

W Insecticide-treated net coverage in Africa: mapping progress in 2000–07

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Summary

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Background Insecticide-treated bednets (ITNs) provide a means to improve child survival across Africa. Sales figures of these nets and survey coverage data presented nationally mask inequities in populations at biological and economic risk, and do not allow for precision in the estimation of unmet commodity needs. We gathered subnational ITN coverage sample survey data from 40 malaria-endemic countries in Africa between 2000 and 2007.

Methods We computed the projected ITN coverage among children aged less than 5 years for age-adjusted population data that were stratified according to malaria transmission risks, proximate determinants of poverty, and methods of ITN delivery.

Findings In 2000, only 1·7 million (1·8%) African children living in stable malaria-endemic conditions were protected by an ITN and the number increased to 20·3 million (18·5%) by 2007 leaving 89·6 million children unprotected. Of these, 30 million were living in some of the poorest areas of Africa: 54% were living in only seven countries and 25% in Nigeria alone. Overall, 33 (83%) countries were estimated to have ITN coverage of less than 40% in 2007. On average, we noted a greater increase in ITN coverage in areas where free distribution had operated between survey periods.

Interpretation By mapping the distribution of populations in relation to malaria risk and intervention coverage, we provide a means to track the future requirements for scaling up essential disease-prevention strategies. The present coverage of ITN in Africa remains inadequate and a focused effort to improve distribution in selected areas would have a substantial effect on the continent's malaria burden.

Funding Wellcome Trust.

Introduction

Although international donor funding for malaria control in Africa has increased since 2002,^{1,2} funding remains inadequate^{2,3} and our understanding of how increased financial resources have influenced equitable and targeted coverage of key malaria control strategies across Africa is incomplete. Insecticide-treated bednets (ITNs) are one of the most important methods for achievement of the Millennium Development Goal 6 target to reduce child mortality by 2015.⁴ Progress toward the Roll Back Malaria target of 80% ITN coverage among vulnerable groups is reported by the Global Fund for AIDS, Tuberculosis and Malaria (GFATM), WHO, and UNICEF as yearly increases in ITN procurement, and coverage data from national sample surveys summarised nationally.^{5,6} National survey data represent the most precise benchmark of progress toward internationally agreed targets. Definition of biological and economic vulnerability against intervention coverage targets subnationally, however, is central to the appropriateness of scaling up intervention coverage. In this report, we present a subnational analysis of temporal changes in ITN coverage among African children that also quantifies the risks of *Plasmodium falciparum* transmission and proximate determinants of poverty.

Methods

ITN coverage data

The main sources of ITN coverage data were national-household cluster-sample surveys undertaken as part of multiple indicators cluster surveys,⁷ demographic and health surveys,⁸ and national sample surveys—referred to as malaria indicator surveys—in countries with GFATM or bilateral donor funding. The multistage sampling design from first-level administration (eg, province, state, or governorate) to national-census-defined enumeration clusters is common to all these surveys, and sample sizes are determined so as to provide precision in health and population indicators at the first-level administrative unit (ADMIN1). We have reconstructed information from survey reports, websites, and other published sources on the numbers of children aged less than 5 years; number of these children reported sleeping on the night before the survey under a net that was treated in the past 6 months or that was a long-lasting treated net; and dates of the survey and the first-level sampling geographical extent reported in each survey. We have selected two periods of ITN coverage data by choosing national surveys undertaken as close as possible to 2000 and 2007. ITN coverage data were not available for Botswana, Cape Verde, Reunion, Gabon, and Liberia in either period. For Comoros, ITN data were only

available for 2000. These six countries are therefore not analysed further and represent only 1·0% (1·18 million) of the total childhood population in malaria-endemic Africa and 0·9% (1·03 million) of children exposed to stable *P falciparum* in 2007.

For early multiple indicators cluster surveys and demographic and health surveys that predated a standardised malaria module,⁹ some ITN coverage data were reported in a non-standard format—eg, proportion of households in which all or some children slept under a net or ITN (Mali, 2001; Tanzania and Zimbabwe, 1999);

proportion of nets used by children that were ITN (Uganda, 2000–01); proportion of women aged 15–49 years who were sleeping under a net (Mozambique, 2003); or were reported for some ADMIN1 units and not others (Sudan, 1999). In each case we made an informed decision on the likely association between the reported indicators and the proportion of children sleeping under an ITN. These adjusted survey data indicate very low ITN coverage (mean 2·6% [SD 2·4]) and thus absolute errors resulting from these assumptions are likely to be small.

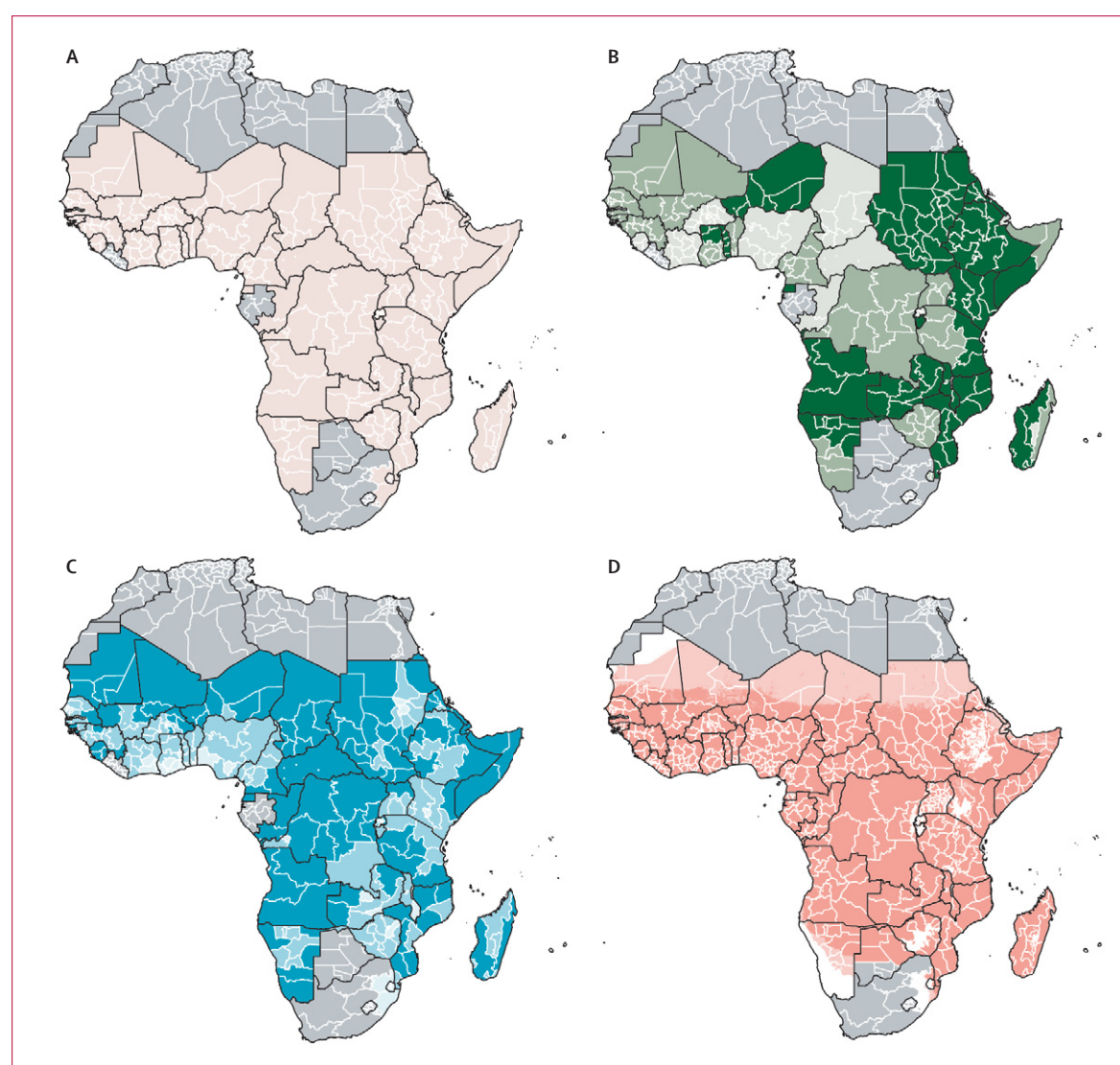


Figure 1: Availability of insecticide-treated bednet (ITN) data for two study periods, delivery methods, poverty mapping, and risk of malaria
National boundaries are shown in black and first-level administrative boundaries are shown in white. (A) First-level administrative units used to define ITN use between 2000 and 2007. Countries shown in grey are those where no baseline or matched follow-up data were available (Botswana, Cape Verde, Comoros, Gabon, Liberia, and Reunion) or that were not at risk of *Plasmodium falciparum* malaria (Algeria, Egypt, Lesotho, Libya, Morocco, Tunisia, and seven provinces in South Africa). (B) Main delivery methods adopted by countries after 2000 and before follow-up national surveys as indicated in table 1. Light green is cost recovery through public sector or subsidised private or public sector; middle green is highly subsidised routine distribution through public sector; and dark green is free mass campaigns, either localised or nationally, or routine free distribution through public sector. (C) Poverty map showing the least poor quintile (light blue), the two moderately poor quintiles (middle blue), and the two poorest quintiles (dark blue), based on the mean brightness of night-time lights in the first-level administration unit. (D) Map of malaria showing areas of no malaria risk (white) and those under unstable (light pink) and stable (dark pink) transmission.¹²

ADMIN1 2000-03 (baseline)			2004-07 (follow-up)			Projection for July, 2007		Start year and modality of ITN scale-up								
	Source (year)	Months	Children <5 years	ITN use	Source (year)	Months	Children <5 years	ITN use	ITN use	2000	2001	2002	2003	2004	2005	2006-07
Angola	MICS (2001)	March to October	5663	113 (2%)	MIS (2006-07)	November to April	2739	493 (18%)	19%	..	..	Spps	..	..	HSrp, RFD	FMCN
Benin	DHS (2001)	May to June	4689	328 (7%)	DHS (2006)	July to November	15 941	3188 (20%)	22%	..	Spps	..	..	HSrp	..	..
Burkina Faso	DHS (2003)	January to July	9894	198 (2%)	MICS (2006)	April to June	5384	538 (10%)	13%	..	CRps	..	..	..	Spps	..
Burundi	MICS (2000)	April to May	3325	33 (1%)	Other (2007) ¹³	September	2845	910 (32%)	32%	..	..	..	Spps	..	RFD, FMCL	FMCN
Cameroon	MICS (2000)	July to August	3385	34 (1%)	MICS (2006)	May to June	6361	827 (13%)	15%	CRps	..	..	..	CRps, RFD	..	RFD*
CAR	MICS (2000)	April to December	14 268	285 (2%)	MICS (2006)	October to December	9585	1438 (15%)	16%	CRps	..	..	..	..	..	..
Chad	MICS (2000)	May to September	5384	54 (1%)	DHS (2004)	July to December	6206	310 (5%)	7%	..	..	..	..	..	..	HSrp
Congo	Estimated	Estimated	..	<5%†	DHS (2005)	July to November	4340	260 (6%)	7%	..	..	..	..	..	Spps	..
Côte d'Ivoire	MICS (2000)	June to August	7952	80 (1%)	MICS (2006)	August to October	8650	519 (6%)	7%	CRps	..	..	..	..	..	..
Djibouti	Estimated	Estimated	..	<1%†	MICS (2006)	July to October	2245	22 (1%)	2%	..	..	..	..	..	..	FMCN*
DRC	MICS (2001)	April to October	9954	100 (1%)	DHS (2007)	May to August	8913	980 (11%)	11%	CRps	..	..	Spps	..	..	FMCL
Equatorial Guinea	MICS (2000)	September to November	3033	30 (1%)	Other (2007)†	February to May	3456	346 (10%)	10%	..	CRps	..	..	..	..	FMCN
Eritrea	DHS (2002)	March to July	5935	237 (4%)	Other (2004) ^{§44}	October to November	1266	608 (48%)	85%	Spps	RFD\$	RFD\$	RFD\$	RFD\$	RFD\$	RFD\$
Ethiopia	DHS (2000)	February to May	11 771	0	MIS (2007))	October to December	5225	1724 (33%)	33%	..	..	..	Spps	..	FMCN	FMCN
Gambia	MICS (2000)	May to June	3620	543 (15%)	MICS (2005-06)	December to March	6543	3207 (49%)	58%	..	Spps	..	..	..	..	..
Ghana	DHS (2003)	July to October	3593	144 (4%)	MICS (2006)	August to October	3467	763 (22%)	27%	..	..	RFD	FMCL	FMCL	FMCL	FMCN*
Guinea	Estimated	Estimated	..	<1%†	DHS (2005)	February to June	6839	<1%†	1%	..	..	..	Spps	HSrp	..	..
Guinea Bissau	MICS (2000)	April to May	5856	410 (7%)	MICS (2006)	May to June	5845	2280 (39%)	45%	..	..	..	..	..	Spps	..
Kenya	MICS (2000)	September to October	7116	213 (3%)	MIS (2007)	June to July	6783	2985 (44%)	44%	..	..	Spps	..	HSrp	..	FMCN
Madagascar	MICS (2000)	August to October	6561	59 (<1%)	Other (2008) ¹⁵	April to May	3355	2047 (61%)	61%	..	..	Spps	..	..	..	HSrp, FMCN
Malawi	DHS (2000)	July to November	10 559	317 (3%)	MICS (2006)	July to November	19 628	4907 (25%)	28%	..	..	HSrp	..	..	..	FMCN
Mali	DHS (2001)	January to May	11143	557 (5%)	DHS (2006)	April to September	13 359	3607 (27%)	31%	..	..	Spps	..	HSrp	..	..
Mauritania	Estimated	Estimated	..	<2%†	DHS (2003-04)	August to February	3239	65 (2%)	3%	CRps	RFD
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	ADMIN1 2000-03 (baseline)				2004-07 (follow-up)				Projection for July, 2007		Start year and modality of ITN scale-up						
	Source (year)	Months	Children <5 years	ITN use	Source (year)	Months	Children <5 years	ITN use	ITN use	ITN use	2000	2001	2002	2003	2004	2005	2006-07
	(Continued from previous page)																
Mozambique	11	DHS (2003)	August to December	10 648	532 (5%)	MIS (2007)	June to July	5187	363 (7%)	7%	..	..	..	Spps	..	FMCL	..
Namibia	13	DHS (2000)	September to December	3785	114 (3%)	DHS (2006-07)	October to March	5453	600 (11%)	12%	..	..	..	Spps	FMCL	..	..
Niger	8	MICS (2000)	April to August	5080	51 (1%)	DHS (2006)	January to June	8236	576 (7%)	8%	Spps	..	..	..	..	FMCL	FMCL
Nigeria	6	DHS (2003)	March to August	5861	57 (1%)	MICS (2007)	March to April	16 549	579 (3%)	4%	..	..	..	..	..	CRps HSrp	..
Rwanda	12	MICS (2000)	July to October	3153	126 (4%)	DHS (2005)	February to July	7534	979 (13%)	18%	..	..	..	Spps	..	..	RFD, FMCL*
São Tomé and Príncipe	2	MICS (2000)	August to September	2185	503 (23%)	MICS (2006)	May to July	3125	1313 (42%)	46%	CRps	..	..	..	..	FMCL	..
Senegal	10	MICS (2000)	May to July	9033	181 (2%)	MIS (2006)	November to December	4683	749 (16%)	17%	..	..	Spps	..	..	..	HSrp
Sierra Leone	4	MICS (2000)	March to May	2686	54 (2%)	MICS (2005)	October to November	5245	262 (5%)	6%	CRps	..	..	..	..	..	FMCL*
Somalia	3	MICS (1999)	November to December	4487	54 (1%)	MICS (2006)	August to September	6304	567 (9%)	10%	..	..	..	..	Spps	FMCL	..
South Africa	2	Other (2001) ¹⁹	..	..	1%†	PC (2007) ¹¹	..	..	<5%†	5%	..	..	..	..	..	..	..
Sudan	26	MICS (2000) ¹¹	July to August	23 297	443 (2%)	Other (2006) ¹⁶	March to June	2363	189 (8%)	10%	..	..	..	..	CRps	FMCL	FMCL
Swaziland	4	MICS (2000)	July to September	3508	21 (<1%)	DHS (2006-07)	July to February	3268	20 (<1%)	1%	..	..	..	Spps	..	..	..
Tanzania	9	DHS (1999)	September to November	3011	60 (2%)	Other (2006-07) ¹⁷	June to August	8608	2324 (27%)	33%	..	..	..	..	Spps	..	HSrp, FMCL
Togo	5	MICS (2000)	August to September	3126	56 (2%)	MICS (2006)	May to June	4073	1548 (38%)	45%	..	..	..	..	FMCL	..	..
Uganda	4	DHS (2000-01)	September to March	8049	<1%†	DHS (2006)	May to October	8402	840 (10%)	11%	CRps	..	..	Spps	..	..	..
Zambia	9	DHS (2001-02)	November to May	5786	58 (1%)	MIS (2006)	May to June	2700	621 (23%)	29%	..	..	..	Spps FMCL	HSrp	FMCL	FMCL*
Zimbabwe	10	DHS (1999)	August to November	3269	<3%†	DHS (2005-06)	August to March	5751	173 (3%)	4%	..	..	..	..	..	Spps	HSrp

The recorded ITN distribution mechanisms are cost recovery through public sector (CRps), subsidised private or public sector (Spps), highly subsidised routine distribution through public sector (HSrp), routine free distribution through public sector (RFD), localised free mass campaigns (FMCL), and national free mass campaigns (FMCLN); and are summarised in figure 1B. Botswana, Cape Verde, Reunion, Comoros, Gabon, and Liberia were not included because they had no survey data for baseline or follow-up years. ADMIN1—first-level administrative unit. CAR—Central African Republic. DHS—demographic and health surveys. DRC—Democratic Republic of Congo. MIC—multiple indicators cluster surveys. MIS—malaria indicator surveys. PC—personal communication. *Countries where free mass campaigns of long-lasting treated nets were undertaken after the follow-up survey are Djibouti; in November, 2006; Ghana in November, 2006; Rwanda in September, 2006; Sierra Leone in November, 2006; Cameroon in 2007; Mali in 2007; and Zambia in 2007. †Values are estimates because survey data were not available for the country during a particular period. ‡Derived from household sample survey data from 2007 (Kleinschmidt I, London School of Hygiene and Tropical Medicine, personal communication). §In Eritrea data for four of six ADMIN1 units were obtained from a published source¹⁴ and an averaged assumption was imputed for the remaining two on the basis of November, 2006; Cameroon in 2007; Mali in 2007; and Zambia in 2007. ¶For the two malaria endemic provinces in neighbouring ADMIN1 coverage, Eritrea uses regular free distribution through the routine public sector as the main channel to deliver ITNs and is classified with free mass campaign in figure 1B. ¶¶For the two malaria endemic provinces in South Africa, we have assumed that ITN is less than 5% in 2007 after communications with provincial malaria control programme managers in both areas who indicated that over the past 5 years the focus of malaria vector control has been on indoor residual spraying rather than ITN distribution (Kruger P, Limpopo Malaria Control Programme, personal communication). ||In Sudan, baseline ADMIN1 data were available only for north Sudan (n=16). For south Sudan, ITN coverage data for the ADMIN1 units (n=10) were estimated from the means of nearest neighbours (n=5); or were assigned the national average of 1.9% from the MICS in 2000 (n=5). **Tanzania data were obtained from a survey on the national ITN voucher scheme undertaken in 2006¹⁷ and sample surveys undertaken on the islands of Zanzibar and Pemba in 2007.¹⁸

Table 1: National summary of insecticide-treated bednet (ITN) coverage data sources for baseline, follow-up, and target periods, and evolution of ITN distribution mechanisms for 40 African malaria-endemic countries

The reference ADMIN1 digital boundaries for Africa were obtained through a combination of data from the UN Geographic Information Working Group,¹⁰ and the Food and Agriculture Organisation.¹¹ These boundary units matched the reported information on ITN for 34 of 40 national survey reports assembled for the baseline period (2000–03) and 30 of 40 national surveys for the follow-up period (2004–07). For Angola, Benin, Chad, Djibouti, Guinea Bissau, Mali, Mauritania, Madagascar, Nigeria, and Uganda, non-standard ADMIN1 units were reported in the national sample surveys and these were digitised with ArcGIS (version 9.1) to replace existing ADMIN1 boundaries and thus create one ITN spatial reporting surface. In Angola, Central African Republic, Somalia, Madagascar, Equatorial Guinea, Burundi, and Tanzania, baseline and follow-up national surveys were sampled and presented at different administrative resolutions between surveys. These were reconciled to the largest unit reported in either type of survey to maintain the integrity of the sample-size precision and represent temporally congruent units. Figure 1A shows the 286 spatial units used to define ITN use between 2000 and 2007 in the 40 countries where analysis was undertaken. We computed the absolute difference in ITN use between baseline and follow-up surveys for each ADMIN1. We then computed the number of months between surveys and obtained the monthly change in ITN, which we used as our ITN growth rate. We used this growth rate to project all ADMIN1 survey data described during the second-period survey to just one time reference in July, 2007.

Since 2003, a wide range of approaches was used to improve the delivery of ITN to young children across Africa. These approaches can be classified broadly as cost recovery through the public sector, subsidised private or public sector, highly subsidised routine distribution through the public sector, routine free distribution through the public sector, and free mass campaigns; and are localised within specific ADMIN1 areas or nationally. We identified the adoption of these varied approaches by individual countries at different times between 2000 and 2007 through various literature and web searches. Table 1 shows the national adoption of each strategy and figure 1B summarises this information spatially according to the distribution methods post-baseline and pre-follow-up survey.

Definition of poverty

Roll Back Malaria targets emphasise the need to target specifically those population groups living in the two poorest quintiles in areas of biological vulnerability.¹⁹ The definition of poverty is fraught with difficulties and most health indicators are expressed against composites of household assets as measures of economic vulnerability but are difficult to compare between countries. A spatially consistent and simpler alternative is to use a proxy for poverty—ie, illumination from night-time lights that are

seen from earth-orbiting satellites. Data for these lights have been used as a surrogate for economic vulnerability and poverty mapping in North America, Europe, and globally²⁰ and were shown to be highly discriminatory in the separation of the most and least poor administrative areas in Africa.²¹

Here we use operational linescan system night-time lights gridded data that are produced by the US Defence Meteorological Satellite Program and the National Oceanic and Atmospheric Administration's National Geophysical Data Center. We downloaded global night-time light data at about 1 km×1 km spatial resolution for the year 2000 from the National Geophysical Data Center-US Defence Meteorological Satellite Program website²⁰ in raster-grid format and extracted data for Africa. We computed the mean brightness of the light pixels for each ITN ADMIN1 and then ranked them across Africa into quintiles with the most economically vulnerable represented by the two lowest quintiles of night-time lights (figure 1C).

Children at risk of *P falciparum* transmission

We used recently completed work on the limits of stable *P falciparum* transmission.¹² We assumed no transmission when medical intelligence from international travel advisories or national malaria-control programmes stated no malaria risk or when temperature was too low for sporogony to complete within the average lifespan of the local dominant vector species. Unstable malaria in Africa refers to areas where transmission is plausible biologically but limited by the effects of aridity on anopheline adult and larval survival, and the clinical incidence is less than one case per 10 000 population per year. A definition of stable malaria was assumed to be a minimum of one clinical case per 10 000 population per year in a particular administrative unit, similar to rules used during the global malaria eradication programme. Within this range of stable transmission, conditions of transmission intensity vary enormously but cover all those in Africa where ITN is recommended as a key malaria prevention strategy.²² The three classifications of malaria risk are shown in figure 1D.

Definition of projected population estimates for 2007

The Global Rural Urban Mapping Project (version alpha) provides gridded population counts and population density estimates for the years 1990, 1995, and 2000, both adjusted and unadjusted to the UN national population estimates.²³ We projected the adjusted population counts for the year 2000 forward to create seven further population count surfaces for each year from 2001 to 2007 by applying national, medium variant, intercensal growth rates by country, with methods previously described.²⁴ We then stratified these population counts nationally by age group using UN-defined²⁴ population age structures to obtain population count surfaces for children younger than 5 years for each year from 2000 to 2007. We used these population maps in combination with the ADMIN1

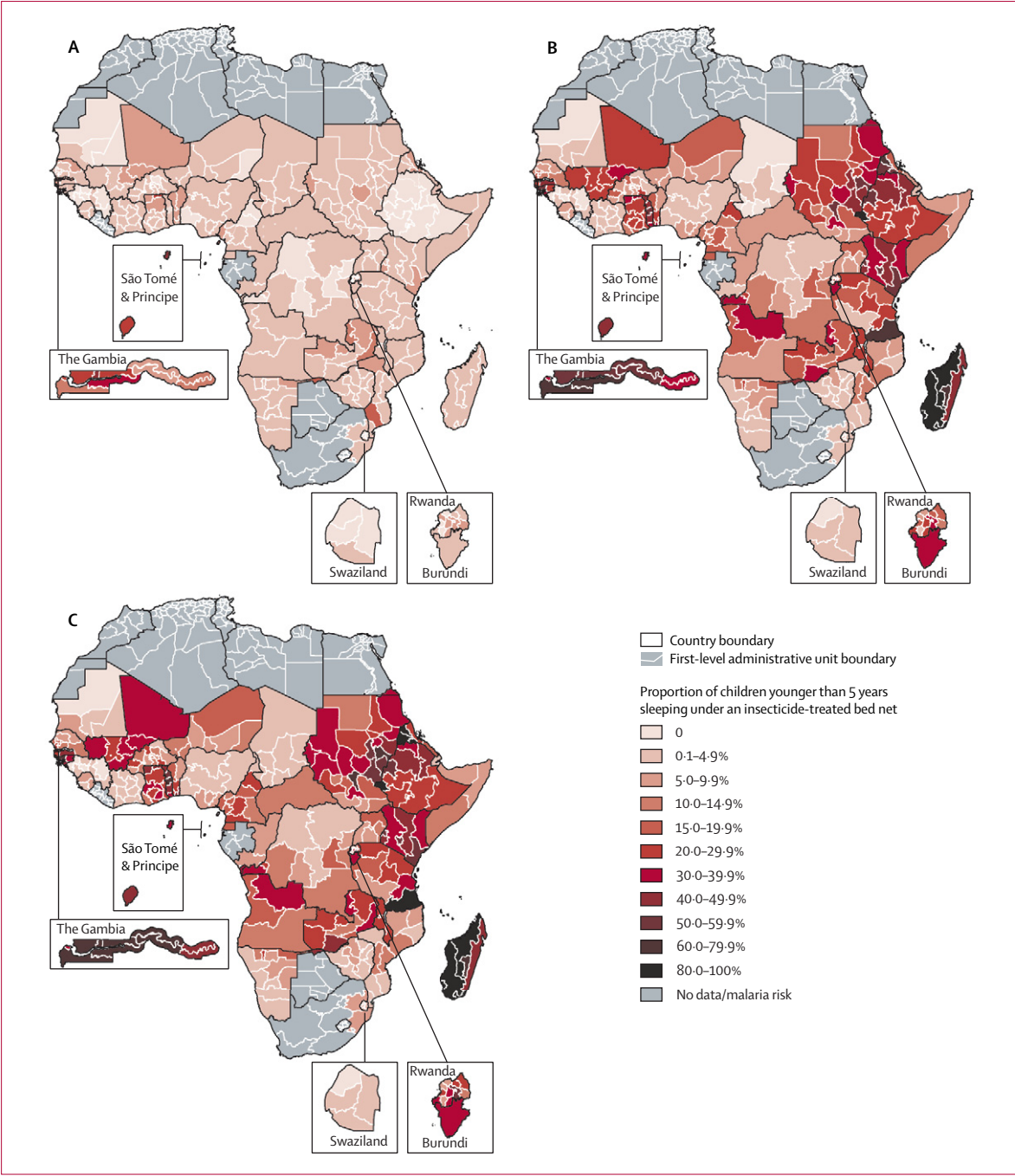


Figure 2: Insecticide-treated bednet (ITN) coverage among children under the age of 5 years reported in (A) 1999–2003 (baseline) and (B) 2004–07 (follow-up), and (C) projected to July, 2007 (target period)

boundaries to extract the numbers of children less than 5 years of age living with no risk, or unstable and stable *P falciparum* transmission risk for each reconstituted ADMIN1 polygon in ArcView (version 3.2).

Role of the funding source

The sponsor of the study had no role in study design, data collection, analysis, interpretation of data, or writing

of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Table 1 shows that data were obtained from multiple indicators cluster surveys (n=21), demographic and health surveys (n=14), or alternative sources (n=5), and

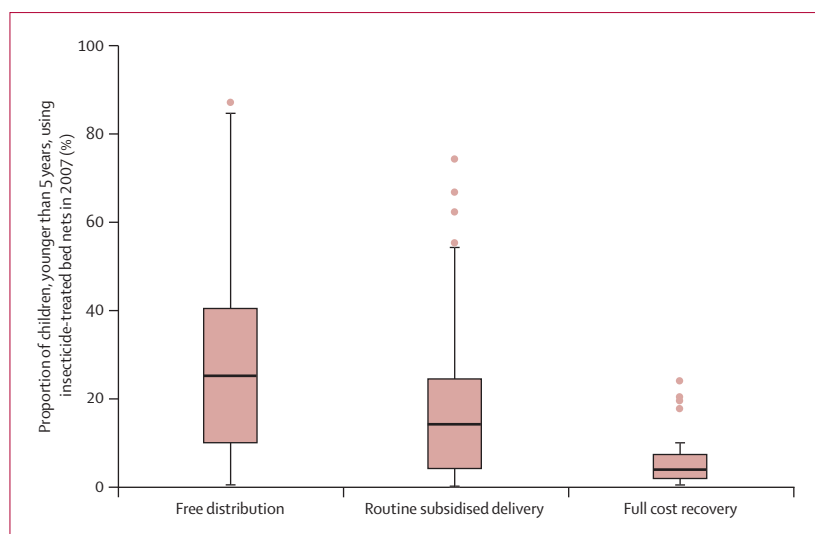


Figure 3: Insecticide-treated bednet (ITN) use among children under the age of 5 years in 2007 by the main country ITN delivery mechanism

The box indicates the IQR (25% and 75%); the thick line within the box represents the median; and the error bars represent the 2.5% and 97.5% centiles; and outliers are plotted as circles outside this range. ITN distribution was free (n=117), moderately or highly subsidised (n=117), and full cost recovery (n=50). The two malaria-endemic first-level administration units (ADMIN1) in South Africa (KwaZulu Natal and Mpumalanga) are not included. Median ITN coverage among children less than 5 years of age was higher in ADMIN1 without free distribution than in those with routine subsidised delivery (ANOVA $p=0.05$) or full cost recovery ($p=0.02$).

used to define ITN use in the 286 ADMIN1 areas between 1999 and 2003, with median ITN use among children aged less than 5 years of 3.04% (IQR 0.50–3.71). We used 2003 demographic and health survey data for Burkina Faso, Ghana, Mozambique, and Nigeria because there were no earlier nationally representative surveys with ITN data within the baseline period. Although there were no national sample survey data close to 2000, data gathered between 2005 and 2006 showed that ITN coverage among children less than 5 years of age was between 0 and less than 5% for Mauritania, Congo, Djibouti, and Guinea. With such a low coverage, a reasonable assumption is that a negligible change in ITN coverage occurred between baseline and our reference year of 2007. For the two malaria-endemic provinces of South Africa (KwaZulu Natal and Mpumalanga), we used data from a Roll Back Malaria report in 2001²⁵ as the baseline. In the surveyed countries, 94 million children were likely to be living in areas of stable malaria-endemic risks in 2000. Figure 2A shows almost universally poor ITN use across these countries in 1999–2003, with only 50 (17%) of the ADMIN1 areas surveyed on the continent during this period showing more than 5% of children using an ITN. Additionally, 1.7 million (1.8%) children were protected by an ITN in areas of stable *P falciparum* malaria in 2000.

Between 2004 and 2007, we obtained data from 13 demographic and health surveys, 14 multiple indicators cluster surveys, and 13 other national surveys and personal communications (table 1).^{13–18,26–31} Figure 2B shows the ADMIN1 ITN use distribution across countries

reporting data after 2003. The average duration between the data shown in figure 2B and figure 2A was 5.3 years. In 2004–07, 205 of 286 (72%) administrative polygons reported childhood ITN use to be greater than 5%, 109 (38%) reported ITN use in excess of 20%, 11 (4%) above 60%, and three (1%; one in Ethiopia and two in Madagascar) had reached the Roll Back Malaria target of 80%. The fastest yearly growth in ITN usage estimates between 2000 and 2007 was in Eritrea, Madagascar, Ghana, Togo, Kenya, Gambia, Guinea Bissau, Zambia, Ethiopia, and Burundi—all are countries that had promoted the delivery of free nets through mass campaigns between survey periods, except Eritrea, which relied on free distribution through the routine public-health system (figure 1B). The median reported ITN use for 2004–07 for ADMIN1, where the main delivery channel was free distribution (national and local), was 25.2% (n=117, IQR 11.2–40.3) compared with 14.1% (n=117, 4.2–24.4) for ADMIN1 areas where no free mass campaigns had been implemented, but where subsidised and heavily subsidised delivery had been promoted. Unsurprisingly, areas without free or subsidised programmes, relying mainly on full-cost recovery mechanisms of ITN delivery, had the lowest ITN coverage during the period of observation (n=50, median 3.9%, 1.8–7.4; figure 3).

The coverage data shown in figure 2B indicate varying periods after 2004 and we have standardised the estimates of ITN use to the base year 2007 by use of expected ITN use growth rates per ADMIN1 for the 40 countries reporting in 2007. Mean projection periods were 14 months from the reported follow-up survey through to July, 2007 (figure 2C). These estimates of adapted ITN usage suggest that 218 (76%) of 286 areas had childhood ITN use reported as greater than 5% in 2007, 20 (7%) administrative areas reported ITN use in excess of 60%, and 10 (3%) of the ADMIN1 areas had reached the Roll Back Malaria ITN use target of at least 80% (figure 2C).

With the projected ITN use data adjusted to childhood populations at risk of stable *P falciparum* transmission, we estimate that 20.3 million (18.5%) children younger than 5 years were protected by an ITN in 2007, whereas 89.6 million (81.5%) remained unprotected, of which 30 million unprotected children lived in the poorest areas of stable malaria-endemic Africa (table 2). Among communities in unstable transmission areas or areas at no risk of transmission, similar proportions of children were likely to have been protected by an ITN (table 2). On a continental scale, ITN coverage in 2007 showed equity in relation to proximate determinants of poverty without significant differences in ITN coverage between children living in the most poor areas compared with those in the least poor (21% vs 16% [table 2]; ANOVA $p=0.275$) with similar observations across all malaria risk classes (data not shown). Biological equity scaled less well, however, with more children protected in areas of no or

	No <i>P falciparum</i> risk (N=11.6 million)	Unstable <i>P falciparum</i> risk (N=2.2 million)	Stable <i>P falciparum</i> risk (N=109.9 million)	Total (N=123.7 million)
Least poor (highest NTL quintile, N=22 500 000)				
Children protected by ITN	441 000 (18.2%)	1 200 000 (16.8%)	3 080 000 (15.9%)	3 640 000 (16.2%)
ADMIN1 with ITN use	40 (13.9%, 4.4–38.4)	11 (5.05%, 2.2–19.0)	57 (15.6%, 4.7–32.5)	57 (15.6%, 4.7–32.4)
Moderately poor (NTL quintiles 2 and 3, N=58 700 000)				
Children protected by ITN	1 406 000 (25.9%)	83 000 (30.3%)	9 779 000 (18.5%)	11 268 000 (19.2%)
ADMIN1 with ITN use	61 (17.3%, 5.1–34.0)	24 (36.5%, 20.9–50.0)	112 (21.4%, 6.1–37.5)	114 (19.6%, 6.0–37.1)
Most poor (lowest NTL quintiles 4 and 5, N=42 500 000)				
Children protected by ITN	1 124 000 (29.8%)	319 000 (27.3%)	7 484 000 (19.9%)	8 927 000 (21.0%)
ADMIN1 with ITN use	62 (13.6%, 6.3–32.3)	52 (11.1%, 2.5–31.1)	113 (12.5%, 6.1–29.9)	116 (12.3%, 5.7–29.8)
Total				
Children protected by ITN	2 972 000 (25.5%)	522 000 (24.2%)	20 343 000 (18.5%)	23 837 000 (19.2%)
ADMIN1 with ITN use	163 (15.6%, 5.1–35.2)	87 (16.6%, 4.5–35.6)	282 (15.0%, 5.6–32.9)	286 (14.3%, 5.1–32.6)

Data are number (%) or number (median, IQR). The *P falciparum*-endemic countries not included are Botswana, Cape Verde, Comoros, Gabon, Liberia, and Reunion, and represent 1.0% of children in all malaria-endemic countries of Africa in 2007. ADMIN1=first-level administrative units. NTL=night-time lights.

Table 2: Children aged less than 5 years who were protected by an insecticide-treated bednet (ITN) in 2007 according to classes of *Plasmodium falciparum* and poverty risks across 40 malaria-endemic countries

unstable risk compared with areas with stable endemic malaria (25.3% vs 18.5% [derived from data in table 2]; $p=0.032$).

Discussion

We estimate that only about a fifth of children at risk of stable malaria transmission were protected by an ITN in 2007. Conversely, nearly 90 million African children living under conditions of stable malaria transmission have been neglected by the calls for rapid scaling up of ITN coverage made by the Roll Back Malaria movement in 2000.³² This neglect comes at a time when these same agencies and international partners are calling for elimination³³ and a malaria-free world.³⁴ A large proportion of these unprotected children live in some of the poorest parts of Africa, but the differences in ITN use between spatially defined areas of least and most poor seem less obvious than has been reported before intervention coverage was scaled up (table 2). The procurement of more than 60 million long-lasting treated nets³⁵ and the reports of rapid scaling up of ITN delivery in a few select countries have been hailed as a clear indication of progress toward Roll Back Malaria and Millennium Development Goals' targets.^{5,6} Reports of sales figures or percentage coverage changes from selective examples mask underlying inequities in ITN use on a continental scale, adjusted for actual populations at risk of developing malaria.

Almost 25 years have elapsed since the first clinical trials of ITN were completed in Africa and more than 10 years since large-scale clinical trial evidence was provided on the contribution of ITN as a major method to reduce childhood mortality across most malaria-endemic settings in Africa. Why then is coverage so poor in 2007? An analysis of international donor funding in relation to populations exposed to stable transmission highlights huge disparities

and inadequacies in malaria funding across Africa,² which must contribute to inability to scale up coverage. Some controversy remains about the best approaches to ITN delivery.^{36,37} In this report, we have shown that the areas of Africa that have promoted free ITN distribution (figure 1B) have overall achieved more rapid progress than those that rely on cost recovery (21% lower median coverage) or routine subsidised public-sector promotion (11% lower median coverage). Fortunately, increasing numbers of countries are complementing existing delivery strategies with free distributions as national or localised strategies after the period of observations reported here, and current ITN coverage in these countries might be higher than our projected estimates.

In some cases, biological vulnerability has scaled up with differences in ITN use within a country, notably Angola, Eritrea, Kenya, Madagascar, and Zambia, and less strategically elsewhere, notably Sudan. National ITN coverage was less than 15% in 2007 in 13 countries, including seven countries (Nigeria, Democratic Republic of Congo, Uganda, Sudan, Mozambique, Côte d'Ivoire, and Cameroon) that account for 53.5 million (48.6%) of all children (110 million) in Africa living under conditions of stable malaria transmission and 48.3 million (54%) of all unprotected children (89.6 million) in these transmission areas. Nigeria alone accounts for 22.2 million (25%) of all African children (89.6 million) living under conditions of stable malaria transmission who were not protected by an ITN in 2007. A focus of attention on these areas in Africa must be seen as a priority if health effects at the continental level are to be realised by 2015.

Such approaches to mapping intervention coverage and risk come with caveats and opportunities for improvement. We have attempted to standardise the ITN coverage to 1 year (2007) of assessment using

subnational resolution estimates of ITN use growth rates. For the most part, this process required minor extrapolations, but in a few countries these estimates would have been affected by the timing of the follow-up surveys (table 1). More regular survey data corresponding to changes in delivery modalities is central for improvement of the precision of such temporal interpolation. Additionally, standardised information on coverage of other vector control strategies, such as indoor residual spraying, needs to be generated at the same resolution as ITN to measure the combined effect of these complementary strategies. To generate this information, we need more investment in measurement of progress than is currently available to countries and should be redressed if international agencies are serious about an analysis of whether money is spent where it should be to achieve the intended goals.³⁸ The available evidence suggests that ITNs are similarly effective under a wide range of transmission intensities in averting new infections,²² but the subsequent public-health effect varies,³⁹ and deaths and disease events averted will be highest in communities exposed to high transmission. To assess the public-health impact with changes in ITN coverage will require a more detailed mapping of malaria risk and the effect of seasonality on ITN use at a continental scale. Although not presently available, this work is ongoing as part of the Malaria Atlas Project⁴⁰ and will provide a more informed map of biological risk with which to plan and assess resource allocation.

Definition of vulnerability and unmet need is central to effective investment strategies by the donor community. Mapping risks, target populations, vulnerability, and coverage provides a means to redress deficiencies in the international calls for 80% coverage of ITN by 2015. These targets remain elusive across vast areas of Africa. Increased funding and more informed use of this funding is desperately needed to protect more children in the most vulnerable and most populated areas of Africa.

Contributors

AMN was responsible for the design of the study, gathering, collation, preparation, analysis, and interpretation of the data, and produced the final report. JJM was responsible for gathering and checking the data. AJT provided population projection data. SIH was responsible for interpretation and preparation of the final report. RWS was responsible for the conception, overall scientific management, analysis, interpretation of data, and preparation of the final report.

Conflict of interest statement

We declare that we have no conflict of interest.

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