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GEOGRAPHICAL PERSPECTIVES ON BEDNET USE AND MALARIA TRANSMISSION IN THE GAMBIA, WEST AFRICA

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Abstract—Insecticide-impregnated bednets are now widely accepted as an important tool in reducing malaria-related deaths in children in Africa. Defining the circumstances in which net treatment programmes are likely to be effective is essential to a rational development of this control strategy. In The Gambia a National Impregnated Bednet Programme was introduced into the primary health care system in 1992. Prior to its introduction baseline epidemiological and entomological studies were conducted throughout the country. These studies showed that in areas where mosquito biting nuisance was high, people protected themselves with bednets and that where mosquito densities (and therefore bednet usage) was low malaria prevalence rates were relatively high. Since the national programme is designed to assist only those people who already own a bednet (by providing the insecticide) an understanding of the factors which determine bednet ownership is needed to help evaluate the programme's effectiveness and provide guidelines for increasing bednet usage. Village scale bednet usage rates and malaria prevalence rates obtained from the baseline survey were correlated with certain geographical variables: dominant ethnic group, area, habitat, distance from the River Gambia and distance from the 'bluffline' (the interface between the sandstone soils and alluvial soils which border the river system). In a multiple regression analysis, bednet usage was independently associated with area ($P < 0.001$), ethnic group ($P = 0.010$), habitat ($P = 0.006$) and distance from the river ($P = 0.013$). A negative association of bednet usage with malaria prevalence persisted after allowing for the other variables. Malaria prevalence was not independently associated with area, ethnic group, habitat or distance from the river. Our analysis showed that the impregnated bednet programme is likely to be most effective in villages which are sited near to or on the alluvial soils in the middle and lower river zones. These villages, which were originally settled for easy access to the river (for transport) and its swampy margins (for rice production) are within the flight distance of mosquitoes that have their breeding sites on the poorly drained alluvial soils. Variation in malaria prevalence rates (after bednet usage has been taken into account) may be related to factors such as poverty and access to health care, and/or to localized differences in the ecology of The Gambia, which determine the duration and intensity of transmission. If the National Bednet Programme is to be effective throughout The Gambia it is vital to develop promotional activities which will encourage bednet usage in areas where nuisance biting by mosquitoes is low. Copyright © 1996 Elsevier Science Ltd

Key words—malaria, *Anopheles gambiae*, The Gambia, impregnated bednets, rice

INTRODUCTION

In sub-Saharan Africa the pattern of malaria transmission varies markedly from region to region, depending on climate and biogeography and broad ecological categories have been widely used to describe variation in the observed epidemiological patterns [1–3]. Local stratification for improving the planning and evaluation of malaria control programmes has been widely promoted [4, 5] but only occasionally undertaken in practice [6].

The Gambia (one of the smallest countries in Africa) is located on the most westerly section of the west African coast. Its territory stretches inland, along the banks of the River Gambia and largely consists of flat woodland savanna and riverine swamps. Despite its small size and relative geographical homogeneity, major differences in the prevalence of malaria have been noted in different rural areas of The Gambia by surveys undertaken in recent years. An extensive range of genetic, environmental and behavioural factors may be involved in determining these differences [7]. Understanding the key factors involved is an important prerequisite to effective evaluation of malaria intervention programmes. The success or otherwise of a programme may depend heavily on localized differences in one or two important variables.

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In recent years, the community-based use of insecticide-treated bednets for malaria control has been widely promoted by the World Health Organisation (WHO) and others [8] as a control method which can be delivered via the primary health care (PHC) systems operating in endemic countries. This approach has been pioneered in The Gambia where the British Medical Research Council Laboratories (The Gambia) undertook a series of trials which demonstrated the effectiveness of this technique in reducing child morbidity [9–11] and mortality [11]. These studies were either conducted in villages where the proportion of people sleeping under a bednet was normally very high (over 90%) [11] or where bednets had been provided to the village population prior to the study [9, 10].

In view of the success of these studies and the fact that at least 25% of the high mortality rates found in Gambian children (aged 1–4 yr) are attributed to malaria [12] the Gambian Government introduced a National Impregnated Bednet Programme (NIBP) into the PHC system of The Gambia in 1992. The NIBP aims to treat all the bednets belonging to residents of PHC villages with an insecticide at the beginning of the rainy season.

Whereas bednets have been used for at least a century in The Gambia [13], there is considerable variation in their adoption by different communities. Early studies suggest that differences in bednet usage are, at least in part, related to ethnic group. MacCormack and Snow [14] found that nearly all Mandinka families in their study area used bednets, while very few Wolof or Fula families did so. They suggested that, amongst the Mandinka, the need for privacy in polygamous households was a major inducement for using bednets—which were often used throughout the dry season when mosquito densities were low [15]. Opaque white sheeting is the preferred material for bednets [14] which are frequently found for sale in the local markets.

A national bednet survey conducted before the implementation of the NIBP revealed that approximately 60% of beds in the rural areas had an associated bednet but there was considerable regional variation—with highest net usage being found in the centre of the country [16]. Surprisingly the national study revealed little difference in bednet usage between ethnic groups, with Wolofs and Fulas having an overall rate of 56% and 55% respectively. In a survey designed to elicit information on people's perceptions of malaria (and associated methods of prevention and treatment) 99% of rural Gambian respondents cited protection from mosquito bites as the main reason for possessing a bednet. However, only 25% of these respondents associated mosquitoes with malaria [13]. Surprisingly the authors of this study were unable to show any relationship between bednet ownership and income, education or occupation.

Significant variations in the prevalence of malaria and splenomegaly have been found among members of the three main ethnic groups resident in The Gambia. In a study conducted in the North Bank Division (note—area II in our study) it was found that, among young children, splenomegaly and malaria were less prevalent in Mandinkas than in Wolofs or Fulas, suggesting that some genetic or environmental factors protect Mandinka children from malaria infection. Among older children and adults splenomegaly was found most frequently in Fulas [17].

There is some evidence that conventional bednets are effective at reducing malaria in children who sleep under them. Two retrospective studies on untreated bednets in The Gambia demonstrated a reduction in parasite and spleen rates in children who slept under bednets when compared with children who did not [18,19]. However, the interpretation of these results was made difficult by the confounding effects of geographical variation in ethnic group and bednet usage. A significant reduction in malaria in children sleeping under conventional nets in The Gambia has since been observed in a much larger study [20]. However, despite their protective effect, the benefits of insecticide-treated bednets over untreated bednets in reducing malaria morbidity and mortality is now well documented [9–11, 20, 21].

In 1991, before the introduction of NIBP, the Medical Research Council Laboratories (The Gambia) undertook baseline epidemiological and entomological studies in order to provide data for the subsequent evaluation of the effectiveness of the NIBP. One hundred and four study villages, from five study areas were involved in different aspects of the baseline study (Fig. 1).

The results of the 1991 baseline study showed that malaria prevalence and intensity varied considerably from area to area, with children from villages in the east (areas IV and V) of the country having the highest malaria parasite and spleen rates and the lowest packed cell volume [22]. Considerable variation was also found between areas in terms of the mosquito vectors—with significant differences in vector density, species composition, infection with *Plasmodium falciparum* sporozoites and human blood index (a measure of the propensity of vectors to bite humans as opposed to animals). Whilst mosquito abundance was highest in areas II and III, the sporozoite rate and human blood index were highest in areas IV and V, where malaria transmission was more intense [22].

Two important observations made from these baseline studies were that there is: (i) a highly significant positive correlation between bednet usage (the proportion of beds in villages that had a net) and mosquito vector densities ($r = 0.89$, $n = 8$, $P < 0.003$) in the entomology study villages (Fig. 2); and (ii) a significant negative correlation ($r = -0.6102$, $n = 42$,

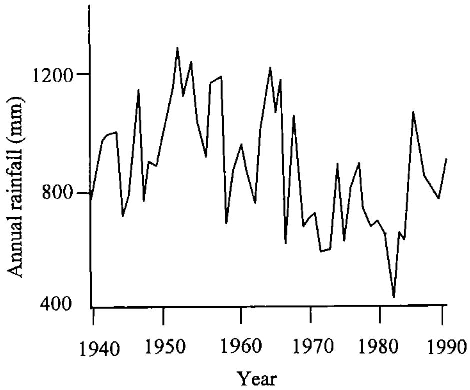

Fig. 4. Annual rainfall at Georgetown (Area III) from 1940–91. (Redrawn from Rawlings *et al.*, 1993 [42].)

pronounced reduction in average annual rainfall—c. 800 mm (Fig. 4).

The geomorphology of The Gambia is dominated by the River Gambia which meanders through it, east to west, for approximately 485 km. The Gambia is part of the tertiary continental terminal plateau which in the east forms extensive surfaces dissected by rather narrow valleys. This sandstone plateau dips gently westwards and becomes progressively more dissected so that in most of the west of the country the landform comprises a series of low gently sloping, sandstone interfluves with associated broad alluvial valleys [23]. The soil structures throughout The Gambia can thus be broken down into two main groups: the tertiary ferruginous sandstone 'groundnut' soils and the pleistocene–recent river alluvium deposited along the River Gambia and its drainage network—with the border between these groups being termed the 'bluffline' [24] (Fig. 5).

Flow in the River Gambia is highly seasonal and dependent on precipitation within its catchment area in the Futa Jallon highlands of Guinea. The river is extremely flat and therefore tidal throughout its last 500 km. Consequently it is subject to salt water intrusion—the 'salt front' moving up and down the river during the course of the year. The front is at its highest in the late dry season (June) and at its lowest at the end of the rainy season (October). The tidal characteristics of the river, with its seasonal flow of freshwater from its catchment area, and the changing form of the river banks along its length, allow lands bordering the river to be categorized into three main ecological zones which grade into one another [25] (Fig. 5).

The Lower River Zone

The ecology of the first 180 km from the mouth of the river is dominated by the salinity of the water. Along these lower reaches the river borders consist of low-lying alluvial terraces which are subject to tidal flooding and, below 110 km, their high salt content makes them generally unsuitable for cultivation. The lower river has a number of large channels (bolons) which act as a drainage network for the river. Tidal agriculture, which is possible upstream beyond the 110 km point, depends on the extent to which rainfall and river flooding are able to wash salt from the fields and suppress the saltwater front.

The Middle River Zone

Above 180 km there is, generally, freshwater throughout the year. Traditional tidal rice agriculture is practised most extensively between 180 and 290 km where the river borders consist of marshy, inter-tidal, flatlands.

The Upper River Zone

In the east of the country, from 290 km upriver, the river banks rise and distinct elevated levees isolate poorly drained alluvial basins along the border of the river and the edge of its previous course. Flooding of

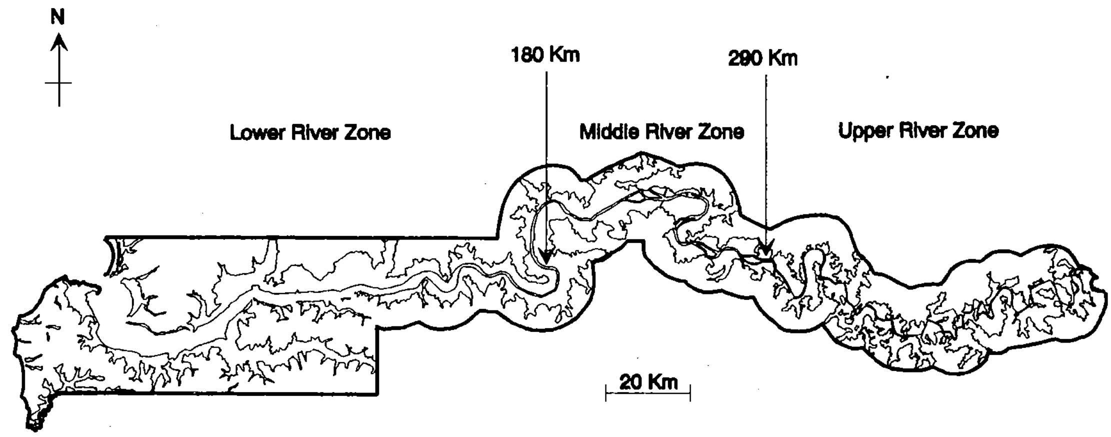

Fig. 5. Map of The Gambia indicating the bluffline (alluvial soils bordering the River Gambia and drainage network) and the three ecological zones of the country (lower river zone < 180 km; middle river zone > 180 km < 290 km; upper river zone > 290 km).

the banks has become more and more confined to exceptional high tides.

Vector population

Malaria in The Gambia is transmitted predominantly by anopheline mosquitoes that belong to the *Anopheles gambiae* Giles species complex. Three members of the complex have been identified from The Gambia [26]: (a) the salt water species *An. melas*, a relatively poor vector, which breeds abundantly in the estuarine mangrove swamps bordering the lower reaches of the River Gambia; (b) the highly anthropophilic freshwater species *An. gambiae* s.str. (known to be the most important malaria vector in Africa [27]) and is widely distributed throughout the Gambia during the rainy season; and (c) the freshwater species *An. arabiensis* (which tends to prefer drier habitats to *An. gambiae* s.str., and is more zoophilic in its feeding habits [27]) has been recorded in highest numbers in the east of the country [26].

Human population

The population of The Gambia is made up largely of the following ethnic groups: Mandinka (40%); Fula (19%); Wolof (15%); Jola (10%); Serahuli and others (16%). The majority of the population live in the rural areas, where their main occupation is farming during the agricultural season and trading during the long dry season. Rice cultivation is important as a food source and as a cash crop and traditional rice farming is extensively practised in the inter-tidal margins of the lower and middle river zone. The Mandinka are the dominant rice growers in The Gambia but this crop is also widely grown by Serahuli and Jola communities [28]. The Fulas are the major group of cattle owners and herdsmen in The Gambia and are often employed on a contract basis by other tribes [28, 29]. The heaviest concentration of Gambian Wolofs is on the north bank of the middle river zone where they neighbour a large Wolof block across the Senegalese border. Their main agricultural interest is groundnut production as a cash crop [30].

Before the post-World War II urban expansion in the coastal areas the upper river zone was the most densely populated part of The Gambia. The high population density was partly attributed to the fact that there tended to be fewer 'dangerous insects' (mosquitoes and tsetse flies) present in the east where the high river banks reduced the amount of seasonal flooding [24].

In the early part of this century those villages that were located between the 110 and 290 km river mark were mainly located along the bluffline. This was in order to reduce the cost of transporting the dominant cash crop, groundnuts (which are grown on the sandstone soils) to the river barges for ferrying to the coast [24].

The low population density in the middle river zone changed dramatically in response to the Government's expansion of traditional swamp rice cultivation in this area during the 1950s. Villages relocated to the area and settled on the borders of the alluvial soils where swamp rice farmers could take advantage of the 150 km of new causeways that had been built to improve access into the swampy areas [25]. In particular there was a pronounced shift of the Mandinka population into the areas along the river, especially in the lower-middle river zone [24].

Good rainfall in the river's catchment areas during the 1950s and 1960s (Fig. 4) resulted in substantial increases in yields of swamp rice—this was in part due to the rainfall producing strong flows which pushed back the salt front. The decrease in annual rainfall which began in the 1970s again forced farmers to re-adjust their agricultural interests and the government began to consider ways of achieving large scale industrial rice production. Shifts in agricultural practices were most noticeable in the east of the country where rain-fed rice production had been widespread. In the 1980s there was a switch from rice to groundnut and coarse grain production in the upper river zone [31].

The Gambia is subject to cyclical variation in rainfall levels and this will play a major role in determining not only mosquito abundance and species but also host behaviour. The effect of low rainfall on malaria transmission in The Gambia has been well documented in Keneba, a small village bordering the alluvial soils in area II [32]. The exceptionally low rainfall levels in the early 1970s were associated with a marked reduction in malaria parasitaemia and spleen rates in all age groups. Total rainfall in the River Gambia catchment area will determine the amount of river flooding and therefore the extent of the breeding sites in the inter-tidal zone. However, the distribution of rainfall, within a season may be of more direct relevance to local rain-fed mosquito breeding sites in the upper river zone, than the total rainfall, since small rainfed pools are highly susceptible to drying out.

MATERIAL AND METHODS

Study villages

One hundred and four PHC villages (total population approximately 115,000) from five study areas (chosen to be representative of different geographical areas in The Gambia) were involved in different aspects of the study. Areas I and II were situated on the south and north bank of the lower river zone, area III on the south bank of the middle river zone and areas IV and V on the north and south bank of the upper river zone (Fig. 1).

A census of the study population (104 villages) was carried out in March 1991 in which information was obtained on all individuals resident in study villages (including ethnic origins and whether or not they slept under a bednet). Villages were classified according to the dominant ethnic group (usually over 80%).

If no ethnic group reached 50% or more of the population the village was classified as 'mixed'. The proportion of beds with associated nets for each study village was calculated.

A cross-sectional clinical survey was undertaken in November–December 1991 using cluster sampling. Malariometric indices (including parasite rates, spleen rates and packed cell volume) were assessed in 30 randomly sampled children (aged 1–4) from each of 42 study villages selected from the five study areas. Longitudinal monitoring of the main malaria vectors in The Gambia throughout the rainy season (including population densities, species composition and infection with *Plasmodium falciparum* parasites) was undertaken in two ecologically comparable villages from each study area, using standardized collecting methods [33]. Mosquito densities were assessed from fortnightly collection of indoor resting and indoor feeding mosquitoes in 16 study bedrooms from each village using pyrethrum spray and exit trap catches. Detailed description of the methodologies and overall results of these studies are given elsewhere [20, 22, 34].

Geomorphology and ecology

An aerial photographic survey of the study villages and their surrounding environments was conducted in August 1991. A Brittan-Norman Islander aircraft flew the length of the country at an altitude of 1000 ft. The photographs and a verbal log were subsequently used to produce maps of the various study villages and their environs and, along with the map—Geology and Mineral Resources of The Gambia [35]—were used to classify the geological environment of each village as being (a) alluvial and (b) sandstone. Since alluvial soils are more likely to retain surface water than sandstone soils we made the assumption that they are more likely to provide mosquito breeding sites. Given that the normal flight distance of *An. gambiae* s.l. is known to be relatively short, villages sited on sandstone soils were divided into two classes: those that were sited close to the bluffline (close to the alluvial soils) and those sited further away. The distance of 2.75 km was chosen to separate these two classes on the basis that the majority of *An. gambiae* s.l. fly within this distance [36, 37]. The coordinates of each village were determined from the Ordinance Survey Map 1976 (1:250,000 scale) and their distance from the bluffline and the border of the River Gambia were recorded.

Statistical methods

A multiple regression analysis was used to ascertain the importance of different variables (study area, ethnic group, habitat, distance from the river) in determining bednet usage and malaria prevalence. The P values shown are thus for the independent effect of each of these variables after allowance for area and also for each other. This analysis did not take account of spatial autocorrelation. To assess the possible importance of spatial effects we have expressed the observations on a variable as differences between pairs of villages, calculated for each possible pair, and formed these into an $(n) \times (n)$ distance matrix where (n) is the number of villages. Association between the variables of interest, adjusting for confounders including spatial distance, is then assessed by multiple regression using the elements of the distance matrices as the data [38]. A significance test is obtained by comparing with the randomization distribution produced by randomly permuting the villages (based on 4999 randomizations plus the original data). The coefficient of distance between villages obtained in this study was not significant for either bednet usage or malaria prevalence and therefore it was concluded that autocorrelation was not an important factor in the results presented.

RESULTS

The rains began first in the east of the country (areas IV and V) on 4th June, exactly a month before their arrival at the coast. Relative humidity increased rapidly in all areas with the onset of the rains. Mean daily temperatures were higher inland than on the coast (Fig. 6).

Bednets were found in all villages surveyed (104) although the percentage of beds with nets in a village varied from 1–99%. Malaria infection was also found in sample children from all villages investigated (42) and the prevalence rates varied from 1–89%.

The relationship between bednet usage and malaria prevalence with numeric variable (vector densities, distance from the river and distance from the bluffline) and categorical variables (study area, ethnic group and habitat) are presented in Figs 7 and 8, respectively.

As reported earlier, a highly significant relationship was observed between vector densities and bednet usage and an inverse relationship between bednet usage and malaria prevalence. There was a negative correlation between bednet usage and distance from the bluffline for all villages sited on sandstone soils ($r = -0.69$, 33 *df*, $P < 0.001$) which persisted after adjustment for area, ethnic group and distance from the river—but the data does not suggest a linear relationship. Nearly all villages with a high bednet usage were sited either on the alluvial soils or within 2.75 km of the bluffline. It was therefore considered that categorizing the villages by 'habitat' is more appropriate for further analysis.

In a multiple regression analysis, bednet usage was independently associated with area ($P < 0.001$), ethnic group ($P = 0.010$), habitat ($P < 0.006$) and distance from the river ($P = 0.013$). Mean bednet usage was higher among the Mandinka (66.2%) and lowest among the Wolof (44.0%). Usage was higher in the middle river zone in area III (77.7%) where swamp rice production is most extensive and lowest

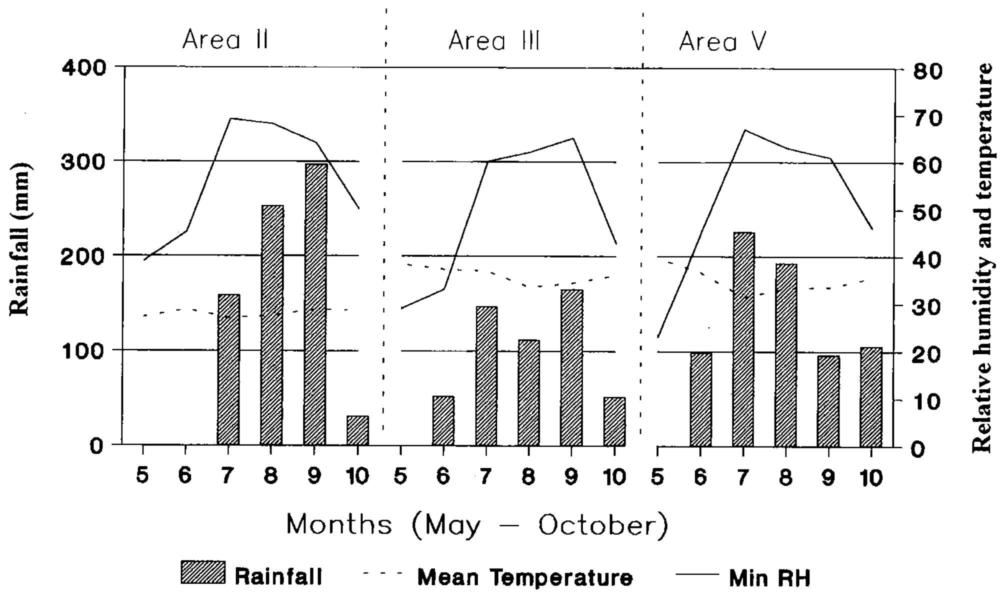

Fig. 6. Monthly meteorological data: rainfall (mm) relative humidity (%) and temperature (°C) from three weather stations (Keneba: area II; Sapu: area III and Basse: area V) in The Gambia for the rainy season of 1991. Data obtained from the Water Resources Department, Banjul.

in areas IV and V (49.8% and 43.7%, respectively) where high river banks diminished the frequency of river flooding. However, both ethnic group and study area showed considerable variation. In the lower and middle river zones mean bednet usage on sandstone soils >2.75 km from the bluffline (14.2%) was significantly lower ($P < 0.001$) than that on either sandstone <2.75 km (72.0%) or alluvial soils (92.0%).

Differences in the relationship between habitat type, distance from the river and net usage were found between villages that were sited in the different ecological zones. In the lower and middle river zones habitat was the most important determinant of bednet usage. This is most clearly seen in area II (Fig. 9), where villages in which bednet usage was high were invariably sited along the bluffline. In this area there was no independent association between bednet use and distance from the River Gambia—presumably because many villages were sited closer to bolons (tributaries) than the main river. In the upper river zone (areas IV and V) only 5 out of 51 study villages were sited on the sandstone >2.75 km from the bluffline. In this region there was no significant association with distance from the bluffline in villages sited on the sandstone soils, but a significant negative association of bednet usage with distance from the River Gambia ($r = -0.57$, 46 df, $P = 0.001$) in all villages.

The distribution, by study area, of villages dominated by one or other ethnic group also shows considerable variation. Mandinka villages were included in all study areas, whereas all Wolof villages were found in areas II and III and Serahuli villages dominated area V. In the lower river zone where the river floods extensively during the rains no villages were sited on the alluvial soils. In the middle river zone 11 out of 21 villages investigated were sited on alluvial soils, whereas in the upper river zone, where river flooding is diminished by the high river banks, most study villages (46 out of 51) were sited on or near the alluvial soils.

Differences in village habitat were found between ethnic groups. Only 2 out of 40 Mandinka villages were sited away from the bluffline on the sandstone soils as was 1 out of 25 Serahuli villages. In contrast 8 out of 15 Wolof villages were sited on the sandstone more than 2.75 km away from the bluffline.

The negative association of bednet usage with malaria prevalence reported earlier persisted after allowance for ethnic group, area, habitat and distance from the river in a multiple regression analysis. In this analysis malaria prevalence was not independently associated with area, ethnic group, habitat or distance from the river.

DISCUSSION

The NIBP in The Gambia has been set up to deliver a malaria vector control programme to the rural areas that can be implemented via the PHC system. Before the inception of the NIBP a controlled trial of permethrin impregnated bednets undertaken in The Gambia had shown that, when combined with chemoprophylaxis, this technique could reduce child mortality in children aged 1–4 yr by 63%, clinical attack by 52% and parasitaemia by 39.5% [11]. It was hoped that these impressive results could be repeated throughout the PHC villages on a national scale. Since the programme only intended to provide insecticide for net dipping (and not provide nets) it was based on the assumption that bednets are widely used throughout the country in areas where malaria is an important determinant of child morbidity and mortality.

In a previous paper [22] we have shown that there is an inverse relationship between mosquito vector density and malaria prevalence rates in The Gambia. This unexpected relationship can, at least in part, be explained by the fact that people who experience high mosquito biting densities protect themselves with bednets. In the rural areas of The Gambia *Anopheles gambaie* s.l. is often the dominant night-time nuisance biting mosquito and high vector densities are correlated with high numbers of Culicines [22]. From this result it might be inferred that the NIBP in its present form is likely to be least effective in areas where malaria transmission is relatively high since it is in these areas that bednet usage is lowest.

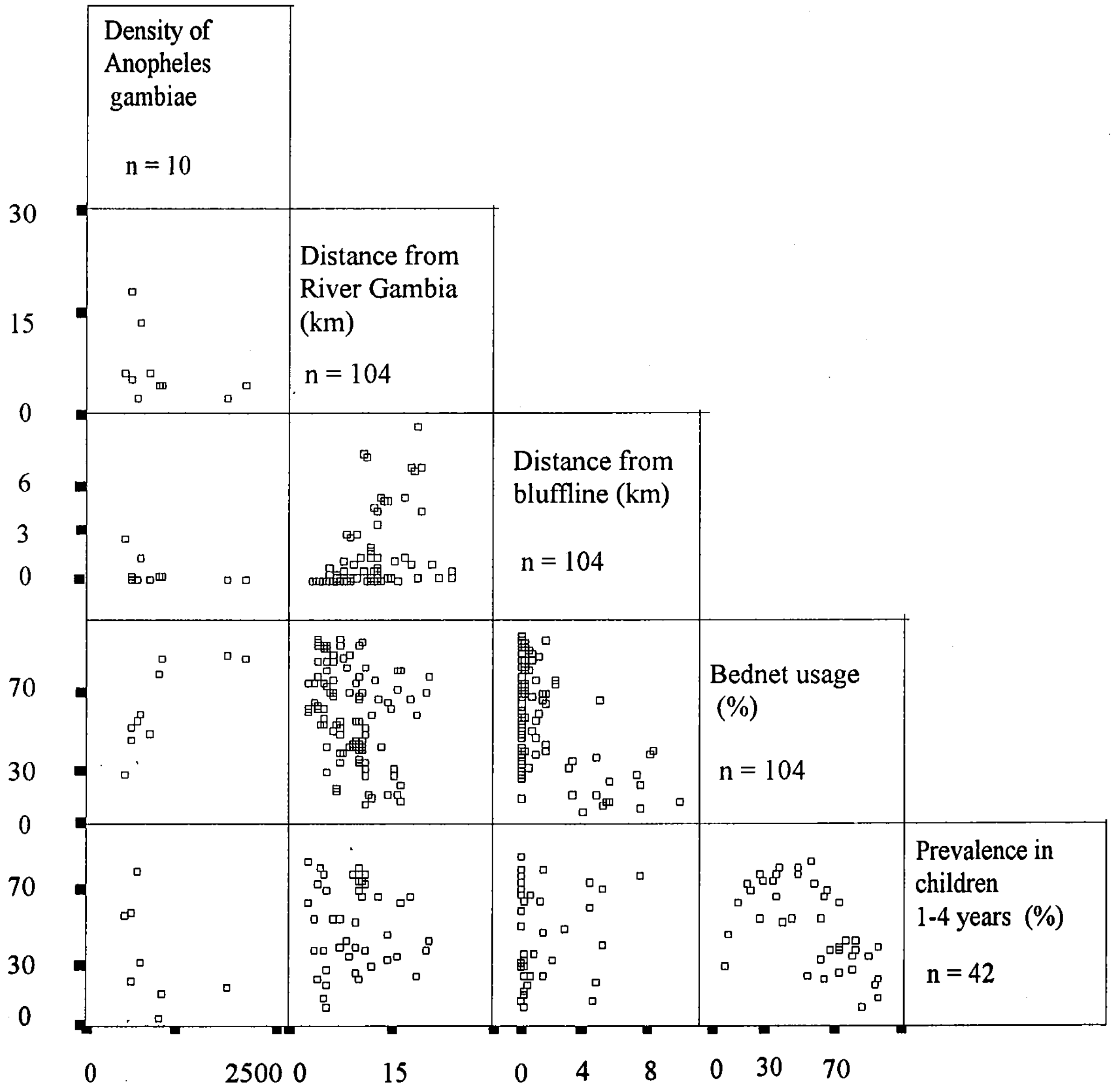

Fig. 7. Scatter diagrams showing interrelationships between: (a) Bednet usage (% of beds with nets per village); (b) Malaria prevalence rates (% of children, 1–4 yr, with malaria parasites from sample of 30 children per village); (c) Vector density (mean number of indoor resting *An. gambiae* s.l. room per village per season); (d) Distance from the River Gambia (km); and (e) Distance from the bluffline (km) (all villages on alluvial soils are classified as 0).

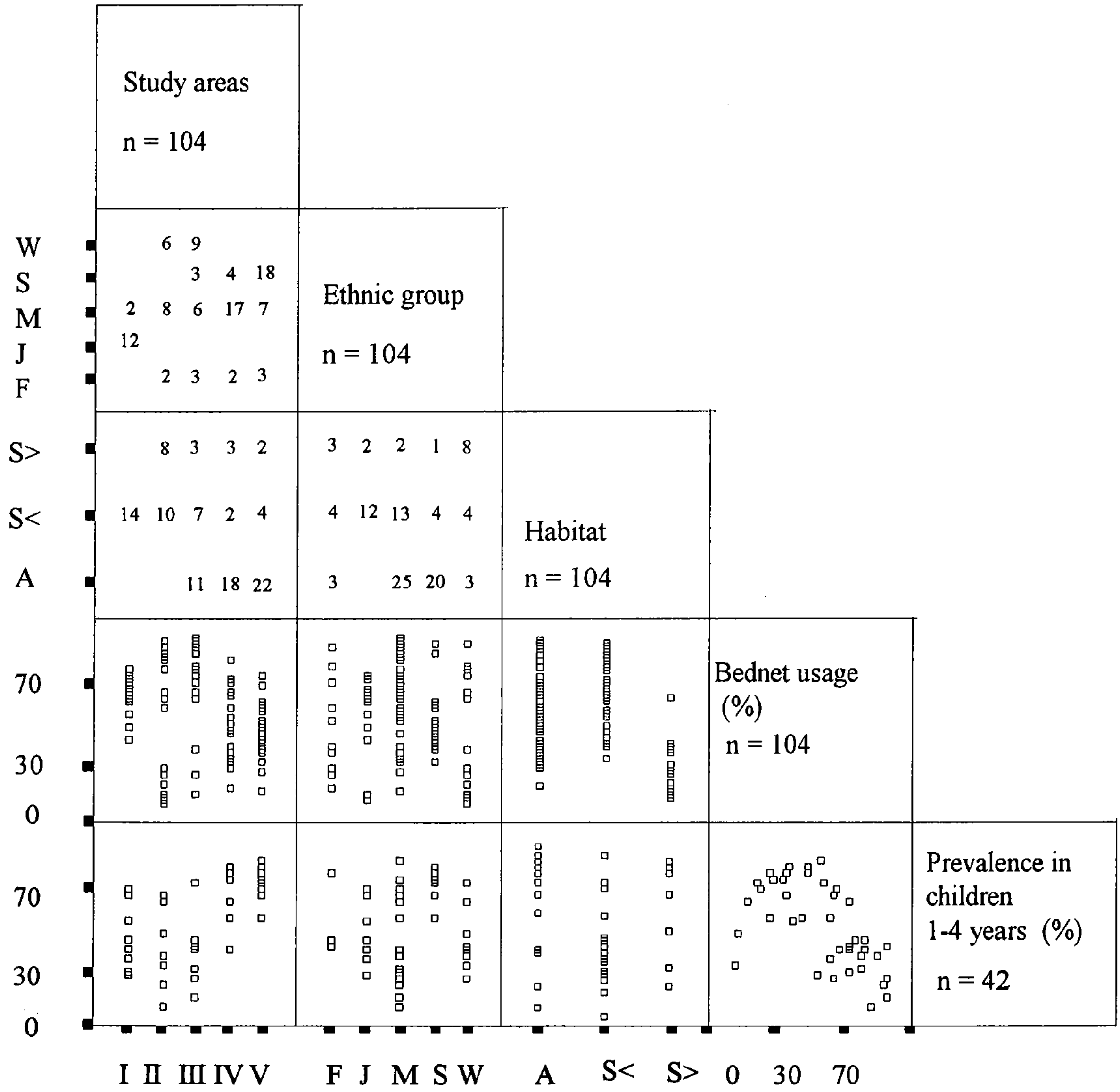

Fig. 8. Scatter diagrams showing interrelationships between: (a) Bednet usage (% of beds with nets per village); (b) Malaria prevalence rates (% of children, 1–4 yr, with malaria parasites from sample of 30 children per village); (c) Study areas (I, II, III, IV and V); (d) Dominant ethnic group (W = Wolof; S = Serahuli; M = Mandinka; J = Jola; and F = Fula); (e) Habitat type (A = alluvial; S< = Sandstone < 2.75 km of bluffline; and S> = Sandstone > 2.75 km of bluffline).

In line with previous work [39] we found a strong relationship between bednet usage in villages and their distance from the river. However in the lower and middle river zones this relationship disappeared when the correlation was controlled for distance from the bluffline. It appears that, in the lower and middle zone of The Gambia, bednet usage is highest in villages that are settled within the flight distance of mosquitoes, whose breeding sites can be found on the alluvial soils which follow the present and previous course of the River Gambia and its associated drainage network. While habitat is still a significant determinant of bednet usage in the upper river zone, the increase in height of the river banks beyond the 290 km river mark means that the alluvial soils bordering the river are only flooded at very high tides. Here the alluvial soils are probably better drained further from the river as the land tends to be higher. Bednet usage was independently associated with ethnic group and this reflects the historical settlement patterns of different communities in response to their economic interests.

From our analysis we conclude that malaria prevalence rates in Gambian children are not

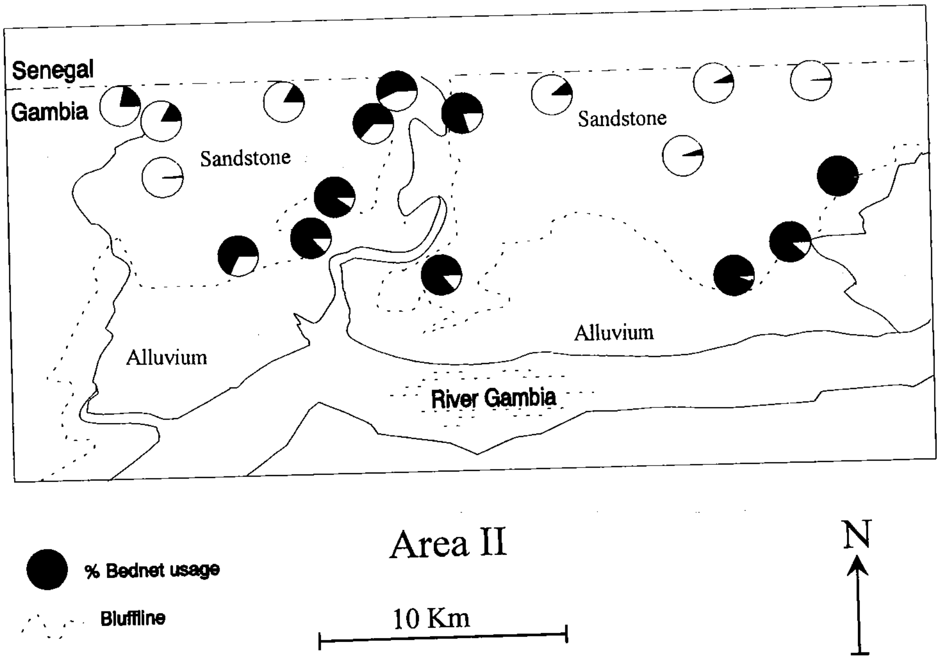

Fig. 9. Bednet usage (filled portion of circle indicates %) and position of study villages in area II in relation to distance from the bluffline and distance from the River Gambia.

independently associated with the area, ethnic group, habitat or distance from the river. They are however, inversely related to bednet usage, which is itself largely determined by nuisance mosquito biting. The latter is associated with the siting of villages near to productive mosquito breeding sites, which in turn is a consequence of the economic interests of different communities. Since both mosquito densities and agricultural practices are affected directly by climate, one might expect changes in rainfall (both quantity and distribution) to have an important influence on malaria transmission in The Gambia.

The spatial analyses of the village-based data has revealed the importance of habitat, bluffline and distance from the river in determining use of bednets in the study villages. The differences in bednet usage between villages are readily explained by factors which can be directly associated with our knowledge of the Gambian ecology and its effect on mosquito populations. In contrast, explanations for the differences in malaria prevalence within areas, once bednet usage is taken into account, are not so apparent. Perhaps it relates to other human factors—such as poverty, access to health care and/or localized ecological differences—which affect the longevity (and hence infectivity) of the vector, the length of the transmission season or the availability of alternative hosts.

The localized stratification of regions according to their malaria transmission dynamics has become a widely accepted prerequisite for developing malaria control programmes which are appropriate to their different epidemiological contexts [5]. In the context of insecticide impregnated bednet programmes, it becomes important to stratify the seasonal and spatial variation in bednet usage in the target region. In The Gambia, where malaria transmission is confined to the rainy season [40] when maximum net usage occurs, spatial variation in net usage seriously limits the programme's effectiveness [14]. In countries where transmission occurs throughout the year, but increases in the rainy season(s) seasonal variation in net usage may also seriously limit the potential impact of a net treatment programme [41].

Insecticide-impregnated bednets are now widely accepted as an important tool in reducing deaths among children in Africa. Defining the circumstances in which net treatment programmes are likely to be effective is essential for a rational development of this control strategy. It should now be a priority to determine the promotional activities needed to encourage bednet usage (and treatment) in areas (or where appropriate—during periods) of low-nuisance mosquito biting, since this will greatly increase the number of participants who could then benefit from a bednet treatment programme.

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