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

Part III: Relationships between urbanization and the intensity of malaria transmission

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

The authors present a map of malaria transmission intensity in Brazzaville from which they analyse the impact of urbanization on anopheline density and transmission of malaria. Whereas at first each new human settlement promotes the introduction or the proliferation of *A. gambiae*, the major vector of malaria in Central Africa, urban growth later proves to be unfavourable to this vector. Apart from the canalization of surface water and improvement in sanitation, it is the increase in population density which seems, by its direct or indirect consequences in urban areas, to determine the decrease in malaria transmission intensity. By favouring the absorption of the last remaining open spaces and by the accompanying domestic pollution, urbanization tends to eliminate an increasing number of *A. gambiae* breeding places; by limiting the dispersion of anopheles from breeding sites, it tends to focus malaria transmission and by thinning out the subsisting anopheline population among a denser human population, it tends to reduce the degree of exposure of each person.

Introduction

In a previous article (TRAPE & ZOULANI, see pp. 10-18) we reported our studies of the present entomological component of malaria transmission in Brazzaville, and showed the diversity of epidemiological situations existing in the different districts of this town. With an average of 1·78 anopheles bites per night and per person with a sporozoite rate of 3·47%, the inhabitants of Brazzaville receive on average 22·5 infective bites per person per year. However, considerable differences are observed between the districts, the number of infective bites varying from over 100 per person and per year to less than one per person every three years.

The existence of such important differences between the districts of the same town is of great interest for the epidemiological study of numerous clinical and biological aspects of malaria in tropical African regions. It also raises the problem of urbanization and its repercussion on morbidity and mortality due to malaria.

In this article we present a map of malaria transmission intensity in Brazzaville, from which the impact of urbanization on the anopheline density and the transmission of malaria are analysed.

Mapping Malaria Transmission Intensity in Brazzaville

Material and Methods

The data necessary for drawing up a map of malaria transmission intensity in Brazzaville were collected during three studies carried out between October 1982 and June 1984. The studies were of the breeding places of *A. gambiae*, the anthropophilic fauna which is active at night, and the house-resting fauna.

Survey of A. gambiae *breeding sites*

Collections of water of all kinds in which *A. gambiae* larvae are liable to be found are numerous in the town. We classified them into five main categories: (i) the banks of the river and the streams which cross the town, (ii) wells and installations for watering vegetable gardens and crops, (iii) ditches, gutters and puddles in ruts and car-tracks on the roads, (iv) the borrow-pits and draining wells in plots under construction and various building sites and (v) marshy hollows on non-urbanized ground.

For each district of the town we first localized or determined the frequency of these potential breeding places from field surveys, aerial photographs (I.G.N., 1978), existing information in the literature (MERLE & MAILLOT, 1955; BRADY, 1961; NOAMESY *et al.*, 1972) and the archives of the ORSTOM Centre and Service d'Hygiène in Brazzaville. Then, we tried to establish their importance as breeding sites of *A. gambiae* by looking for larvae and analysing the results of captures in nearby dwellings.

Night-bite collections on human bait and house-resting collections

We carried out 92 night-bite collections on human bait (550 man-nights) and 234 house-resting collections. The techniques used as well as the main results of these collections are published in a previous article (TRAPE & ZOULANI, see pp. 10-18). To interpret the results of each collection we took into account the season of the year, the external conditions, the results of captures in neighbouring areas, information found on the location and type of breeding places and, for the house-resting collections, of the number of houses and rooms visited.

Drawing up the map

Four levels of exposure to malaria were chosen to draw up the map: (i) less than one infective bite per person per half-year, (ii) from one infective bite per person per half-year to one infective bite per person per month, (iii) from one infective bite per person per month to one infective bite per person per week and (iv) at least one infective bite per person per week. For convenience, each corresponding area is referred to as having a transmission intensity (i) very low, (ii) low, (iii) moderate and (iv) high. The sporozoïte rate of *A. gambiae* was assumed to be the same for the whole of the town and only the results of collections carried out between October and June were taken into account. The map thus represents the average transmission intensity during the nine months of the year when it is at its maximum.

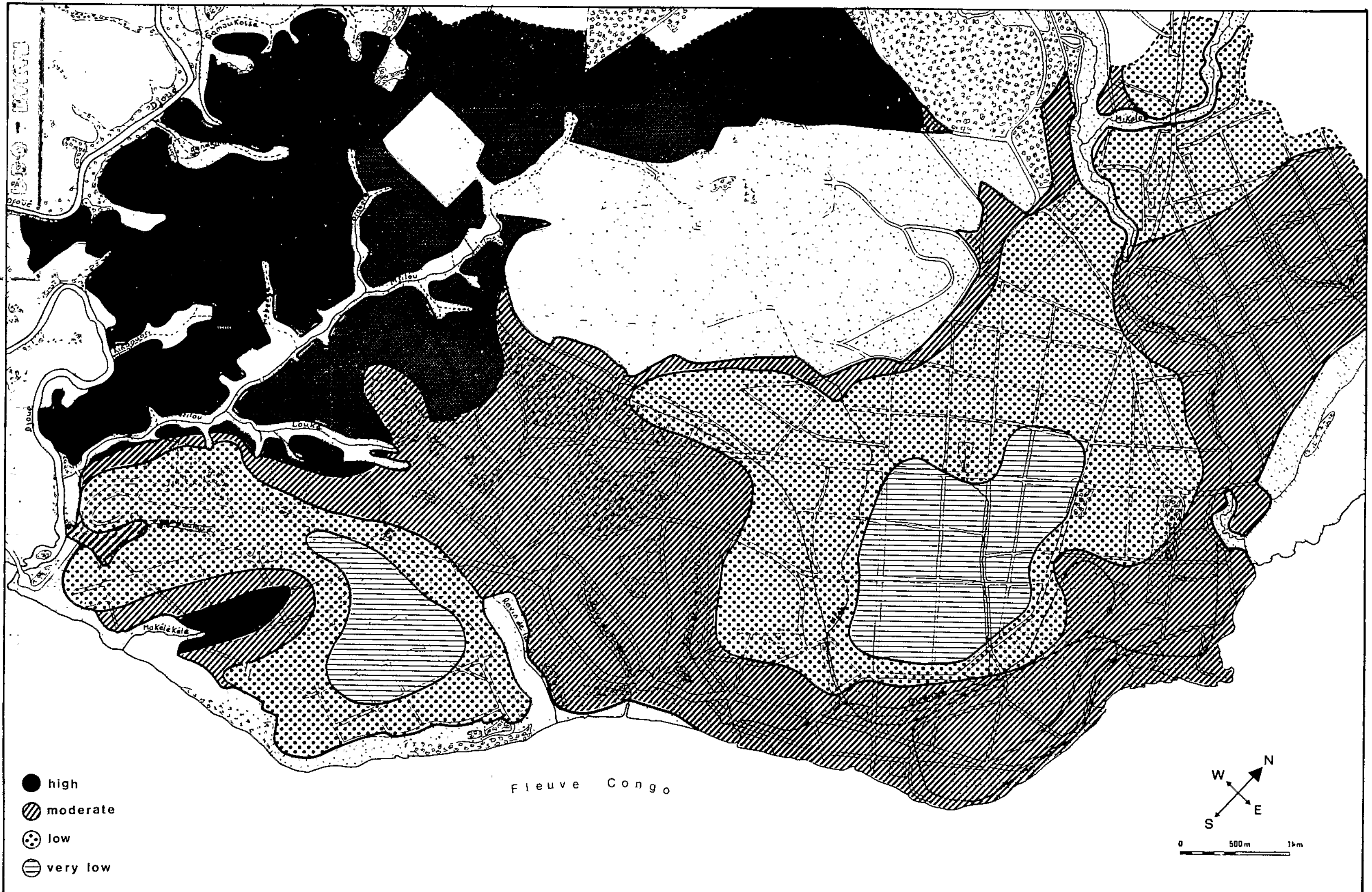

Fig. 1. Map of malaria transmission intensity in Brazzaville. *High transmission*: at least one infective bite per person per week; *moderate transmission*: from one infective bite per person per week to one infective bite per person per month; *low transmission*: from one infective bite per person per month to one infective bite per person per half-year; *very low transmission*: less than one infective bite per person per half-year. The boundaries on the map are approximate.

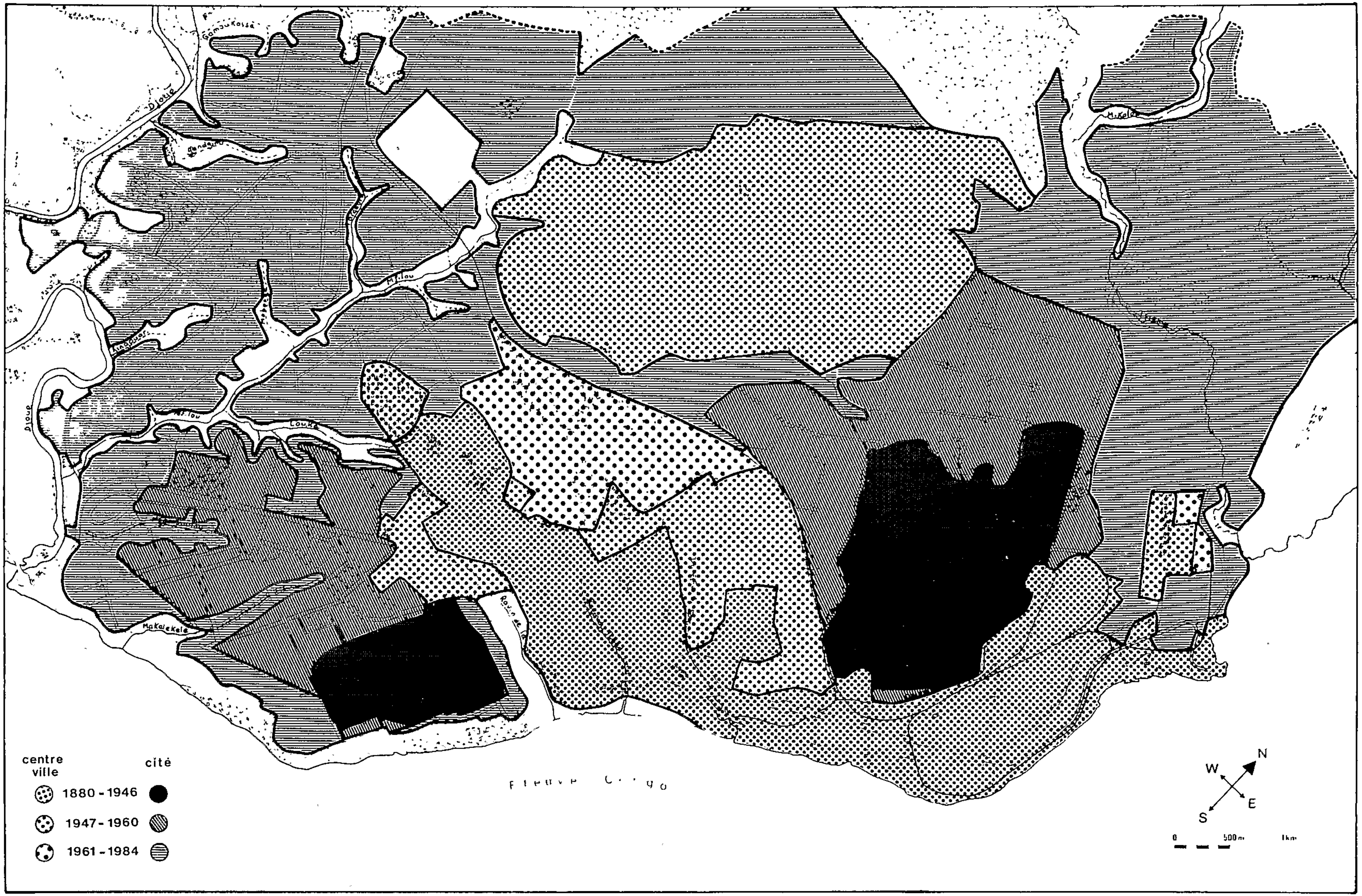

Fig. 2. The stages of growth of Brazzaville since the creation of this town. Map established from I.G.N. aerial photographs (C.R.E.T.H., 1980).

However, allowing for the fact that the vectorial density observed during collections on human bait was slightly underestimated (capturing started at 9 p.m. and the collectors possibly became less vigilant as the night advanced), it is probable that the figures on the map represent, in fact, the average yearly intensity of malaria transmission.

Results

Map 1 shows that the four degrees of malaria transmission intensity previously defined are largely represented in Brazzaville. Transmission is high in the western and north-western districts of the town (Mfilou, Ngamaba, Ngangouoni, Massina, Kinsoundi, Kingouari, Moukoundzi-Ngouaka) as well as in a narrow area situated on either side of Makelekele stream. The areas for low and very low transmission form two distinct concentric zones to the east and south-west of the town. The first is centred around the junction of Poto-Poto, Ouenze and Moungali and covers the whole of these three districts. Transmission is very low in the central part, and higher on the periphery. However, we noticed that the area of low transmission is very narrow in the southern part of Poto-Poto and Ouenze, near the town centre: only a few hundred metres separate the areas of very low and moderate transmission. The second group of districts where transmission is low or very low is situated to the south-west of the town, and includes the major part of Bocongo and Makelekele. These two districts are partly separated by the Makelekele stream beside which transmission is high. Moving away from this stream, transmission rapidly decreases: the area of high transmission is separated from the area of very low transmission by only a few hundred metres. Lastly, the town is divided into two by a vast area of moderate transmission corresponding to the town centre districts: airport, Patte d'oie, Plateau, Tchad, Plaine. This area continues towards the north to include the districts bordering the River Congo: Plaine, Mpila and Talangai.

Relationship between Malaria Transmission Intensity and Urbanization

The Urbanization Process

Map 2 shows the stages of growth of Brazzaville since the creation of this town in 1880. It was originally a simple administrative and military post. Later, as capital of the original French Equatorial Africa, it expanded rapidly and important commercial and administrative activities developed for which a great deal of space was reserved. Until the beginning of the 1950s the African population was fairly low, and concentrated in two *cités indigènes* on the outskirts of the town. The space occupied by these two *cités* was then relatively small compared with the rest of the town. Later, the extension of the administrative, commercial and high level residential part of the town slowed down considerably, while the two African *cités* developed rapidly.

The comparison of Maps 1 and 2 shows a striking relationship between the malaria transmission intensity and the progression of urbanization. The two areas of very low transmission closely correspond to the two oldest African districts of Brazzaville, as they were in the 1940s, and the two areas of low transmission correspond to the expansion of these districts about 1960. The areas of moderate and high transmission correspond to their most recent expansion without, however, maintaining the same close parallelism as previously between the transmission intensity and the progression of urbanization.

Contrary to the African town, this relationship does not exist for the town centre, a vast, usually old, heterogeneous urbanized area, comprising the airport, numerous open spaces and high-level administrative, commercial, industrial or residential districts. Although we only carried out a limited number of investigations, because of the small population (only 3·6% of the inhabitants of Brazzaville live in the town centre), the information collected clearly indicated a much higher density of *A. gambiae* than in the districts of the African town of similar age. Malaria transmission reaches a moderate level in most of the districts of the town centre.

Types of A. gambiae *Breeding Places found in Brazzaville*

Unlike the breeding places of Culicidae which are numerous and varied, the breeding places of *A. gambiae* which we found in Brazzaville were fairly rare. They fall mainly into the following categories: (i) *streams and waterside gardens*; various streams cross the town, and most of them, particularly in the western half which is situated on a raised plateau, have formed small fertile valleys where vegetable gardens and crops have been planted; the breeding sites are on the banks of the streams and in the adjacent hollows which fill up with rain or when the water level is high, and also in the waterside gardens in the diverse installations for watering. These represent the main breeding places in Brazzaville; (ii) *rainwater breeding places*; despite the high number of potential breeding places, anopheles actually breed in only a few; the ditches, gutters and puddles in ruts and car-tracks which are particularly numerous all over the town are only exceptionally used by *A. gambiae* in most districts; this is not consistent with the findings of CHINERY (1969, 1970) in Accra, RAGEAU *et al.* (1953) and DOBY & MOUCHET (1957) in the Cameroon and our own findings in the rural areas of the Congo.

In fact, among all the stagnating rain-water breeding places, the only ones frequently used by *A. gambiae* are the small marshy hollows, fairly numerous in areas which are not built up particularly in industrial zones and along railways tracks and in the forest reserve.

Relationship between A. gambiae *and* C. quinquefasciatus

C. quinquefasciatus is a typical urban mosquito and is the dominating species in large tropical towns. The breeding places are situated in the drainage wells for waste domestic water and rain-water and, to a lesser extent, in ditches, gutters and various receptacles (SUBRA, 1971; CHAUVET & RASOLONIAINA, 1968). Its rapid multiplication seems to be recent in tropical Africa. Initially, two explanations were put forward for this, namely, the use of insecticides and urban progression (MATTINGLY, 1962; SERVICE, 1966). However, *C. quinquefasciatus* is also abundant in localities where no insecticide has been used and in localities which have not been sprayed for many years.

Hence SUBRA (1973) suggested that the increasing use of washing powder and industrial detergents modifies the breeding sites to favour *C. quinquefasciatus* and could be one of the causes of the rapid multiplication of this species.

The abundance of *C. quinquefasciatus* is thus linked to urban development in at least two ways: firstly, the multiplication of breeding places particular to this species (drainage wells and diverse receptacles), and secondly, the pollution of breeding places where competition between species could have occurred (gutters and ditches) and which favours this species.

For each of the four areas of increasing intensity of malaria transmission marked on Map 1, we calculated, from the results of 92 night-bite collections on human bait, the average number of *C. quinquefasciatus* bites per man and per night. For the area of moderate transmission, which corresponds to certain districts of the African town and the whole of the town centre, the results of these two different sectors were analysed separately.

The average number of *C. quinquefasciatus* bites per person per night was 9·33 in the high transmission area, 19·64 in the low transmission area and 30·79 in the very low transmission area. For the moderate transmission area the results differ considerably between the African town and the town centre, with respectively 18·38 and 37·19 *C. quinquefasciatus* bites per person and per night. The ratio between the number of *C. quinquefasciatus* bites and the number of anopheles bites is 1·84 in high transmission areas, 42·46 in low transmission areas and 2,032 in very low transmission areas. In moderate transmission areas, it is 9·13 in the African town and 14·88 in the town centre.

Discussion

Human Activities and Vectorial Density in Rural Areas

The natural central African landscape comprises two kinds of vegetation: the tropical rain forest and the forest-savanna mosaic. The former is highly unfavourable to *A. gambiae* which prefers small collections of clear sunlit water. The other potential vectors of malaria exist here in small numbers, the only good breeding places for *A. moucheti* and *A. nili* being a few rivers in the forest; *A. paludis*, which is better adapted to the forest, is never an important vector and *A. funestus*, a very good potential vector, is always very rare in forests unmodified by man (ADAM, 1956; LIVADAS *et al.*, 1958; HAMON & MOUCHET, 1961; MOUCHET, 1962, 1976; GILLIES & DE MEILLON, 1968).

The forest-savanna mosaic, the main type of vegetation in the Brazzaville region, is more favourable to *A. gambiae* and *A. funestus*. However, two factors limit their distribution considerably: the existence of gallery forests alongside rivers and streams, and the sandy nature of the soil which does not retain rain-water. Because of this, in forest as well as in the forest-savanna, it is essentially human activity which allows the introduction of *A. gambiae* by deforestation, particularly along the clay river banks, and the direct or indirect creation of numerous breeding places favourable to this species (RAGEAU *et al.*, 1953; LIVADAS *et al.*, 1958). This is particularly the case in villages of the Brazzaville region: nearly all *A. gambiae* breeding places are the results of human environmental modifications (TRAPE & ZOULANI, 1987b).

Thus each human settlement initially favours the multiplication of breeding places and the presence of high density populations of *A. gambiae*. Since the length of the wet season allows this vector to exist in abundance for most of the year, the transmission of malaria is perennial and intense: in most of the villages in the Brazzaville region it is about one infective bite per person per night, sometimes more (TRAPE & ZOULANI, 1987b).

Impact of Construction Pressures in Urban Areas

In urban areas, diverse new phenomena are observed which prove to be unfavourable to *A. gambiae*. Firstly, the demographic growth requires more and more space, particularly as dwellings are still built in the traditional way, i.e., small low constructions surrounded by a yard. The town spreads rapidly but the actual populating of the new districts is slow and progressive because of the "do-it-yourself" building of dwellings. At the same time, the increase in density of dwellings is high in the older districts where the last empty spaces are progressively eliminated. Among the fields, vegetable gardens and remains of the forest, only those areas where construction is impossible because of the relief or flooding of the rivers are preserved. The population density is less than 50 inhabitants per hectare in recently urbanized districts, about 150 inhabitants per hectare in most of the districts urbanized between 1955 and 1965 and reaches 200 to 250 inhabitants per hectare in the older districts.

The growing scarcity of *A. gambiae* breeding places caused by urbanization can be clearly seen by comparing the maps of malaria transmission intensity and the expansion of Brazzaville. The apparent exception of the town centre is mainly due to its layout. Since Brazzaville began to grow, plenty of space has been reserved for the future extension of administrative, commercial and industrial activities, or kept as open spaces. These grounds thus constitute an exception to the normal construction pressures in the rest of the town. Since the growth of activity in the modern sector is low, many un-urbanized areas remain where construction sites are few and scattered. Vast areas are thus considerably rearranged without being built up and this favours the stagnation of rain-water in small marshy hollows which constitute good breeding places for *A. gambiae*. Furthermore, no district of the town centre is far from the banks of a river or stream and population density is very low: only 3·6% of the Brazzaville population resides in the town centre even though this represents about a quarter of the town's area.

Influence of Environmental Pollution

Another new phenomenon accompanies urbanization: the canalization of the streams which cross the town and of the surface water by the building of ditches and gutters. These installations are expensive, are mainly in the oldest districts of the town and considerably modify the nature of the potential breeding sites.

In rural areas, ditches are usually dug alongside the roads which run through villages, in order to drain rain-water and thus slow down pothole formation.

These ditches are usually colonized by *A. gambiae* since they present ideal conditions for larval development. In urban areas, in districts where a dense network of ditches and gutters exist, no anopheles larvae were observed although there are often numerous culicine larvae.

Ditches and gutters in urban areas, being badly kept and insufficiently washed by rain, contain highly polluted water which does not allow *A. gambiae* to develop, but which remains favourable to *C. quinquefasciatus*. The main pollution factor is domestic waste water from local houses (soap and detergents). The interconnection of ditches and the continual mixing of the water by rain leaves no possibility for *A. gambiae* to find a favourable breeding place.

The ditches being unsuitable for *A. gambiae*, the only remaining potential breeding sites in dense urban areas would be puddles and potholes on the roads. These sites are particularly suitable in villages in rural areas. However, *A. gambiae* is absent from these sites in all the older urbanized districts, whereas culicine larvae are often present. The possibility of pollution of this type of breeding site in urban areas cannot be excluded, but seems hardly plausible. The most probable explanation is that potholes and puddles are sites too minor in themselves to maintain *A. gambiae* when fierce competition exists from *C. quinquefasciatus*, the latter being particularly abundant in urban areas due to domestic drainage and septic tanks. Comparison of the results concerning the absolute and relative densities of these two species in the different districts of the town shows the existence of a negative relationship, but the amplitude of density variations of *C. quinquefasciatus* is small whereas it is considerably larger for *A. gambiae*.

Different Chronology According to the Type of Site used for Urbanization

Brazzaville is built on the site of two geological formations: (i) the *plateau des cataractes* on which the major part of the town centre is founded (with the exception of the Plaine and Mpila districts) and also the Bacongo, Makelekele and Mfilou-Ngamaba administrative districts and (ii) the sandy plain and hills of the *retombée du plateau de Mbé* where the Poto-Poto, Moungali, Ouenze and Talangai administrative districts are built. Brazzaville has developed simultaneously on these two formations, starting from Bacongo on one side and Poto-Poto on the other. In both cases the intensity of malaria transmission has decreased considerably in relation to the length of time since the beginning of urbanization. However, for the same length of time, the level of malaria transmission is higher in the districts of the *plateau des cataractes*. This is due to the numerous streams which cross this plateau making valleys with clay soils which are very favourable to market-gardening and various plantations. These valleys have held out against urbanization for a long time because of their good agricultural value. On the contrary, the low marshy banks of the streams which cross the plain where the main parts of the Poto-Poto, Ouenze and Talangai districts are situated have little agricultural value; they were immediately divided into lots for construction as urbanization progressed.

Focalization of Transmission

The observations carried out in certain older districts of the African town situated near non-urbanized areas where there are numerous larval habitats show that *A. gambiae* is very narrowly dispersed in densely populated urban environments. Flight ranges of several kilometres are frequent for this species in sparsely populated savanna regions, but much rarer in areas of dense vegetation and high population (GILLIES & DE MEILLON, 1968). In Bacongo and Poto-Poto where the population density is about 250 inhabitants per hectare, it would seem that the anopheline density decreases by more than 30 times over a few hundred metres distance from larval habitats. So whereas the inhabitants of Bacongo living along the banks of the Makelekele stream receive more than one infective bite per person per week, those living at a distance of 500 metres receive less than one infecting bite per person per half-year. The narrow dispersion of mosquitoes in urban areas, compared to that observed in rural areas, has already been emphasized by SUBRA (1972) for *C. quinquefasciatus*.

Indirectly this phenomenon may limit considerably the intensity of malaria transmission in areas of low density population when more densely populated areas are situated on the edge of breeding sites and thus constitute a sort of protective screen. This is observed in particular in recent districts of Brazzaville situated on sandy hills to the north-east of the town (Tout-pour-le-Peuple district and the high parts of Talangaï) where the relief and constitution of the soil prevent the local formation of breeding sites.

Conclusion

The increase in human population density seems, by its direct or indirect consequences in urban areas, to play the determining role in the decrease in intensity of malaria transmission in Brazzaville: it favours the absorption of the last remaining open spaces and, by the accompanying domestic pollution, tends to eliminate a growing number of *A. gambiae* breeding sites; it limits the dispersion of anopheles from breeding sites and tends to focus malaria transmission; it thins out the remaining anopheline populations in a denser human population and so tends to reduce the degree of exposure of each person.

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