TRANSACTIONS OF THE ROYAL SOCIETY OF TROPICAL MEDICINE AND HYGIENE (1987) VOL. 81, SUPPLEMENT NO. 2, 10-18

Malaria and urbanization in Central Africa: the example of Brazzaville.

Part II: Results of entomological surveys and epidemiological analysis

J. F. TRAPE AND A. ZOULANI
Laboratoire de Parasitologie et d'Entomologie Médicale, Centre ORSTOM de Brazzaville, B.P. 181, Brazzaville, République Populaire du Congo

Summary

92 night-bite collections on human bait (550 man-nights) and 234 collections of the house-resting fauna were carried out from October 1982 to May 1984 in Brazzaville. A total of 19,531 Culicidae were captured, of which 1,893 were *Anopheles,* almost exclusively *A. gambiae*. An average sporozoite rate of 3·41% was found from dissection of 1,291 *A. gambiae:* one female *A. moucheti* was also found to be infected. Considerable differences in the intensity of transmission of malaria were observed in the different districts of the town. Whereas the inhabitants of Brazzaville received on average 22·5 infective bites per person per year, in reality this number varies according to the district, from over 100 infective bites per person per year, to less than one infective bite per person every three years. With the help of classical quantitative epidemiological models, the authors analyse here the over-all results, as well as those of two areas of the town, the first area characterized by a high anopheline density, and the second by the rarity of anopheles.

Introduction

The very nature of the urbanization process and of its consequences — demographic growth and spread, sanitation policy, equipment, environmental pollution, etc. — suggest that urban growth is liable to alter considerably the main entomological parameters affecting the transmission of malaria. Whereas the epidemiology of malaria at present is well known in rural areas of central Africa where transmission is generally intense and perennial, for urban regions there is very little recent information on the main entomological parameters necessary for a thorough epidemiological study of present conditions for transmission of malaria. In this article, we present the results of a study of these main parameters in Brazzaville and analyse certain characteristics of the epidemiology in different districts of the town. In the following paper, we shall present and analyse the relationship observed with the phenomenon of urbanization.

Material and Methods

From October 1982 to May 1984, 92 night-bite collections on human bait and 234 house-resting collections were carried out in Brazzaville. The captures took place in turn in each district of the town. The collection stations were different each time, and spread over the whole of the town. (Fig. 1). All the collections were made by the same team of collectors.

Night-bite collections on human bait

The collections were made by six collectors and a team leader, working from 9 p.m. until 6 a.m. in three dwellings close together. Three collectors were positioned indoors, generally in a bedroom, and three others outdoors in front of each dwelling. The mosquitoes were captured in small individual glass tubes collected every hour. After identification, the anopheles were dissected to look for sporozoites and to determine their physiological age using Detinova's method (DETINOVA, 1945, 1963). Dissection took place either immediately or the next day after preservation at +4°C.

House-resting collections

The aim of these captures was to complete the compilation of information necessary to draw up a map of the intensity of transmission of malaria in Brazzaville (TRAPE & ZOULANI, see pp. 19-25). Most of the house-resting collections were carried out by a team of two, though no strict method was used: the time and duration of collections as well as the number of rooms or dwellings involved, were very variable. For 15 collections in selected stations, the pyrethrum spray technique was used. The anopheles captured were identified and dissected the same day or the next day after preservation at +4°C.

Results

Results of night-bite collections on human bait

With the exception of one collection where only four collectors were used, all night-bite collections were made with six collectors, making a total of 550 man-nights.

The total number of Culicidae collected was 13,994 among which were 977 anopheles (6·98%). These were 967 *A. gambiae* (98·98%), 7 *A. funestus* (0·72%) and 3 *A. nili* (0·30%). The 13,017 other Culicidae collected belonged mainly to the species *Culex quinquefasciatus* (11,117♀), except for a few collections carried out in the immediate vicinity of the river Congo where *Mansonia uniformis* and *M. africana* were also captured. The average number of bites per man per night was 25·44 for all the Culicidae and 1·78 for the anopheles.

The dissection and examination of the salivary glands of 817 anopheles (812 *A. gambiae,* 4 *A. funestus,* and one *A. nili*) showed the presence of sporozoites in 27 *A. gambiae,* giving a sporozoite rate of 3·33% for *A. gambiae*.

The maximum man-biting activity of *A. gambiae* was between midnight and 3 a.m. However, man-biting activity was high from 10 p.m. and decreased moderately from 3 a.m., possibly because the collectors became less vigilant as the night advanced.

The physiological age was determined using Detinova's method (DETINOVA, 1945) for 745 *A. gambiae*. 614 females were parous and 131 nulliparous.

The numbers of *A. gambiae* captured indoors and outdoors were equivalent (496 and 471 respectively).

Results of house-resting collections

From October 1982 to February 1984, 234 house-resting collections were made. 5,537 Culicidae were

Fig. 1. Localization of night-bite collections on human bait (black squares) and house-resting collections (black points). The shaded areas represent the Mfilou-Ngamaba-Ngangouoni district (to the West) and the central area of the Poto-Poto-Ouenze-Moungali district (to the East).

captured, of which 3,900 were female and 1,637 male. Of these 916 (16·45%) were anopheles, 763 female and 153 male. The remainder were mostly *Culex quinquefasciatus*.

Out of 763 female anopheles collected (19·56% of all the female Culicidae), 745 were *A. gambiae* (97·64%), 15 *A. funestus* (1·97%), 2 *A. moucheti* (0·26%) and one *A. nili* (0·13%).

Examination of the salivary glands of 479 *A. gambiae* and two *A. moucheti* showed sporozoites in 17 *A. gambiae* and one *A. moucheti*, making a sporozoite rate of 3·55% for *A. gambiae.*

Variations between different collections

The number of anopheles collected and the ratio of anopheles to other Culicidae varied greatly with the different collections. Out of 92 collections on human bait, 31 (33·70%) contained no anopheles although 4,776 Culicidae were captured during this time. 20 collections produced one to five anopheles, 17 from 6 to 11 anopheles, and 24 produced 12 or more anopheles. The maximum number of anopheles captured on human bait in a single collection was 144. For all Culicidae, the maximum and minimum numbers captured during a single collection were respectively 906 and 4. Of 234 house-resting collections, 120 produced no anopheles.

Analysis of the results according to the capture station shows that the differences observed are essentially due to considerable variation in anopheline density between the different districts of the town and, to a lesser degree, to seasonal variations. Thus, out of 27 night capture stations where no anopheles were collected during the wet season and the beginning of the dry season (October to June), 13 are grouped together in two areas of the town and form two perimeters within whose limits no anopheles were collected, neither during night-bite collections nor during house-resting collections. The 14 other night capture stations where no anopheles were collected during the wet season are scattered over the areas of the town where anopheline density has always been very low.

Conversely, the 24 capture stations where at least two anopheles were collected per person and per night are all situated on the border of non-urbanized areas or in districts of the town where anopheline density is always very high in the wet season.

Epidemiological Analysis

Although some of the parameters used were not studied specifically in the conditions of Brazzaville, the results were analysed using the classical formulae of MACDONALD (1957) and GARRETT-JONES (1964) in view of the interest of these formulae applied to Brazzaville, and the rarity of similar studies in urban environments. The advantages as well as the limitations of such an approach have often been emphasized, particularly by HAMON & COZ (1966), GARRETT-JONES & SHIDRAWI (1969), GARRETT-JONES (1970), NAJERA (1974) and BRUCE-CHWATT (1976).

First, we analyse the over-all results from Brazzaville, then, separately, two different districts of the town, the first characterized by a high anopheline density, and the second by the rarity of anopheles.

Results for Brazzaville in general

Entomological inoculation rate

The entomological inoculation rate h_e is calculated using the formulae $h_e = mas$ and MBR $= ma$, where MBR (man-biting rate) is the number of anopheles bites per man day (here estimated from night-bite collections on human bait), m is the anopheline density in relation to man, a the average number of men bitten by one mosquito in one day and s the proportion of mosquitoes with sporozoites in their salivary glands.

For the whole of Brazzaville we obtained the following values: MBR $= 1{\cdot}78$ and $s = 0{\cdot}0347$. We can thus calculate the entomological inoculation rate: $h_e = 0{\cdot}062$, which corresponds to one infective bite per person every 16 nights, or 22·5 infective bites per year.

Daily survival rate

Various methods may be used to estimate the daily survival rate(p). They are based on the immediate and delayed sporozoite rates (MACDONALD, 1952; DAVIDSON, 1955; DAVIDSON & DRAPER, 1953), the ratio between the oocyst rate and the sporozoite rate (DAVIDSON, 1957; GARRETT-JONES, 1970), determination of the physiological age (DAVIDSON, 1954; HAMON *et al.*, 1961; COZ *et al.*, 1961; BRENGUES & COZ, 1973), and studies after marking and recapturing (GILLIES, 1961; GILLIES & WILKES, 1965).

The simplicity of the determination of physiological age according to DETINOVA's method (1945) has led most authors to use DAVIDSON's formula (1954): $p = \sqrt[x]{A}$, where A is the proportion of parous females and x the number of days separating two blood meals.

Concerning A, this formula is valid only if the anopheline population is relatively stable, i.e., excluding in particular the rise in number of nullipares due to the arrival of water in breeding sites as well as the older populations remaining after drying-out of the breeding sites. Therefore we have considered only the results of dissections carried out from November to May. In these conditions A = 0·822 for 701 *A. gambiae* examined.

The time between two blood meals varies for *A. gambiae* between two and three days (MUIRHEAD-THOMSON, 1951; GILLIES & WILKES, 1965; BRENGUES & COZ, 1973). It varies in particular with the temperature (GILLIES, 1953) and the distance from breeding places (CARNEVALE *et al.*, 1979). Because insufficient information was available for Brazzaville, we took into consideration the value $x = 2$ days.

We can thus calculate the daily survival rate:

$$p = \sqrt{0{\cdot}822} = 0{\cdot}906.$$

Expectation of life and expectation of infective life

From the daily survival rate, it is possible to calculate the expectation of life ($1/\text{-}\log_e p$) and the expectation of infective life of the vector ($p^n/\text{-}\log_e p$) (MACDONALD, 1957).

The expectation of life of *A. gambiae* in Brazzaville is 10·18 days. The expectation of infective life varies firstly with the daily survival rate, and secondly with the duration of the plasmodium extrinsic cycle in the anopheles (n), which itself varies with the temperature (T). According to MOSHKOVSKY (1950), for *P. falciparum* $n = 111/\text{T-}16 = 12{\cdot}2$ days in the climatic conditions of Brazzaville (Mean annual temperature = 25·1°C). We thus obtain a value of 3·13 days for the expectation of infective life of *A. gambiae* in Brazzaville.

Vectorial capacity

The vectorial capacity (C), as defined by GARRETT-JONES (1964), reflects the expected quantum of new infections per infective case per day. It varies with the expectation of infective life of the vector ($p^n/\text{-}\log_e p$), the man-biting rate (*ma*) and the man-biting habit (*a*): $C = ma^2\ p^n/\text{-}\log_e p$.

The value of *a* is equal to the ratio of the human blood index to the duration of the gonotrophic cycle. Although we did not study the human blood index of *A. gambiae* in Brazzaville, we can estimate that it is very close to 100% because of the absence of livestock. In diverse semi-urban areas of the Congo, GUEYE & ODETOYINBO (1974) found a human blood index of 100%. In the rural areas of central Africa, high human blood index values of *A. gambiae* have always been observed (BRUCE-CHWATT *et al.*, 1960; GILLIES & DE MEILLON, 1968). We therefore considered the human blood index of *A. gambiae* in Brazzaville to be 99% which allows the calculation of the daily frequency of blood meals on man: $a = 0{\cdot}99/2 = 0{\cdot}495$, and we obtain the vectorial capacity: $C = 2{\cdot}76$.

Stability index

MACDONALD's stability index (1957) represents the mean number of bites on man taken by a vector during its entire lifetime. The higher this index (stable malaria), the lower is the anopheline density necessary to continue transmission. This index varies with the man-biting habit and the daily survival rate: stability index $= a/\text{-}\log_e p$.

By applying this formula we found a stability index for Brazzaville of 5·04.

The districts of Mfilou-Ngamaba and Ngangouoni

Presentation

Extending to the west of the town, the administrative district of Mfilou-Ngamaba and the Ngangouoni district (administratively incorporated into the Makelekele district) represent one of the more recent extensions of Brazzaville. The present population is over 50,000, whereas in 1974 it was only 16,810 (census of 1974 and of 1983). Until the mid 1960s, only a few scattered villages existed within the present periphery of these districts, with a total population of fewer than 1,500 inhabitants.

As in all recently urbanized districts, the number of inhabitants per hectare is low, generally less than 50. This area has the aspect of a mosaic, with plots which are unoccupied, under construction or inhabited. Several streams pass through the districts, with vegetable gardens and food crops planted along their banks (Fig. 2). A detailed description of this district can be found in AUGER & VENNETIER (1976).

Results of the collections

In this area of Brazzaville, we carried out 63 house-resting collections and 12 night-bite collections on human bait (72 man/nights).

The total number of Culicidae collected on man was 1,058, of which 392 were anopheles (390 *A. gambiae* and 2 *A. funestus*). 13 (3·67%) of 354 *A. gambiae* dissected, were found to carry sporozoites.

The 63 house-resting collections produced 1,070 Culicidae (853♀ and 217♂) of which 497 were anopheles (411♀ and 86♂). These were 486 *A. gambiae* (400♀ and 86♂), 9 *A. funestus* and 2 *A. moucheti*. Out of 249 anopheles dissected (244 *A. gambiae*, 3 *A. funestus* and 2 *A. moucheti*), 14 (5·62%) were found to carry sporozoites (13 *A. gambiae* and one *A. moucheti*).

Epidemiological analysis

For the analysis of the results we considered two separate periods, the first covering the eight months of the wet season and the first month of the dry season, and the second the last three months of the dry season.

The average number of anopheles bites per man and per night was 7·26 in the wet season and 0·94 in the dry season. For the wet season, the sporozoite rate used was the one we found after dissection of 552 anopheles collected in this area during this season: 4·89%. We thus obtain an inoculation rate of 0·355 in the wet season, which corresponds to one infective bite every 2·82 nights. For the nine months of the period considered, this gives a result of 96·9 infective bites per person. In the dry season, only 51 anopheles were dissected (none was infected) which is insufficient to obtain a reliable sporozoite rate. To determine the inoculation rate, we used the over-all sporozoite rate for all the anopheles dissected originating in this district. In fact, the sporozoite rate in the dry season was probably inferior as a result of the longer extrinsic cycle due to the fall in average temperature during this season. The inoculation rate thus calculated is 0·0426, or one infecting bite every 23·47 nights. For the three months of the period considered this gives a maximum of 3·9 infective bites per person. We can thus calculate that the total annual number of infective bites in this district of Brazzaville is 100·8 per person.

We determined the physiological age of 331 *A. gambiae* collected from November to May when the vectorial population is at its most stable. The proportion of parous females was 83·7%. Taking the same values previously used for the duration of the gonotrophic cycle ($x = 2$), the duration of the *P. falciparum* cycle in *A. gambiae* ($n = 12$) and the man-biting habit ($a = 0{\cdot}495$), we obtain the following parameters for the wet season:

Daily survival rate: $p = 0{\cdot}915$
Expectation of life: $1/\text{-}\log_e p = 11{\cdot}24$
Expectation of infective life: $p^n/\text{-}\log_e p = 3{\cdot}865$
Vectorial capacity: $C = 13{\cdot}89$
Stability index: $a/\text{-}\log_e p = 5{\cdot}56$

In the dry season, the daily survival rate and the expectation of life of *A. gambiae* are probably unchanged, since the longevity of this vector is not modified (GILLIES & DE MEILLON, 1968).

On the other hand, the expectation of infective life is decreased due to the fall in temperature (mean temperature from July to September = 23·3°C) : the duration of the extrinsic cycle, calculated from MOSHKOVSKY's formula (1950) is 15 days. The expectation of infective life is thus only 2·96 days, and we observe a considerable decrease in the vectorial capacity: $C = 1{\cdot}38$.

Poto-Poto centre and adjacent part of the districts of Ouenze and Moungali

Description

Although divided administratively into three districts (Poto-Poto, Ouenze and Moungali), this homogeneous area is one of the oldest parts of Brazzaville and corresponds approximately to the ancient African *Cité* of Poto-Poto in the 1940s (Fig. 3).

The population density is the highest in the town with about 250 inhabitants per hectare. The typical dwelling house unit, built on a plot, is similar to those in other districts of the town, except that a second low construction of one to three rooms is generally added to the first, thus reducing the empty space on each plot. Within the limits of our study the area covered was 232 hectares for a population of about 60,000 inhabitants. This is also an important commercial district, with two local markets and many small traders and traditional workshops.

Results of the collections

In this area we carried out 20 house-resting collections and seven night-bite collections on human bait (42 man-nights). The total number of Culicidae collected on man was 1,523, an average of 36·26 per man and per night. No anopheles were found among these, all the Culicidae collected being *Culex quinquefasciatus*. 757 Culicidae were caught during the house-resting collections; these were almost exclusively *C. quinquefasciatus* and there were no anopheles.

Epidemiological analysis

Since no anopheles were collected in this area we were unable to determine the real inoculation rate, only the possible upper limit. The maximum number of anopheles bites/man/night is less than 1/42, or MBR $< 0{\cdot}0238$. Assuming that the rare anopheles likely to be present in this area comes from neighbouring districts and that they have the same sporozoite rate (3·47%), we can calculate the upper limit of the inoculation rate to be: $h_e < 8{\cdot}259 \times 10^{-4}$, or less than one infective bite per person every three years and four months. The maximum upper limit of the inoculation rate taking into account the sample fluctuations can be calculated using Poisson's law. The greatest number of bites compatible with an observation of 0 bites is given by Poisson's table: 3·7. We thus obtain $h_e = 0{\cdot}00306$, or one infective bite every 327 nights. We can also calculate that the maximum upper limit of vectorial capacity is 0·137.

Discussion

This study shows the existence of considerable differences in anopheline density in different districts of the town: the average number of bites per man and per night is at least 238 times greater in the Mfilou-Ngamaba-Ngangouoni area, where it reaches 7·26 in the wet season and 0·94 in the dry season, than in the central area of Poto-Poto-Ouenze-Moungali where no anopheles were collected during 42 man-nights. However, even in the areas where it is highest, the anopheline density in Brazzaville remains considerably lower than in the surrounding rural region, where it is several dozen bites/man/night: 96 bites/man/night for *A. gambiae* alone in Djoumouna (CARNEVALE, 1979), 77 bites/man/night in Loukanga (BITSINDOU, 1984), 35 bites/man/night in Linzolo (TRAPE & ZOULANI, 1987b).

Although four species of anopheles were collected within the limits of the town (*A. gambiae*, *A. funestus*, *A. moucheti* and *A. nili*) and two of these species were found to be infected, only *A. gambiae*, which represents 99% of the collections, is involved in the transmission of malaria. The predominance of *A. gambiae* in Brazzaville had already been observed by MAILLOT (1953), MERLE & MAILLOT, (1955), BRADY (1961), ADAM & SOUWEINE (1962), NOAMESI *et al.* (1972) and GUEYE & ODETOYIMBO (1974). In the surrounding rural areas *A. gambiae* represents about 90% of the collections (BRADY, 1961; CARNEVALE & LE PONT, 1973; CARNEVALE, 1979; NZIAMBOUDI, 1982; TRAPE & ZOULANI, 1987b) and its predominance in thus even more accentuated in urban regions.

Unlike the anopheline density, the sporozoite rate is remarkably similar in urban and surrounding rural regions: from 3·47% to 4·48% in Brazzaville, 3·37% in Djoumouna (CARNEVALE, 1979), 3·51% in Yalavounga and 4.16% in M'bamou (NZIAMBOUDI, 1982) and 2·60% in Linzolo (TRAPE & ZOULANI, 1987b). However, most of the previous studies carried out in Brazzaville and the surrounding areas mention higher sporozoite rates, usually between 4·5% and 7·5% (MAILLOT, 1953; MERLE & MAILLOT, 1955; BRADY, 1961; ADAM & SOUWEINE, 1962; ADAM *et al.*, 1964; CARNEVALE, 1972). If this is effectively the case, the present decrease in sporozoite rate is probably due to the more intensive use of antimalarial drugs in infants and young children.

The considerable difference in intensity of malaria transmission in the different districts of the town, the causes of which will be analysed in the following paper, (see pp.19-25) shows the limitations of a study based on localized surveys, which do not take into account the diversity of the epidemiological situations existing in the same town. Thus, in the case of Pikine in Senegal (VERCRUYSSE & JANCLOES, 1981; VERCRUYSSE *et al.*, 1983), where all the collections were carried out on the border of a marshland where *A. arabiensis* breeding places were found, it is probable that the choice of another district farther from the marshland would have given different results for the vectorial density. Although only a close longitudinal study of a given district allows a precise estimation of several of the essential entomological parameters, it is in practice difficult to carry out the number of studies necessary because of the large area of African towns. Moreover, the decrease in vectorial density observed in urban environments creates specific problems for the estimation of several parameters. Thus, in the case of Poto-Poto-Ouenze-Moungali, a greater number of captures would have given a more precise result for the anopheline density, but would not have permitted a reliable estimation of the sporozoite rate or the proportion of parous females, because of the extreme rarity of vectors. We are thus obliged to use a series of assumptions concerning these parameters. In the case of the sporozoite rate, two opposing suppositions are equally plausible: either the rare anopheles likely to be observed in the Poto-Poto-Ouenze-Moungali area come from the surrounding districts, in which case the sporozoite rate would probably be equal to, or even greater than, that observed in these districts, or these anopheles come from minute, temporary, local breeding places, in which case the sporozoite rate would be much less than that observed elsewhere because of the very low gametocyte rate of the population residing in this district (see pp. 26-33).

Fig. 2. A typical view of the Mfilou-Ngamaba-Ngangouoni district.

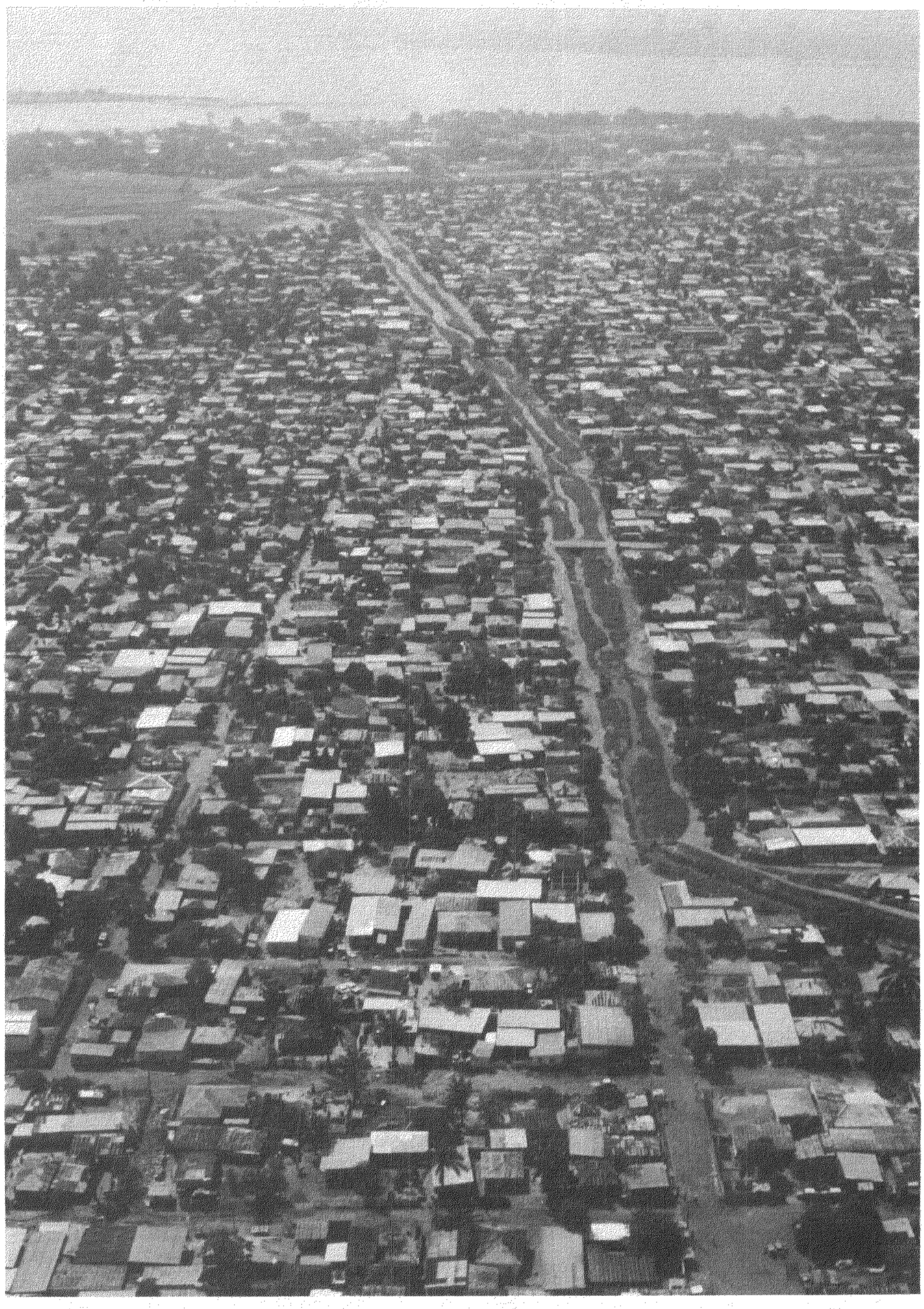

Fig. 3. General view of the central area of the Poto-Poto-Ouenze-Moungali district.

However, even assuming that the sporozoite rate is high, the entomological rate of inoculation remains very low. Likewise, a very low vectorial capacity, less than 0·137, shows that malaria cannot exist spontaneously in this district of Brazzaville: it is imported or introduced.

In the case of the Mfilou-Ngamba-Ngangouoni district, the epidemiological analysis shows on the contrary a high level of transmission, about 100·8 infective bites per year and per person. Such a high transmission intensity is frequent in the Guinean region of tropical Africa (HAMON *et al.*, 1962; COZ *et al.*, 1966). In regions of the Sudan, and especially of the Sahel, the annual number of infective bites per person is generally considerably lower (BRUCE-CHWATT, 1954; CHOUMARA *et al.*, 1959; SERVICE, 1963; HAMON *et al.*, 1965; DRAPER *et al.*, 1972; KRAFSUR & ARMSTRONG, 1978; MOLINEAUX & GRAMICCIA, 1980) because of a sharp decrease in the vectorial density during the driest season of the year, and the fact that *A. arabiensis* has a low anthropophilic tendency in rural areas. In urban regions, the only recent study on this subject is by VERCRUYSSE & JANCLOES (1981) in Senegal. They observed in Pikine a cumulative entomological rate of inoculation of 43 infective bites per year.

The main entomological parameters in Brazzaville (daily survival rate, expectation of life, expectation of infective life, stability index) have values close to those observed in the surrounding rural areas (CARNEVALE, 1979; BITSINDOU, 1984; TRAPE & ZOULANI (1987b), and in other regions of central Africa (RICHARD, 1983). Because *A. gambiae* has a high daily survival rate and human blood index, the stability index is high, more than 5. So, only a considerable reduction in the anopheline density is liable to affect transmission appreciably: this is precisely what we found in certain districts of Brazzaville.

Acknowledgement

This work was supported by a grant from the Ministère de l'Industrie et de la Recherche (Paris).

References

Adam, J.P. & Souweine, G. (1962). Etude de la sensibilité aux insecticides des culicidae de Brazzaville (République du Congo) avec quelques notes de faunistique et de biologie. *Bulletin de l'Institut de Recherches Scientifiques au Congo,* **1,** 31-43.

Adam, J.P., Progent, A. & Demellier, A. (1964). Organisation actuelle et problèmes de la lutte antipaludique à Brazzavile (République du Congo). Etude de la sensibilité d'*A. gambiae* à divers insecticides. *Médecine Tropicale,* **24,** 437-446.

Auger, A. & Vennetier, P. (1976). La croissance périphérique des villes: naissance et développement d'une banlieue brazzavilloise. *In* : croissance périphérique des villes : cas de Bangkok et de Brazzaville. *Travaux et Documents de Géographie Tropicale* (Bordeaux), No. 26, 223-286.

Bitsindou, P. (1984). *Impact des traitements insecticides (Deltamethrine) sur la transmission du paludisme et sa morbidité dans un village des environs de Brazzaville.* Thèse, Université de Paris-Sud, Centre d'Orsay, France.

Brady, J.N. (1961). Rapport sur une enquête entomologique à Brazzaville et dans les villages environnants. Mai 1961. World Health Organization, AFR/MAL/47. (Unpublished document.)

Brengues, J. & Coz, J. (1973). Quelques aspects fondamentaux de la biologie d'*Anopheles gambiae* Giles (sp. A) et d'*Anopheles funestus* Giles, en zone de savane humide d'Afrique de l'Ouest. *Cahiers O.R.S.T.O.M., Série Entomologie médicale et Parasitologie,* **11,** 107-126.

Bruce-Chwatt, L.J. (1954). Report on pre-control malaria surveys on the Western Sokoto area in 1953. Malaria Service Report, Yaba-Lagos, Nigeria.

Bruce-Chwatt, L.J. (1976). Mathematical models in the epidemiology and control of malaria. *Tropical and Geographical Medicine,* **28,** 1-8.

Bruce-Chwatt, L.J., Gockel, C. W. & Weitz, B. (1960). Study of blood feedings patterns of Anopheles mosquitoes through precipitin tests. *Bulletin of the World Health Organization,* **22,** 685-720.

Carnevale, P. (1972). Epidémiologie du paludisme humain en République Populaire du Congo. I. Le complexe *Anopheles gambiae* dans la région brazzavilloise. *Cahiers O.R.S.T.O.M., Série Entomologie Médicale et Parasitologie,* **10,** 281-286.

Carnevale, P. (1979). Le paludisme dans un village des environs de Brazzaville, *Thèse Sciences.* Université Paris XI, No. 2175.

Carnevale, P. & Le Pont, F. (1973). Epidémiologie du paludisme humain en République du Congo. II. Utilisation des pièges lumineux "C.D.C." comme moyen d'échantillonnage des populations anophèliennes. *Cahiers O.R.S.T.O.M., Série Entomologie Médicale et Parasitologie,* **11,** 263-270.

Carnevale, P., Bosseno, M.F., Molinier, M., Lancien, J., Le Pont, F. & Zoulani, A. (1979). Etude du cycle gonotrophique d'*Anopheles gambiae* (Diptera, Culicidae) (Giles, 1902) en zone de forêt dégradée d'Afrique Centrale. *Cahiers O.R.S.T.O.M., Série Entomologie Médicale et Parasitologie,* **17,** 55-75.

Choumara, R., Hamon, J., Bailly, H., Adam, J.P. & Ricosse, J. H. (1959). Le paludisme dans la zone pilote antipaludique de Bobo Dioulasso. *Cahiers O.R.S.T.O.M.,* **1,** 1-123.

Coz, J., Gruchet, H., Chauvet, G. & Coz, M. (1961). Estimation du taux de survie chez les anophèles. *Bulletin de la Société de Pathologie Exotique,* **54,** 1353-1358.

Coz, J., Hamon, J., Sales, S., Eyraud, M., Brengues, J. & Subra, R. (1966). Etudes entomologiques sur la transmission du paludisme humain dans une zone de forêt humide dense, la région de Sassandra, République de Côte d'Ivoire. *Cahiers O.R.S.T.O.M., Série Entomologie Médicale et Parasitologie,* **7,** 13-42.

Davidson, G. (1954). Estimation of the survival-rate of anopheline mosquitoes in nature. *Nature,* **174,** 792-793.

Davidson, G. (1955). Further studies on the basic factors concerned in the transmission of malaria. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* **49,** 339-350.

Davidson, G. & Draper, C.C. (1953). Field studies of some of the basic factors concerned in the transmission of malaria. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* **47,** 522-535.

Detinova, T.S. (1945). [Determination of the physiological age of female *anopheles* from the change of the tracheal system of the ovaries]. *Meditsinskaya Parazitologiya i Parazitarnye Bolezni,* **14,** 45-49. (In Russian.)

Detinova, T.S. (1963). *Méthodes à appliquer pour classer par groupes d'âge les diptères présentant une importance médicale.* World Health Organization, Monograph séries No. 47, Geneva.

Draper, C.C., Lelijveld, J.L.M., Matola, Y.G. & White, G.B. (1972). Malaria in the Pare area of Tanzania. IV. Malaria in the human population 11 years after the suspension of residual insecticide spraying, with special reference to the serological findings. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* **66,** 905-912.

Garrett-Jones, C. (1964). Prognosis for interruption of malaria transmission through assessment of the mosquito's vectorial capacity. *Nature,* **204,** 1173-1175.

Garrett-Jones, C. (1970). Problems of epidemiological entomology as applied to malarialogy. *Miscellaneous Publications of the Entomological Society of America*, **7**, 168-180.

Garrett-Jones, C. & Shidrawi, G.R. (1969). Malaria vectorial capacity of a population of *Anopheles gambiae*. *Bulletin of the World Health Organization*, **40**, 531-545.

Gillies, M.T. (1953). The duration of the gonotrophic cycle in *Anopheles gambiae* and *Anopheles funestus*, with a note on the efficiency of hand catching. *East African Medical Journal*, **30**, 125-135.

Gillies, M.T. (1961). Studies on the dispersion and survival of *Anopheles gambiae* Giles in East Africa, by means of marking and release experiments. *Bulletin of Entomological Research*, **52**, 99-127.

Gillies, M.T. & De Meillon, B. (1968). *The Anophelinae of Africa south of the Sahara (Ethiopian zoogeographical region)*. South African Institute of Medical Research, Publication No. 54, 2nd edit.

Gillies, M.T. & Wilkes, T.J. (1965). A study of the age-composition of populations of *Anopheles gambiae* Giles and *A. funestus* Giles in north-eastern Tanzania. *Bulletin of Entomological Research*, **56**, 237-262.

Gueye, I. & Odetoyinbo, J.A. (1974). Le paludisme en République Populaire du Congo. World Health Organization, AFR/MAL/138. (Unpublished document.)

Hamon, J. & Coz, J. (1966). Epidémiologie générale du paludisme humain en Afrique occidentale. Répartition et fréquence des parasites et des vecteurs et observations récentes sur quelques-uns des facteurs gouvernant la transmission de cette maladie. *Bulletin de la Société de Pathologie exotique*, **59**, 466-483.

Hamon, J., Dedewanou, B. & Eyraud, M. (1962). Etude entomologique sur la transmission du paludisme humain dans une zone forestière africaine, la région de Man, République de Côte d'Ivoire. *Bulletin de l'I.F.A.N.*, **24**, 854-879.

Hamon, J., Grejbine, A., Adam, J.P., Chauvet, G., Coz, J. & Gruchet, H. (1961). Les méthodes d'évaluation de l'âge physiologique des moustiques. *Bulletin de la Société entomologique de France*, **66**, 137-161.

Krafsur, E.S. & Armstrong, J.C. (1978). An integrated view of entomological and parasitological observations of *falciparum* malaria in Gambela, Western Ethiopia Lowlands. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **72**, 348-356.

Macdonald, G. (1952). The analysis of the sporozoite rate. *Tropical Diseases Bulletin*, **49**, 569-586.

Macdonald, G. (1957). *The epidemiology and control of malaria*. London: Oxford University Press.

Maillot, L. (1953). Etudes de l'infection palustre et de l'indice maxillaire chez *Anopheles gambiae* Giles à Brazzaville de décembre 1950 à février 1951. *Bulletin de la Société de Pathologie exotique*, **46**, 839-847.

Maillot, L. & Grejbine, A. (1947). Enquêtes entomologiques effectuées en Afrique Equatoriale Française au cours de l'année 1947. In: *Rapport sur le fonctionnement technique de l'Institut Pasteur de Brazzaville en 1947*, Institut Pasteur, Brazzaville, French Congo.

Merle, F. & Maillot, L. (1955). Campagnes de désinsectisation contre le paludisme à Brazzaville. *Bulletin de la Société de Pathologie exotique*, **48**, 242-269.

Molineaux, L. & Gramiccia, G. (1980). *The Garki Project*. Geneva: World Health Organization.

Moshkovsky, S.D. (1950). [The mains laws governing the epidemiology of malaria.], Moscow. (In Russian.)

Muirhead-Thomson, R.C. (1951). Studies on salt-water and fresh-water *Anopheles gambiae* on the East African coast. *Bulletin of Entomological Research*, **41**, 487-502.

Najera, J.A. (1974). A critical review of the field application of a mathematical model of malaria eradication. *Bulletin of the World Health Organization*, **50**, 449-457.

Noamesi, G.K., Conejo, M.G. & Colussa, M.B. (1972). Assainissement à Brazzaville et dans ses environs. World Health Organization, AFR/EH/122. (Unpublished document.)

Nziamboudi, P. (1982). Rapport de stage. O.R.S.T.O.M., Brazzaville, Congo.

Richard, A. (1983). *Aspects épidémiologiques et cliniques du paludisme dans les villages de la forêt du Mayombe (République Populaire du Congo)*. Thèse Médecine, Paris.

Service, M.W. (1963). The ecology of the mosquitoes of the northern Guinea Savannah of Nigeria. *Bulletin of Entomological Research*, **54**, 601-632.

Trape, J.F. (1987a). Malaria and urbanization in Central Africa: the example of Brazzaville. I. Presentation of the town and review of previous surveys. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **81** (Suppl. No. 2), 1-9.

Trape, J.F. (1987b). Malaria and urbanization in Central Africa: the example of Brazzaville. IV. Parasitological and serological surveys in urban and surrounding rural areas. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **81** (Suppl. No. 2), 26-33.

Trape, J.F. & Zoulani, A. (1987a). Malaria and urbanization in Central Africa: the example of Brazzaville. III. Relationships between urbanization and the intensity of malaria transmission. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **81** (Suppl. No. 2), 19-25.

Trape, J.F. & Zoulani, A. (1987b). Etudes sur le paludisme dans une zone de mosaïque forêt-savane d'Afrique centrale, la région de Brazzaville. I. Résultats des enquêtes entomologiques. *Bulletin de la Société de Pathologie exotique*, **80**, 84-99.

Vercruysse, J. & Jancloes, M. (1981). Etude entomologique sur la transmission du paludisme humain dans la zone urbaine de Pikine, Sénégal. *Cahiers O.R.S.T.O.M., série Entomologie Médicale et Parasitologie*, **19**, 165-178.

Vercruysse, J., Jancloes, M. & Van De Velden, L. (1983). Epidemiology of *falciparum* malaria in an urban area of Senegal. *Bulletin of the World Health Organization*, **61**, 821-831.

ISSN 0035-9203
Vol. 81 (Supplement No. 2) 1987 pp. 1-42

Malaria and urbanization in Central Africa: the example of Brazzaville (People's Republic of Congo)

Transactions of the Royal Society of Tropical Medicine and Hygiene

ZONAE TORRIDAE TUTAMEN

INSTITUT FRANÇAIS
DE RECHERCHE
SCIENTIFIQUE POUR LE
DÉVELOPPEMENT EN
COOPERATION

Patron: HER MAJESTY THE QUEEN

Royal Society of Tropical Medicine and Hygiene
Manson House, 26 Portland Place, London, W1N 4EY
Telephone: 01-580-2127 Telegrams: ANOPHELES LONDON, NW1