

Influence of deltamethrin treatment of bed nets on malaria transmission in the Kou valley, Burkina Faso

V. Robert¹ & P. Carnevale²

A 3-year entomological study was carried out on the transmission of malaria in a village of 900 inhabitants in a rice-growing area of Burkina Faso. In the study area inhabitants use bed nets to protect themselves from mosquito bites. In the first year of the study, baseline data were collected; in the second year, the village was divided in two parts and all the bed nets in the southern part were sprayed with deltamethrin (25 mg/m²); and in the third year, all the bed nets in both parts of the village were sprayed. The inoculation rate was estimated by hand collection of mosquitos on human volunteers who were not protected by bed nets. The overall inoculation rate in the first year was 55 infected bites per person and was higher in the southern than in the northern part of the village. During the second year the rate increased to 70 bites per person on average (but was slightly lower than this in the southern part of the village). During the third year, the inoculation rate fell to three infected bites per year, i.e., a reduction of 94% compared with the first year. This reduction arose primarily because of a marked decrease in the sporozoitic index and a lower density of vectors. Thus, use of pyrethroid-impregnated bed nets by all members of the community appears to be a major tool in preventing transmission of malaria.

Introduction

The treatment of bed nets with insecticide is a recently developed vector control method that is suitable for use at the community level (10). Nets treated in this way act as physical and chemical barriers, protecting sleepers from mosquito bites and parasite inoculation. Investigations of this method in the Gambia (13, 14), Burkina Faso (1), China (5), Mali (16), and Papua New Guinea (4) have reported that, if used on a sufficiently large scale, it reduces the number of bites and also malaria morbidity (11). Such bed nets seem to have been well accepted by communities (3, 6). The general introduction of treated bed nets could be a novel weapon for vector control (2), and we investigated this possibility in a village of the Kou valley, a rice-growing area in south-west Burkina Faso.

A total of 12 000 inhabitants (mostly rice farmers and a few cattle breeders) live in the seven villages of the Kou valley. The rice fields, which yield two crops per year, are irrigated semi-permanently with water from the Kou river. The village of Vallée du Kou No. 4 (VK4) is located in the centre of this area. In this village unprotected sleepers are subjected to a total of about 35 000 mosquito bites per

year. Since mosquitos are viewed as a significant nuisance by the inhabitants, bed nets are extensively used.^a

In the study area *Anopheles arabiensis* occurs, but since this constitutes less than 5% of the endophilic population of the *A. gambiae* complex (9) and is almost exclusively zoophilic, its contribution to the transmission of malaria is negligible. *A. funestus*, a malaria vector, does occur in the area but its density is low, while *A. pharoensis* bites humans but is not a vector.

In the Kou valley the main malaria vector is *A. gambiae s.s.*, and only the Mopti cytotype is found in VK4. This cytotype is quite capable of transmitting malaria in West Africa; however, in the Kou valley its anthropophilic index is low (50%), as is the mean physiological age of the anthropophilic fraction of the mosquito populations (annual parity rate, 30%). The sporozoitic index is therefore small and, despite high vector densities, malaria transmission is low; we estimate that the inoculation rate in VK4 (where everyone sleeps under a net) is 20 infected bites per adult per year (17). This rate was observed over approximately 4 months during the periods mid-May to mid-July and from October to mid-

¹ Medical Entomologist, Chargé de Recherche, Antenne ORSTOM, OCEAC, Boîte postale 288, Yaoundé, Cameroon. Requests for reprints should be sent to Dr Robert at this address.

² Medical Entomologist, Directeur de Recherche, Antenne ORSTOM, OCEAC, Yaoundé, Cameroon.

Reprint No. 5230

^a Carnevale, P. & Robert, V. Introduction of irrigation in Burkina Faso and its effect on malaria transmission. Effects of agricultural development on vector-borne diseases. Working Papers presented at: Seventh Meeting of the Joint WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control, Rome, 7-11 September 1987. FAO unpublished document AGL/MISC/12/87, 1987, pp. 57-67.

December. Both these periods correspond to rice-harvesting seasons and to low vector densities. Anopheles densities and malaria transmission are therefore directly linked to rice cultivation (12) rather than to the occurrence of the rainy season, as is usually the case in the African savanna.

In the present article we have focused on the entomological data; the parasitological, serological, and clinical observations will be published later.

Materials and methods

The village of VK4 is situated about 30 km north of Bobo-Dioulasso, the second largest city in Burkina Faso. It is located in the centre of a rice-growing area of about 1000 hectares and 2-km radius, which excludes any other agricultural activity.

During the first year of the project, which began in May 1985, baseline data were collected on the inhabitants, who used their own nonsprayed bed nets. All bed nets in the southern half of the village were treated with deltamethrin at the end of the first year. At the end of the second year, the nets in this half of the village were retreated with the insecticide and those in the northern half were also treated. The 3-year study continued until April 1988.

Because a large variety of fabrics had been used to make the nets, deltamethrin was applied, not by dipping (15), but by spraying using hand compressors. The spraying coverage was calculated to result in 25 mg of deltamethrin per m² of fabric. At the end of the first year all the 233 nets in the southern part of the village were sprayed. At the end of the second year the 520 nets in the entire village were sprayed with 170 g of deltamethrin (active ingredient) diluted in 273 litres of water; with two sprayers and a team of seven persons, this process took 1.5 days.

The evaluation was performed using mosquitoes caught at night on humans who were not protected by bed nets but who were receiving regular malaria chemoprophylaxis (during the study no chloroquine-resistant strains of *Plasmodium falciparum* were detected in the area). Catches were made on a total of 156 nights, corresponding to 1019 man-nights. The mosquito catchers were located in the bedrooms of eight houses, scattered over the whole village. On the first night, catches were made in four houses in the southern half by two teams of individuals (one from 20h 00 to 01h 00 and the other from 01h 00 to 06h 00). On the second night the same protocol was conducted in four houses in the northern half of the village. Parallel outdoor catches were also made in front of these houses during the second and third years using the same protocol. These catches, on two consecutive nights, were repeated every 14 days,

without interruption, throughout the 3-year study period.

The identification of all the mosquitos and the dissection of the malaria vectors caught indoors were performed the following morning at the Medical Entomology Section, Centre Muraz, Bobo-Dioulasso. The physiological age of the insects was established from examination of the ovarian tracheoles using Detinova's technique. The salivary glands of fresh mosquitos were examined for sporozoites, without staining or squashing.

Results

More than 99% of the mosquitos caught belonged to one of the species shown in Table 1. Two species were involved in malaria transmission, *A. gambiae* and *A. funestus*, and the findings for these are outlined below.

Anopheles gambiae

Biting rate. A 34% reduction in the biting density compared with the pretreatment data was observed during the second year of the study. The reduction reached 61% during the third year (Table 2). There was no difference in the densities in the two parts of the village over the study period or between the indoor and outdoor catches. While seasonal variations were similar over this period, the biting rate in the second year was always lower than that in the first year, while that in the third year was lower than that in the second (Fig. 1). The highest aggressiveness was observed between 22h 00 and 23h 00 (Fig. 2), and the pattern of this did not vary over the study period.

Table 1: Numbers of the principal mosquito species caught and dissected during the 3 years of the study

	Study year			Total
	First	Second	Third	
Caught indoors				
<i>Anopheles gambiae</i> s.l.	14 999 (7701)*	9414 (4884)	5452 (2940)	29 865 (15 525)
<i>A. funestus</i>	312 (192)	237 (217)	368 (212)	917 (621)
<i>A. pharoensis</i>	1583	1914	1983	5480
<i>A. coustani</i>	284	122	124	530
<i>Mansonia uniformis</i>	1120	1112	788	3020
<i>M. africana</i>	989	622	218	1829
<i>Culex quinquefasciatus</i>	1066	695	1327	3088
<i>C. univittatus</i>	289	318	338	945
<i>C. poicilipes</i>	274	201	168	643
Caught outdoors				
<i>A. gambiae</i>	—	6869	4606	11 475

* Figures in parentheses indicate the number of mosquitos that were dissected.

Table 2: Daily biting rate (ma), parity rate (PR), sporozoite rate (s), daily inoculation rate (dh), yearly inoculation rate (yh), and percent modification relative to the first year of the study in the northern and southern halves of the village

		First year			Second year			Third year		
		South (control)	North (control)	Mean	South (treated)	North (control)	Mean ^a	South (treated)	North (treated)	Mean ^b
Caught indoors										
<i>Anopheles gambiae</i>										
ma		71.8	67.1	69.4	46.4	44.6	45.4 (-34%)	25.2	29.3	27.3 (-61%)
PR (%)		30.7	22.9	27.0	25.0	21.9	23.5 (-13%)	18.5	19.5	19.0 (-30%)
s (%)		0.249	0.136	0.195	0.359	0.463	0.410 (+110%)	0	0	0 (-)
dh		0.179	0.091	0.136	0.166	0.205	0.186 (+37%)	0	0	0 (-)
<i>A. funestus</i>										
ma		2.04	0.85	1.44	1.20	1.09	1.14 (-21%)	1.87	1.81	1.84 (+28%)
PR (%)		71	60	67	76	38	59 (-12%)	35	42	39 (-42%)
s (%)		0.74	1.75	1.04	0	0.98	0.46 (-56%)	0	0.94	0.47 (-55%)
dh		0.015	0.015	0.015	0	0.011	0.005 (-67%)	0	0.017	0.009 (-40%)
<i>A. gambiae</i> + <i>A. funestus</i>										
yh		70.7	38.8	54.9	60.7	79.2	69.9 (+27%)	0	6.4	3.2 (-94%)
Caught outdoors										
<i>A. gambiae</i>										
ma		—	—	—	34.2	35.9	35.0 (-)	21.6	24.4	23.0 (-)

^a Figures in parentheses are the % change in the means between the second and first years of the study.

^b Figures in parentheses are the % change in the means between the third and first years of the study.

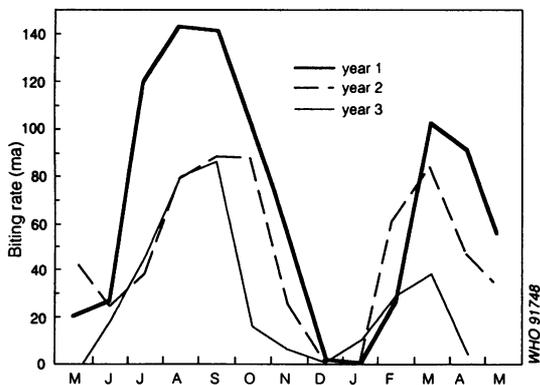
Parity rate. The parity rate during the second year was 13% less ($\chi^2_1 = 16.25$; $P < 0.001$) than that during the first year, while during the third year it was 30% less (Table 2). Seasonal variations in parity rate were similar during the 3 years (Fig. 3).

Vectorial capacity. If it is assumed that there was a uniform reduction in longevity and no variation in the man-biting habit and that the gonotrophic cycle was 2.5 days with a sporogonic cycle of 10 days, the vectorial capacity established using the Garret-Jones formula decreased from 0.141 in the first year to 0.011 in the third year. This would reduce the vectorial capacity of *A. gambiae* by a factor of 13. In the

Garki Project, Molineaux & Gramiccia observed that propoxur reduced the vectorial capacity by a factor of about 10 (16).

Sporozoite index. During the first year, the salivary glands of 15 *A. gambiae* were found that contained sporozoites from May to July and from October to December, with maxima in July and November. During the second year, 20 positive salivary glands were found in June, July, September, November and December. The mean sporozoite index in the second year was significantly greater than that in the first year ($\chi^2_1 = 5.06$; $P < 0.05$); only one peak (in July) was observed, and this was largely responsible for the elevated mean sporozoite index in the second year. During the third year no positive salivary gland was found and the sporozoitic index was zero (Table 2).

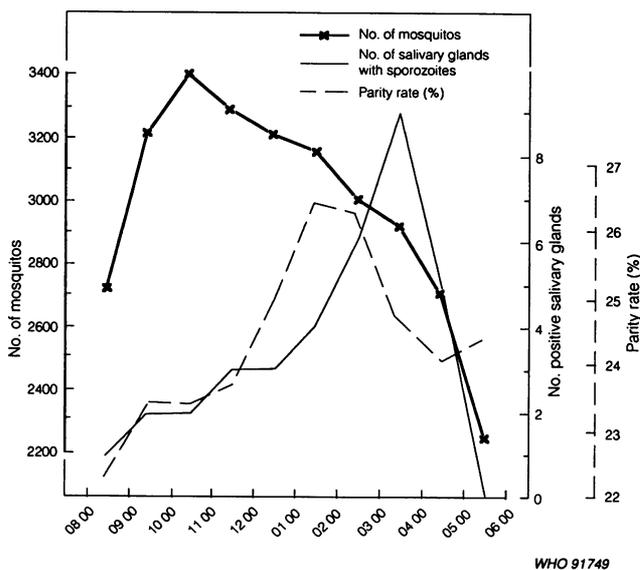
Fig. 1. Monthly evolution of *Anopheles gambiae* s.l. biting rate (ma) over the 3 years of the study.



Inoculation rate. The inoculation rate was 37% greater in the second year compared with that in the first year, and was zero in the third year (Table 2). During the first year the inoculation rate in the southern half of the village was twice that in the northern half; in contrast, in the second year the rate was lower in the southern half, where nets were treated. Seasonal variations in the inoculation rate were similar during the first two years of the study; two peaks were observed in July and November, and no transmission was observed in the middle of the dry season (February–April).

Infected *A. gambiae* were observed throughout the night, predominantly during the second half.

Fig. 2. Cumulative data on indoor biting characteristics of *Anopheles gambiae*, through the night, per hour.



WHO 91749

This distribution was linked to the parity rate but not the biting cycle (Fig. 2).

Anopheles funestus

A. funestus was 32.6 times less numerous than *A. gambiae* and had an accessory role in the transmission of malaria in the rice-growing area of the Kou valley. Its biting rate remained quite stable during the 3-year study period. The parity rate decreased slightly in the second year and considerably more so in the third year. In the first, second, and third years

of the study the number of *A. funestus* salivary glands found with sporozoites was two, one, and one, respectively. The sporozoite index decreased in the same proportion in the second and third years compared with the first year, and the inoculation rate was lower in the second and the third years relative to that in the first year (Table 2).

Reduction of malaria transmission

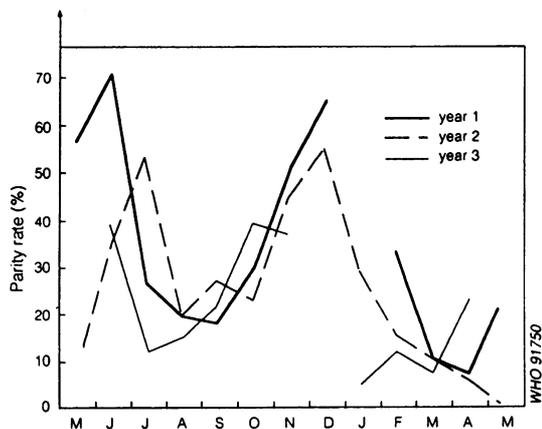
The total annual inoculation rate (*A. gambiae* + *A. funestus*) in the second year of the study was 27% greater than that in the first. In the third year it was 17 times less than that in the first year, which resulted in a 94% reduction (Table 2). During the first year, transmission was twice as high in the southern half of the village than in the northern. In contrast during the second year, transmission was a little higher in the northern than in the southern half, where the nets had been treated.

Transmission occurred throughout the night, but was more important during the second half of the night: 12 infected mosquitoes were observed from 20h 00 to 01h 00 and 27 from 01h 00 to 06h 00.

Nonmalaria vector mosquitoes

The density of some mosquito species increased over the study period, e.g., *A. pharoensis*. Others, such as *A. coustani*, *Mansonia uniformis*, *M. africana*, and *Culex poicillipes*, decreased. Still others did not present any evidence of variation, e.g., *C. quinquefasciatus* and *C. univittatus* (Table 1).

Fig. 3. Monthly evolution of anthropophilic *Anopheles gambiae* s.l. parity rate for the 3 years of the study.



WHO 91750

Discussion

After all the bed nets of the inhabitants of the study village had been sprayed with deltamethrin, transmission of malaria by *A. gambiae* decreased to such an extent that it could not be measured during the third year of the study using classical entomological methods involving examination of 3000 salivary glands. At this time the mean parity rate was 19%; according to Coz et al. (18) this corresponds to an expectation of survival after 10 days (duration of the extrinsic cycle of *P. falciparum*) of 2.08×10^{-4} . In other words transmission due to *A. gambiae* in the third year was almost zero.

The increase of transmission in the second year compared with that during the first year of the study was due to the occurrence of a sporozoite index peak in July. This peak seems to have been a consequence of a month's delay in the usual cycle of rice cultivation.

The treatment of the bed nets with deltamethrin did not increase the exophilic behaviour of the main malaria vector:

- the aggressiveness of *A. gambiae* was similar in the northern and southern halves of the village; and
- the lower biting rates of *A. gambiae* in the third year of the study, compared with those in the second, were similar for indoor and outdoor catches, indicating that deltamethrin is not very repellent at the dose used, and confirming that the *A. gambiae* population had decreased.

The constancy, or even increase over one year compared with the preceding, of the aggressive density of *A. funestus*, *A. pharoensis*, *M. uniformis*, *C. quinquefasciatus* and *C. univittatus* suggests that the reduction in the number of *A. gambiae* caught was not due to any lassitude on the part of the catchers.

Although the parity rate for *A. funestus* was 42% less in the third year compared with that in the pretreatment year, its aggressive density was unchanged. This is in accord with the hypothesis that the *A. funestus* originate outside the rice-field area (8). Transmission of malaria might have been completely stopped had the treated area been large enough to prevent intrusion by infected anophelines. It should be possible to supply large areas with pyrethroid-treated bed nets and therefore strongly limit malaria transmission, which occurs only rarely after indoor treatment with DDT.

One criticism frequently made about treated bed nets is that protection is only afforded when an individual is under the net.^b It should nevertheless be

borne in mind that transmission of malaria is lowest during the early hours of the night, when individuals usually engage in social activities and are therefore not under nets.

In conclusion, the results of the study indicate that the population of the main malaria vector decreased by 34% in the one half of a rice-field village where bed nets were treated with deltamethrin (25 mg/m²), but that the total level of malaria transmission did not change. Subsequent treatment of all bed nets in the study village resulted in a 94% reduction in the number of infective malaria vectors.

Acknowledgements

We acknowledge the help given by Dr J.-M. Klein, who supervised the final stage of the programme, and Dr J. Mouchet, for correcting the manuscript. We are very grateful to the technical assistance provided by the Medical Entomology Section, Centre Muraz, where this study was carried out and especially to V. Ouedraogo, J.-P. Kienou, Sanou Mamourou II, D. Dabré and B. Balaji. The gift of K-Othrine® from Roussel-Uclaf was much appreciated. This study received funding from the UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases.

Résumé

Influence du traitement des moustiquaires par la deltaméthrine sur la transmission du paludisme dans la vallée du Kou, Burkina Faso

Le village "Vallée du Kou n°4", situé au centre d'une rizière dans le sud-ouest du Burkina Faso, abrite 900 personnes et présente une haute densité d'anophèles vecteurs du paludisme humain. Il a servi de cadre à un essai de lutte antipaludique basé sur l'imprégnation des moustiquaires des habitants par pulvérisation d'un pyréthrianoïde, la deltaméthrine, à la dose de 25 mg de matière active par m² de tissu.

L'étude de la transmission du paludisme a duré trois ans, de mai 1985 à avril 1988. La 1^{ère} année a permis le recueil des données de prétraitement alors que tous les habitants utilisaient déjà leurs propres moustiquaires. Au début de la 2^{ème} année, les moustiquaires de la partie sud du village ont été imprégnées. Au début de la 3^{ème} année, toutes les moustiquaires des parties nord et sud du village ont été imprégnées.

La transmission du paludisme a été estimée à partir de 156 nuits de capture de moustiques sur sujets humains n'utilisant pas de moustiquaires. Au total plus de 1000 "hommes-nuits" de capture à l'intérieur et à l'extérieur des maisons ont

^b The use of impregnated bed nets and other materials for vector-borne disease control. Unpublished document WHO/VBC/89.981.

permis la collecte de plus de 60 000 moustiques; 8% étaient des anophèles dont 16 146 ont été disséqués pour rechercher la présence de sporozoïtes dans les glandes salivaires.

La 1^{ère} année, la transmission du paludisme était assurée à 90% par *Anopheles gambiae* s.s. et à 10% par *A. funestus*. Le taux annuel d'inoculation était de 55 piqûres infectées par homme et il était plus élevé dans la partie sud du village que dans sa partie nord.

La 2^{ème} année le taux annuel d'inoculation était de 70 (soit +27% par rapport à la 1^{ère} année, probablement en raison de modifications dans le cycle de la riziculture) en étant devenu légèrement supérieur dans la partie nord. Ce taux était comparable en captures intérieures comme en captures extérieures. L'imprégnation des moustiquaires d'une moitié du village a donc été relativement inefficace pour réduire la transmission du paludisme.

La 3^{ème} année l'avantage des moustiquaires imprégnées est apparu par rapport aux moustiquaires simples: le taux annuel d'inoculation était tombé à 3 piqûres infectées par homme (soit 94% de réduction par rapport à l'année témoin). Cette réduction de l'infectivité des anophèles vecteurs était due à une baisse de la densité (-61% pour le taux de piqûre) et de la longévité (-30% pour le taux de parturité d'*A. gambiae*). Aucun *A. gambiae* n'a été trouvé infecté sur 2940 glandes salivaires disséquées (s = 0%) alors que lors de la 1^{ère} année 15 moustiques positifs sur 7701 ont été observés (s = 0,20%). Seul 1 *A. funestus*, probablement originaire de l'extérieur de la rizière, a été trouvé positif au cours de la 3^{ème} année.

L'utilisation de moustiquaires imprégnées d'un pyréthrinoloïde par la totalité d'une communauté constitue une nouvelle arme efficace dans la lutte contre la transmission du paludisme.

References

1. Carnevale, P. et al. La lutte contre le paludisme par des moustiquaires imprégnées de pyréthrinoloïdes au Burkina Faso. *Bulletin de la Société de Pathologie exotique*, **81**: 832-846 (1988).
2. Curtis, C.F. et al. Impregnated bed nets and curtains against malaria mosquitos. In: Curtis C.F., ed. *Appropriate technology for vector control*. Boca Raton, FL, CRC, 1989.
3. Desfontaine, M. et al. Evaluation des pratiques et des coûts de la lutte antivectorielle à l'échelon familial en Afrique Centrale. I. Ville de Yaoundé (mars 1988). *Bulletin de la Société de Pathologie exotique*, **82**: 558-565 (1989).
4. Graves, P.M. et al. Reduction in incidence and prevalence of *Plasmodium falciparum* in under-5-year-old children by permethrin impregnation of mosquito nets. *Bulletin of the World Health Organization*, **65**: 869-877 (1987).
5. Li Zuzi et al. Trial of deltamethrin-impregnated bed nets for the control of malaria transmitted by *Anopheles sinensis* and *Anopheles anthropophagus*. *American journal of tropical medicine and hygiene*, **40**: 356-359 (1989).
6. MacCormack, C.P. & Snow, M.W. Gambian cultural preferences in the use of insecticide-treated bednets. *Journal of tropical medicine and hygiene*, **89**: 295-302 (1986).
7. Ranque, P. et al. Etude expérimentale sur l'utilisation de moustiquaires imprégnées de deltaméthrine dans la lutte contre le paludisme. *Parassitologia*, **26**: 261-271 (1984).
8. Robert, V. et al. La succession des espèces anophéliennes et le cycle du riz; étude écologique des *Culicidae* adultes et larvaires dans la rizière de la Vallée du Kou, Burkina Faso. *Acta tropica*, **45**: 351-359 (1988).
9. Robert, V. et al. Analyse cytogénétique du complexe *Anopheles gambiae* dans la région de Bobo-Dioulasso, Burkina Faso. *Annales de Parasitologie humaine et comparée*, **64**: 290-311 (1989).
10. Robert, V. et al. Pyrethroid-impregnated bed nets in the malaria control strategy at community level. *Acta tropica*, **46**: 267-268 (1989).
11. Rozendaal, J.A. Impregnated mosquito nets and curtains for self-protection and vector control. *Tropical diseases bulletin*, **86**: 1-41 (1989).
12. Service, M.W. Rice, a challenge to health. *Parasitology today*, **5**: 162-165 (1989).
13. Snow, R.W. et al. A trial of permethrin-treated bed nets in the prevention of malaria in Gambian children. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **81**: 563-567 (1987).
14. Snow, R.W. et al. Permethrin-treated bed nets (mosquito nets) prevent malaria in Gambian children. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **82**: 838-842 (1988).
15. Snow, R.W. et al. How best to treat bed nets in the prevention of malaria in Gambian children. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **82**: 647-648 (1988).
16. Molineaux, L. & Gramiccia, G. *The Garki project*. Geneva, World Health Organization, 1980.
17. Robert, V. et al. La transmission du paludisme humain dans un village au centre de la rizière de la Vallée du Kou, Burkina Faso. In: Robert, V. et al. *Le paludisme en Afrique de l'Ouest*. Paris, ORSTOM, 1991.
18. Coz, J. et al. Estimation du taux de survie chez les anophèles. *Bulletin de la Société de Pathologie exotique*, **54**: 1353-1358 (1961).