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Impact of mass net distributions on malaria prevalence, anemia, and intervention coverage in Abia and Plateau states, Nigeria

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By

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Bachelor of Science

University of Notre Dame

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Abstract

Impact of mass net distributions on malaria prevalence, anemia, and intervention coverage

in Abia and Plateau states, Nigeria

By Elizabeth Heilmann

Nigeria accounts for more than 25% of global malaria cases. As part of the National Strategic Plan for malaria elimination, scaled-up mass distribution of free long-lasting insecticidal nets (LLINs) began in 2009. Abia state, in South East zone, distributed 710,530 nets in 2012; Plateau state, in North Central zone, distributed 1.5 million nets in 2010 and 2.1 million in 2015. Modified malaria indicator surveys were conducted in 2010 (pre-distribution), 2012 (Plateau only) and in September 2015 (post-distribution) to assess the impact of mass net distribution on malaria and anemia prevalence. LLIN ownership increased significantly in both states: the proportion of households owning at least 1 net rose from 10.1% in 2010 to 58.7% in 2015 in Abia and from 35.1% to 85.5% in Plateau. Reported net use the previous night in all individuals increased significantly in Abia from 3.4% to 24.2% and in Plateau from 14.7% to 65.6%. Net use in children under 5 and pregnant women was 3-4 times higher in 2015 compared to 2010. Age-adjusted microscopy-diagnosed *Plasmodium* prevalence significantly decreased in Abia from 36.1% in 2010 to 26.4% in 2015. In Plateau, a non-significant increase from 36.6% to 43.4% occurred. *Plasmodium* infection was significantly associated with net use in Plateau, but not Abia. Over the same period, anemia in children 10 years and younger also significantly declined in Abia from 74.7% to 58.3%, with a non-significant reduction observed in Plateau from 57.1% to 52.5%. A behavior change communication project launched in Kanke local government area (LGA) aimed to maximize net coverage through regular net distribution, education and monitoring by community drug distributors—community volunteers responsible for distributing drugs to prevent lymphatic filariasis. No significant differences in net use were detected after implementation. In summary, significant gains in net coverage and use occurred in both states, with reductions in *Plasmodium* and anemia prevalence observed in Abia, but not Plateau. Despite the improvements, net ownership and use generally failed to meet national coverage targets. Additional efforts are needed to continue improving malaria intervention coverage in Nigeria.

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Abbreviations

ACT	Artemisinin-based combination therapy
ANC	Antenatal care
BCC	Behavior change communication
CDD	Community directed distributor
CI	Confidence interval
DALY	Disability-adjusted life year
DDT	Dichloro-diphenyl-trichloroethane
DHS	Demographic and health survey
EA	Enumeration areas
EIR	Entomologic inoculation rate
FMOH	Federal Ministry of Health
GMAP	Global Malaria Action Plan
Hb	Hemoglobin
IPTp	Intermittent preventive treatment in pregnancy
IRS	Indoor residual spraying
ITN	Insecticide-treated net
LF	Lymphatic filariasis
LGA	Local government area
LLIN	Long-lasting insecticidal net
MDA	Mass drug administration
MICS	Multiple Indicator Cluster Survey
MIS	Malaria indicator survey
NMEP	National Malaria Elimination Programme
NMSP	National Malaria Strategic Plan
PMI	President's Malaria Initiative
RBC	Red blood cell
RBM	Roll Back Malaria Partnership
RDT	Rapid diagnostic test
SCP	Seasonal chemoprevention
SD	Standard deviation
SP	Sulfadoxine-pyrimethamine
TCC	The Carter Center
UN	United Nations
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WHO	World Health Organization

Background

Global burden of malaria

Malaria is a debilitating disease caused by the *Plasmodium* parasite. With 91 endemic countries around the world, 3.4 billion people are at risk of contracting the disease and an estimated 212 million cases and 429 thousand deaths occur annually (1). The majority of malaria cases lie in Africa, and among those, children under 5 and pregnant women are most severely affected. Malaria accounts for much of the global disease burden, ranking eighth for disability-adjusted life years (DALYs) worldwide and second in Africa (2).

The disease burden of malaria in high transmission countries deters economic development, causing a slower growth in per-capita GDP in endemic countries compared to non-endemic countries and an annual global expense reaching billions of dollars for prevention, healthcare, and wages lost (3). Malaria imposes a high cost burden on households both in direct costs for prevention and treatment measures and in indirect costs from wages lost by sick adults or adults caring for sick children. These costs are highly variable between countries, ranging from $1.88 to $26 per month per household, and cannot be afforded by many families as they often amount to more than 25% of household income for low-income families (4). Where ownership of insecticide-treated nets (ITNs) is dependent on user purchase, coverage is inversely associated with socio-economic status (5). Investment in ITNs or free distribution during mass campaigns is estimated to cost $11 per DALY averted (2).

Five *Plasmodium* species are known to cause malaria in humans. Four complete their life cycles among humans and mosquitoes: *P. falciparum, P. vivax, P. ovale,* and *P.*

malariae, while *P. knowlesi* is zoonotic from macaques (6). *P. falciparum* is responsible for most of the global malaria burden, both in number of cases caused and number of deaths, and is the dominant species in Africa. The *Plasmodium* life cycle consists of a sexual stage in the mosquito vector, a single replication cycle in liver hepatocytes, and a blood stage of repeated asexual reproduction in erythrocytes (7).

Pathogenesis corresponds to the blood stage of the *Plasmodium* life cycle. Invasion of red blood cells (RBCs) by merozoites causes erythrocytic membrane changes and release of parasite toxins that are targeted by the host's immune system (8). Pro-inflammatory cytokines are released, causing malaria's characteristic high fevers which cycle with parasitic development and antigenic variation (9). Comorbidity with anemia occurs when RBCs (infected and uninfected) are destroyed by the spleen, and is of particular concern in young children (7). Severity of symptoms increases with co-infections and suppression of erythropoiesis. Unique to *P. falciparum*, infected RBCs are sequestered in the microvasculature of various organs and tissues, avoiding destruction in the spleen, but preventing proper circulation of healthy, oxygenated blood (10). This is especially devastating when sequestration occurs in the brain or placenta.

Each stage of parasite development in the host presents unique opportunities for treatment. Most antimalarial drugs target parasites in the blood stage, while very few are able to reach hypnozoites, quiescent liver-stage parasites, produced by *P. vivax* and *P. ovale* (11). These drugs are highly effective when used properly, but poor infrastructure often results in limited access to care in remote settings (7). Chemoprophylaxis may be administered to certain vulnerable populations to stop the progression of infection early on and prevent the onset of clinical symptoms. In areas with highly seasonal transmission,

mass seasonal chemoprevention (SCP) can be very effective in reducing malaria morbidity and mortality among children (12). Intermittent preventive treatment in pregnancy (IPTp) is encouraged during the second and third trimesters because of the increased rate of infection and likelihood of adverse pregnancy outcomes (13). Despite vigilant surveillance and policies overseeing drug administration, antimalarial drug resistance is a constant threat against control and elimination progress globally. Resistance hotspots limit the number of drugs that can be used effectively, putting pressure on drug companies and governments to provide different and often more expensive treatments (14). Widespread resistance of *P. falciparum* first to chloroquine then to sulfadoxine-pyrimethamine has led the World Health Organization (WHO) to recommend artemisinin-based combination therapies as first-line treatment for uncomplicated malaria cases in most regions of the world (15).

Malaria parasites are transmitted from person to person by mosquitoes of the genus *Anopheles*. Female mosquitoes host the sexual stage of parasite reproduction. Microgametocytosis is triggered in the midgut following uptake of gametocytes during a blood meal (16). After several stages of development over 10 or more days, mature sporozoites travel from the midgut to the salivary glands of the mosquito to be injected into a human during the next blood meal.

There are more than 450 anopheline species, although only 70 are capable of transmitting human malaria parasites and 40 are considered dominant vector species (17). The most prominent species in Africa are *An. funestus, An. gambiae,* and *An. arabiensis*. The range of mosquito species depends on environmental factors such as temperature, precipitation, altitude, and land cover, and fitness as a vector depends on biological factors

such as length of parasite incubation period, daily survival rate, and rate of feeding (18). Differences in vector species behaviors, including feeding times, exophagy/endophagy (outdoor vs indoor feeding), and exophily/endophily (outdoor vs indoor resting), play a role in determining when and where humans are most likely to come into contact with infectious mosquitoes and what interventions may be effective against vector populations (19).

Mosquito ecology and behaviors have been exploited by interventions aimed at reducing the vector population and controlling malaria. ITNs and long-lasting insecticidal nets (LLINs) protect people while sleeping and poison mosquitoes when they attempt to feed at night (20). A randomized control trial in Kenya showed reduced *Anohpheles gambiae* and *An. funestus* populations by 58.5% and 94.5%, respectively, in intervention areas given ITNs corresponding to an estimated 90% lower transmission of *Plasmodium falciparum* compared to control areas (21). Indoor residual spraying (IRS) reduces the life span of endophilic mosquitoes, causing death before sporozoite maturation and transmission (20). IRS using dichloro-diphenyl-trichloroethane (DDT) was the main intervention driving the Global Malaria Eradication Programme in the 1950s and 60s, and was instrumental in eliminating malaria from several countries (22). Insecticide resistance and changing vector behavior as a result of prolonged use of a single intervention impedes the efficacy of IRS and DDT, requiring diligent monitoring of mosquito susceptibility and rotation of insecticides when necessary (23). Integrated vector management is recommended by the World Health Organization to incorporate additional vector control tools and support evidence-based policy decisions that are locally acceptable and adaptable (24).

Endemicity can be defined in terms of transmission seasonality and intensity. Ideally, malaria intensity would be measured by force of infection, that is, the number of new infections acquired in an area over a certain period of time (25). However, this is usually difficult to measure directly as it requires a large cohort and sensitive diagnostic capacity. Instead, the entomologic inoculation rate (EIR) is used which measures the number of infectious bites a person receives in one year (26). Ranging from less than 1 to more than 1,000, annual EIRs are associated with transmission stability and observed malaria prevalence. Transmission season varies by region, with some countries experiencing year-round transmission while others are affected only a few months out of the year, often during the rainy season (7). Together, EIRs and seasonality classify endemicity of a country. Holoendemic is the most intense, with malaria prevalence exceeding 75% in children under 5 (27), but is now rarely seen due to recent scale-ups of interventions. Hyperendemicity is slightly less severe, describing areas with stable transmission and 50-75% prevalence of malaria in children. The majority of countries are classified as mesoendemic or hypoendemic, having less than 50% and 10% prevalence, respectively. As countries transition from more intense endemicity to less, the distribution of infection by age tends to shift from a peak in young children to more oven across age groups (28).

Malaria in Nigeria

The Federal Republic of Nigeria is located in West Africa on the Gulf of Guinea and bordered by Chad, Niger, Cameroon, and Benin (29). There are 6 geopolitical zones in Nigeria: North Central, North East, North West, South East, South South, and South West that are divided into 36 states and 774 local government areas (LGAs) plus the Federal

Capital Territory. Nigeria's climate is well-suited for malaria transmission with a wet season from April to September and temperatures between 25 and 40 degrees Celsius. Transmission in the northern zones lasts 4-6 months per year, while high transmission can occur in parts of the southern zones all year long (30).

Nigeria carries the highest burden of malaria in the world, accounting for more than a quarter of global malaria cases (1). Out of a population of 195 million, 97% is at risk of contracting malaria (31). Almost 110 million malaria cases are treated in health facilities each year, accounting for 60% of outpatient visits and 30% of admissions (32). Prevalence of malaria is much higher when considering asymptomatic cases and those that did not seek care at a health facility. Malaria disproportionately affects pregnant women and young children, accounting for 11% of maternal mortality and 25-30% of infant and under 5 mortality. National malaria data are compiled from a combination of routine health facility reporting through the Health Management Information System as well as periodic health facility and population-based surveys such as the Integrated Management of Childhood Illnesses instrument, Demographic and Health Surveys, and national Malaria Indicator Surveys (29).

Efforts for malaria control and elimination

Global efforts for malaria control and elimination have gained momentum in recent years. 17 countries eliminated malaria between 2000 and 2015, and an additional 19 are approaching elimination, each having reported fewer than 1,000 indigenous cases in 2015 (1). In 2000, the United Nations (UN) established the Millennium Development Goals, a set of 8 goals for improved health, education, and equality to be achieved globally by 2015

(33). Three of the goals either directly or indirectly addressed malaria: Goal 4 to reduce child mortality, Goal 5 to improve maternal health, and Goal 6 to combat HIV/AIDS, Malaria, and other diseases. The goals encouraged endemic countries to scale-up coverage of interventions and treatments to reduce incidence of and mortality from malaria, particularly in vulnerable populations such as pregnant women and children under 5.

Eradication returned to the global agenda in 2008 by way of the Global Malaria Action Plan (GMAP) laid out by the Roll Back Malaria Partnership (RBM) (34). Though still a long way off, GMAP asserted that a malaria-free world is possible through aggressive control in highly endemic countries, progressive elimination from low transmission areas, and continued research into improved interventions and treatments to combat drug resistance (35). In 2015, the UN renewed its dedication toward malaria reduction in Goal 3 of the Sustainable Development Goals which aims to "ensure healthy lives and promote well-being for all at all ages" by reducing maternal mortality, eliminating preventable deaths in children under 5, and ending the malaria epidemic (36). WHO released a new Global Technical Strategy for Malaria in response which aims to reduce malaria incidence and mortality by 90%, eliminate malaria from at least 35 countries, and prevent re-establishment of transmission in malaria-free countries between 2015 and 2030 (37).

Malaria control and elimination efforts in Nigeria are designed and implemented by the National Malaria and Vector Control Division in the Department of Public Health of the Federal Ministry of Health (FMOH). In 2014, the FMOH released its ambitious National Malaria Strategic Plan 2014-2020 (NMSP) and announced changing the National Malaria Control Programme to the National Malaria Elimination Programme (NMEP), promising a future free from malaria (38). Transitioning from control to elimination is no

easy task, but the NMEP has outlined a comprehensive plan involving the scale-up of malaria interventions and investments in improving the national health system to make this dream an eventual reality. Success of the NMSP will depend on integrated community case management, public-private partnerships, and improved surveillance and information management.

Through partnerships with the Global Fund to fight AIDS, TB and Malaria, WHO, and the United Nations Children's Fund (UNICEF), United States Agency for International Development (USAID)/President's Malaria Initiative (PMI), the Malaria Consortium, The Carter Center, and many others, the Nigerian FMOH is equipped to put into action its NMSP to scale up IRS, IPTp, and seasonal malaria chemoprevention (SMC), and to provide universal access to LLINs and prompt treatment. The NMSP laid out broad 2020 goals of reducing mortality by 1/3 and morbidity by 40% from 2015 levels, looking at these specific targets (not full list) (31, 38):

1. ≥80% of households have at least 1 net per 2 people
2. ≥80% of targeted populations (pregnant women and children under 5) sleep under LLINs nightly
3. 100% of pregnant women receive at least 3 doses of SP for IPTp
4. ≥40% of households in targeted areas protected by IRS
5. 100% of all care-seeking people with suspected malaria tested using RDT or microscopy
6. 100% of confirmed malaria cases treated with an effected anti-malarial drug

The Carter Center (TCC) played a critical role in scaling-up malaria interventions through mass distribution of LLINs in seven Nigerian states. TCC involvement in malaria prevention in Nigeria began in 2004 with net distribution integrated in mass drug administration (MDA) for lymphatic filariasis (LF) and onchocerciasis (39). The program successfully enabled sharing of resources to improve net ownership and use without adversely affecting MDA coverage. In coordination with nationwide Malaria Indicator Surveys (MIS) conducted by FMOH in 2010 and 2015, The Carter Center sponsored state-level MIS in Abia and Plateau states in 2010 and 2015 to evaluate the impact of mass net distribution on malaria prevalence and anemia. A mid-term MIS was also conducted in Plateau state alone in 2012.

Specific thesis aims

Mosquito nets (ITNs and LLINs) have been proven to be effective tools in fighting malaria. A Cochrane Review found that sleeping under a bed net improved hemoglobin levels and reduced mortality in children under 5, reduced incidence of uncomplicated malaria by 50%, and provided a 45% protective effect against severe malaria in stable transmission areas (40). However, most net efficacy studies have a limited scope as short-term, randomized controlled trials showing significant protection under ideal conditions of net access and use. In many cases, net ownership is dependent upon wealth index, region of residence, and the presence of a child under 5 in the household, among other factors (41). The Nigerian FMOH announced in its 2009-2013 Strategic Plan a major scale-up of free LLIN distributions, expanding from just targeted populations (pregnant women and children under 5 years) to all households and individuals (42). Few studies have been published examining the effects of such mass distribution campaigns on malaria, and those

that do tend to focus on a particular population such as children under 5 or pregnant women (43). In this thesis, I will fill this gap by comparing net ownership and access, net use last night, malaria prevalence in all individuals, and anemia prevalence in children 10 years and younger at the state-level before and after mass net distribution campaigns. Specifically, I will assess whether an increase in net ownership and use is associated with decreases in malaria and anemia.

While there is early evidence showing that national net distribution campaigns improve overall coverage and equity of net ownership in Nigeria, net use remains low (44). A study conducted in Enugu state in the South-East region of Nigeria found that although most respondents ranked malaria as a high risk overall, they perceived no or low personal or household risk to the disease, making them less likely to use mosquito nets (45). Furthermore, objections to free net distribution campaigns focus on concerns over recipients valuing nets less and misusing them (46, 47). To combat this, The Carter Center piloted a novel behavior change communication (BCC) project aimed at maximizing net ownership, use, and care by emphasizing their dual protection against lymphatic filariasis (LF), a debilitating mosquito-borne disease characterized by severe swelling (particularly in the legs and scrotum) caused by parasitic worms blocking and inducing dysfunction to the lymphatic system(48). This thesis is the first to analyze the results of that project and discuss the potential for similar projects to be implemented in areas endemic for both diseases. Specifically, I will see whether increased knowledge of LF is associated with improved net use in the test site compared to the rest of the state.

Methods

The Carter Center Malaria Control Program and 2010 baseline survey

In 2010, TCC coordinated with state ministries of health in Abia and Plateau States to begin a multi-year evaluation of scale-up of malaria interventions, beginning with a modified malaria indicator survey in September 2010 prior to planned net distribution (49) (Figure 1). The national and Carter Center MIS surveys are timed to coincide with peak malaria transmission season (September-October) across much of Nigeria. Nearly 11.5 million nets have been distributed with Carter Center assistance since 2004 (Figure 2). Nets distributed prior to 2006 were insecticide-treated nets (ITNs) that required periodic retreatment, while nets distributed thereafter were long-lasting insecticidal nets (LLINs). Large-scale distributions occurred in Abia in 2012 and in Plateau in 2010 and 2015. The 2010 survey aimed to measure state-specific baseline prevalence of malaria and anemia as well as net ownership and use.

Results of the 2010 baseline survey found an overall age-adjusted prevalence of *Plasmodium* of 36.1% in Abia and 36.6% in Plateau (49). Among children 10 years and younger, 76.9% were found to be anemic in Abia and 57.1% in Plateau. Net ownership was significantly lower in Abia with 10.1% of households owning at least 1 net and 35.1% of households in Plateau. Only 3.4% and 14.7% of individuals reported sleeping under a net last night in Abia and Plateau, respectively. Mass LLIN distribution was expected to improve access to nets, and follow-up surveys were planned to evaluate progress toward net ownership and use targets and their effects on the disease burden of malaria. The 2015

follow-up survey was designed and conducting using the same methods as those for the 2010 baseline survey described by Noland *et al.* in 2014 (49).

Overview of BCC Project in Kanke LGA

The behavior change communication (BCC) project in Kanke was designed to increase the number of people using LLINs correctly and consistently through the use of community-based behavior change and social mobilization strategies emphasizing net use in preventing both LF and malaria. The BCC project took place in Kanke, one of 17 LGAs in Plateau State with a population of about 122,000. The project consisted of training community directed distributors (CDDs), community volunteers who distribute annual treatments against LF, to supply nets for universal coverage (defined as 1 net per 2 people) and to promote proper net use and care through targeted education about malaria and LF. CDDs conducted home visits on a quarterly basis to monitor net access, use, hanging, and maintenance, and to provide additional nets to reach universal coverage. A midline survey was conducted in Plateau in 2012 before the Kanke BCC project was launched in September 2013 (Figure 3). Kanke was oversampled in both the midline survey in 2012 and the follow-up survey in 2015 to evaluate the potential additional impact of the BCC project.

Follow-up survey study area and sample selection

The follow-up survey was scheduled to take place in September 2014. However, due to Nigeria's response to Ebola cases detected in the country in August of 2014, the MIS survey was postponed until September 2015. Surveys were conducted in Abia State (estimated population 2.9 million) in the South East geopolitical zone and Plateau State

(estimated population 3.2 million) in the North Central zone (50). The malaria transmission season lasts from March to December in Abia and from May to November in Plateau (30).

Cluster sampling was used to select state-level representative samples in Abia and Plateau states and LGA-level samples in Mangu and Kanke LGAs, Plateau state (for analysis of BCC projects). Clusters were defined as census enumeration areas (EA) from the Nigerian National Population Commission. 45 clusters per state were randomly selected, and an additional 20 each from Mangu and Kanke LGAs for a total of 130 clusters (Figure 4). Clusters were expected to have an average of 25 households, but in EAs with a large number of houses, the areas were segmented and a single segment was randomly selected to represent the EA, according to Multiple Indicator Cluster Survey (MICS) methods (51).

All households within selected clusters were eligible for inclusion in the survey. Interviewers revisited vacant households several times in an attempt to include all eligible households. A household was defined as a married man, his wives, and all of his dependents who live with him; an unmarried woman and her dependents; or 2 or more unmarried adults who sleep and share meals in the same living space.

Survey questionnaire

The survey questionnaire was modified from the household and women's questionnaires of the Roll Back Malaria (RBM) Monitoring and Evaluation Group's Malaria Indicator Survey (MIS) and updated to reflect changes in the RBM *Household Survey Indicators for Malaria Control* published in 2012 (52, 53). Questionnaires were translated and printed in Igbo for Abia and Hausa for Plateau, with additional languages available through

translators. Consenting heads of households, or another resident in the event that the head of household could not respond, completed the household questionnaire which covered demographic information and net use for all household residents, education level, household assets and construction, mosquito prevention methods used in the home, (including bed net ownership and care) and knowledge of malaria and LF. Condition of nets was verified by direct observation. One woman of reproductive age (15-49 years) was selected at random from each household to complete an additional women's survey which asked about recent fever in her children and related care-seeking behavior, knowledge of malaria and LF, and recent pregnancy and preventive malaria treatment received during antenatal care visits. Household coordinates were logged using handheld global positioning system units (Garmin eTrex H, Garmen International). The survey protocol was approved by the Emory University Institutional Review Board and the Nigeria Health Research Ethics Committee.

Blood testing

All children 10 years and younger were eligible for blood testing to detect malaria parasites and anemia. Additionally, all residents in every third household were eligible to be tested for *Plasmodium* infection. Verbal informed consent for blood testing was sought from all eligible adults 18 years and older or from parents of minors, and verbal assent was given by minors at least 6 years of age. Households with eligible individuals who were absent on the day of sample collection were revisited later in the day to enable maximum participation.

Plasmodium infection was detected by rapid diagnostic test (RDT) and microscopy. Finger-prick blood samples were collected for RDT to diagnose and treat malaria cases on site. CareStart Malaria HRP2/pLDH combination RDTs (Access Bio, Inc., model G0131) were used according to manufacture instructions to diagnose cases and distinguish between *P. falciparum* and pan-*Plasmodium* infections. Individuals with positive RDT results were offered on-site malaria treatment in accordance with national guidelines: artesunate-amodiaquine (Sanofi-Aventis Groupe) or artemether-lumefantrine (Coartem, Novartis AG) for non-pregnant individuals at least 4 months old, or sulfadoxine-pyrimethamine for pregnant women. Children under 4 months with positive RDT results as well as symptomatic individuals of all ages with negative RDT results were referred to the nearest health facility for further evaluation. Thick and thin blood smears were prepared on the day of sample collection by laboratory technologists. Slides were read by certified laboratory scientists in TCC laboratories located in Owerii in Imo State for Abia samples and Jos in Plateau State for Plateau samples. All positive slides and 10% of negative slides were verified by a WHO-certified microscopist for quality control.

Anemia was detected in children 10 years and younger by measuring hemoglobin (Hb) concentration using handheld spectrophotometers (Hb201+, HemoCue, Inc.). Altitude-adjusted Hb levels were classified as normal or mild, moderate, or severe anemia based on WHO guidelines: mild (10.0 g/dL ≤ Hb 11.0 g/dL), moderate (7.0 g/dL ≤ Hb 10.0 g/dL), severe (Hb < 7.0 g/dL) for children <5 years; mild (11.0 g/dL ≤ Hb 11.5 g/dL), moderate (8.0 g/dL ≤ Hb 11.0 g/dL), severe (Hb < 8.0 g/dL) for children 5-11 years. Children found to have moderate anemia were provided on-site treatment in accordance with national guidelines: presumptive anti-malarial chemotherapy (artesunate-

amodiaquine or artemether-lumefantrine), iron supplementation (iron syrup for children 4 months to 5 years or iron-folate tablets for children less than 5 years), and a single dose 400 mg albendazole for children less than 2 years. Children with severe anemia were referred to the nearest health facility for evaluation and treatment.

Data analysis

Questionnaires were inspected in the field by supervisors before being dually entered into Microsoft Access databases. My participation in the project began here. I compared the raw datasets for consistency using EpiInfo v3.5.4 (Centers for Disease Control and Prevention) and then traveled to The Carter Center office in Jos, Nigeria, to resolve discrepancies between the digital datasets with responses on the original paper questionnaires.

Upon return to the United States, I began cleaning the dataset in preparation for analysis. I converted the Access files to Stata databases (version 14.2 StataCorp LP) and worked through every question on the survey to repair logical inconsistencies. For example, if an individual was listed as a 9-year-old boy from whom blood was taken for anemia testing, he could not have a response for a question about pregnancy and antenatal care. Cleaned datasets were combined based on household-level (e.g. net ownership, household construction, wealth indicators) and individual-level (e.g. age, sex, blood tests, net access and use) information.

To address the complex nature of the cluster survey design, sampling weights were calculated and added to the dataset to use with Stata's SURVEY (SVY) set of commands. This process took into account state and cluster numbers for the 2015 descriptive survey,

and year was added as an additional level of complexity for the impact comparison and BCC project. Descriptive statistics of the 2015 follow-up survey were calculated using the TABULATE (TAB) function for categorical data and the MEANS function for continuous variables. Reported data includes raw counts and weighted point estimates and confidence intervals. For 2 binary categorical variables, the TAB function automatically calculated a χ^2 test of independence and reported an uncorrected χ^2 statistic, a weighted F statistic, and the corresponding p-value. The PROPORTION (PROP) function was used for significance testing in cross-tabulation of nominal categorical variables. LINCOM statements were used after PROP and MEANS functions to detect significant pairwise differences between states, or in the case of the multi-survey comparative analysis, combinations of state and year. The significance threshold and probability of type I error (α) was set to 0.05, but corrected using the Bonferroni method in cases of repeated 2-way tests. Dual- and multi-variable analysis with the LOGISTIC function was used to identify associations between variables.

Prevalence maps were created using ArcMap in ArcGIS (version 10.4.1) from cluster-level *Plasmodium* prevalence. A central geo-coordinate was calculated for each cluster and plotted on an existing map of Nigeria. *Plasmodium* prevalence as detected by microscopy was reported for each cluster and added to the ArcMap shapefile.

A household wealth index was constructed according to the methods of Vyas and Kumaranayake using possession of assets (electricity, household appliances, and modes of transportation), main source of drinking water, type of toilet facility, type of fuel used for cooking, house construction materials, number of rooms in the house, and density of people per room (54). The first principal component was generated and broken into quintiles for

the wealth index. The net indicators “percent of household with at least one net for every two people” and “percent of population with access to a net within a household” were calculated using the methods described by Kilian *et al.* (55).

Results

2015 follow-up survey descriptive statistics

Characteristics of study population

124 clusters out of the selected 130 were sampled in Abia and Plateau States (Figure 4). These clusters contained 1,058 eligible households in Abia (mean number of households per cluster: 23.5; range: 9-36) and 2,001 eligible households in Plateau (mean number of households per cluster: 25.3; range: 11-40). Of these, 955 (90.3%) households in Abia and 1,898 (94.9%) households in Plateau completed the survey. In Abia, 47 households refused to participate in the survey and 56 households were absent for an extended period of time. In Plateau, 33 households refused to participate and 68 were absent for an extended time.

Characteristics of respondent households are shown in Table 1. Households in Abia had an average of 4.8 people (SD=2.0), which was significantly lower than the average 6 people per house in Plateau (SD=4.3, p=0.011). Altitude was significantly higher in Plateau, where 63.2% of households lived above 1000 m, compared to Abia, where 55.2% of households lived below 100 m. The majority (57.3%) of households in Abia were placed in the richest wealth quintile while the majority (51.8%) of households in Plateau were placed in the second and third poorest wealth quintiles.

A total of 4,297 individuals lived in participating households in Abia and 11,618 individuals in Plateau. Demographic characteristics for all individuals are shown in Table 1. Age distributions were similar in both states and approximately 1/3 of all individuals were children under the age of 10 ($p<0.0001$). About half of individuals were female in

both Abia and Plateau (53.1% and 50.2%, respectively). Among women of reproductive age (15-49 years), 6.1% were pregnant in Abia and 7.8% were pregnant in Plateau.

Malaria prevention measures

A summary of household malaria prevention measures by state can be found in Table 2. Less than 1% of households in both Abia and Plateau received IRS in the past 12 months. Net ownership was higher in Plateau than in Abia. Just over half (58.7%) of households in Abia reported owning at least one net, while significantly more households did so in Plateau (85.8%, $p<0.001$). The average number of nets per household was 1.5 (SD=1.4) in Abia and 2.6 (SD=2.2) in Plateau (Figure 5). 70-75% of households without a net in both satates said the reason they lack one is because they did not receive one in the campaign. The states did not differ significantly in percent of households with net availability for all individuals: merely 37.3% of households in Abia had at least 1 net for every 2 people compared to 50.0% of households in Plateau. Considering only households with at least 1 net, ownership of 1 net per 2 people in Abia (63.4%) surpassed that in Plateau (57.9%). Households in Abia had an average of 0.57 (SD=0.56) nets per sleeping space, while households in Plateau had an average of 0.92 (SD=0.64).

In addition to IRS and LLINs, households used other methods against mosquitoes and other insects. In Abia, the most popular prevention measures were spray insecticides (39.1%), mosquito coils or paper (30.3%), otapiapia (15.4%), and piff puff powder (13.5%). The same methods were similarly popular in Plateau: otapiapia (25.9%), mosquito coils or paper (20.8%), spray insecticides (13.3%), and piff puff powder (9.4%). Placing or burning leaves and cream or soap repellant were not commonly used in either state.

A total of 1,384 nets was reported in Abia and 5,876 in Plateau (Table 3). 80-90% of nets were directly observed by interviewers and almost all nets (>90%) were without holes or mends. The vast majority of nets in Abia (83.2%) and Plateau (93.0%) were obtained by households during mass distribution campaigns, while health facilities provided an additional 12.8% of nets in Abia and 3.2% of nets in Plateau. Two-thirds of all nets were less than 1 year old. Less than 10% of nets in Abia have been washed, compared to 36% in Plateau. Among nets that have been washed at least once, approximately 90% in both states have been washed fewer than 6 times.

Use of household nets was significantly higher in Plateau compared to Abia ($p<0.0001$; Table 4). Only 52.4% of all nets owned were reported ever having been used, while 84.3% of nets in Plateau had been used for sleeping at least once. Reasons for never having used the nets for sleeping were different between states. In Abia, the most common reasons were that people do not like the nets (33.9%), there were no mosquitoes present (20.8%), and the nets were being saved for later (15.7%). In Plateau, households responded saving the net for later (47.0%), already having enough nets (18.1%), and having no place to hang the net (14.4%) most frequently. Among nets that had been used to sleep in at least once, 80-85% were used last night in both states.

Overall net use was just under a quarter of all individuals in Abia (24.2%), while nearly two-thirds of all individuals in Plateau reported sleeping under a net last night (65.6%). Reported net use was lower in children under 5 than in all individuals in Abia at just 20.9%, but it was higher in Plateau at 73.5%. Net use in pregnant women was significantly higher in Plateau (68.0%) than in Abia (16.8%, $p<0.0001$).

Considering only individuals with access to a net, reported use was still significantly higher among all individuals in Plateau (82.3%) compared to Abia (44.3%, p<.0001). The most common reason provided in both states for not using a net was that it is too hot (Abia: 39.5%, Plateau: 29.3%), followed by travel in Plateau (19.1%) and lack of mosquitoes in Abia (10.1%). Among targeted populations, 40.6% of children under 5 in Abia slept under a net last night and 29.9% of pregnant women. In Plateau, 90.3% of children under 5 were reported to have used a net and 81.0% of pregnant women.

Plasmodium prevalence

Plasmodium prevalence was measured by microscopy and rapid diagnostic test (RDT) for all children 10 years and younger and individuals of all ages in every third household. Malaria prevalence was similar by RDT in Abia (30.6%, 95% CI: 29.4-37.9) and Plateau (35.0%, 95% CI: 29.1-41.4; Table 5). Age-adjusted prevalence by microscopy differed significantly between states and was lower in Abia (26.4%, 95% CI: 20.1-31.5) than in in Plateau (43.4%, 95% CI: 39.9-46.9). Concordance of results among valid RDT and microscopy slides was low in both Abia and Plateau. In Abia, 1,047 of 1,457 valid tests were in agreement (71.9%) and 3,644 of 5,395 valid tests were in agreement in Plateau (67.5%). Age group-specific prevalence was significantly higher in children under 5 (p<0.001), children 5-9 years (p=0.001), and adults 20-49 years (p<0.001) in Plateau compared to Abia (Figure 6). Cluster-level *Plasmodium* prevalence by microscopy is shown in Figure 7. While range of cluster-level prevalence was wider in Abia (0-100%) than Plateau (15-76%), most clusters in Abia fell below 40%, while half of the clusters in Plateau were between 40 and 60%. 80 to 85% of all infections were *Plasmodium falciparum*, with the rest being *P. malariae* and co-infections of the two species.

Pairwise associations were calculated between microscopy-detected *Plasmodium* infection and demographic data and net use. In Abia, *Plasmodium* infection was significantly associated with age (χ^2=26.84, p=0.0047). Prevalence was highest in the 5-9 and 15-19 age groups and lowest in the 20-49 and 50+ age groups. Infection in Abia was not significantly associated with socioeconomic status (p=0.0727) or net use (p=0.2689). *Plasmodium* infection in Plateau was also significantly associated with age (p=0.0047) as well as net use (p=0.0305) and socioeconomic status (p=0.0032). Prevalence was highest in the 5-9 age group and lowest in the 50+ age group, highest in the poorest wealth quintile and lowest in the richest, and higher in non-net users. *Plasmodium* infection was not significantly associated with sex or elevation in either state.

Anemia prevalence

The mean age- and altitude-adjusted hemoglobin concentration for children less than 11 years old was lower in Abia at 9.9 g/dL (SD=1.9) versus Plateau at 10.8 g/dL (SD=1.7), although the difference was non-significant (p=0.482). There was no significant difference between percent of children with anemia (any type) between Abia (58.3%) and Plateau (52.5%, p=0.1964). Anemia was split almost evenly between mild, moderate, and severe cases in both states (p=0.3083; Table 6). Microscopy-detected *Plasmodium* prevalence was significantly associated with anemia in both states, with 73.4% of children with malaria also anemic in Abia (p<0.0001) and 63.7% in Plateau (p<0.0001). Anemia was significantly higher among children under 5 than children 5-10 years in Plateau (p=0.0001) but there was no significant association between age and anemia in Abia (p=0.9702). In Abia, anemia was higher among boys than girls (p=0.0019), but no significant association

between anemia and sex was seen in Plateau (p=0.1241). Anemia was significantly and inversely associated with wealth index in both states (Abia: p=0.0013; Plateau: p=0.0261).

Malaria treatment in targeted populations

The women's survey asked respondents to answer several questions about recent fevers (within 2 weeks) in their children (<11 years of age) and subsequent behavior in seeking care and treatment. Additionally, the questionnaire asked mothers who had a live birth in the past 2 years about antenatal care attendance and reception of intermittent preventive treatment. Pooling all children of female respondents, there was a total of 1,191 children under 11 in Abia and 2,662 in Plateau (Table 7). Half (50.0%) of the children in Abia were reported to have had a fever in the last 2 weeks compared to less than a quarter of children in Plateau (23.5%). Mothers reported seeking care for feverish children in 40.0% of cases in Abia and 69.9% of cases in Plateau. More than half (54.8%) in Abia sought care at a private clinic or health facility compared to 38.9% in Plateau. About 30% of children with fever in each state were taken to a government health facility, and 23% in Plateau were taken to a private hospital. Among those children for whom care was sought, only 14.7% in Abia were tested for malaria compared to 28.5% in Plateau. Regardless of whether children were taken for care and tested for malaria, mothers responded that almost all feverish children in Abia (98.9%) and Plateau (94.3%) received some form of treatment. Most frequently (Abia: 36.9%, Plateau: 50.2%), children were given Paracetamol for fever reduction, while 23% in both states were given an artemisinin-based combination therapy (ACT) and an additional 6.5% in Plateau and 7.9% in Abia were given either quinine or Fansidar for treatment of malaria. Mothers did not know or forgot the drug given to their child in almost one third of cases.

Among female respondents, 281 had given a live birth in the past 2 years in Abia and 649 in Plateau (Table 8). 97.0% of those in Abia sought prenatal care compared to 86.9% in Plateau. Women in Abia most frequently saw a doctor for antenatal care (ANC; 46.8%), while women in Plateau usually sought care from a nurse or midwife (52.6%). Regardless of ANC visits, 76.4% of women with a recent live birth in Abia reported having taken a drug to prevent malaria during pregnancy versus only 46.2% of women in Plateau. Most women who reported taking a drug to prevent malaria in pregnancy in Abia did not know what drug they took (69.7%), while 19.5% reported taking SP/Fansidar. In Plateau, 48.0% of women reported taking SP/Fansidar during pregnancy and 45.3% did not know what drug they took. Considering only women who received ANC, 15.4% in Abia and 25.2% in Plateau said they took SP/Fansidar for IPTp, and among those, 84.8% in Abia and 47.9% in Plateau received at least 3 doses.

Knowledge of malaria and LF

Respondents were asked to name symptoms of malaria, knowledge of which is crucial in identifying the disease and seeking prompt care. Questionnaires also asked about causes and prevention of lymphatic filariasis (big legs/elephantiasis, large scrotum) to gauge understanding of the dual protection of mosquito nets against both diseases. Relevant responses are recorded in Table 9. 53.4% of respondents in Abia identified the characteristic fevers of malaria compared to 44.8% in Plateau. Other non-specific flu-like symptoms were commonly named including chills, aches, headache, and fatigue. Barely 1% of respondents in each state listed anemia as a possible symptom of malaria. Respondents to the women's questionnaire were also asked to name the antimalarial drug

recommended by FMOH. 18.1% in Abia and 15.4% in Plateau correctly answered an ACT, while almost 60% of women could not name any antimalarial drug.

Knowledge of LF was quite limited, with more than 50% of respondents in each state answering "Don't know" to questions about big legs and large scrota. Respondents in Plateau knew significantly more about LF than respondents in Abia. In Plateau, mosquito bites were identified as the cause of transmission by 9-14% of respondents compared to only 1-1.5% of respondents in Abia. Fewer, 1-3% in Plateau and ~0.5% in Abia, said that worms or parasites are the actual cause of lymphedema. A greater number of respondents in Plateau also mentioned sleeping under a mosquito net to prevent LF (8-12%) than in Abia (1%). Respondents in Abia were more likely to say that they take drugs during MDA to prevent LF (2-3%) than sleep under a mosquito net. In general, respondents in both states were more knowledgeable about LF in the context of big legs than large scrota.

Baseline and follow-up survey comparative analysis

Net ownership and use

Net ownership increased significantly in both states from 2010 to 2015 (Figure 8). At baseline, barely 10% of households in Abia owned even 1 net, increasing 6-fold to almost 60% of households in 2015 ($p<0.001$, Figure 8A). Ownership of at least 2 nets increased from just 2% of households in 2010 to 45.5% in 2015 ($p<0.001$). Households with at least 1 net per 2 people rose from 1.4% in 2010 to 37% in 2015 ($p<0.001$). Improvements in net ownership were similar in Plateau where baseline coverage was higher (Figure 8B). 85% of households had at least 1 net in 2015 compared to 35% in 2010 ($p<0.001$). The majority of households (69%) also had at least 2 nets in 2015 versus only 14.5% in 2010 ($p<0.001$).

Half had one net for every 2 people in the household in 2015, a significant improvement from just 6.3% in 2010 ($p<0.001$).

Individual access to a net was not measured in 2010, so net use was compared first among individuals living in households that owned at least 1 net and then among individuals living in all households. Net use among all individuals in Abia increased from 27.6% in 2010 to 41.3% in 2015, ($p=0.006$; Figure 9A). Net use did not change significantly in targeted populations where only 34-38% of children under 5 and about 30% of pregnant women reported sleeping under a net last night ($p=0.311$ and $p=0.882$, respectively). There was significant improvement in net use by all individuals in Plateau from 40 to 75% ($p<0.001$; Figure 9B). Net use in children under 5 increased significantly from 52.6% in 2010 to 84% in 2015 ($p<0.001$). The amount of pregnant women who reported having slept under a net last night rose to 77.2% in 2015 from 62.7% in 2010, but the difference was not significant ($p=0.114$).

Taking into account households without nets as well, reported net use was lower in all individuals, but improvements from 2010 to 2015 were significant (Figure 10). Net use increased in most categories in both states, including children under 5 and pregnant women (Plateau only), where net use was 3 to 4 times higher in 2015 compared to 2010. From only 3.4% in 2010, net use among all individuals in Abia increased to 24.2% in 2015 ($p<0.001$; Figure 10A). Net use in targeted populations rose from about 6% in 2010 to 20.9% among children under 5 and 16.8% among pregnant women in 2015 ($p<0.001$ and $p=0.156$, respectively). In Plateau, 65.6% of all individuals reported having slept under a net last night in 2015 compared to 14.7% in 2010 ($p<0.001$; Figure 10B). Targeted populations

increased net use from about 20% in 2010 to 73.5% among children under 5 and 68% among pregnant women in 2015 ($p<0.001$ and $p<0.001$, respectively).

Prevalence of malaria and anemia

In Abia, there was a significant decrease in age-adjusted malaria prevalence from 36 to 26%, detected by microscopy ($p=0.001$). Prevalence decreased the most in children 5-9 years old from 42% in 2010 where it had been highest to 27% in 2015 ($p=0.001$; Figure 11A). Significant decreases were also seen in children under 5 and adults aged 20-49 ($p=0.001$ and $p<0.001$, respectively). 2015 *Plasmodium* prevalence was relatively even among children and adolescents in Abia, and lower among adults. While Plateau had a similar baseline prevalence to Abia of 36.6%, age-adjusted malaria prevalence increased to 43% in 2015, although the change was non-significant ($p=0.934$; Figure 11B). Broken down by age group, the largest increases were seen in adults, with a significant increase from 22 to 34% in 20 to 49 year olds, and a non-significant increase from 20 to 28% in adults 50 years and older ($p<0.001$ and $p=0.100$, respectively). The highest prevalence in Plateau remains in children under 10 years.

Similar to the reduction of *Plasmodium* prevalence in Abia, a significant 22% decrease in anemia was detected in children 10 years and younger ($p<0.001$; Figure 12A). Mean age and altitude adjusted hemoglobin concentrations increased from 9.9 (SD=1.9) grams per deciliter in 2010 to 10.7 (SD=1.2) in 2015. Like malaria, anemia in Plateau did not change significantly from 2010 to 2015 and only a 9% change was detected ($p=0.365$; Figure 12B). Mean hemoglobin concentration remained just under 11 grams per deciliter

between 2010 and 2015. Classification of anemia includes mild, moderate, and severe cases.

Evaluation of BCC Project in Kanke LGA

Net ownership and use

Kanke LGA in Plateau State was oversampled to evaluate impact of BCC projects supplementing mass net distribution. Comparisons were made between Kanke LGA and the rest of Plateau State for 2010, 2012, and 2015 (note: Kanke was not oversampled in 2010 baseline survey, so 2010 Kanke data are derived from the 95 clusters in Kanke randomly included in the 2010 state-wide Plateau survey). Net ownership, that is, households owning at least 1 net, was significantly higher in Kanke LGA compared to the rest of Plateau State all years of the survey. In 2010, before mass distribution campaigns, 82.0% of households in Kanke already owned at least 1 LLIN compared to just 33.0% in the rest of Plateau ($p<0.001$). After the first state-wide distribution campaign, 96.6% of households in Kanke and 73.7% in Plateau reported owning at least 1 net ($p<0.001$). By 2015, 95.5% of households in Kanke LGA had at least 1 net compared to 85.5% in the rest of Plateau State ($p=0.007$).

The Kanke BCC project operated under a goal of universal coverage, defined as at least 1 net for every 2 people in each household. Significant improvements in universal coverage were seen in Plateau each survey year, but only increased significantly from 2010 to 2012 in Kanke and not after initiation of the BCC project (Figure 13). At baseline, only 5.6% of households in Plateau had at least 1 net for every 2 people compared to almost a quarter in Kanke ($p=0.013$). Following the first round of net distributions in 2011, the

proportion of households with universal net coverage in Kanke increased significantly to 59.8% ($p<0.001$). A similar increase was seen in the rest of Plateau, rising to 34.9% of households ($p<0.001$), but coverage was still significantly lower than in Kanke ($p<0.001$). After initiation of the BCC project, universal coverage in Kanke rose to 69% of households, significantly higher than the 49% of households covered in Plateau ($p=0.003$).

Net use in all households followed a same trend as with net ownership. Kanke LGA started out with higher reported net use than the rest of Plateau State and improved over time (Figure 14). Net use for all individuals started at 33% in 2010 and rose significantly to 74.3% in 2012 ($p<0.001$). In both of these years, net use was significantly higher in Kanke than Plateau which only had 14% use in 2010 and 48% in 2012 ($p<0.001$). There was no significant change in net use from 2012 to 2015 in either area (Kanke: $p=0.308$; Plateau: $p=0.012$), nor was there a significant difference between the areas in 2015 ($p=0.032$). The same trends held for net use in children under 5 and pregnant women, but use was generally higher in these targeted populations. Net use in children under 5 was 43.5% at baseline and rose significantly to 84.7% in 2012 ($p<0.0010$), and both years were significantly higher than in Plateau that saw a significant increase from 17.3% in 2010 to 57.8% in 2012 ($p<0.001$). Net use did not change significantly from 2012 to 2015 in Kanke ($p=0.716$) or Plateau ($p=0.060$), and no significant difference was detected between these areas in 2015 ($p=0.139$). Among pregnant women, net use in Kanke LGA rose significantly from 46% in 2010 to 75% in 2012 ($p<0.001$) and in the rest of Plateau from 17% to 48% ($p<0.001$). No significant changes occurred from 2012 to 2015. Since over 95% of households owned at least 1 net by 2012, this population was not extracted for net use analysis, as results were not markedly different from those reported.

Prevalence of malaria and anemia

Again, we looked into the impact that scaled-up interventions had on prevalence of malaria and anemia. *Plasmodium* prevalence, although slightly higher in 2015 than in 2010, as seen before, has additional depth when considering the 2012 survey data. From 2010 to 2012, prevalence as detected by microscopy dropped from 43% to 19% in Kanke LGA before rising back up to 41% in 2015 (Figure 15). A similar trend was observed in the rest of Plateau State where malaria prevalence fell significantly from 37% in 2010 to just 20% in 2012 ($p<0.001$), but then rose again significantly to 44% in 2015 ($p<0.001$).

Anemia does not follow the same trend as malaria, and is actually higher in 2012 than the other years. This difference was significant in Kanke LGA, where age- and altitude-adjusted anemia rose from 58% in 2010 to 69% in 2012 before dropping back down to 51% in 2015 ($p<0.001$; Figure 16). The change in anemia prevalence between surveys was non-significant in the rest of Plateau State where anemia remained between 50 and 57% for all years of the survey.

Knowledge of malaria and LF

Respondent heads of households in Kanke LGA and Plateau State were asked to answer a series of questions to assess their basic knowledge of malaria and LF (Table 10). These responses were only provided for the 2012 and 2015 surveys. The BCC project emphasized the shared causes of malaria and LF and how to prevent both diseases using a single bed net intervention.

Knowledge of possible malaria symptoms varied only slightly between Kanke and Plateau. The percent of respondents who identified fever as a symptom of malaria actually

decreased in Kanke LGA, though the difference was non-significant (p=0.143), and decreased significantly in Plateau State (p<0.001) from 2012 to 2015. While the proportion was higher in Kanke than Plateau in 2012 (76.9% vs 75.3%, respectively), Plateau surpassed Kanke in 2015 (66.1% vs 61.6%, respectively). Both differences were non-significant (2012: p=0.654; 2015: p=0.493). There were no significant differences in symptoms identified between 2012 and 2015 within Kanke LGA, but significantly more respondents provided chills and headache as symptoms of malaria in Plateau State in 2015 compared to 2012 (p=0.016 and p=0.001, respectively). Significantly more respondents provided body aches and pains as symptoms in 2015 in Plateau compared to Kanke (p<0.001). Very few individuals knew that anemia is a possible symptom of malaria, just 1.6% in Kanke and 1.1% in Plateau in 2015, and there were no significant differences between 2012 and 2015.

Baseline 2012 knowledge of LF was higher in Kanke compared to the rest of Plateau even before the BCC project began. Respondents in both areas were less knowledgeable about the causes and prevention of large scrotum than they were about big legs. In Kanke LGA, almost 50% of respondents in 2015 knew that mosquito bites cause big legs, a non-significant improvement from 37.6% in 2012 (p=0.143). In the rest of Plateau State, this knowledge increased significantly from 8.9% of respondents in 2012 to 19.5% in 2015 (p<0.001), but still remained significantly lower compared to Kanke (p<0.001). The proportion of respondents attributing big legs to worms or parasites was much lower, just 4-6% in 2015. There were significant improvements in knowledge of mosquito bites as the cause of large scrotum from 2012 to 2015 in both areas (Kanke: 16.7-30.1, p=0.007; Plateau: 5.8-12.6, p=0.003), but it was still more than twice as high in Kanke

in 2015 compared to Plateau. The proportion of respondents who knew that worms or parasites cause large scrotum was lower in Kanke at baseline (0.4% vs 2.1%), but surpassed Plateau in 2015 (3.3% vs 1.8%), although the differences were non-significant. Knowledge of the use of mosquito nets to prevent LF (big legs and large scrotum) was significantly higher among Kanke respondents in 2015 compared to Plateau (big legs: $p<0.001$; large scrotum: $p=0.013$), although significant yearly improvements were seen in Plateau overall (big legs: $p<0.001$; large scrotum: $p=0.002$) and not specifically in Kanke (big legs: $p=0.254$; large scrotum: $p=0.067$). Only knowledge of the role of mosquito nets in preventing large scrotum was significantly associated with net use in Kanke ($p=0.0122$).

Discussion

The multi-year malaria impact survey conducted by The Carter Center and state Ministries of Health in Abia and Plateau states, Nigeria, measured baseline malaria prevalence, anemia, and intervention coverage and tracked changes following state-wide mass net distribution campaigns. This study was the first of its kind in Nigeria, as most malaria indicator surveys conducted by the Federal Ministry of Health report at the national or zone level. Furthermore, the surveys evaluated a novel behavior change communication project piloted in Kanke LGA to assess the impact of regular net distribution, education, and monitoring.

Nigeria has set a target to reach universal net coverage (defined as at least 1 net per 2 people) in 80% of households by 2020 (42). Significant progress has been made since 2010 due to the scale-up of net distributions, but both Abia and Plateau remain well below the 2020 goal. Net ownership of at least 1 LLIN increased 6-fold in Abia to 60%, while Plateau only experienced a 2.5-fold increase to 85%. The difference in magnitude of increased net ownership is likely due to the smaller-scale Carter Center-supported net distributions that have been ongoing in Plateau since 2004 providing a much higher 2010 baseline level. Our data are consistent with the 2015 National MIS that found that 55.2% of households in the North Central Zone (78.3% in Plateau) and 63.3% in the the South East Zone (50.6% in Abia) owned at least 1 LLIN in 2015 (56).

Net coverage at follow-up was understandably higher in Plateau because of the second distribution before the 2015 survey. However, even after this second round, 15% of households still did not own even 1 net and half did not reach universal coverage. Plateau

had an average of 2.6 nets per household and 0.5 nets per person, which should theoretically be enough to cover all individuals at 1 net per 2 people. Average net ownership was slightly lower in Abia with 1.5 nets per household and 0.4 nets per person. The net distribution process should be re-examined to ensure that households are receiving enough nets to cover all occupants.

Nets provide little protective effect against malaria if they are not being used for sleeping, so households were asked to report net use by all individuals who slept in the house the previous night. Overall net use increased significantly from baseline to follow-up, mostly due to increased net availability. Both states reported higher net use in this 2015 survey than the 2015 National MIS. 30% of individuals in the North Central Zone reported using a net in the national survey compared to 65.6% in The Carter Center's survey (56). Looking at only respondents from Plateau, the 2015 MIS reported slightly higher net use at 38.4%. Reported net use in Abia according to this survey (24.2%) was well above that in the MIS (6.6%), but it did not differ significantly from overall net use in the whole South East Zone (21.0%). We found net use in Plateau to be above the national estimate of 37.2%, while Abia was below.

Individuals can only sleep in a net as long as one is available to them, so we broke net use down to look at just individuals living in households owning at least one net. Although concerns were raised over reducing the perceived value of nets as a result of free distribution, significant improvements in net use were seen in both Abia and Plateau. This indicates that access to nets and their cost were likely prohibitive for many households that would have liked to use them. Even with this encouraging increase in net use, we have to address those who own nets but do not use them, more than 50% in Abia and 25% in

Plateau. The chief complaint against nets is that they are too hot. The fine mesh that prevents mosquitoes from accessing human hosts also prevents light breezes from cooling sleepers during the hot season. Since electric fans and air conditioning are rare commodities in most households, my best suggestions for addressing the heat of sleeping under a net would be to increase space between occupants to reduce body heat or to keep windows open at night to air out the home. Some individuals opt to sleep outside when heat inside the home is too intense, but this can be problematic as hanging a net outside becomes more difficult. Many households also used other mosquito prevention measures that have the potential to protect the whole household without requiring individuals to sleep under a stuffy net. However, these alternative interventions, such as otapiapia and mosquito coils, are not quite as effective as they do not provide a physical barrier between vector and host. Additionally, these interventions are not provided by national campaigns and are not reusable like nets, requiring substantial out-of-pocket payments to be made regularly by households utilizing these alternatives.

The FMOH emphasized reaching 80% net use for children under 5 and pregnant women, populations experiencing a high burden of malaria and greater risk for severe malaria and death (56). This target was met or nearly met for targeted populations in Plateau in 2015 among households owning at least 1 net. In Abia, net use was well below the 80% target in children under 5 and pregnant women, and was even lower than the net use among all individuals, indicating that some households prioritize older individuals (not including pregnant women) for use of nets. This may be due to higher prevalence of malaria in children and adolescents 5-19 years old.

Unlike with LLINs, coverage of indoor residual spraying as a malaria intervention has not improved. There is very little IRS in both states, less than 1%, and no change in the 5 years between surveys. The FMOH set a 2020 goal of 45% IRS coverage in targeted areas where there is high prevalence of malaria and low utilization of nets (56). Since this IRS scale-up only began in 2014, implementation had not yet begun in most states. According to the 2015 National MIS, only 1.3% of households throughout the country received IRS in the past 12 months.

Despite significant improvements in LLIN ownership as a result of mass net distribution campaigns, *Plasmodium* prevalence remains high in Abia and Plateau states. While age-adjusted malaria prevalence did decrease significantly in Abia from 36% to 26%, it did not reach the FMOH goal of 50% reduction by 2013. Plateau made even less progress with a non-significant increase from 37% in 2010 to 43% in 2015. While many individuals reported sleeping under a net the night before the survey, this information could not be verified by interviewers, and we have no way of knowing whether nets were used consistently throughout the transmission season for all hours the mosquitoes were actively biting. Failing to do this would result in only partial protection.

The 2015 National MIS only reported data on malaria in children under 5 because cases are generally thought to be concentrated in this young population. However, our results show that malaria may be more prevalent in older children and adolescents. Significant associations were detected between age and infection in both Abia and Plateau. Misconceptions about the age of individuals affected by malaria may have resulted in lower net use by older age groups and an increase in malaria among adults over 20 years old in Plateau. Future net campaigns should emphasize the importance of net use for individuals

of all ages and the FMOH should consider expanding surveillance of malaria in national surveys to older age groups as well to detect shifts in prevalence.

Plasmodium infection was only significantly associated with net use in Plateau and not Abia. This is surprising considering the magnitude of increase in net use in Abia due to increased ownership and the significant reduction that was observed. In Plateau, net use increased significantly, but not to the magnitude of Abia, and *Plasmodium* prevalence actually increased, though non-significantly. This may indicate that reported net use in Abia is not a good reflection of actual practice. While respondents may have reported sleeping in a net the previous night, they were not asked to provide information on the time they went to bed or whether the net was hung properly. Additionally, as a cross-sectional study, it is difficult to draw conclusions from associations because *Plasmodium* infection would have to have occurred several days before the survey in order to reach a level detectable in the blood, but only the previous night's sleep in a net was inquired about.

Both the FMOH and TCC surveys detected *Plasmodium* infection by RDT and microscopy. RDT detected much greater prevalence than microscopy in the FMOH survey (add values), while the tests provided closer prevalence in our results (56). Higher RDT prevalence in other surveys has been attributed to antigen persistence after treatment or detection of submicroscopic infections (57). Different RDTs were used by TCC and the FMOH which may have had different sensitivities. The FMOH only reports *P. falciparum* infections as detected by its single-plex RDT, while TCC utilizes a combination RDT that can detect *P. malariae* as well. Although *P. falciparum* is the predominant species in Nigeria, multi-species RDTs should be used as more than 15% of cases were identified as *P. malariae* or co-infections of multiple species in this survey. While the FMOH survey

did not report concordance of RDT and microscopy results, I was able to calculate it for TCC data and found it to be fairly low at just about 70% in both states. Since concordance was similar in both states, it is unlikely due to systematic error between teams in collecting and reading samples. Concordance was much lower in 2015 than in 2010 and further exploration by TCC teams is needed to discover the cause.

Anemia is a major complication in children with malaria, affecting nearly 60% of children 10 years and younger in Abia and just over 50% in Plateau. Anemia dropped significantly in Abia from 2010 to 2015 reflecting the similar change in *Plasmodium* prevalence. However, anemia in Plateau actually decreased slightly in contrast to the increase in malaria, though both differences were non-significant. This may be due to changes in the many other causes of childhood anemia, some of which include malnutrition (particularly iron deficiency) and infection with certain helminths (58). Additionally, state-wide MDA for lymphatic filariasis concluded in Plateau in 2012, which was likely preventing many cases of anemia not associated with malaria. It is concerning that only 1% of respondents identified anemia as a potential symptom of malaria, and education regarding this important problem should be addressed in future malaria campaigns. The 2015 National MIS only reported on severe anemia in children under 5, but prevalence was similar with that of our survey for that particular population. Due to the high prevalence of malaria in the 5-10 year age group, our survey also measured anemia in these children and found anemia to be just as common as in children under 5. The FMOH may need to expand its anemia testing and treatment to older children as well to address the entire high burden population.

In addition to anemia, fever was common among children. Half of the children in Abia and nearly a quarter of children in Plateau were reported to have had a fever in the 2 weeks preceding the survey. These estimates are consistent with the 2015 National MIS that found 30% of children recently had a fever in the North Central zone (containing Plateau) and almost 40% in the South East zone (containing Abia) (56). Three-quarters of children with fever were reported to have been taken for care in these zones, but our data show lower care-seeking behavior. Just 41% of children with fever in Abia were taken for care, while 70% of children in Plateau were. These differences are likely due to different attitudes and access to care in different states of the North Central and South East zones. The FMOH recommends that all care-seeking individuals with suspected malaria (i.e. presenting with fever) receive a blood test, but only 15% did so in Abia and 30% in Plateau. The FMOH should look into reasons behind this low adherence to policy and ensure that sufficient quantities of RDTs are available in health facilities and staff are adequately trained in their use. Further recommendations by the FMOH state that all confirmed malaria cases be treated with an effective antimalarial drug appropriate for the severity of the case and the state of the patient. In most cases of uncomplicated malaria, artemisinin combination therapies are recommended, specifically artemether-lumefantrine or artesunate-amodiaquine. However, among children who received treatment for their fever, less than 25% in Abia and Plateau received an ACT. The FMOH should work with health facilities to ensure that appropriate treatment is available when needed and that substandard drugs are not being administered.

The FMOH and WHO recommend that pregnant women receive intermittent preventive treatment (IPTp) at antenatal care (ANC) visits to reduce the incidence of

malaria during pregnancy and the detrimental birth outcomes associated with placental malaria (56). Ideally, all women attending ANC should receive at least 3 doses of sulfadoxine-pyrimethamine (SP). According to the most recent national survey, 46.6% of all women who had a live birth in the past 2 years received at least 1 dose of SP for IPTp. Only 19% received the recommended 3 or more doses. In our survey, 87-97% of women who had a live birth in the past 2 years attended ANC, but only 15% in Abia and 25% in Plateau reported receiving any SP for IPTp. However, among those who received any IPTp in Abia, 85% received at least 3 doses of SP, meeting the FMOH recommendation. Less than 50% of women who received any IPTp in Plateau received the recommended 3 or more doses. It appears that when IPTp is given, the full regimen is often adhered to, giving pregnant women maximum protection against malaria. It is likely that when fewer then 3 doses were received, the woman attended fewer than 3 ANC visits. Future surveys should explore reasons why many women were not given any IPTp during ANC. Possibly, women only attended ANC when they were early in pregnancy and could not yet receive IPTp, but this probably does not account for all cases. The FMOH should ensure that all ANC facilities are stocked with SP and that healthcare providers are educated on the importance and proper administration of IPTp. Furthermore, awareness of the benefits of IPTp should be spread throughout villages so that pregnant women are aware of the treatment and can ask for it at ANC visits knowing that it is safe for them and the baby.

The BCC project in Kanke provided an additional layer of complexity and understanding of annual trends relating to malaria prevalence and prevention. A midline survey was conducted in Plateau state, with oversampling in Kanke LGA, following the first round of net distribution but before the BCC project was initiated. The midline survey

shows significant annual variation in *Plasmodium* prevalence that is missed when looking at just the 2010 baseline and 2015 follow-up surveys. Malaria reduced by almost half from 2010 to 2012 before rising back to baseline levels by 2015. Knowing that changing weather patterns can have a large impact on mosquito populations and subsequently malaria transmission, I searched for extreme weather patterns that may have affected *Plasmodium* prevalence and found severe that severe flooding devastated parts of Nigeria in the months leading up to the survey (59). However, due to its high altitude, Plateau state was not affected as severely as surrounding states. Unfortunately, neither a national MIS or DHS was conducted in 2012, making it difficult to interpret the malaria situation in Plateau in the context of the rest of the country.

Net ownership was already significantly higher in Kanke LGA compared to the rest of Plateau State at baseline, and continued to rise following mass net distributions. However, the BCC project aimed to reach universal coverage for all households through quarterly inspection of household nets, but only 69% of households had at least 1 net per 2 people at the time of the follow-up survey. Kanke had more success in reaching net use targets as use by all individuals, children under 5, and pregnant women all reached or exceeded 80%. These advances cannot be attributed specifically to the BCC project because there was no significant change in net use before and after implementation of the project. Kanke had higher ownership and use due to a long history of integrated MDA for LF and net distribution for malaria. The project would have been better tested in a LGA that did not have such above-average intervention coverage so that baseline levels were closer to the state average and clearer conclusions can be made from the resultant data.

We were interested in measuring a potential association between knowledge regarding the causes and prevention of LF and net use. Overall, changes in knowledge of LF were non-significant in Kanke, but knowledge that mosquito bites cause large scrotum did improve significantly, almost doubling from 16.7% to 30.1%. This increase was not associated with an increase in net use. However, knowledge that mosquito nets could be used to prevent large scrotum was significantly associated with increased net use, indicating a disconnect between identified risks and ways to prevent them. No other LF knowledge was significantly associated with net use in Kanke, although respondents were significantly more knowledgeable about LF than respondents in the rest of Plateau State. Again, since baseline knowledge was also much higher than Plateau, it is difficult to attribute improvements to the BCC project. However, detecting a significant association between net use and knowledge of mosquito nets preventing large scrotum is encouraging, and I would recommend that similar BCC projects be piloted in areas with lower baseline knowledge and intervention coverage.

All malaria surveys of this sort have limitations, and this study is no exception. First, the surveys represent a cross-sectional prevalence of malaria and anemia at different time points, and cannot be extrapolated to annual incidence rates. Each of the Carter Center surveys described here was conducted in September of the given year, the peak of seasonal malaria transmission in Abia and Plateau. The National MIS was completed in October and November of 2015, partially explaining some of the variation between the 2015 surveys as *Plasmodium* transmission is highly dependent on seasonal changes and net use varies with perceived risk of malaria (60). Although the survey instruments were field tested, they were conducted by a different team in each state, potentially introducing

systematic error. Malaria surveys are dependent on self-reported data for many indicators which could not be verified by interviewers. Visual inspection of nets was performed when possible to determine if a net had ever been used, but net use the previous night, recent fever in children, and IPTp in pregnant women, among others, could not be confirmed. Finally, different lengths of time elapsed before the follow-up surveys in Abia and Plateau, which may explain some of the differences in coverage between the states. Net ownership was much lower in Abia 3 years after state-wide net distributions because the majority of nets were only kept for about 1 year. In Plateau, nets were kept for the same amount of time, but the second distribution in 2015 provided replacements for many of the older nets. We did not measure household ownership immediately after net distributions to know how effective campaigns were in reaching all households. Furthermore, the second net distribution in Plateau took place only 1 month before the 2015 follow-up survey was conducted, so this very recent increase in net ownership may not yet have taken effect in preventing malaria.

This thesis provides the first multi-year survey data comparing malaria prevalence, anemia, and intervention coverage at the state-level in Nigeria before and after mass LLIN distributions. The data show significant improvements in net ownership and use that are on track to reach FMOH targets by 2020. Changes in malaria prevalence and anemia were less substantial, but significant decreases were seen in Abia. A significant association between net use and *Plasmodium* prevalence was observed in Plateau, but not Abia. The BCC project in Kanke LGA did not reveal any significant associations between LF knowledge and net use, but it did reveal significant annual variation in malaria prevalence and gaps in net distribution coverage. The FMOH and partners seem to be distributing enough nets to

theoretically protect all vulnerable populations in Nigeria, but inequity in distribution and attitudes against use must be addressed. Periodic net distributions are needed to replace worn out nets and health facilities need to be stocked with appropriate diagnostic tests and treatment to provide prompt patient care. With multi-party cooperation and determination, Nigeria can continue to reduce malaria and work toward eventual elimination.

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Tables

Table 1. Characteristics of study households and individuals in Abia and Plateau states, Nigeria, 2015

	Abia	Plateau
Number of clusters sampled	45	79
Household characteristics		
Number of households sampled	955	1898
Mean (SD) number of people per household	4.8 (2.0)	6.0 (4.3)
Mean (SD) number of sleeping spaces per household	3.1 (1.7)	3.0 (2.2)
Altitude		
<100m (%)	55.2	1.8*
100-1000m (%)	44.8	35.0
>1000m (%)	0	63.2*
Household wealth index, quintiles		
Poorest (%)	0.9	17.7*
Second (%)	1.7	24.3*
Third (%)	7.6	27.5*
Fourth (%)	42.4	18.7
Richest (%)	57.3	11.8*
Individual characteristics		
Number of persons in sampled households	4,297	11,618
Age		
<5yrs (%)	19.7	17.9
5-9yrs (%)	13.6	16.0
10-14yrs (%)	9.6	12.6*
15-19yrs (%)	6.0	9.3*
20-49yrs (%)	36.6	36.2
≥50yrs (%)	14.4	8.1*
Sex		
Female (%)	53.1	50.2
Pregnant women, self-reported (% of all individuals/% of women age 15-49)	1.4/6.1	1.8/7.8

*statistically significant difference between states (t-test, α=0.05)

Table 2. Household malaria prevention measures in Abia and Plateau states, Nigeria, 2015

	Abia % (95% CI)	Plateau % (95% CI)
All households	n=955	n=1,897
Households that received IRS in past 12 months	0.1 (0.0, 0.6)	0.6 (0.2, 1.8)
Households owning at least one net	58.7 (53.3, 63.9)	85.8 (77.5, 91.4)*
Households owning two or more nets	45.5 (40.2, 50.9)	69.2 (58.1, 78.5)*
Households with at least one net for every two people	37.3 (30.8, 44.2)	50.0 (39.0, 61.0)
Population with access to net within household[1]	50.7 (45.3, 56.2)	73.8 (64.5, 82.6)*
Households using other mosquito prevention measures (multiple responses possible)		
Otapiapia	15.4 (11.7, 19.9)	25.9 (20.3, 32.5)
Piff Puff (powder)	13.5 (7.0, 24.5)	9.4 (5.8, 14.7)
Mosquito coils/paper	30.3 (18.2, 46.0)	20.8 (15.1, 26.4)
Spray cans	39.1 (34.9, 43.5)	13.3 (9.9, 17.5)
Place leaves in house	1.7 (0.6, 4.6)	2.4 (1.0, 5.5)
Burn leaves in house	2.3 (0.9, 6.2)	1.7 (0.8, 3.5)
Soap/cream repellant	0.2 (0.0, 1.0)	2.2 (1.4, 3.5)
Households owning at least 1 net	n=547	n=1,756
Households with at least one net for every two people	63.4 (54.7, 71.2)	57.9 (47.8, 67.4)
Population with access to net within household[1]	86.2 (83.7, 88.7)	85.5 (80.8, 90.2)

[1]Assuming each net used by 2 people

*statistically significant difference between states (F-test, α=0.05)

Table 3. Net characteristics in sampled households in Abia and Plateau states, Nigeria, 2015

	Abia (n=1,384) % (95% CI)	Plateau (n=5,876) % (95% CI)
Nets observed by interviewer	81.6 (74.3, 87.2)	90.5 (86.5, 93.5)*
Nets with holes	3.3 (2.2, 5.1)	6.9 (5.0, 9.4)*
Nets with mends	1.4 (0.5, 4.0)	3.9 (2.7, 5.6)
Net age		
<12 months	76.3 (52.7, 90.2)	78.8 (72.4, 84.0)
12-24 months	10.4 (3.7, 26.0)	8.4 (5.5, 12.6)
25-36 months	0.6 (0.1, 2.3)	1.1 (0.4, 3.0)
>36 months	8.0 (4.3, 14.4)	6.4 (4.4, 9.4)
Not sure	4.8 (1.7, 12.6)	5.2 (3.5, 7.7)
Source of nets		
Mass distribution campaign	83.2 (72.0, 90.4)	93.0 (87.1, 96.3)
Health facility	12.8 (6.2, 24.7)	3.2 (1.3, 7.8)
Other	4.0 (3.0, 5.4)	3.8 (1.9, 7.2)
Nets ever washed	9.2 (6.4, 13.1)	35.9 (29.7, 42.5)*
Number of washes (among nets ever washed)		
1-5 times	91.1 (73.1, 97.5)	88.8 (85.3, 91.5)
>5 times	7.9 (2.0, 26.3)	7.7 (5.4, 10.9)
Not sure	1.0 (0.2, 5.0)	3.5 (2.2, 5.5)

*statistically significant difference between states (F-test, α=0.05)

Table 4. Reported net use[1] in sampled households in Abia and Plateau states, Nigeria, 2015

	Abia		Plateau	
	n	% (95% CI)	n	% (95% CI)
Household net use				
Nets ever used for sleeping	1,384	52.4 (42.5, 62.2)	5,876	84.3 (80.0, 87.8)*
Reasons why net never used for sleeping	589		1,014	
No mosquitoes		20.8 (11.3, 35.2)		3.1 (1.2, 8.1)*
No malaria		9.1 (2.3, 30.0)		0.1 (0.0, 0.8)*
Don't like nets		33.9 (29.2, 39.0)		9.1 (4.2, 18.4)*
Saving for later		15.7 (5.4, 37.6)		47.0 (31.5, 63.2)*
Already have enough nets		1.7 (0.5, 5.7)		18.1 (9.2, 32.4)*
No place to hang net		7.1 (5.3, 9.4)		14.4 (9.2, 21.8)*
Using for other purpose		12.7 (5.8, 25.6)		0.4 (0.1, 2.6)*
Don't know how to hang		1.4 (0.3, 6.7)		2.8 (0.9, 8.7)
Other		15.2 (9.6, 23.4)		7.9 (3.7, 15.9)
Unknown		6.9 (2.9, 15.5)		1.7 (0.4, 7.5)
Nets used last night - nets ever used	795	81.1 (70.0, 88.7)	4,862	85.6 (81.6, 88.9)
All individuals				
All individuals	4,297	24.2 (20.1, 28.9)	11,618	65.6 (53.8, 75.8)*
Children <5 years	730	20.9 (15.1, 28.1)	1,972	73.5 (59.9, 83.8)*
Pregnant women	68	16.8 (6.8, 35.8)	197	68.0 (52.7, 80.1)*
Individuals with access to a net				
All individuals	2,225	44.3 (37.6, 51.1)	10,090	82.3 (75.1, 87.7)*
Reasons why individual did not sleep in net last night	1,159		1,526	
No mosquitoes		10.1 (7.2, 14.0)		3.8 (1.6, 8.4)*
Too hot		39.5 (26.6, 54.0)		29.3 (15.9, 47.6)
Don't like the smell		6.4 (2.6, 15.0)		4.6 (1.6, 12.4)
Feel "closed-in"/afraid		1.6 (0.4, 5.6)		2.2 (0.6, 7.8)
Being washed		0		5.2 (2.6, 10.2)*
Got home too late/too dark		0.0 (0.0, 0.5)		1.5 (0.5, 4.4)
Other person didn't want to use		0.3 (0.0, 2.6)		3.1 (0.9, 9.8)
No place to hang/slept outside		2.3 (0.7, 7.8)		11.5 (7.1, 17.9)*
Traveling		2.0 (0.5, 7.0)		19.1 (12.3, 28.3)*
Other		33.9 (14.0, 61.9)		13.7 (7.8, 23.1)
Unknown		3.8 (2.7, 5.6)		6.2 (3.4, 11.0)
Children <5	367	40.6 (30.7, 51.3)	1,780	90.3 (86.2, 93.3)*
Pregnant women	37	29.9 (12.5, 56.1)	179	81.0 (69.5, 88.9)*

[1]reported having slept in a net the previous night
[2]pregnancy in women is self-reported
*statistically significant difference between states (F-test, α=0.05)

Table 5. Age-adjusted malaria prevalence in sampled individuals by rapid diagnostic test and microscopy, Abia and Plateau states, Nigeria, 2015

	Abia		Plateau	
	n	% positive (95% CI)	n	% positive (95% CI)
Rapid diagnostic test	1,457	30.6 (24.1, 37.9)	5,395	35.0 (29.1, 41.1)
Microscopy	1,651	26.4 (20.1, 31.5)	5,853	43.4 (39.9, 46.9)*
Concordance		71.9%		67.5%

*statistically significant difference between Plateau and Abia (OR=2.13, p<0.001)

Table 6. Anemia classification in children less than 11 years of age in Abia and Plateau states, Nigeria, 2015

	Abia (n=1,387) % (95%CI)	Plateau (n=3,960) % (95%CI)
Normal[1]	41.7 (37.4, 46.1)	47.5 (39.8, 55.4)
Mild[2]	18.2 (16.2, 20.4)	17.4 (15.3, 19.2)
Moderate[3]	19.8 (17.4, 22.6)	17.6 (14.5, 21.1)
Severe[4]	20.3 (18.7, 22.0)	17.6 (12.9, 23.5)

[1]For age <5 years: hemoglobin (Hb) ≥11.0g/dL; for age 5-11 years: Hb≥11.5g/dL
[2]For age <5 years: 10.0g/dL<Hb<11.0g/dL; for age 5-11 years: 11.0g/dL<Hb<11.5g/dL
[3]For age <5 years: 7.0g/dL<Hb<10.0g/dL; for age 5-11 years: 8.0g/dL<Hb<11.0g/dL
[4]For age <5 years: Hb<7.0g/dL; for age 5-11 years: Hb<8.0g/dL

Table 7. Care-seeking behavior and treatment of feverish children 10 years and younger

	Abia		Plateau	
	n	% (95% CI)	n	% (95% CI)
Fever in past 2 weeks	1,191	50.0 (34.6, 65.4)	2,662	23.5 (17.2, 31.3)*
Sought care[1]	398	41.0 (38.1, 43.9)	638	69.9 (59.2, 78.7)*
Tested for malaria[2]	176	14.7 (9.9, 21.3)	456	28.5 (18.0, 42.0)*
Received treatment for fever[1]	398	98.9 (94.9, 99.8)	638	94.3 (90.9, 96.5)*
Drugs taken for fever[3] (multiple responses possible)	384		600	
ACT (Coartem/AA)		22.5 (17.5, 28.3)		23.0 (15.0, 33.7)
S/P Fansidar		6.5 (5.1, 8.3)		1.6 (0.6, 4.1)*
Quinine		1.4 (0.3, 6.4)		4.9 (2.3, 10.4)
Paracematol		36.9 (31.5, 42.5)		50.2 (37.4, 63.0)
Other		17.3 (14.4, 20.7)		22.7 (15.1, 32.8)
Unknown		30.7 (26.8, 34.9)		33.1 (20.3, 49.1)

[1]Among children with fever
[2]Among children who sought care; blood from finger or heel stick tested by RDT or microscopy
[3]Among children who received treatment for fever
*statistically significant difference between states (F-test, α=0.05)

Table 8. Antenatal care and intermittent preventive treatment among women who gave a live birth in the past 2 years.

	Abia		Plateau	
	n	% (95% CI)	n	% (95% CI)
Attended at least 1 prenatal care visit	281	97.0 (90.5, 99.1)	649	86.9 (81.2, 91.1)*
Took drugs to prevent malaria	281	76.4 (72.0, 80.4)	649	46.2 (38.7, 53.9)*
Drug taken (multiple possible)	221		337	
SP/Fansidar		19.5 (14.9, 25.1)		48.0 (36.4, 59.8)*
Chloroquine		1.6 (0.4, 5.8)		4.6 (1.4, 14.1)
Other		9.2 (7.0, 11.9)		6.0 (2.9, 12.2)
Unknown		69.7 (62.8, 79.5)		45.3 (35.7, 55.2)*
Received SP for IPTp[2]	266	15.4 (11.4, 20.4)	575	25.2 (18.2, 26.4)
Number of SP doses[3]	47		155	
1 dose		1.4 (0.2, 11.3)		29.1 (17.4, 44.4)*
2 doses		13.8 (4.2, 36.8)		23.0 (15.9, 32.1)
>=3 doses		84.8 (60.7, 95.3)		47.9 (33.9, 62.2)*

[1]Among women who reported taking any drug to prevent malaria during pregnancy
[2]Among women who reported seeking antenatal care
[3]Among women who received SP for IPTp
*statistically significant difference between states (F-test, α=0.05)

Table 9. Knowledge of malaria and lymphatic filariasis among respondent women and heads of households in Abia and Plateau states, Nigeria, 2015

	Abia (n=1,330) % (95% CI)	Plateau (n=2, 632) % (95% CI)
Malaria		
Possible symptoms of malaria		
Fever	75.9 (68.8, 81.8)	65.2 (58.8, 71.0)*
Chills	25.2 (20.0, 31.1)	38.7 (33.3, 44.4)*
Aches/body pain	32.6 (27.3, 38.3)	36.9 (32.7, 41.3)
Headache	57.7 (46.4, 68.3)	57.6 (51.7, 63.3)
Fatigue	21.8 (16.6, 28.2)	25.7 (20.6, 31.7)
Diarrhea	0.9 (0.3, 2.5)	8.3 (6.2, 11.1)*
Vomiting	10.1 (8.3, 12.2)	26.0 (22.0, 30.5)*
Anemia/low blood	1.5 (0.4, 5.2)	1.7 (0.9, 3.4)
Convulsions	0.2 (0.0, 0.9)	2.0 (1.2, 3.5)*
Other	18.1 (12.0, 26.5)	16.2 (10.5, 24.0)
Don't know	1.94 (1.5, 2.5)	6.9 (4.0, 11.7)*
Treatment for malaria (women's survey only)		
ACT (AL/AA/CoArtem)	15.3 (8.1, 27.1)	17.6 (11.9, 25.3)
SP	0.6 (0.1, 3.2)	7.0 (3.4, 13.8)*
Chloroquine	2.5 (0.8, 8.0)	4.0 (1.7, 9.0)
Amodiaquine	0.3 (0.0, 1.5)	3.1 (1.0, 9.2)*
Quinine	0.2 (0.0, 1.6)	5.0 (1.6, 14.2)*
Other	2.1 (0.6, 7.5)	1.4 (0.6, 3.0)
Don't know	79.9 (62.3, 90.5)	76.5 (68.4, 83.1)
Lymphatic filariasis		
Causes of big legs (elephantiasis)		
Mosquito bites	2.1 (0.7, 6.0)	20.0 (16.5, 24.0)*
Worms/parasites	0.7 (0.2, 2.0)	5.4 (3.4, 8.6)*
Prevention of big legs		
Sleep inside a mosquito net	1.5 (0.4, 5.0)	16.9 (13.8, 20.5)*
Take drugs/MDA	3.1 (1.0, 9.4)	7.0 (4.9, 10.0)
Causes of large scrotum		
Mosquito bites	1.2 (0.4, 4.1)	12.9 (9.9, 16.5)*
Worms/parasites	0.3 (0.1, 1.5)	1.8 (1.0, 3.1)*
Prevention of large scrotum		
Sleep inside a mosquito net	1.1 (0.3, 3.5)	11.4 (8.3, 15.4)*
Take drugs/MDA	2.6 (0.8, 7.9)	5.5 (3.7, 8.2)

* statistically significance between Abia and Plateau (F-test, α=0.05)

Table 10. Knowledge of malaria and lymphatic filariasis among respondent heads of households in Kanke LGA and Plateau State, Nigeria, 2012 and 2015

	Kanke LGA		Plateau State	
	2012 % (n=429)	2015 % (n=510)	2012 % (n=1,335)	2015 % (n=1,388)
Malaria				
Possible symptoms of malaria				
Fever	76.9	61.6	75.3	66.1*
Chills	38.8	31.8	29.5	39.1*
Aches/body pain	29.5	24.4	33.1	38.1^{+}
Headache	50.2	51.6	45.7	59.8*
Fatigue	24.1	18.2	22.4	26.1
Diarrhea	9.0	6.4	7.1	8.3
Vomiting	31.9	34.7	20.8	26.0
Anemia/low blood	1.2	1.6	0.6	1.1
Convulsions	2.4	1.0	3.4	2.0
Other	19.3	21.2	15.6	17.1
Don't know	7.6	9.6	5.7	6.1
Lymphatic filariasis				
Causes of big legs (elephantiasis)				
Mosquito bites	37.6	48.9	8.9	19.5*$^{+}$
Worms/parasites	3.2	4.1	4.9	6.0
Prevention of big legs				
Sleep inside a mosquito net	27.5	34.2	6.2	16.4*$^{+}$
Causes of large scrotum				
Mosquito bites	16.7	30.1*	5.8	12.6*$^{+}$
Worms/parasites	0.4	3.3	2.1	1.8
Prevention of large scrotum				
Sleep inside a mosquito net	12.2	19.8	4.4	10.8*$^{+}$

* statistically significant difference between 2012 and 2015 (t-test, Bonferroni-corrected α=0.017)

$^{+}$ statistically significant difference between Kanke LGA and Plateau State, 2015 (t-test, Bonferroni-corrected α=0.017)

Figures

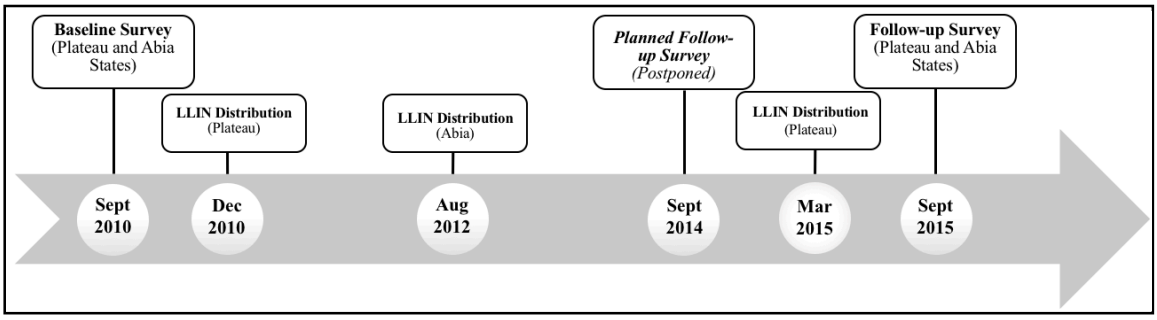

Figure 1 Multi-year survey timeline in Abia and Plateau states, Nigeria. Baseline survey conducted in September 2010 in Abia and Plateau prior to mass net distributions. Follow-up survey planned for 2014, but postponed due to Ebola outbreak. Follow-up survey completed in September 2015 to evaluate scale-up of recommended malaria interventions in Abia and Plateau States, Nigeria.

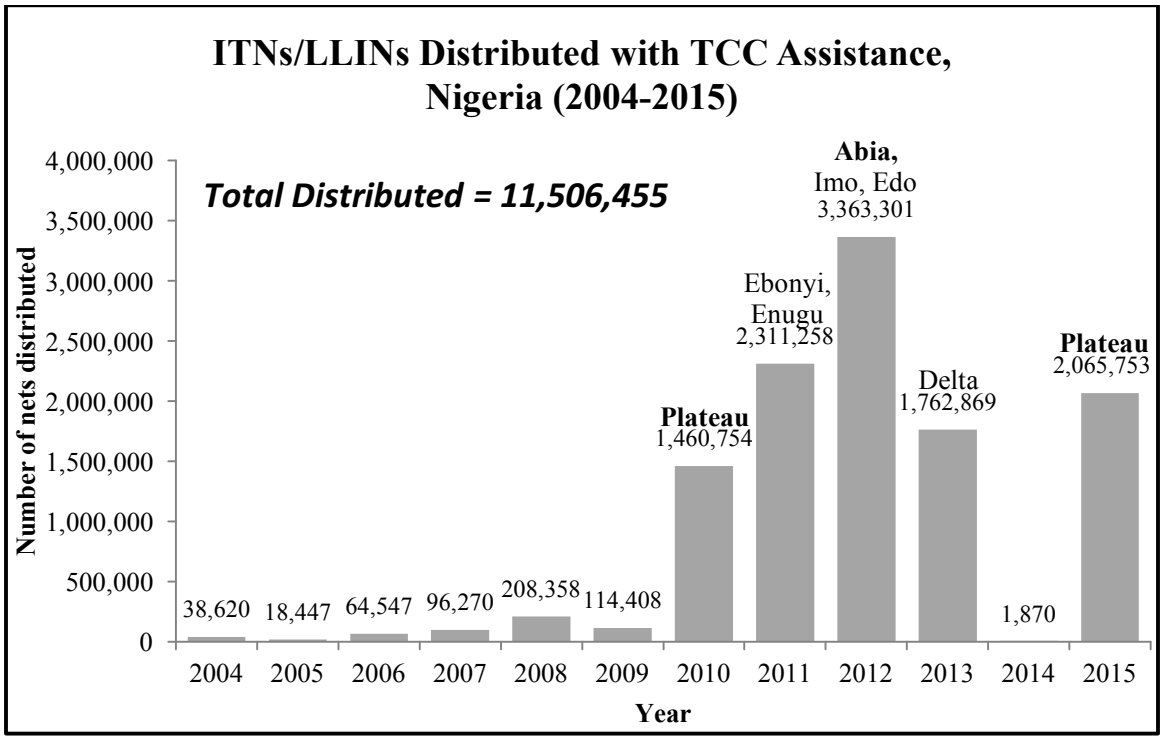

Figure 2 TCC-Assisted net distribution in Nigeria. Annual number of insecticide treated nets (ITNs) and long-lasting insecticidal nets (LLINs) distributed in Nigeria with support from The Carter Center between 2004 and 2015. All nets distributed since 2006 have been LLINs. However, the nets distributed prior to 2006 were ITNs that required periodic re-treatment. Large-scale distributions took place in Abia in 2012 and in Plateau in 2010 and 2015.

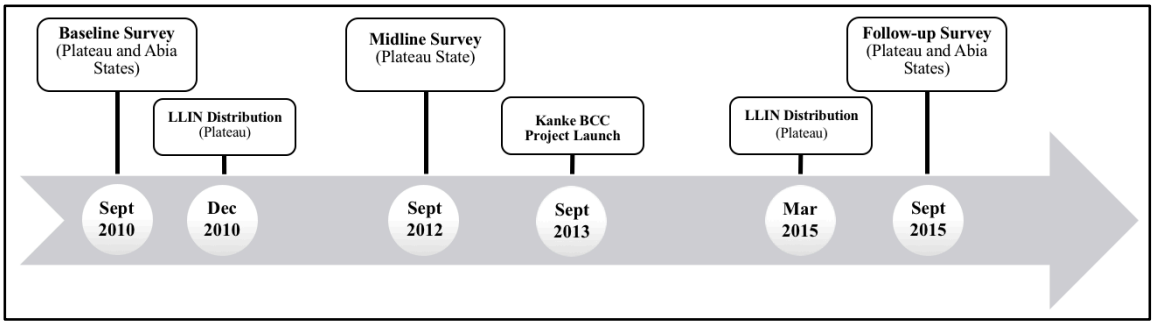

Figure 3 Survey timeline to assess behavior change project in Kanke LGA. A midline survey was conducted in Plateau in 2012 before the Kanke BCC project was launched in September 2013. Kanke was oversampled in both the midline survey in 2012 and the follow-up survey in 2015 to assess the impact of BCC accompanying mass net distributions.

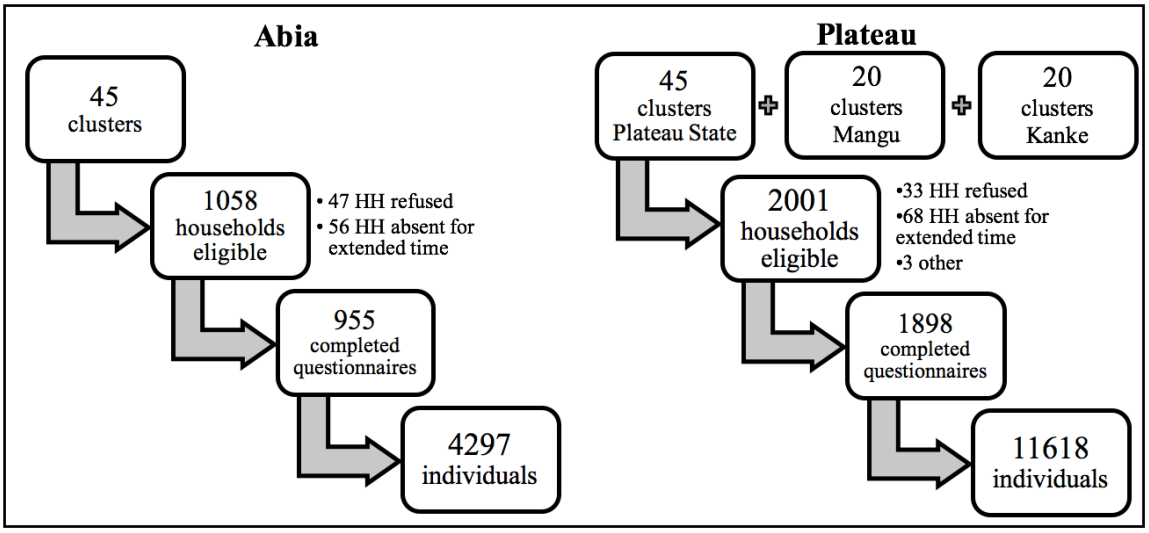

Figure 4 Cluster sampling design of 2015 follow-up survey in Abia and Plateau states, Nigeria. 45 clusters were randomly sampled from each Abia and Plateau states, with an additional 20 clusters from each Mangu and Kanke LGAs. All 1,058 households in selected Abia clusters and 2,001 households in selected Plateau clusters were eligible to participate in the survey. 955 households completed the survey in Abia for a total of 4,297 individuals and 1,898 households completed the survey in Plateau for a total of 11.618 individuals.

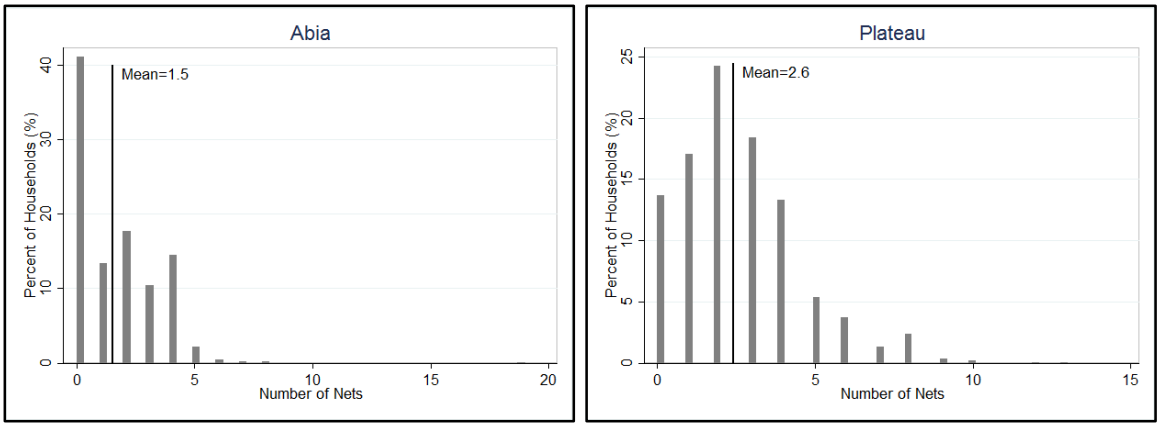

Figure 5 Frequency distribution of nets per household in Abia and Plateau states, Nigeria, 2015. (A) Households in Abia owned an average of 1.5 nets (SD=1.4, range: 1-19). 41.2% (95% CI: 36.0-46.6) of households did not own a net. (B) The average number of nets per household was 2.6 (SD=2.2, range: 0-13) in Plateau and 13.7% (95% CI: 8.6-21.1) of households did not own any nets.

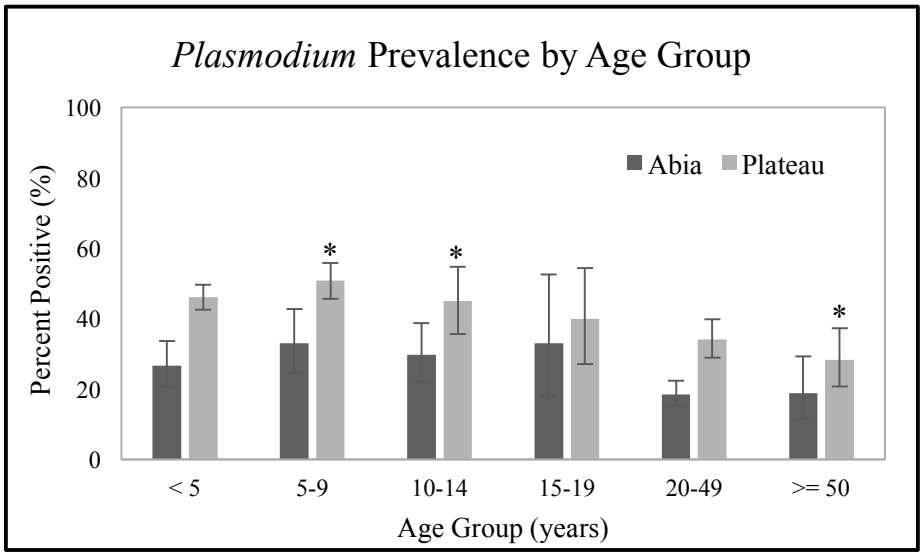

Figure 6 *Plasmodium* Prevalence by age group in Abia and Plateau States, Nigeria, 2015. Age group-specific prevalence as detected by microscopy. Prevalence was significantly higher in children under 5 ($p<0.001$), children 5-9 years ($p=0.001$), and adults 20-49 years ($p<0.001$) in Plateau compared to Abia. * indicates statistically-significant difference between Abia and Plateau (Bonferroni-corrected $\alpha=0.008$).

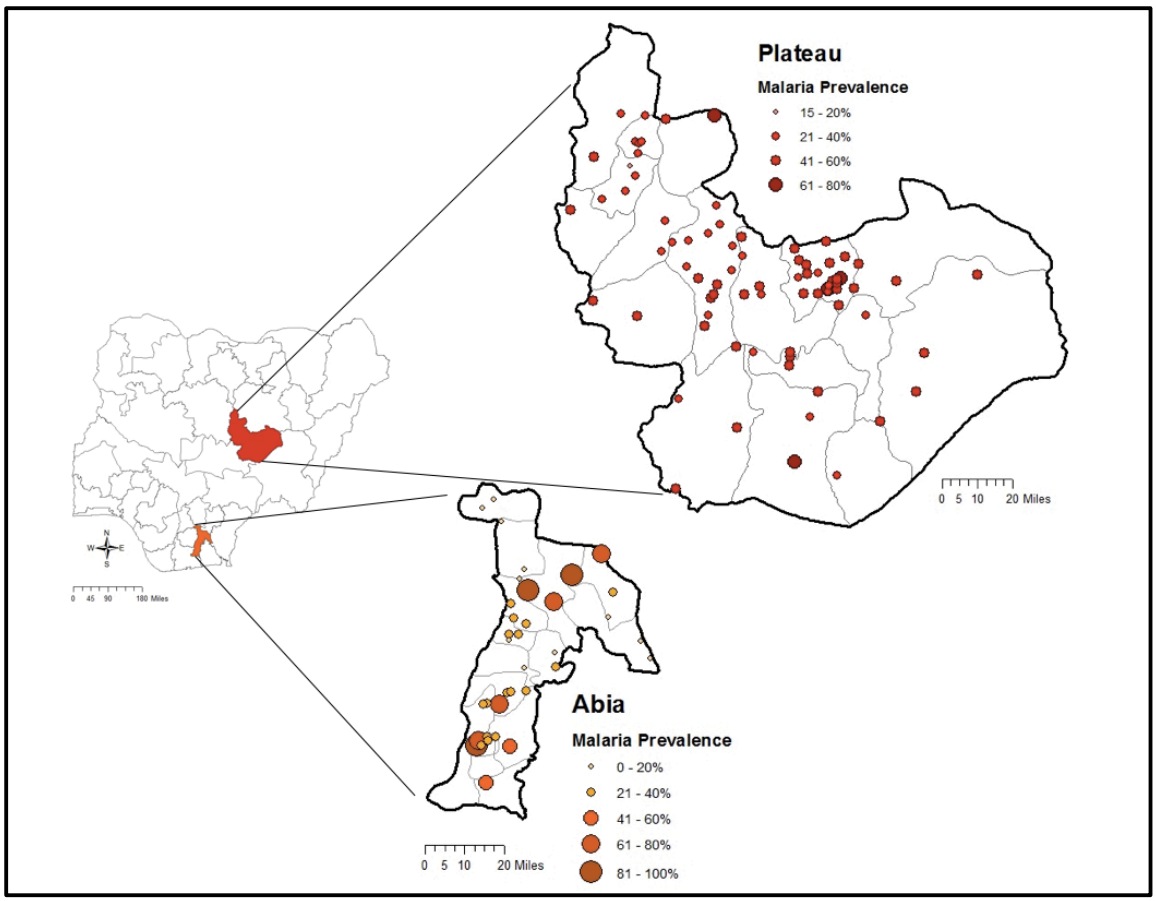

Figure 7 Map of cluster-level malaria prevalence in Abia and Plateau states, Nigeria, 2015. Cluster-level age-adjusted *Plasmodium* prevalence ranged from 0% to 100% in Abia and 15% to 76% in Plateau. Although there was a wider spread of prevalence in Abia compared to Plateau, most clusters in Abia fell below 40%, while half of the clusters in Plateau were between 40 and 60%.

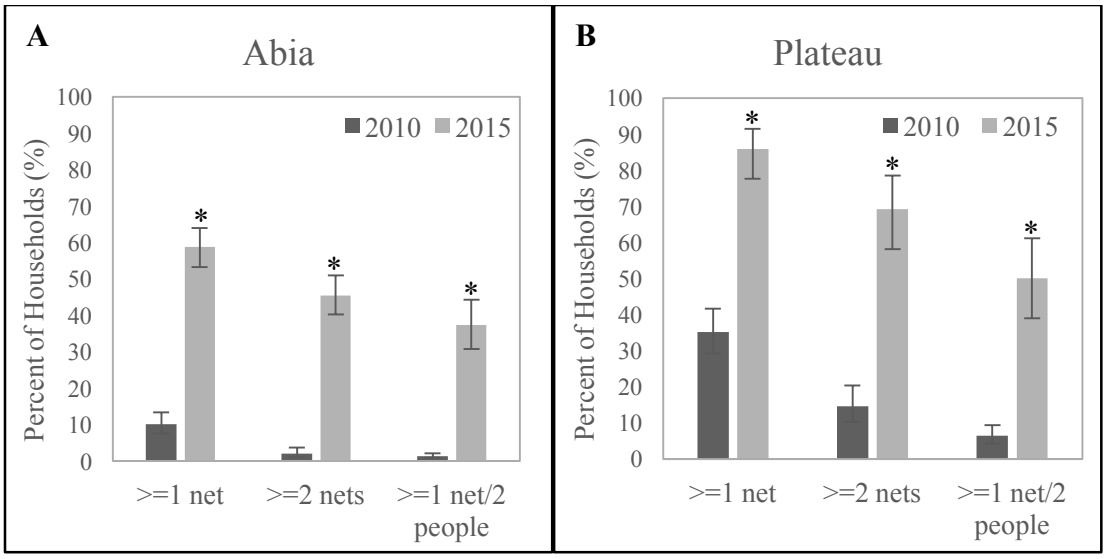

Figure 8 Household net ownership, 2010 baseline vs 2015 follow-up in Abia and Plateau states, Nigeria. Impact of mass net distribution campaigns on net ownership in (A) Abia and (B) Plateau. Significant increases from 2010 to 2015 in all categories in both states, indicated by * (α=0.05). (A) 6-fold increase of households owning at least 1 net from 10% to almost 60%. Households owning at least 1 net for every 2 people increased from less than 2% in 2010 to 37% in 2015. (B) 86% of households owned at least 1 net in 2015, up from 35% in 2010. Half of households owned at least 1 net per 2 people in 2015 compared to 6% in 2010.

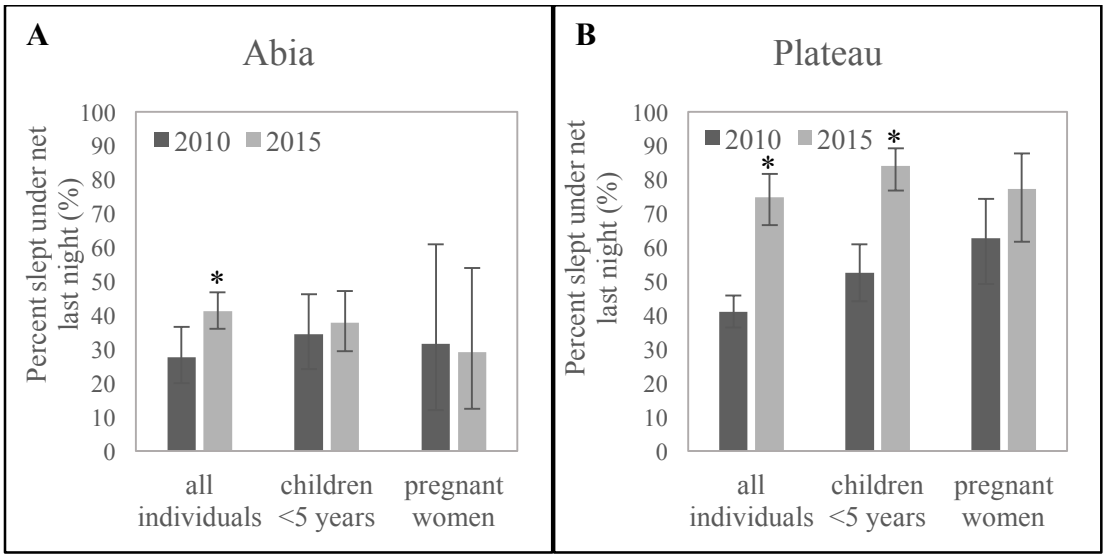

Figure 9 Reported net use among individuals living in households with at least 1 net in Abia and Plateau states, Nigeria, 2010 vs 2015. (A) Increase in net use among individuals living in households with at least 1 net in Abia from 27.6% to 41.3%. No significant difference in net use among targeted populations, remaining near 35% in children under 5 and 30% in pregnant women. (B) Increase in net use among all individuals in Plateau from 41.1% in 2010 to 74.9% in 2015. Net use increased significantly among children under 5 from 52.6% to 84% and non-significantly among pregnant women from 62.7% to 77.2%. * indicates statistically significant difference between 2010 and 2015 (α=0.05).

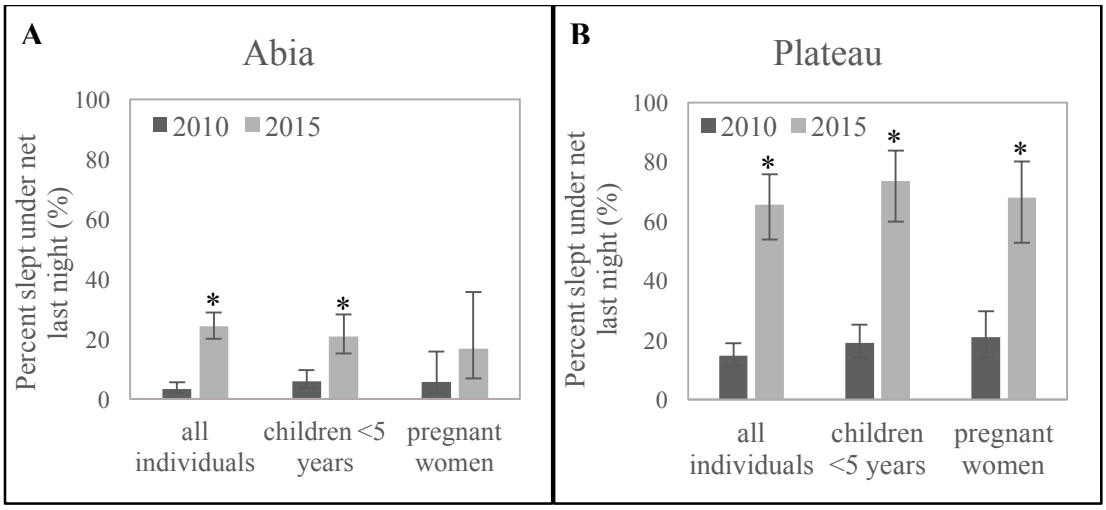

Figure 10 Net use among individuals living in all sampled households in Abia and Plateau states, Nigeria, 2010 vs 2015. (A) Net use increased for all individuals from 3.4% to 24.2% in Abia. Net use among children under 5 also increased significantly from 6.0% to 20.9%, but there was no significant improvement among pregnant women. (B) Net use increased significantly in all groups in Plateau from 15-20% in 2010 to 65-75% in 2015. * indicates statistically significant difference between 2010 and 2015 (α=0.05).

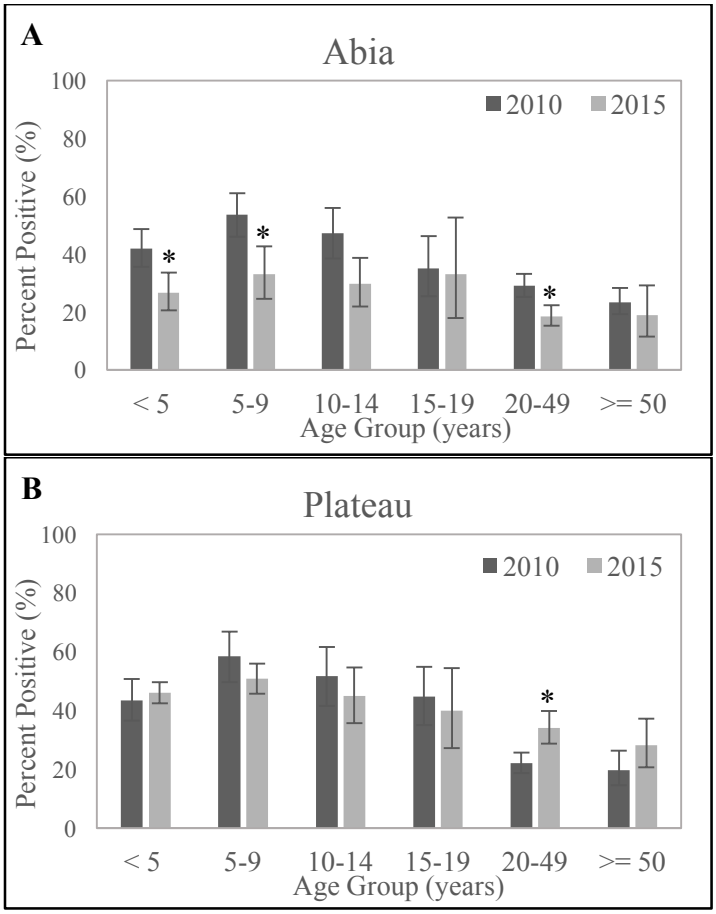

Figure 11 *Plasmodium* prevalence by age group in Abia and Plateau states, Nigeria, 2010 vs 2015. (A) Overall age-adjusted *Plasmodium* prevalence decreased significantly in Abia from 36.1% (95% CI: 32.3-40.1) in 2010 to 26.4% (95% CI: 20.1-31.5) in 2015. Significant age-specific decreases were seen in children under 5, children 5-9, and adults aged 20-49. (B) A non-significant increase in overall age-adjusted *Plasmodium* prev-alence was seen in Plateau from 36.6% (95% CI: 31.3-42.3) in 2010 to 43.4% (95% CI: 39.9-46.9) in 2015. A significant age-specific increase was seen in adults 20-49 years from 22% in 2010 to 34% in 2015. 80 to 85% of all infections were *Plasmodium falciparum*, with the rest being *P. malariae* and co-infections of the two species. Positive infections were detected by microscopy. * indicates statistically significant difference between 2010 and 2015 (Bonferroni-corrected α=0.008).

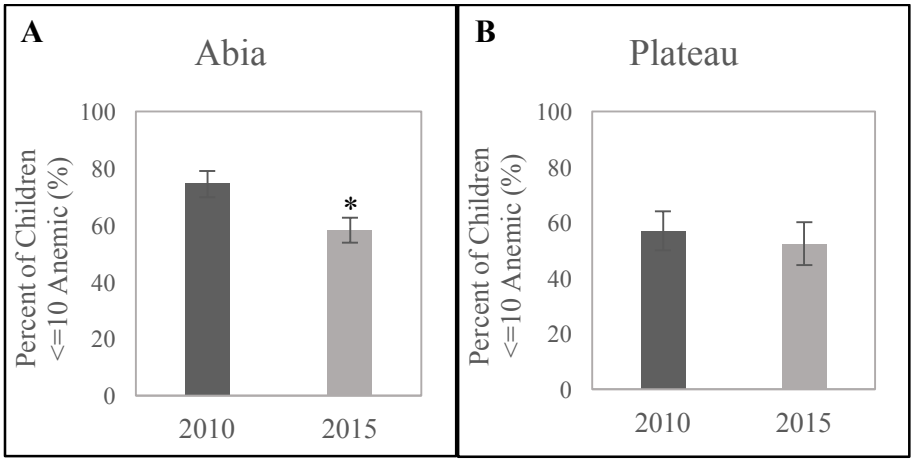

Figure 12 Anemia in children 10 years and younger, 2010 baseline vs 2015 follow-up in Abia and Plateau states, Nigeria. (A) Age- and altitude-adjusted anemia decreased significantly in Abia from 74.7% in 2010 to 58.3% in 2015. (B) A non-significant decrease in anemia in children 10 and younger was seen in Plateau from 57.1% in 2010 to 52.5% in 2015. * indicates statistically significant difference (α=0.05).

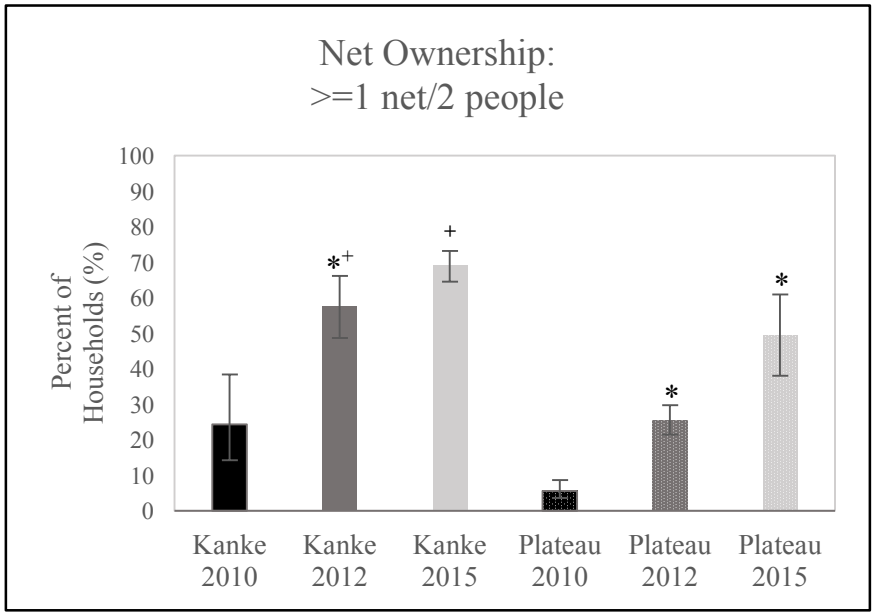

Figure 13 Net ownership in Kanke LGA and Plateau State, Nigeria, 2010, 2012, and 2015 surveys. Significant improvement in households owning at least 1 net per 2 people in both areas following the first round of net distributions. Coverage increased significantly from 2010 to 2012 in Kanke LGA, though not from 2012 to 2015, and increased significantly each year in Plateau State. Net ownership was significantly higher in Kanke compared to Plateau in 2012 and 2015. * denotes statistically significant difference from previous year. + indicates statistically significant difference between Kanke LGA and Plateau State. Bonferonni-corrected α=0.007.

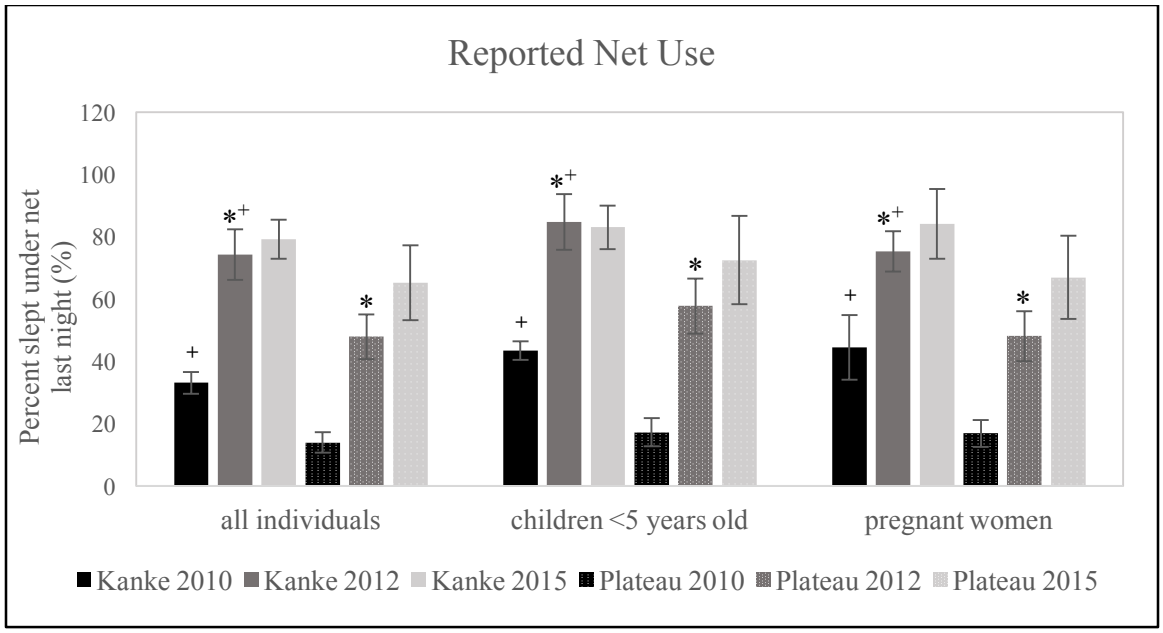

Figure 14 Reported net use in Kanke LGA and Plateau State, Nigeria, 2010, 2012, and 2015 surveys. Reported net use was higher in Kanke LGA compared to the rest of Plateau state in all populations in 2010 and 2012, but no significant difference was detected between the areas in 2015. Significant increases were seen in net use from 2010 to 2012 in both areas, but there was no significant difference from 2012 to 2015. * denotes statistically significant difference from previous year. + indicates statistically significant difference between Kanke LGA and Plateau State. Bonferonni-corrected α=0.007.

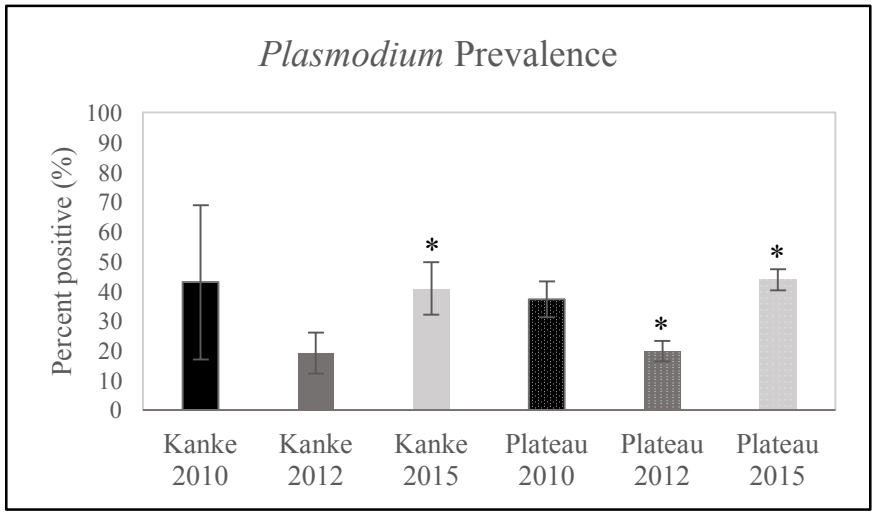

Figure 15 *Plasmodium* prevalence among sampled individuals in Kanke LGA and Plateau State, Nigeria, 2010, 2012, and 2015 surveys. *Plasmodium* prevalence did not differ significantly between Kanke LGA and Plateau State in any survey year. Prevalence decreased from 2010 to 2012 and rose again from 2012 to 2015. * denotes statistically significant difference from previous year (Bonferonni-corrected α=0.007).

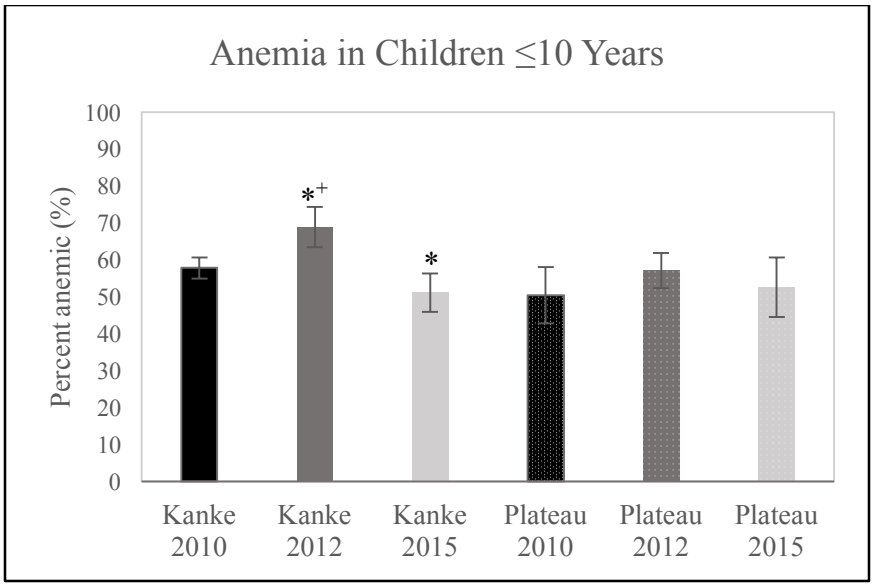

Figure 16 Anemia among children 10 years and younger in Kanke LGA and Plateau State, Nigeria, 2010, 2012, and 2015 surveys. Anemia was higher in 2012 than in 2010 and 2015 in both areas. The difference was significant in Kanke LGA, but not the rest of Plateau State. Anemia did not differ significantly between Kanke LGA and Plateau state except for 2012 where it was higher in Kanke. * denotes statistically significant difference from previous year. + indicates statistically significant difference between Kanke LGA and Plateau State. Bonferonni-corrected α=0.007.