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Effects of community-wide use of lambdacyhalothrin-impregnated bednets on malaria vectors in rural Sierra Leone

E. B. MAGBITY, N. T. MARBIAH, G. MAUDE,[1] C. F. CURTIS,[1] D. J. BRADLEY,[1] B. M. GREENWOOD,[2] E. PETERSEN[3] and J. D. LINES[1] Medical Research Centre, Bo, Sierra Leone; [1]London School of Hygiene and Tropical Medicine, U.K.; [2]Medical Research Council, Fajara, The Gambia, and [3]Department of Parasitology, Serum Institute, Denmark

Abstract. The effect of community-wide use of bednets treated with lambdacyhalothrin 10 mg/m^2 on the malaria vector *Anopheles gambiae* (forest form) was evaluated in Sierra Leone. Sixteen similar villages near the town of Bo were randomly allocated either to remain without nets or to receive treated bednets for all inhabitants, with effect from June 1992. Mosquitoes were sampled using human biting catches on verandas, light-trap catch (beside an occupied untreated bednet), window exit-trap catch and pyrethrum spray collections. During the first year of intervention (June 1992 to July 1993) the treated bednets provided personal protection for people sleeping under them, but had very little impact on densities of *An.gambiae* collected on human bait. The human blood index (HBI) of *An.gambiae* was not affected (HBI = 99% in villages with and without nets). *An.gambiae* parous rates were significantly reduced in all intervention villages, but malaria sporozoite rates fell in only some of the villages. These results are intermediate between those obtained from other projects in Tanzania and Burkina Faso, where treated bednets reduced man-biting, parity and sporozoite rates, versus The Gambia where treated bednets had no significant impact on any of these factors. Possible reasons for these contrasted findings are discussed.

Key words. *Anopheles gambiae*, malaria vector, malaria control, lambdacyhalothrin, randomized trial, bednets, mass effect, personal protection, Sierra Leone.

Introduction

The use of mosquito nets impregnated with pyrethroid insecticide such as permethrin, deltamethrin or lambdacyhalothrin, is an important advance in malaria vector control, greatly reducing malaria morbidity and mortality, especially in tropical Africa (Lengeler *et al.*, 1996). Pyrethroid-impregnated bednets act both as a physical barrier – by protecting the sleeper from mosquito bites – and as a chemical barrier – by repelling mosquitoes away from the sleeper and also killing mosquitoes that contact the nets (Snow *et al.*, 1987). The use of an impregnated bednet protects the person sleeping under it and, in some cases when used by an entire community, can result in a 'mass killing effect' on the local mosquito population –manifest as reductions in the density, parity and malaria sporozoite rate of the mosquitoes. Hence this 'mass killing effect' can benefit the entire community, even people who do not habitually sleep under a net – or are not currently using one (Curtis *et al.*, 1990).

Correspondence: Mr. Edward B. Magbity, Department of Medical Parasitology, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, U.K.

Field trials have evaluated the impact of community-wide use of pyrethroid-treated bednets on anopheline vectors of malaria, and on malaria transmission (Curtis, 1996). In some trials there has been clear evidence of a 'mass effect' on the local vector population indicated by reduced density, sporozoite rate or longevity, such as in Burkina Faso (Carnevale *et al.*, 1988; Robert & Carnevale, 1991), Ghana (Armah *et al.*, 1997), Cameroon (Le Goff *et al.*, 1992), Zaire (Karch *et al.*, 1993), Tanzania (Magesa *et al.*, 1991), Papua New Guinea (Charlwood & Graves, 1987) and China (Cheng *et al.*, 1995). In The Gambia, Kenya and Thailand, however, no such effect has been seen (Lindsay *et al.*, 1989, 1993; Thomson *et al.*, 1995; Somboon *et al.*, 1995; Mbogo *et al.*, 1996; Quiñones *et al.*, 1997): treated bednets did not seem to reduce the mosquito survival, outdoor biting rate, sporozoite rate or human blood index. The inconsistent nature of results obtained from trials in separate areas indicates that the effect of bednets on different populations of *Anopheles* depends on local circumstances. Reduction in the number of infective bites is expected to be greater in areas where mosquitoes bite indoors, late at night, even if they are not completely anthropophilic (Rozendaal, 1989). In such places with a 'mass effect' (e.g. Tanzania and Burkina Faso) the impact of treated bednets, employed by as many members of the community as possible, confers partial protection for people without nets, whereas in situations where there is no 'mass effect' (e.g. The Gambia) treated nets benefit only those who use them properly. Treated nets should therefore be targeted more selectively at vulnerable members of the community, especially young children and pregnant women, in areas where it is difficult to achieve a 'mass effect' on vector populations.

Malaria control by impregnated bednets has not been assessed previously in the rain forest zone of West Africa under conditions of perennial transmission maintained by low vector abundance. This study (Barnish *et al.*, 1993b; Petersen *et al.*, 1993; Bockarie *et al.*, 1994; Marbiah *et al.*, 1997) investigated the effect of community-wide use of lambdacyhalothrin-treated bednets on transmission of malaria in such an area. The entomological evaluation was designed to measure any 'mass effect' of the nets on the local malaria vector mosquito populations.

Materials and Methods

Study area. The study area 20–60 km northeast of Bo town (lat. 8°N, long. 12°30′W) was described by Barnish *et al.* (1993a) with a map showing villages mostly <2 km apart. The initial population of 11,157 inhabited 16 villages, ranging from 115 to 1575 people. Villages nearer Bo are ≤100 m above sea level ('lowland'); surrounding vegetation is mainly secondary palm-bush, interspersed with numerous swamps which are mostly cultivated for rice. About 40 km northeast from Bo the area rises to 320 m altitude ('highland') where the vegetation is a mixture of grassland, secondary forest and swamps. Total rainfall at Bo was 3200 mm during the 12 months from June 1992 to May 1993, mostly from May to October (wet season), followed by 6 months without rain (dry season).

Inhabitants of the study area are mainly subsistence rice farmers, Mende by tribe, who also grow ground-nuts, oil-palm, banana, cassava, coffee and cocoa. In some villages the people rear sheep, goats and pigs, which are allowed to rove around freely in the villages. Before this study, bednets were very scarce. A Knowledge Altitude and Practice (KAP) survey (E. B. Magbity and K. David, unpubl. data) showed that the people were not using bednets because of their high cost, unaffordable by most villagers.

Malaria is hyperendemic and transmission is perennial in the study area, with overall prevalence of about 60% in mass surveys of children, regardless of fever symptoms (Barnish *et al.*, 1993a, b). *Plasmodium falciparum* is the predominant species of malaria in the area. Preliminary entomological studies on the biology, ecology and distribution of the anopheline vectors of malaria were reported by Bockarie *et al.* (1993, 1994) from four of our sixteen villages. The main malaria vector is *Anopheles gambiae* Giles *sensu stricto*, forest form of Coluzzi *et al.* (1985), usually breeding in temporary pools – such as flooded pot-holes on roads, open pits and gutters, but not in swamps (Bockarie *et al.*, 1993). This vector is anthropophilic and endophagic, biting late at night (Bockarie *et al.*, 1994). Further entomological baseline data were collected from all the sixteen villages from March to May 1992, just before introduction of the bednets, showing that the lowland villages were similar to each other in respect of mosquito density, sporozoite rates and parity rates. Highland villages were all similar for these factors but had lower mosquito densities than the lowland villages.

Study design. The study design was described by Petersen *et al.* (1993). Briefly, ten lowland and six highland villages were paired on the basis of parasite and spleen rates in 0–6-year-old children, and population size. For each set of paired villages, one village was randomly allocated to receive treated nets and the other did not receive nets. In this way the residents of four lowland and four highland villages received impregnated bednets, and six lowland and two highland villages remained without nets as control.

Bednet impregnation and distribution. Bednets were made of nylon, 156 mesh per square inch (SiamDutch Mosquito Net Co., Bangkok). Three different sizes of nets were used: small (11.6 m^2), medium (14.5 m^2) and large (15.5 m^2). Bednets were impregnated with lambdacyhalothrin at a target rate of 10 mg/m^2 of net and installed in June 1992. Procedures for impregnation and distribution of the nets were described by Petersen *et al.* (1993).

Mosquito sampling. Mosquitoes were sampled monthly from June 1992 to July 1993 in each village by four collection methods (W.H.O., 1975): human-biting catches (HBC), light-trap collections (LTC), pyrethrum 'knockdown' spray catches (PSC) and window exit-trap collections (WEX). HBCs were carried out monthly in each village on the veranda of a designated house by two pairs of catchers working alternate 3 h shifts from 19.00 to 07.00 hours. LTCs were carried out monthly in three designated bedrooms per village using a CDC light-trap (Sudia & Chamberlain, 1962) operated beside an occupied untreated bednet for the whole night (Lines *et al.*, 1991; Magesa *et al.*, 1991). In each study village WEXs were fitted to three other designated bedrooms (with or without bednets) wherein PSCs were made in the morning immediately after removing the exit-traps.

Mosquito processing. All the anopheline mosquitoes caught were identified morphologically according to the keys provided by Gillies & Coetzee (1987), and their gonotrophic stage assessed. Ovaries of unfed female anophelines were routinely dissected for parity (Detinova, 1962). Freshly blood-fed female abdomens were squashed onto filter paper and the bloodmeal origin identified later by the ELISA method of Service *et al.* (1986). The head and thorax of all anophelines collected were tested for the presence of circumsporozoite antigen, by the ELISA method (Wirtz *et al.*, 1987).

Data analysis. Monthly catches from each village were log-transformed, log 10 $(x + 1)$, and subjected to analysis of variance (ANOVA) using a split-unit design by means of STATA statistical software. The effects of nets and altitude were calculated, and compared with the within-village residual. Seasonal parous and malaria sporozoite rates, and the entomological inoculation rate of malaria (EIR) representing the potential number of infective bites/person/night (Macdonald, 1957), were compared for villages with *v* without nets and lowland *v* highland villages, by Chi-square test.

Results

Mosquito density

Overall proportions of *Anopheles* species collected by different methods are summarized in Table 1, showing that *An.gambiae* predominated (>99%) in all samples. After bednets were installed in June 1992 the monthly fluctuations of *An.gambiae* density in villages with and without nets were similar in the lowland and highland villages (Fig. 1), HBC man-biting rates being consistently less in highland than in lowland villages (Table 2, F = 15.98, 1 d.f., $P < 0.0001$). Wet season densities were very much greater than dry season densities ($P < 0.0001$; Table 3).

During the wet season months (June–October 1992 and May–July 1993) of highest mosquito density, no significant difference was found in man-biting rates of *An.gambiae* between villages with and without nets ($P = 0.19$). Significantly more mosquitoes ($P < 0.0001$) were also collected per light-trap/night in lowland compared with highland villages (Fig. 3), but there was no significant difference in the number of female *An.gambiae*/trap/night between villages with and without nets ($P = 0.84$).

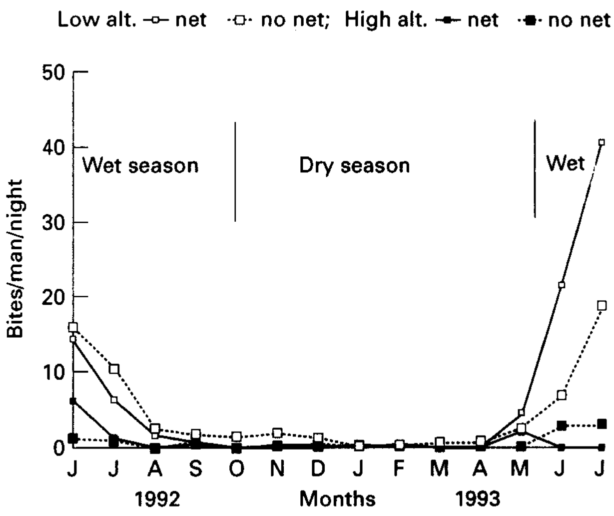

Fig. 1. Monthly geometric mean man-biting rates of *An.gambiae* in different classes of villages, during the first year of intervention, following installation of impregnated bednets during June 1992.

Table 1. Proportions of *Anopheles* spp. females caught by each sampling method.

Sampling method (see text)	Total	*An.gambiae*	*An.funestus*	Other *Anopheles* spp.
HBC	1572	99.7%	0.3%	0
PSC	2443	99.0%	0.7%	0.3%
LTC	427	99.5%	0.5%	0
WEX	427	99.1%	0.5%	0.5%
Total	4869	99.3%	0.5%	0.2%

Table 2. ANOVA table for the effect of introducing treated nets on man-biting rates of *An.gambiae* mosquitoes.

Source	Partial SS	DF	MS	F	*P*
Altitude	2.708	1	2.708	15.98	0.0001
With/without net	0.294	1	0.294	1.74	0.189
Altitude × Net × Village	2.499	13	0.192	1.13	0.333
Residual	27.62	163	0.169		
Total	33.837	178	0.190		

Endophily, exophily and personal protection

Indoor-resting densities of *An.gambiae* females during the rainy season (Fig. 4) were very significantly greater in villages without nets than in those with treated nets ($P < 0.0006$). More *An.gambiae* were caught leaving rooms without than from rooms with treated bednet (Fig. 5), but this difference of exit-trap collection was of limited significance ($P < 0.096$). Comparison

Table 3. *An.gambiae* seasonal and annual man-biting rate per night and parous rate (with 95% confidence interval, CI) in each type of village, i.e. low or high altitude, with or without bednets.

Village type		Man-biting rates (95% CI)			Parity rates (95% CI)		
Altitude	Net	Wet	Dry	Annual	Wet	Dry	Annual
Low	Yes	3.90 (1.92–7.23)	0.20 (0.04–0.39)	1.75 (0.90–2.99)	45% of 297 (39–51%)	1/3 (1–90%)	45% of 300 (39–51%)
		*3.17 (2.23–6.8)	*0.20 (0–0.47)	*1.45 (0.61–2.74)	*53% of 171 (45–60%)	*1/3 (1–90%)	*52% of 174 (45–60%)
	No	4.62 (3.06–6.79)	0.55 (0.23–0.96)	2.16 (1.4–3.17)	61% of 475 (56–65%)	75% of 32 (57–88%)	61.5% of 507 (57–75%)
High	Yes	0.95 (0.38–1.72)	0.10 (0–0.21)	0.51 (0.26–0.82)	64% of 73 (52–75%)	0	64% of 73 (52–75%)
	No	0.86 (0.26–1.75)	0.10 (0–0.36)	0.56 (0.19–1.11)	61% of 36 (44–77%)	0	61% of 36 (44–77%)

* Excluding Buma, village 8, see Table 5.

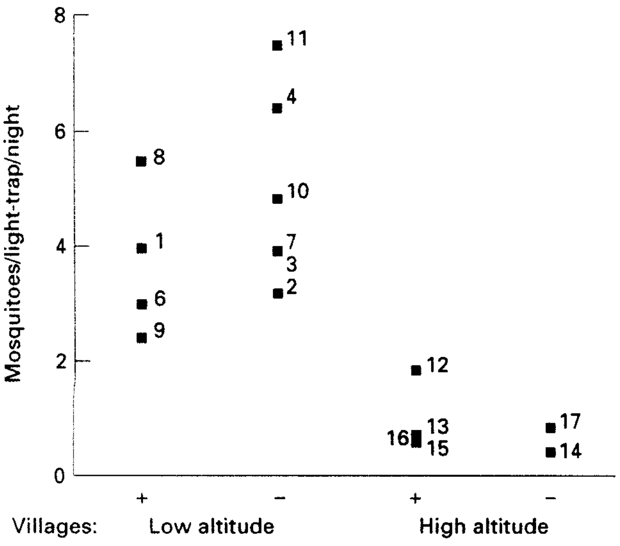

Fig. 2. Geometric mean man-biting rates of *An.gambiae* in each village with (+) or without (−) nets during the wet season, June–October 1992 and May–July 1993. See Table 5 for names of numbered villages.

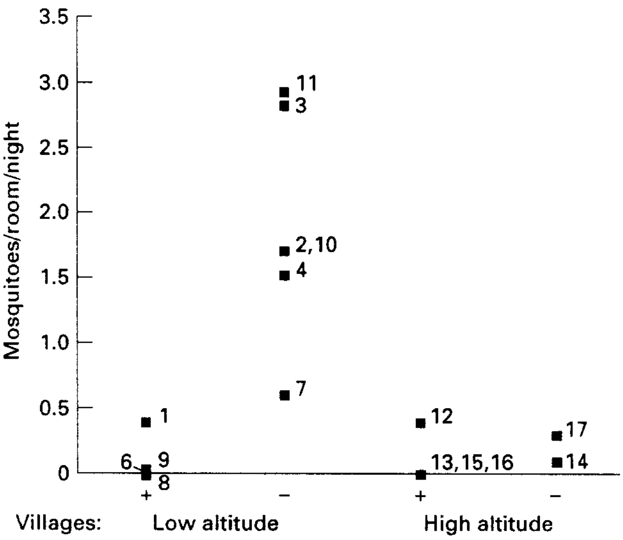

Fig. 4. Geometric mean indoor-resting density of *An.gambiae* in the different classes of villages with (+) or without (−) nets during the wet season, June–October 1992 and May–July 1993. See Table 5 for names of numbered villages.

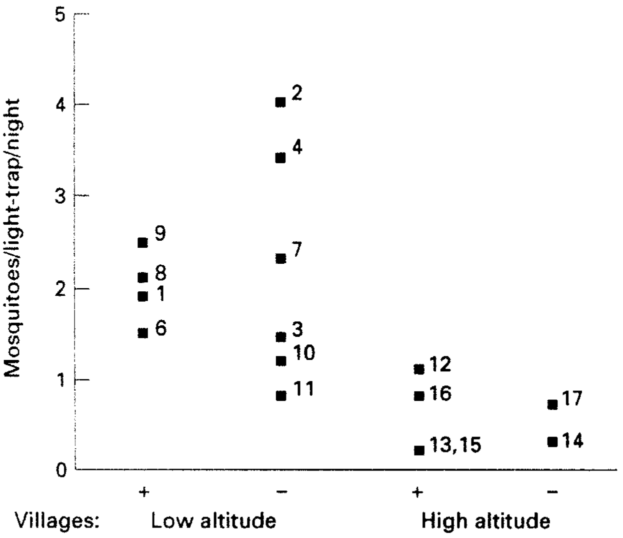

Fig. 3. Geometric mean light-trap density of *An.gambiae* in the different classes of villages with (+) or without (−) nets during the wet season, June–October 1992 and May–July 1993. See Table 5 for names of numbered villages.

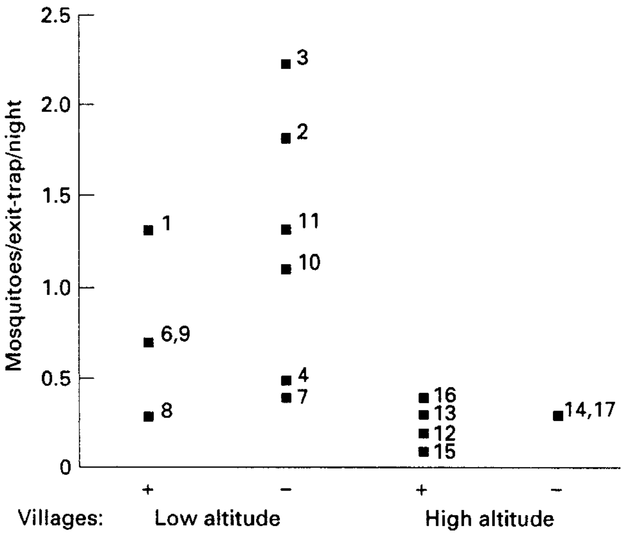

Fig. 5. Geometric mean exit-trap density of *An.gambiae* in the different classes of villages with (+) or without (−) nets during the wet season, June–October 1992 and May–July 1993. See Table 5 for names of numbered villages.

of the proportion of *An.gambiae* females exiting from rooms (Fig. 6), calculated as number in exit-trap/(no. in exit-trap + no. in spray catch), indicated a significantly greater degree of exophily from rooms with treated nets compared to rooms without nets ($\chi^2 = 11.38$, 1 d.f., $P < 0.001$).

Among 657 fed females of *An.gambiae* tested, representing all sampling methods in the villages with and without nets, 98.9% of 253 and 99.2% of 401 respectively were positive for human blood.

Survival and sporozoite rates (Tables 3 and 4)

The overall parous rate of the pooled samples of *An.gambiae* caught in villages with treated nets was 48.8% ($n = 373$), very significantly less than 61.5% ($n = 543$) in villages without nets ($\chi^2 = 14.52$, 1 d.f., $P < 0.0001$). Comparisons of parous rates among lowland villages confirmed the highly significant difference between those with and without nets ($\chi^2 = 20.87$, 1 d.f., $P < 0.0001$), but no such contrast was found between *An.gambiae*

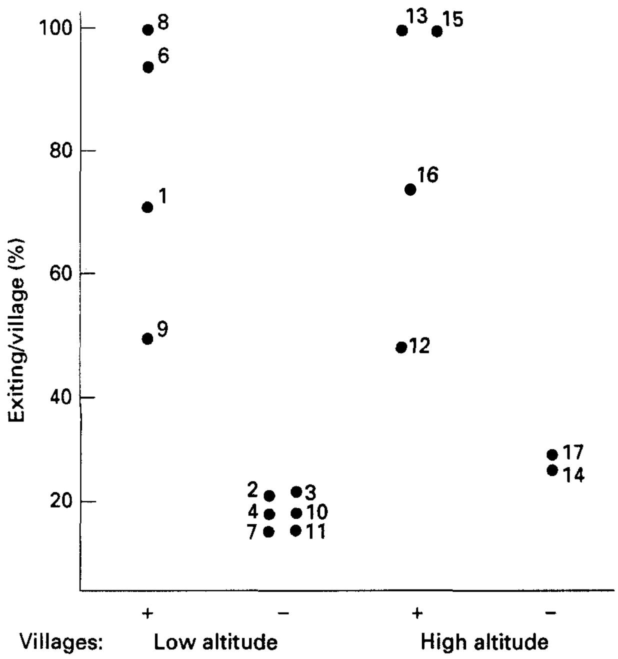

Fig. 6. Percentage of *An.gambiae* females caught exiting from rooms in the different classes of villages with (+) or without (–) nets during the first year of intervention. See Table 5 for names of numbered villages.

from highland villages with and without nets ($\chi^2 = 0.11$, d.f. = 1, $P > 0.74$) (Table 3).

During the wet season, the overall sporozoite rate in *An.gambiae* in villages with nets was 4.2%, not significantly less than the rate of 5.3% in villages without nets ($\chi^2 = 1.64$, 1 d.f. $P = 0.202$; Table 4). In the dry season, the overall malaria sporozoite rate of 9.4% for *An.gambiae* was significantly more than the rate of 5.3% in the wet season ($\chi^2 = 6.98$, 1 d.f., $P < 0.01$). Full details of mosquito density (man-biting rates), parous rate, sporozoite and the entomological inoculation rate (EIR, for each village, during the wet season, are given in Table 5.

Annual EIR values in highland villages without nets averaged 0.04, 2-fold less than 0.09 in lowland villages, whereas in villages with nets the annual EIR was only 0.003 in highlands, 31-fold less than 0.09 in lowlands. The last of these mean values was strongly affected by the Buma village (no. 8), having an exceptionally high sporozoite rate of 12%, without which the mean EIR for lowland villages with nets was reduced to 0.026, still 8-fold more than the mean EIR of 0.003 for highland villages with nets (Table 4).

Discussion

Malaria transmission in our study area is perennial, maintained by a very low abundance of vectors, mainly *An.gambiae s.s.* forest form (Bockarie *et al.*, 1993), which accounted for more than 99% of all anopheline bites on humans. For houses with treated nets, significantly fewer mosquitoes rested indoors during the daytime than for houses without nets; nocturnal exophily from rooms with treated nets (WEX collections) was also significantly greater than from those without nets, indicating that the nets had both deterrent and excito-repellent effects on mosquitoes. Thus lambdacyhalothrin treated bednets provide personal protection against mosquito bites. This finding agrees with results of (a) experimental hut studies in West Africa (Darriet *et al.*, 1984; Linsday *et al.*, 1991; Miller *et al.*, 1991), whereby less mosquitoes were found resting in huts with pyrethroid-treated nets than in those without nets; (b) field trials in Burkina Faso (Robert & Carnevale, 1991) whereby permethrin-impregnated nets caused much larger percentages of both fed and unfed mosquitoes to exit from huts; and (c) house curtain studies with marked *An.albimanus* in Mexico (Arredondo-Jiménez *et al.*, 1997) showing multiple effects of lambda-cyhalothrin-treated nets on mosquito behaviour and survival.

Our human-biting catches on verandas and light-trap collections indoors were designed to assess any possible 'mass effect' of treated bednets on mosquito biting rates (Curtis *et al.*, 1990; Jana-Kara *et al.*, 1994; Lines, 1996), but showed that the treated

Table 4. *Anopheles gambiae* seasonal and annual sporozoite rate (with 95% confidence interval, CI) and entomological inoculation rate (EIR) of malaria in each type of village, i.e. low or high altitude, with or without bednets. EIR for each village type calculated from sporozoite rate multiplied by man-biting rate (Table 3).

Village type		Sporozoite rates (95% CI)			EIR		
Altitude	Net	Wet	Dry	Annual	Wet	Dry	Annual
Low	Yes	5.1% of 724 (3.6–7.0%)	10.8% of 37 (3–25.4%)	5.4% of 761 (3.9–7.2%)	0.201	0.022	0.094
		*1.8% of 491 (0.8–3.5%)	*0/23	*1.8% of 514 (0.8–3.3%)	*0.058	*0	*0.005
	No	5.2% of 3074 (4.4–6.0%)	9.7% of 134 (5.3–16%)	4.1% of 4208 (3.6–4.8%)	0.241	0.053	0.089
High	Yes	0.6% of 183 (0.01–3.0%)	0/13	0.5% of 196 (0.01–3.0%)	0.005	0	0.003
	No	6.3% of 112 (2.0–11.3%)	12.5% of 112 (0.3–53%)	7.1% of 112 (3.1–13.6%)	0.054	0.001	0.040

* Excluding Buma, village 8, see Table 5.

Table 5. *An.gambiae* man-biting (density per man-night indoors), parous and sporozoite rates (with 95% confidence intervals, CI) and EIR* of malaria in seventeen villages during the wet season.

Village name (number code)	Altitude	Net	Man-biting rate (95% CI)	Parous rate	Sporozoite rate	EIR*
Bumbeh (1)	Low	Yes	3.97 (1.98–7.31)	57% of 66 (44.8–69.7%)	1.6% of 194 (0.3–4.5%)	0.06
Blama (5, 6)	Low	Yes	2.99 (1.97–4.36)	53.7% of 56 (44.5–68.7)	3.4% of 118 (1.1–9.9%)	0.10
Buma (8)	Low	Yes	5.47 (3.19–9.00)	34.8% of 126 (23.9–41.1%)	12% of 233 (8.1–16.9%)	0.67
Sami (9)	Low	Yes	2.42 (1.34–3.99)	47.2% of 49 (34.4–63.7%)	1.1% of 179 (2.6–5.8%)	0.03
Nengbema (2)	Low	No	3.18 (1.90–5.01)	68.1 of 69 (55.8–78.8%)	4.0% of 650 (2.6–5.8%)	0.13
Nyandeyama (3)	Low	No	3.87 (2.75–5.33)	69.6% of 60 (62.1–85.3%)	4.1% of 611 (2.7–6.0%)	0.16
Tondoya (4)	Low	No	6.44 (4.26–9.54)	61.1% of 103 (50.1–69.7%)	6.0% of 333 (3.7–9.1%)	0.39
Ngalu (7)	Low	No	3.92 (2.50–5.90)	57.8% of 45 (42.1–72.3%)	5.6% of 214 (2.9–9.6%)	0.22
Konjodorma (10)	Low	No	4.82 (3.14–7.18)	56.1% of 106 (43.6–64.8%)	3.8% of 684 (2.3–5.3%)	0.18
Kpetema (11)	Low	No	7.45 (5.30–10.35)	58.4% of 106 (44.7–64.7%)	8.9% of 582 (6.5–11.3%)	0.66
Palima (12)	High	Yes	1.84 (1.06–2.90)	–	0/65	0
Kpakuma (13)	High	Yes	0.75 (0.42–1.16)	–	1.7% of 58 (0.4–9.2%)	0.01
Njala Komboya (15)	High	Yes	0.63 (0.31–1.03)	–	0/28	0
Sahn (16)	High	Yes	0.74 (0.43–1.11)	–	0/32	0
Mendewa (14)	High	No	0.41 (0.20–0.67)	–	4.8% of 42 (0.5–16.2%)	0.02
Gumahun (17)	High	No	0.83 (0.41–1.37)	–	7.1% of 70 (2.4–15.9)	0.06

* EIR, entomological inoculation rate of malaria in each village calculated from sporozoite rate multiplied by daily mean biting rate of *An.gambiae*.

nets had no impact on man-biting rates. One would have thought that, since the *An.gambiae* was strongly endophagic and fed late at night, treated nets would have had a strong impact on vectorial capacity and malaria transmission as measured by EIR. For example, in other areas where *An.gambiae* is strongly endophagic and anthropophilic, reductions of 90% in the EIR and 94% of the man-biting rate were reported in Tanzania by Magesa *et al.* (1991), and a 34% reduction in man-biting rate was reported in Burkina Faso (Robert & Carnevale, 1991).

The lack of impact on mosquito density might be due to entomological circumstances (Quiñones *et al.*, 1997) or the relatively low dosage of lambdacyhalothrin (10 mg a.i./m^2) on the nets. In Thailand, Somboon *et al.* (1995) also used lambdacyhalothrin 10 mg/m^2 impregnated bednets giving substantial reduction of malaria incidence (Aramrattana, 1993) but found no mass effect on vector populations (mainly *An.minimus* Theobald species A). In contrast, Das *et al.* (1993) in India reported a mass effect on the biting rate of *An.culicifacies* Giles when nets were impregnated with a higher dosage of 25 mg/m^2 of lambdacyhalothrin. Similarly, Robert & Carnevale (1991) and Karch *et al.* (1993) in Africa and Huailu *et al.* (1995) in China reported mass effects on biting rates when nets were treated with 25 mg/m^2 of deltamethrin – another α-cyanopyrethroid. Apart from finding the optimum dosage for each insecticide (Curtis *et al.*, 1996), much remains to be understood about the effects of pyrethroid-impregnated bednets on various species of *Anopheles* populations, in different ecological situations with locally appropriate systems for distribution and usage of impregnated bednets (Lines, 1996).

Despite the lack of a 'mass killing effect', our Sierra Leone intervention did achieve a clear and substantial epidemiological impact: 49% reduction in clinical malaria cases (Marbiah *et al.*, 1997). This implies that the nets worked primarily by giving personal protection to the users rather than by reducing the actual density of *An.gambiae* females in relation to man, an important component of vectorial capacity (Macdonald, 1957; Garett-Jones, 1964). Since the human bait/collectors sat outdoors without treated nets, whereas most of the villagers slept indoors with treated nets, possibly there were fewer mosquitoes in treated villages but they were concentrated on the small number of unprotected hosts. The implication of such a balance between mass-killing and diversion of vectors away from treated nets was discussed by Lines (1996).

Parous rates of *An.gambiae* in villages with impregnated nets were significantly less than in villages without nets, suggesting that treated nets reduce vector survival and hence vectorial capacity. This result agrees with those from Burkina Faso (Carnevale *et al.*, 1988; Robert & Carnevale, 1991), Ghana (Armah *et al.*, 1997), Cameroon (Le Goff *et al.*, 1993), Tanzania (Magesa *et al.*, 1991) and Papua New Guinea (Charlwood & Graves, 1987). In contrast, little or no entomological impact has been detected in The Gambia (Quiñones *et al.*, 1997), Kenya (Mbogo *et al.*, 1996) or Thailand (Somboon *et al.*, 1995), despite the efficacy of pyrethroid-impregnated bednets in reducing malaria incidence in all these situations. With such an effect on mosquito survival rate in the lowland villages, a reduction in malaria sporozoite rates would have been expected in villages with impregnated nets, but our results are rather ambiguous as to whether such a reduction actually occurred. If the village of Buma (no. 8) is excluded from consideration, a clear effect is apparent: of the fifteen remaining villages, the seven lowest sporozoite rates were all in villages with treated bednets and the eight highest in non-intervention villages. On the other hand, Buma, a treated village, had a sporozoite rate of 12%, by far the highest sporozoite rate of all. No firm conclusion is therefore possible, but on balance the evidence suggests that sporozoite rates were reduced in most villages.

The results obtained in this trial are unusual because the reductions in parous and sporozoite rates in most treated villages were not accompanied by a reduction in mosquito density. If there was a 'mass killing effect' on *An.gambiae* populations, at least in some treated villages, it was detectable only in measures of longevity, and not in measures of density. Hence our results with lambdacyhalothrin-impregnated bednets are intermediate between those obtained with permethrin-impregnated bednets against Afrotropical malaria vectors in (a) Tanzania and Burkina Faso, where the impact was on density as well as parous and sporozoite rates, and (b) The Gambia and Kenya, where treated nets do not seem to affect any of these factors.

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