		
1993	Lochouarn and Gazin[39]	Bobo-Dioulasso, Burkina Faso	2		
1993	Githeko et al[70]	Ahero, Kenya			91; 416
1993	Njan Nloga et al[71]	Ebogo, Cameroon			355
1993	Mbogo et al[72]	Kilifi, Kenya	1.5		8
1994	Dossou-yovo et al[20]	Bouake, Ivory Coast		126; 88	
1994	Bockarie et al[73]	Bo, Sierra Leone			21; 36; 22; 26
1995	Dossou-yovo et al[30]	Alloukoukro, Bouake area, Ivory Coast			230
1995	Schiff et al[74]	Coastal Tanzania			218; 272; 577; 236; 703; 221; 94
1995	Mbogo et al[75]	Kilifi area, Kenya			3.8; 3; 18; 1.6; 3.6; 0; 0.001; 2.5; 59.6
1997	Thompson et al[23]	Maputo, Mozambique	0	20	
1997	Fontenille et al[76]	Dielmo, Senegal			159
1997	Fontenille et al[77]	Ndiop, Senegal			31
1997	Lemasson et al[78]	Barkedji, Senegal			114
1998	Diallo et al[32]	Southern district, Dakar, Senegal	0		
1998	Robert et al[79]	Niakhar, Senegal			9; 12; 26
1999	Elissa et al[22]	Franceville, Gabon		81	365
2000	Diallo et al[33]	Central district, Dakar, Senegal	0		
2000	Akogbéto[35]	Cotonou, Benin	29	47	12
		No. of values	21	14	55
		Mean	7.07	45.84	167.74
		Median	2.00	36.50	91.00

local transmission at levels lower than the sensitivity threshold of standard entomologic methods. In Dakar, there is some evidence of local transmission from reports of malaria among permanent residents.[34] The number of infective bites per person has been estimated for the central area as 0.05/year, or 1 infective bite every 20 years.[33]

Variability in EIRs among and within cities is evident (Table 1). Studies in the urban centers of Cotonou, Kinshasa, and Edea report the highest EIRs.[35–37] The highest EIR reported for any urban area is 30/year; the lowest is 0. The univariate shape of the distribution in central urban areas is skewed toward the lower end, with more than two thirds of the studies reporting EIRs <4/year. The variation across the periurban areas is more diverse, ranging from 0.4/year in Dakar[29] to 126/year in Bouake, Ivory Coast.[30]

Important interquarter or interdistrict variations can be observed. The studies conducted in 3 areas of central Bobo-Dioulasso estimated EIRs at 0.1, 0.5, and 2.[38,39] In Edea, this figure was 4/year and 30/year across 2 distinct quarters.[37] In 1 quarter in Pikine, large differences were detected for parasitologic incidence in children who lived close to marshland: about 1 infection per year for children residing at a distance of 10 to 160 m and 1 infection every 4 or 5 years for children residing at a distance of 785 to 910 m.[4] In Pikine, during the dry season, 93% of the *An. arabiensis* mosquitoes were collected in dwellings situated <285 m from the marshland.[29] In Ouagadougou, Burkina Faso, at a distance of 415 m from a lake, the density of *An. gambiae s.l.* per room decreased by 67% compared with the density observed closer to the lake.[40] Comparable results were obtained in the suburb of Maputo, Mozambique.[41]

The heterogeneity of malaria transmission in urban areas results in large differences in malaria prevalence in humans living in different parts of the cities. In Brazzaville, the prevalence among schoolchildren varied from 3% in a central quarter to 81% in peripheral areas, and these differences were

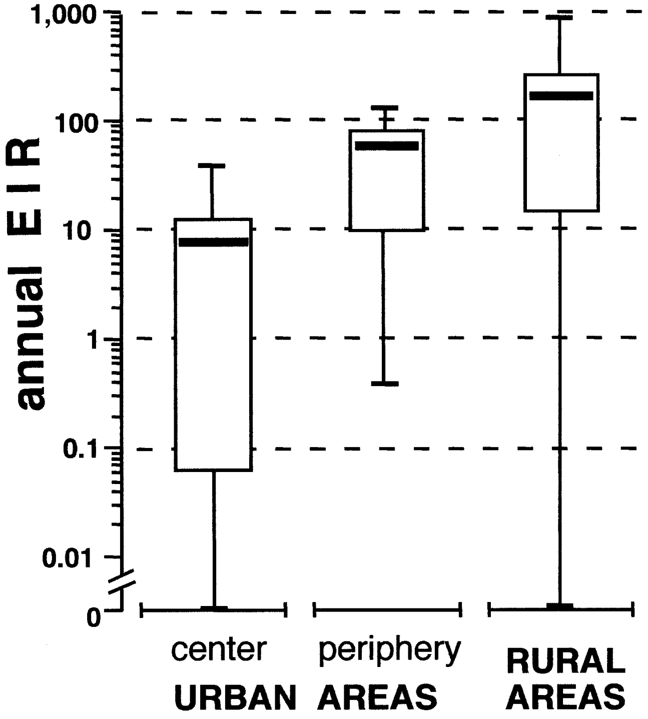

FIGURE 1. Box plot shows the annual entomologic inoculation rates (EIRs), expressed in number of infected anophelines per human per year, in 3 environmental categories. Data for the centers of urban areas, peripheries of urban areas, and rural areas are from 21, 14, and 55 nos. of values (references in Table 1). Per categories, the mean value is shown as a bold line inside the box, the 25th to 75th percentile is shown by the box, and the range of values is shown by the lines outside the box.

reflected in annual EIRs that varied from 1 to 100.[13] The impact of urbanization is more marked in areas where the mean rainfall is low and seasonal (Table 2). The mean EIRs are 0.96 in urban centers of cities located in dry savannas and Sahel and 12.62 in urban centers of towns located in wet savannas and forest zones ($P < 0.0009$ by Mann-Whitney U test). In periurban areas, these values are 14.67 and 77 ($P < 0.0027$). In rural areas, they are 94.03 and 197.98 and are not significantly different. When comparing the mean EIR of urban centers with the mean EIR of rural areas, a 98-fold decrease in EIR is seen in dry savannas and Sahel, and a 16-fold decreaseis seen in wet savannas and forest zones.

DISCUSSION

Four main conclusions are evident from this meta-analysis. First, nearly all studies concluded that anopheline species density and the likelihood of malaria transmission are lower in urban than rural areas. This likelihood of low transmission is stronger in central urban areas compared with periurban areas. Second, although a small difference can be identified between the periurban and rural studies, this is much less dramatic than the comparison between central and rural areas. Third, the variation in the range is much less across the periurban than across the central urban areas. Fourth, the impact of urbanization on transmission is as marked as the mean rainfall is low and seasonal.

Figure 2 presents a summary of the relationships across the major components of urban malarial ecology. The outcome is illustrated on the right as increases or decreases in urban malaria transmission. The central boxes reflect the entomologic factors that influence the level, timing, and intensity of vector competence. The boxes to the left represent an array of socioeconomic human factors and factors related to the physical environment thought to influence mosquito habitats. Human and vector components are influenced by climate and topographic variations, as indicated along the top of the figure. This framework was designed to facilitate the understanding of relationships that influence malaria transmission in urban areas across SSA.

TABLE 2

Annual entomologic inoculation rates (EIRs) presented by climatologic areas

	Dry savannas and Sahel			Wet savannas and forest zones		
	Urban center	Urban periphery	Rural	Urban center	Urban periphery	Rural
No. values	10	7	16	11	7	39
Mean	0.96	14.67	94.03	12.62	77.00	197.98
Median	0.005	10	57.5	11	81	97

Dry savannas and Sahel = 16 references: reference nos. 11, 12, 23, 29, 31, 32, 33, 38, 39, 62, 63, 65, 76–79.

Wet savannas and forest zones = 23 references: reference nos. 10, 13, 20, 22, 24, 30, 35, 36, 37, 54, 55, 61, 64, 66–75.

Land use and demographic factors. Urban environments may influence malaria transmission in several ways. By replacing vegetation with asphalt and concrete, urbanization may reduce the number of larval habitats. Yet in many urban areas, vegetation remains. This fact, coupled with urban farming, often provides ample aquatic habitats for mosquitoes. Physical deterioration (e.g., broken or blocked water drains, potholes, rubbish, tires), new construction activities (e.g., excavation, building construction, and irrigation schemes), and increases in human activity may increase opportunities for mosquitoes through the enhancement of shallow bodies of water and through an increase in the number of artificial water collection reservoirs. In these areas, water pipes sometimes are intentionally broken to procure water for sale and consumption or to sustain informal economic activities, such as car washes and irrigation (J. Keating, personal observation, 2001).

There is some evidence that anopheline species may be adapting to urban ecosystems. Chinery[42,43] observed some adaptation of *An. gambiae s.s.* to urban aquatic habitats, such as water-filled domestic containers and polluted water habitats created as a result of urbanization in Accra, Ghana. In a recently urbanized area of Kenya, Khaemba et al[44] concluded that *An. gambiae* showed a strong preference for man-made, temporary aquatic sites over permanent aquatic habitats in the rainy season, although dams and swamps remained the preferred sites during the dry season.[44]

Although some adaptation may be occurring, many observers assume that the pollution of aquatic sites most likely has a negative effect on anopheline species density and longevity.[45] Robert et al[21] noted that larval populations of *An. arabiensis* in market-garden wells in Dakar are regulated by interacting environmental variables, such as high nitrate concentrations, low pH, murky water, and other factors. Other studies indicated that detergents are important pollutants that may inhibit the development of anopheline larvae.[13] Barbazan et al[45] concluded that pollution was a major factor responsible for the scarcity of larval sites in Maroua, a large city in the savanna region of Cameroon.

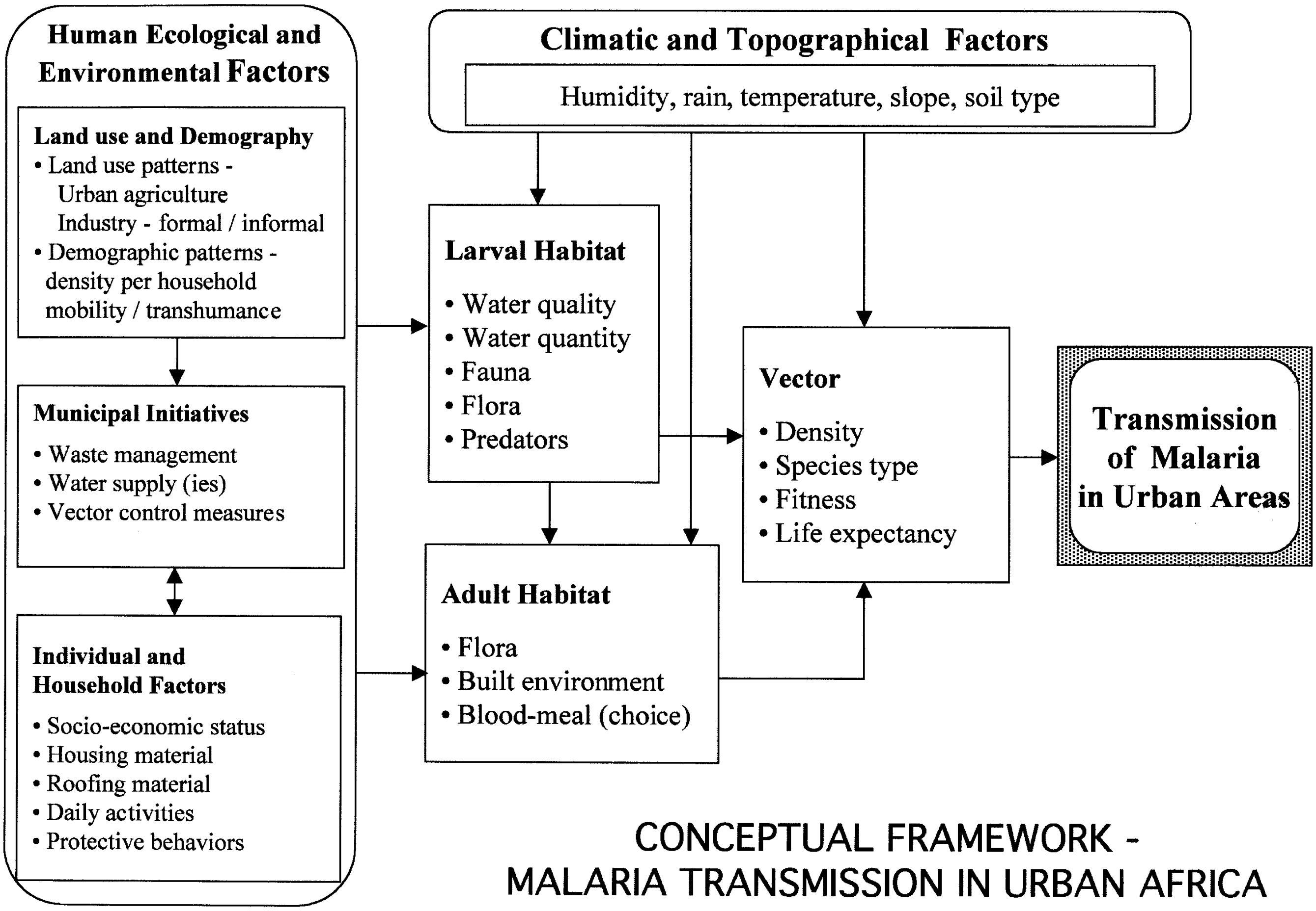

FIGURE 2. Conceptual framework of malaria transmission in urban sub-Saharan Africa.

Another explanation for the low EIRs relates to high human population density, which provides easier access to human blood meals for mosquitoes. This increase in potential hosts is thought to reduce the chance of any single host receiving an infective bite, lowering the overall human-biting rate. Sabatinelli et al[40] found that *An. gambiae* tend to bite near their breeding places in densely settled environments, however, and that their dispersion is restricted. An alternative hypothesis for low EIR argues that rapid urbanization in periurban areas and increases in population density in and around anopheline aquatic habitats increase the risk of malaria transmission. In other words, a large number of people living in close proximity to mosquito habitat increase blood meals available, which increases the number of mosquitoes an area can support, resulting in a greater number of total infective bites.[46]

Vector biting habits in urban contexts also may help account for some of the measurement challenges. *An. gambiae s.s.* and *An. arabiensis* feed on humans inside and outside houses. Preferential biting times may vary across and within small areas. In areas where humans typically stay outside later in the evenings, the protective effect of using bed nets or protection inside their houses is nullified if they are exposed during evening hours outside the home. Given this fact, the low EIRs calculated for urban areas may reflect the fact that finding female mosquitoes that have fed on a human outside as opposed to finding females resting inside houses may reflect challenges to existing entomologic field methods.

Human migration patterns also may explain variation in malaria transmission patterns among and within urban locations.[18,47] For many urban residents, travel to rural areas on a regular basis is predictable and regular. Depending on immunity, people can be categorized as either active transmitters or passive acquirers.[48] Passive acquirers are exposed to the parasite while traveling to an endemic area, whereas active transmitters harbor the parasite and increase the transmission risk when they travel to an area with an efficient vector. We can predict that when the relatively nonimmune individuals from urban areas travel to rural endemic zones, they may acquire infection and become transmitters when back home. Highland cities may be at risk of becoming malarious through the action of the rural migrants bringing infection with them.[49,50]

Municipal initiatives. Heterogeneity in malaria transmission may be explained by minor variations in the quality or type of water and waste management. In many urban contexts, the central business district is the only area with working water and sewage systems. It also may be the most sparsely inhabited area, especially at night during peak biting hours. From these central districts, the urban development is often characterized by growth in approximate concentric circles, with the newest construction in more marginal areas. These marginal areas can include swamplands or steep denuded hillsides. Generally, malaria transmission seems to decline from these peripheral areas toward the center. There are, however, several scenarios that may explain unexpected variations in this general trend. In Niamey, Niger,[51] and Karthoum, Sudan,[52] the city centers are located along rivers, which provides generous larval habitats for anopheline species.

Individual and household factors. In general, poorer populations are at greater risk of vector contact and infection, owing to physical proximity to water sources and lowered capacity (lack of education and resources) to use health care services and preventive measures to protect against malaria.[53] Human-vector contact is influenced by housing type (e.g., number of screens, doors), housing and roofing material, and house location (gradient, surrounding drainage, and cleanliness of immediate environment).[53] The use of screens, insecticides, prophylaxis, and bed nets, which is a function of income and education, also can affect the life expectancy of the mosquito, although whether this operates to influence vectorial capacity is unclear. On the one hand, shorter survival times of mosquitoes (reflected by the proportion of mosquitoes that had already laid eggs) were found in cities such as Pikine,[11,29] Kinshasa,[36] Edea,[37] and Bobo-Dioulasso,[38] in which the parity rate was significantly lower than in the neighboring rural areas. On the other hand, in other cities, including Brazzaville,[13] Franceville,[22] and Yaounde,[54,55] the parity rate was similar between cities and their neighboring rural areas.

Malaria surveys were conducted during the 1930s in the port cities of Mombassa, Dar es Salaam, and Tanga.[7–9] The authors of these studies believed that the problem of malaria in urban areas could be solved. The fact that it has not been solved has become a matter of concern.[2,56–58] The lower level of transmission, shown through this meta-analysis in urban areas, has important parasitologic, immunologic, clinical, and control implications. With urbanization, cities become populated with individuals who reach adulthood without significant malaria immunity. An increasing proportion of adults have little immunity. Given the rapid urbanization in recent years, such a situation is new for large segments of the population. This transition from a low endemic situation to a potentially epidemic one may be of great public health significance. This situation of islands of low immunity in an ocean of high endemicity is alarming, especially given the fragile ecologic state of the periurban areas and the considerable and regular migration patterns between these islands and their hinterlands.

Our analysis shows that these populations with low immunity do not constitute a fragile situation *per se* and that most cities rarely experience severe, widespread malarial epidemics. This situation is due, for the most part, to the major impact that urbanization (e.g., pollution, human density, increased built environment, protective and treatment measures taken by urban inhabitants) has on the larval ecology of the anopheline mosquitoes. Sudden changes in weather patterns (e.g., El niño) or civil unrest could affect the validity of these respective conclusions.

We propose that the city may be one of the most favorable African environments in which to envisage efficient and efficacious antimalarial activities. Although studies in rural areas report marginally significantly higher EIRs compared with periurban studies, these latter areas are much more densely inhabited. It can be assumed that if vector control can be successful in periurban areas, a greater number of people would be affected. Vector control must take into account variation in transmission patterns at the scale of a district, subdistrict, or quarter. In many urban areas, larval sites are few. They also are easily located and accessible. This fact can constitute a keystone for effective control. The arsenal for the antivectorial includes antilarval insecticide treatments, larvivorous fishes, house spraying, impregnated mosquito nets, and curtains.[59] In some favorable situations, the final goal can be to make cities malaria-free areas. The implementation of a malaria-free area, small in surface area but large with regard to population, would stimulate neighboring areas, local authorities, and eventually funding agencies for their extension.[60]

Many valuable future research areas emerge from this analysis. We need more information not only on the human behavioral determinants, but also on the entomologic characteristics of different districts within cities before we can advise health organizations confidently how best to proceed toward reducing the burden of malaria in urban settings. Vector control seems to be an efficient weapon to reduce transmission with direct consequences in lowering the incidence of malaria cases. This reduction of malaria transmission in the most favorable situations within urban SSA might be efficient enough to create malaria-free areas.

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REFERENCES

1. Lines J, Harpham T, Leake C, Schofield C, 1994. Trends, priorities and policy directions in the control of vector-borne diseases in urban environments. *Health Policy Planning 9:* 113–129.
2. Warren M, Billig P, Bendahmane D, Wijeyaratne P, 1999. *Malaria in Urban and Peri-Urban areas in Sub Saharan Africa.* Environmental Health Project Activity, Report no. 71. Washington, DC: USAID.
3. United Nations, 1999. *World Urbanization Prospects: The 1999 Revision, Key Findings.* New York: United Nations Population Division.
4. Trape JF, Lefebvre-Zante E, Legros F, Druilhe P, Rogier C, Bouganali H, Salem G, 1993. Malaria morbidity among children exposed to low seasonal transmission in Dakar, Senegal and its implications for malaria control in tropical Africa. *Am J Trop Med Hyg 48:* 748–756.
5. Imbert P, Sartelet I, Rogier C, Ka S, Baujart G, Candito D, 1997. Severe malaria among children in a low transmission area, Dakar, Senegal. *Trans R Soc Trop Med Hyg. 91:* 22–24.

6. Granja AC, Machungo F, Gomes A, Bergstrom S, Brabin B, 1998. Malaria related maternal mortality in urban Mozambique. *Ann Trop Med Parasitol 52:* 257–263.
7. Wiseman RH, Symes CB, McMahon JB, Teesdale C, 1939. Report on a malaria survey of Mombasa. Nairobi, Kenya: The Government Printer.
8. MacKay R, 1935. Report on work done at Dar es Salaam during 1932–1934. London: Government Printer.
9. Wilson DB, 1936. Report of Malaria Unit, Tanga, 1933–34. Nairobi, Kenya: The Government Printer.
10. Krafsur ES, 1977. The bionomics and relative prevalence of *Anopheles* species with respect to the transmission of *Plasmodium* to man in Western Ethiopia. *J Med Entomol 14:* 180–194.
11. Vercruysse J, Jancloes M, 1981. Etude entomologique sur la transmission du paludisme humain dans la zone urbaine de Pikine, Sénégal. *Cah ORSTOM. Ser Ent Med Parasitol 19:* 165–178.
12. Robert V, Gazin P, Boudin C, Molez JF, Ouedraogo V, Carnevale P, 1985. La transmission du paludisme en zone de savane arborée et en zone rizicole des environs de Bobo-Dioulasso, Burkina Faso. *Ann Soc Belge Med Trop 65 (suppl 2):* 201–214.
13. Trape JF, Zoulani A, 1987. Malaria and urbanization in Central Africa: the example of Brazzaville: Part II. Results of entomological surveys and epidemiological analysis. *Trans R Soc Trop Med Hyg 81 (suppl 2):* 10–18.
14. Trape JF, 1987. Malaria and urbanization in Central Africa: the example of Brazzaville: Part I. Description of the town and review of previous surveys. *Trans R Soc Trop Med Hyg 81 (suppl 2):* 1–9.
15. Trape JF, Quinet MC, Nzingoula S, Senga P, Tchichelle F, Carme B, Candito D, Mayanda H, Zoulani A, 1987. Malaria and urbanization in Central Africa: the example of Brazzaville: Part V. Pernicious attacks and mortality. *Trans R Soc Trop Med Hyg 81 (suppl 2):* 34–42.
16. Coquery-Vidrovitch C, 1993. *Histoire des villes d'Afrique noire. Des origines à la colonisation*. Paris: Albin Michel Ed.
17. Mumford L, 1961. *The City in History: Its Origins, its Transformations and its Prospects*. New York: Harcourt, Brace & World.
18. Knudsen AB, Slooff R, 1992. Vector borne disease problems in rapid urbanization: new approaches to vector control. *Bull WHO 70:* 1–6.
19. World Bank Development Report, *2000–2001, Attacking Poverty*. Washington, DC: World Bank.
20. Dossou-yovo J, Doannio J, Rivière F, Duval J, 1994. Rice cultivation and malaria transmission in Bouaké city (Côte d'Ivoire). *Acta Trop 57:* 91–94.
21. Robert V, Awono-Ambene HP, Thioulouse J, 1998. Ecology of larval mosquito, with special reference to *Anopheles arabiensis* (Diptera: Culicidae) in market-garden wells in the urban area of Dakar, Senegal. *J Med Entomol 35:* 948–955.
22. Elissa N, Karch S, Bureau P, Ollomo B, Lawoko M, Yangari P, Ebang B, Georges AJ, 1999. Malaria transmission in a region of savanna-forest mosaic, Haut-Ogooué, Gabon. *J Am Mosq Contr Assoc 15:* 15–23.
23. Thompson R, Begtrup K, Cuamba N, Dgedge M, Mendis C, Gamage-Mendis A, Enosse SM, Barreto J, Sinden RE, Hogh B, 1997. The Matola malaria project: a temporal and spatial study of malaria transmission and disease in a suburban area of Maputo, Mozambique. *Am J Trop Med Hyg 57:* 550–559.
24. Smith T, Charlwood JD, Kihonda J, Mwankusye S, Billingsley P, Meuwissen J, Lyimo E, Takken W, Teuscher T, Tanner M, 1993. Absence of seasonal variation in malaria parasitaemia in an area of intense seasonal transmission. *Acta Trop 54:* 55–72.
25. Beier JC, Killeen GF, Githure JI, 1999. Entomologic inoculation rates and *Plasmodium falciparum* malaria prevalence in Africa. *Am J Trop Med Hyg 61:* 109–113.
26. Rickman LS, Jones TR, Long GW, Paparello S, Schneider I, Paul CF, Beaudoin R, Hoffman SL, 1990. *Plasmodium falciparum*-infected *Anopheles stephensi* inconsistently transmit malaria to humans. *Am J Trop Med Hyg 43:* 441–445.
27. Beier JC, Oster CN, Onyango FK, Bales JD, Sherwood JA, Perkins PV, Chumo DK, Koech DV, Whitmire RE, Roberts CR, Diggs CL, Hoffman SL, 1994. *Plasmodium falciparum* incidence relative to entomological inoculation rates at a site proposed for testing malaria vaccines in Western Kenya. *Am J Trop Med Hyg 50:* 529–536.
28. Hay SI, Rogers D, Toomer JF, Snow RW, 2000. Annual *Plasmodium falciparum* entomological inoculation rates (EIR) across Africa: literature survey, internet access and review. *Trans R Soc Trop Med Hyg 94:* 113–127.
29. Trape JF, Lefebvre-Zante E, Legros F, Ndiaye G, Bouganali H, Druilhe P, Salem G, 1992. Vector density gradients and the epidemiology of urban malaria in Dakar, Senegal. *Am J Trop Med Hyg 47:* 181–189.
30. Dossou-yovo J, Doannio JMC, Rivière F, Chauvancy G, 1995. Malaria in Côte d'Ivoire wet savannah region: the entomological input. *Trop Med Parasitol 46:* 263–269.
31. Rossi P, Belli A, Mancini L, Sabatinelli G, 1986. Enquête entomologique longitudinale sur la transmission du paludisme à Ougadougou, Burkina Faso. *Parassitologia 28:* 1–15.
32. Diallo S, Konaté L, Faye O, Ndir O, Faye M, Gueye A, Diouf M, 1998. Le paludisme dans le district sanitaire sud de Dakar, Sénégal: 2. Données entomologiques. *Bull Soc Pathol Exot 91:* 259–263.
33. Diallo S, Konaté L, Ndir O, Dieng T, Dieng Y, Bah IB, Faye O, Gaye O, 2000. Le paludisme dans le district sanitaire centre de Dakar, Sénégal: Données entomologiques, parasitologiques et cliniques. *Cahiers Santé 10:* 221–229.
34. Diallo S, Ndir O, Faye O, Diop BM, Dieng Y, Bah IB, Dieng T, Gaye O, Konaté L, Faye O, 1998. Le paludisme dans le district sanitaire sud de Dakar, Sénégal: 1. Parasitémie et accès paludéens. *Bull Soc Pathol Exot 91:* 208–213.
35. Akogbéto M, 2000. Le paludisme côtier lagunaire à Cotonou: données entomologiques. *Cahiers Santé 10:* 267–275.
36. Coene J, 1993. Malaria in urban and rural Kinshasa: the entomological input. *Med Vet Entomol 7:* 127–137.
37. Robert V, Le Goff G, Toto JC, Mulder L, Fondjo E, Manga L, Carnevale P, 1993. Anthropophilic mosquitoes and malaria transmission at Edea, Cameroon. *Trop Med Parasitol 44:* 14–18.
38. Robert V, Gazin P, Ouedraogo V, Carnevale P, 1986. Le paludisme urbain à Bobo-Dioulasso: 1. Etude entomologique de la transmission. *Cah ORSTOM. Ser Ent Med Parasitol 24:* 121–128.
39. Lochouarn L, Gazin P, 1993. La transmission du paludisme dans la ville de Bobo-Dioulasso, Burkina Faso. *Ann Soc Belge Med Trop 73:* 287–290.
40. Sabatinelli G, Rossi P, Belli A, 1986. Etude sur la dispersion d'*Anopheles gambiae s.l.* dans une zone urbaine à Ouagadougou, Burkina Faso. *Parassitologia 28:* 33–39.
41. Mendis C, Jacobsen JL, Gamage-Mendis A, Bule E, Dgedge M, Thompson R, Cuamba N, Barreto J, Sinden RE, Hogh B, 2000. *Anopheles arabiensis* and *An. funestus* are equally important vectors of malaria in Matola coastal suburb of Maputo, southern Mozambique. *Med Vet Entomol 14:* 171–180.
42. Chinery WA, 1984. Effects of ecological changes on the malaria vectors *Anopheles funestus* and the *Anopheles gambiae* complex of mosquitoes in Accra, Ghana. *J Trop Med Hyg 87:* 75–81.
43. Chinery WA, 1990. Variation in frequency in breeding of *A. gambiae sl* and its relationship with in-door adult mosquito density in various localities in Accra, Ghana. *East Afr Med J 67:* 328–335.
44. Khaemba BM, Mutani A, Bett MK, 1994. Studies of anopheline mosquitoes transmitting malaria in a newly developed highland urban area: a case study of Moi University and its environs. *East Afr Med J 71:* 159–164.
45. Barbazan P, Baldet T, Darriet F, Escaffre H, Haman Djoda H, Hougard JM, 1998. Impact of treatments with *Bacillus sphaericus* on *Anopheles* populations and the transmission of malaria in Maroua, a large city in a savannah region of Cameroon. *J Am Mosq Contr Assoc 14:* 33–39.
46. Manga L, Fondjo E, Carnevale P, Robert V, 1993. Importance of low dispersion of *Anopheles gambiae* (Diptera: Culicidae) on malaria transmission in hilly towns in south Cameroon. *J Med Entomol 30:* 936–938.
47. Martens P, Hall L, 2000. Malaria on the move: human population movement and malaria transmission. *Emerg Infect Dis 6:* 3–16.

48. Prothero RM, 1977. Disease and mobility: a neglected factor in epidemiology. *Int J Epidemiol 6:* 259–267.
49. Lindsay SW, Martens WJM, 1998. Malaria in the Africa highlands: past, present and future. *Bull WHO 76:* 33–45.
50. Crowe S, 1997. Malaria outbreak hits refugees in Tanzania. *Lancet 350:* 41.
51. Julvez J, Mouchet J, Michault A, Fouta A, Hamidine M, 1997. Eco-épidémiologie du paludisme à Niamey et dans la vallée du fleuve, République du Niger, 1992–1995. *Bull Soc Pathol Exot 90:* 94–100.
52. El Sayed BB, Arnot DE, Mukhtar MM, Baraka OZ, Dafalla AA, Elnaiem DE, Nugud AH, 2000. A study of the urban malaria transmission problem in Khartoum. *Acta Trop 25:* 163–171.
53. Koram KA, Bennett S, Adiamah JH, Greenwood BM, 1995. Socio-economic risk factors for malaria in a peri-urban area of The Gambia. *Trans R Soc Trop Med Hyg 89:* 146–150.
54. Manga L, Robert V, Messi J, Desfontaine M, Carnevale P, 1992. Le paludisme urbain à Yaoundé, Cameroun: 1. etude entomologique dans deux quartiers centraux. *Mém Soc R Belg Ent 35:* 155–162.
55. Fondjo E, Robert V, Le Goff G, Toto JC, Carnevale P, 1992. Le paludisme urbain à Yaoundé, Cameroun: 2. Etude entomologique dans deux quartiers peu urbanisés. *Bull Soc Pathol Exot 85:* 57–63.
56. Bruce-Chwatt LJ, 1983. Paludisme et urbanisation. *Bull Soc Pathol Exot 76:* 243–249.
57. Carnevale P, Robert V, Le Goff G, Fondjo E, Manga L, Akogbéto M, Chippaux JP, Mouchet J, 1993. Données entomologiques sur le paludisme urbain en Afrique tropicale. *Cahiers Santé 3:* 239–245.
58. Phillips DR, 1993. Urbanization and human health. *Parasitology 106:* S93–S107.
59. Trape JF, Rogier C, 1996. Combating malaria morbidity and mortality by reducing transmission. *Parasitol Today 12:* 236–240.
60. Trape JF, Pison G, Spiegel A, Enel C, Rogier C, 2002. Combating malaria in Africa. *Trends Parasitol 18:* 224–230.
61. Carnevale P, Bosseno MF, Zoulani A, Michel R, Molez JF, 1985. La dynamique de la transmission du paludisme humain en zone de savane herbeuse et de forêt dégradée des environs nord et sud de Brazzaville, R.P. du Congo. *Cah ORSTOM. Ser Ent Med Parasitol. 23:* 95–115.
62. Vercruysse J, 1985. Etude entomologique sur la transmission du paludisme humain dans le bassin du fleuve du Sénégal (Sénégal). *Ann Soc Belg Med Trop 65:* 171–179.
63. Robert V, Carnevale P, Ouedraogo V, Petrarca V, Coluzzi M, 1988. La transmission du paludisme humain dans un village de savane du sud-ouest du Burkinba Faso. *Ann Soc Belg Med Trop 68:* 107–121.
64. Richard A, Zoulani A, Lallemant M, Trape JF, Carnevale P, Mouchet J, 1988. Le paludisme dans la région forestière du Mayombe, République Populaire du Congo: 1. Présentation de la région et données entomologiques. *Ann Soc Belg Med Trop 68:* 293–303.
65. Lindsay SW, Campbell H, Adiamah JH, Greenwood AM, Bangali JE, Greenwood BM, 1990. Malaria in a peri-urban area of The Gambia. *Ann Trop Med Parasitol 84:* 553–562.
66. Beier JC, Perkins PV, Onyango FK, Gargan TP, Oster CN, Whitmire RE, Koech DK, Roberts CR, 1990. Characterization of malaria transmission by *Anopheles* (Diptera: Culicidae) in Western Kenya in preparation for malaria vaccine trials. *J Med Entomol 27:* 570–577.
67. Karch S, Asidi N, Manzambi ZM, Salaun JJ, 1992. La faune anophélienne et la transmission du paludisme humain à Kinshasa (Zaïre). *Bull Soc Pathol Exot 85:* 304–309.
68. Fontenille D, Lepers JP, Coluzzi M, Campbell GH, Rakotorivony I, Coulanges P, 1992. Malaria transmission and vector biology on Sainte Marie Island, Madagascar. *J Med Entomol 29:* 197–202.
69. Carnevale P, Le Goff G, Toto JC, Robert V, 1992. *Anopheles nili* as the main vector of human malaria in villages of southern Cameroon. *Med Vet Entomol 6:* 135–138.
70. Githeko AK, Service MW, Mbogo CM, Atieli FK, Juma FO, 1993. *Plasmodium falciparum* sporozoite and entomological inoculation rates at the Ahero rice irrigation scheme and the Miwani sugar-belt in western Kenya. *Ann Trop Med Parasitol 87:* 379–391.
71. Njan Nloga A, Robert V, Toto JC, Carnevale P, 1993. *Anopheles moucheti*, vecteur principal du paludisme au Sud-Cameroun. *Bull Liais Doc OCEAC 26:* 63–67.
72. Mbogo CNM, Snow RW, Kabiru EW, Ouma JH, Githure JI, March K, Beier JC, 1993. Low-level of *Plasmodium falciparum* transmission and the incidence of severe malaria infections on the Kenyan coast. *Am J Trop Med Hyg 49:* 245–253.
73. Bockarie MJ, Service MW, Barnish G, Maude GH, Greenwood BM, 1994. Malaria in a rural area of Sierra Leone III. Vector ecology and disease transmission. *Ann Trop Med Parasitol 88:* 251–262.
74. Shiff CJ, Minjas JN, Hall T, Hunt RH, Lyimo S, Davis JR, 1995. Malaria infection potential of anopheline mosquitoes sampled by light trapping indoors in coastal Tanzanian villages. *Med Vet Entomol 9:* 256–262.
75. Mbogo CNM, Snow RW, Khamala CPM, Kabiru EW, Ouma JH, Githure JI, Marsh K, Beier JC, 1995. Relationships between *Plasmodium falciparum* transmission by vector populations and the incidence of severe disease at nine sites on the Kenyan Coast. *Am J Trop Med Hyg 52:* 201–206.
76. Fontenille D, Lochouarn L, Diagne N, Sokhna C, Lemasson JJ, Diatta M, Konaté L, Faye F, Rogier C, Trape JF, 1997. High annual and seasonal variations in malaria transmission by anophelines and vector species composition in Dielmo, a holoendemic area in Senegal. *Am J Trop Med Hyg 56:* 247–253.
77. Fontenille D, Lochouarn L, Diatta M, Sokhna C, Dia I, Diagne N, Lemasson JJ, Ba K, Tall A, Rogier C, Trape JF, 1997. Four years' entomological study of the transmission of seasonal malaria in Senegal and the bionomics of *Anopheles gambiae* and *An. arabiensis. Trans R Soc Trop Med Hyg 91:* 647–652.
78. Lemasson JJ, Fontenille D, Lochouarn L, Dia I, Simard F, Ba K, Diop A, Diatta M, Molez JF, 1997. Comparison of behavior and vector efficiency of *Anopheles gambiae* and *An. arabiensis* (Diptera: Culicidae) in Barkedji, a Sahelian area of Senegal. *J Med Entomol 34:* 396–403.
79. Robert V, Dieng H, Lochouarn L, Traoré SF, Trape JF, Simondon F, Fontenille D, 1998. La transmission du paludisme dans la zone de Niakhar, Sénégal. *Trop Med Int Health 3:* 667–677.