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TECHNICAL REPORT

SHIFTING RISKS OF MALARIA IN SOUTHERN AFRICA

A REGIONAL ANALYSIS



February 2020

This document was produced for review by the United States Agency for International Development. It was prepared by Sadie Ryan (University of Florida), Anna Steynor, Chris Jack, Piotr Wolski, Lisa van Aardenne, Chris Lennard (Climate Systems Analysis Group of the University of Cape Town), and Fernanda Zermoglio (Chemonics International) for the Adaptation Thought Leadership and Assessments (ATLAS) Task Order No. AID-OAA-I-14-00013, under the Restoring the Environment through Prosperity, Livelihoods, and Conserving Ecosystems (REPLACE) IDIQ.

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Adaptation Thought Leadership and Assessments (ATLAS)

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This report is made possible by the support of the American people through the United States Agency for International Development (USAID). The contents of this report are the sole responsibility of the author or authors and do not necessarily reflect the views of USAID or the United States Government.

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ACRONYMS

CORDEX	Coordinated Regional climate Downscaling Experiment
GIS	geographic information system
MODIS	Moderate-Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
PMI	President's Malaria Initiative
RCP	Representative Concentration Pathway
SRTM	Shuttle Radar Topography Mission
SSP	Shared Socioeconomic Pathways

EXECUTIVE SUMMARY

Temperature impacts both the life cycle and habitat of malaria-carrying mosquitoes (genus *Anopheles*) and malaria parasites. Warmer temperatures may result in new locations becoming suitable for malaria transmission, while currently suitable locations may become too hot, leading to reductions in malaria's seasonal duration and overall risk. This report analyzes the shift in malaria transmission suitability based on projected temperature rise over two time periods: short and medium term (2030s and 2060s); under two climate pathways: best-case and worst-case (Representative Concentration Pathways [RCP] 4.5 and 8.5); and two climate models (less hot and hotter), and critically the change in the number of people at risk.

CONTEXT

Climate variability and change present both current and future risks to human health. For example, changes in temperature, precipitation, and extreme weather events alter the geographic range, seasonality, and survival of pathogens and the vectors that transmit them. Similarly, extreme weather events, such as floods, heat waves, and droughts, put at risk health infrastructure necessary to reduce disease transmission (e.g., health centers, supply chains). Knowledge of how, when, and under what circumstances climate variability and change impact health outcomes is limited, especially in sub-Saharan Africa. Region-specific information on climate science and projections of future climate are also limited. In this report, we describe an analysis of climate-induced malarial transmission risk for the Southern Africa region, using a set of regionally calibrated climate models, to better capture the impact of climate variability and change on malaria risk.

KEY FINDINGS, IMPLICATIONS, AND HOTSPOTS

OVERALL

- Temperatures across the region will rise on average between 0.7°C and 2.7°C by the 2030s to 2060s, under both best-case and worst-case climate pathways, with some spatial variability.
- Endemic areas of transmission suitability (10–12 months of the year) are currently restricted to the north of the Southern African region, focused in Angola, northern Mozambique, and Madagascar. Endemic suitability will spread into western Angola, Northern Zambia, and further into Mozambique, and Malawi, where no suitability currently exists, adding up to 2.9 million people newly at endemic risk by the 2060s under the hotter model and the less hot model.
- Seasonal suitability (7–9 months of the year) will shift from a current hotspot centered on Zambia, outward to the East and West, but newly impacting large numbers of people in Madagascar, Malawi, Mozambique, Zambia, and Zimbabwe, affecting as many as 4.0 to 12.9 million people by the 2060s under all climate models and pathways.

- The most dramatic shift in Southern Africa for malaria suitability is the shift from no months of suitability to moderate or marginal malaria risks (1–6 months), newly affecting up to 23–59 million people at risk from transmission by the 2030s to 2060s under all climate models and pathways.

BOX 1: DEFINING SUITABILITY

We modified the Mapping Malaria Risk in Africa (MARA) definitions of malaria suitability to better illustrate the impact of changing climate and to provide information that decision-makers can use to carry out control and/or intervention activities. Our definitions specify the duration in months per year of malaria transmission suitability:

- **Endemic:** 10–12 months
- **Seasonal:** 7–9 months
- **Moderate:** 4–6 months
- **Marginal:** 1–3 months

Current malaria suitability provides a measure of current malaria incidence. Therefore, it should only be used in either scenario:

- When data (survey data, HMIS data) are unavailable or insufficient and/or
- When calibrating the model, providing a baseline that aligns with current incidence, from which to confidently and accurately project future incidence

NEW AREAS OF MALARIA SUITABILITY

There are several areas in Southern Africa currently unsuitable for malaria that may become **areas of endemic, seasonal, moderate, or marginal malaria suitability** based on projected increases in temperatures. Current malaria suitability provides a measure of current malaria incidence.

- **New areas of suitability that were previously unsuitable.** The shift from no months of suitability to moderate or marginal suitability (1–6 months) is significant in this analysis, newly affecting up to 23–59 million people by the 2030s to 2060s under all climate pathways.
- **Regions of endemic suitability** will likely emerge in the northern parts of Southern Africa, in Angola, parts of Mozambique, Madagascar, and northern Zambia, becoming more pronounced by mid-century (2060s). This will add 2.9 million people newly at endemic risk by the 2060s under the hotter model.
- **Concentrated regions of seasonal suitability** will likely emerge in central Angola, northern Zambia, northern Mozambique, and moving southward through Southern Africa, affecting Madagascar, Zimbabwe, parts of Botswana, Namibia, and northern South Africa (including parts of Eswatini [Swaziland]). This will affect as many as 4.0 to 12.9 million people by the 2060s under all climate pathways.

Implication: Malaria outbreaks in areas where people have little or no immunity to the disease can often lead to epidemic conditions. This has implications for the distribution of malaria services and their use by impacted communities.

SHORTENING OF MALARIA SEASON

There are areas where the **duration of suitability for malaria transmission will be reduced from endemic to seasonal**.

- This shortening of the malaria transmission suitability season from endemic to seasonal will occur in Angola, Mozambique, and Madagascar, and will impact 2.2 to 3.1 million people by the 2030s under both climate pathways. While the geographic area is a small part of the overall region, it nonetheless impacts high-density population areas. (Note: key dynamics occur in Angola, and the climate model region does not include a portion of the northwest part of Angola, leading to underestimates of people affected by changes in Angola).

Implication: Pinpointing regions where transmission could be reduced lowers the cost of interventions and provides an opportunity to reach pre-elimination or elimination of malaria.

CONCLUSIONS AND INSIGHTS FOR ACTION

Addressing the changing malaria risk profile due to temperature increases will require modifying current interventions and programs, and potentially implementing new programs, that can adapt and respond to changing climate conditions. With these challenges come opportunities for improving monitoring, surveillance, and responses, including detailed geographic targeting, optimizing strategies (i.e., finding the right combination of vector and case management), and aligning interventions to changing seasonality.

MEETING ELIMINATION TARGETS

Eliminating malaria is the goal of all development partners working in Africa (WHO 2015). Understanding how temperature may change the seasonality of malaria in Southern Africa, particularly for new areas at risk of malaria transmission or areas where the length of the season may shorten or extend, can inform malaria policy and programs, and help reach the goal of elimination. In areas where the months of malaria suitability decrease, opportunities will arise to focus resources on making surveillance and response systems increasingly sensitive and focused to identify, track, and respond to malaria cases and any remaining transmission foci (e.g., infected mosquitoes or affected patients). Elimination efforts informed by these analyses could better target resources to reduce the potential burden of additional cases through timely treatment and preventive measures to avoid disease spread in exposed populations, such as the distribution of bed nets or indoor residual spraying.

ADAPTING TO CHANGING EPIDEMIOLOGY AND INCORPORATING NEW TOOLS

There are many examples across sub-Saharan Africa where investments have improved malaria control strategies. These gains, however, could be compromised if future investments do not consider the role of rising temperatures in changes to epidemiology. This analysis offers critical insight with respect to these risks, and especially how *the targeting of current management and control interventions may need to be reviewed and revised to account for likely changes in malaria incidence*. This information offers an opportunity to lengthen the investment timeframe (seasonal to year-round), optimize vector control, and improve case management, by providing the evidence base to support these actions. Targeted and

concentrated surveillance at the edge of malaria's range, for example, presents an opportunity to focus on potential epidemic outbreaks as they happen and can reduce the risk of new outbreaks.

IMPROVING A COUNTRY'S CAPACITY FOR COLLECTING AND USING INFORMATION

Understanding how rising temperatures could impact vector ranges, and thus have the potential to alter disease dynamics, is an important step to build the knowledge base to evaluate the impact of climate on malaria incidence and to inform investments.

This analysis indicates that as temperatures rise, even within the next 11 years (by the 2030s), important changes are anticipated in *Anopheles* transmission suitability. Importantly, temperature-driven changes in vector dynamics are themselves mediated by direct and indirect environmental and societal factors, such as changes to ecosystems and land use that may reduce or increase the vulnerability of certain groups to malaria risks.

Public health observatories, many already operational around the world, can analyze health data in the context of other climate and environmental parameters (health observatories are virtual platforms that can link health systems to weather data). These observatories can pave the way for the timely use of remotely derived weather and climate information to inform investments and strategies in malaria control.

BUILDING CAPACITY IN HEALTH SYSTEMS

In order for malaria programming and health services to respond to climate risks, investments need to be made in building the skills and capacity of health workers to understand and address the health risks posed by climate. These include:

- **Training health workers on the links between health and climate change** to improve their understanding and increase capacity to address changing climate risks. Establishing health early warning systems—as an extension of the analytic work that a health observatory can provide—educational and advisory systems for disseminating clinical guidelines, and even the guidance offered by community health workers, will all require building awareness of the risks and responses available to address climate factors. USAID/AFR, for example, has developed a one-week training course on climate and health issues.
- **Leveraging information technology** such as GIS (geographic information system) and other tools to integrate information from various sectors and sources in order to rapidly evaluate the potential risks from specific weather events to a country, region, or health post.
- **Streamlining supply chain management**, especially in countries where malaria control interventions have been successful, to guarantee the delivery of commodities and services for remote and mobile populations.
- **Ramping up research** on applied, regionally responsive health services for a future of climate change. To date, there is a clear lack of service-oriented research to drive regional health service development for climate change, with potentially serious adverse implications for future control efforts.

STRATEGIC BUDGETING AND EARLY AND TARGETED PLANNING

One of the core operating principles of many malaria intervention programs and for the President's Malaria Initiative (PMI) is having data-informed distribution of malaria interventions. Based on this report, temperature may play a role in putting large percentages of populations within countries, and in the region overall, at risk of both seasonal and endemic malaria.

In many instances, information on projected temperature increases is criticized because it cannot address immediate disease planning needs. However, much like preventive medicine, which aims to promote long-term well-being, planning 10–12 years and even further into the future when fighting malaria can save lives and money over the long term and promote sustainable elimination efforts. For example, if we know that temperature is likely to increase malaria burden in a certain country or region where there is currently little investment to fight malaria, including in some Southern Africa countries, an investment in surveillance and prevention now could prevent the need for large, immediate, crisis-driven investments in the future.

A NOTE ON METHODS AND DATA SOURCES

This analysis explored malaria transmission suitability based on the linked relationship of the vector and pathogen response to different temperature climate pathways derived from climate model projections. The empirical transmission model is derived from temperature response curves for the mosquito species *Anopheles gambiae* and the malaria pathogen *Plasmodium falciparum*. The metric for transmission suitability, called R_0 , which is scaled from 0 to 1, is described in quantiles; the top quantile (top 25 percent) of the curve is selected to represent the range of temperature in which transmission suitability is expected. This conservative measure of the overall temperature curve corresponds visually to existing maps of ongoing transmission under current temperatures. This model does not apply to any other mosquito species. Temperature response curves for other mosquito species would have to be added for this model to project malaria incidence for which those species are the vector.

A Coordinated Regional Downscaling Experiment (CORDEX), a method used to downscale climate projections for specific regions, was run for the Southern Africa region. Future climate pathways were generated for the 2030s and 2060s time periods for a “less hot” model (representing rising temperatures between 0.69°C to 1.74°C), and a “hotter” model (representing rising temperatures between 1.27°C and 2.7°C) (see Section II). Arid areas that preclude *Anopheles* development are excluded using satellite data that measure vegetation, specifically using a long-term mean Moderate-Resolution Imaging Spectroradiometer (MODIS)-derived and normalized difference vegetation index (NDVI). This method, called aridity masking, was compared with a comparable proxy, mean annual precipitation (MAP). We found the aridity mask to be the more conservative approach and retained it for our analyses.

Population data are derived from the Shared Socioeconomic Pathways (SSP) project (Jones & O'Neill, 2016). Baseline calculations use 2010 population data, while projected population data are extracted for the 2060s and the 2050s. In the analyses for this report, we used the Shared

Socioeconomic Pathway (SSP2) population projections, which take into account population movement, including furthering urbanization rates in Africa as well as migration patterns.

OVERVIEW

INTRODUCTION

Climate variability and change present both current and future risks to human health (McMichael & Haines, 1997; McMichael & Lindgren, 2011; WHO, 2019). For example, changes in temperature, precipitation, and extreme weather events alter the geographic range, seasonality, and survival of pathogens and the vectors that transmit them. The extreme weather events, such as floods, heat waves, and droughts, threaten health infrastructure necessary to reduce disease transmission (e.g., health centers, supply chains).

Low-income regions are expected to experience the brunt of the public health impacts of climate change (Büchs, et al. 2011; Hallegatte et al., 2015; McMichael & Haines, 1997). These regions, in many cases, have higher sensitivity to climate-related hazards (such as extreme rainfall or temperature events) because they have low capacity to respond to and manage those hazards (Downing et al. 1997; Keim, 2008; McMichael & Haines, 1997). Compounding these issues, knowledge of how, when, and under what circumstances climate change will impact health outcomes is limited, especially for African countries.

Temperature impacts both the life cycle and habitat of malaria-carrying mosquitoes (genus *Anopheles*) and parasites. Warmer temperatures may result in new locations suitable for malaria transmission, while currently suitable locations may become too hot, leading to reductions in malaria's seasonal duration and overall risk. This report analyzes the shift in malaria transmission suitability based on projected temperature rise in the short and medium, term (2030s, 2060s), as well as the changes in the number of people at risk of malaria.

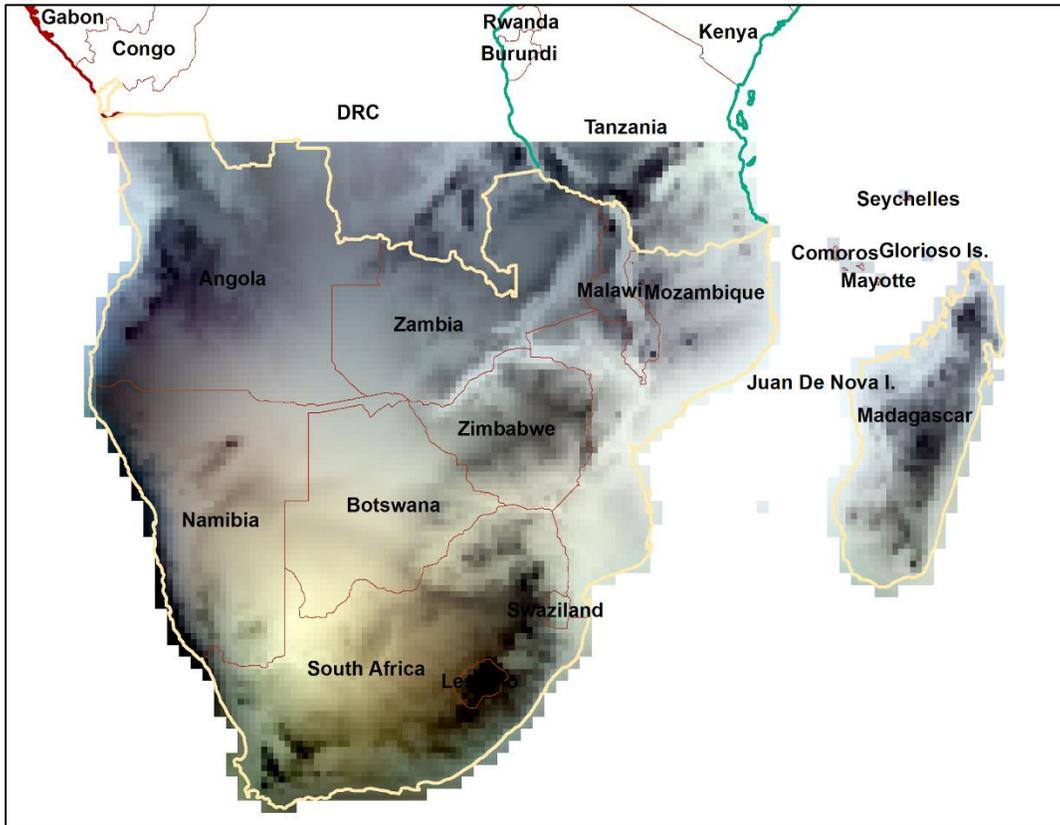
OBJECTIVES

The primary objective of this report is to examine rising temperatures and regional and national malaria incidence in Southern Africa to provide health practitioners and development planners with actionable information.

GEOGRAPHIC SCOPE OF STUDY

The focus of this report is Southern Africa due to demand from stakeholders in this region for more information. The analysis includes Botswana, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe, and parts of Angola, the DRC, and Tanzania. We report on these countries, acknowledging that a small portion of northern Angola, as shown in Figure 1 below, will be excluded.

Figure 1. Geographic scope of study



Note: Yellow regional boundary lines denote the Southern Africa region, while the shaded areas represent the available downscaled data used, sourced from the Coordinated Regional Climate Downscaling Experiment (CORDEX¹) boundary layer for the Southern Africa region.

SOUTHERN AFRICA'S RISING TEMPERATURES

CONTEXT

Regional climate change projections of daily temperature are used to explore climate change and its impact on the spatial extent and season length of malaria transmission. A sensitivity analysis of these projections to available observational climate datasets and aridity assumptions was also conducted. This will be published as a separate annex to the report.

METHODS

CORDEX-AFRICA

We use daily mean temperature processed to form monthly averages for two periods of time: the historical period (1986–2005) and the future period, including a short-term (2015–2044, referred to as the 2030s) and a medium-term (2045–2075, referred to as the 2060s) under the Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 climate pathways (see Box 1), calculated from an ensemble of 18 Regional Climate Model (RCM) projections from the Coordinated Regional Climate Downscaling Experiment (CORDEX) over Southern Africa.¹ To reduce model bias in temperature (some models are warmer or less hot than reality), we used future changes (anomalies) rather than the absolute values projected for the future. The future changes were calculated as the difference between the future time periods from the historical time period, added to the WATCH Forcing Data ERA-Interim–Shuttle Radar Topography Mission (WFDEI–SRTM) observed time period.

To align the spatial resolution of all these models, the data were regridded to the 0.05° resolution of the WFDEI–SRTM dataset using a bicubic interpolation method.²

PROJECTED CHANGES IN CLIMATE

The projected increase in temperature by the 2030s (2015–2044 period) for the RCP 4.5 and RCP 8.5 climate pathways (Table 1) shows only limited difference in temperature rise for this period. Therefore, this analysis focuses on the more distant medium-term future period (2060s, the 2045–2074 period) and the RCP 8.5 pathway, highlighting significant potential differences in temperature rise. The average increase in temperature under this worst-case climate pathway (RCP 8.5) is ~2.7°C, with a large variation in the projected increase in temperature between

¹ The ensemble includes five regional climate models (CLMcom-CCLM4-8-17, DMI-HIRHAM5, KNMI-RACMO22T, MPI-CSC-REMO2009, and SMHI-RCA4) where each model was driven by up to nine different global climate models from the Intergovernmental Panel on Climate Change's (IPCC) archive, the Coupled Model Intercomparison Project (CMIP5) using the historical (baseline), and the RCP 4.5 and RCP 8.5 experiments.

² It is important to note that this process is not the same as the process of interpolation of historical data that included elevation as a covariate. Here, we interpolate temperature anomalies (future–past change) rather than temperature itself. Unlike with air temperature, there is no basis to consider that temperature anomalies are related to surface elevation. As a result, elevation is not considered as a covariate here.

models of 1.3°C. Figure 2 (next page) shows that the models also differ substantially in the spatial pattern of change, with some models simulating the largest change over the more northern parts of the region, while others project the strongest warming to occur over the western interior of region.

Table 1. Summary of projected change in annual average daily mean temperature (in °C) for an ensemble of 18 CORDEX-Africa models over the Southern Africa domain for the 2030s (2015–2044) and 2060s (2045–2074) period under the RCP 4.5 and RCP 8.5 climate pathways

Model Ensemble	2030s (2015–2044)		2060s (2045–2074)	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Mean	1.0	1.2	1.8	2.7
Maximum	1.4	1.5	2.5	3.4
Minimum	0.7	0.9	1.4	2.1
Spread	0.7	0.6	1.1	1.3

EXTREMES IN THE MODEL DISTRIBUTION

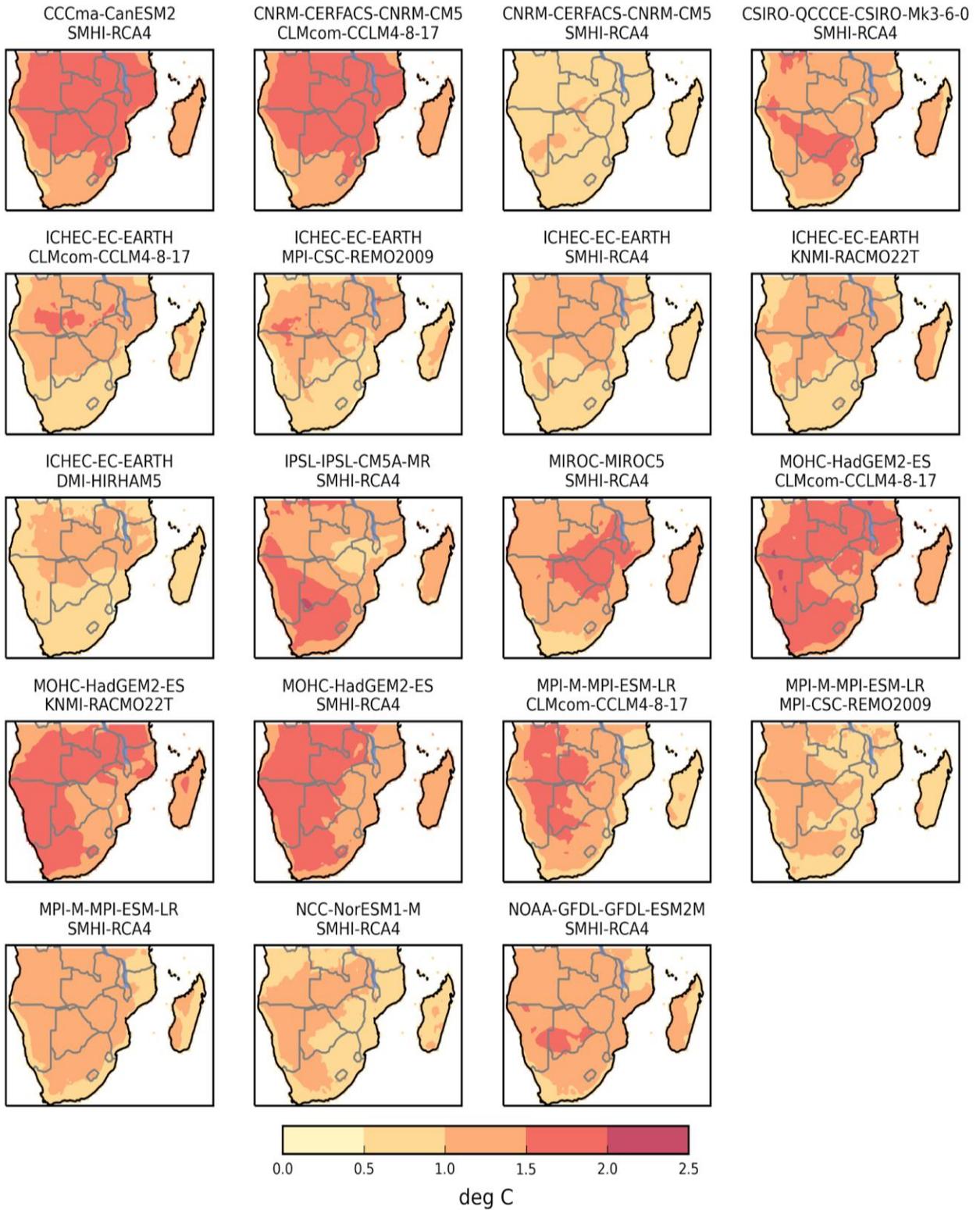
Because higher temperatures are projected across all pathways and time periods, but variability is significant across these, two models were chosen for subsequent analysis, representing the full range of projections for a hotter future: a hotter and a less hot model (Table 2).

Table 2. Average annual temperature increases (°C) from baseline (1985 to 2005) by RCP (climate pathway), GCM (climate model), and time period, referenced in the empirical model results presented here

	Time period	2030s		2060s	
	Climate Pathway	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Model	HADLEY (HOTTER)	1.27	1.46	1.92	2.70
	CNRM (LESS HOT)	0.69	0.84	1.26	1.74

Note: Average projected changes in mean temperatures calculated within CORDEX boundaries.

Figure 2. Projected change in the daily mean temperature by 2020–2039 projected by CORDEX-Africa models under the RCP 8.5 climate pathway



MALARIA RISKS IN A HOTTER SOUTHERN AFRICA

The following analysis makes use of the climate projections explained above to determine the spatial distribution of changes in malaria seasonal suitability by exploring six scenarios of changing suitability (see Box 2 for definitions of suitability).

We measured malaria suitability based on temperatures, using a variety of models and studies described in the methods section below, that suggest the optimal temperature for transmission potential is between 22.9 and 27.8 degrees Celsius. We also excluded areas that were too dry for malaria by measuring the amount of moisture in the ecosystem and average annual precipitation, as described in the methods section.

The six scenarios of changing suitability are:

New areas of malaria suitability

1. Where and when are new areas of **endemic** suitability going to emerge where malaria was previously unsuitable? How many people are at risk from this change?
2. Where and when are new areas of **seasonal** suitability going to emerge where malaria was previously unsuitable? How many people are at risk from this change?

Areas where the malaria season will be extended

3. Where and when will seasonal areas become endemic? How many people are at risk from this change?
4. Where and when will moderately or marginally suitable areas become endemic? How many people are at risk from this change?
5. Where and when will moderately or marginally suitable areas become seasonal? How many people are at risk from this change?

Areas where the malaria season will be shortened

6. Where and when will endemic areas become seasonal? How many people are affected by this change?

A quantitative analysis of responses to each set of questions follows.

BOX 2: DEFINING SUITABILITY

We modified the Mapping Malaria Risk in Africa (MARA) definitions of malaria suitability to better illustrate the impact of changing climate and to provide information that decision-makers can use to carry out control and/or intervention activities. Our definitions specify the duration in months per year of malaria transmission suitability:

- **Endemic:** 10–12 months
- **Seasonal:** 7–9 months
- **Moderate:** 4–6 months
- **Marginal:** 1–3 months

The suitability measure is derived from temperature response curves for the mosquito species *Anopheles gambiae* and the malaria pathogen (*Plasmodium falciparum*). The report assesses the shifting suitability as temperatures rise under two climate scenarios— a “hotter” and a “cooler” [“less hot” used more often than cooler] model of the future (2030s and 2060s), using a moderate temperature increase (RCP 4.5) and higher-temperature increase (RCP 8.5):

1. Unsuitable to endemic
2. Unsuitable to seasonal
3. Seasonal to endemic
4. Moderately or marginally suitable to endemic
5. Moderately or marginally suitable to seasonal
6. Endemic to seasonal

We limited the study to these six changes because in our view they are among the most relevant of the over 200 possible changes for the four levels of malaria suitability (plus unsuitable), two time periods, and the extreme set of climate scenarios, a hotter model and a less hot model.

METHODS

We mapped areas of malaria suitability in a model combining future temperature change projections and current knowledge about the life cycles of malaria-carrying mosquitoes and the malaria parasite. We projected malaria suitability across two future time periods: the short-term 2030s (representing the period between 2015 and 2044), and the medium-term 2060s (representing the period between 2045 and 2074).

The analysis of vector suitability considering future temperature projections is based on an empirical modeling methodology described in the Shifting Burdens report (USAID 2019). The method of Ryan et al. 2015 is extended, applying the mechanistic model from Mordecai et al., 2013 to climate model layers (described in the Input Data section below). All calculations are conducted in R [3.5.0], using the “raster,” “rgdal,” “sp,” and “maptools” functions, and mapped output is produced in ArcGIS (Version 10.5.1).

INPUT DATA

- CORDEX information under two climate pathways of future climate (a best-case and a worst-case scenario of climate change as represented by the Representative Concentration Pathways (RCPs) —RCP 4.5 (best case) and RCP 8.5 (worst case) —for two future time periods: the 2030s (short-term) and 2060s (medium-term). Two future climate models were selected for comparison to represent the range of possible outcomes – a “hotter” future and a “less hot” future.
- To exclude arid areas that preclude *Anopheles* development, the Moderate-Resolution Imaging Spectroradiometer (MODIS)-derived normalized difference vegetation index

(NDVI) based on MODIS NDVI data (MOD13C, MODIS/Terra Vegetation Indices 16-Day L3 Global 0.05° CMG V006), are used to create an “aridity mask,” as described below. The sensitivity of this aridity mask is explored in Annex B.

- Population data are derived from the SSP2 Shared Socioeconomic Pathways project (Jones & O’Neill, 2016). Baseline calculations used 2010 data, while projected populations are extracted from the 2060 and 2050 layers.

MODEL DESCRIPTION

Malaria transmission suitability model. Using the mechanistic model mentioned above (Mordecai et al. 2013, Mordecai et al. 2017), R_0 , the metric for transmission suitability, scaled from 0 to 1, is described in quantiles. The top quantile (top 25 percent, representing a temperature range of 22.9°C–27.8°C) of the curve is selected to represent the range of temperature in which transmission suitability is expected. This conservative measure of the overall temperature curve is used because it was previously shown to correspond visually to existing maps of ongoing transmission under current temperatures (Ryan et al. 2015). Using this “most suitable” quantile, this temperature range is incorporated into projections of suitability, as described in the following sections.

Aridity masks. To exclude areas that are too arid for the *Anopheles* mosquitoes’ life cycle, the methods of Ryan et al. (2015) are used to create a geographic or “aridity” mask, based on available moisture (see Figure 3). This mask incorporates NDVI values derived from postprocessed MODIS data (Suzuki, et al. 2006), and if month-to-month thresholding calculated for two consecutive months falls below 0.125, an aridity boundary is crossed (Suzuki et al., 2006), indicating that the area (pixel) is too dry for malaria transmission.

Figure 3. Areas of Southern Africa with NDVI-based aridity mask



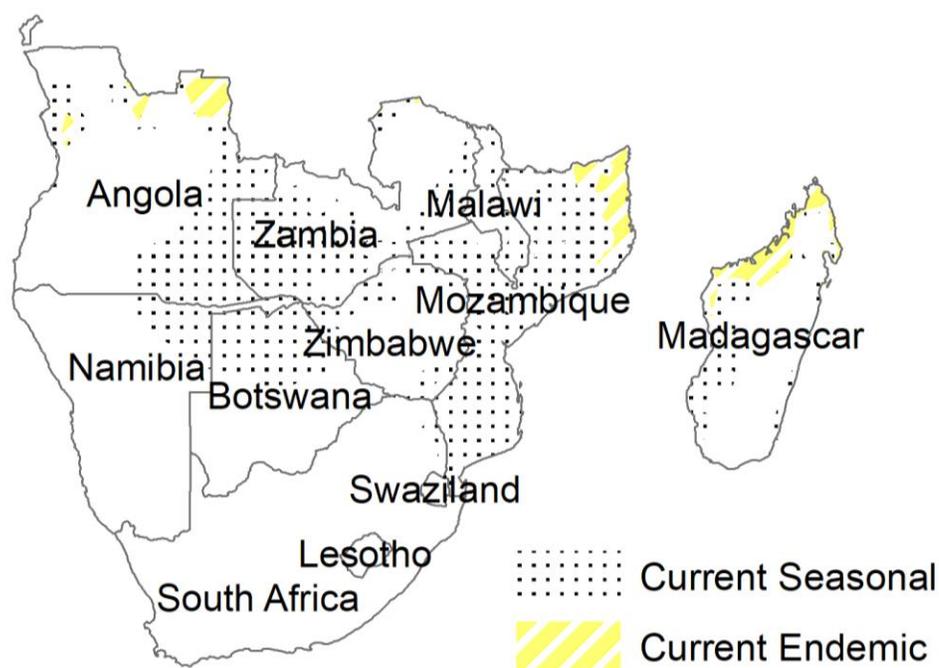
Note: Areas in yellow estimate where it is too dry for *Anopheles* to live and include large bodies of water. Areas in green have suitable moisture for *Anopheles gambiae*, based on the NDVI analysis; blue areas are water bodies. The northern part of Angola, the area in the box, was excluded because the climate data we used, CORDEX, did not include that area.

BASELINE AND OVERVIEW OF PROJECTED CHANGES

CURRENT DISTRIBUTION OF MALARIA

The modeled current distribution of areas using the downscaled baseline as described in Figure 4 aligns visually well with areas with current endemic malaria suitability (10–12 months) and seasonal malaria suitability (7–9 months). This baseline analysis (1985-2005) shows that the seasonality definitions capture well the current dynamics and can be used in future analyses. It is important to note that the aridity mask used in this model to screen out areas currently considered too arid to allow the *Anopheles gambiae* mosquito to propagate calculates aridity conservatively, so as not to overestimate projected future malaria suitability. It therefore may be obscuring some areas that in fact are currently suitable. Additionally, *current* malaria suitability provides a measure of current malaria incidence. It is used here to calibrate the model projecting new areas of suitability and provides a baseline that aligns with current incidence, from which future incidence can be confidently and accurately projected.

Figure 4. Current extent of areas classified as endemic (10–12 months of suitability) and seasonal (7–9 months of suitability) for malaria with the NDVI-based aridity mask



CHANGES IN OVERALL MALARIA SUITABILITY

The geographic and temporal shifts of future suitability of areas for malaria-transmitting *Anopheles* mosquitoes is closely tied to expected temperature changes under both RCP 4.5 and RCP 8.5 (Figure 5 and Figure 6). Note that areas in tan these figures do not necessarily represent a complete elimination in months of suitability of malaria under endemic or seasonal conditions; in fact, tan areas could represent areas that continue to be either moderately or marginally suitable. These scenarios indicate that as temperatures rise, important changes are expected in *Anopheles* transmission suitability:

- The range of endemic (10–12 months) and seasonal (7–9 months) suitability is projected to increase in Southern Africa under all climate pathways examined, but the spatial distribution shifts.
- By the 2030s:
 - Under the less hot model, 4.0 to 6.4 million more people will be at risk of endemic suitability when compared to the baseline (1985-2005).
 - Under the hotter model, 3.7 to 3.9 million more people will be at risk of endemic suitability than at baseline.
- By the 2060s, under the less hot model, 7.4 to 8.8 million more people will be at risk of endemic suitability than at baseline, and under the hotter model, around 40–66 million people overall are predicted to be at endemic risk.
- The discrepancies (i.e. remaining endemic areas in the cooler scenario for both northern Mozambique and Madagascar) we see at the regional scale between these less hot and hotter future climate pathways in 2030s are largely due to the shift of suitability over the high-density population areas of Angola, Madagascar, Mozambique, and to a smaller extent, Zambia.
- Under the less hot models, we see endemic areas increasing in northern Mozambique and Madagascar in the near term (2030s), and in all climate pathways, we see increases in endemic areas across parts of northern Angola and Zambia.

Figure 5. Extent of areas classified as seasonal and endemic by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the less hot model

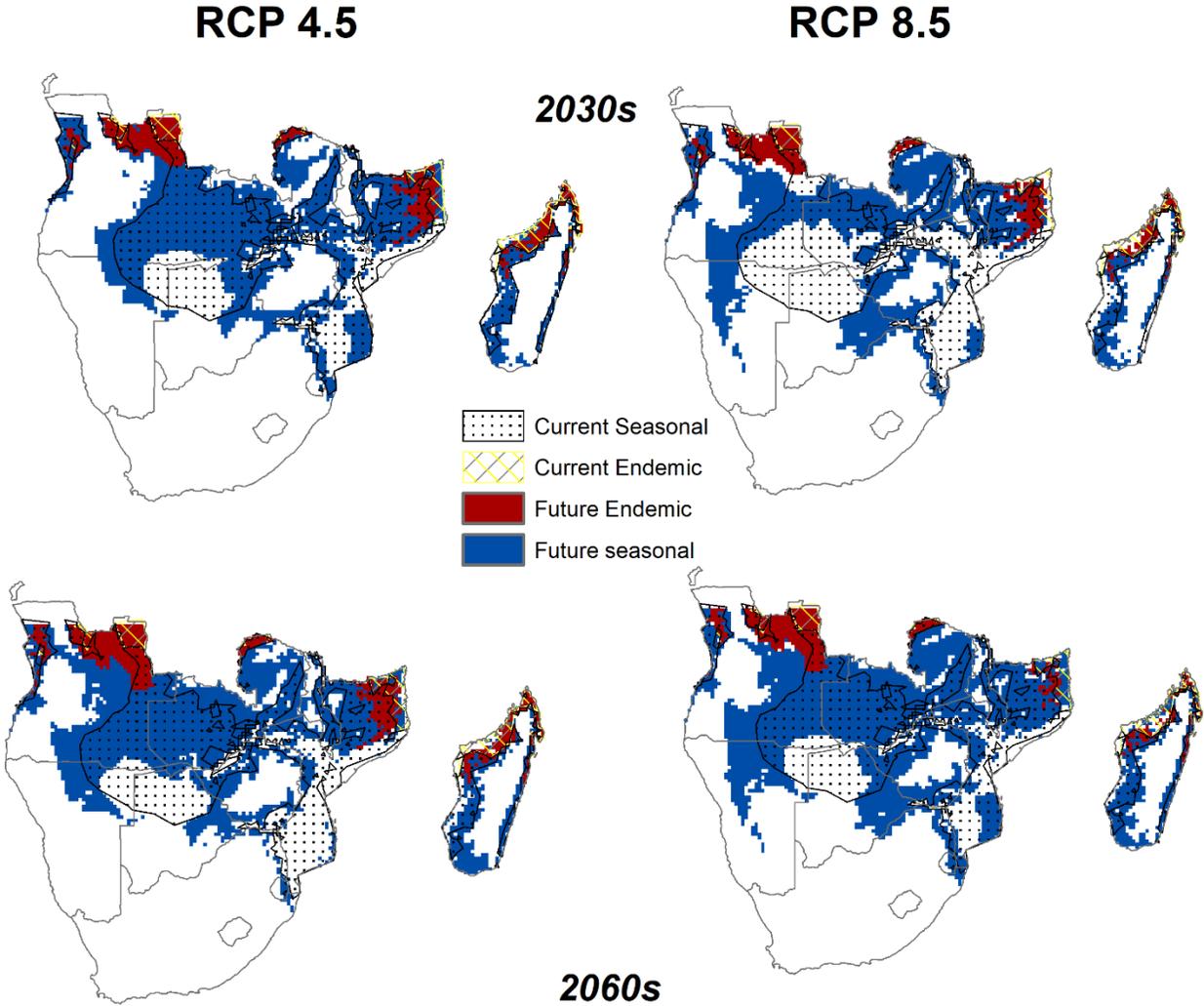
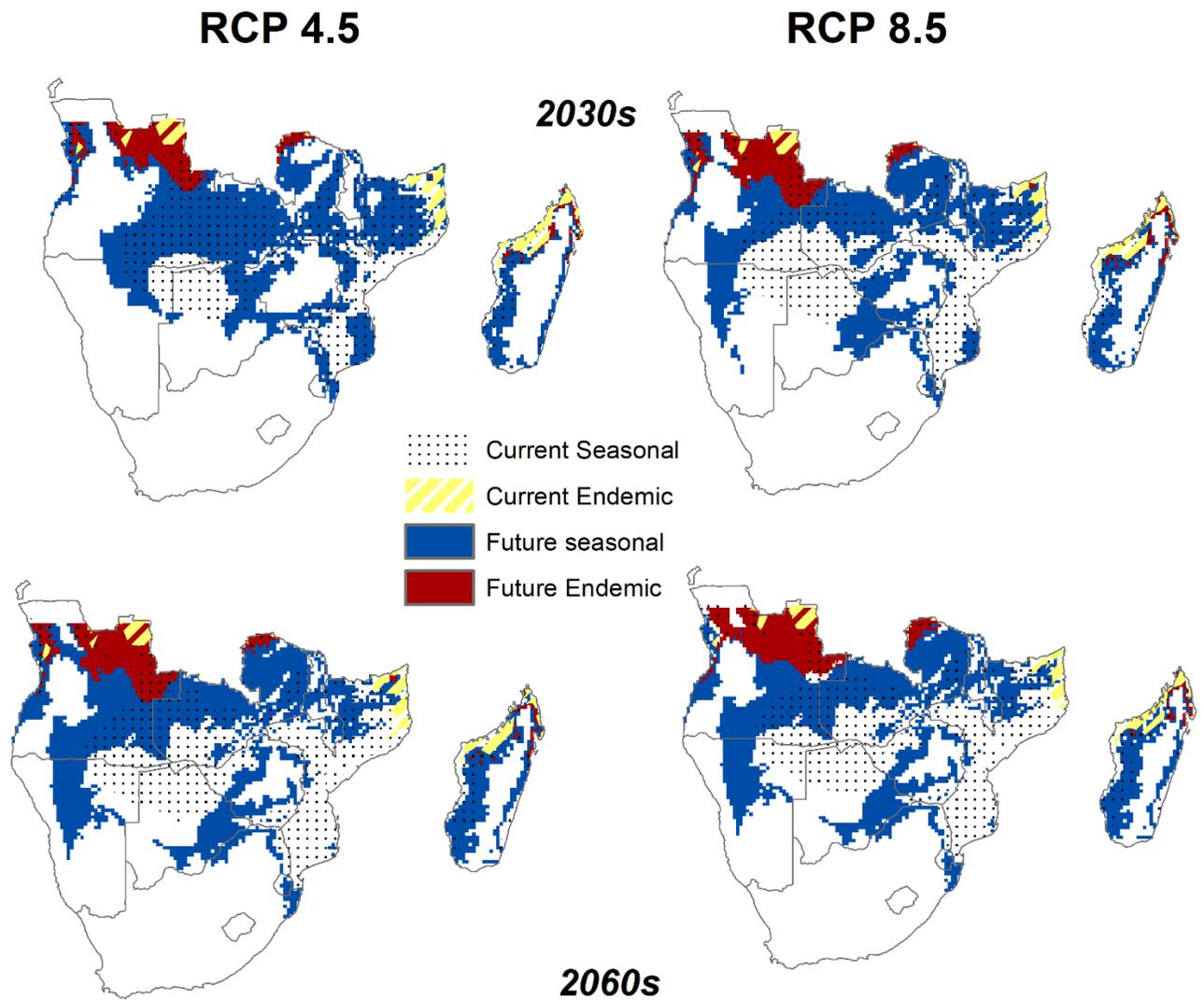


Figure 6. Extent of areas classified as seasonal and endemic by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the hotter model



These changes in the geographic range of malaria suitability, broadly consistent across both climate pathways of future climate, suggest that the number of people exposed to conditions of suitability will likely increase in some areas and decrease in some areas. Nevertheless, the maps also show that there is significant spatial variability in these dynamics which are not apparent at the country level.

PROJECTED CHANGES IN DETAIL

Shifts in both the areas and populations exposed to malaria risks will require a change in the responses to address those risks. Many countries with a high burden of malaria have weak surveillance systems and are not able to assess disease distribution and trends. The following analysis offers insights for programming decisions by exploring six scenarios of changing suitability. Not all potential scenarios of change were evaluated; rather, these scenarios highlight the changing profile of risk across the region but could be expanded to include other shifts, such as from endemic or seasonal to marginal or moderate suitability. These will be evaluated in subsequent studies. The six scenarios of changing suitability are:

New areas of malaria suitability

1. Where and when are new areas of **endemic** suitability going to emerge where malaria was previously unsuitable? How many people are at risk from this change?
2. Where and when are new areas of **seasonal** suitability going to emerge where malaria was previously unsuitable? How many people are at risk from this change?

Areas where the malaria season will be extended

3. Where and when will seasonal areas become endemic? How many people are at risk from this change?
4. Where and when will moderately or marginally suitable areas become endemic? How many people are at risk from this change?
5. Where and when will moderately or marginally suitable areas become seasonal? How many people are at risk from this change?

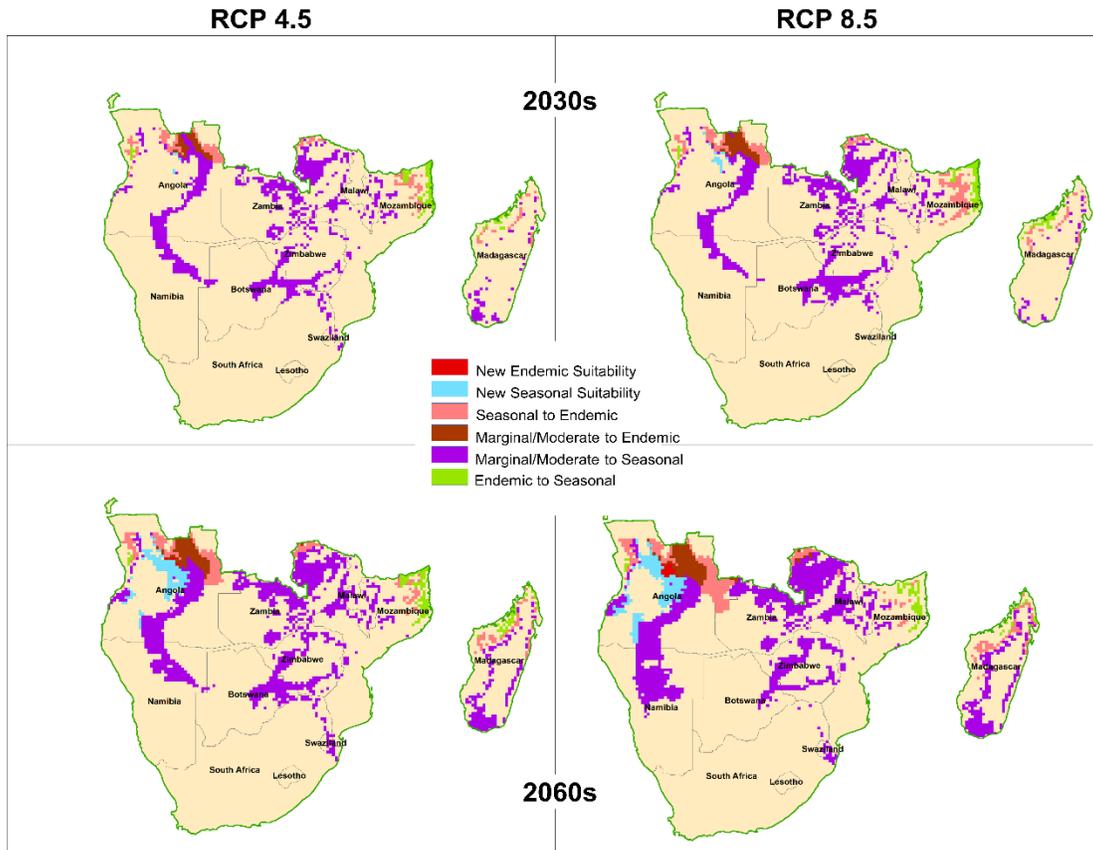
Areas where the malaria season will be shortened

6. Where and when will endemic areas become seasonal? How many people are affected by this change?

A quantitative analysis of responses these questions follows. However, key insights are summarized in Figure 7 (for the less hot climate) and Figure 8 (for the hotter climate model) below. These models represent the range of potential temperature rise across southern Africa, and important differences in scenarios of change exist across these. Namely:

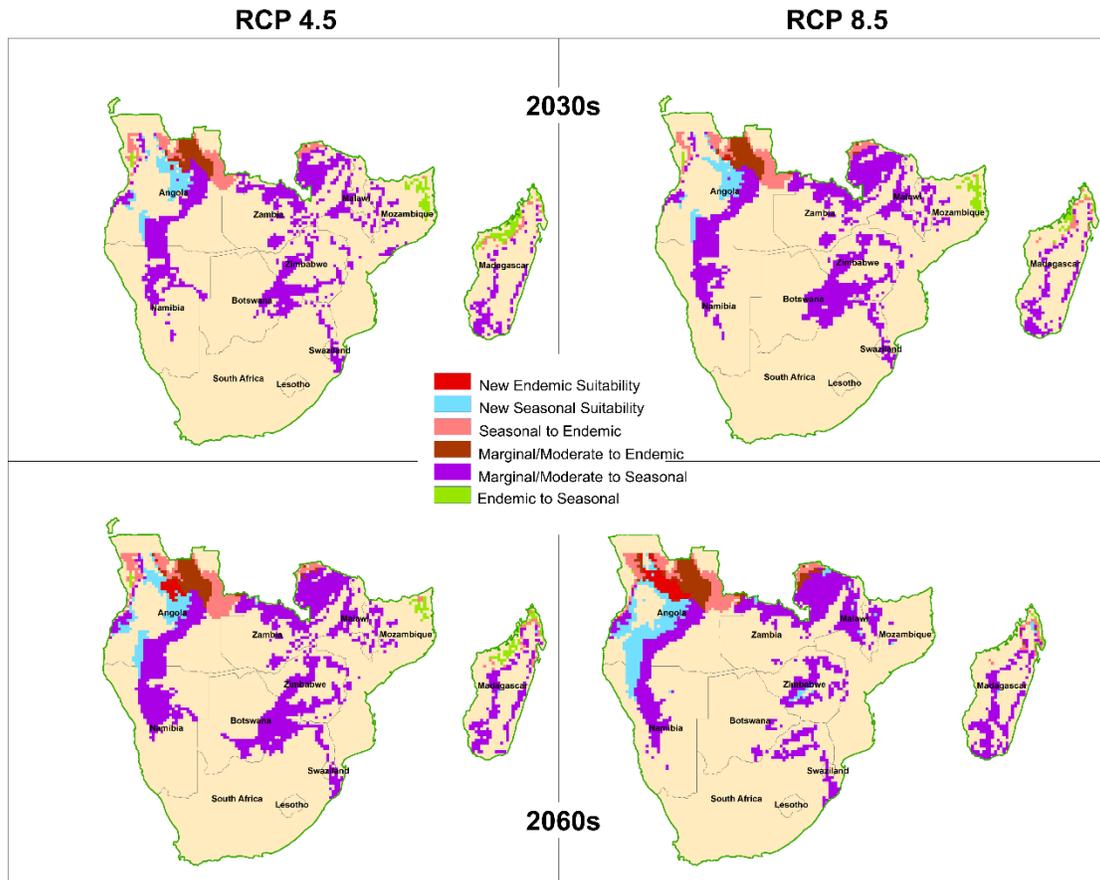
- Under the less hot model (Figure 7) new areas of endemic suitability emerge in northern Mozambique and northwestern Madagascar, while under the hotter model (Figure 9), by the 2060s, and under the worst-case climate pathway (RCP 8.5), in areas such as western Madagascar and northern Mozambique, temperatures become too hot for the mosquito to survive, eliminating endemic areas of risk.
- Under the hotter model (Figure 8), new seasonal areas of suitability (turquoise areas) are spread wider under hotter temperatures, especially in the higher elevation areas of Angola and Namibia as early as the 2030s. expanding seasonal malaria suitability into areas previously too cold.

Figure 7. Projected selected changes in malaria suitability under a changing climate by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the less hot model



Note: Tan regions indicate no change.

Figure 8. Selected projected changes in malaria suitability under a changing climate by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the hotter model



Note: Tan regions indicate no change.

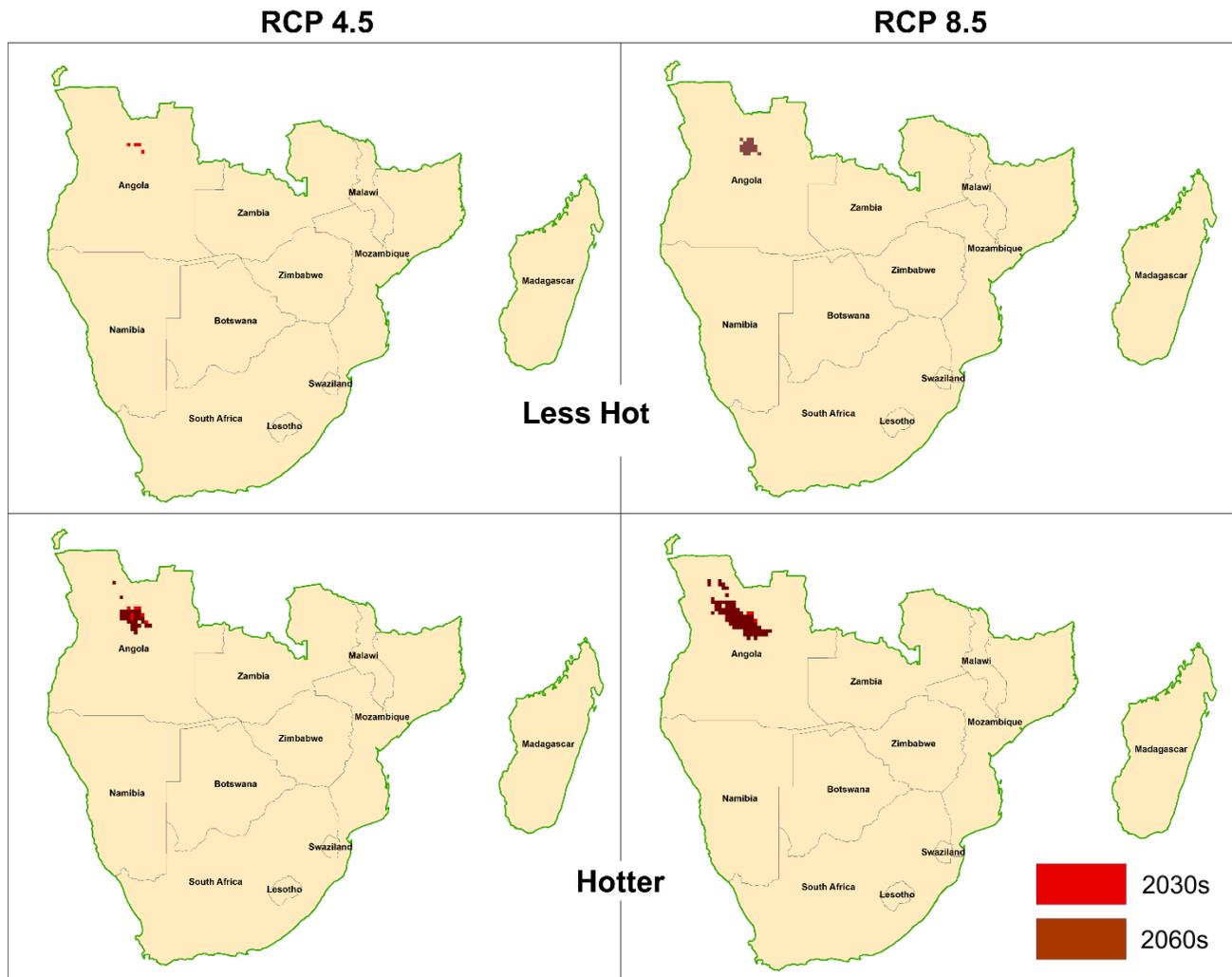
NEW AREAS OF MALARIA SUITABILITY

Malaria outbreaks that occur where people have little or no immunity to the disease can often lead to epidemic conditions (Dondorp et al., 2009; Yanda, Kangalawe, & Sigalla, 2005). For a pregnant woman, the risk of infection increases due to changes in her hormone levels and immune system, which can increase the risk of anemia and miscarriage, while for children, their vulnerability is a function of the lack of acquired immunity during childhood. These research questions aim to identify such “hotspots.” These areas could see epidemic “flares” as climate conditions affect vector survival and reproduction.

Research Question 1: Where and when are new areas of endemic suitability going to emerge where malaria was previously unsuitable? How many people are at risk from this change?

Figure 9 shows areas previously unsuitable for malaria that will shift to endemic conditions (10–12 months per year of malaria suitability) for the two future time periods, and the hotter and less hot models. Hotspots of endemic suitability begin to emerge in northern Angola and become more pronounced in the 2060s, and under RCP 8.5. In these new areas of suitability, under the hotter model and the worst-case RCP (8.5), an estimated 2.9 million people will be at risk by the 2060s.

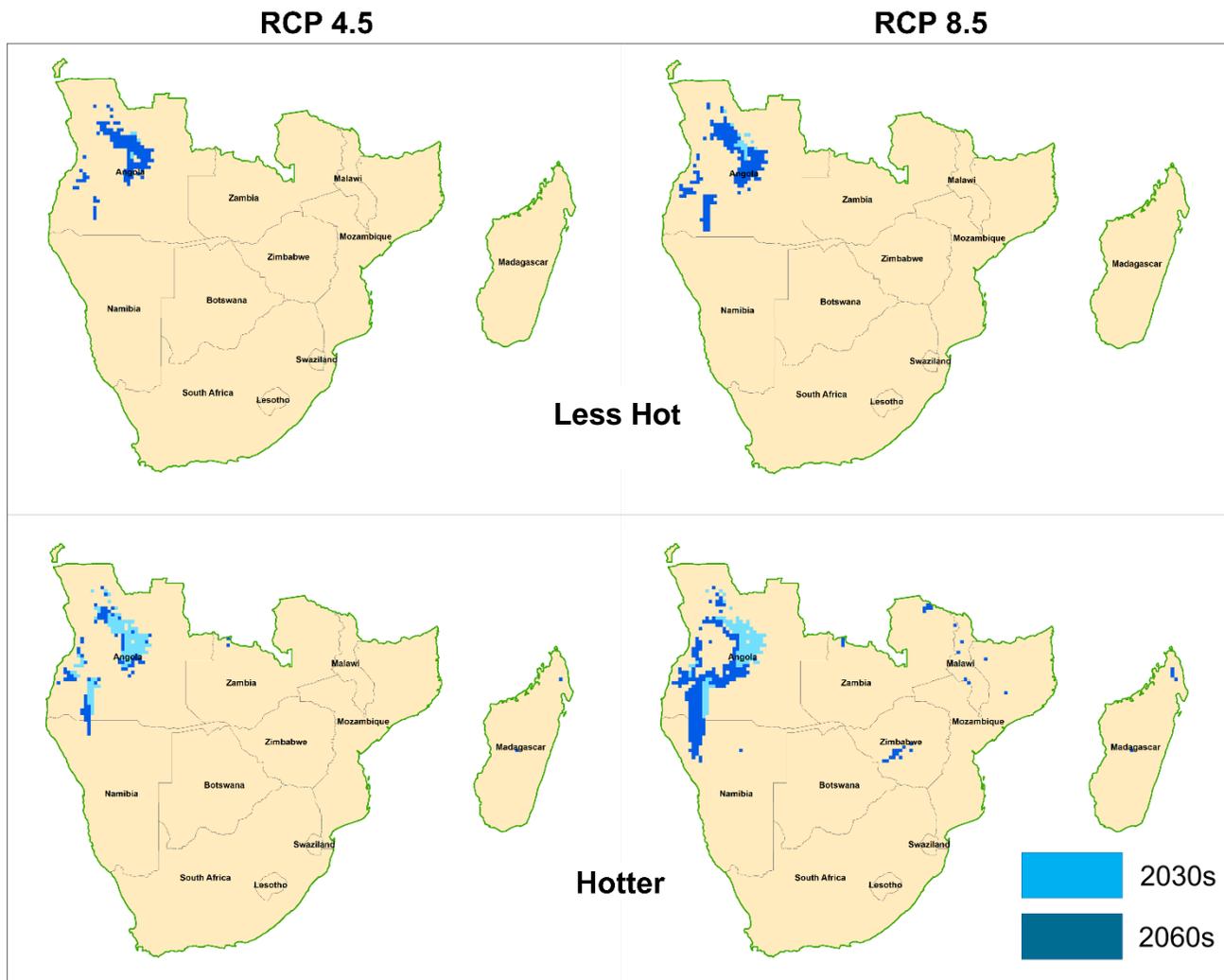
Figure 9. Areas previously unsuitable for malaria that become endemically suitable by the 2030s and 2060s under rising temperatures under RCP 4.5 and RCP 8.5 for the less hot and hotter models



Research Question 2: Where and when are new areas of seasonal suitability going to emerge where malaria was previously unsuitable? How many people are at risk from this change?

Figure 10 shows where areas previously unsuitable for malaria will shift to conditions of seasonal exposure (7–9 months per year of suitability). Concentrated hotspots of seasonal suitability begin to emerge in central Angola, northwestern Zambia, Zimbabwe, and parts of northern Madagascar. These hotspots will either continue to concentrate or will move southward into Namibia in the 2060s.

Figure 10. Areas previously unsuitable for malaria that will become seasonally suitable under rising temperatures under RCP 4.5 and RCP 8.5 for the less hot and hotter models



These new areas of suitability will put as many as 12.9 million people at risk of exposure to seasonal outbreaks, with the most marked increases in Namibia, Angola, Madagascar, Mozambique, and Zimbabwe (Table 3).

Table 3. The number of people at risk in areas of new seasonal suitability in Southern Africa by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the less hot and hotter models

Number of People at Risk							
Country	Angola	Zambia	Zimbabwe	Malawi	Mozambique	Namibia	Madagascar
<i>Less Hot Model</i>							
RCP 4.5 2030s	69,491	-	-	-	-	-	-
RCP 4.5 2060s	4,521,456	-	-	-	-	-	-
RCP 8.5 2060	350,364	-	-	-	-	-	-
RCP 8.5 2060s	6,134,859	-	-	-	-	-	-
<i>Hotter Model</i>							
RCP 4.5 2030s	3,162,024	-	-	-	-	-	-
RCP 4.5 2060s	5,736,421	28,086	-	-	-	59,212	137,979
RCP 8.5 2030s	2,921,698	-	-	-	-	-	-
RCP 8.5 2060s	8,499,211	294,149	2,580,372	815,449	367,729	156,753	202,783

EXTENSION OF THE MALARIA SEASON

In areas where people have acquired immunity due to prolonged malaria exposure, outbreaks of malaria trigger interventions such as vector control and case management to prevent or reduce transmission. The goal is to pinpoint areas where elimination and elimination targets need to be revisited to consider the effect of climate on malaria risk profiles.

Research Question 3: Where and when will seasonal areas become endemic? How many people are at risk from this change?

Areas where the malaria season will be longer will require extended responses, increasing resource needs (e.g., staff time, medicines) as well as costs. In the 2030s and 2060s, parts of northern Zambia, Mozambique, Madagascar, and coastal, north central and eastern Angola will see lengthening seasonality to year-round transmission. Under the less hot future model (Figure 11), these areas are more pronounced than under the hotter model (Figure 12). By the 2030s this will put an additional 3.6 million people at risk, 4.8 to 6 million by the 2060s, with the highest changes in total numbers of people affected expected in Angola, Madagascar, Mozambique, and Zambia (Table 4).

Figure 11. New areas of endemic suitability (10–12 months) by the 2030s and 2060s, where currently suitable for seasonal transmission (7–9 months), under RCP 4.5 and RCP 8.5 for the less hot model

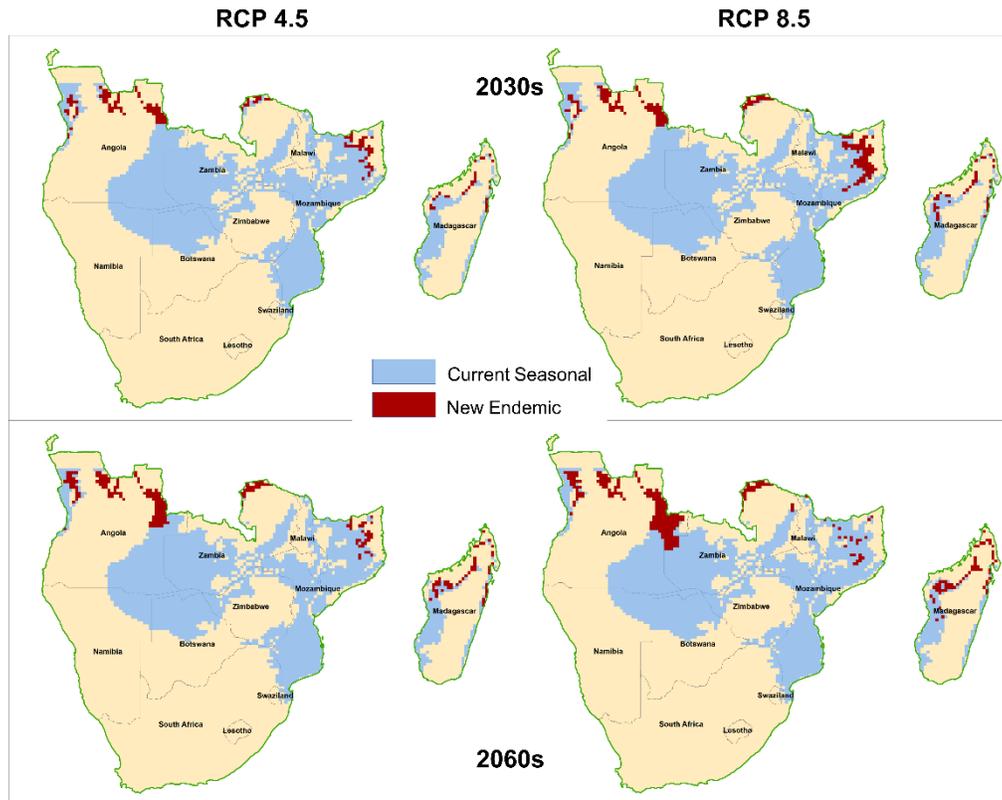


Figure 12. New areas of endemic suitability (10–12 months) by the 2030s and 2060s, where currently suitable for seasonal transmission (7–9 months), under RCP 4.5 and RCP 8.5 for the hotter model

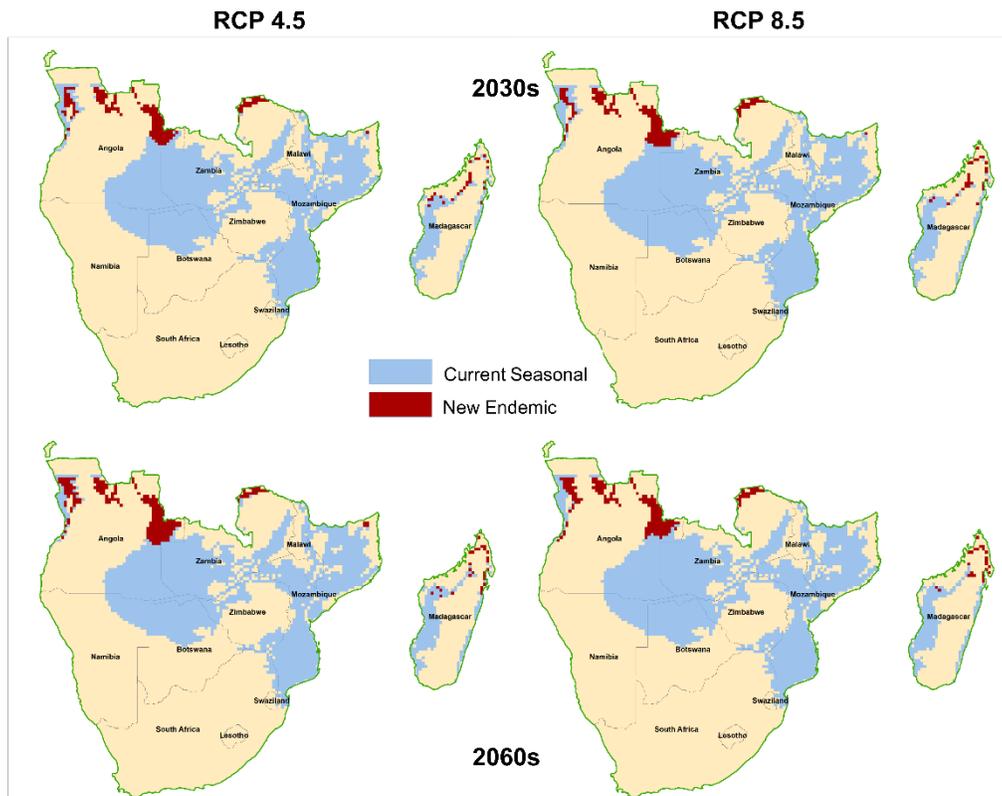


Table 4. The number of people at risk in areas currently suitable for seasonal transmission which become endemically suitable (10–12 months) by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the less hot and hotter models

Number of People at Risk						
Country	Angola	Botswana	Zambia	Malawi	Mozambique	Madagascar
<i>Less Hot Model</i>						
RCP 4.5 2030s	1,060,752	-	340,584	-	1,056,083	1,304,467
RCP 4.5 2060s	2,161,140	-	790,146	-	1,053,855	2,421,871
RCP 8.5 2060	1,252,464	-	473,943	26,617	2,735,897	1,461,965
RCP 8.5 2060s	2,618,358	-	1,155,605	33,094	726,945	2,397,669
<i>Hotter Model</i>						
RCP 4.5 2030s	1,598,770	-	566,962	-	41,833	700,104
RCP 4.5 2060s	2,899,410	-	550,618	-	199,552	1,402,054
RCP 8.5 2060	1,597,665	-	586,433	-	41,833	872,521
RCP 8.5 2060s	2,913,035	-	725,480	-	-	1,153,991

Research Question 4: Where and when will moderately or marginally suitable areas become endemic? How many people are at risk from this change?

Given the strong empirical relationship between vector survival and temperature, and provided there is enough moisture for vector reproduction, as temperatures rise, exposure to malaria transmission is expected to increase in previously moderately or marginally suitable regions. Areas likely to be impacted by this change are in Angola. By the 2060s, impacted areas may extend into western Angola and northeastern Zambia (Figure 13 and **Error! Reference source not found.** 14). These changes could affect 313,000 to 764,000 people by the 2030s, and as many as 2.6 million people in the RCP 8.5 2060s hotter model (Table 5).

Research Question 5: Where and when will moderately or marginally suitable areas become seasonal? How many people are at risk from this change?

Areas that are currently moderately or marginally suitable for *Anopheles* transmission but will shift to seasonally suitable include large portions of Zambia, Malawi, eastern South Africa, Botswana, the highlands of Zimbabwe, northern Mozambique, and the Zambezi River Basin. These changes will put approximately 23–59 million additional people at increased risk from transmission, with this new seasonal suitability disproportionately impacting people in Zambia, Malawi, and Madagascar (Table 6).

Figure 13. Areas currently suitable moderately (3–6 months) or marginally (1–3 months) for malaria that will become endemic or seasonal by the 2030s and 2060s, under RCP 4.5 and 8.5 for the hotter model

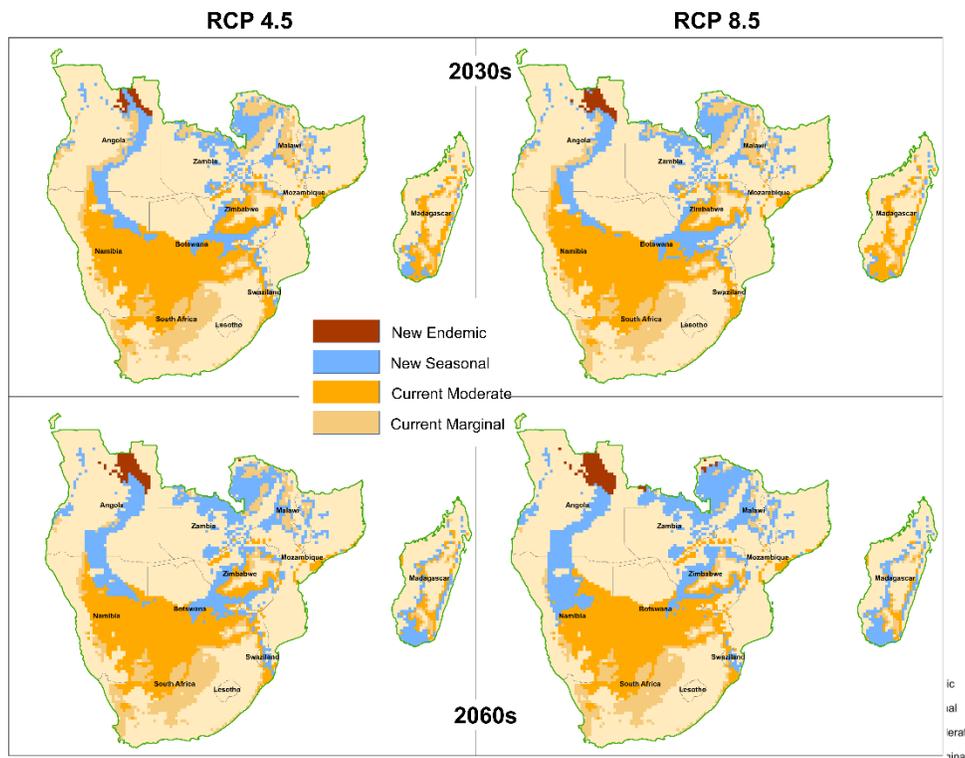


Figure 14. Areas currently suitable moderately (3–6 months) or marginally (1–3 months) for malaria which will become endemic or seasonal by the 2030s and 2060s, under RCP 4.5 and 8.5 for the hotter model

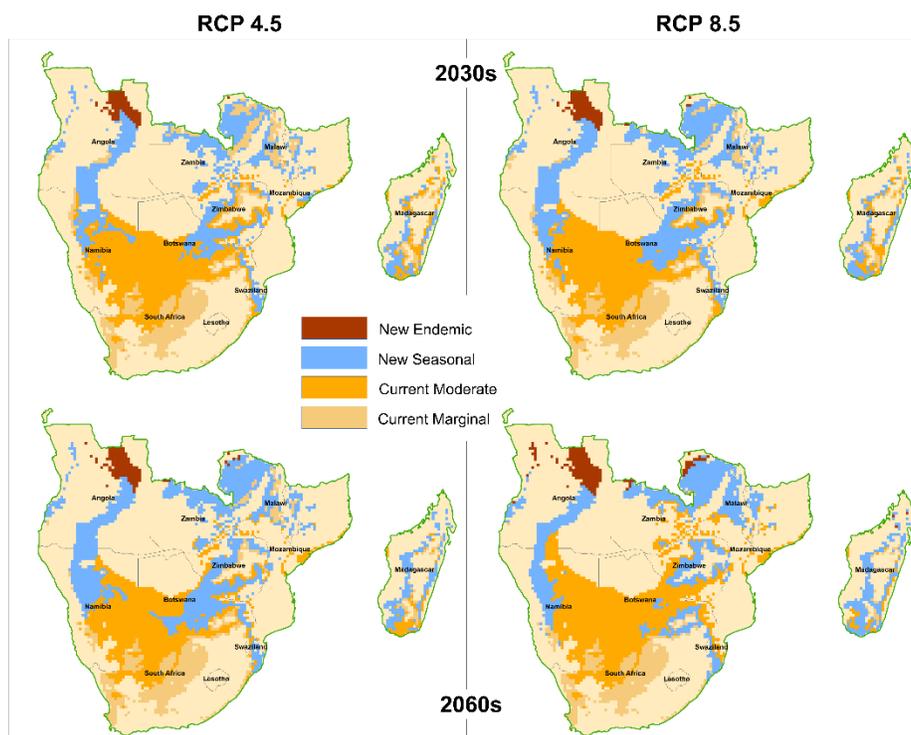


Table 5. People newly at risk of endemic suitability for transmission (10–12 months) in areas currently experiencing marginal or moderate suitability (1–6 months) by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the less hot and hotter models

Country	Number of People at Risk		
	Angola	Zambia	Madagascar
Less Hot Model			
RCP 4.5 2030s	313,393	-	-
RCP 4.5 2060s	935,339	17,946	-
RCP 8.5 2060	479,780	-	-
RCP 8.5 2060s	1,154,010	134,432	-
Hotter Model			
RCP 4.5 2030s	650,809	17,502	-
RCP 4.5 2060s	1,179,130	121,729	-
RCP 8.5 2060	716,224	48,110	-
RCP 8.5 2060s	1,920,736	609,318	120,026

Table 6. People newly at risk of seasonal suitability for transmission (7–9 months) in areas currently experiencing marginal or moderate suitability (1–6 months) by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the less hot and hotter models

Number of People at Risk									
Country	Angola	Botswana	Zambia	Zimbabwe	Mozambique	South Africa	Swaziland	Namibia	Madagascar
<i>Less Hot Model</i>									
RCP 4.5 2030s	1,831,179	348,169	10,038,363	1,386,686	4,072,233	1,650,982	1,085,067	174,620	314,231
RCP 4.5 2060s	3,382,595	583,488	16,736,499	2,141,172	12,169,977	2,642,782	1,383,363	455,491	976,775
RCP 8.5 2060s	1,885,040	568,995	10,519,051	1,680,631	4,146,977	1,666,509	1,185,684	-	278,994
RCP 8.5 2060s	3,349,303	252,864	17,899,773	2,717,202	19,055,640	2,813,990	770,582	417,930	1,213,563
<i>Hotter Model</i>									
RCP 4.5 2030s	2,491,140	651,969	11,503,192	2,131,841	6,684,560	3,003,151	1,642,396	550,717	887,055
RCP 4.5 2060s	3,330,387	1,585,161	17,502,899	3,272,683	14,066,125	2,476,953	3,817,436	515,031	1,221,185
RCP 8.5 2060s	2,485,828	1,083,967	12,408,346	3,207,113	8,994,848	2,154,129	2,793,658	496,006	1,022,389
RCP 8.5 2060s	2,297,973	345,723	12,142,552	3,880,660	21,351,781	2,287,988	7,257,919	558,833	1,212,821

SHORTENING OF THE MALARIA SEASON

In addition to climate and weather conditions, other factors affect malaria's seasonal cycle across Africa, such as changing agricultural activities which alter mosquito larval source availability. Thus, during some periods of the year, climate conditions are not conducive to spread of the disease. A key opportunity lies in the possibility of climate change reducing the period during which the *Anopheles* mosquito thrives and transmits malaria. This may ultimately present an opportunity to alter control efforts and/or shift resources to other more critical areas.

Research Question 6: Where and when will endemic areas become seasonal? How many people will be affected by this change?

Where the number of months of suitability for *Anopheles* survival decreases, opportunities will emerge to reduce the cost of interventions or eradicate malaria. As shown in **Error! Reference source not found.** 15 and Figure 16, these areas are in Angola, Madagascar, and Mozambique. In the near term (2030s), approximately 2.2 to 3.1 million people will live in these additional areas of decreased malaria suitability, where malaria caseloads will likely also decrease. By the 2060s, the estimates range from about 750,000 people under the hotter model and RCP 8.5, to 5.1 million under the less hot model and RCP 4.5 (Table 7). This is because under the hotter model it is likely that many areas become too hot for suitability to extend.

Figure 15. Areas currently endemic that will experience a shortening of transmission suitability season risk from 10–12 months to 7–9 months under RCP 4.5 and RCP 8.5 in 2030 and 2060 for the less hot model

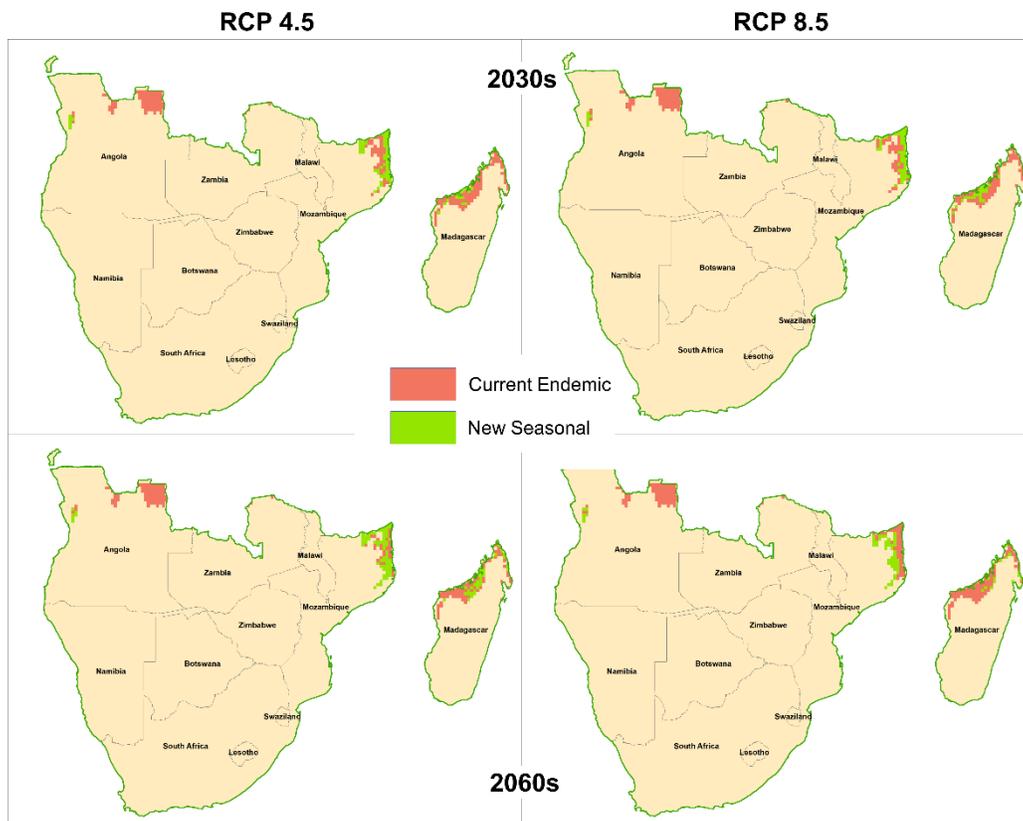


Figure 16. Areas currently endemic that will experience a shortening of transmission suitability season risk from endemic suitability (10–12 months) to seasonal suitability (7–9 months), under RCP 4.5 and RCP 8.5 by the 2030s and 2060s for the hotter model

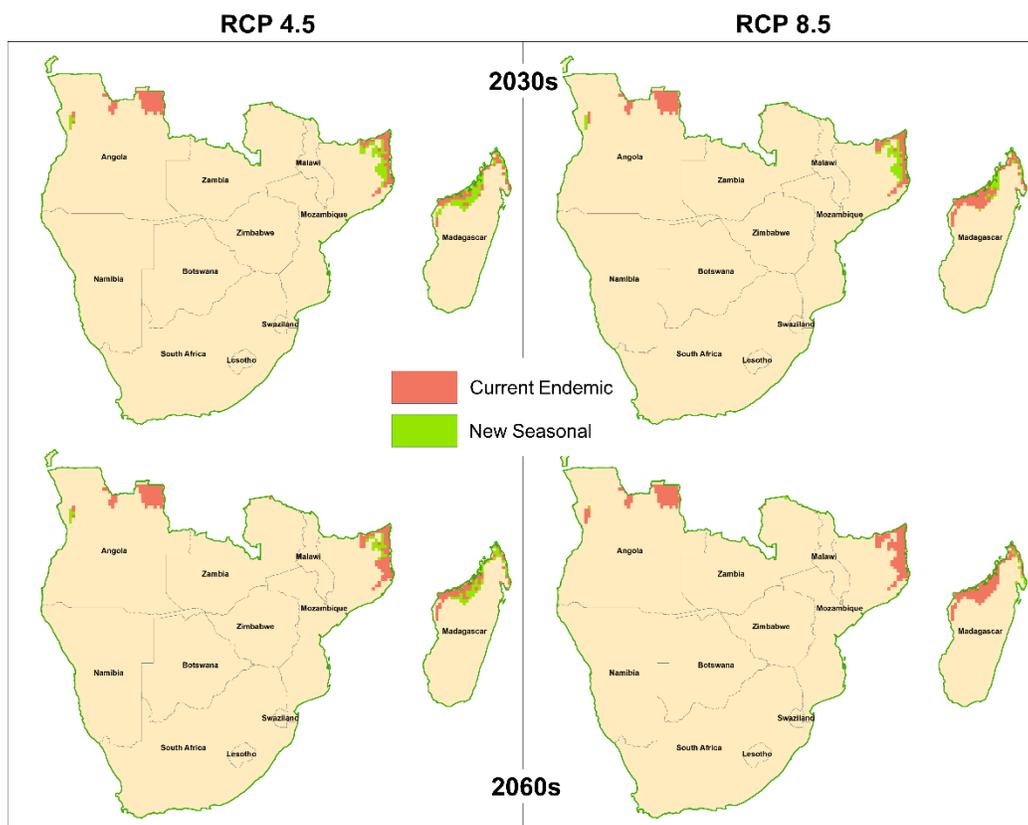


Table 7. The number of people affected by a shortening of transmission suitability risk (endemic to seasonal) by the 2030s and 2060s, under RCP 4.5 and RCP 8.5 for the less hot and hotter models

Number of People at Risk									
Country	Angola	Botswana	Zambia	Zimbabwe	Mozambique	South Africa	Swaziland	Namibia	Madagascar
Less Hot Model									
RCP 4.5 2030s	1,831,179	348,169	10,038,363	1,386,686	4,072,233	1,650,982	1,085,067	174,620	314,231
RCP 4.5 2060s	3,382,595	583,488	16,736,499	2,141,172	12,169,977	2,642,782	1,383,363	455,491	976,775
RCP 8.5 2060	1,885,040	568,995	10,519,051	1,680,631	4,146,977	1,666,509	1,185,684	-	278,994
RCP 8.5 2060s	3,349,303	252,864	17,899,773	2,717,202	19,055,640	2,813,990	770,582	417,930	1,213,563
Hotter Model									
RCP 4.5 2030s	2,491,140	651,969	11,503,192	2,131,841	6,684,560	3,003,151	1,642,396	550,717	887,055
RCP 4.5 2060s	3,330,387	1,585,161	17,502,899	3,272,683	14,066,125	2,476,953	3,817,436	515,031	1,221,185
RCP 8.5 2060	2,485,828	1,083,967	12,408,346	3,207,113	8,994,848	2,154,129	2,793,658	496,006	1,022,389
RCP 8.5 2060s	2,297,973	345,723	12,142,552	3,880,660	21,351,781	2,287,988	7,257,919	558,833	1,212,821

CONCLUSIONS AND INSIGHTS FOR ACTION

This analysis offers a new, initial view of potential changes in malaria seasonality due to projected rising temperatures. This study alone is not meant to guide programmatic decisions. Additional field studies are needed to verify the conclusions of this analytical methodology and to use these findings as predictive insights.

Addressing the changing risk profile of malaria due to temperature increases combined with other drivers will require modifying current interventions and programs, and potentially implementing new programs, that can adapt and respond to changing climate conditions. With these challenges come opportunities for improving observations, surveillance, and responses, including detailed geographic targeting, optimizing strategies (i.e., finding the right combination of vector and case management), and aligning interventions to changing seasonality. Some of the implications for action and decision-making of this research are discussed below.

MEETING ELIMINATION TARGETS

Eliminating malaria is the goal of all malaria-focused development partners working in Africa (WHO 2015). Understanding how temperature may change the seasonality of malaria in Southern Africa, particularly for new areas at risk of malaria transmission or areas where the length of the season may shorten or extend, can help inform malaria programs and policy and help reach the goal of elimination. In areas where the months of malaria suitability decrease, surveillance and response systems should be strengthened to identify, track, and respond to malaria cases and any remaining transmission foci (e.g., infected mosquitoes or affected patients). Elimination efforts informed by these analyses could better target resources to reduce the potential burden of additional cases through timely treatment and prevention, such as the distribution of bed nets or indoor residual spraying.

ADAPTING TO CHANGING EPIDEMIOLOGY AND INCORPORATING NEW ANALYTICAL TOOLS

There are many examples across sub-Saharan Africa where investments have shown marked progress in malaria control strategies. These gains, however, could be compromised if future investments do not consider the role of rising temperatures in changes to epidemiology. This analysis offers critical insight with respect to these risks. Especially how *current management and control interventions may need to be reviewed and revised to address likely changes in malaria incidence*. This information offers an evidence base to support lengthening the investment timeframe (seasonal to year-round, or vice versa), optimizing vector control, and improving case management. Targeted and concentrated surveillance at the edge of malaria's range, for example, presents an opportunity to focus on potential epidemic outbreaks as they happen and can reduce the risk of new outbreaks.

IMPROVING A COUNTRY'S CAPACITY FOR COLLECTING AND USING INFORMATION

Significant progress has been made to improve data and information available for malaria programming, management, and evaluation via investments in strengthening routine disease reporting and health management information systems. Nevertheless, challenges remain, including the need to increase reporting rates and shorten the time before reporting data are available to inform planning and monitoring to near real-time.

Understanding how rising temperatures could impact vector ranges, and thus have the potential to alter disease dynamics, is an important first step in building the knowledge base to evaluate the impact of climate on malaria incidence and to inform investments. This analysis indicates that as temperatures rise, even within the next 11 years (by the 2030s), important changes are anticipated in transmission suitability. For example, in some areas in the northern part of the Southern Africa region, temperatures are expected to exceed the thermal limit of mosquitoes' tolerance, reducing the months of malaria suitability. At the same time, some areas of Southern Africa will become newly viable for Anopheline survival, raising the risks to people living there. Importantly, temperature-driven changes in vector dynamics are themselves mediated by direct and indirect environmental and societal factors. The same temperature changes that affect vector dynamics also influence changes to ecosystems, land use, and other factors that may reduce or increase the vulnerability of certain groups to malaria risks. The bottom line is that the environmental and social factors that define malaria incidence and risk are complex.

New methods of data collection, integration, and analysis will help explain the complex links between these factors. Public health observatories, many already operational around the world, offer a mechanism for analysis of health data in context with other climate and environmental parameters, paving the way for the timely use of remotely derived weather and climate information to inform investments and strategies in malaria control. In general terms, health observatories are virtual platforms that can link health systems to weather data, supporting health policies and planning. According to the WHO (2016), the purpose of health observatories “vary but the major objectives are: monitoring health situations and trends, including assessing progress toward agreed-upon health-related targets; producing and sharing evidence; and, supporting the use of such evidence for policy and decision making.” Integrating weather data and climate analysis is consistent with these overarching objectives.

Establishing a health observatory in countries where PMI is working could help scale up interventions, fine-tune investments focused on improving the timeliness and completeness of surveillance during critical periods, *and*:

- *Build a community of practice on malaria*—Communities of practice beyond traditional PMI partners could explore the links between environmental parameters of interest (including weather and climate) and strategic and programmatic decisions that need to be made in a malaria program.
- *Further research on critical questions that remain about using climate information to inform malaria planning*—This research includes, but is not limited to, understanding

more fully the links between increased temperature, changing rainfall patterns, extreme weather events, and malaria incidence; determining specific climatic thresholds of concern for surveillance; and improving analytic tools to visualize cross-sectoral information.

- *Formalize interdepartmental links and data sharing* —To further research and monitoring to better understand climate and weather impacts on epidemiology, it is essential to have access to historical climate and trend information, together with the health data related to past events. Furthermore, most government agencies lack the mandate to coordinate interactions between the many stakeholders in the health sector. Improved communication and coordination across the sector will facilitate more widespread use and understanding of the information available for planning.

BUILDING CAPACITY IN HEALTH SYSTEMS

In order for malaria programming and health services to respond to climate risks, investments need to be made in building the skills and capacity of health workers to understand and address the health risks posed by climate. These include:

- **Leveraging information technology** such as GIS and other tools to integrate information from various sectors and sources in order to rapidly evaluate the potential risks from specific weather events to a country, region, or health post.
- **Streamlining supply chain management**, especially in countries where malaria control interventions have been successful, to guarantee the delivery of commodities and services for remote and mobile populations.
- **Ramping up research** on applied, regionally responsive health services for a future of climate change. To date, there is a clear lack of service-oriented research to drive regional health service development for climate change, with potentially serious adverse implications for future control efforts.

STRATEGIC BUDGETING AND EARLY AND TARGETED PLANNING

One of the core operating principles of many malaria intervention programs and for PMI is using data to inform targeting of malaria interventions. This analysis indicates that temperature may play a role in putting large percentages of populations within countries, and in the region overall, at risk of both seasonal and endemic malaria.

In many instances, information on projected temperature increases is criticized because it cannot address immediate disease planning needs. However, much like preventive medicine, which aims to promote long-term well-being, planning 10–12 years and even further into the future when fighting malaria can save lives and money over the long term and promote sustainable elimination efforts. For example, if we know that temperature is likely to increase malaria burden in a certain country or region where there is currently little investment to fight malaria, including in some Southern Africa countries, an investment in surveillance and prevention now could avoid the need for large, immediate, crisis-driven investments in the future.

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