Four years' entomological study of the transmission of seasonal malaria in Senegal and the bionomics of *Anopheles gambiae* and *A. arabiensis*

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Abstract

From 1993 to 1996, an entomological survey was conducted in the village of Ndiop, Senegal, as part of a research programme on malaria epidemiology and the mechanisms of protective immunity. Mosquitoes were captured on human bait and by indoor spraying. Species from the *Anopheles gambiae* complex were identified using the polymerase chain reaction, and *Plasmodium falciparum* infections were detected by enzyme-linked immunosorbent assay for circumsporozoite protein. The vector species identified were *A. gambiae* (33·9%), *A. arabiensis* (63·2%), *A. melas* (0·3%) and *A. funestus* (2·5%). Similar proportions of *A. gambiae* (74·2%) and *A. arabiensis* (73·8%) contained human blood; 27·0% of *A. gambiae* and 28·3% of *A. arabiensis* had fed on cattle. The sporozoite rates were similar for *A. gambiae* (3·2%) and *A. arabiensis* (3·7%). The annual entomological inoculation rates varied greatly depending on the year. There were 63, 17, 37 and 7 infected bites per person per year in 1993, 1994, 1995 and 1996 respectively. Transmission was highly seasonal, from July to October. *A. arabiensis* was responsible for 66% of malaria transmission, *A. gambiae* for 31%, and *A. funestus* for 3%.

Keywords: malaria, *Plasmodium falciparum*, transmission, *Anopheles arabiensis*, *Anopheles gambiae*, *Anopheles melas*, Senegal

Introduction

Comparison of areas with different levels of malaria endemicity is a means of understanding the relationships between transmission, infection and morbidity of malaria and for investigating the mechanisms leading to protective immunity (BEIER *et al.*, 1994; MCELROY *et al.*, 1994; SNOW *et al.*, 1994; BEADLE *et al.*, 1995; MBOGO *et al.*, 1995). Such understanding of the effects of the intensity and seasonality of transmission is essential for a long-term prediction of the efficacy of vector control measures or malaria vaccines (SAUL, 1993; SNOW & MARSH, 1995; TRAPE & ROGIER, 1996).

For this reason, 2 Senegalese villages, Dielmo and Ndiop, only 5 km apart but with different malaria patterns, were selected for a longitudinal study of vectorial transmission, parasitaemia, clinical attacks, immunological data, and genetic diversity of *Plasmodium falciparum* (see ROGIER & TRAPE, 1995).

In Dielmo, where malaria is holoendemic and transmission continuous throughout the year, the longitudinal study began in 1990, while in Ndiop, where malaria is mesoendemic and transmission seasonal, it began in 1993. The results of the study in Dielmo have been reported by KONATE *et al.* (1994), TRAPE *et al.* (1994) and FONTENILLE *et al.* (1997).

This study presents the data obtained in Ndiop. The aims of this longitudinal study were to identify the malaria vectors, using the polymerase chain reaction (PCR) to identify species of the *Anopheles gambiae* complex, to understand their behaviour, and to evaluate the level and the seasonality of malaria transmission. These transmission data will be useful for the evaluation of the relationships of morbidity, immunity and genetic diversity of *P. falciparum* in Ndiop in successive years and between Dielmo and Ndiop during the same year.

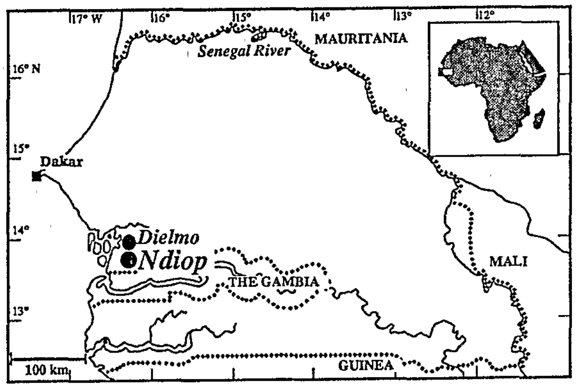

Fig. 1. Map of Senegal showing the villages of Ndiop and Dielmo in the Saloum region.

are Wolof and Peuhl, who are mainly farmers. The vegetation is wooded savannah, almost entirely cleared for cultivation of peanuts and millet. Most of the houses are built in the traditional style with mud walls and thatched roofs. In 18 of the 58 houses, corrugated iron has replaced the thatch, but generally a space is left between the roof and the tops of the walls. Small herds of domestic animals stay for the night within the village. Ndiop is representative of villages in this area, contrary to Dielmo which is situated on the marshy bank of a small permanent stream which permits the persistence of anopheline larval development sites throughout the year. The rainy season extends from June to October. Rainfall varies annually: 602 mm in 1993, 709 mm in 1994, 860 mm in 1995 and 521 mm in 1996. The nearest temporary ground pool, which floods during the rainy season, is 1 km from the village. The average minimum monthly

Table 1. Number of malaria vectors caught from April 1993 to December 1996 by two different methods in Ndiop, Senegal

	No. of mosquitoes	
	Feeding on human bait	Resting in bedrooms

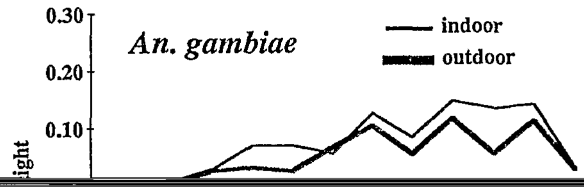

Table 3. Circumsporozoite rates in the three main vector species of *Anopheles*; Ndiop, Senegal, 1993–1996

	Circumsporozoite rate (%)[a]		
	A. gambiae	*A. arabiensis*	*A. funestus*
1993			
No. tested	265	474	4
P. falciparum	3·4 (1·6–6·3)	4·4 (2·8–6·7)	0
P. malariae	0·43 (0·001–2·1)	0·4 (0·05–1·5)	0
P. ovale	0	0	0
1994			
No. tested	89	271	18
P. falciparum	1·1 (0·03–6·1)	3·0 (1·3–5·7)	0
P. malariae	0	0·7 (0·1–2·6)	0
P. ovale	1·1 (0·03–6·1)	0·4 (0·001–2·0)	0
1995			
No. tested	190	375	28
P. falciparum	3·2 (1·2–6·7)	3·5 (1·9–5·9)	7·1 (0·9–23·5)
P. malariae	0	0·3 (0·001–3·5)	0
P. ovale	0	0·5 (0·06–1·9)	0
1996			
No. tested	49	33	3
P. falciparum	6·1 (1·3–16·9)	3·0 (0·1–15·7)	0
P. malariae	0	0	0
P. ovale	0	0	0

[a]Circumsporozoite rate calculated by ELISA from heads/thoraces of female mosquitoes captured on human bait. Exact 95% confidence intervals calculated according to the binomial distribution are shown in parentheses.

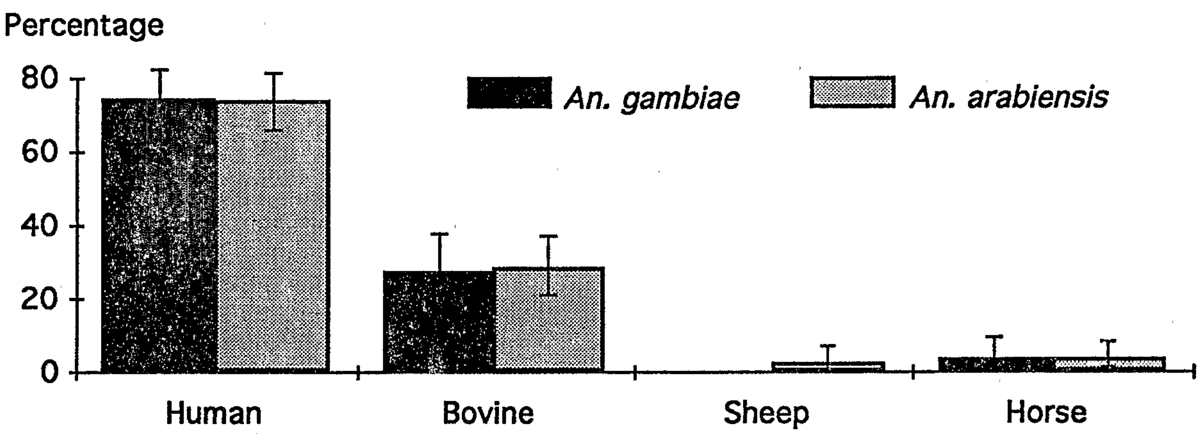

Fig. 4. Blood meal identification of indoor resting *Anopheles* spp., Ndiop, Senegal, 1993–1996.

Circumsporozoite protein rates

The CSP rate was calculated monthly for each species. Overall, 86·5% of those identified were *P. falciparum*, 8·1% were *P. malariae* and 5·4% were *P. ovale*. In total, 3·2% (95% CI 1·9–4·9) of *A. gambiae* and 3·7% (95% CI 2·7–5·0) of *A. arabiensis* tested were positive for *P. falciparum* (Table 3). This difference was not statistically significant (χ^2=0·31, d.f.=1, *P*=0·58). No significant difference was observed each year between *A. gambiae* and *A. arabiensis* (*P*=0·49, 0·46, 0·85 and 0·65, respectively from 1993 to 1996, using χ^2 or Fisher's exact test). Only 53 *A. funestus* were captured on human bait and tested; 2 of 28 captured in 1995 contained CSP. The average CSP rate was 3·8% (95% CI 0·5–13·0). Six and 4 mosquitoes contained *P. malariae* and *P. ovale* CSP, respectively. Two mixed infections were found in 2 *A. arabiensis* captured on human bait, one with *P. falciparum* and *P. malariae* and one with *P. falciparum* and *P. ovale*.

Entomological inoculation rates

The mean annual EIR for the 4 years was 31 infected bites per human per year. The annual EIR varied greatly; in 1993, it was 63 (95% CI [Poisson distribution] 37–97), in 1994 it was 17 (95% CI 5–35), in 1995 it was 37 (95% CI 21–61), and in 1996 it was 7 (95% 2–19). Transmission took place from July to October (Fig. 2). *A. arabiensis* was responsible for 66% of malaria transmission, *A. gambiae* for 31%, and *A. funestus* for 3%.

Discussion

There was a nine-fold variation in the malaria transmission rate depending on the year. The EIR ranged from 7 to 63, mainly due to variation in the HBR of each vector species.

Transmission was highly seasonal, occurring for only 1–4 months, depending on the year. To limit overestimation of the CSP rate, only the heads and thoraces were tested. A comparison between dissection and ELISA in 1995 showed that ELISA detected 1·5 times more positive mosquitoes than dissection (unpublished data). These results are in accordance with other studies (ROBERT *et al.*, 1998; BEIER *et al.*, 1990). Thus the mean EIR of 31 which we estimated should be considered to be a maximum value, and the mean annual transmission rate was certainly lower—about 21 infective bites per human per year.

No correlation was observed between the HBR and rainfall or temperature. However, rainfall in 1996 was lower than in previous years and the main mosquito breeding site, a temporary ground pool 1 km west of Ndiop, dried up earlier than it usually does. Only 85 mosquitoes were captured on human bait during 180 person–nights in that year (Fig. 2).

The malaria transmission pattern in Ndiop was typical of that in the Sahel–Sudanian region, as opposed to the nearby village of Dielmo, which is an exception where mosquitoes are present even during the dry sea-

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