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VECTOR DENSITY GRADIENTS AND THE EPIDEMIOLOGY OF URBAN MALARIA IN DAKAR, SENEGAL

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Abstract. The dispersion of anopheline mosquitoes from their breeding places and its impact on malaria epidemiology has been investigated in Dakar, Senegal, where malaria is hypoendemic and almost exclusively transmitted by *Anopheles arabiensis*. Pyrethrum spray collections were carried out along a 910-meter area starting from a district bordering on a permanent marsh and continuing into the center of the city. According to the distance from the marsh, vector density (the number of *An. arabiensis* per 100 rooms) at 0–160, 160–285, 285–410, 410–535, 535–660, 660–785, and 785–910 meters was 84, 40, 5, 2, 2, 0.4, and 0, respectively, during the dry season, and 414, 229, 110, 84, 99, 69, and 21, respectively, during the rainy season. The proportion of 8–11-year-old children with negative immunofluorescent antibody test results for *Plasmodium falciparum* was 17%, 28%, 44%, 54%, 50%, 63%, and 73%, respectively, in these different sections. Malaria prevalence in the community was maximum in the area bordering on the marsh where it ranged from 1% to 15% (average 6%) according to age and season of the year. These findings show the epidemiologic importance of vector density gradients in Dakar. The implications for malaria control in urban areas are discussed.

In tropical Africa, urbanization has had a significant impact on malaria epidemiology. The level of endemicity is considerably lower in urban areas than in rural environments, and varies greatly among the districts within a given town.[1–5] Entomologic studies have shown that the main factor in these variations is vector density.[6,7] Other potential factors, such as the use of antimalarial drugs, type of residence, or individual protection efforts against vectors only have a geographic significance if places of residence are socially segregated.[8]

Previous studies have established that three mechanisms contribute to the reduction of vector density in urban areas.[7,9] First, by favoring the reduction of open space and increasing domestic pollution, urbanization tends to curtail anopheline breeding places. Second, by spreading the persistent anopheline population over a denser human population, it tends to reduce the degree of exposure of each person. Third, by limiting the dispersion of anopheles from breeding sites, it tends to localize malaria transmission. The latter mechanism is primarily responsible for the difference in exposure to malaria of urban populations according to the district of residence.[7,9]

The present study was carried out as part of a program of research into malaria control strategies in urban areas of Sudan-Sahelian Africa. Its aim was to specify the relationship between the dispersion of *Anopheles arabiensis* from its larval breeding sites and malaria epidemiology in Dakar, Senegal.

MATERIALS AND METHODS

Study area

The city of Dakar (14°45′N, 17°25′W) covers the major part of the Cap Vert peninsula, the westernmost point of Africa, and with 1,375,000 inhabitants, contains one-fifth of the population of Senegal (1988 census). Two distinct seasons exist: a hot, wet season from June to November (maximum average temperature 28.2°C in October), and a cool, dry season from December to May (minimum average temperature 20.4°C in February). The first rains generally occur at the end of June or the beginning of July, and the last ones occur at the beginning of October. The average annual rainfall is 511 mm (1898–1990). In 1987 and 1988 (the period covered by the study), rainfall was 422 mm and 497 mm, respectively.

Previous studies have shown that malaria prevalence was low in this area, usually less than

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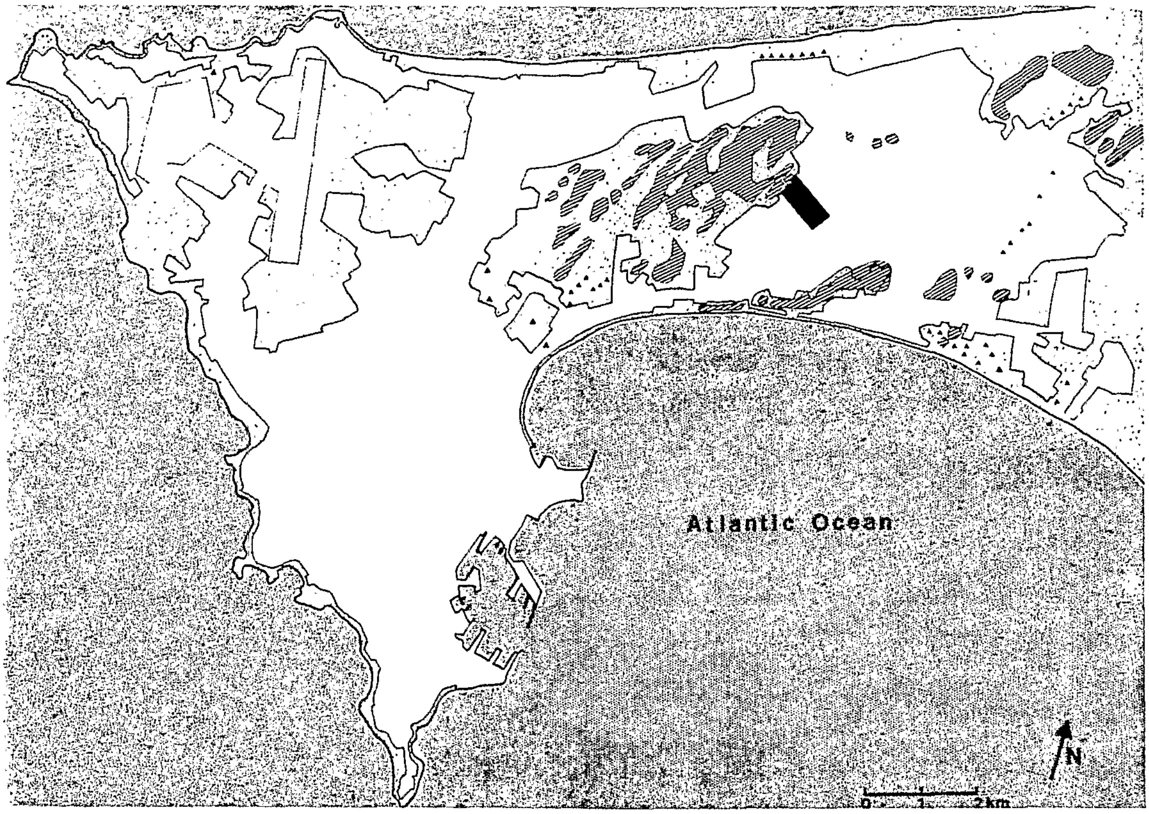

FIGURE 1. Map of Dakar, Senegal, showing the localization of the main breeding sites of *Anopheles arabiensis* (**shaded areas and triangles**). The study area is indicated by the black region.

3% (Trape J-F, unpublished data), but it reached 10% in the districts bordering the permanent marshland to the center and east of the city.[10] Transmission was exclusively by *An. arabiensis,* which represented 99% of the total *An. gambiae* s.l. collected in dwellings,[11] and was seasonal from August to December. The sporozoite rate increased progressively from approximately 0.001 in August/September to 0.01 in December, then decreased sharply during the cool season.[11]

A preliminary study (December 1986–April 1987) consisted of the accurate mapping of potential *An. arabiensis* breeding sites during the dry season: natural marshy hollows (niayes), furrows dug for market garden irrigation (ceanes), areas of prolonged stagnation of rainwater (often ancient niayes recently urbanized due to the long drought of 1970–1984). These surveys were completed in September–October 1987 for the main breeding sites during the rainy season (Figure 1).

Based on the results of this preliminary study, one district with homogeneous housing (Pikine Ancien) was selected for a area study of vector density and its relationship to malaria epidemiology (Figure 1). The western part of this district is situated on the edge of a vast area of marshland (Grande Niaye), and we expected this area to have the highest vector density in Dakar.

Entomologic surveys

From May 1987 to September 1988, indoor pyrethrum spray collections were made twice a week in seven areas at increasing distances (from 0 to 910 meters) from the marsh (Figure 2). As a general rule, five rooms in the same house (the first five bedrooms) in each area were sampled during each collection. Different dwellings were selected at each session, and most dwellings of the study area were investigated once, but rarely twice, over a 17-month period. A total of 658 different dwellings were visited.

In the region of Dakar, almost all dwellings have roofs tightly joined to the walls, making it difficult for mosquitoes to enter the houses when the doors and windows are closed. Therefore, individual human behavior would considerably influence the actual level of exposure to malaria.

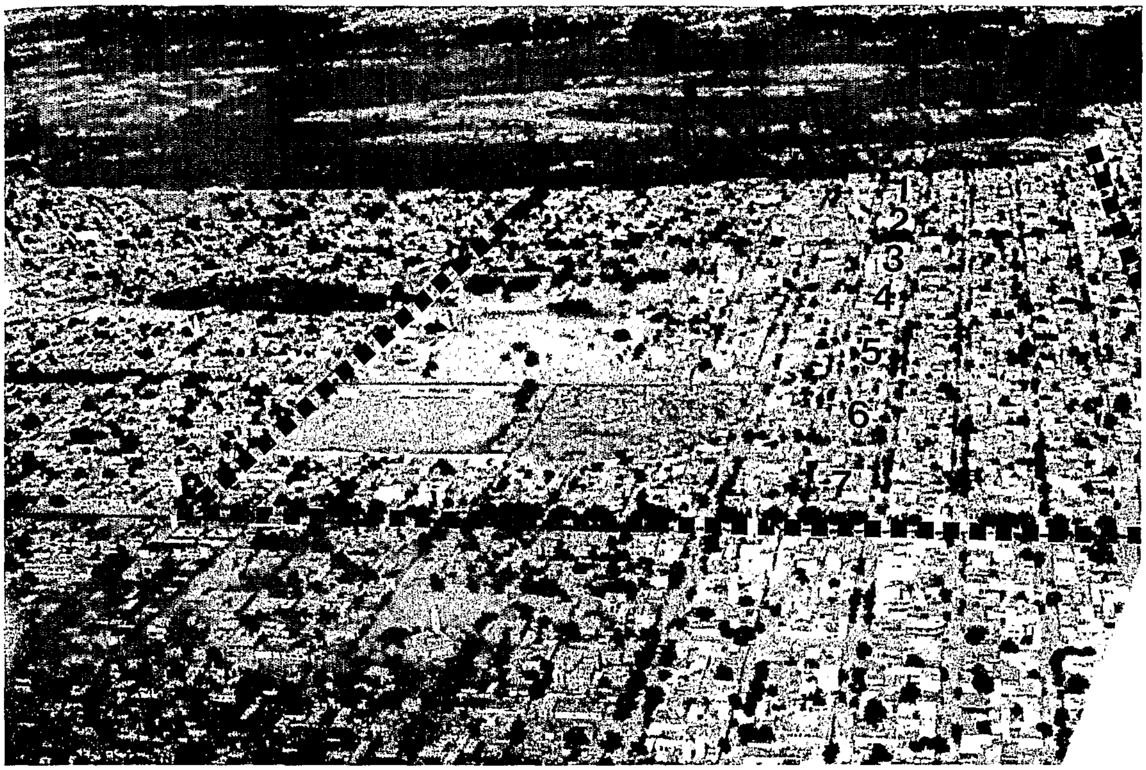

FIGURE 2. General view of the study area. The marshland (the Grande Niaye) is seen in the background. Blocks of 18 plots are arranged perpendicular to the marshland. The seven sectors (1-7) of the study area correspond to seven series of 6–12 blocks.

To estimate this influence, 14 night-biting collections on human bait were made from February to June 1988. Each consisted of 1) a collector placed outside the dwelling, 2) a collector placed in a bedroom with the doors and windows open, and 3) a collector placed in a bedroom with all the doors and windows closed. The collectors changed places every hour. Each collection was carried out in a different house (half were in areas 1 and 5 of the sector studied) and the bedrooms were randomly allocated. All mosquitoes caught were identified by species. Anophelines were examined for the presence of salivary gland sporozoites. Their abdomens were examined directly and the mosquitoes were classified as unfed, fed, half-gravid, and gravid. The proportion of fed or half-gravid mosquitoes was used to determine the entomologic inoculation rate. For each area, the sum of 12 estimated monthly (January to December) values of this rate (average number of fed and half-gravid *An. arabiensis* females per sleeping individual × 30 days × the presumed value of the sporozoite rate) was determined. The abdomens were also examined after dissection to establish parity.

Serologic surveys

In November 1987, February 1988, and June 1988, three serologic surveys were carried out in a school situated in the center of the study area as part of a cohort study of the incidence of clinical malaria in schoolchildren. A questionnaire was sent to parents to determine the exact place of residence of the children. Three capillary blood samples were taken by finger prick from 343 schoolchildren (age range 8–11 years) residing in the seven sectors of the study area. An indirect fluorescent immunoassay (IFA) test with *P. falciparum* as antigen was used to titrate antibody levels.

Parasitologic surveys

Since the expected malaria prevalence was very low even in the area bordering the marsh, and the number of investigated individuals needed to observe significant differences between the different areas was expected to be several hundred, these surveys took place in sectors 1 (0–160 meters from the marsh and with maximum vector

TABLE 1

*Results of pyrethrum spray collections carried out along a 910-meter area originating from a permanent marsh (Pikine ancien) in Dakar, Senegal**

Area	Distance from marsh (meters)	No. of rooms visited		No. of *Anopheles arabiensis*				Total no. of mosquitoes			
				Females		Males		Females		Males	
		RS	DS	RS	DS	RS	DS	RS	DS	RS	DS
1	0–160	205	327	849	276	90	21	1,775	1,202	457	449
2	161–285	185	277	424	112	54	8	1,500	1,217	545	538
3	286–410	195	296	214	14	3	1	1,309	1,622	555	748
4	411–535	190	285	159	6	14	0	1,288	1,726	485	811
5	536–660	185	309	184	7	9	1	1,159	954	481	701
6	661–785	195	270	135	1	3	0	1,452	705	616	304
7	786–910	205	280	43	0	3	1	1,531	688	1,007	349
Total	0–910	1,360	2,044	2,008	416	176	32	10,014	8,114	4,146	3,900

* RS = rainy season (July–October 1987 and July–September 1988); DS = dry season (May–June 1987 and November 1987–April 1988).

density) and 5 (535–660 meters from the marsh and the center of the study when areas 1 and 2, with high vector density, are excluded). In each of these areas, 67 plots from the cadastral register were randomly selected. An initial survey was carried out in October 1987 (end of the rainy season) and a second survey was carried out in June 1988 (end of the dry season). Thick blood films were taken from all inhabitants present, and a second visit was made if an individual was absent. Infants under the age of six months were excluded from this survey. During the October survey, each person was asked about any clinical symptoms that existed at the present time or during the previous week.

The thick blood films were examined according to a technique previously described.[12] Two hundred microscopic oil immersion fields were systematically examined (approximately 0.5 μl of blood) and the parasite density was estimated from the parasite:leukocyte ratio, on the basis of 8,000 leukocytes/μl.

RESULTS

Entomology

General results of pyrethrum spray collections. From May 1987 to September 1988, 3,404 rooms were examined. A total of 26,174 mosquitoes were collected, of which 18,128 were female and 8,046 were male. Of these, 2,648 (10.1%) were anopheles: *An. gambiae* s.l. (*An. arabiensis*), 2,424 females and 208 males, and *An. pharoensis,* 16 females. The other species collected were *Culex quinquefasciatus* (12,348 females and 6,573 males), *Culex* ssp. (3,275 females and 1,255 males), *Mansonia* (38 females), and *Aedes aegypti* (27 females and 10 males).

Significant monthly variations in the density of *An. arabiensis* were observed, with a minimum of 0.06 females per room in June 1987, and a maximum of 2.41 females per room in August 1988. The density of this vector increased sharply two weeks after the first rain (1.25, 1.34, 1.21, and 0.94 females per room, respectively, from July to October 1987), and decreased just as abruptly approximately three weeks after the last rain (0.10 females per room in November 1987), even though there was a greater number of potential breeding sites than in July for several more months.

Examination of the salivary glands of 2,424 *An. arabiensis* females did not reveal any sporozoites. The number of salivary glands studied was 337 (January–June), 359 (July), 741 (August), 690 (September), 229 (October), and 68 (November–December).

Examination of mosquito abdominal appearance to detemine the inoculation rate indicated that 76 (3.1%) of the *An. arabiensis* females were unfed, 1,302 (53.7%) were fed or half gravid, and 1,046 (43.2%) were gravid.

Vector density according to area. Results of mosquito collection by sector are shown in Table 1. In all seasons, an anopheline density gradient was observed between the area bordering the marshland and the area farthest away. In contrast, this relationship was not observed for *Cx. quinquefasciatus*, and there were only slight variations between the sectors for the overall number of mosquitoes collected.

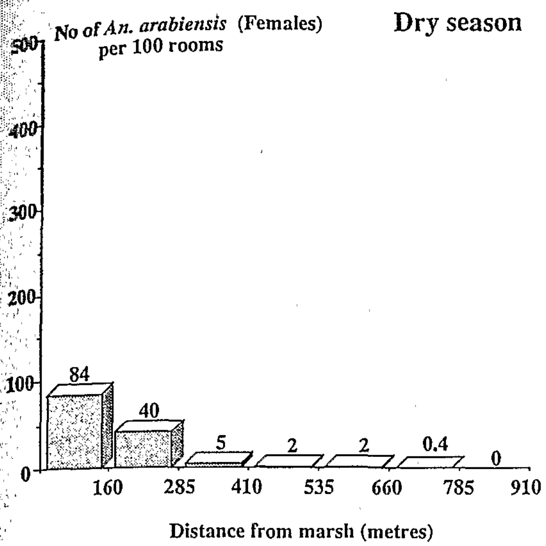

FIGURE 3. Mean indoor resting density of *Anopheles arabiensis* during the dry season, according to the distance from the marsh.

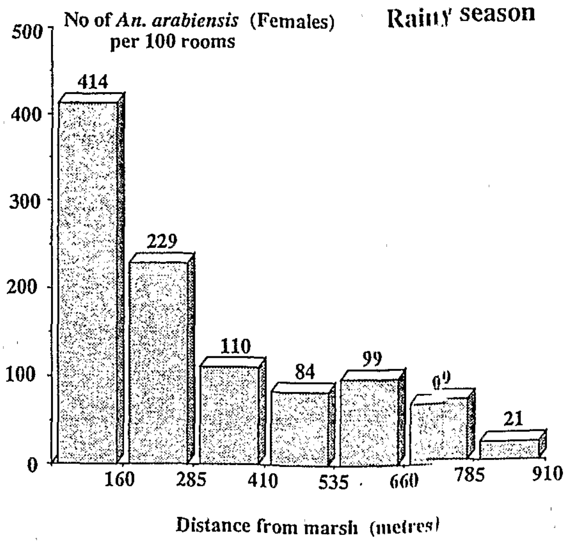

FIGURE 4. Mean indoor resting density of *Anopheles arabiensis* during the rainy season, according to the distance from the marsh.

In the dry season, 93% of the *An. arabiensis* mosquitoes collected were in dwellings situated less than 285 meters from the marshland. Vector density was about 40 times higher on the edge of the marsh than 500 meters away (Figure 3). In the rainy season, vector density on the edge of the marsh was on average five times higher than in the dry season. Seventy-three percent of the *An. arabiensis* mosquitoes were collected less than 285 meters from the marshland. Vector density was five and 20 times lower at a distance of 500 and 800 meters, respectively, from the marsh than at a distance of 0–160 meters (Figure 4).

Collections on human bait inside and outside dwellings. During the 14 night collections on human bait (42 person/night), 1,121 mosquitoes were collected, of which 227 were anophelines (225 *An. arabiensis* and 2 *An. ziemanni*). The number collected varied greatly with respect to the location of the collector; the numbers of mosquitoes collected outside, inside with doors and windows open, and inside with doors and windows closed were 581 (121 anophelines and 460 miscellaneous), 497 (106 anophelines and 391 miscellaneous), and 43 (10 anophelines and 33 miscellaneous), respectively.

Malaria transmission gradient To compare malaria transmission in the seven sectors of the study area, we used the following data: 1) monthly results in each area of vector density measured by pyrethrum spray collections, 2) estimated monthly values of the sporozoite rate (estimates were derived from the combined data of this study and a previous one[11] in the same district of Pikine: range 0.001–0.01 according to the season), 3) the average number of persons sleeping in a room the night of the collections (2.84), and 4) the average proportion of fed and half gravid *An. arabiensis* females (0.537).

Estimates of the entomologic inoculation rate ranged from 0.382 to 0.014 infective bites per person per year according to the distance from the marsh (Figure 5).

Serology

A total of 343 children were studied in November 1987, February 1988, and June 1988 (1,029 tests). The distribution of IFA test titers is shown in Figure 6. The proportion of children with three negative IFA test results (titres ≤ 1: 200) increased progressively with the distance from the marsh, from 17% for children living in the area situated less than 160 meters from the marsh to 73% for those living 785–910 meters away (Figure 7).

Parasitology

Malaria prevalence. Of 2,465 thick blood films examined, 93 (3.8%) were parasite positive. *Plas-*

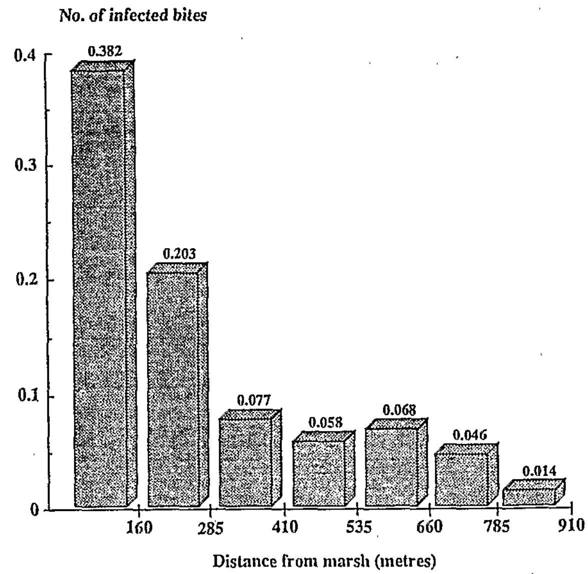

FIGURE 5. Estimates of the yearly entomologic inoculation rate, according to the distance from the marsh.

modium falciparum was found in 87 cases (3.5%), *P. malariae* in seven cases (0.3%), and *P. ovale* in one case (0.04%). (*P. falciparum* was associated with *P. malariae* in one case and with *P. ovale* in another case.) The presence of *P. falciparum* gametocytes was observed in 32 cases (1.3%). The average malaria prevalence was 5.5% in the area situated less than 160 meters from the marsh and 2.1% in the area 535–660 meters away. Variations according to age and season are shown in Table 2. The proportion of *P. falciparum* infections with a parasite density > 5,000 parasites/μl was 23.2% (13 of 56) in October and 6.5% (2 of 31) in June ($P < 0.05$, by chi-square test). The parasite density was < 500 parasites/μl in 57.1% (32 of 56) of the infections in October and in 87.1% (27 of 31) of the infections in June ($P < 0.01$, by chi-square test).

Relationship of parasitemia with febrile attacks. Fourteen percent of the persons studied in October indicated that they experienced a febrile attack or headache within the previous eight days. In the area bordering the marsh, this proportion was 61.5% (24 of 39) among persons with positive thick blood films and 14.8% (79 of 532) among those with negative blood films ($P < 0.001$ by chi-square test). In the area farthest from the marsh, this proportion was 27.8% (5 of 18) among persons with positive blood films and 10.6% (64 of 606) among those with negative blood films ($P = 0.07$ [not significant], by Fisher's exact test).

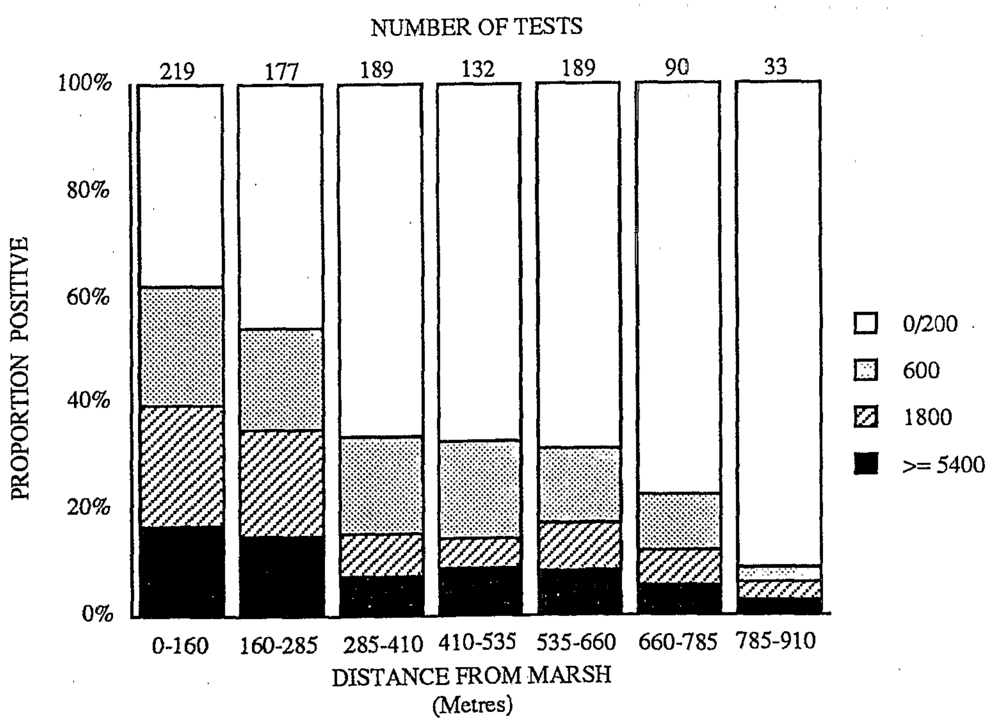

FIGURE 6. Distribution of indirect fluorescent immunoassay test titers for antibodies to *Plasmodium falciparum* children in the study, according to the distance from the marsh of their place of residence.

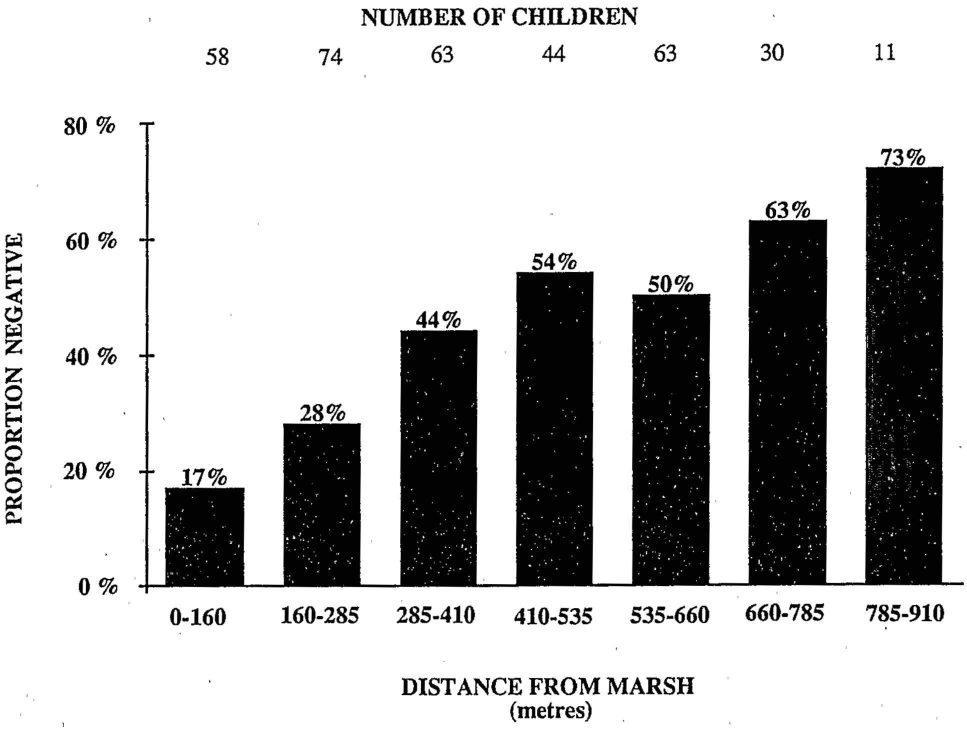

FIGURE 7. Proportion of children in the study with negative indirect fluorescent immunoassay test titers for antibodies to *Plasmodium falciparum* during three consecutive surveys (November 1987, February 1988, and June 1988), according to the distance from the marsh of their place of residence. Titers > 1:200 were considered positive (compared with 100 healthy French blood donors).

DISCUSSION

The entomologic results show the existence of a vector density gradient between the area closest to the main larval breeding sites and the area farthest away. It is obvious that in the densely populated urban environment, the majority of female *An. arabiensis* do not move far from their breeding sites, probably because there are plenty

TABLE 2

*Prevalence of malaria parasites, according to age, in sectors 1 and 5 of the study area in Dakar, Senegal (Pikine ancien), October 1987–June 1988**

Age group (years)	Prevalence: Area 1 (0–160 meters)† October	Area 1 June	Area 5 (536–660 meters)† October	Area 5 June
<2	2/48 (4.2)	1/59 (1.7)	0/42 (0)	1/45 (2.2)
2–4	5/104 (4.8)	7/112 (6.3)	3/96 (3.1)	1/95 (1.1)
5–9	3/77 (3.9)	5/99 (5.1)	1/108 (0.9)	2/129 (1.6)
10–14	8/53 (15.1)	6/73 (8.2)	2/71 (2.8)	1/84 (1.2)
15–19	9/73 (12.3)	4/75 (5.3)	2/63 (3.2)	2/61 (3.3)
20–39	10/145 (6.9)	4/145 (2.8)	5/163 (3.1)	1/146 (0.7)
≥40	2/71 (2.8)	1/78 (1.3)	5/81 (6.2)	0/69 (0)
Total	39/571 (6.8)‡§	28/641 (4.4)¶	18/624 (2.9)#	8/629 (1.3)

* Values are the no. positive/no. tested (%).
† Distance from the marsh.
‡ $P < 0.05$ versus area 1 (June), by chi-square test.
§ $P < 0.01$ versus area 5 (October), by chi-square test.
¶ $P < 0.01$ versus area 5 (June), by chi-square test.
\# $P < 0.05$ versus area 5 (June), by chi-square test.

of potential hosts in the immediate vicinity. As a result, the level of exposure to this vector varies considerably over very short distances.

The epidemiologic importance of the vector density gradient is demonstrated by the results of the parasitologic and serologic surveys. The children studied had a parasite rate that was on average three times higher in the immediate vicinity of the breeding sites than at 600 meters away, and their IFA test titers decreased steadily as their distance from the breeding sites increased. This relationship, although seemingly logical, was not an a priori certainty, since infections contracted during trips into highly endemic rural areas could mask differences in transmission in urban areas. The fact that this is not so indicates the local origin of most infections, at least for persons living in areas with the highest vector densities.

The parasite rate in children living near the marshland was similar to that of schoolchildren from villages around Dakar, usually between 5% and 20% (Trape J-F, unpublished data). Two factors can explain what was a relatively low level, by tropical Africa standards, of malaria prevalence in the Dakar region. The first factor is climatic. There is a long dry season and even in the case of permanent breeding sites, transmission is seasonally interrupted, probably because the temperature is insufficient for sporozoite development from January or February until May. The second factor is the type of local housing, which makes it difficult for mosquitoes to enter. An accurate estimation of inoculation rate by the usual entomologic methods is difficult because collections on human bait performed outdoors or indoors with open windows considerably overestimate the person-vector contact (the high values of the entomologic inoculation rate previously reported for Pikine[10] were obtained from indoor collections with open windows), whereas indoors pyrethrum spray collections may measure only part of the transmission. Wherever the district of residence, significant individual variations in the actual level of exposure to vectors are probable. When estimated by parasitologic and serologic methods, the rate of malaria inoculation in schoolchildren residing in the immediate vicinity of the marsh was 0.86 infective bites per person per year (Trape J-F, unpublished data). The fact that most persons with a positive thick blood film in October described a recent fever attack confirms the low level of immunity of the population of Dakar.

The first cases of chloroquine resistance were observed in Dakar the year following this study (October 1988).[13, 14] The proportion of chloroquine-resistant strains, which was 7% at the end of 1988,[13] increased to 47.5% by the end of 1990.[15] This explosive increase in resistance in an area with low seasonal transmission is probably the consequence of high drug pressure, since most infections are symptomatic.

The rapid spread of chloroquine resistance in tropical Africa underlines the need for a re-examination of malaria control strategies, particularly in urban environments. The epidemiologic characteristics of malaria in Dakar suggest that two lines of research should be given priority. First, in outpatient clinics, cost-benefit analysis of different treatment policies (including choice of different drugs for first and second line presumptive treatments and/or thick blood smear examinations prior to treatment for defined categories of patients) should be developed, taking into account not only the level of drug resistance and clinical criteria in patients, but also epidemiologic parameters, particularly the place of residence of the patients and the season of the year. Second, mosquito control operations in a limited number of carefully selected areas may have a significant impact on malaria morbidity because of low and localized transmission and should be instituted.

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