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Sleeping arrangements and mass distribution of bed nets in six districts in central and northern Mozambique

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Abstract

OBJECTIVE Universal coverage with insecticide-treated bed nets is a cornerstone of modern malaria control. Mozambique has developed a novel bed net allocation strategy, where the number of bed nets allocated per household is calculated on the basis of household composition and assumptions about who sleeps with whom. We set out to evaluate the performance of the novel allocation strategy.

METHODS A total of 1994 households were visited during household surveys following two universal coverage bed net distribution campaigns in Sofala and Nampula provinces in 2010–2013. Each sleeping space was observed for the presence of a bed net, and the sleeping patterns for each household were recorded. The observed coverage and efficiency were compared to a simulated coverage and efficiency had conventional allocation strategies been used. A composite indicator, the product of coverage and efficiency, was calculated. Observed sleeping patterns were compared with the sleeping pattern assumptions.

RESULTS In households reached by the campaign, 93% (95% CI: 93–94%) of sleeping spaces in Sofala and 84% (82–86%) in Nampula were covered by campaign bed nets. The achieved efficiency was high, with 92% (91–93%) of distributed bed nets in Sofala and 93% (91–95%) in Nampula covering a sleeping space. Using the composite indicator, the novel allocation strategy outperformed all conventional strategies in Sofala and was tied for best in Nampula. The sleeping pattern assumptions were completely satisfied in 66% of households in Sofala and 56% of households in Nampula. The most common violation of the sleeping pattern assumptions was that male children 3–10 years of age tended not to share sleeping spaces with female children 3–10 or 10–16 years of age.

CONCLUSIONS The sleeping pattern assumptions underlying the novel bed net allocation strategy are generally valid, and net allocation using these assumptions can achieve high coverage and compare favourably with conventional allocation strategies.

keywords malaria, bed nets, universal coverage, Mozambique

Introduction

As in most of sub-Saharan Africa, malaria is a principal cause of morbidity and mortality in Mozambique [1]. Malaria prevalence is highest in the central and northern provinces of the country, with up to 55% of children <5 infected in 2011 [2].

In an effort to reduce the burden of malaria in the country, the National Malaria Control Program in Mozambique adopted a policy of universal access to at least one means of vector control. According to this policy, every Mozambican either should sleep in a space covered by an insecticide-treated bed net, or have had their house sprayed with insecticide in the last 6 months. The change in policy from only targeting the distribution of bed nets to high-risk populations to include the entire population is driven by the idea that the population-level protective effect of bed nets can be larger than the individual-level protective effect once a certain proportion (35%–65%) of the entire population is covered [3].

Covering the entire population with bed nets usually involves mass distribution campaigns, in contrast to the ongoing, routine distribution of bed nets to high-risk populations, for example during visits to antenatal clinics. Mass distribution campaigns are complex activities, involving a calculation of the number of bed nets to procure, a pre-census of the population, the allocation of a certain amount of bed nets for each household, and the actual distribution of the bed nets.

One of the crucial steps of the process is deciding how many bed nets to allocate per household on the basis of the data collected during the pre-census [4]. Ideal allocation strategies maximise coverage, the proportion of sleeping spaces covered by bed nets, and minimise inefficiency, when a household receives more bed nets than the number of sleeping spaces in the household. Conventional allocation strategies include distributing a fixed number of bed nets per household or a fixed number of bed nets per person.

The Mozambican National Malaria Control Program developed a unique strategy to guide planning and allocation of bed nets. First, data on the age, sex and relationship to head of household are collected during the pre-census. These data are then analysed for each household, and the number of expected sleeping spaces for each household is estimated on the basis of a set of standardised sleeping pattern assumptions that were developed based on a qualitative study conducted in 2009 [5].

This novel bed net allocation strategy was adopted as national policy following a pilot test in Gaza Province in 2009. However, the sleeping pattern assumptions have not yet been validated, and it is unknown whether the novel strategy performs better than conventional allocation strategies. Here, data from two series of household surveys designed to evaluate mass bed net distribution campaigns using this novel strategy are analysed. The first of the distribution campaigns took place in 2010 in four districts in Sofala Province, central Mozambique, and the second took place in 2013 in two districts in Nampula Province, northern Mozambique. Indicators of coverage, efficiency and equity achieved during the campaigns were compared to simulated indicators using conventional allocation strategies. Finally, the observed sleeping arrangements are characterised to validate the sleeping pattern assumptions used during the campaigns.

Methods

Study site and population

Data from two cross-sectional post-campaign household surveys were analysed. The first survey followed a mass bed net distribution campaign in Nhamatanda, Gorongosa, Cheringoma and Muanza districts in Sofala Province in April 2010 [6] (Figure 1). The four districts are contiguous and encircle the Gorongosa National Park. The predominant language spoken in all four districts is Ndau, and the main religious affiliations are the Zionist and Roman Catholic churches. All four districts are rural, and the primary economic activity is subsistence agriculture.

The second survey followed a six-district mass bed net distribution campaign in Nampula Province. The campaign was evaluated in two of the six districts, in the coastal district of Nacala-a-Velha in September 2013 and in the interior district of Mecubúri in December 2013. The main language spoken in both districts is Macua, and the populations are predominantly Muslim. Both districts are rural, with subsistence agriculture the primary economic activity.

Study design

Prior to the distribution campaign in each site, a pre-census was carried out by community leaders, who were responsible for visiting each household and recording the age, sex and relationship to head of household for each inhabitant. These data were then used by trained workers to calculate the expected number of sleeping spaces following standard assumptions on sleeping patterns [5] (Box 1). The allotted number of bed nets was then distributed to each household during the mass distribution campaign, independent of presence or absence of existing bed nets. Bed nets were marked with permanent markers prior to distribution to be identifiable as campaign bed nets.

Following the campaigns, households were randomly selected using two-stage cluster sampling, with sampling strategies differing between the two provinces. In the Sofala survey, 33 villages were chosen at random using probability proportional to size from a list of all villages in the four districts, and 50 households were chosen at random in each village, using a sampling frame derived from the household lists prepared during the pre-census prior to the distribution. Four villages were inaccessible by road and were replaced by four accessible villages, which were conveniently chosen. In the Nampula survey, sampling was performed separately for each district; in each district, 20 enumeration areas were chosen with

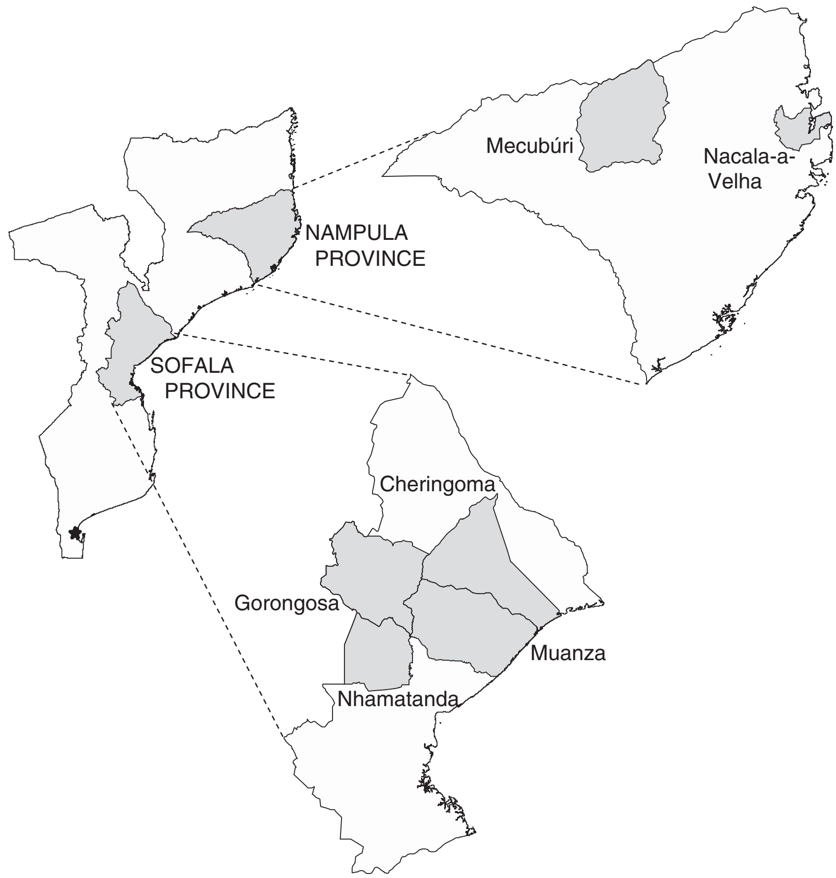


Figure 1 Map of Mozambique showing districts where study household surveys took place.

probability proportional to size using estimated population size from the national census. Prior to the household visits, each of these enumeration areas was visited by a team that enumerated and recorded coordinates for all households in the enumeration area, and 16 households were visited at random from each enumeration area.

Independent evaluation teams visited the selected households 1 month following the campaign in Sofala and 2 weeks after the campaigns in Nampula. Teams asked the head of household to recall the number of bed nets received during the campaign, completed a roster with the age, sex and relationship to head of household of each household member, recorded who slept with whom in which sleeping space and observed each sleeping space for the presence of a bed net, recording whether or not the bed net was from the campaign. A sleeping space was defined as a separate space where any member (s) of the household regularly slept. Data on socio-economic status (SES) indicators, including level of education and occupation of head of household and ownership of household goods, were collected by interviewing an adult member of the household.

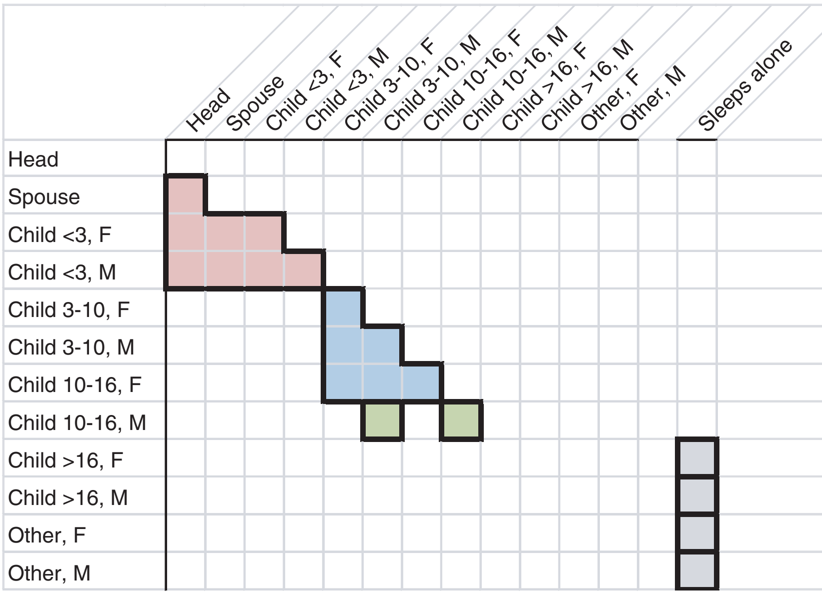
Assessment of coverage

For households that received at least one bed net during the campaign, the number of distributed bed nets was compared to the number of observed sleeping spaces. Coverage was calculated as the proportion of sleeping spaces for which the household had received a campaign bed net, even if the sleeping space was previously covered by an existing non-campaign bed net. The efficiency, defined as the proportion of bed nets distributed that covered a sleeping space, was calculated for each campaign. Confidence intervals for the coverage and efficiency indicators were calculated using the exact binomial test.

On the basis of the observed sizes of households, the hypothetical coverage and efficiency were calculated for each of four alternate conventional allocation strategies: two bed nets per household; three bed nets per household; one bed net per two people, rounding down for households with an odd number of members; and one bed net per two people + 1, rounding up for households with an odd number of members.

Box 1 Sleeping pattern assumptions

A qualitative analysis of sleeping patterns in southern Mozambique resulted in the elaboration of a set of assumptions regarding who sleeps with whom [5]. The assumptions are illustrated in the figure below, showing the groups of individuals that are expected to share a sleeping space. The first assumption is that the head of household will sleep with his or her spouse together with any children <3 years old (red shading in the figure). The second assumption is that male children 3–10 years old and female children 3–16 years of age will sleep together (blue shading). Male children 10–16 years will not sleep with female siblings but will sleep with male siblings 3–10 and 10–16 years of age (green shading). Up to four children are expected to share a bed. Finally, male and female children >16 years of age and adult relatives (uncles, aunts, grandparents) are assumed to sleep alone (grey shading).



Graphic representation of sleeping pattern assumptions: each colored boxes represent individuals that are assumed to share sleeping spaces. F – female, M – male.

For the actual distribution campaign and each of the conventional strategies, the average number of people per distributed bed net was calculated. For each strategy, a composite measure of performance, defined as coverage × efficiency, was calculated. This composite measure ranges from 0 to 100%, reaching its maximum when all households receive exactly one bed net per sleeping space. The composite measure equally penalises inefficient allocation of bed nets and incomplete coverage, so a campaign distributing 100 bed nets to cover 80 sleeping spaces and a campaign distributing 80 bed nets to cover 100 sleeping spaces would both have a score of 80%.

For each household, a composite SES index was calculated from a principal components analysis of the SES questions [7] (See Supporting information). The SES indicators were calculated and analysed separately for the Sofala and Nampula surveys. Households were categorised by SES quintile (5th being the poorest and 1st being the richest), and coverage was calculated separately for each quintile for each distribution strategy. Socio-economic equality in coverage was assessed by calculating the concentration index using a regression analysis [8] for data from the distributions using the novel allocation strategy and simulated data for the conventional strategies. The concentration index was scaled to fall between −1 (maximum pro-poor inequality) and 1 (maximum pro-rich inequality), with 0 indicating an equitable distribution. Confidence intervals were directly calculated from the regression analyses used to estimate the concentration index.

Validation of sleeping pattern assumptions

All household members were classified according to 12 age, sex and relationship categories (Box 1). For each possible pairwise combination of categories, the total number of instances a pair of individuals from each category shared a sleeping space was calculated. This was divided by the total number of times two individuals in these categories belonged to the same household to calculate the proportion of times this pair of age and sex categories shared a sleeping space. This proportion was then compared to the null probability that any two individuals at random would share a bed using a chi-square test. Next, the same analysis was repeated, but with more, smaller age categories. For this analysis, pairs of categories were classified either as having a greater-than-expected or lower-than-expected probability of a sleeping space being shared.

Finally, for each assumption, all possible violations of the assumption were enumerated. For example, for the assumption that the head of household sleeps with his or her spouse and any children <3 years, violations include the spouse not sleeping together with the head of household, a child <3 years not sleeping with the head of household and a child >3 years sleeping with the head of household. For all households for which each assumption was applicable (for the first assumption, all households with a head of household and at least one child), the proportion of households where the assumption held was calculated, as well as the proportion of households violating the assumption. For each possible violation, the relative risk of a violating household not receiving sufficient bed nets was calculated, with the reference group being the households meeting the assumption. Finally, the population attributable risk for each violation was calculated, representing the proportion of incomplete coverage attributable to a specific violation of a certain sleeping pattern assumption.

All statistical analyses were performed in R version 3.0.1 (R Foundation for Statistical Computing, Vienna, Austria).

Ethical considerations

An adult member of each household provided written informed consent to provide data on sleeping arrangements and coverage of sleeping spaces by bed nets. Both surveys were approved by the Mozambican National Committee on Bioethics, and the Sofala survey was also approved by the Hospital Clinic Bioethics Committee (Barcelona, Spain).

Results

A total of 1944 households were visited, 1362 in Sofala in 2010 and 582 in Nampula in 2013, yielding a total number of 4724 sleeping spaces observed (Table 1). The sleeping arrangements of 6555 people in Sofala and 2615 people in Nampula were recorded. The average household size was 4.8 people in Sofala and 4.5 in Nampula and the average number of people per sleeping space was 2.0 and 1.9, respectively.

The novel bed net allocation strategy resulted in households receiving a number of bed nets equal to the number of sleeping spaces 71% of the time in Sofala and 58% in Nampula (Table 2). This was higher than what would have been achieved had any of the alternative conventional allocation strategies been used, which would have matched the number of sleeping spaces 28–57% of the time. One bed net was distributed for every 1.9 people in Sofala and 2.1 people in Nampula, while conventional strategies would have resulted in 1.6–2.4 people per bed net (Table 2). Overall, the achieved coverage using the novel allocation strategy was 93% (95% CI: 93–94%) in Sofala and 84% (82–86%) in Nampula, with the conventional strategies ranging from 72% (69–75%) for the two bed nets per household strategy in Nampula to 93% (92–93%) for the one bed net per two people +1 strategy in Sofala.

Efficiency for the novel allocation strategy was also high, reaching 92% (91–93%) in Sofala and 93% (91–95%) in Nampula; only the one bed net per two people strategy was more efficient, achieving 94% (93–95%) in Sofala and 96% (94–97%) in Nampula. Overall, using the composite indicator, the novel allocation strategy performed best in Sofala at 86% (85–87%), compared to 80% (79–81%) for the second best strategy (one bed net per two people). In Nampula, the estimates of the composite index for the novel allocation strategy (78% [76–81%]), the one bed net per two people strategy (78% [75–80%]) and the one bed net per two people +1 strategies (81% [79–83%]) had overlapping confidence intervals. In both provinces, the fixed number of bed nets per household strategies performed most poorly, a consequence of the wide variation of the number of

Table 1 Sample size for surveys of bed net coverage and sleeping arrangements, Sofala and Nampula provinces

	Sofala	Nampula
Number of households visited	1362	582
Number of sleeping spaces observed	3351	1373
Number of household members	6555	2615

Table 2 Comparison of performance of bed net allocation models, using data from surveys in Sofala and Nampula provinces

Allocation Model	Number of people per bed net distributed	Proportion of households receiving %			Performance % (95% CI)			Concentration Index % (95% CI)*
		Correct no. of nets†	Too few nets	Too many nets	Coverage‡	Efficiency§	Composite¶	
Sofala								
Novel allocation model	1.9	71	13	16	93 (93–94)	92 (91–93)	86 (85–87)	−0.08 (−0.2, 0.02)
1 net per 2 people**	2.2	57	31	12	85 (84–86)	94 (93–95)	80 (79–81)	**0.09 (0.03, 0.2)**
1 net per 2 people + 1**	1.8	50	16	34	93 (92–93)	86 (84–87)	79 (78–81)	**0.13 (0.04, 0.2)**
2 nets per household**	2.4	30	45	24	71 (69–73)	88 (86–89)	62 (61–64)	−0.05 (−0.1, 0.01)
3 nets per household**	1.6	28	17	55	89 (88–90)	73 (72–75)	66 (64–67)	**−0.15 (−0.2, −0.07)**
Nampula								
Novel allocation model	2.1	58	29	13	84 (82–86)	93 (91–95)	78 (76–81)	**−0.16 (−0.3, −0.04)**
1 net per 2 people**	2.2	51	41	8	81 (78–83)	96 (94–97)	78 (75–80)	−0.05 (−0.2, 0.07)
1 net per 2 people + 1**	1.8	54	18	28	92 (90–93)	88 (86–90)	81 (79–83)	0.00 (−0.2, 0.2)
2 nets per household**	2.3	34	46	20	72 (69–75)	90 (88–92)	65 (62–68)	**−0.22 (−0.3, −0.1)**
3 nets per household**	1.6	30	16	54	90 (88–92)	75 (73–78)	68 (65–71)	**−0.28 (−0.4, −0.1)**

*Estimates with confidence intervals excluding 0 marked in bold. Positive values correspond to pro-rich distributions, and negative values correspond to pro-poor distributions.
†One net per sleeping space.
‡Proportion of sleeping spaces covered by a campaign bed net.
§Proportion of bed nets distributed that covered a sleeping space.
¶Coverage X efficiency.
**Simulated.

sleeping spaces per household, observed in both Sofala and Nampula (Figure S1).

In both Sofala and Nampula, richer households tended to have larger household sizes (Pearson's correlation *P*-value <0.01 in both provinces). As a result, the fixed number of bed nets per household strategies would have resulted in a progressive distribution, with higher coverage in poorer households (Table 2; Figure 2). The novel allocation strategy resulted in an equitable distribution of bed nets by SES in Sofala, with the 95% confidence intervals for the concentration index encompassing 0, and a pro-poor distribution in Nampula. The one bed net per two people and one bed net per two people +1 strategies would have resulted in slightly regressive (higher coverage in richer households) distributions in Sofala and equitable distribution in Nampula. The differences in equity of the novel distribution strategy, one bed net per two people strategy and one bed net per two people +1 strategy compared to the fixed number of bed nets per household strategies are explained by the fact that the number of bed nets distributed per household increases as SES and household size increase (Table S1).

The results of the analysis of the sleeping arrangements of the surveyed households are shown in Figure 3. Spouses shared a bed 95% of the time in Sofala and 93% of the time in Nampula. Children <3 shared a sleeping space with a parent in 71–90% of analysed sleeping arrangements. However, while in Sofala, two children <3 would generally share the same bed, this was not the case in Nampula. As specified in the assumptions, children shared a sleeping space more often than expected with other children in their own age and sex categories (diagonal in Figure 3). However, while the assumptions predict that male children 3–10 and female children 3–10 or 10–16 will generally sleep together, the data show that male children 3–10 preferentially slept with other male children 3–10 and male children 10–16, but were found to share a sleeping space with a female child less often than expected by chance. These patterns were consistent in both Sofala and Nampula, although the smaller sample size in Nampula meant that not all results were statistically significant there. The final assumption that older children and other adult relatives generally sleep alone is also supported by the data from both provinces.

Analysis of the expanded age and sex categories (Figures S2 and S3) suggests that the age thresholds in the original assumptions are well specified, with the possible

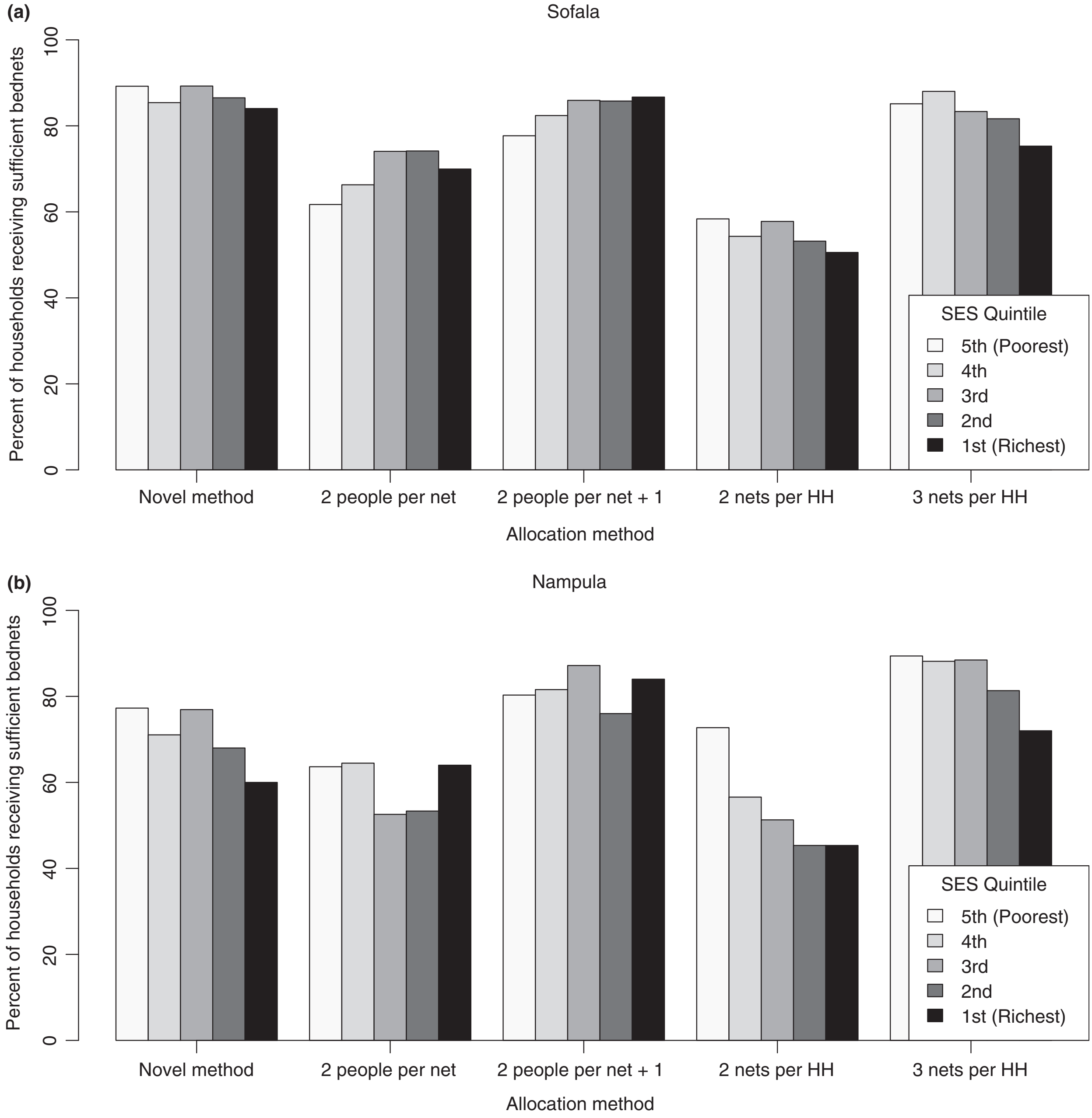


Figure 2 The proportion of households (HHs) receiving sufficient bed nets, by SES quintile for different allocation models, for Sofala (a) and Nampula (b).

exception of the 3-year cut-off for a child sleeping with his or her parents. In Sofala, children 3–4 years of age were still found to share a sleeping space with their parents more often than expected.

Analysis of the individual violations of the assumptions confirms the results of the sleeping arrangements analyses. Overall, 66% of the households in Sofala and 56% in Nampula had observed sleeping arrangements that met all the sleeping pattern assumptions (Table 3). The first assumption was met in roughly two-thirds of households in Sofala and Nampula. In both provinces, the most common violation was the head of household and spouse not

(a)

	Head	Spouse	Child <3, F	Child <3, M	Child 3-10, F	Child 3-10, M	Child 10-16, F	Child 10-16, M	Child >16, F	Child >16, M	Other, F	Other, M	Sleeps alone
Head													0.09–
Spouse	0.95+												0.01–
Child <3, F	0.84+	0.90+	0.62+										0.01–
Child <3, M	0.84+	0.85+	0.64+	0.42									0.04–
Child 3-10, F	0.13–	0.15–	0.23	0.12–	0.57+								0.18
Child 3-10, M	0.16–	0.16–	0.19–	0.18–	0.21–	0.49+							0.19
Child 10-16, F	0.00–	0.00–	0.03–	0.00–	0.43+	0.12–	0.58+						0.33+
Child 10-16, M	0.00–	0.00–	0.00–	0.03–	0.07–	0.38+	0.05–	0.48+					0.42+
Child >16, F	0.00–	0.00–	0.11	0.00	0.19	0.02–	0.39	0.08–	0.24				0.51+
Child >16, M	0.00–	0.00–	0.03–	0.00–	0.03–	0.10–	0.02–	0.16–	0.02–	0.25			0.71+
Other, F	0.00–	0.00–	0.00	0.21	0.18	0.07	0.14	0.07	0.00	0.22	0.00		0.60+
Other, M	0.03–	0.00–	0.12	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.27	0.50	0.62+

* on average, a pair of people are expected to share a sleeping space with a probability of 0.27

(b)

	Head	Spouse	Child <3, F	Child <3, M	Child 3-10, F	Child 3-10, M	Child 10-16, F	Child 10-16, M	Child >16, F	Child >16, M	Other, F	Other, M	Sleeps alone
Head													0.11–
Spouse	0.93+												0.00–
Child <3, F	0.71+	0.82+	0.31										0.03–
Child <3, M	0.80+	0.88+	0.35	0.67									0.04–
Child 3-10, F	0.09–	0.09–	0.19	0.13–	0.61+								0.16
Child 3-10, M	0.09–	0.10–	0.17	0.13–	0.30	0.47+							0.22
Child 10-16, F	0.01–	0.01–	0.04	0.05–	0.45+	0.23	0.26						0.32+
Child 10-16, M	0.01–	0.01–	0.00–	0.03–	0.10–	0.31	0.18	0.42					0.38+
Child >16, F	0.08	0.06	0.12	0.25	0.22	0.17	0.41	0.04–	0.00				0.33
Child >16, M	0.00–	0.00–	0.00	0.00	0.07	0.20	0.10	0.24	0.00	0.25			0.65+
Other, F	0.00–	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.25	0.25	0.00		0.56+
Other, M	0.00–	0.00–	0.00	0.00	0.00	0.05	0.25	0.40	0.00	0.29	0.40	0.33	0.65+

* on average, a pair of people are expected to share a sleeping space with a probability of 0.28

Figure 3 Probability of two people in a household sharing a sleeping space in Sofala (a) and Nampula (b), classified by age and sex categories. + denotes a significantly increased probability of sharing a sleeping space (*P* value <0.01), – denotes a significantly reduced probability of sharing a sleeping space (*P* value <0.01). Colors represent sleeping pattern assumptions (Box 1).

Table 3 Evaluation of validity of sleeping pattern assumptions using observed sleeping patterns from household surveys in Sofala and Nampula provinces

	Sofala				Nampula			
	Number of Households (%)	Proportion without Sufficient Nets	RR of Not Having Sufficient Nets	Population Attributable Risk %	Number of Households (%)	Proportion without Sufficient Nets	RR of Not Having Sufficient Nets	Population Attributable Risk %
All Assumptions Met	899 (66)	0.09	–		326 (56)	0.19	–	
Households with head, spouse, and ≥1 child								
Assumption Met	531 (67)	0.15	Ref	0	276 (68)	0.34	Ref	0
Head and spouse do not share bed	28 (3.5)	0.42	**2.8 (1.7–5)**	**4.0**	26 (6.4)	0.63	**1.9 (1.3–3)**	**5.1**
>1 children <3 and not sleeping in same bed	10 (1.3)	0.10	0.7 (0.1–4)	–	20 (4.9)	0.10	0.3 (0.05–2)	–
Child <3 not sleeping with head and spouse	15 (1.9)	0.20	1.3 (0.5–4)	0.4	19 (4.7)	0.31	0.9 (0.4–2)	–
Children ≥3 sleeping with head and spouse	213 (27)	0.16	1.1 (0.7–2)	1.1	67 (17)	0.24	0.7 (0.4–1)	–
Households with head, spouse, and >1 child								
Assumption Met	400 (58)	0.11	Ref	0	196 (55)	0.29	Ref	0
M > 10 sleeping with any F	31 (4.5)	0.16	1.5 (0.6–3)	0.9	24 (6.7)	0.47	1.6 (0.9–3)	2.8
F > 16 sleeping with an M > 10	4 (0.58)	0.25	2.3 (0.4–13)	0.3	6 (1.7)	0.75	**2.6 (1.4–5)**	**1.7**
>4 children sharing a bed	2 (0.29)	0.17	1.5 (0.1–19)	0.1	1 (0.28)	0.25	0.9 (0.08–10)	–
M < 10 sleeping alone	68 (9.8)	0.29	**2.7 (1.7–4)**	**7.2**	43 (12)	0.57	**2.0 (1.3–3)**	**9.0**
F < 16 sleeping alone	124 (18)	0.41	**3.8 (3–5)**	**21.0**	63 (18)	0.55	**1.9 (1.3–3)**	**11.3**
F < 16 and M < 10 not filling up 4 to bed	65 (9.4)	0.14	1.3 (0.6–2)	1.1	32 (9)	0.53	**1.8 (1.1–3)**	**4.1**
F > 16 not sleeping alone	37 (5.3)	0.19	1.8 (0.9–4)	1.8	40 (11)	0.54	**1.9 (1.2–3)**	**5.9**
M > 16 not sleeping alone	45 (6.5)	0.27	**2.4 (1.4–4)**	**4.1**	24 (6.7)	0.31	1.1 (0.5–2)	0.3
Households with older dependents								
Assumption Met	2 (40)	0.17	Ref	0	5 (45)	0.25	Ref	0
Older dependent not sleeping alone	3 (60)	0.12	0.75 (0.02–28)	–0.1	6 (55)	0.5	2 (0.3–14)	0.9

Bold denotes statistically significant results.

sharing a bed, responsible for 4% and 5% of the incomplete coverage achieved during the campaigns in Sofala and Nampula, respectively. Agreement with the assumptions surrounding sleeping arrangements among children was lower, with 58% of households in Sofala and 55% in Nampula meeting the assumptions. The most common violations were male children <10 and female children <16 sleeping alone when there were sleeping spaces with younger children that they could have shared. Households with these sleeping arrangements were significantly more likely to have insufficient bed nets to cover all sleeping spaces. These two violations were together responsible for 28% of incomplete coverage in Sofala and 20% of incomplete coverage in Nampula.

Discussion

In both provinces, the novel bed net allocation strategy achieved consistently high coverage and efficiency. As judged by the composite indicator, the novel allocation strategy would have outperformed conventional allocation strategies in the Sofala campaign and would have performed equally well as the one bed net per two people, and the one bed net per two people +1 strategies in the Nampula campaigns. Among the simulated allocation strategies, the performance of the two and three bed nets per household strategies was poorest. Since the novel allocation strategy performed well in identifying the true number of sleeping spaces per household, it provided a generally equitable distribution of bed nets.

The novel allocation strategy evaluated here is more complex than the conventional allocation strategies, requiring an extra data collection and analysis step during the distribution campaign. Determining whether the added cost and complexity are justifiable based on the increased efficiency and coverage would require further analysis of the distribution campaigns as a whole, including quantification of the additional costs. The conclusions from the data presented here are limited to those that can be drawn from the observed efficiency and coverage results.

The accuracy of the novel allocation model is a consequence of the study's finding that the sleeping pattern assumptions underlying the model generally predict real-world sleeping arrangements. While there is a possibility that sleeping patterns were modified as a result of the number of bed nets received during the campaign, the analysis of the observed sleeping arrangements suggests that the assumptions about sleeping patterns are generally valid. Moreover, there is evidence that these assumptions are robust, as they hold true in two distinct populations, around 1000 km apart, with different languages, religions and local customs.

While the sleeping patterns' assumptions generally reflected the observed sleeping arrangements, the analysis reveals that contrary to the assumptions, male children 3–10 years of age tend not to share sleeping spaces with female children 3–10 or 10–16 years of age. Households with sleeping arrangements violating this assumption are at increased risk for not receiving sufficient bed nets, and this violation is responsible for the largest population attributable risk fraction of insufficient coverage. Together, this is evidence that this particular assumption should be altered for future distribution campaigns, at least in these two regions of Mozambique.

The results presented here suggest that allocation strategies aimed at efficiently achieving universal coverage of bed nets, where every sleeping space is covered by a bed net, can be informed by data on the sleeping arrangements of the target populations. The study described here is among the first large, systematic surveys of sleeping arrangements in Africa. While universal coverage campaigns are sometimes preceded by qualitative studies on local sleeping arrangements [9, 10], there is in general a paucity of published literature on sleeping arrangements in Africa, with most previous work focusing on who is prioritised to sleep under bed nets in situations with incomplete coverage [11, 12].

Periodic surveys like those analysed here can both guide the initial choice of allocation strategy and fine-tune sleeping pattern assumptions as they change over time. Adjusting the assumptions over time will likely be necessary to account for both regional differences in sleeping patterns and sociocultural changes due to economic growth, particularly in diverse and rapidly developing countries such as Mozambique.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Histogram of number of sleeping spaces, defined as a separate space where any member(s) of the household regularly slept, per household by site.

Figure S2. Likelihood of two people in a household sharing a sleeping space in Sofala, classified by expanded age and sex categories.

Figure S3. Likelihood of two people in a household sharing a sleeping space in Nampula, classified by expanded age and sex categories.

Table S1. Average number of bed nets allocated per household by SES quintile.

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