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Mapping Malaria Transmission Intensity in Malawi, 2000–2010

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Abstract. Substantial development assistance has been directed towards reducing the high malaria burden in Malawi over the past decade. We assessed changes in transmission over this period of malaria control scale-up by compiling community *Plasmodium falciparum* rate (*Pf*PR) data during 2000–2011 and used model-based geostatistical methods to predict mean $PfPR_{2–10}$ in 2000, 2005, and 2010. In addition, we calculated population-adjusted prevalences and populations at risk by district to inform malaria control program priority setting. The national population-adjusted $PfPR_{2–10}$ was 37% in 2010, and we found no evidence of change over this period of scale-up. The entire population of Malawi is under meso-endemic transmission risk, with those in districts along the shore of Lake Malawi and Shire River Valley under highest risk. The lack of change in prevalence confirms modeling predictions that when compared with lower transmission, prevalence reductions in high transmission settings require greater investment and longer time scales.

INTRODUCTION

Malaria remains a significant public health problem in Malawi, with approximately seven million suspected cases reported in 2010 among a population of approximately 14 million.[1] With support from the President's Malaria Initiative, Global Fund, and the Malawi government, a substantial financial commitment has been directed towards the control of malaria in Malawi over the past six years; funding for malaria accounted for 19% of all expenditures on health in 2009.[2] Most of this development assistance has focused on scaling-up vector control with insecticide-treated mosquito nets (ITNs) or long-lasting insecticide-treated nets (LLINs) and improving access to artemisinin-combination therapies. However, although household ownership of at least one ITN increased from 27% in 2004 to approximately 60% in 2010,[3,4] there has been little evidence of a corresponding decrease in outpatient facility incidence or slide positivity rates over this period,[5] and a recent national prevalence survey found 43% of children less than five years of age to have a *Plasmodium falciparum* infection.[6]

Improving access to timely, high-resolution maps of malaria infection prevalence is essential for evidence-based malaria program evaluation and decision-making, especially in high-transmission countries dealing with high disease burdens.[7,8] A map of malaria risk in Malawi was previously produced by using historical infection prevalence data from surveys undertaken at 73 communities during 1977–2002 and incorporated within model-based geo-statistical (MBG) methods to produce an interpolated risk map.[9] Several large-scale household surveys have been conducted since this first product was developed, thereby enabling significantly more geo-referenced parasite prevalence data available to define the spatial definition of risk at high resolutions through to 2010 covering the period of recent scale-up of malaria control.

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In this study, we combine numerous national and sub-national malaria prevalence surveys to produce comparative geo-statistical risk maps for Malawi in 2000, 2005, and 2010 to examine whether the spatial distribution of malaria risk in this high transmission setting has been influenced by increasing overseas development assistance to support scaled malaria prevention. In addition, we categorize risk map outputs at the district level because districts represent the fundamental administrative unit for allocating malaria control resources.

MATERIALS AND METHODS

Country context. The primary malaria-transmitting vectors in Malawi include *Anopheles arabiensis*, *An. funestus*, and *An. gambiae s.s.*[10] Vectorial capacity is high because of ample rainfall (725 - > 2,000 mm/),[11] high year-round temperatures, and high humidity, especially in low-lying areas along the lakeshore, Shire River Valley, and central plains.[12] Transmission is perennial, with seasonal increases in disease incidence after rains during November–April. Administratively, Malawi is divided into 28 districts among three regions (Northern: 6 districts, Central: 9 districts, and Southern: 13 districts).

Malawi has a strong history of malaria control. Malawi began piloting a subsidized ITN program in 1998,[13] and by 2003, subsidized ITNs were available through a nationwide social marketing campaign, the first of its kind in sub-Saharan Africa.[14] As in several neighboring countries, the bulk of scale-up occurred after 2005 coincidental with increases in development partner assistance. The 2005–2010 Malaria Strategic Plan set goals of 85% coverage among high risk groups (children less than five years of age and pregnant women) through rapid scale-up of ITNs, indoor residual spraying (IRS), and prompt access to artemisinin-combination therapies.[14] From 2007 to early 2010, approximately four million LLINs were distributed through antenatal care clinics and the Expanded Program on Immunization. Household ownership of at least one net (treated or untreated) was estimated as 13% in 2000,[15] and ownership of at least one ITN was estimated as 27% in 2004,[3] 38% in 2006,[16] and 57% in 2010.[4] Since 2007, more than 21 million courses of

artemether-lumefantrine have been distributed, and treatment has been available free to fever patients nationwide. Indoor residual spraying has been piloted since 2007 in Nkhotakota District, and in late 2010 was expanded to six other high-prevalence districts.[12]

Community survey data. Cross-sectional community *Plasmodium falciparum* parasite rate (*Pf*PR) data for 2000–2011 for Malawi were assembled by year from a combination of published and unpublished sources. These sources included data from national micro-nutrient surveys conducted in 2001 and 2009 by the Ministry of Health (MoH) in collaboration with the Centers for Disease Control and Prevention, Irish Aid, the United Nations Children's Fund,[17,18] the National Malaria Indicator Survey conducted in 2010,[6] anemia and parasitemia surveys conducted by the College of Medicine Malaria Alert Center in eight districts annually during 2005–2009,[19,20] MoH reports, peer-reviewed journals, conference abstracts, and unpublished data obtained through direct contacts with researchers and program staff.

Most surveys used two-stage cluster sampling, where clusters represented by villages or census standard enumeration areas were randomly selected at the first-stage, and households randomly selected at the second stage within clusters. For all surveys, households were classified as belonging to the standard enumeration area within which they were located. For each survey cluster, household data were summarized on the number of persons examined, number positive for *P. falciparum* malaria, age range, month and year of survey, and method for malaria testing, and linked spatially to the geographic location of the cluster centroid. All malaria testing was conducted by using either rapid diagnostic tests or microscopy; where rapid diagnostic tests and quality-assured microscopy results were available for the same persons, results of microscopy were chosen. Survey cluster locations were geo-coded by using combinations of global positioning systems, electronic gazetteers (Google Earth, Encarta, and Alexandria), and other sources of longitude and latitude. The assembled *Pf*PR data were standardized to the classical age-range of 2 to > 10 years ($Pf\mathrm{PR}_{2-10}$) by using an algorithm based on modified catalytic conversion models.[21]

Assessment of ecologic and climatic predictors of malaria risk. Data at 1 × 1 km spatial resolution on urbanization,[22] temperature suitability index,[23] elevation,[24] annual mean precipitation,[25,26] and enhanced vegetation index[27] were assembled for the period of the study. The values of these underlying ecologic and climatic covariates were extracted to each survey location by using the ArcGIS 10 Spatial Analyst Tool (ESRI, Redlands, CA).[28] These covariates were then included in a total-sets analysis, which is an automatic model selection process based on a generalized linear regression model and implemented by using the *bestglm* package in R.[29,30] This approach selects the best combination of covariates based on the value of the Bayesian Information Criteria statistic,[31] where the lowest Bayesian Information Criteria indicates the best model fit.

Space-time Bayesian geostatistical model for predicting *P. falciparum* distribution in Malawi. The continuous surfaces of the age-standardized data ($Pf\mathrm{PR}_{2-10}$) were generated by using a space-time MBG framework,[32] whereby Bayesian inference was implemented using the Markov Chain Monte Carlo algorithm within the open-source statistics package PyMC.[33] Details of model code[32] and statistical procedures[34] are provided in Supplemental Information 1. In brief, the value of $Pf\mathrm{PR}_{2-10}$ was modeled as a transformation of a spatiotemporally structured field superimposed with unstructured (random) variation on a regular 1 × 1 km grid during 2000–2011. The number of *P. falciparum*-positive responses from the total sample at each survey location was modeled as a conditionally independent binomial variate given the unobserved underlying age-standardized $Pf\mathrm{PR}_{2-10}$ value[21] and a linear function of the climatic and environmental predictors. The unstructured component was represented by a Gaussian distribution with zero mean. The spatiotemporal component was represented by a stationary Gaussian process[35] with covariance defined by a spatially anisotropic version of the space-time covariance function proposed by Stein.[36] To partly model seasonality, the covariance function was modified to enable the time-marginal model to include a periodic component of wavelength 12 months in the temporal covariance structure. Each survey was referenced temporally by using the mid-point (in decimal years) between the recorded start and end months. For each grid location, samples of the annual mean of the full posterior distribution of $Pf\mathrm{PR}_{2-10}$ for each year were generated. These $Pf\mathrm{PR}_{2-10}$ samples were then used to generate continuous maps of the annual mean for 2000, 2005, and 2010. The continuous maps were also binned into the following $Pf\mathrm{PR}_{2-10}$ classes: 10% to < 20%; 20% to < 30%, 30% to < 40%, and 40–50%.

Assessing uncertainty of model predictions. As a first step for assessing uncertainty around predictions of $Pf\mathrm{PR}_{2-10}$ by using the Bayesian geostatistical model, the continuous mean maps were accompanied by estimates of the posterior standard deviation. In addition, a spatially representative validation set of $Pf\mathrm{PR}_{2-10}$ survey data was also selected by using a spatially de-clustered sampling algorithm.[32] The annual predictions were then repeated in full using the remaining data to predict mean $Pf\mathrm{PR}_{2-10}$ at the validation locations. The ability of the model to predict point-values of *Pf*PR at unsampled locations was quantified by using two simple summary statistics: the mean prediction error (MPE) and the mean absolute prediction error (MAPE). The MPE provides a measure of the model bias, and the MAPE is a measure of the average accuracy of individual predictions.

Estimating population at risk. Populations at risk were estimated from the 2010 map by $Pf\mathrm{PR}_{2-10}$ class (defined here as lower meso-endemic [10–40%] and higher meso-endemic [40–50%]) and district for the total population and for children less than five years of age. Totals were calculated from Afripop rasters[22] for total populations and populations less than five years of age by using ArcGIS 10 Spatial Analyst Tools. Population-adjusted prevalences were also calculated by district by multiplying the continuous $Pf\mathrm{PR}_{2-10}$ rasters by the population rasters and computing estimated infected populations out of total populations.

RESULTS

Predictions of mean annual $Pf\mathrm{PR}_{2-10}$ for 2000, 2005, and 2010. The community survey data assemblage included 1,057 *P. falciparum* survey clusters, from which 33,041 persons were examined and 9,239 were positive during 2000–2011 (Table 1 and Figure 1). Most (88%, n = 933) survey data were for 2005–2011 (Table 1). Most blood examinations for *P. falciparum* infection (76%, n = 805) were performed by

TABLE 1

Summary of community *Plasmodium falciparum* parasite rate data, Malawi 2000–2011*

Characteristic	No. survey clusters	No. persons examined	No. persons positive
Year			
2000	39	1,372	588
2001	55	425	266
2002	20	2,990	720
2003	10	366	164
2005	49	1,269	211
2006	191	4,000	1,086
2007	51	3,596	820
2008	56	4,715	644
2009	336	9,369	2,742
2010	206	4,373	1,789
2011	44	566	209
Malaria testing method			
Microscopy	805	26,971	6,466
RDT	252	6,070	2,773
Sample size			
5–49	930	16,993	4,880
50–99	68	4,542	1,020
100–1,721	59	11,506	3,339
Age range, years			
< 5	844	23,895	5,834
5–14	187	7,958	3,353
≥ 15	26	1,188	51
Total	1,057	33,041	9,239

*RDT = rapid diagnostic test.

microscopy. In most (88%, n = 930) clusters, sample sizes for malaria testing were less than 50 persons; none were less than five persons. Almost all (98%, n = 1,032) survey clusters included testing among children < 14 years of age, of which 82% (n = 844) included testing only among children less than five years of age.

Results of the total-set analysis showed that the model with urbanization and the temperature suitability index was the best fit in predicting $Pf\text{PR}_{2–10}$. These variables were subsequently included in the malaria prediction model (Supplemental Information 2). The spatial distribution of malaria risk remained largely consistent throughout the recent scale-up period, with the highest predicted prevalence (40–50%) along the shore of Lake Malawi, along the Shire River Valley, and portions of the central plains (Figures 2 and 3). Compared with 2000 and 2005, there was some evidence of increased prevalence along the Zambian border in Mchinji and Kasungu Districts and the western portions of Rumphi and Mzimba Districts in 2010. Similarly, predicted prevalence increased slightly around Mulange District and nearby lowlands in 2010. Across the entire period, prevalence was lowest in urban areas (notably urban areas within Lilongwe, Blantyre, and Mzuzu Districts, where prevalence was 10–20%) and along the northern and central highlands. There was little evidence of a decrease in prevalence during 2005–2010.

The MPE and MAPE associated with the full space-time geostatistical model were 0.04% and 2.7%, respectively, indicating low bias and a slight over-prediction of risk. The standard deviations of the annual mean $Pf\text{PR}_{2–10}$ predictions were similar across the predictions years and ranged from 20% to approximately 30% (Figure 4). Uncertainty appeared to be lowest for predictions to urban areas.

Estimates of population at risk. The entire population of Malawi is under at least moderate transmission risk (historically meso-endemic or 10–50% $Pf\text{PR}_{2–10}$). Of a total national population of 13.6 million and a population of children less than five years of age of 2.7 million in 2010, 6.5 million (48%) persons and 1.3 million (49%) children less than five years of age were estimated as residing in the higher transmission intensity areas (40–50% $Pf\text{PR}_{2–10}$) (Table 2), yet no areas

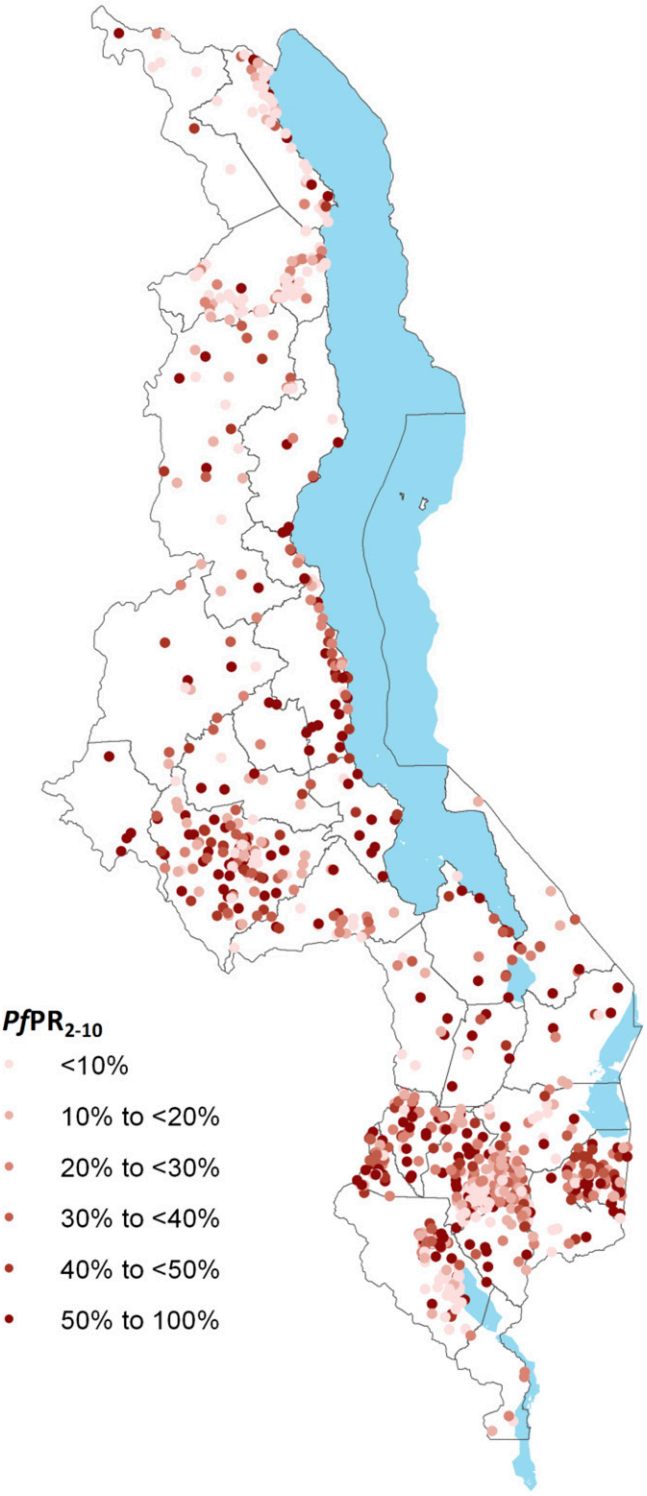

FIGURE 1. Districts map of Malawi showing the distribution of the age-standardized community *Plasmodium falciparum* parasite rate ($Pf\text{PR}_{2–10}$) data (n = 1,057) during 2000–2011.

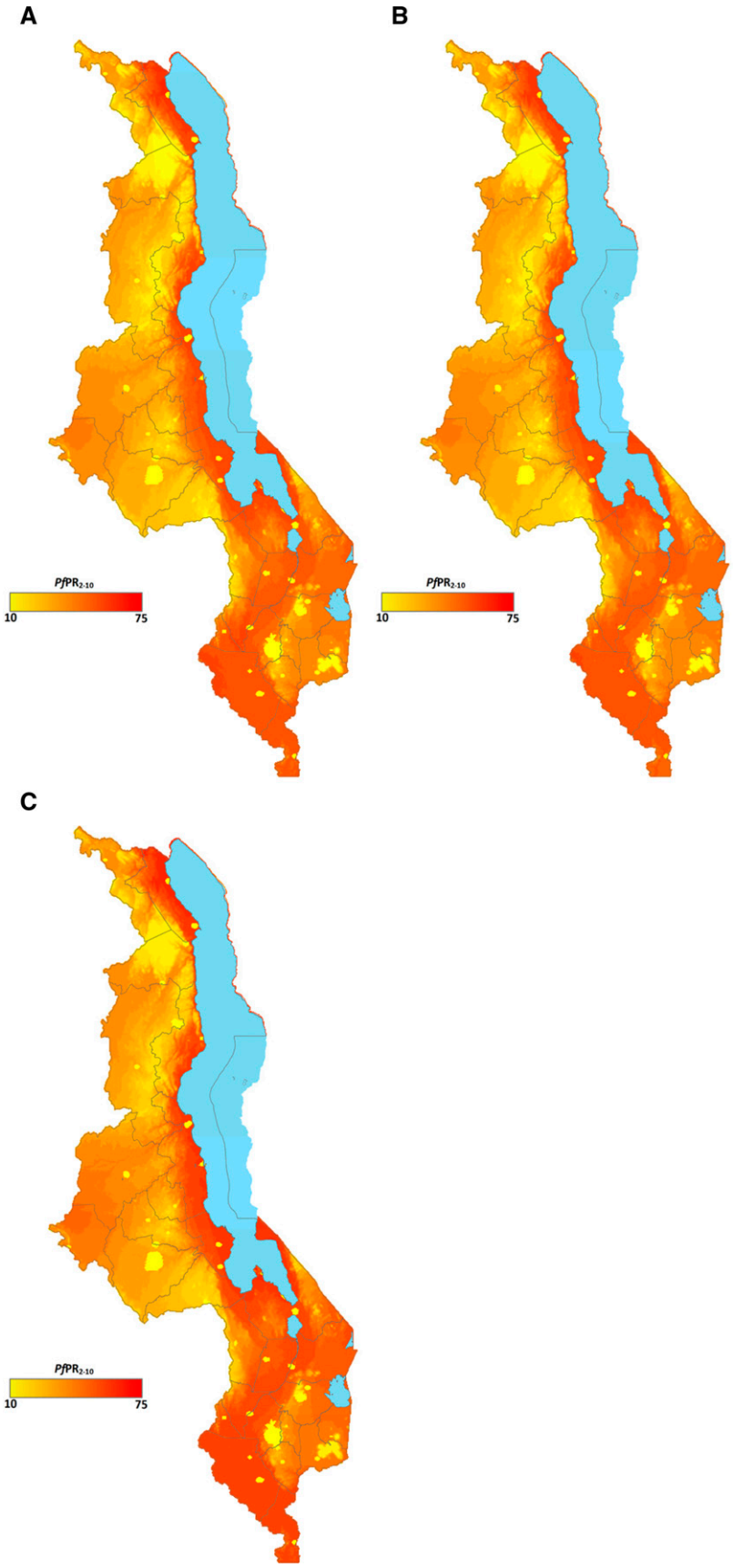

FIGURE 2. Maps of the continuous posterior annual mean *Plasmodium falciparum* parasite rate ($Pf\text{PR}_{2-10}$) prediction 1 × 1 km locations in Malawi in **A**, 2000; **B**, 2005; and **C**, 2010.

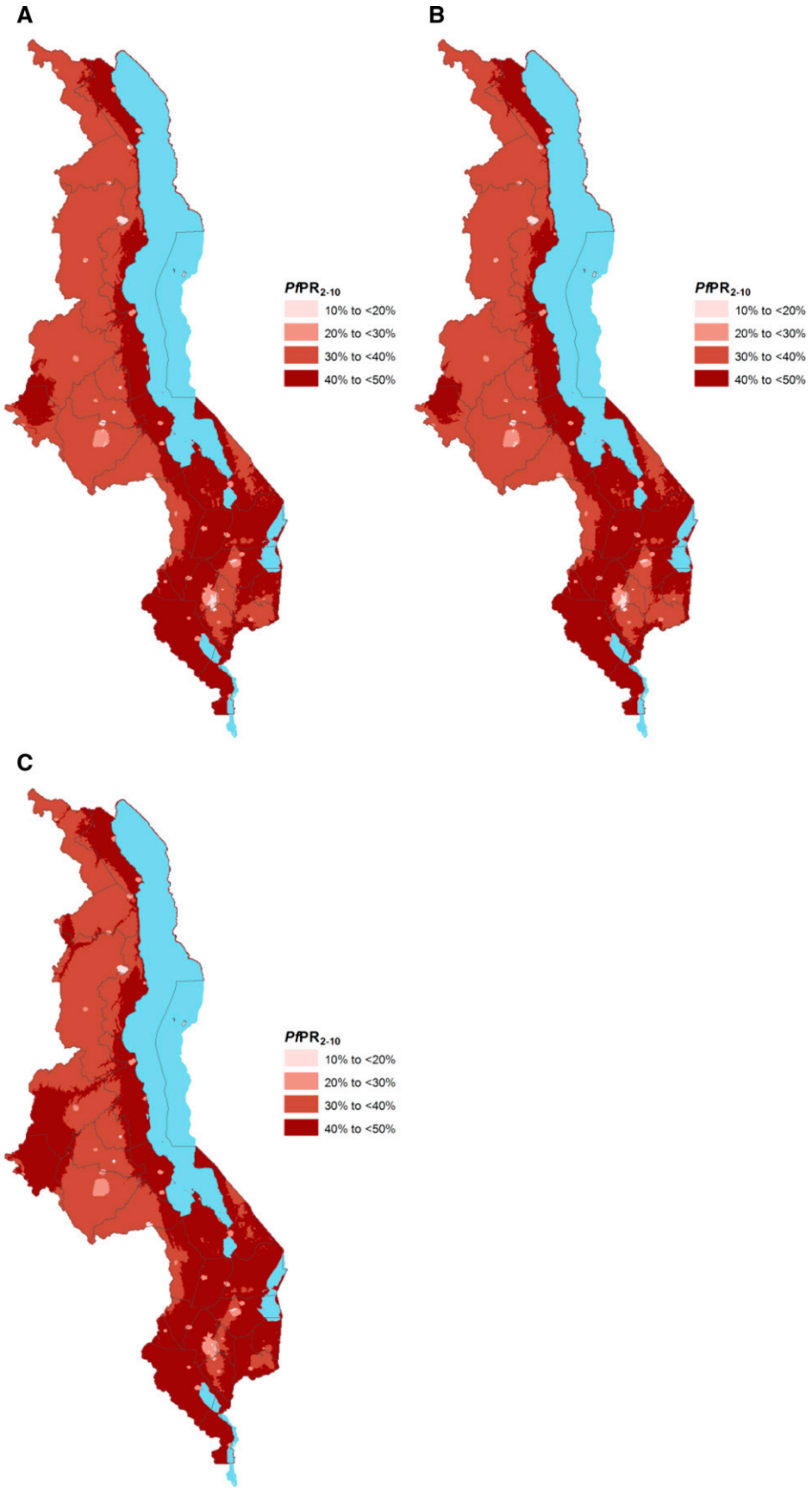

FIGURE 3. Maps of the classified posterior annual mean *Plasmodium falciparum* parasite rate ($Pf\text{PR}_{2–10}$) prediction 1 × 1 km locations in Malawi in **A**, 2000; **B**, 2005; and **C**, 2010.

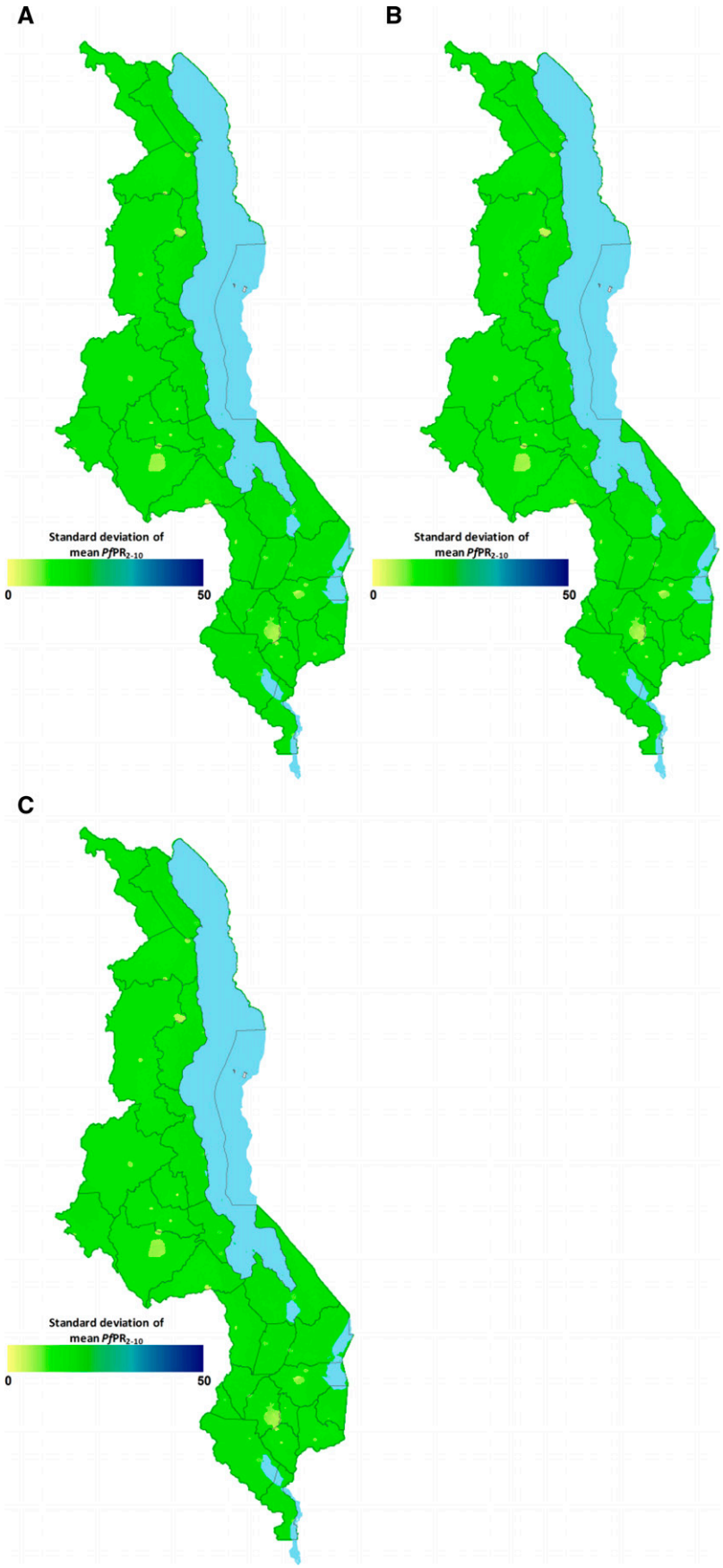

FIGURE 4. Maps of the standard deviation of the posterior annual mean *Plasmodium falciparum* parasite rate ($Pf\text{PR}_{2-10}$) prediction 1 × 1 km locations in Malawi in **A**, 2000; **B**, 2005; and **C**, 2010.

TABLE 2

Percentage of children less than five years of age and total populations at risk by district and endemicity class, population less than five years of age and total population, and PA*Pf*PR$_{2–10}$, Malawi, 2010*

District	Endemicity class		Population < 5 years of age (in thousands)	Endemicity class		Total population (in thousands)	PA*Pf*PR$_{2–10}$
	10–40%	> 40%		10–40%	> 40%		
Northern region†							
Chitipa	86.4	13.6	37.2	87.6	12.4	186.3	37.6
Karonga	16.6	83.4	53.4	18.1	81.9	281.6	42.4
Mzimba	95.9	4.1	183.8	96.2	3.8	895.1	34.8
Nkhata Bay	44.7	55.3	38.0	42.8	57.2	189.1	40.0
Rumphi	87.1	12.9	34.8	87.5	12.5	169.0	36.6
Central region							
Dedza	82.4	17.6	139.7	82.8	17.2	649.9	36.9
Dowa	86.8	13.2	114.8	86.5	13.5	543.2	37.7
Kasungu	65.8	34.2	139.0	67.2	32.8	652.9	38.7
Lilongwe	95.1	4.9	397.7	95.6	4.4	2,008.7	32.1
Mchinji	11.5	88.5	98.3	14.8	85.2	474.4	40.1
Nkhotakota	14.4	85.6	64.5	16.5	83.5	317.6	41.9
Ntcheu	41.8	58.2	94.4	44.0	56.0	480.7	40.0
Ntchisi	82.7	17.3	63.5	82.7	17.3	304.5	38.4
Salima	18.1	81.9	71.4	17.6	82.4	348.9	41.4
Southern region							
Balaka	11.3	88.7	67.2	12.8	87.2	336.7	41.3
Blantyre	77.8	22.2	165.6	82.1	17.9	1,097.5	25.7
Chikwawa	3.7	96.3	92.0	4.1	95.9	452.3	43.5
Chiradzulu	48.0	52.0	52.6	49.3	50.7	295.0	38.2
Machinga	4.2	95.8	106.6	4.9	95.1	501.8	42.4
Mangochi	13.1	86.9	174.7	14.0	86.0	834.7	41.8
Mulanje	6.1	93.9	101.3	6.3	93.7	550.6	40.4
Mwanza	6.7	93.3	25.8	10.3	89.7	122.3	41.7
Neno	19.0	81.0	17.0	19.4	80.6	84.3	42.1
Nsanje	7.4	92.6	50.9	7.4	92.6	245.0	42.4
Phalombe	6.8	93.2	63.5	7.0	93.0	317.2	41.1
Thyolo	38.5	61.5	114.4	39.2	60.8	609.2	39.8
Zomba	29.2	70.8	134.5	30.8	69.2	700.9	37.5
Total	50.8	49.2	2,696.4	52.2	47.8	13,649.1	37.4

*PA*Pf*PR$_{2–10}$ = population-adjusted *Plasmodium falciparum* rate
†Predictions do not include Likoma Island, which is in northern Lake Malawi.

had a predicted prevalence > 50%. The national population-adjusted prevalence (PA*Pf*PR$_{2–10}$) was 37.4%. Districts with the highest proportion of the population under higher transmission intensity included Karonga (82%) in the Northern region, Nkhotakota (84%) and Mchinji (85%) in the Central region, and Machinga (95%), Chikwawa (96%), Mulanje (94%), and Phalombe (93%) in the Southern region (Figure 5); in close to half (46%) of the districts, greater than 75% of the population resided in areas with > 40% predicted prevalence. Similarly, the highest PA*Pf*PR$_{2–10}$ was found in Chikwawa (44%), Machinga (42%), Nsanje (42%), and Karonga (42%). Districts with the lowest proportions of the population under higher transmission intensity included Mzimba (4%), Lilongwe (4%), and Chitipa (12%). The lowest PA*Pf*PR$_{2–10}$ was found in Blantyre (26%), Lilongwe (32%), and Mzimba (35%). Comparisons of district PA*Pf*PR$_{2–10}$ across the three prediction years (2000, 2005, and 2010) showed only slight (≤ 1%) differences by year. Therefore, only data for 2010 are presented (PA*Pf*PR$_{2–10}$ for 2000 and 2005 are shown in Supplemental Information 3).

DISCUSSION

We have developed a high-resolution risk map for malaria transmission intensity in Malawi by modeling an unevenly distributed space-time dataset with geo-statistical methods and predicting to three points in time over a period of malaria control scale-up, achieving high precision in our estimates. This map represents a novel application of time-space modeling that has not before been conducted in a high-transmission setting. As a result, our findings have important ramifications for reductions of parasite prevalence that can be expected with malaria control scale-up in high transmission areas.

Although household ownership of ITNs increased substantially during 2004–2010, our modeled predictions of transmission intensity failed to provide any persuasive evidence of a change in the mean predicted prevalence over this period. While there may have been slight decreases between 2000 and 2005, a period without major scaled prevention, by 2010 there was some evidence that predicted prevalence increased slightly in some areas. In addition, we found a similar spatial distribution of risk to that based on data from 1977–2002.[9]

Although encouraging decreases in malaria morbidity and mortality associated with scale-up of vector control in sub-Saharan Africa are well documented, most reports are from areas with relatively lower baseline transmission intensity.[37–39] Less published evidence exists on similar decreases in areas of high baseline transmission intensity, and some have shown increases in burden.[40] Similar findings have been observed at high-transmission intensity hospital settings in Malawi,[5,41] and at sites in Uganda and Kenya characterized by hyper-holoendemic transmission and coincidentally similar levels of scaled prevention to Malawi.[40,42] Taken together with these studies, our finding of a lack of change in predicted prevalence in Malawi suggests that transmission reductions experienced through scale-up in lower baseline transmission countries may not translate into reductions of equivalent

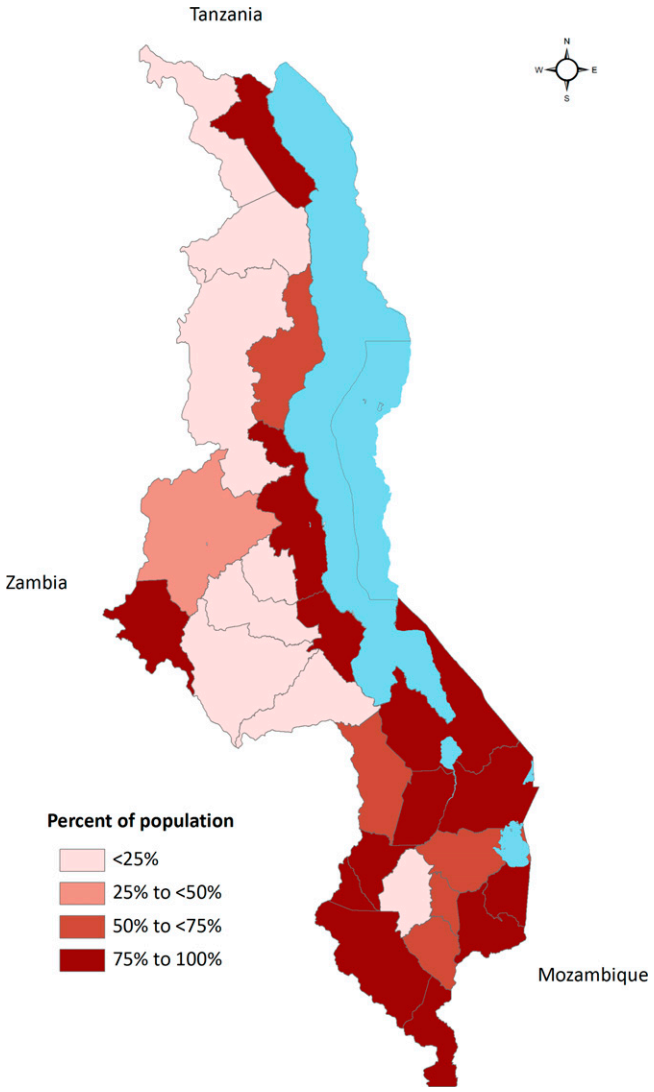

FIGURE 5. Map of percent of population by district under highest transmission intensity (predicted *Plasmodium falciparum* parasite rate [$Pf\text{PR}_{2-10}$] 40–50%), Malawi 2010.

magnitude or occur on similar time scales in high baseline transmission settings.

Mathematical modeling has shown that higher ITN effective coverage and a longer time scale is required to achieve similar gains in high transmission settings.[43,44] These models have predicted that ITN effective coverage requirements to reduce prevalence to specific benchmark targets are roughly equivalent to baseline transmission intensity and will be sensitive to the time taken for scale-up.[43] In Malawi, this finding means that absolute increases in ITN effective coverage (ownership times use in the entire population) of at least 35% would need to be realized to halve baseline $Pf\text{PR}_{2-10}$ after a period of 2–4 years, and quicker reductions would be possible with more rapid scale-up.

Ownership and use rates of ITNs among children less than five years of age and pregnant women in Malawi only recently reached levels > 50%,[6] and rates were lower for the population as a whole. Scale-up of ITNs occurred gradually during 2005–2010; most LLIN distributions occurred starting in 2008, and delay in a recent mass distribution campaign may have limited additional gains by 2010. Community ITN effects are likely to operate more strongly as coverage of the entire population increases to levels > 50%,[45–47] and therefore would not have contributed meaningfully to reduce transmission until late in scale-up. Furthermore, IRS was piloted only in Nkhotakota before 2010 and scale-up to six additional districts occurred after our study. As predicted, such moderate ITN coverage levels, scaled-up over several years, and low IRS coverage in the setting of high baseline transmission intensity cannot be expected to dramatically or quickly reduce transmission.

Several other factors may have limited potential prevalence reductions by 2010. There is recent evidence that insecticide resistance may be reducing ITN and IRS effectiveness in Malawi and elsewhere.[48,49] Changes in vector biting behavior may also have factored to reduce ITN effectiveness,[50] but specific data for this purpose are not available for Malawi. Finally, there is some evidence that transmission reductions with ITN and IRS scale-up may be dampened where exophilic *An. arabiensis* is a primary vector,[44] as in Malawi.

Inter-annual climate factors were also likely involved in limiting reductions in prevalence because resurgence occurred in 2010 in several nearby countries,[51] possibly in association with recent *El Niño* cycle anomalies. Increases in parasite prevalence, health facility malaria case incidence, and malaria mortality during 2008–2010 were noted in Zambia and Rwanda, as well as sub-nationally in Malawi, suggesting that 2010 was an unusually high transmission year. Cross-border population movement between Malawi and high-burden districts in Zambia, Mozambique, and Tanzania over this period may have confounded the ability to reduce transmission.[52]

These mapping results provide an important guide for control planning in Malawi, as well as in other similar high-transmission countries. Reductions in transmission in these settings will require broader, more impressive and longer term scale-up of LLINs nationwide and concomitant expansion of the IRS program to all of the highest burden districts. Because the entire population is exposed to at least meso-endemic transmission, priorities in Malawi include districts with high proportions of their population under highest transmission, namely those on the lakeshore and lower Shire Valley, where IRS expansion is already ongoing.

Until recently LLIN coverage was targeted to children less than five years of age and pregnant women through routine distribution channels. However, Malawi has recently adopted universal coverage with LLINs, or one LLIN for every two household members as a programmatic goal.[53] Benchmarking progress towards universal coverage is encouraging because high rates of ownership and use of LLINs by the entire population will be needed to achieve substantial prevalence reductions. However, on-going financial crises, compounded by delay in the Global Fund–supported mass distribution campaign, have created a challenging environment within which to quickly achieve and maintain high levels of intervention coverage. As a result, there remains an acute need to target existing resources towards the highest burden areas.

High-resolution geo-statistical risk-mapping products are important tools for national malaria control programs for guiding these decisions, and will become more readily available as new statistical and computing tools are further developed. Although the increasing availability of map products for country level priority setting is encouraging, the use of

modern risk mapping products in national planning remains rare.[8] Where possible, these outputs should be focused on district-specific outcomes because districts represent the political and administrative units for resource allocation planning, and district platform analysis is increasingly necessary for evaluation of national program impact.[8,54] Efforts should be increased to promote the combined use of district-resolved risk maps and mathematical models to predict epidemiologic impacts of various intervention suites because these maps and models can provide malaria control programs with strong empirical rationale to inform national strategic plans.

Our results were limited by data gaps in some areas and periods. However, the bulk of our data were for the period of more intense scale-up, and given the large number of studies and small geographic size of Malawi, our validation tests showed good predictive performance; we found only slight evidence of over-prediction. In addition, we used simple cartographic approaches to compute population-adjusted $Pf\mathrm{PR}_{2-10}$ at the district level, which did not enable us to estimate area-level uncertainty.[55] Efforts to model within-district heterogeneity for district level uncertainty are warranted but beyond the scope of this study because of the high computational cost and only marginal benefit in this setting.[56]

In conclusion, we sought to assess changes in transmission over a period of malaria control scale-up in the high transmission setting of Malawi by compiling a large assemblage of community parasite prevalence data and predicting to three points in time by using MBG methods. Our finding of no change in predicted prevalence over this period highlights the need to avoid one-size-fits-all benchmarking of malaria control progress and to properly contextualize expectations of impact to each unique transmission setting. This finding holds true nationally and sub-nationally. Focusing risk-map products to sub-national administrative units will improve their utility by malaria control program managers facing heterogeneous transmission conditions within their national borders and enable appropriate intervention targeting and goal setting at this level.

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