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EVOLUTION OF MALARIA IN AFRICA FOR THE PAST 40 YEARS: IMPACT OF CLIMATIC AND HUMAN FACTORS

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ABSTRACT. Different malarial situations in Africa within the past 40 years are discussed in order to evaluate the impact of climatic and human factors on the disease. North of the equator, more droughts and lower rainfall have been recorded since 1972; and in eastern and southern Africa, there have been alternating dry and wet periods in relation to El Niño. Since 1955, the increase in human population from 125 to 450 million has resulted in both expansion of land cultivation and urbanization. In stable malaria areas of West and Central Africa and on the Madagascar coasts, the endemic situation has not changed since 1955. However, in unstable malaria areas such as the highlands and Sahel significant changes have occurred. In Madagascar, cessation of malaria control programs resulted in the deadly epidemic of 1987–88. The same situation was observed in Swaziland in 1984–85. In Uganda, malaria incidence has increased more than 30 times in the highlands (1,500–1,800 m), but its altitudinal limit has not overcome that of the beginning of the century. Cultivation of valley bottoms and extension of settlements are in large part responsible for this increase, along with abnormally heavy rainfall that favored the severe epidemic of 1994. A similar increase in malaria was observed in neighboring highlands of Rwanda and Burundi, and epidemics have been recorded in Ethiopia since 1958. In contrast, in the Sahel (Niayes region, Senegal), stricken by droughts since 1972, endemic malaria decreased drastically after the disappearance of the main vector, *Anopheles funestus,* due to the destruction of its larval sites by cultivation. Even during the very wet year of 1995, *An. funestus* did not reinvade the region and malaria did not increase. The same situation was observed in the Sahelian zone of Niger. Therefore, the temperature increase of 0.5°C during the last 2 decades cannot be incriminated as a major cause for these malaria changes, which are mainly due to the combination of climatic, human, and operational factors.

KEY WORDS Malaria, Africa, *Anopheles gambiae, Anopheles funestus,* climatic factors, human factors

MALARIA IN AFRICA

Since the 15th century, travelers described the unhealthy nature of African coasts where Europeans were decimated by fevers, and where, inland, life expectancy did not exceed 2–3 months (Carlson 1984). After 1950, global malaria eradication became a worldwide goal for public health, resulting in a number of pilot projects in Africa with remarkable studies on vectors and parasite prevalence. However, studies on morbidity and mortality were not conducted.

Africa is a continuous malaria focus from the southern border of the Sahara (20°N) to South Africa and Namibia (30°S). However, endemicity disappears above 1,800–2,000 m in the mountainous regions of Central and East Africa. The 3 major vectors involved are *Anopheles gambiae* Giles 1902, *Anopheles arabiensis* Patton 1905, and *Anopheles funestus* Giles 1900. The 1st 2 species are mainly linked to rainfall, and the 3rd is dependent on accumulation of rain water in pools. Vectorial competence of *An. gambiae* s.s. and *An. funestus* is remarkable, and their sporozoitic indices (SIs) are greater than 1%, if not 3%. *Anopheles arabiensis* is not as good a vector with an SI often lower than 1%.

Even though malaria occurs throughout Africa, there are significant differences between regions. Malaria stability and equilibrium between host, vector, and parasite are conditioned by the competence and longevity of vectors (Macdonald 1957). In stable malaria regions, transmission occurs every year at high levels and can be either perennial or seasonal. The human population acquires a strong immunity during the 1st few years of life at the price of a high infantile–juvenile mortality. In unstable malaria regions, transmission is lower and irregular from year to year, with the human population acquiring less immunity and epidemics occurring in all age classes (Macdonald 1957).

Stable malaria covers most of West and Central Africa, the eastern coast of Africa, Madagascar coasts, and Comoro Islands, with *An. gambiae* s.s. and *An. funestus* as the main vectors. Unstable malaria, with *An. arabiensis* as the major vector, includes the southern border of the Sahara, the mountainous areas of Central Africa, countries south of the Zambezi River, and the highlands of Madagascar. However, local presence of *An. funestus* and *An. gambiae* s.s. can sustain local stable malaria foci. Between these 2 situations of stable and unstable malaria, all intermediates occur, in particular in Sahel and East Africa (Mouchet et al. 1993).

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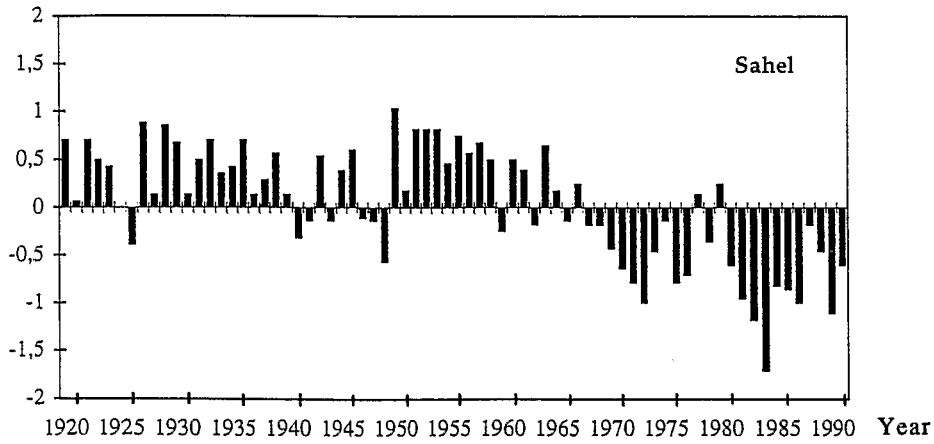

Fig. 1. Annual rainfall anomaly indices in the Sahel. Anomaly indices were calculated with respect to mean 1931–90 rainfall (from Hulme 1992).

MAJOR CLIMATIC EVENTS

The principal climatic factors influencing malaria transmission are temperature and rainfall. The former determines the length of the larval mosquito cycle and the sporogonic cycle of the parasite in the mosquito; the latter determines the number and productivity of breeding sites and consequently the vector density.

Numerous studies on the Quaternary period showed that the African continent went through tremendous climatic variations during the last interglacial era. During the humid Holocene (9,000 before present [BP]), the Great Rift lakes were at their highest level, and rainfall was relatively constant all year round, most likely 30% higher than the average recorded in 1931–60. Temperatures were 2°C below current levels. During the past 100 years for which quantified records are available, climatic variations have been noticed.

Temperature

Jones and Briffa (1992) used a temperature database available since 1895 and covering an area between latitudes 35°N and 40°S and between longitudes 20°W and 55°E. Based on one century, all tendencies have been detected including an atmospheric warming of 0.55°C in 1905 and 1940, a distinct cooling between 1940 and 1955, followed by temperature stability until 1980. In the early 1990s, another temperature increase of 0.2°C was recorded, followed by atmospheric cooling in 1992–93. However, 1995 was the warmest year recorded globally.

Rainfall

Africa south of the Sahara has a wide range of pluviometric regimes, from desert to equatorial zones. Three geographic groups can be identified (Nicholson et al. 1988): 1) West and Central Africa (including the Congolese basin), fed by a humid Atlantic flow; 2) East Africa, fed not only by this flow but mainly by the Indian Ocean's maritime flow; and 3) Southern Africa and Madagascar, significantly affected by the El Niño/Southern Oscillation (ENSO) phenomenon.

These 3 main geographic groups have their own specificities. The Sahelian zone, from Mauritania to western Ethiopia, has undergone an extended rain deficit since 1965 (Hulme 1992), resulting in the shift of mean isohyets 100–200 km south, as well as a 20–30% deficit of pluviometric means during 1961–90 compared to 1931–60 (Fig. 1). Drought paroxysms were recorded in 1972–73 and 1983–84. During these periods the flow of the Senegal, Niger, and Chari rivers dropped significantly and Lake Chad was reduced by ⅔.

In East Africa, exceptional rainfall occurred during the early 1960s resulting in a 10–15% increase of current means, which explains the augmentation of the flow of the White Nile during the past decades. In mountainous areas, the spatial heterogeneity of rainfall can be important even a few kilometers away. For instance, during the 1st semester of 1994, rainfall at Kabale (Uganda) was consistent with the normal mean (492.7 mm), whereas at Kisizi (50 km away) rainfall was twice as high (1,004.6 mm).

In southern Africa, alternating dry and humid years were observed during the past decades. El Niño/Southern Oscillation events have a significant impact; all El Niño years (1972–73, 1982–83, 1986–87) were both hot and dry.

IMPACT OF HUMAN FACTORS

In 1955, the Second Pan-African Conference on Malaria estimated the population living in Africa south of the Sahara at 125 million. In 1995, the

estimate exceeded 450 million; this population increase has resulted in galloping urbanization and environmental changes due to expansion of land cultivation and development of new agricultural methods, in particular irrigation.

A forest is a closed environment where the sun's rays do not reach the ground and heliophilic vectors are absent. Forest clearing for cultivation has resulted in the development of *An. gambiae* s.s. (Livadas et al. 1958). In Central African mountains, cultivation of valley bottoms was detrimental to the original papyrus marshes; the oil produced by this plant served to inhibit development of anophelines (McCrae 1976). Now the new environment is suitable for development of *An. gambiae* s.s. and *An. funestus.* Also, cultivation of ground depressions in dry areas of Sahel suppressed the habitats of *An. funestus* (Mouchet et al. 1996).

Dams, irrigation channels, and rice fields constitute favorable larval habitats for *An. gambiae* s.s. and *An. arabiensis* (Mouchet and Brengues 1990). In Madagascar, grown rice sustains *An. funestus* development; however, this species does not occur in rice fields of continental Africa (Laventure et al. 1996). The reason for this difference is still unknown.

Since 1960, urbanization has developed at a rate of 6–9%. Cities are surrounded by satellite villages that maintain rural characteristics and contrast with an urban downtown. The anophelines in the urban environment are the same as those in rural neighborhoods, mainly the *An. gambiae* complex. Because polluted water surfaces limit the availability of anopheline larval habitats, in Africa there is no specific urban vector. Therefore, malaria transmission is reduced, and the incidence of malaria decreases from the outskirts to the city center. This phenomenon has been thoroughly studied in Burkina Faso at Bobo-Dioulasso (Robert et al. 1986, Gazin et al. 1987) and Ouagadougou (Sabatineli et al. 1986), in Cameroon at Yaounde (Fondjo et al. 1992), and in the Congo at Brazzaville (Trape 1987).

Epidemics can also be linked to occupational activities, such as gold mining (Uganda) and river poaching (Zimbabwe), which bring people in close contact with vectors. Seasonal workers may bring back parasites to malaria-free zones. These human population movements can create some confusion in epidemiologic studies (Van der Stuyft et al. 1993) but the impact of such movement on malaria epidemiology is very low. The reason is that, with no vector, the malaria cycle is interrupted, and, with the presence of vectors, malaria is already endemic. Thus, seasonal migrations constitute a risk for migrants only and they do not change the malaria epidemiologic pattern.

Massive population movements can be due to forced governmental measures that bring populations from malaria-free areas to highly endemic ones, such as Ethiopia, where populations from the plateaux were moved to the western plains and paid a high price to the disease (Krafsur and Armstrong 1978). The presence of refugee camps can also temporarily increase malaria endemicity in areas where it is low.

EVOLUTION IN STABLE MALARIA ZONES

In stable malaria zones comparison of plasmodic indices recorded in 1950–65 and 1980–95 showed a remarkable similarity. In humid savanna zones of Burkina-Faso, Choumara et al. (1959) observed indices higher than 70% among children 2–9 years old during the rainy season and indices around 30% at the end of the dry season. In 1987, Gazin et al. reported identical values. In the forest region of Cameroon, Fondjo et al. (1992) found indices (45–70%) similar to those of Languillon et al. (1956). In post-forested savannas of the Congo, Carnevale et al. (1985) obtained the same indices (50–60%) as did Lacan (1957).

A remarkable phenomenon concerns the absence of impact of irrigated rice fields on malaria in Burkina-Faso. The number of anopheline bites increased 7-fold but the SI decreased 10-fold compared to a village with pluvial cultivation. Nevertheless, incidence of malaria was identical in the 2 situations (rice fields vs. pluvial cultivation) (Robert et al. 1985). Stable malaria has an inertia that tends to absorb environmental changes caused by human activities.

The only noticeable, but transitory, modifications were brought about by campaigns of indoor residual spraying in the forest zone. In Cameroon, malaria indices dropped from more than 50% to less than 3% in 2 years (Livadas et al. 1958), and the same happened in Liberia (Guttuso 1961). Such good results can be explained by the absence of alternative hosts for anophelines in the forest, resulting in their imperative endophagy. However, after cancellation of control programs in 1961, indices again returned to previous levels.

In contrast, in the savanna pilot zones the results of spraying of dichlorodiphenyltrichloroethane (DDT) were disappointing due to the irritant effect of the insecticide and the availability of alternative hosts (cattle) (Cavalié and Mouchet 1962). Large malaria control programs have never been undertaken in malaria stable areas.

EVOLUTION IN UNSTABLE MALARIA ZONES

General Considerations

Zones of unstable malaria are more sensitive to climatic variations and environment changes that have a strong impact on the level of malaria endemicity and the increase of epidemics. During the past 5 years, we have tried to sort out the causes of recent malaria fluctuations in Africa. In our stud-

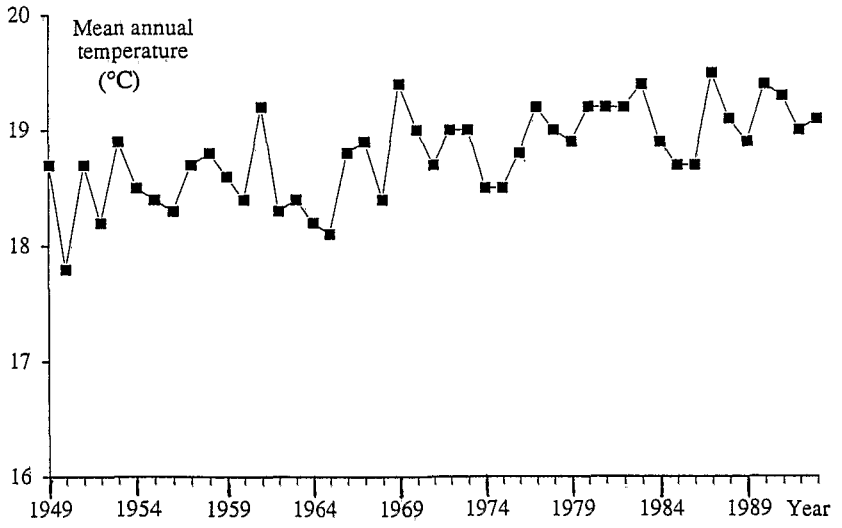

Fig. 2. Mean annual temperatures at Ivato (Madagascar) during 44 years.

ies, we targeted specific cases observed in Madagascar, Uganda, Swaziland, Zimbabwe, Botswana, and Senegal where we simultaneously found information on entomology, epidemiology, and meteorology. Even though these studies are not exhaustive, they cover a large number of situations in unstable malaria zones of Africa, ranging from the increase to the decrease of malaria.

We compared data on malaria prevalence and vector ecology recorded before 1970 with the current conditions. For this purpose, we selected health centers in Madagascar and Uganda for their reliable records based on microscopic observation. We carried out an investigation on current malaria epidemiology and vector ecology in the vicinity of these centers. Valuable local information was also gained by research teams in Senegal and Zimbabwe.

Madagascar Highlands

As opposed to the unhealthy coastal plain, the highlands or Plateaux of Madagascar were considered malaria-free until the mid-19th century. However, in 1878, a serious epidemic occurred, most likely as a consequence of development of irrigation. Rice fields constitute the main larval habitats for the vector *An. arabiensis* and even more so for *An. funestus.* The latter species reaches its peak densities at rice maturation from March to May, when more than 70% of malaria cases occur (Laventure et al. 1996). Malaria remained endemic in the highlands until 1949 when a control program was launched. It was based on indoor DDT spraying associated with chemoprophylaxis for children and chemotherapy for the general population using chloroquine. These measures resulted in malaria eradication from the highlands. The main vector, *An. funestus,* disappeared from most villages. In 1962 (Lumaret 1962), the general house spraying effort was stopped with the exception of 3 foci kept under surveillance and treated only according to the epidemiologic situation until 1974. The treatment centers were maintained, but between 1975–79 control of the centers was transferred from the central government to the communities and supplies were no longer regularly brought.

In 1987, a serious malaria epidemic occurred that hit all age groups of a nonimmune population. This epidemic was particularly deadly due to the difficulties of access to medication. In 1988, wide availability of chloroquine and DDT indoor spraying in the most serious foci significantly reduced malaria morbidity. Since 1993, coverage of the whole Plateaux by DDT house spraying has drastically reduced the incidence of malaria.

This epidemic arrived as a surprise for health authorities. Different mortality estimates were made in 1987: 15,000–30,000 deaths by the Health Ministry, as well as by Mouchet and Baudon (1988); between 70,000 and 100,000 by Noguer and Zulueta (Zulueta 1988); and up to 300,000 by some media. The origin of the epidemic was unknown; Zulueta (1988) suggested a succession of hot years and other authors incriminated cyclones.

For a better understanding of the epidemic genesis, we studied malaria data obtained from records of the Analaroa Health Center, located in 1 of the 3 epidemiologic surveillance zones of the Plateaux. Managed by Ursuline nuns since 1971, it is one of the few medical centers that based malaria diagnosis on microscopic observation and continuously kept drug supplies.

Meteorologic data were recorded at Ivato station, a rural area, at the same altitude (1,200 m) as Analaroa. Remarkable temperature stability can be observed during the past 20 years (Fig. 2). We re-

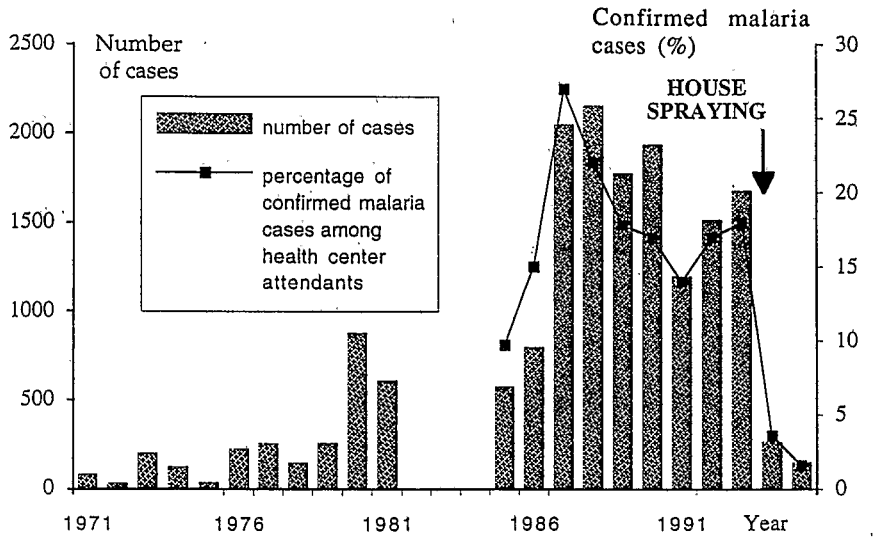

Fig. 3. Number of malaria cases in the Analaroa Health Center, Madagascar highlands, from 1971 to 1995. The exact number of patients between 1971 and 1981 is not available; it can be estimated between 5,000 and 10,000 per year. Records are based on 11 months per year. In August, the center is closed. Data from 1982 to 1985 were not reported because they were not reliable due to reorganization of the center.

jected data obtained at the Antananarivo station that presented a significant temperature increase because data were biased by 2 factors: the station was moved down 80 m in 1975 and the growth of the capital produced a greenhouse effect.

From 1971 to 1979, records of the Analaroa Center showed a moderate but constant increase of the number of malaria cases (Fig. 3). In 1980, this number suddenly quadrupled due to the closing of treatment centers and also to an important malaria outbreak that forced the local communities to spray with DDT at the end of 1979 (Ranjana, personal communication). From 1981 to 1985, the dispensary was reorganized and statistical data were not available. From 1985 to 1987, the number of malaria cases increased exponentially. After 1988, the number of cases decreased slightly, most likely as a consequence of ease of self-treatment. However, the number of cases stayed at a high level until 1994. Following the DDT house sprayings of December 1993, the number of cases decreased by 80%; then this decrease accelerated to 90% after the 1994–95 round of treatments.

In April 1993, the Epidemiological Surveillance Unit reported (Blanchy et al. 1993) mesoendemic parasitic indices (PIs) of 30–67% in the Analaroa area with irregularities among the villages. These values were comparable to those (25–30%) recorded by Joncour in 1949 (Joncour 1956) before the beginning of malaria control, which reduced PI to 0.18% in 1956. In 1988, the malaria situation was back to 1949 conditions before control measures were begun (Mouchet et al. 1997).

This reconquest of the highlands by malaria was slowed by the efficacy of surveillance measures until 1979 (Mouchet et al. 1996). After this year, no more control programs were operating, and malaria increased exponentially until the severe epidemic of 1987. The comeback of malaria is largely due to the reestablishment of the main vector, *An. funestus,* which had disappeared after the spraying in the late 1950s (Rakoto 1979, Fontenille and Rakotoarivony 1988). The transfer of cattle to inside houses to avoid theft possibly has attracted the mostly zoophilic vector, *An. arabiensis,* to the vicinity of humans, increasing its vector capacity. From our analysis, climatic warming cannot be blamed as a cause for a malaria epidemic that was mainly due to the cancellation of control measures, an epidemic that became dramatic with the deterioration of health services.

Swaziland and Zimbabwe

In Swaziland, considered to be a malaria control model, the disease came close to being eradicated in 1955, but successive reorganizations of health services and integration of malaria control within primary health care produced an irregularity or even an absence of vector control. Therefore, in 1985–86, a serious malaria epidemic occurred (Fontaine et al. 1987). For instance, in one dispensary covering 10,000 people, 1,000 presumptive malaria cases were recorded including 70 complicated cases in 1986 (Mouchet 1987).

Even though Zimbabwe had an efficient malaria control program, most of the small outbreaks (of a few hundred cases each) pointed out by the Health Ministry seemed to be due to failure of insecticide treatments (Taylor, personal communication). The

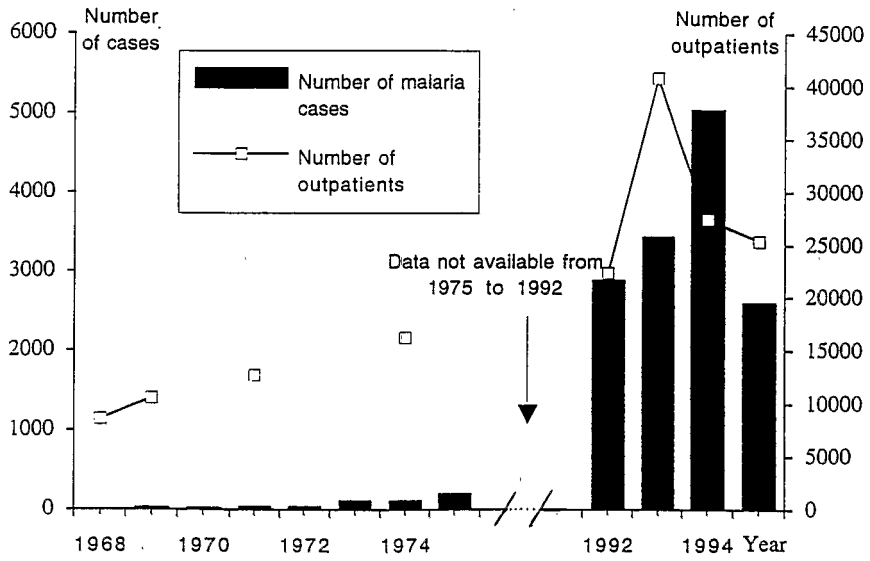

Fig. 4. Number of malaria cases among outpatients at the Kisizi Hospital, Uganda, from 1968 to 1995. Due to modifications in the reporting system, data from 1976 to 1992 are not available.

origin of these epidemics was similar to that in Madagascar.

Uganda and Central African Mountains

The highlands of southeastern Uganda have been known as an epidemic malaria region since 1948 (Garnham et al. 1948), and endemic foci have been identified since 1919 around Bunyonyi Lake at an altitude of 1,800–2,000 m (Zulueta et al. 1964). When the malaria eradication program was set up in 1961, extensive surveys showed either the absence or low prevalence of malaria above 1,500 m, except near Bunyonyi Lake (1,900 m), Mutanda Lake (1,900 m), and Kimbugu Lake (1,650 m).

At Bunyonyi Lake, *An. funestus* is the main vector. Due to its strong endophily, transmission can occur above 2,000 m because the lowest temperature in houses is always 3–5°C higher than that outside (Meyus et al. 1962). Therefore, altitude and temperature are not limiting factors for transmission (Zulueta et al. 1964). Transmission depends on the vector density, which is itself dependent on the extent of breeding habitats provided by cattail marshes around lakes. For instance, cattail clearing along the shore of Bunyonyi Lake resulted in a drastic decrease in transmission. In 1962, when villages surrounding the lake were treated with DDT, vectors and consequently malaria disappeared.

In valleys around Kisizi (Rukungiri District), *An. gambiae s.l.* was considered the major vector. Since 1990, an increase in malaria has been pointed out in both Rukungiri and Kabale districts (former Kigezi District) in areas above 1,500 m. These zones were previously considered nearly malaria-free. Nevertheless, reports showed that indoor DDT spraying was carried out from 1963 to 1966.

The Kisizi Mission Hospital, situated at an altitude of 1,650 m, is an excellent observatory for studying the malaria situation in highlands and it has been functioning nonstop with constant medication supplies since 1968. Also, malaria diagnoses have been confirmed by microscopic examination. The Kabale meteorologic station (1,800 m), located 50 km away from the hospital, has been recording data since 1969. By adding 1.5°C to buffer the altitude difference with Kabale, an extrapolation of Kisizi temperature tendencies can be made. Rainfall has been recorded at Kisizi itself since 1992 only.

Hospital records provide the status of malaria cases among in- and outpatients from 1967 to 1995. However, due to a change in the reporting system, data are missing from 1976 to 1992 (Fig. 4). We tried to fill this gap by gathering the data of the hospital laboratory from 1982 to 1994, but due to the work load, we checked only the month of July, the peak month for malaria.

A constant increase in the number of malaria cases annually has been detected, with 19 cases in 1968 among outpatients, 215 cases in 1976, to more than 2,900 cases in 1992 and 4,875 in 1994. In the meantime the total number of outpatients went from 8,580 in 1968, 16,219 in 1976, and 22,344 in 1992, to 27,491 in 1994. Even though the number of outpatients increased only 3.5-fold, the number of malaria cases increased 250-fold. Therefore, malaria incidence increased 70-fold among outpatients between 1968 and 1994. There are malaria cases all year round; however, the peak is in July, which is

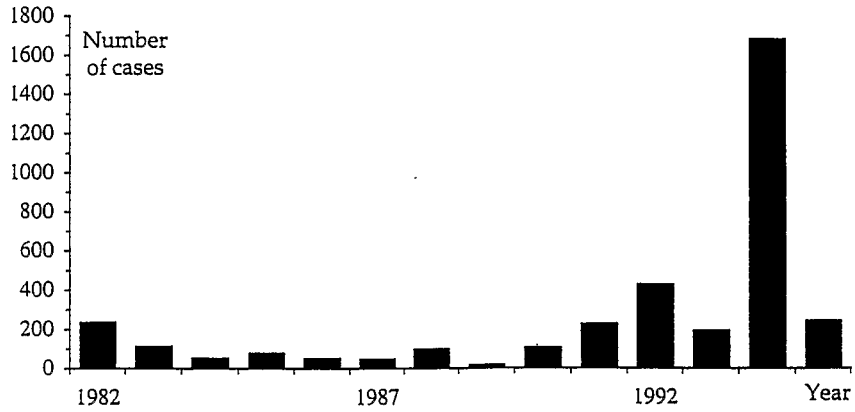

Fig. 5. Malaria cases recorded at the Kisizi Hospital laboratory, Uganda, each July from 1982 to 1995.

at once the driest and coldest month, following the March–June rainy season.

In July 1994, a deadly epidemic occurred in both the regions of Kisizi (Rukungiri District) and Kamwezi (Kabale District). At the hospital 1,684 cases were diagnosed (Fig. 5). In 1995, the situation returned to normal again with only 225 cases in July. We noticed that in July the number of cases showed important variations from one year to the next highlighting the instability of malaria, such as 240 cases diagnosed in 1982, 50 in 1987, 240 in 1991, 450 in 1992, and 200 in 1993.

Identification of the causes for the increase of endemicity and occurrence of outbreaks has been complicated. In Kabale between 1965, the coldest year (mean: 16.6°C), and 1994, the warmest year (mean: 17.8°C), the difference does not exceed 1.2°C. Even if warming could have played some role in this drastic increase in malaria, it cannot be considered as the main factor because transmission occurred already at Bunyonyi Lake (1,800–2,000 m) where the temperature was 1.5–2°C lower than in the Kisizi area.

Abnormal rainfall, more than 2-fold normal amounts, is linked to the epidemic of July 1994 in the Kisizi and Kamwesi areas. We should recall that in the Ethiopia highlands the 1958 epidemic was due to heavy rainfall (Fontaine et al. 1961).

In addition to climatic phenomena, environmental changes should be taken into consideration, especially those linked to demographic growth (greater than 3% per year). In their search for arable land, inhabitants spread into foothills and valleys covered with papyrus marshes. Humans replace the marshes with food crops and fish ponds, suitable breeding habitats of anophelines, mainly *An. gambiae*. On maps drawn before 1960, all valley bottoms were covered with natural wetlands, most of them now cultivated. Most of the villages of the valley bottoms, victims of the 1994 epidemics, were not noted on these maps. However, no recent study on the evolution of space occupancy in this area is available.

During our June 1996 survey, corresponding to the end of the rainy season, 185 *An. gambiae* s.s. and 10 *An. funestus* were collected in 8 of the 20 houses using indoor pyrethrum spraying. The circumsporozoite rate in *An. gambiae* s.s. determined by enzyme-linked immunosorbent assay (ELISA) was 14.5% and 1 of 9 *An. funestus* was also positive. These results are the sign of an intense transmission at this time of the year, but it seems limited to valley bottoms where the 8 positive houses were located. Moreover, all but 1 of the 56 blood meals tested were taken on humans.

Information was completely lacking on species of the *An. gambiae* complex in this area. McCrae (1976) noted the presence of *An. arabiensis* in the mountains of Uganda. Coosemans et al. (1984) reported the presence of the same species in Burundi at 900 m altitude. On the other hand, White (1972) showed the presence of *An. gambiae* s.s. in the Nangi Mountains in southwestern Kenya at an altitude ranging between 1,200 and 1,600 m. Therefore, it is impossible to state if the presence of *An. gambiae* s.s. above 1,500 m in Uganda is recent or if it was already present in the 1960s. However, what seems sure is that expansion of the species has been favored by the cultivation of valley bottoms, replacing natural papyrus wetlands.

In 1946, Vincke and Jadin had already noticed the linkage between malaria outbreaks and marsh clearing around Butare (Rwanda). Coosemans et al. (1984) demonstrated the incidence of rice cultivation on malaria progression in the Rusizi Valley (Burundi).

In Rwanda, Loevinsohn (1994) found a correlation between a temperature rise of 0.6°C from 1984 to 1987 and an increase in the number of malaria cases from 200 to 600 in a health center. His work takes into account neither the high rainfall of 1987, nor the vectors (*An. gambiae* s.s., *An. arabiensis*,

or *An. funestus*, with a different ecology), environmental changes, or migration of human populations. In addition, during the period preceding the study (1977–84), minima were only 0.2°C lower than in 1987, therefore higher than in 1984, and malaria stayed at a very low level. Through simulations made with the Macdonald (1957) model, we never could demonstrate that a temperature increase of 0.6°C could lead to a 6-fold increase in the transmission necessary for a 3-fold increase in the number of cases.

Senegalese Sahel

During the past 40 years in Sahel, temperatures increased 0.5–1°C depending on the localities (Fofana and Touré 1994), and rainfall decreased from 743 mm during 1950–59 to 427 mm during 1980–89. Major droughts occurred in 1972–73 (228 mm) and 1983–84 (241 mm), as well as the 1st 3 years of the 1990s (259 mm in 1992). These droughts had a drastic impact on the environment. Bushes replaced tropical ligneous vegetation; pools covered with cattails dried out. However, some humidity remained in soil depressions of pools allowing gardening. Since then, this gardening activity has continued and the original vegetation (cattails) has never recovered.

A study made in 1991–93 in Senegal along the subcoastal area of Niayes, northeast of Dakar, showed a profound modification of malaria endemicity when current malaria indices were compared to those recorded in the same region before 1970 (Faye et al. 1995). Based on the 1963 and 1967 surveys, malaria was then at the hyperendemicity limit. In 1991–92, PIs were lower than or equal to 10%, characteristic of a hypoendemic situation. Among a cohort of 100 children, only 4 malaria cases were recorded in 1991. This strongly contrasts with the situation of 1967, where nearly 50% of the children (812) from a nearby dispensary with similar recruitment had clinical malaria.

In 1967, the most abundant vector was *An. funestus* with 33 bites per man/night with an SI ranging between 1.2 and 3.1%. In 1991, this vector had almost disappeared. The biting activity of the *An. gambiae* complex also decreased, and in 1991 its SI was lower than 1% in 1 of the 2 studied villages and 0% in the other. In 1995, rains were abundant (similar to the 1960s). However, *An. funestus* was still rare in the Niayes region because appropriate larval habitats had not become available again; consequently malaria stayed at a low level.

In Niger, *An. funestus* became rare in the Niger River valley and in districts near Lake Chad (Sahelian zones), where it was the main species in the past (Ochrymowicz et al. 1965); malaria indices also decreased drastically. This spontaneous decrease in malaria, one rarely recorded in rural Africa, showed the role of drought compared to rainfall and emphasized the impact of environmental changes (Mouchet et al. 1996).

CONCLUSIONS

During the past 40 years, stable malaria was subject to few changes. In contrast, in areas of unstable malaria, rise or fall of the disease has frequently been observed with temporary or lasting fluctuations. The rise of endemicity occurred either slowly or quickly, sometimes taking an epidemic pattern until a higher endemic plateau was reached. In contrast, epidemic episodes limited in time and due to climatic or human factors can spontaneously disappear when the causal agent disappears.

The suppression of vector control programs is the most important cause for the increase in malaria, as shown in Madagascar, Zimbabwe, and Swaziland, as well as in South America (Roberts et al. 1997) and in Vietnam (Mouchet, personal communication).

The temperature, stable in Madagascar or increasing in the Sahel, has not changed the distribution patterns of malaria, which did not go beyond the limits already reached at the beginning of this century both in altitude (Uganda) and latitude (South Africa).

In Africa, rainfall is the main factor potentiating the productivity of anopheline larval sites, and consequently their biting rate. Rainfall excess causes seasonal epidemics (Botswana, Uganda). On the contrary, a long-term rainfall deficit combined with environment changes resulted in the disappearance of some vector species, such as *An. funestus* in the Sahel, followed by a decrease in the prevalence and incidence of malaria.

Among the environmental changes in Africa, deforestation is considered as a factor in the increase in malaria due to the development of sun-exposed anopheline larval sites. However, the modification of herbaceous vegetation is also an important factor (e.g., cattail in Niger and Senegal, papyrus in Uganda). The importance of irrigation for rice cultivation should be evaluated from place to place according to the ecological and epidemiologic situation.

Migratory flow and labor at risk, such as gold mining (Uganda) and poaching (Zimbabwe) at night, can bring localized epidemics.

However, the same causes do not necessarily produce the same effect according to the disease epidemiology (stability) and the environment. Under these conditions, predictions based upon variations in only one parameter, such as temperature, may be hazardous and are therefore not scientifically acceptable (Reiter 1996). All the malaria epidemiology components should also have been taken into consideration.

In conclusion, there is no single explanation for the reemergence of malaria in Africa. Each situation requires a specific study taking into account

climatic events, human factors, and operational activities.

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