RADEK BOROVKA

LIVELIHOOD-FOCUSED CLIMATE RISK ASSESSMENT

Stress testing livelihood options in the world's largest terrestrial transboundary conservation area

Kavango Zambezi Transfrontier Conservation Area

By Nik Steinberg, Climate Group at Chemonics International
December 2023

Contract No. 720-674-18-C-00007

This publication was produced for review by the United States Agency for International Development (USAID). It was prepared by Chemonics International Inc. for the USAID Resilient Waters Program. United States Agency for International Development (USAID)/Southern Africa USAID Contracting Officer's Representative: Graham Paul

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ERA5	5th atmospheric reanalysis data set produced by ECMWF
CORDEX	Africa Coordinated Regional Climate Downscaling Experiment
ETCCDI	Climate Change Detection and Indices
CRIDF	Climate Resilient Infrastructure Development Facility
CSA	Climate-Smart Agriculture
CBNRM	Community-based Natural Resource Management groups
COVID	Coronavirus disease
Tx35	Count of days when maximum temperature is above 35°C
R95p	Count of days when precipitation is above the historical 95th percentile
CMIP5	Coupled Model Intercomparison Project Phase 5
DFO	Dartmouth Flood Observatory
FWI90p	Days above FWI's 90th percentile
DEM	Digital Elevation Model
ESGF	Earth System Grid Federation
ENSO	El Nino-Southern Oscillation
ECMWF	European Centre for Medium-Range Weather Forecasts
FWI	Fire Weather Index
FABDEM	Forest and Buildings removed Copernicus DEM
GCM	Global Climate Model
GFSAD	Global Food Security-support Analysis Data
HRSLF	High Resolution Settlement Layer
HWC	Human-wildlife conflicts
IPCC	Intergovernmental Panel on Climate Change
KAZA TFCA	Kavango Zambezi Transfrontier Conservation Area
Rx5day	Maximum consecutive 5-day precipitation
CDD	Maximum consecutive dry days (precipitation < 1mm)
CHRD	Maximum consecutive number of high-risk days (FWI > 30)
TXx	Maximum value of daily maximum temperature
MODIS	Moderate Resolution Imaging Spectroradiometer
NRM	Natural Resources Management
NRT	Near Real-Time
NTFP	Non-timber forest products
NDVI	Normalized Difference Vegetation Index

FWI130	Number of days when FWI is "high risk" (FWI > 30)
Tx10p	Number of days with maximum temperature above the historical 10th percentile
Tx90p	Number of days with maximum temperature above the historical 90th percentile
WS	Number of warm spells (TXx > 35°C for ≥ 3 days)
PES	Payments for ecosystem services
R95ptot	Percentage of days where precipitation is above the historical 95th percentile
Fpop	Population exposed to 1-in-100-year flood events
REDD+	Reducing Emissions from Deforestation and Forest Degradation, plus the sustainable management of forests
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SSP	Shared Socioeconomic Pathway
SPEI-6	Standardized Precipitation Evapotranspiration Index (SPEI), on a 6-month rolling basis
FIRMS	The Fire Information for Resource Management System
SADC	The Southern Africa Development Community
FAO	United Nations Food and Agriculture Organization
USAID	United States Agency for International Development
WDD	Warm and dry days
WWF	World Wildlife Fund

EXECUTIVE SUMMARY

The vision for Kavango Zambezi (KAZA) Transfrontier Conservation Area (TFCA) is "to establish a world-class trans frontier conservation and tourism destination [that]…improve[s] the livelihoods of local communities and thus contribute[s] towards poverty reduction." The conservation and livelihood objectives of KAZA are inextricably linked because many of the traditional livelihoods within and around KAZA depend on the same healthy, functioning ecosystems.

Climate change impacts are already being felt across KAZA. In recent years, residents have reported significant impacts to their livelihoods due to a combination of decreased rainfall, higher incidences of drought, changes in the timing of seasons, hotter days with increased incidents of heat waves, and dwindling supplies of water for such purposes as drinking, irrigation, and livestock production, among other uses.

Climate changes unfolding across KAZA will have profound impacts on the livelihoods of residents. Shorter and increasingly variable rainfall patterns will decrease the reliability of rainfed agriculture, which is vital for regional food security. Drying patterns will further constrain the growth of the tourism industry, as it relies heavily on water to support the wildlife that draws thousands of tourists every year. A longer dry season will also affect livestock production and compound more negative human-wildlife conflicts (HWCs), requiring a more concerted effort to conserve and manage water to meet agricultural, wildlife, and ecological demands. Wildfire weather conditions are growing more perilous, increasing the likelihood of large, runaway fires following rainy seasons and threaten the viability of conservation and carbon storage opportunities and programs. Our modeling also suggests that the spatial extent of flooding will increase and extend well beyond existing floodplains during future flood events. Standing in harm's way is an intricate network of roadways, tourist lodges, and a patchwork of rural and urban unplanned settlements.

Given the rapid amplification of climate threats alongside relatively low levels of adaptive capacity, expanded investments into new markets and new income opportunities (i.e., community-led tourism, conservation-based payment programs, and some non-timber forest products) must first pursue a deeper understanding of anticipated climate risks and what is needed to adapt to them. Solutions for adaptation exist, and many resource- and climate-dependent livelihoods may endure in areas with adequate support. Activities such as farming, fishing, and foraging can benefit from climate information services and expanded access to climate risk finance options. Meanwhile, authorities can help incentivize personal adaptation by making financing more accessible, promoting indigenous knowledge and practices, delivering technical guidance, and ensuring necessary climate-adaptive materials are available in local markets.

ACKNOWLEDGEMENTS

We would like to recognize the facilitation support of the KAZA Secretariat, the invaluable input from members of the KAZA Community Working Group, the technical support of the Resilient Waters/ USAID team members, and the tireless efforts by Dr. Nyambe Nyambe of the KAZA Secretariat to socialize these findings among KAZA's Partner States.

The climate risk assessment is based on data and analysis generated as part of the Coupled Model Intercomparison Project (CMIP) and contributions from Fathom, which is gratefully acknowledged. Background information about the figures and analysis presented in this assessment is available upon request.

USAID provided funding for the development of this assessment through the Resilient Waters Program.

PURPOSE

This *Climate Risk Assessment* seeks to answer how and in what ways a changing climate limits progress toward diversifying livelihoods for KAZA's resident communities. Findings from this work will supplement the *KAZA Livelihoods Diversification Strategy* 2023-2033 with an analysis of how climate risks are evolving across the landscape and may affect the viability and resilience of current livelihood activities. To align with the *Livelihood Diversification Strategy 2023-2033* (KAZA Secretariat, 2023), this assessment takes focus on rural livelihoods, and thus may not provide a comprehensive review of anticipated climate impacts across the entirety of KAZA or other, less commonly practiced livelihoods. We anticipate the outcome of this work will serve to strengthen the base of knowledge that is necessary for climate programming in the KAZA TFCA, and ultimately, help inform decisions, policies and actions that bolster the livelihoods and socio-economic resilience of its residents.

KAZA TFCA

The KAZA TFCA is the largest transboundary conservation area in the world (~520,000 km2), roughly equivalent to the size of Sweden. Five partner countries (Angola, Botswana, Namibia, Zambia, and Zimbabwe) established the KAZA TFCA to manage shared natural and cultural heritage resources and biodiversity to support healthy and viable populations of wildlife species, including migratory species, and to facilitate tourism. The KAZA TFCA also facilitates the implementation of conservation and sustainable development programs aimed at improving the economic resilience of those that reside within the conservation area.

THE CLIMATE-LIVELIHOOD NEXUS

The KAZA TFCA vision hinges on sustainable economic prosperity of its almost three million inhabitants, many of whom are dependent on natural systems and resources that are under tremendous pressure from economic development, and unsustainable use of natural resources — all of which are further exacerbated by rapidly evolving changes in the local climate and demographic factors including incompatible land uses.

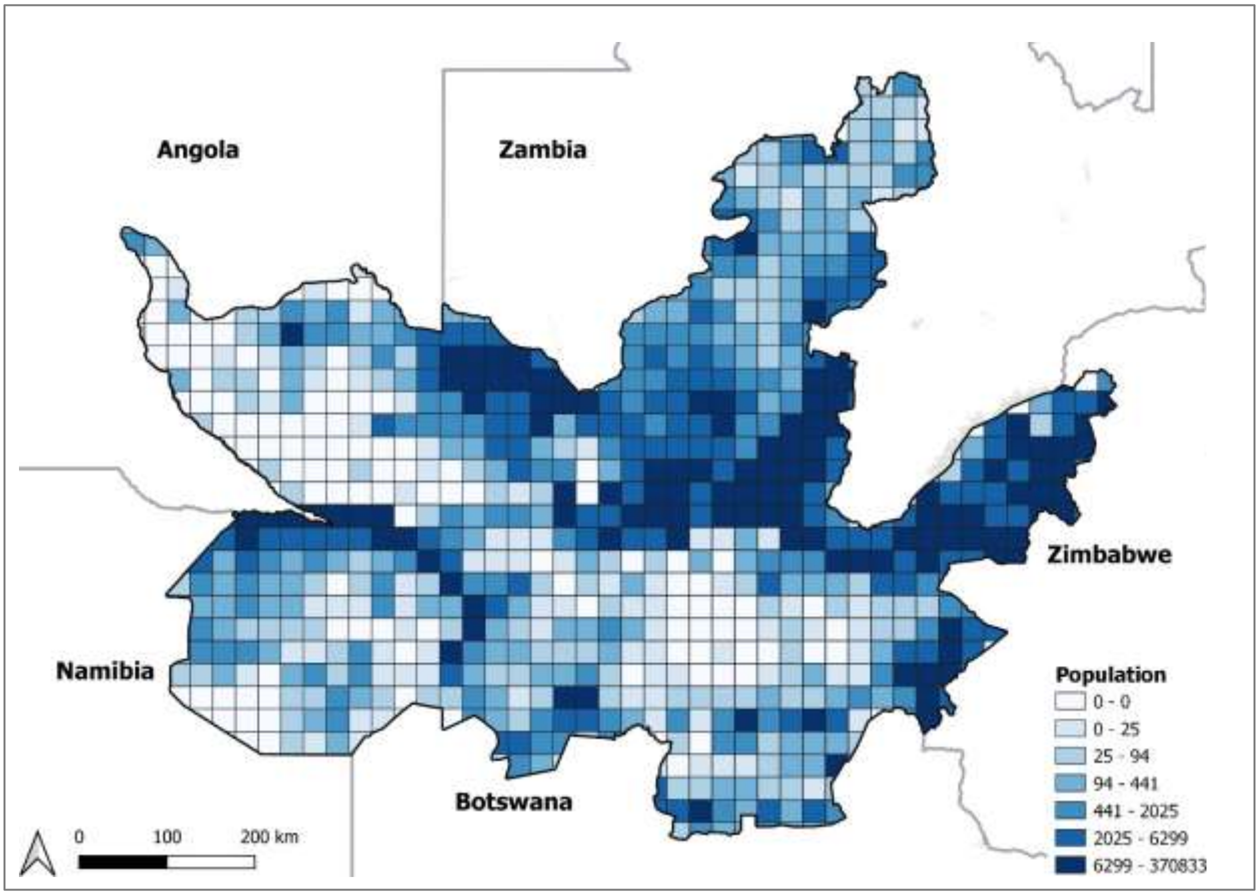
Climate-related impacts typically exacerbate poverty, which in turn constrains land and resource decisions and livelihood strategies in communities with already limited ability to adapt. This vicious loop is evident in KAZA, as changes in temperature and precipitation significantly limit residents' ability to reliably grow food, fish, forage, and raise livestock. As the KAZA landscape continues to warm and dry, residents will need to adapt existing livelihoods, and in some cases, find alternative food and income sources.

Today, most rural residents of within KAZA rely on a combination of low-yield farming, livestock keeping, fishing, and natural resource harvesting to survive in a mostly semi-arid environment. Most livelihoods are thus based on rainfed, subsistence-based crop and livestock production, and supplemented by natural resource harvest for food and income (Salerno *et al.,* 2020; Gaughan *et al.,* 2019). Most households are located within remote villages with limited access to markets and the cash economy. The spatial concentration of people varies between large swaths of sparsely populated land (e.g., Angola and eastern Botswana) to larger cities along Zambia's T1 Lusaka-Livingstone Road and, to the west, around the Okavango Delta and Zambezi River (Figure 1).

The diversity of livelihoods can vary widely by region and even within communities and households. In 2014 and 2021, the KAZA monitoring and evaluation system surveyed households in dozens of communities across Zambia and Zimbabwe and found that communities located near larger towns and protected areas tended to practice a wider diversity of livelihoods and scored better on the KAZA Livelihood Index than their rural counterparts, presumably because of greater access to employment opportunities and natural assets (KAZA Secretariat, 2021). All communities reported practicing 6-7

Figure 1. Estimates of human population distribution across the KAZA TFCA for the year 2015.

SOURCE: FACEBOOK CONNECTIVITY LAB AND CENTER FOR INTERNATIONAL EARTH SCIENCE INFORMATION NETWORK - CIESIN - COLUMBIA UNIVERSITY. 2016. HIGH RESOLUTION SETTLEMENT LAYER (HRSL). SOURCE IMAGERY FOR HRSL © 2016 DIGITALGLOBE. AUTHOR UPSAMPLED TO 25-KM GRIDS)



different livelihood strategies. However, crop and livestock production are, on average, the most practiced livelihoods. Livestock ownership remains an important socio-cultural asset. Elsewhere, along KAZA's many waterways, artisanal fishing is a key livelihood option which also carries strong cultural significance (KAZA Secretariat, 2023). Many residents benefit, both directly and indirectly, from the tourism economy through employment and wages, as well as improved infrastructure and value chains. Employment opportunities in the tourism economy are still rare, but many small producers of agriculture and animal products are well-positioned to sell directly to local tourist lodges (CRIDF, 2017). Other livelihood-focused studies have promoted the expansion and commercialization of non-timber forest products (NTFPs) to supplement incomes and food supplies with NTFPs like devil's claw, caterpillars, honey, fruits, and medicinal plants (KAZA Secretariat, 2023).

Livelihood diversification, with its associated benefits of reducing the impacts from climate shocks, is a key component to climate adaptation for residents. The practice of any single livelihood alone is risky.

The COVID pandemic brought with it a significant decline in visitors to the KAZA TFCA for multiple seasons, demonstrating the fragility of one of the more promising economic sectors in the TFCA. And in recent years, drought has affected agricultural and livestock production in a myriad of ways. Also, the emergence of wildfires, heat waves, and generally drier conditions progressively limit opportunities to harvest key food and income-earning resources, such as thatching grass, wild fruits, caterpillars, devil's claw, and honey. Most rural households are aware of these risks (WWF-led Climate Crowd Surveys, 2017-2022) but may lack the resources to anticipate and plan for changing climate conditions.

There are also several non-climate related threats to these livelihoods, including unregulated and unsustainable resource utilization, lack of financing for loans or insurance, conflict with wildlife, poor infrastructure, weak governance systems, and the lack of opportunities to access and participate in regional value chains. There is a need to consider these factors alongside the climate threats described in this assessment, as they constitute some of the main challenges that will need to be addressed to achieve systemic, transformational adaptation in the region.

While one aim of this assessment is to help inform the mix of livelihood options best suited to the changing climate, the assessment could only explore a limited number of strategies. Based on input from residents participating in the KAZA Community Working Group, as well as guidance from livelihood researchers contributing to the *KAZA Livelihoods Diversification Strategy 2023-2033*, this report focuses on identifying the climate-related threats and opportunities facing the most practiced livelihoods today and in the near future, including:

- Agriculture (subsistence-based and commercial farming, including horticulture)
- Livestock production
- Fishing (subsistence-based)
- Tourism
- NTFPs

BACKGROUND

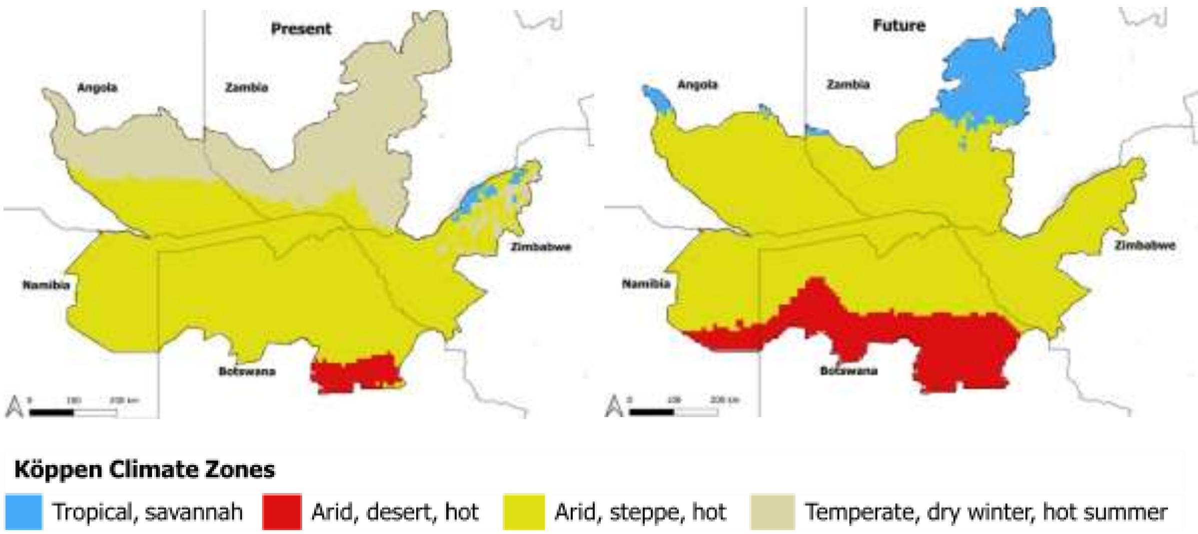
Climate change impacts are already being felt across KAZA. In recent years, residents have reported significant impacts to their livelihoods due to a combination of decreased rainfall, higher incidences of drought, changes in the timing of seasons, hotter days with increased incidences of heat waves, and dwindling supplies of water for drinking, irrigation, and livestock, among other uses. Residents engaged in farming activities have reported significant declines in agricultural productivity and increased reliance on natural resources, such as wild fruits and thatching grass, for food and income, which are also perceived becoming less abundant due to more severe droughts, seasonal shift, and a perception of increased wildfires (WWF-led Climate Crowd Surveys, 2017-2022).

At the landscape scale and over the longer term, climate zones are expected to shift (see Figure 2), with hot and dry climatic zones prevailing across a wider extent of the Botswana and Namibia portions of the KAZA TFCA. Southern KAZA will shift toward more arid and hotter climate zones while the semi-humid regions of northern KAZA are expected to shift toward a drier, more arid climate. As an exception, the upper catchments of the Kafue River in Zambia may become more "tropical," typified by more rainfall (Beck *et al.,* 2018). However, a rainier climate is accompanied by its own hazards, including a greater risk of flood.

Drying patterns may pose the most significant risks to livelihoods, affecting the health of fisheries and limiting resident's ability to grow food and find adequate forage for cattle. Prolonged drought is also often cited as a primary reason for seasonal increases in the frequency of human-wildlife interactions (WWF, 2017-2022). Observed reductions in the duration of the rainy season (Salerno *et al.,* 2021),

Figure 2. Changes to climate zones between the present-day (1980–2016) and projected future conditions (2071–2100), derived from an ensemble of 32 CMIP5 climate model projections (scenario RCP8.5), by superimposing the projected climate change anomaly on present-day climatic maps at 0.0083° resolution (~1 km).

ADAPTED FROM BECK ET AL., (2018).



alongside an uptick in the frequency of severe heat waves and dry spells over the last decade (ERA5, 2023) are already affecting agricultural productivity (WWF, 2017-2022). Climate models show strong agreement in drying patterns under all future climate scenarios[1] across Southern Africa, with significant (-20-40%) seasonal (AMJJAS) precipitation and runoff declines (Cook *et al.,* 2020). In KAZA, Coldrey and Turpie (2020) estimated 4.6% annual decrease in rainfall by mid-century relative to historical (1960-1990) precipitation (600 mm compared to 630 mm), with more pronounced drying during the hot-dry season (August to October) (-33%) (17.2 mm compared to 25.6 mm), similarly significant declines (-22%) during the cool-dry season (May to July), and almost no change during the hot-wet season (November to April). They also found that these warming and drying patterns will significantly reduce the extent of area suitable for growing key crops such as groundnut, maize, millet, and sorghum. Specifically, the study found that the southern and western sections of the KAZA TFCA (e.g., Botswana, Namibia, and southern Angola) are expected to experience the sharpest declines in suitable agricultural area, especially for maize. Despite being highly sensitive to changes in the timing and duration of the rainy season, rain-fed farming remains

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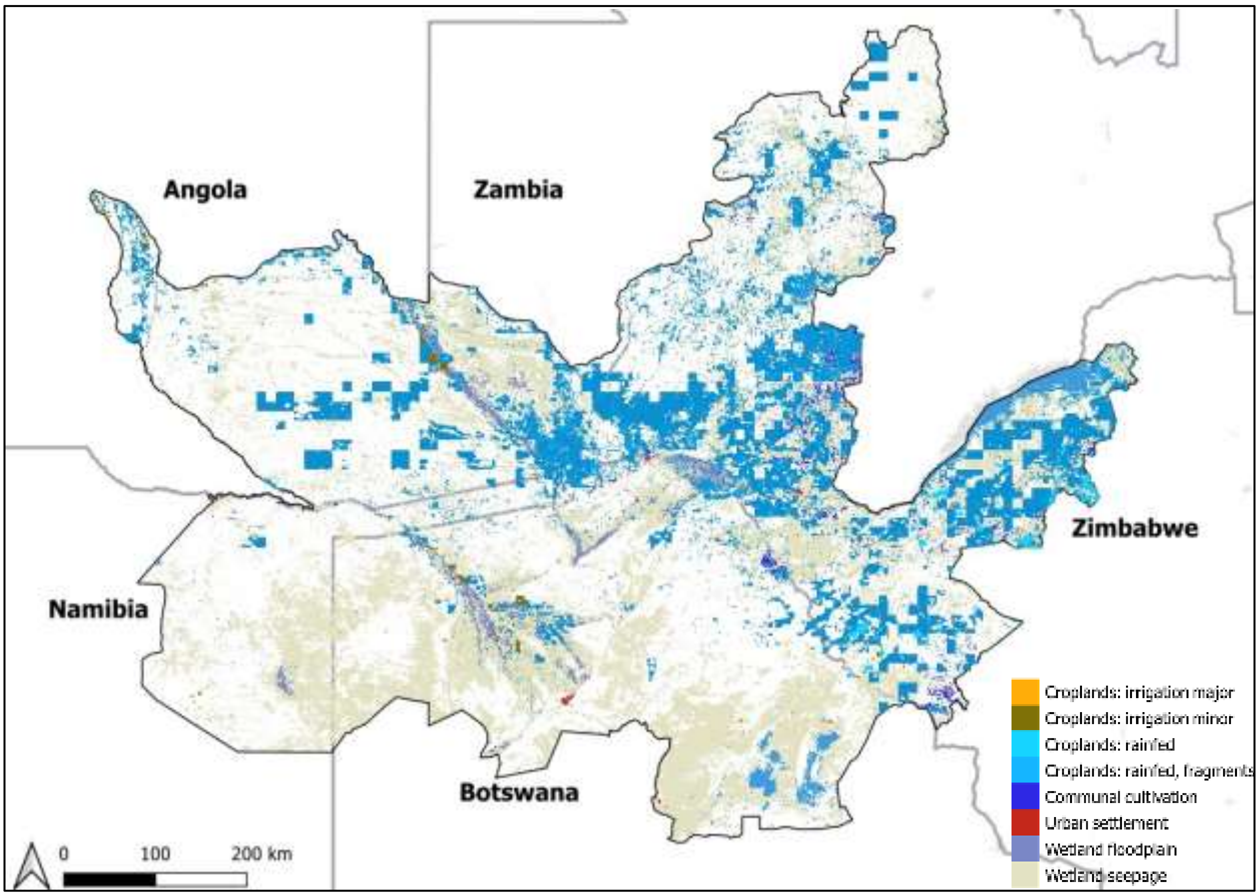
[1] A scenario depicts a plausible future, based on representations of Earth system properties and how those properties respond to natural and human drivers of change (IPCC, 2021). The scenarios used in this assessment, RCP4.5 and RCP8.5, represent emission concentrations and consequent temperature outcomes. It is important to note that scenarios are not associated with explicit probabilities or likelihood and are merely intended to illustrate ranges of potential futures based on a combination of policy decisions and subsequent socioeconomic outcomes that influence future emission levels. Because of the "pipeline" of warming, or the lag between emissions and physical climate impacts, it is worth noting that scenarios do not begin to meaningly diverge for several decades.

the most accessible, and therefore, a key livelihood strategy and is widely practiced throughout KAZA (Figure 3). In more arid and semi-arid regions of the KAZA TFCA, non-irrigated farming is considered dryland cropping — a farming technique that is extremely sensitive to the combination of low rainfall and high potential evaporation (Stewart *et al.,* 2006).

Rainfed agriculture is expected to continue as the dominant agricultural system across sub-Saharan Africa (Cooper et al, 2008), placing farmers — and especially dryland farmers — at the mercy of longer dry periods interrupted by increasingly variable rainfall patterns. The agricultural areas most sensitive to these changes are those primarily reliant on rainfall for irrigation and with limited access to surface water (Figure 3).

Figure 3. Land-use and irrigation types.

SOURCE: LAND TYPES DERIVED FROM SENTINEL-2, A 10-METER LAND-USE PRODUCT DEVELOP BY ESRI AND IMPACT OBSERVATORY (2017-2021). IMAGERY OF CROPLAND IRRIGATION IS DERIVED FROM GLOBAL FOOD SECURITY-SUPPORT ANALYSIS DATA (GFSAD) CROPLAND EXTENT 2015 AFRICA 30-METER (XIONG 2015 *ET AL*., 2015). LAYERS OVERLAYED BY AUTHOR.



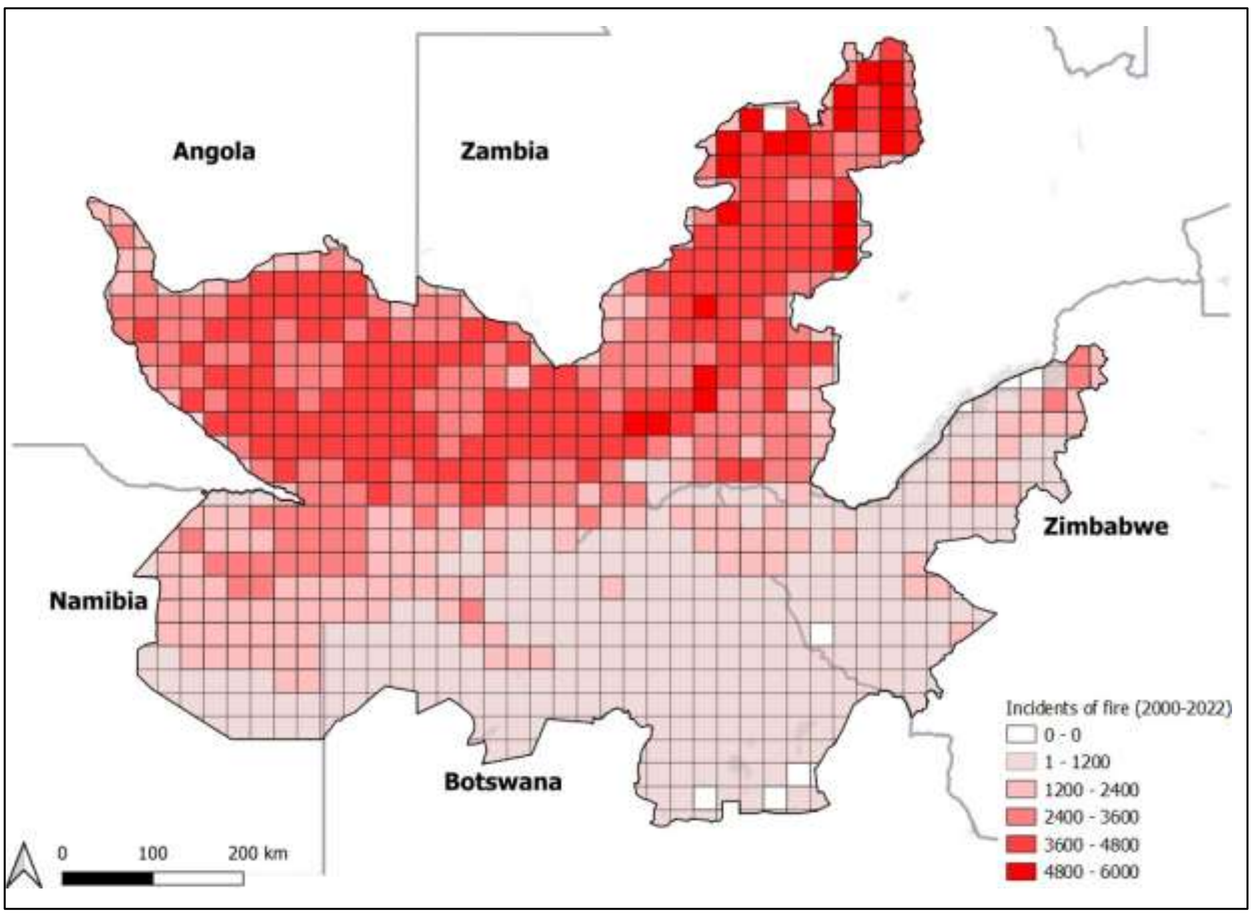
As a response to drier conditions in recent years, many communities have already allocated greater time to gathering wild food sources, which KAZA residents perceive as declining in abundance because of climate change (WWF Surveys, 2017-2021). Longer-term average precipitation trends are uncertain in Southern Africa, and rainfall totals are influenced by high interannual variability.

Wildfires play an important role in KAZA's ecosystem; however, frequent and extensive wildfires can result in "savannisation" and loss of wooded land (Cassidy et al., 2022), including NTFPs, an important source of income and subsistence for many communities. While the sources of wildfire ignition vary, recent wildfire-related studies within KAZA suggest that most fires are started by humans (Mpakairi et al., 2019 and Cassidy et al., 2022). In Botswana, Cassidy et al., (2022) found that wildfire frequency was relatively higher along tarred roads, suggesting linkages to anthropogenic activities with spatial relationship to human settlements, tour operations, road development, and agricultural expansion. However, the causes and dynamic of wildfires have not been widely studied throughout KAZA, and could benefit from further examination through remote sensing products and socio-ecological surveys,

Nevertheless, human-induced ignitions will continue while the climate-driven changes in wildfire weather will invariably increase the likelihood of large runaway fires, which could pose a direct threat to KAZA residents, wildlife, NTFPs, grazing area and resources, and could even threaten the permanence and durability of future nature-based carbon projects. Given the direct causal link to human activity, the frequency of fires may increase because of expanding agriculture and tourist operations alone, suggesting improved management practices are a critical path for future programming. This assessment evaluates the emerging wildfire dynamics driven by climate change and the areas of KAZA most likely to be affected (Figure 4).

Figure 4. Incidents of fire from January 2000 to October 2022

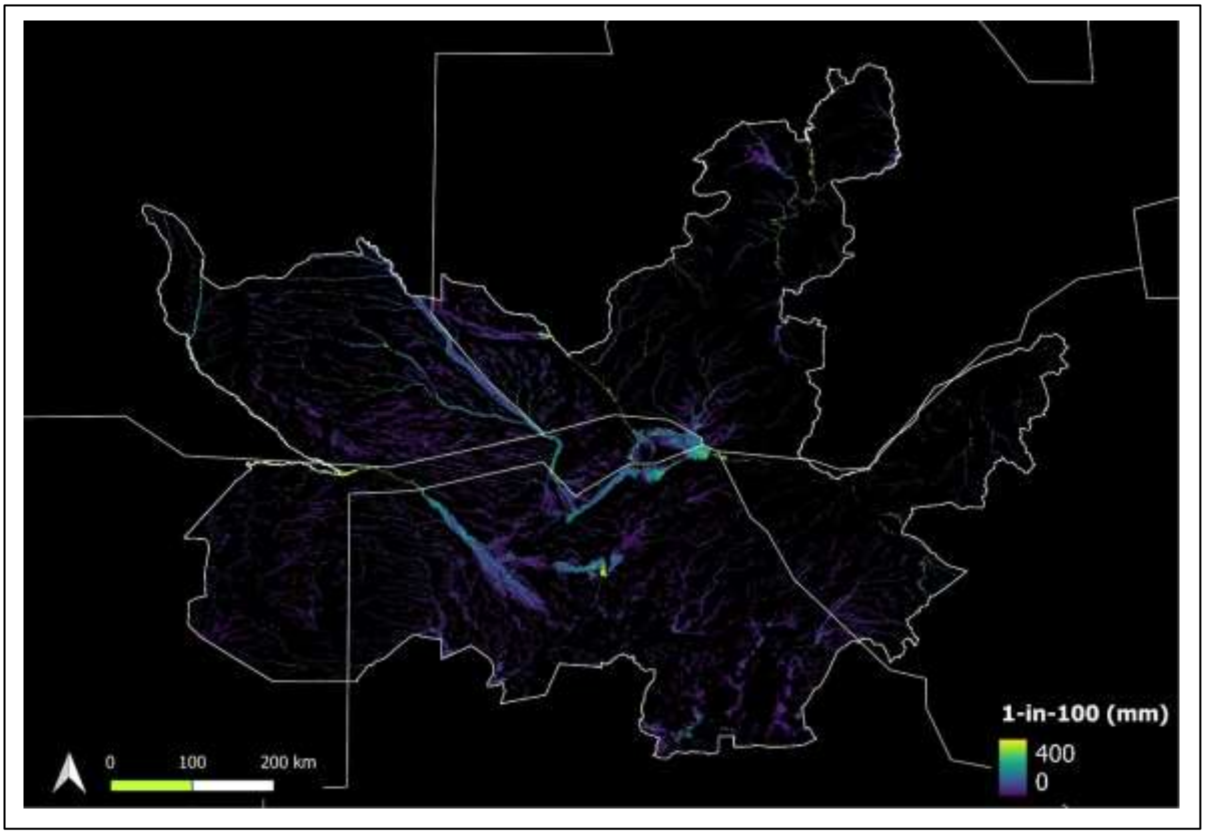
SOURCE: NASA FIRMS FIRE ARCHIVE AND SOURCED FROM THE COMBINED (TERRA AND AQUA) MODIS NRT ACTIVE FIRE PRODUCT (FIRMS, 2022). FIRE/THERMAL HOTSPOT LOCATION REPRESENTS THE CENTER OF A 1-KM PIXEL. AUTHOR RE-SAMPLED INCIDENTS TO 25-KM GRIDS.



While seasonal **flooding** is a regular occurrence across KAZA's major floodplains, it has historically been characterized by relatively predictable timing, volumes and duration but increasingly severe floods have been connected to persistently warmer sea surface temperatures in the South Atlantic, a phenomenon driven by background warming that is expected to amplify the severity of future flooding along KAZA's major river courses and associated drainage areas (Fichi *et al.,* 2021). Wetland drainage and settlement in these areas also increase flood exposure.

In KAZA, there is little protection for river-adjacent communities when flooding becomes especially severe, as seen with major flood events in 2003-2004, 2009, and 2020 that cumulatively displaced tens of thousands along the Zambezi, Cubango-Okavango, and Kafue River systems (DFO, 2003, 2009, 2020). This assessment finds that the existing extent of flooding area (2020) is expected to expand by mid-century by 5 - 7%, depending on the emission scenario, stretching beyond historical floodplains (Figure 5). A more comprehensive description of current and future flood risk exposure is described in the Climate Trends section.

Figure 5. Depth of inundation during a simulated 1-in-100-year fluvial flood event under present-day (2020) conditions.



Climate change is expected to increase average annual temperature and the intensity, duration, and frequency of **extreme heat** events (see Table 1 for definition), which will inevitably put a greater number of people at risk of heat-related medical conditions; limit livestock and crop production, the time allocated to outdoor and physically demanding activities; and potentially affect the tourism season due to a higher number of days exceeding known thresholds of thermal comfort levels. By mid-century, maximum temperatures during the hottest part of year (October and November) over Southern Africa are expected to increase by 2.5 -3.5 °C (Masson-Delmotte, *et al.,* 2021), and within KAZA, this assessment finds that very hot days (days > 35 °C) could increase by 2- to 3-fold (Figure 19).

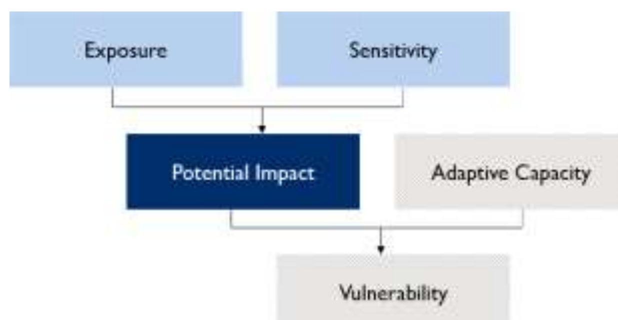
Temperature and precipitation changes will also affect disease patterns. As temperatures rise, areas previously unsuitable for transmission are expected to experience seasonal exposure. Changes in the normalized difference vegetation index (NDVI), a proxy for mosquito presence, suggest that much of the area may become seasonally suitable (7-9 months of the year) between 2030 and 2050, under all emission scenarios, with higher exposure in the northern half of the KAZA (Ryan *et al.,* 2020). Since the late 19th century, the latitudinal range of African *Anopheles,* the primary vector species of **malaria** transmission, has shifted 500 kilometers southward, or about 4.7 km per year (Carlson *et al.,* 2019) Increasing exposure to malaria not only affects the productivity of residents, but countries with malaria risk receive far fewer tourists than countries where the disease is not present (Rosselló et al, 2017), suggesting that the tourism operators within KAZA will need to play an active role in supporting disease-reduction efforts.[2] Dengue and cholera are also connected to climate, and changing climate conditions will similarly increase infection and transmission risks.

Taken together, the climate changes unfolding across KAZA will have profound impacts on the livelihoods of residents. Shorter and increasingly variable rainfall patterns will decrease the reliability of rainfed agriculture; drying patterns will impact resource productivity and further constrain harvesting, fishing, and livestock grazing opportunities while likely increasing negative human-wildlife conflicts. Wildfires and floods are likely to expand into new areas, limiting the availability of NTFPs and grazing and farming land and placing more households and infrastructure at-risk. Extreme heat will invariably affect tourism, wildlife and livestock, and labor productivity through direct health and economic effects, and through the introduction of new or expansion of existing of pests and parasites.

APPROACH

This *Climate Risk Assessment* seeks to answer how, and in what ways, a changing climate limits progress toward diversifying livelihoods for KAZA's resident communities.

Figure 6. Dimensions of vulnerability considered (blue) and excluded (grey).



There are a multitude of complex socio-ecological factors that influence livelihood options in a changing climate, such as governance constraints, cultural preferences, socio-economic changes, and resource trends. For this study, we limited evaluation to climate risk exposure (i.e., the extent to which climate-related risks may adversely affect current and future livelihoods) and sensitivity (i.e., the non-climate factors that contribute to vulnerability) (Figure 6), with no direct measure of vulnerability (i.e., the propensity or susceptibility to suffer from climate change). In part, this limitation is due to a lack of comprehensive household-level survey data across the KAZA TFCA that indicate the extent of assets, knowledge, resources, and other capacities to deal with climate change at a local level. And while vulnerability is central to climate change and adaptation research, the growing risks posed by climate change have amplified the need to better understand which, and in what ways, KAZA residents are

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[2] This assessment does not provide further analysis of climate-related malaria risk. Ryan et al., (2020) provides maps illustrating the spatial patterning and emergent malaria risk areas across Africa, including KAZA.

exposed to changing climate conditions, including what factors contribute to potential livelihood impacts. This assessment explores the intersection of climate risk exposure and sensitivity through climate information to better understand potential impacts, an important pre-requisite to understanding overall vulnerability.

To understand sensitivity to climate risks, we first needed to understand the historical relationship between recent climate trends and the potential effect on the access, viability, and productivity of various livelihoods. To do this, we convened community and country representatives from the KAZA Community Working Group in April 2023. During the workshop, the author led small breakout groups alongside members of the Resilient Waters team, the Namibia Nature Foundation, and the KAZA Secretariat. We asked participants from the KAZA Community Working Group, comprising different stakeholders including senior government officials, park rangers, and researchers representing communities across KAZA to identify the key climate risks facing various livelihood practices and to illustrate the causal pathways connecting climate drivers to impacts in key sectors and livelihoods. Participants then compiled recommended adaptation options for specific livelihoods. These mapping exercises generated a series of livelihood-specific impact chains that helped informed the remaining analysis and subsequent recommendations.

Next, to evaluate how climate change was evolving across KAZA, we modeled 16 extreme weather indicators using an ensemble of regional climate models (Table 1). Rather than focus on changes in average climate conditions, each indicator is designed to capture either a change in duration, timing, or severity of more extreme climate conditions that could lead to extreme heat waves, rainfall-induced flooding, drying patterns, and wildfire weather.[3] These indicators are derived from daily temperature and precipitation data, using definitions recommended by the joint CCI/CLIVAR/JCOMM Expert Team (ET) on Climate Change Detection and Indices (ETCCDI).

Table 1. Extreme weather indicators

All indicators are run daily and summarized monthly, then averaged over the following time periods: reference period (1970-2000), recent conditions (2000-2022), near future (2020-2050), and far future (2050-2080).

HAZARD	INDICATOR	SHORT NAME	UNITS
Extreme Temperature	Maximum value of daily maximum temperature	TXx	Amount (°C)
Extreme Temperature	Number of days with maximum temperature above the historical 90th percentile	Tx90p	Count (days)
Extreme Temperature	Number of days with maximum temperature above the historical 10th percentile	Tx10p	Count (days)
Extreme Temperature	Count of days when maximum temperature is above 35°C	Tx35	Count (days)
Extreme Temperature	Number of warm spells (TXx > 35°C for ≥ 3 days	WS	Count (events)
Floods and Extreme Precipitation	Population exposed to 1-in-100-year flood events	Fpop	Count (people)
Floods and Extreme Precipitation	Maximum consecutive 5-day precipitation	Rx5day	Count (days)

[3] Indicators originally developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), calculated from the Python package, *Xclim*, and processed by Lobelia.

	Count of days when precipitation is above the 95th percentile (precipitation ≥ 1mm, wet day)	R95p	Count (days)
	Percentage of days where precipitation is above the 95th percentile (precipitation ≥ 1mm, wet day)	R95ptot	Percentage (%)
Drying Patterns	Maximum consecutive dry days (precipitation < 1mm)	CDD	Count (days)
	Warm and dry days (where maximum temperature is above the historical 75th percentile and precipitation < 1mm)	WDD	Count (days)
	Standardized Precipitation Evapotranspiration Index (SPEI), a multiscale drought index on a 6-month rolling basis	SPEI-6	Index (unitless)
Wildfire Weather	Fire Weather Index (FWI), a meteorologically based index used worldwide to estimate fire danger	FWI	Index (unitless)
	Days above FWI's 90th percentile	FWI90p	Count (days)
	Number of days when FWI is "high risk" (FWI > 30)	FWI130	Count (days)
	Maximum consecutive number of high-risk days (FWI > 30)	CHRD	Count (days)

We used two datasets to generate the temperature- and precipitation-based indicators listed above. For the historical data (1970-2000), we used the ERA5 global reanalysis dataset[4] from the European Centre for Medium-Range Weather Forecasts (ECMWF) as both an observational dataset and for correcting the climate projections' biases. ERA5 provides hourly fields with a spatial resolution of 0.25° (~25km) with a daily temporal resolution.

To characterize future changes (2020-2050 and 2050-2080), we used a multi-model ensemble[5] of 16 regional climate projections from the Africa Coordinated Regional Climate Downscaling Experiment (CORDEX) domain[6] (see *Appendix*). The CORDEX regional projections uses CMIP5 global projections[7] as boundary conditions, and the spatial resolution of the projections is 0.22° (~22km) with a daily temporal resolution. We selected the Africa CORDEX dataset because of the need to assess climate risks at a local level by incorporating topographic features that have a direct impact on the local weather.[8] To evaluate uncertainty, we combined 10 different GCMs with six different RCMs. The

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[4] A reanalysis data set, like ERA5, provides a synthetic estimation of the climate state through the combination of a numerical model together with as many observations as possible of the Earth system. Reanalysis data sets are commonly used in climate science. Because of the homogeneity and physical consistency of reanalysis products, they are generally preferred over observational datasets when observations are scarce in space and time.

[5] In the analysis below, all temperature and precipitation-based variables are presented as 30-year, annual, or seasonal averages of daily observations. Therefore, each variable (e.g., Rx5day) for a given time period/scenario (e.g., mid-century RCP4.5) is produced by calculating an individual estimate for each of the three time periods and two scenarios, then taking the average of the 16 model runs. This result is the ensemble mean provided at different scenarios, time periods, and percentiles (10th, 50th, and 90th).

[6] All models available in Earth System Grid Federation (ESGF) were included in a multi-model ensemble on the basis that they projected average temperature, maximum temperature, minimum temperature, precipitation, and specific humidity at a daily resolution for RCP4.5 and 8.5 scenarios. The full list of GCM-RCM pairings is provided in the *Appendix*.

[7] The next generation of CORDEX projections using recent CMIP6 global simulations is still in development and not yet available.

[8] This process of downscaling improves on the global circulation models (GCMs), like those used in the IPCC report (CMIP), which simulate climate at spatial resolutions around 1° (>100km), which cannot be directly used in impact assessments at local scales. Instead, regional circulation models (RCMs) simulate the climate for a certain part of the globe, usually a continent, with a much higher spatial resolution (~20km). This higher resolution allows more accurate reproduction of the small-scale features affecting the local weather and in turn a more reliable estimation of the climate extremes occurring at specific locations on Earth.

combination of different RCMs and GCMs provides a broad set of plausible future projections (10th, 50th, and 90th percentiles). To adjust for general bias, the Quantile Delta Mapping bias correction method was used (Cannon *et al.* 2015), which assures the correct adjustment of all the quantiles of the distribution (i.e., including extreme values) while preserving the climate change signal of the raw simulations. These projections, in turn, allow the computation of robust statistics for the estimation of the climate change signal and its corresponding uncertainty (see *Appendix*).

Flood data[9] illustrates flood depths generated by fluvial floods in the present and future climate under multiple scenarios and return periods. Inundation values represent levels of depth relative to the ground level that occur when a river exceeds its capacity and inundates surrounding areas. A limited number of maps are shown within this document. The full data set consists of one present year (2020), one future year (2050) for two pathways (SSP2-4.5, SSP52-8.5), three return periods (1 in 50, 1 in 100, and 1 in 1000) and one percentile (50th). We incorporated terrain data through the FABDEM (Forest and Buildings removed Copernicus DEM), which allows smaller topographic features, such as narrow flow paths, to be represented at 1 arc second (~30m) grid spacing (Hawking *et al.,* 2022).

The spatial patterning of floods and other climate hazards described above were then intersected with several exposure layers, including population at 1 arc second (~30m) (HRSL, 2016); land use and land cover at one-third arc-second (~10m) (ESRI, 2021); crop areas and irrigation type at 1 arc second (~30m) (Xiong *et al.,* 2015); and several points relevant to livelihood assets, such as populated places, tourism hubs, infrastructure, and cultural and biophysical places, all provided by the KAZA Impact Monitoring Working Group.

CLIMATE TRENDS

In this section, we present an overview of current and potential future impacts from climate hazards. Recent climate impacts, particularly those associated with drought, wildfires, and flooding, have already significantly disrupted livelihoods. Climate change will exacerbate these risks and create new, emergent risks due largely to greater climate variability and significant warming and drying patterns across the region. A more detailed description of these patterns is discussed and illustrated in the section below.

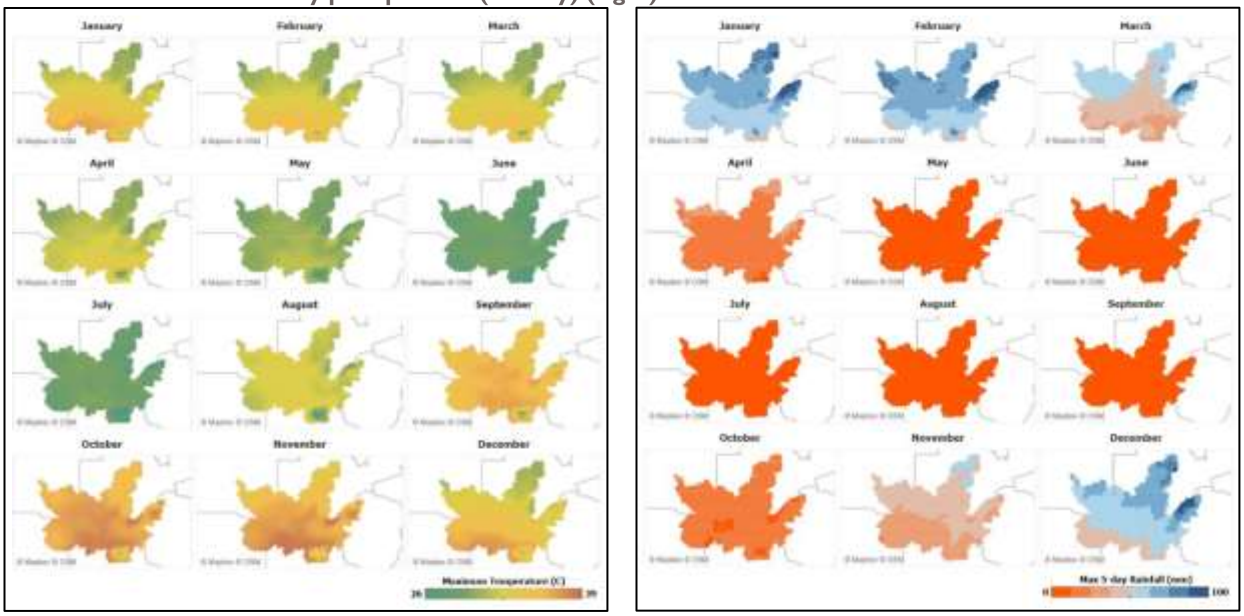
Seasonally, the KAZA TFCA area is characterized by:

- Hot-wet season (November to April)
- Cool-dry season (May to July)
- Hot-dry season (August to October)

The climate model data shows that climate change will impact the evolution and occurrences of extreme events such as heat waves, wildfire and drought conditions, and extreme precipitation. The change in the seasonal cycle for representative indicators is shown in the monthly time series figures in the sections below.

[9] Flood data was generated by Fathom-Global 3.0 dataset.

Figure 7. Historical climatology (1976-2005) of average monthly extreme heat (Txx) (left) and average monthly maximum consecutive 5-day precipitation (Rx5day) (right).



Regarding the two different climate scenarios analyzed (RCP4.5 and RCP8.5), a measurable difference begins to appear for the second future period (2051-2080). As is so often the case, the moderate-mitigation scenario (RCP4.5) shows a weaker change in the occurrence of all extremes relative to the high-emission scenario (RCP8.5). Still, under both scenarios, the more dramatic changes are expected to unfold later in the century.

In the decades ahead, the flood regime in KAZA will invariably change, expanding the size of flood zones and placing more area at-risk. Those dependent on and living near the banks and floodplains of KAZA's many flood-prone areas will be especially vulnerable. Climate-related flood risks emerge when areas unaccustomed to flooding become prone to inundation due to climate change alone.

Spatially, there are significant differences in how certain climate patterns will unfold. The recent period (2000-2022) shows perhaps the strongest differences across space, especially the distribution of extreme precipitation, with heavy rain events clustering on the western side of the KAZA TFCA. Much of this spatial heterogeneity is the result of orography. Additionally, weather patterns in the recent period are largely influenced by recent phases of El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole conditions. It is worth mentioning that a certain degree of disagreement between historical climate patterns and the projected, near, and future climate patterns can be expected. Not only do they represent different temporal periods (recent decades versus future decades) but also, importantly, natural variability represents a major influence in the recent climate because of the occurrence of different interannual and decadal modes of climate oscillations. The recent period, which corresponds to a shorter span of 15 years, does not represent a climatological period (versus the 30 years used for the historical and near- and far-future projections), and should not be interpreted as a baseline, but rather, a reference point of conditions and events that are familiar.

DRYING PATTERNS

Drying patterns regularly persist across much of Southern Africa and represent one of the most damaging and least understood climate-related hazards in the region. Because of the complexity of this phenomenon, we forgo using the term "drought," which denotes a defined period of water shortages. Instead, much of Southern Africa will experience more persistent conditions of dry and hot weather, interrupted by shorter periods of more erratic rainfall patterns. Across the KAZA TFCA, the duration and spatial extent of dry conditions will not only affect agricultural productivity, but also result in a reduction in habitat for wildlife, enhanced opportunities for pests, parasites, and drought-tolerant exotic species, as well as imbalances in the hydrologic cycle, and elevated water stress.

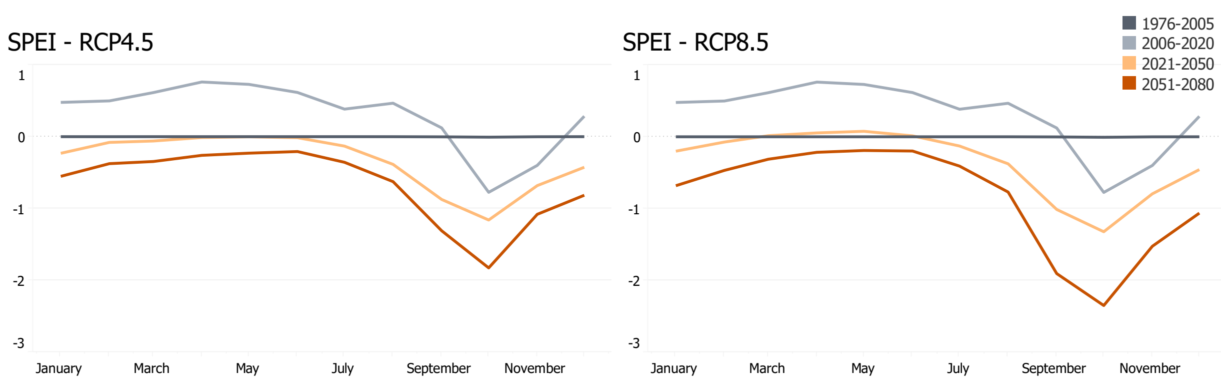
In general, there is strong agreement across indices of a shift in the seasonality and intensity of drier conditions in the coming decades. The change in the seasonal cycle of dry conditions suggest an earlier start to the dry season (Figure 9), higher temperatures, and higher drought potential during the peak of the dry season.

Changes to the severity of dryness appear most acute during the dry season (May to October) (Figure 8). In the near-term period (2021-2050), moderate[10] drought-like conditions (SPEI-6 < -0.5) begin to emerge across all areas of the KAZA TFCA. Of particular concern, is the severity of drying that is expected to occur over the Okavango Delta, an area not only critical for wildlife but also for several communities reliant on fresh waterways for fishing and agriculture. Projections of SPEI-6 suggest that the hot-dry season (September-November) within the Okavango Delta could reach an average of (SPEI-6) -1.3 (-1 to -1.7) under a moderate emissions scenario (RCP4.5) in the near term (2021-2050), which is

SPEI-6

The severity of dryness is measured through the Standard Precipitation Evapotranspiration Index (SPEI) because it is a standardized variable that can be used to compare dry conditions over different spatial and temporal scales. The SPEI was chosen over the commonly used Standardized Precipitation Index (SPI) because it includes both potential evapotranspiration and precipitation. The values indicate how many standard deviations of accumulated rainfall over a 6-month period is above or below the historical mean for a particular month.

Figure 8. Standard Precipitation Evapotranspiration Index (SPEI) values by month across all time periods and scenarios.

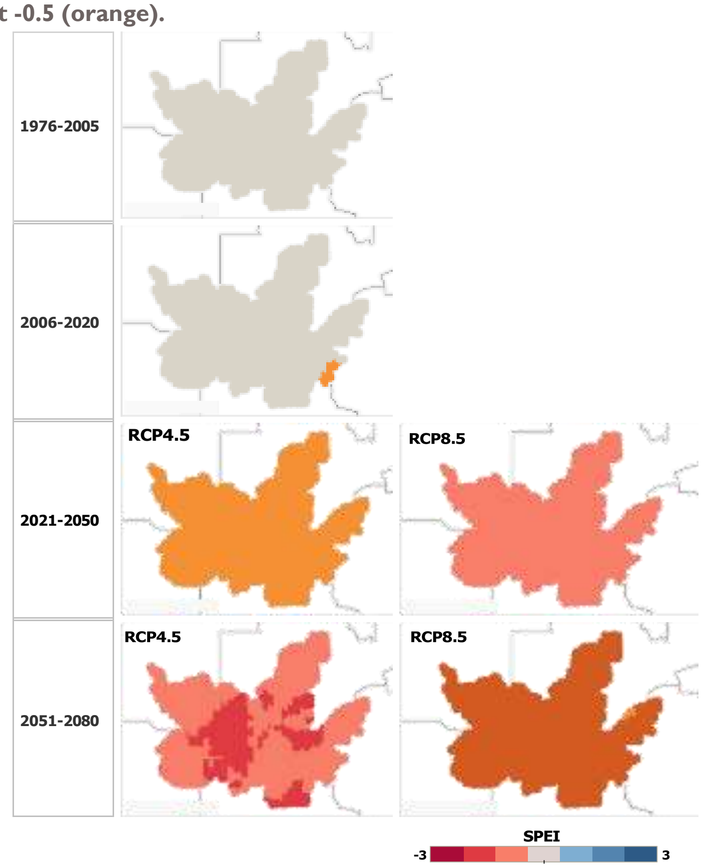


[10] C. T. Agnew. (2000). Using the SPI to identify drought. *Drought Network News*, vol. 12, no. 1

considered severe by international standards,[11] and significantly drier than the observed (1976-2011) maximum dryness of (SPEI-6) -0.2. One important caveat is that downstream catchments of the lower Cubango and Cuito rivers contribute very little additional runoff (OKACOM, 2011). Many of the river systems flowing through KAZA originate in headwaters that lie outside of the TFCA boundary, and downstream flow rates are influenced by upstream rainfall amounts. That is to say that SPEI-6 values within the KAZA TFCA are a better indicator of future evapotranspiration rates than overall river flows. Nevertheless, the water that is lost through evapotranspiration does correspond to less groundwater recharge and less overall water available for drinking, irrigation, and ecological functions. Small flow changes in dry years could have significant implications for the perennial parts of the system, making the downstream deltas highly vulnerable to any changes in the upper and middle sections of the system. Even small changes in flow can negatively affect water quality when introduced to agricultural and livestock-related runoff that can lead to eutrophication, affecting fisheries and increasing nutrient loads that can increase concentrations of bacterial sources from sewage and polluted runoff. The timing of runoff is also critical to downstream socio-ecological processes such as recessional flood farming, fishing, and resource harvesting. Some estimates of runoff have been generated for the Cubango and Cuito Rivers (OAKCOM, 2011), though additional environmental flow assessments/requirements should be conducted for other critical stretches of rivers through KAZA.

The vegetation response to drying is perhaps more direct. In the lands just adjacent to the Okavango Delta, Resener (2019) found that the NDVI had, on average, trended toward a reduction in vegetation cover between 1981 and 2015, indicating a high level of sensitivity between historical drying patterns and vegetation response. And to the west, the western Kalahari in Botswana (and a portion of Namibia) is already a remote and dry landscape, and communities there are heavily reliant on natural foraging, a livelihood that could become more challenging as severely dry conditions are expected to prevail over the region in the near-term climate. Similar levels of severely dry conditions may emerge in the coming decades to the east, and more specifically, the southern reaches of Lake Kariba, and extending southward to Hwange.

Figure 9. SPEI values during the hot-dry season (August-October) across all periods and scenarios. SPEI values below zero are considered "dry" and "moderate" drought-like conditions begin at -0.5 (orange).



Across KAZA, dry conditions intensify in the near and long term under all scenarios (Figure 9). Climate projections suggest that

[13] Ibid

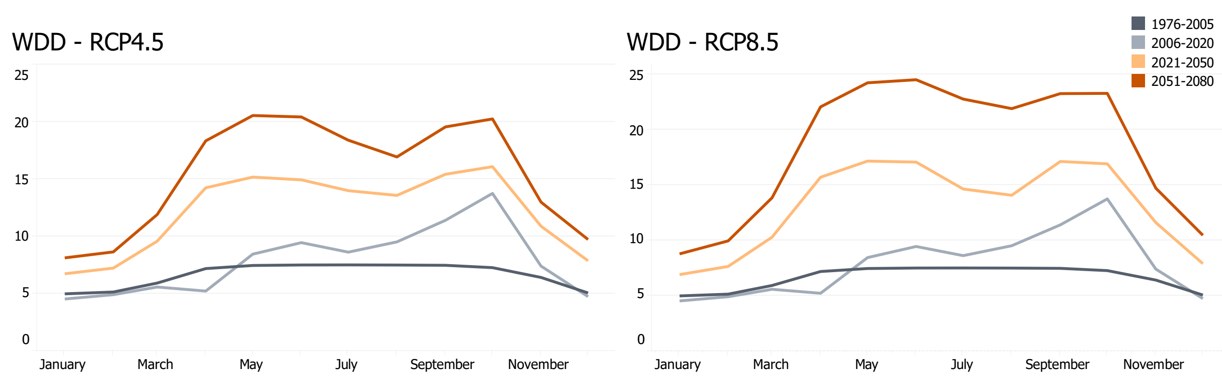
future drying patterns are likely to be much more severe than any other period since the beginning of the modern observational record began in 1976, including the severe drought conditions experienced in 2015 and 2019 that caused major impacts to vegetation and the regional economy.

Observational records and climate projections show strong agreement in that much drier conditions (SPEI-6, WDD, CDD, FWI, FWI30, CHRD) can be expected, especially in the dry season. When dry and hot conditions persist over long periods, soil moisture declines, which limits agricultural productivity and places additional stress on flora. Under all future scenarios, the KAZA TFCA will experience, on average, twice as many warm and dry days (WDDs) as the historical period (Figure 10). During the dry season, WDDs may constitute half of all days, suggesting that periods of severe dryness will often coincide with warmer temperatures with little reprieve in the form of rainfall or cooler temperatures.

WILDFIRES

Historically, wildfires In KAZA occurred almost exclusively during the dry season (May-October). During the recent past (2000-2022), nearly 98% of all detected fires[12] occurred between May 1 and October 31. Incidentally, the frequency of fires across the entirety of KAZA has not increased over this period.[13] During wet years (2004, 2006, 2008/09, and 2017), fire frequency was generally higher than drier years due to higher fuel loads. This relationship between annual precipitation and wildfire frequency is consistent with findings from Fox *et al.* (2017), who found higher incidents of fire in Chobe National Park during years of higher rainfall. Conversely, during drier years (e.g., 2019), fires are less common due to smaller fuel loads.

Figure 10. Warm and Dry Days (WDDs) by month across all time periods and scenarios.



The seasonality in the frequency of fires (Figure 11) is consistent with the FWI values, which provide a numeric rating of fire risk through an index based on a combination of rainfall, relative humidity, and temperature. FWI is a key indicator of extreme fire behavior potential. During the latter months (September and October) of fire seasons, grasslands dry out and deciduous trees have shed their leaves, contributing to the buildup of fuels. High winds often coincide with extremely dry conditions during the

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[12] Of the 1,539.821 detect fires in the KAZA TFCA between 2000 and 2022, nearly 98% occurred between May 1 and October 31. Under non-cloudy conditions, the algorithm can detect a fire about the size of a quarter acre (FIRMS, 2022). Please note, incidents of fire capture all thermal anomalies, and do not distinguish biomass types (i.e., crops versus forests).

[13] Ibid

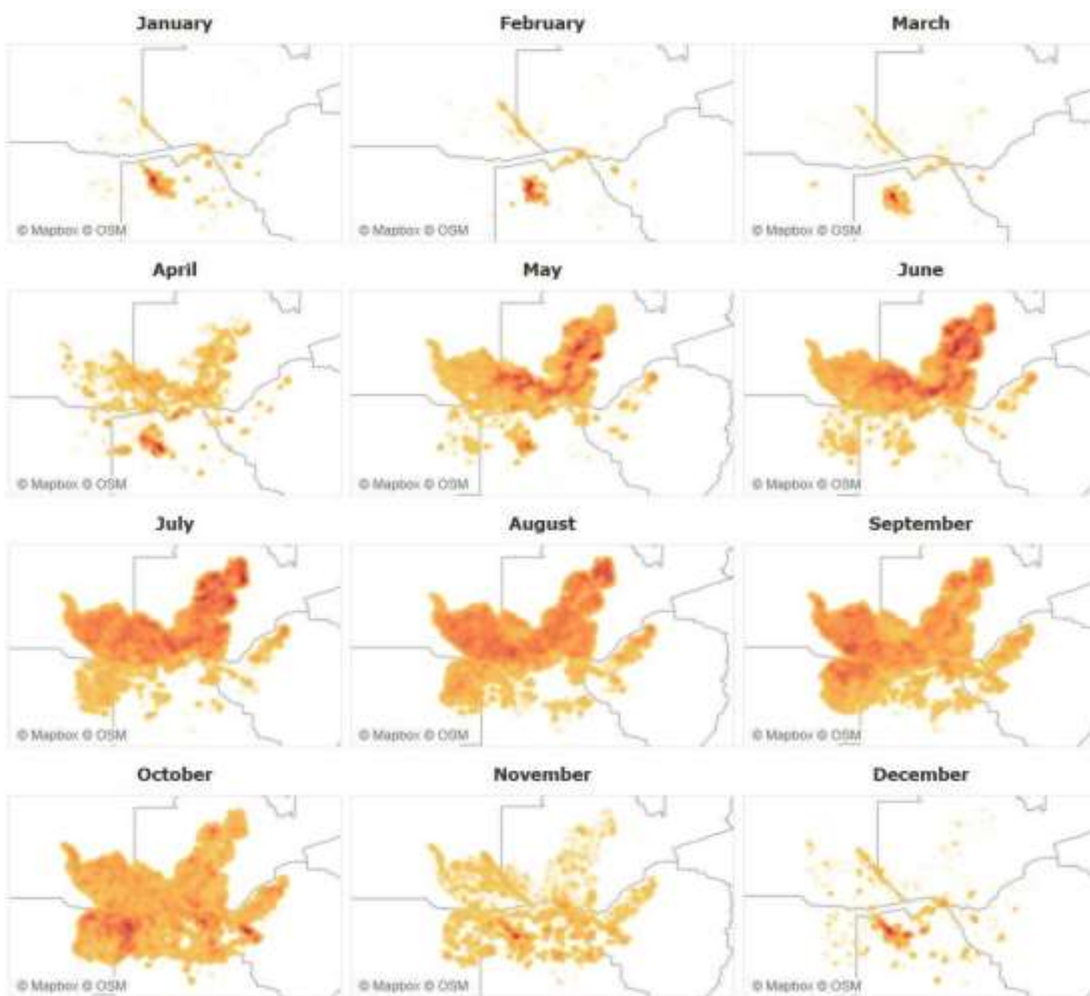
late dry season, which means fires can spread more easily during this period (Archibald *et al*., 2010), resulting in larger and more sever burned areas.

The spatial patterning of fires is distinctive throughout the year (Figure 11). During the hot-wet season, fires are most heavily concentrated alongside the Cuando River and Okavango Delta, then expand to northern areas of the KAZA TFCA through mid-year, and then appear more spatially pervasive through the hottest and driest part of the year (August-October).

Researchers believe that most fires in KAZA are started by humans, because very few lightning storms occur in the late dry season months when fire frequency peaks (Mpakairi et al., 2019 and Cassidy et al., 2022). A combination of reasons can explain why fires are ignited: farmers expanding agricultural land through slash-and burn, poor silviculture practices, charcoal production, timber harvesting (and leaving deadwood behind), and poachers and guides setting grasses ablaze to increase visibility of game (interviews with KAZA Community Working Group, 2023).

Figure 11. Seasonality of detected fires from January 2000 to December 2021

SOURCE: NASA FIRMS FIRE ARCHIVE AND SOURCED FROM THE COMBINED (TERRA AND AQUA) MODIS NRT ACTIVE FIRE PRODUCT (FIRMS, 2022). FIRE/THERMAL HOTSPOT LOCATION REPRESENTS THE CENTER OF A 1-KM PIXEL.



The future wildfire regime in the KAZA TFCA is influenced by the severity and duration of future dry and hot conditions, increasing the chances fires will spread upon ignition. Severe wildfire conditions are more likely following a rainy season when fuel load and continuity are relatively high. In other words, wet seasons followed by hot and dry seasons, also known as 'whiplash' events, have produced the most wildfires in KAZAs. The projections suggest that a higher number of high-risk FWI days (FWI > 30) could occur a month earlier (April) and persist up to one month longer (November) compared to the historical period (Figure 12), increasing the wildfire season from approximately six to eight months in most places.

The climate models also suggest that the number of high-risk FWI days (FWI > 30) will increase most significantly during the shoulder months (March and November) of the fire season. At decadal timescales, fire frequency will be driven by a combination of rainfall variability and length of the dry season. Notably, when fires occur under increasingly hot and dry conditions, burn severity increases limiting re-growth of woodlands, which would otherwise respond positively after low- to moderate-severity. When examining fire patterns in KAZA's remaining woodlands, Ruusa-Magano (2022) indicates that dry-season fires will likely continue to transform KAZA's woodlands into open, tall grass savanna, leaving only isolated fire-tolerant stands of trees in wildfire-prone areas.

As for fire severity, the projections suggest that the evolution of FWI will move south to north in the coming decades (Figure 13), which is consistent with the spatio-temporal patterning associated with growing aridity and shifting climatic zones across KAZA (Beck *et al.,* 2018). In the recent period (2006-2020), the most severe wildfire weather spanned the arid and less populated, southern reaches of KAZA. In the coming decades, these conditions will begin to emerge in the more populated regions of northern Namibia and Botswana, and by mid- century, spread further northward into Angola and Zambia. This new fire regime is especially concerning because the highest historical concentration of fire incidents has occurred in Zambia and Angola where burning restrictions are not tightly controlled (Pricope et al., 2012). For example, in Zambia alone, when fuel loads are driest and at their maximum (September–October), FWI is projected to increase by 11% (19%-29%) by mid-century, under a moderate emissions scenario.

Figure 12. Average monthly value of FWI across time periods and scenarios.

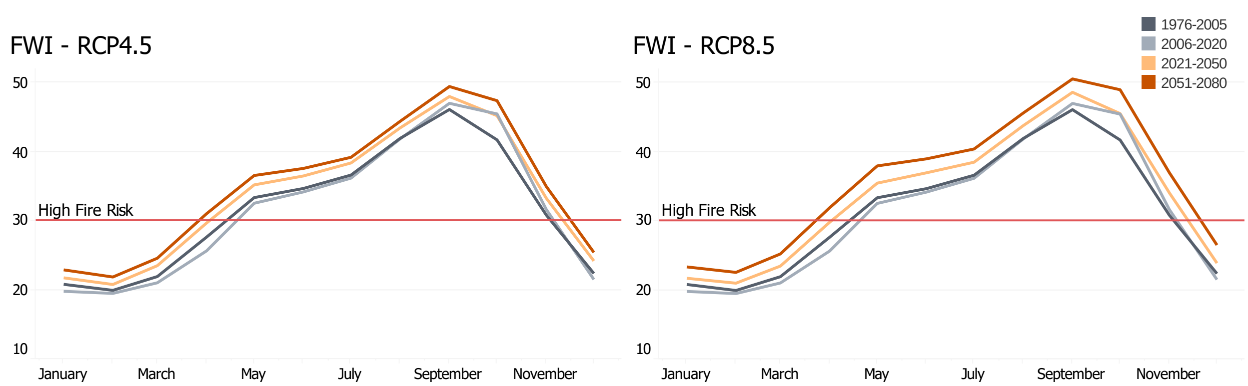
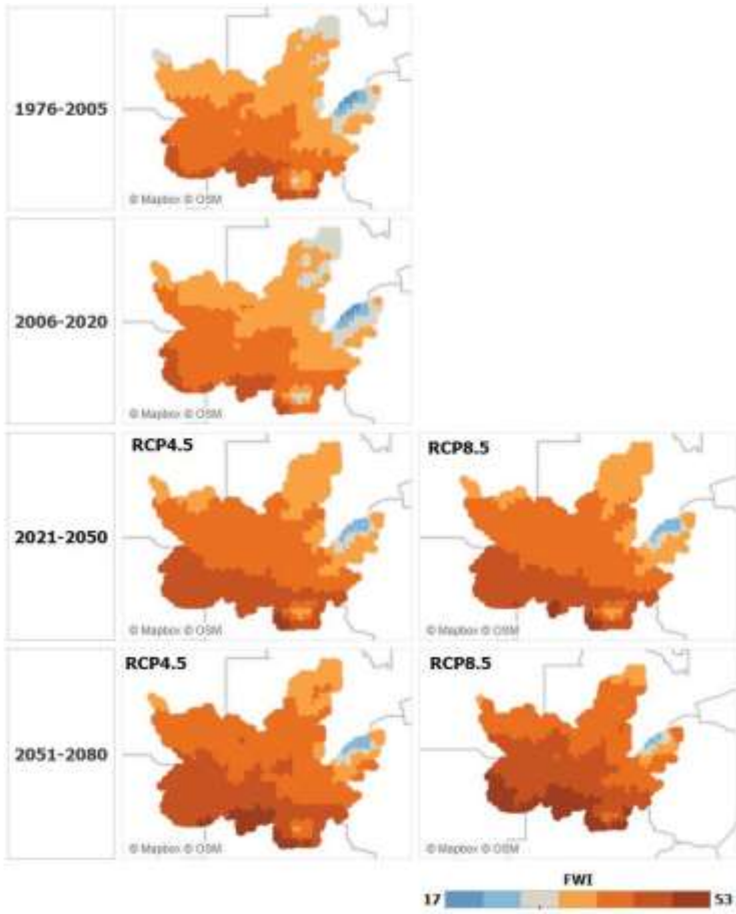


Figure 13. Values of FWI during the hot-dry season.

FWI values greater than 30 (orange red) are considered "high-risk."



> **FWI**
>
> In this assessment, FWI is used as a simplified proxy for wildfire weather, as it provides a numeric rating of wildfire potential based on an index of rainfall, relative humidity, and temperature. Values of 30 and greater indicate high-risk days with high fire weather potential. When such conditions coincide with ignition and high fuel loads, the chances for wildfire spread increases.

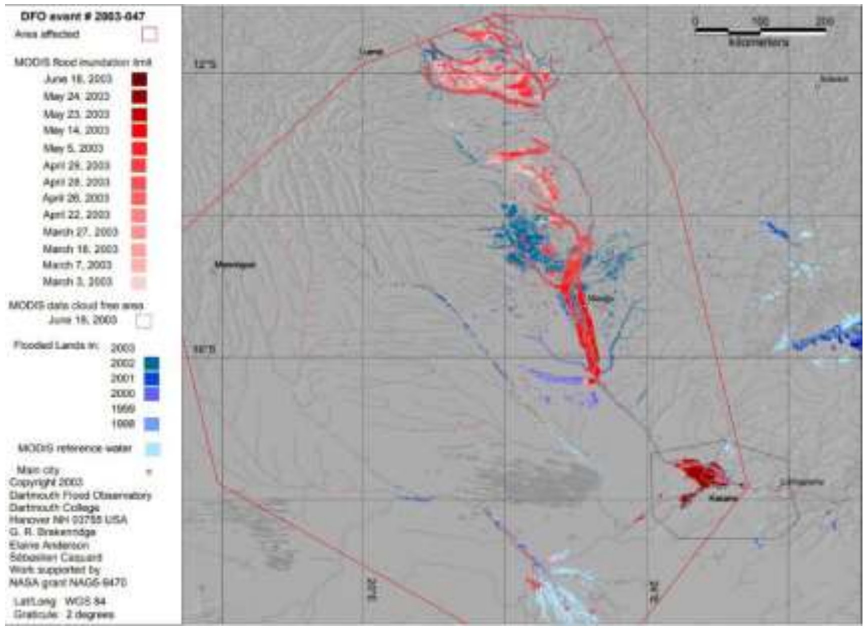
FLOODS AND EXTREME PRECIPITATION

Flooding has an important ecological function in KAZA's major riverways, including many downstream deltas and wetlands. The health of these riparian areas depends on the timing, duration, and depth of seasonal flooding. For example, floodplain recession farming is a popular livelihood activity, especially around the Okavango Delta. Beginning in Angola as the Cubango River, it flows unobstructed through the Namibian panhandle until emptying into the large expanding Okavango Delta in Botswana. The Okavango Delta is one of the largest draws in Botswana's tourism economy, the country's second largest economic sector. These wetlands are seasonally inundated, providing fishing opportunities, forage for livestock and wildlife, water for farming, and grasses and sedges for harvesting.

Many communities live and work near these waterways, adjusting their geographic range and livelihood activities with the pulse of floods. For many communities, especially the transhumant communities, flooding and wetland ecosystems are an integral part of their broader socio-ecological and cultural system. And yet the cost of proximity to waterways can be high. In 2009, the river levels along some parts of the Okavango reached 8.62 meters, the second highest depth recorded and the highest since 1969, displacing many communities surrounding the delta and forcing several tourist operators to close

(Weidlich, 2009). In 2003, along the Zambezi River, 122 days of rainfall between January and May inundated communities living within and just beyond the seasonal floodplains (Figure 14). By July, 22 villages across Zambezi Strip were washed away (DFO, 2003). These semi-formalized settlements practicing floodplain recession agriculture across floodplains boasting rich fluvial soils suitable for crop production are particularly prone to flooding.

Figure 14. Rate of inundation (red) during 2003 flood event along the Zambezi River (DFO, 2003).

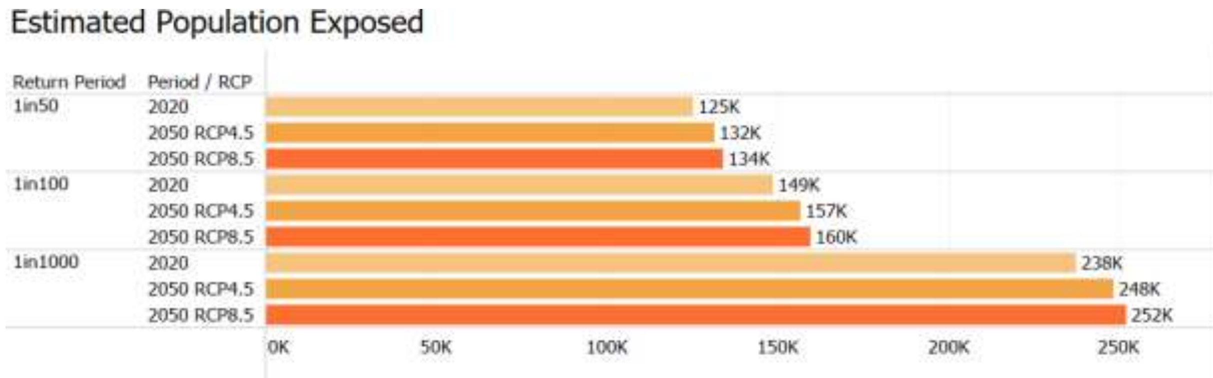


The history of floods in KAZA helps illustrate the extent of potential impacts in today's climate. In decades ahead, this flood regime, which is already prone to extremes, will invariably change, expanding the size of flood zones and placing more residents and their livelihoods at-risk. Those dependent and near downstream waterways will be especially vulnerable to the growing unpredictability associated with climate change, including increased rainfall variability and intensification.

While the frequency of future flood events is difficult to discern from the climate projections alone (see *Appendix*) the spatial extent of future flooding can be more confidently characterized through hydro-climatic models coupled with high-resolution terrain models. The outputs of these models illustrate the effects of climate change on river-based flood events that occur when a river exceeds its capacity and inundates surrounding areas. We simulate the inundation of various flood events (1-in-50 years, 1-in-100 years, and 1-in-1000 years) in today's climate (2020) and a future period (2050) under multiple emission scenarios (RCP4.5 and 8.5) (Figure 16).

An estimated 149,000 people are already at high risk to a 1-in-100-year return period event. Flood risks in KAZA are expected to grow because of both hazards (climate change) and exposure (additional assets, population size, and land-use change). Holding exposure constant, Figure 15 shows the number of residents exposed to inundation under various simulated flood events today and in 2050.

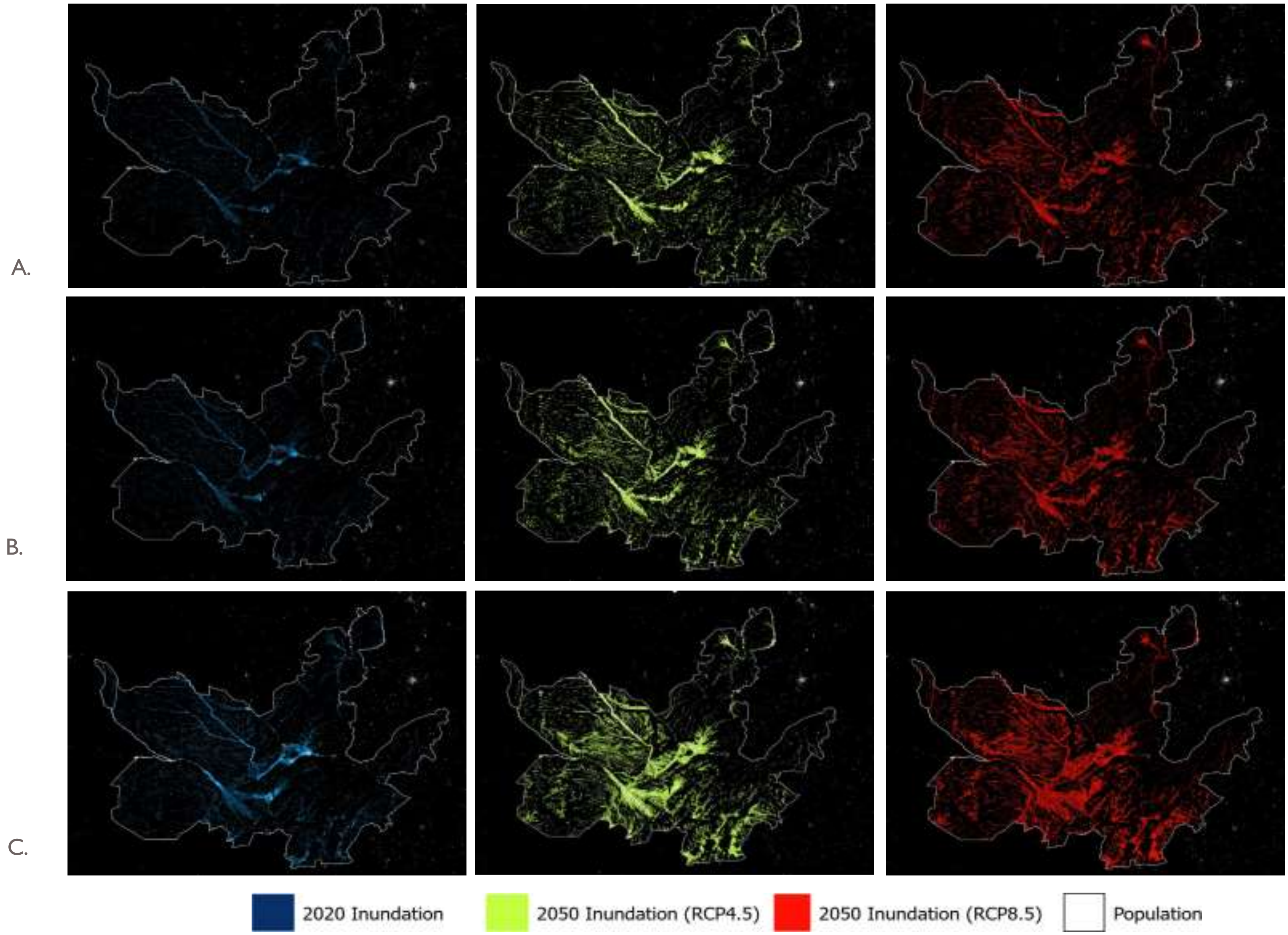
Figure 15. Approximate number of KAZA residents exposed to flooding across all time periods and scenarios, holding population constant (2016 est. population).



Future flooding poses a major threat to communities located near the banks or floodplains of the Okavango, Cuando, Cuanavale, Cuchi, Kwando, Zambezi, Lufupa, Kafue, and Luswishi rivers, including the dozens of related tributaries. Presumably, communities have adapted the geographic range of their livelihood activities to the historical floodplains of these waterways, represented in the 2020 simulations (blue). Climate-related flood risks emerge when areas unaccustomed to flooding become prone to inundation due to climate-driven rainfall intensification. These hotspots constitute areas of new flood potential (green and red) that intersect with concentrations of households (white) (Figure 16).

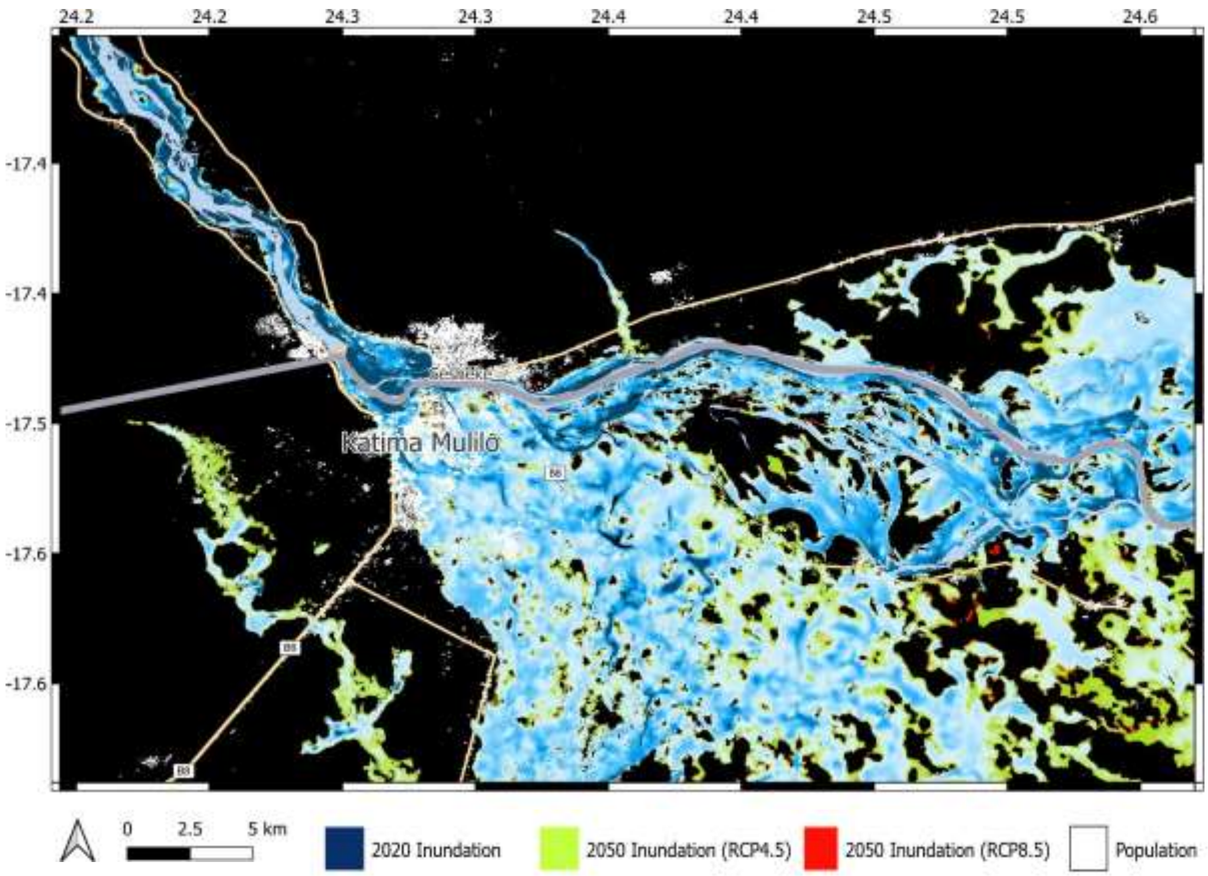
At a landscape level, flooding in the KAZA TFCA will expand in future periods with small but still potentially meaningful differences between the future scenarios. Most notably, the differences between a 1-in-100-year event, and more severe flood events are not only evident in the expansion of flooded area around major deltas and floodplains, but also in the expansion of inundated areas that emerge around the numerous tributaries and isolated waterways that convey floodwaters.

Figure 16. Spatial extent of inundation under 1-in-10 (a), 1-in-100 (b), and 1-in-1000 (c) year flood events in 2020 (left column), moderate mitigation scenario (RCP4.5) in 2050 (middle column), and a high-emissions scenario (RCP8.5) in 2050 (right column).



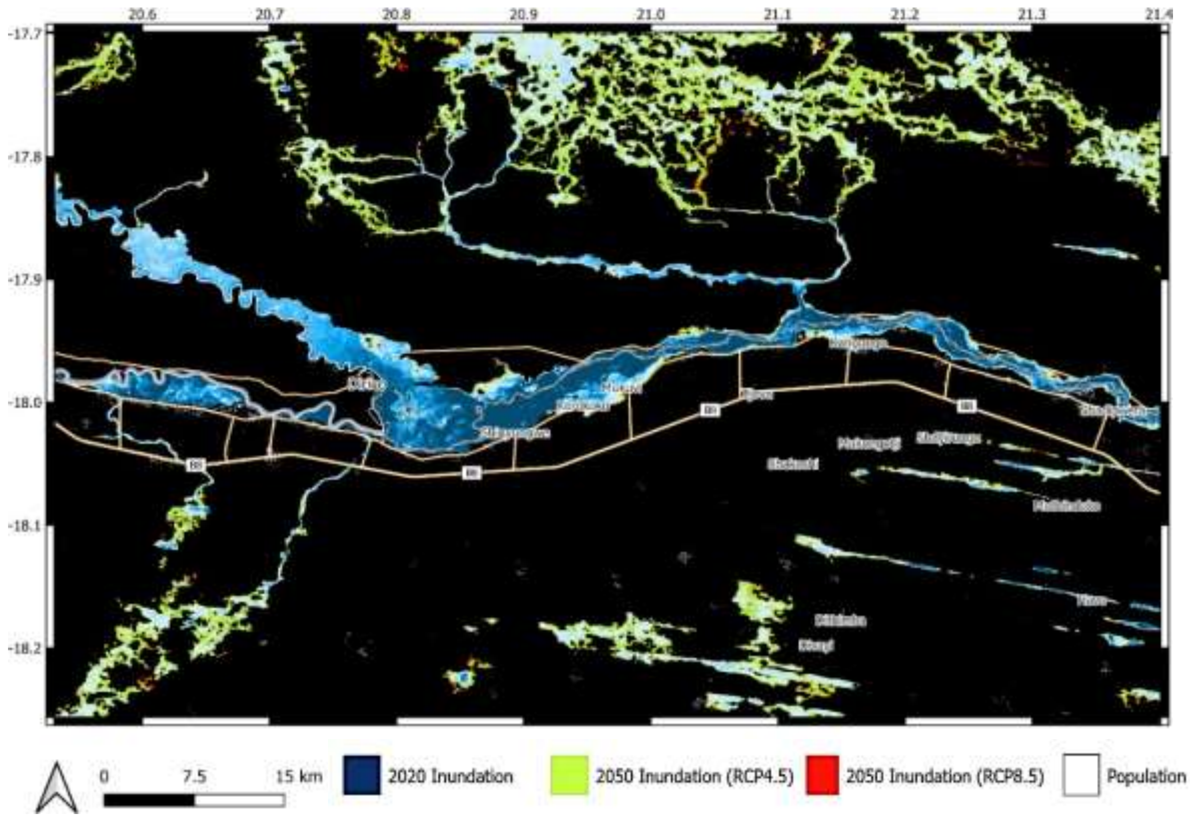
Lying on the northern and southern banks of the Zambezi River, the border towns of Sesheke, Zambia, and Katima Mulilo, Namibia face extensive flood potential from a 1- in-100-year flood (Figure 17). The area is home to thousands of residents and serves as a critical transit and market hub for the surrounding area. Just south of the Zambezi River and adjacent to the Rundu-Divindu (B8) highway, the Ngweze and Mavaluma neighborhoods are particularly exposed to moderate flooding.

Figure 17. Flood inundation areas surrounding Katima Mulilo, Namibia during a simulated 1-in-100-year event in current conditions (blue), and by mid-century under various emission scenarios (green and red).



To the east, along the Okavango River, thousands of KAZA residents live between the river and the roadways spanning the western Namibian panhandle (Figure 18). This stretch of roadway is highly exposed to flooding and is the primary connector for the dozens of tourist operators and farms operating downstream.

Figure 18. Flood inundation areas along the Okavango River during a simulated 1-in-100-year event in current conditions (blue), and by mid-century under various emission scenarios (green and red).



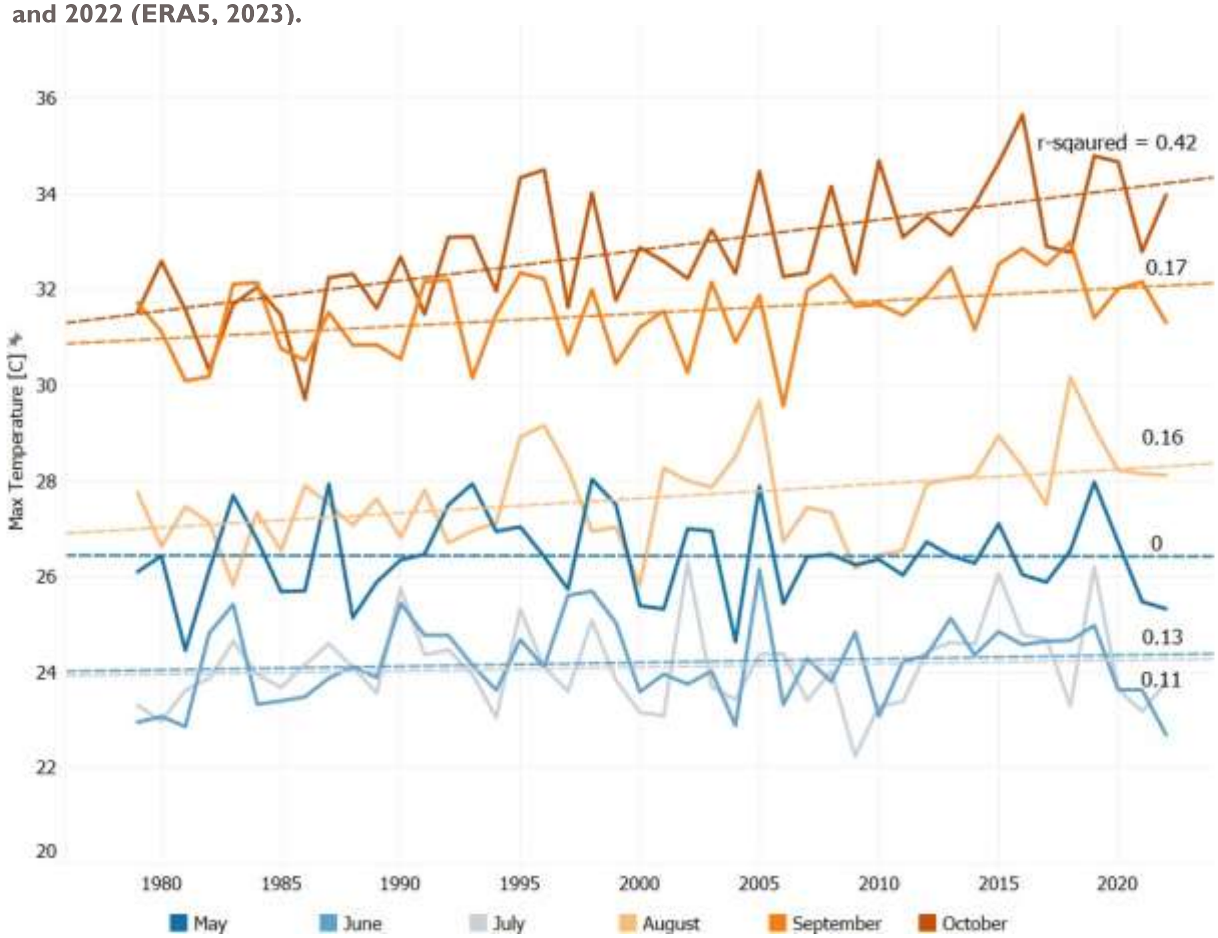
EXTREME HEAT

Extreme heat affects every aspect of life in KAZA, placing people, especially the young and elderly at greater risk of heat-related medical incidents. Increased exposure to high temperatures affects the learning ability of students, makes outdoor labor more strenuous and less productive, limits livestock productivity, spoils post-harvests, and may shorten the tourism season because of a higher number of days exceeding thresholds of thermal comfort levels, resulting in fewer tourists.

From 1979 to 2023, the annual average near-surface temperature over KAZA has steadily increased during the tourist season, especially later into the season (October). In the early dry season (May-July), little upward change in maximum temperature has been observed when averaging across the entire region. However, later in the season, average monthly maximum temperatures during the month of October have surpassed 35°C in three instances (2016, 2019, 2020). Perhaps one of the greatest sources of climate-related climate risk stems from significant departures from typical experiences. In this assessment of extreme temperatures, a daytime temperature of 35°C is used as a crude proxy for thermal discomfort, with this threshold temperature[14] occurring only rarely in recent history.

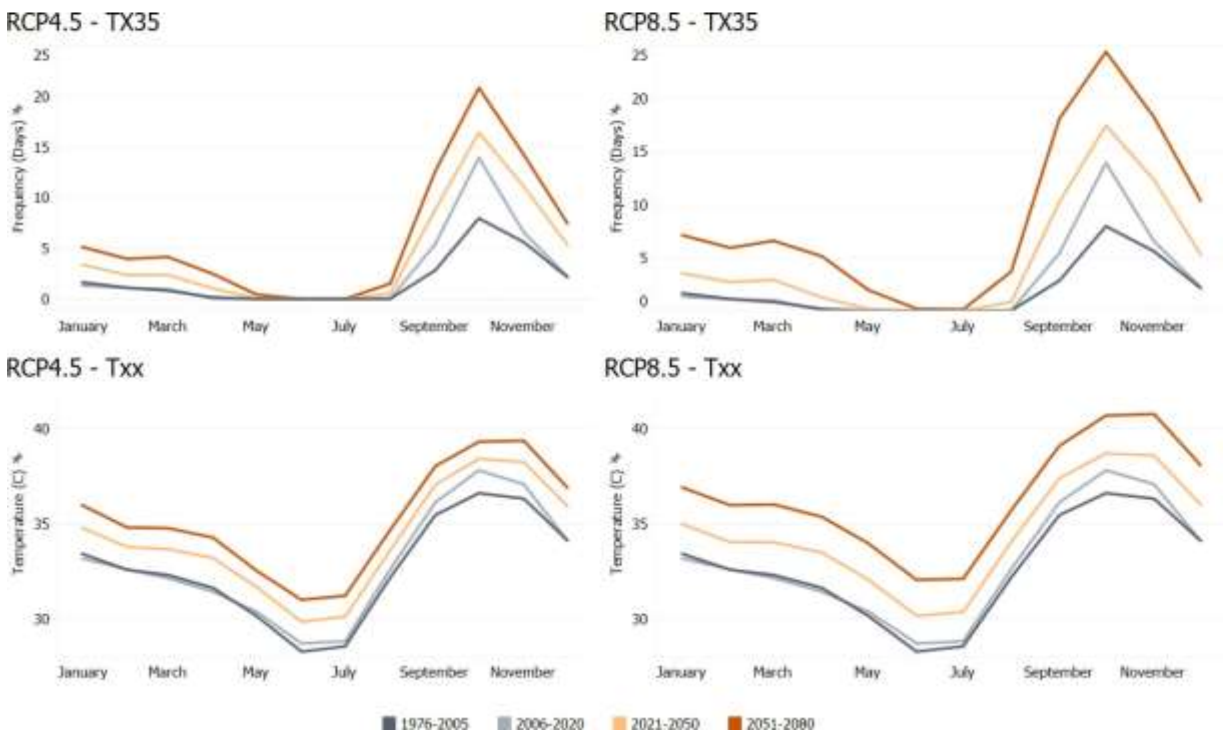
Historically, the incidents of extreme heat days (days > 35°C) have been rather infrequent and limited to the hot and dry season (August-October). By mid-century, the frequency of extreme heat days may increase by 3- or 4-fold, depending on the scenario, and may occur throughout much of the year (Figure 20). The climate projections also suggest that extreme heat days will not only become more frequent, but also more severe. Average daily maximum temperatures (Txx) across all the KAZA TFCA will significantly increase relative to the historic and recent periods, potentially even exceeding 40°C under the highest-emission scenario by mid-century.

Figure 19. Changes in average monthly maximum temperature during the tourist season 1979 and 2022 (ERA5, 2023).



[14] Future studies should consider more sophisticated thermal and tourist comfort indices, combining wind speed, radiation, humidity, and air temperature such as those defined in Bröde, et al., (2012) and Mieczkowski, (1985).

Figure 20. Extreme heat indicators by month across all time periods and scenarios.



The vulnerability of the tourism sector to current climate variability and longer-term warming trends is of particular importance to economic activities dependent on the growing tourism industry. As such, the historical trends and future projections described in this section feature changes during the peak tourist season, which generally occurs between May and October, when vegetation is at its lowest and animal visibility is at its highest.

During the tourist season (May-October), average maximum temperatures across the entirety of KAZA are expected to increase by 2.6°C (1.8°-3.2°) by mid-century under a moderate mitigation scenario. The spatial patterning of extreme heat severity of these changes is mostly uniform, with the exceptions of the salt flats in the Makgadikgadi region of Botswana and Lake Kariba, Zambia (Figure 21).[15] Unfortunately, given the lack of vegetation (salt flats) and remoteness (Lake Kariba), these areas may not be ideal candidates for wildlife seeking cooler zones or for people seeking refuge from future extreme heat.

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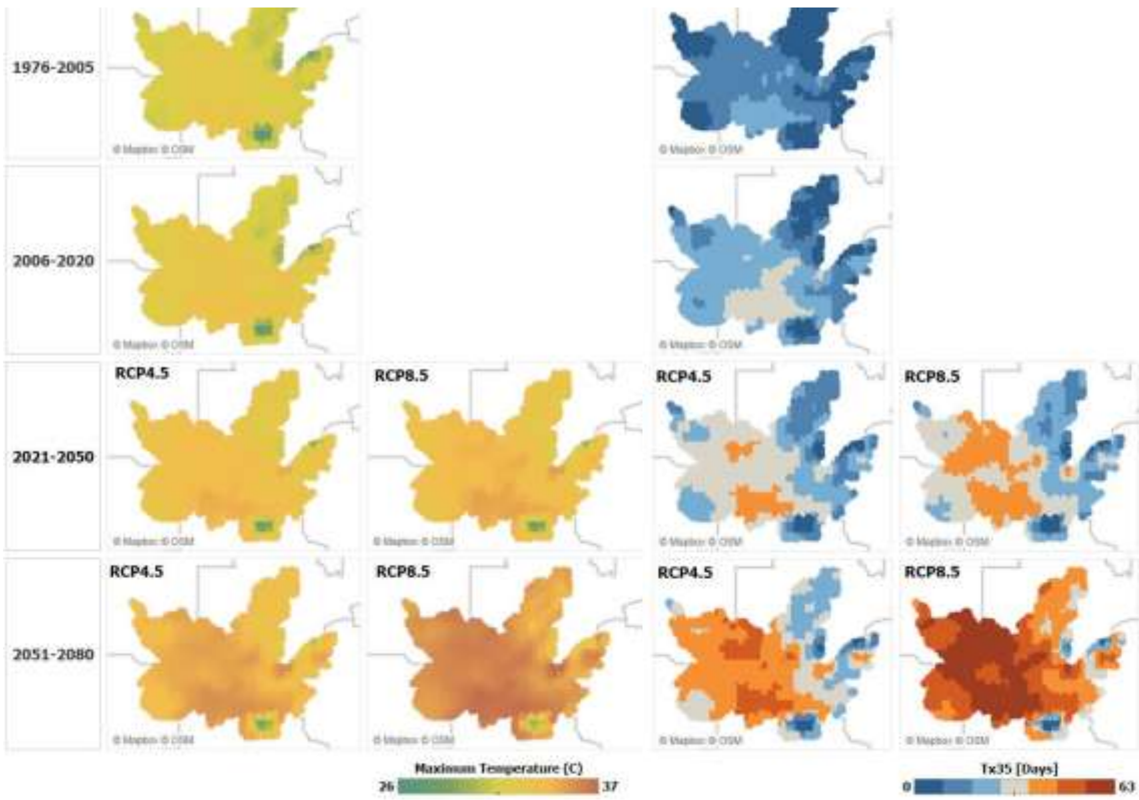
[15] The temperature rises in the salt flats are limited compared to surrounding areas due to higher albedo of the white land surface, which has the effect of reflecting the solar radiation back to the atmosphere, and therefore moderating land surface temperature increases. In the case of Lake Kariba, rising temperature is likewise limited, due to the higher specific heat capacity of water compared to soil and due to enhanced evaporation and the conversion of solar radiation to latent heat. Because of the resolution of the ERA5 model, this cooling effect may appear larger in size than the lake's actual footprint, which is merely an artifact of the spatial re-sampling process.

The spatial patterning of future extreme heat day frequency is more heterogeneous, owing to orographic differences across KAZA. In Figure 21 (right), areas in blue represent the normal range of extreme heat days (0-29 days) during the tourist season, and areas in red represent significant increases in the frequency of extreme heat days (37-63 days) relative to the historic period. The highest relative increases appear in the heart of the KAZA TFCA, extending south and north of the Zambezi Strip toward Mongu, Zambia, and the upper reaches of the Angolan-Zambian border and southward over Maun, Botswana, and the Okavango Delta. Like the drought and wildfire trends illustrated in earlier sections, the upper reaches of the Zimbabwean and Zambian portions of the KAZA TFCA may experience slightly less severe extreme heat conditions. Though for much of the region, every third day of the tourist season (May-October) could reach a daily maximum above 35°C by mid-century.

Figure 21. Maximum temperatures (left) and number of days above 35°C (right) between the tourist season (May and October) under future scenarios and periods.

(Right) areas in blue represent normal range of extreme heat days (0-29 days) during this period and areas in red represent significant increases in the frequency of extreme heat days (37-63 days) relative to the historic period.



SENSITIVITY AND LIVELIHOOD IMPACTS

Climate impacts are often non-linear and can be compounded by a variety of non-climate stressors. For example, factors such as environmental degradation, conflict, and poor resource governance can impair the functioning of key social, economic, and ecological systems, and magnify climate impacts. All of which hinder progress that KAZA can make toward its conservation and poverty reduction goals. This section contains a more comprehensive list of climate and non-climate factors that increase sensitivity to climate change impacts for key livelihoods.

To do this, we convened community and country representatives from the KAZA Community Working Group in April 2023. During the workshop, the author led small breakout groups alongside members of the Resilient Waters team, the Namibia Nature Foundation, and the KAZA Secretariat. We asked participants from the Community Working Group — senior government officials, rangers, and researchers representing communities across the KAZA TFCA — to identify the key climate risks facing various livelihood practices and to illustrate the causal pathways connecting climate drivers to impacts in key sectors and livelihoods, resulting in a series of livelihood-specific impact chains that helped inform the remaining analysis and subsequent recommendations.

AGRICULTURE

Climate-driven drying patterns will disproportionately affect farmers that are highly reliant on rain-fed agriculture. In the absence of significant investment and deployment of irrigation infrastructure, coupled with adequate ground- and surface water resources and management, rainfed agriculture is expected to continue as the dominant agricultural system across sub-Saharan Africa (Cooper et al, 2008). High water stress and rainfed irrigation will place farmers — especially dryland farmers — at the mercy of longer dry periods interrupted by increasingly variable rainfall patterns. Shorter growing seasons (e.g., late rains in 2015, 2018, and 2019) and drier dry seasons (e.g., 2015 and 2019) will make it especially difficult for smallholder farmers with few other income-earning opportunities. Households that maintain small gardens or rely on subsistence agriculture year-round may also find it difficult to generate sufficient yields with the same crops, irrigation method, and planting cycles. The impact on farmers in more rural areas will be more pronounced as they will be less able to access other labor markets and experiment with other livelihood options. Taken together, rural, subsistence, rainfed farming is perhaps the most climate-vulnerable livelihood activity, spurring the need to, among others, broaden market access to foods, climate-smart technology and training, and supplemental income through non-farming livelihoods.

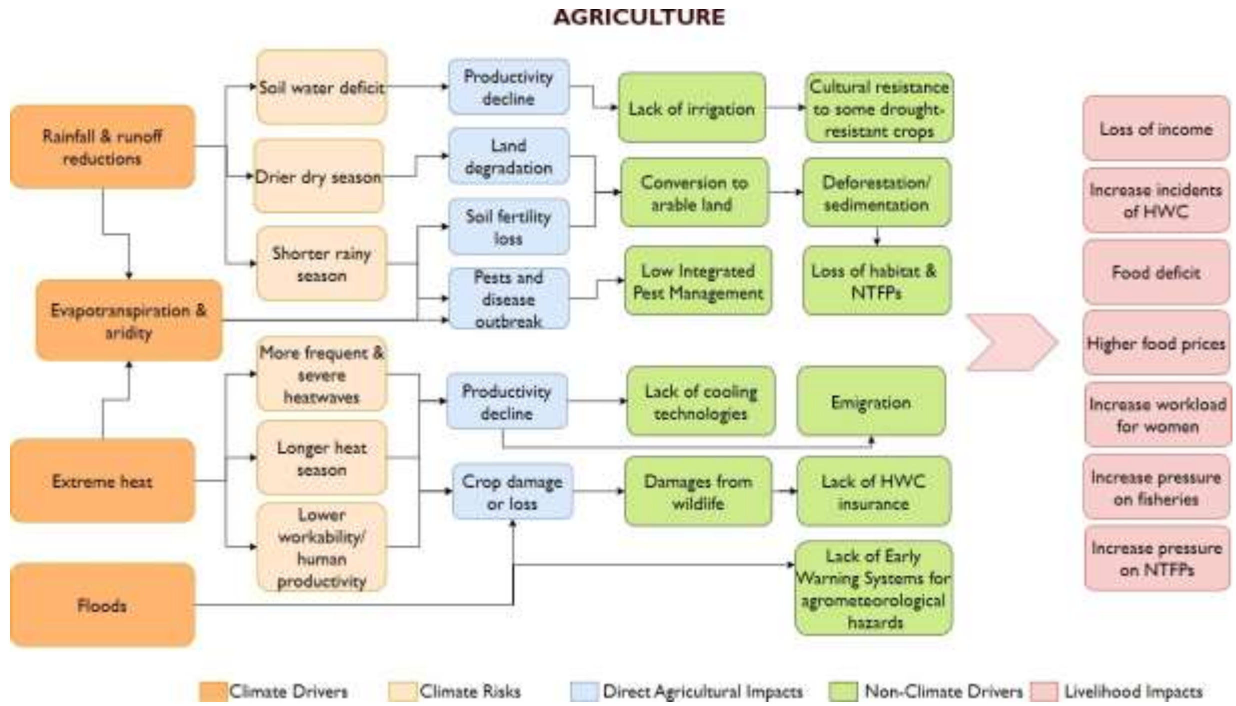
"…rainfall amounts received over some years differs from other years as well as timing which has caused some confusion on [] when to start planting."

Female farmer
Lupane District, Zimbabwe
May 27, 2021
WWF CROWD SURVEYS

Land-use changes will continue through the removal of biomass (e.g., deforestation or erosion), converting KAZA's arable land to produce crops. And yet across many potential agricultural areas, soils will have a severely diminished capacity to retain water and soil nutrients, grow crops, and provide forest products and other essential ecosystem services. This results in significant losses to other livelihoods. Moreover, rural, rainfall-dependent farmers living on degraded land may opt to rely more heavily on harvesting NTFPs or turn to fishing, which could subsequently degrade these resources further and make it especially hard to break the cycle of poverty.

From a programming and investment perspective, climate adaptations in the agricultural sector must consider the sustainable expansion of irrigation, pest management, insurance, early-warning systems, and climate-smart water and soil management. Investments in these practices and technologies must be accompanied by training, technical assistance, finance, monitoring, and technologies.

Figure 22. Agriculture impact chain



LIVESTOCK PRODUCTION

Livestock plays a prominent socioeconomic role in livelihoods of many KAZA residents and is a significant source of food, income, and cultural significance (KAZA Secretariat, 2023). The recent effects of climate change on livestock production in Southern Africa have been well-documented (Ngarava *et al.,* 2021; Zhou et al., 2022). The direct effects of extreme temperatures, higher humidity, and drying patterns directly affects animal's ability to grow, produce milk, and reproduce (Rust *et al.,* 2003). Combinations of high temperature and humidity can lead to heat stress in livestock, by reducing their metabolic rate and limiting their productivity, though thresholds vary be species. For example, in milk cows, Silvia *et al.,* (2022) found that cows produced 10%-14% less milk than their counterparts that were provided with shade during a 2002 heat wave in Argentina. In rural livestock farming, the availability of shaded structures or canopy coverage is limited, posing an adaptation challenge for herders and producers in KAZA. As for productivity, one study estimated that the average grazing capacity of beef cattle in Southern Africa could decline by 30%-50%, depending on the emissions scenario (Furstenberg & Scholtz, 2008). Other impacts associated with extreme heat conditions include decreases in reproduction rates and feed conversion efficiencies as well as an uptick in the prevalence of vector-borne diseases and parasitic infections (Rust *et al.,* 2003).

"Our livestock are [] dying because of drought as there is insufficient grazing and water available."

Village Leader
Kabbe, Namibia
November 17, 2021
Report WWF Crowd Surveys

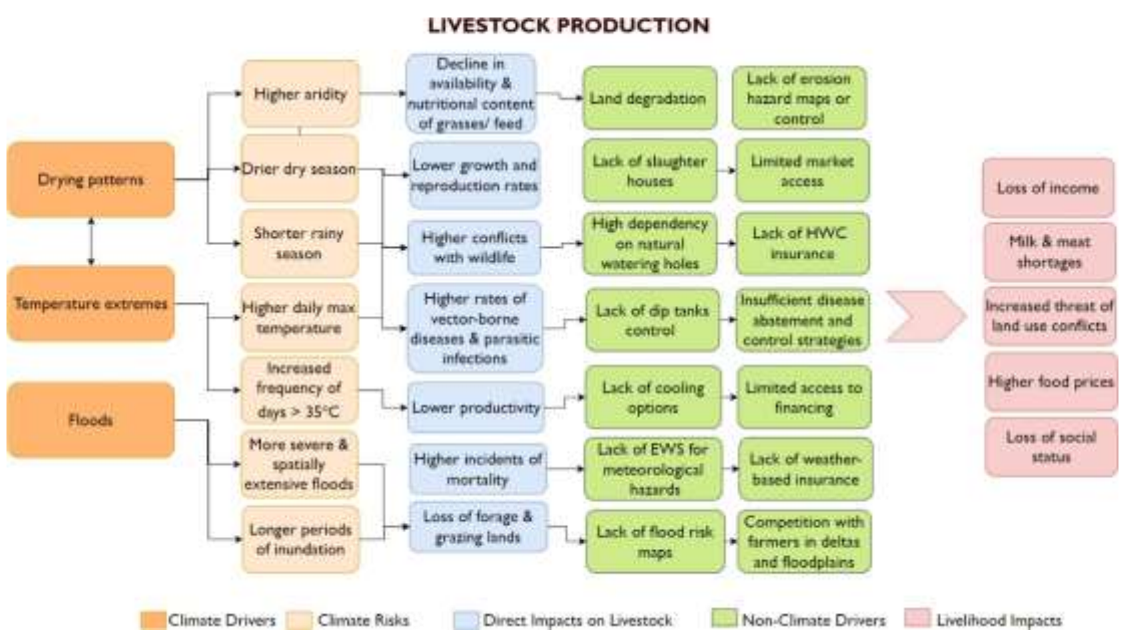
Flooding can also pose direct risks to livestock, as well as the availability and affordability of meat and dairy products in local markets following a flood event. In a study examining the effects of flooding on livestock production in South Africa, Ngarava *et al.,* (2021) found that much of the flood-related losses were the result of damages to grazing lands in flood-prone areas. To better understand the extent to which floods may affect livestock production in the KAZA TFCA, a deeper exposure analysis would need to be conducted, intersecting flood-prone areas identified in this assessment (see Figure 16) with current grazing areas.

Climate change will indirectly affect herders' and producers' ability to manage feed deficits in the dry season due to shrinking rangelands. They may also struggle to ensure animals can access adequate water supplies without encountering predators or getting lost in the pursuit of diminishing watering holes. As rangelands and water sources shrink because of a combination of heating and drying patterns, competition for and conflict over quality rangelands may also increase. Overstocking livestock into smaller areas, likely to be the case with traditional herds where through-put for the market is not a priority, also increases the chances of disease transmission, especially foot and mouth disease. Erosion issues may also develop where livestock are forced closer to rivers in pursuit of dwindling watering holes, and the loss of riverine vegetation may reduce shade and increase sedimentation and flood stages in the event of a flood.

"Cattle are affected by flooding, and [people] are moving cattle to the highlands during the flood season."

Male farmer
Namibia Panhandle
November 16, 2021
Report #2132
WWF Crowd Surveys

Figure 23. Livestock production impact chain.



In many contexts, as temperatures increase, the probability of livestock ownership often increases, as the benefits of crop production typically decline with less overall rainfall (Seo & Mendelsohn, 2006). Currently, many farming households maintain both large (e.g., cows) and smaller ruminant (e.g., goats) species as an insurance policy during drought years (KAZA Secretariat, 2023). It is also worth noting that livestock ownership is often linked to social status (KAZA Secretariat, 2023), and many livestock owners may be slow to adapt or even refuse to adjust carrying capacities at the cost of social status, which could also heighten disease risk.

And while those households that practice both crop and livestock production are more climate resilient, both livelihoods are still sensitive to heating and drying patterns, and the concurrent losses of agricultural and livestock assets could trigger a collapse into chronic poverty and have a lasting effect on rural livelihoods. By themselves, livestock and crop production do not offer sufficient diversification against anticipated climate changes.

FISHING

Fisheries across KAZA's inland waterways are an important, and easily accessible source of protein and income, and many households practice low-tech, artisanal fishing. The emergence of commercial and tourism fishing has put a strain on downstream fishing communities and contributed to shrinking yields, which has spurred the adoption of unsustainable and destructive fishing practices and gear. This vicious cycle is compounded by a combination of increased fishing pressure, incongruous regulations, and climate-related effects on water levels and quality, and many households acknowledge that fishing is an increasingly unreliable livelihood (WWF Climate Crowd Surveys, 2017-2021). Declines in fishing productivity could spur a number of health-related challenges, beginning with drops in protein consumption for many communities.

"There has been extinction of fish along [the] Dibutibu river as [more] people were relying on fish[ing]."

Female Farmer and Church Clerk
Matebeleland North, Zimbabwe
March 14, 2019
WWF Crowd Surveys

Persistent drying patterns and rising temperatures, often exacerbated by El Niño events (e.g., 2015/16), lead to declines in water levels and a deterioration of fisheries. For example, Lake Kariba, which contributes almost 90% of Zimbabwe's fish production (FAO, 2022), has experienced significant declines in most species[16] since 1996 due to a combination of increased fishing pressure from both traditional and industrial fishing methods, low rainfall, increased evaporation rates, and an increase in the lake's temperature, which have risen more than 2°C over the last three decades (Magadza *et al.,* 2011). Taken together, these changes have decreased fish productivity, nutrients, and the abundance of phytoplankton and zooplankton, which are key species in stabilizing the lake's food chain (Ndebele-Murisa *et al.,* 2011)

Increases in ambient air temperature can raise water temperature and affect oxygen dynamics, which can have cascading effects on other water quality parameters that are fundamental to aquatic ecosystems and fish productivity in tropical rivers and lakes (Danladi *et al.,* 2017). High temperatures are also a major contributor to post-harvest fish spoilage, resulting in potential financial losses for fisherfolk downstream, value-chain actors. Temperatures above 20 °C promote conditions for bacteria growth (Diei-Ouadi, *et al.,* 2011), and even fish kept in nets can spoil in water temperatures above 15 °C (Mavuru *et al.,* 2022).

In the river-floodplain ecosystems, floods are a major threat (and dependency) for fisheries — elevating turbidity and sedimentation and limiting access to fisheries. Conversely, low severity floods can limit nutrient flows and fish habitats and can even strand fish in fragmented pools of the floodplain. Thus, the

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[16] Not all fish species are declining in numbers. The sardine species, *Limnothrissa miodon* ('kapenta'), has developed significantly since its introduction on the lake in the late 1960s and now accounts for over 90 percent of the Lake Kariba's total fish production. Kapenta are considered more resilient than other species due to their "high fecundity, short lifespan, rapid growth and fast colonization of the habitat" (FAO, 2022).

productivity of floodplain fisheries, like the Okavango Delta, are highly sensitive to the severity and periodicity of flooding (Mosepele et al, 2022).

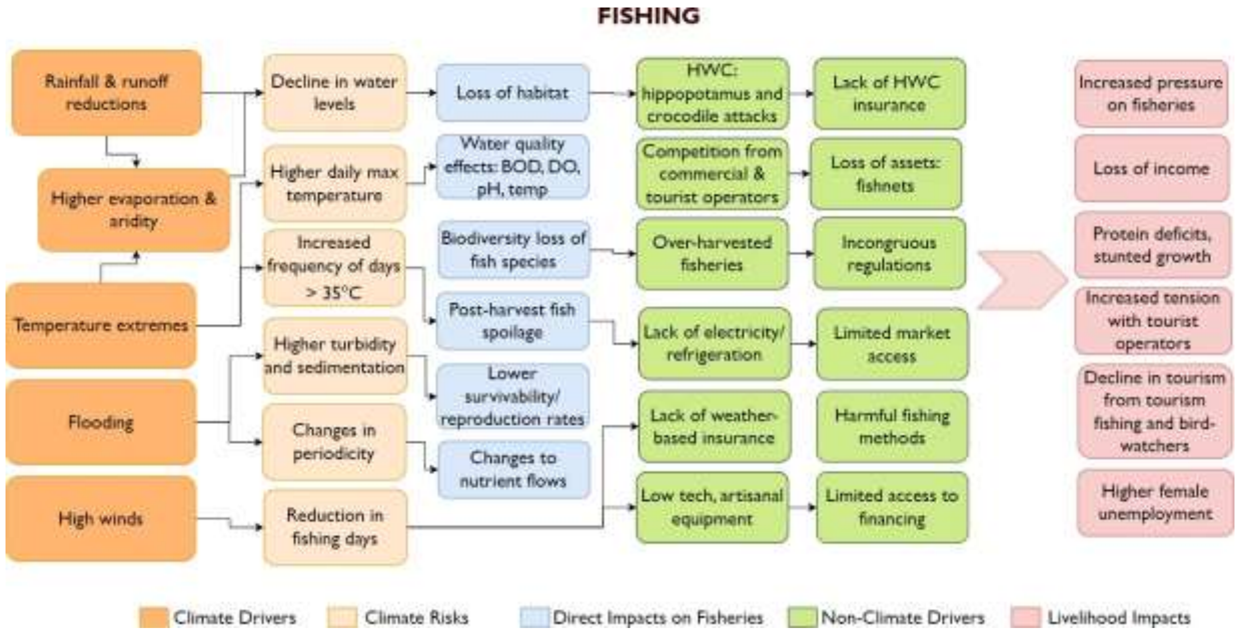
The non-climate-factors affecting fishing include increased pressure on fisheries, human-wildlife conflict (e.g., hippopotamus or crocodile attacks), uneven regulations (e.g., fishing remains banned on the Botswana side of the Chobe River but is permitted on the Namibian side), and increased competition and conflict from commercial fishing, aquaculture, and tourist parties. In a study interviewing 245 fisherfolk around Lake Kariba, approximately one-third of interviewees reported having their fishing nets recently dragged and destroyed by commercial fishing boats or tourist houseboats (Ndhlovu *et al.,* 2017). The same survey in Lake Kariba also found that respondents found it difficult to maximize income from their catches due to lack of refrigeration, poor road infrastructure, and intermittent availability of transport to local markets. Women often work roles downstream in the fishing value chain, including fish processing and trading in the fish markets (FAO, 2022). Much like crop farming, fisherfolk in the KAZA TFCA lack access to finance and insurance, which limits their ability to purchase assets (e.g., boats, nets, etc.) or recover following periods of low harvest or weather-related disruptions (i.e., floods or persistent high winds).

"Fishing does not yield large quantities anymore because of overutilization."

Fisherman,
Namibia Panhandle
January 21, 2021
Report #2124
WWF Crowd Surveys

It is important to note that many individuals may begin practicing fishing when crop production becomes less reliable due to extended periods of drought and rainfall variability. At the same time, fisherfolk often cite increasing fishing pressure as a primary threat to their livelihood. That is to say that in a climate future where shorter growing seasons and sustained drought spur many households to rely more heavily on fishing, then the productivity of local fisheries could further deteriorate because of increasing pressure. The potential collapse of fisheries could effectively eliminate the primary source of protein in communities dependent of fish for sustenance, triggering extensive health impacts such as stunted growth in children and additional risks for pregnant women. Deterioration in fisheries also disproportionately affects women and youth who play a prominent role in downstream value-chain activities such as cleaning, transport, and sale of fish products (FAO, 2022).

Figure 24. Fishing impact chain.



TOURISM

The tourism sector could someday support households and communities throughout much of the KAZA TFCA with training, jobs, and income. However, current access to these opportunities is limited (KAZA Secretariat, 2023). The sale of select crops to tourist operators has been touted as a means to income diversification and climate adaptation, but only a small percent of KAZA's farmers are regular suppliers (CRIDF, 2017) and relatively few are employed as staff supporting tourist operations through maintenance, construction, guest services, transportation, or serving as guides.

Tourism operators, and the individuals and communities that depend on them, are increasingly vulnerable to the impacts of climate change. The climate changes described in this assessment — increased rainfall variability, a delay in the onset of the rainy season and longer dry season, increased severity of heatwaves and wildfires, and more spatially extensive floods — hold implications for tourist operators by affecting their operations directly and the biodiversity and climate conditions they depend on to attract tourists. For example, there is mounting evidence linking drought to declines in tourist numbers (Mathivha *et al.,* 2017; Proebstl-Haider et al. 2021). Tourist numbers at Victoria Falls dropped sharply during a recent period of droughts (e.g., 2016 and 2019) when waterfalls slowed to a trickle. The tourism sector in KAZA is particularly sensitive to rainfall variability and reductions in water, as nearly all attractions (e.g., vegetation, waterways, wildlife) depend on water.

Drying patterns will affect the tourism sector in several ways. Elephant numbers, for example, are predicated by proximity to water sources (Pozo *et al.,* 2018). Some have even suggested that the anticipated severity of dryness across Southern Africa, could mean that the Okavango Delta will no longer able to support large herds of water-dependent herbivores, such as elephants, buffaloes, and zebra (Perkins *et al.,* 2020). In such a scenario, downstream deltas in the southern half of the KAZA may become less attractive to tourists, leading to lower incomes from tourism, which will have consequences for both local employment and contributions to national income while also stunting community-based tourism initiatives before they can be fully realized. Farmers providing select crops to lodges will find it increasingly difficult to grow certain crops year-round, a reason many lodges do not source their vegetables and fruits locally (CRIDF, 2017). And yet there are opportunities to grow more heat- and drought-tolerant crops, such as peppers and tomatoes, which are in high demand at many tourist lodges.

Thermal discomfort caused by higher maximum temperatures is one such change that could affect tourist numbers. This assessment found that during the peak tourist season (May and October), when vegetation is at its lowest and animal visibility is at its highest, max temperatures have increased by 3°C over the last 40 years, and could increase by another 4 °C (3-5 °C) by mid-century under a high-emissions scenario, often exceeding 40°C. The frequency of extreme heat days (days > 35°C) could increase up to 15 days in October under the same time period and scenario.[17] These heat-related changes could alter the desirability of travel during this season and limit the hours that tourist operators can provide fishing, hunting, and wildlife excursions due to the effects on both wildlife and tourists, especially heat-sensitive individuals. Wildfires and the associated smoke could trigger similar effects by impairing air quality, visibility, and affecting tourism operations by reducing wildlife numbers and pose a health threat to staff and visitors.

The infrastructure supporting the tourism sector is also highly vulnerable to flooding. As most tourist operators are in rural areas and within or in close proximity to known wildlife corridors, they are also extremely isolated and dependent on a limited number of roadways and airports. This assessment found that most tourist lodges[18] and connecting roadways are located within today's 1-in-100-year floodplain. Access to flood risk maps that incorporate future flood potential, such as those presented in this assessment, could help guide the design and planning decisions regarding future tourist-related infrastructure.

And while the tourism sector can be a job creator for rural communities, global events, such as the COVID pandemic, can cause a significant decline in tourists to KAZA, and knock on effects in the tourism value chains, highlighting the risk of relying too heavily on tourism as a source of employment and income. Nevertheless, many opportunities exist to supplement incomes through tourism- and conservation-related efforts, such as the provision of direct payments for ecosystem services (PES) or the protection of wildlife and habit corridors, which generate compensation through nature-based carbon projects. At the same time, nature-based carbon projects are increasingly facing the risk of non-permeance, whereas stocks of carbon cannot indefinitely continue to sequester carbon due to deforestation and drying patterns that increase the chances of soil degradation and wildfires. Overall, climate change and increasing land-use pressures pose significant challenges to the durability of such PES and conservation finance efforts.

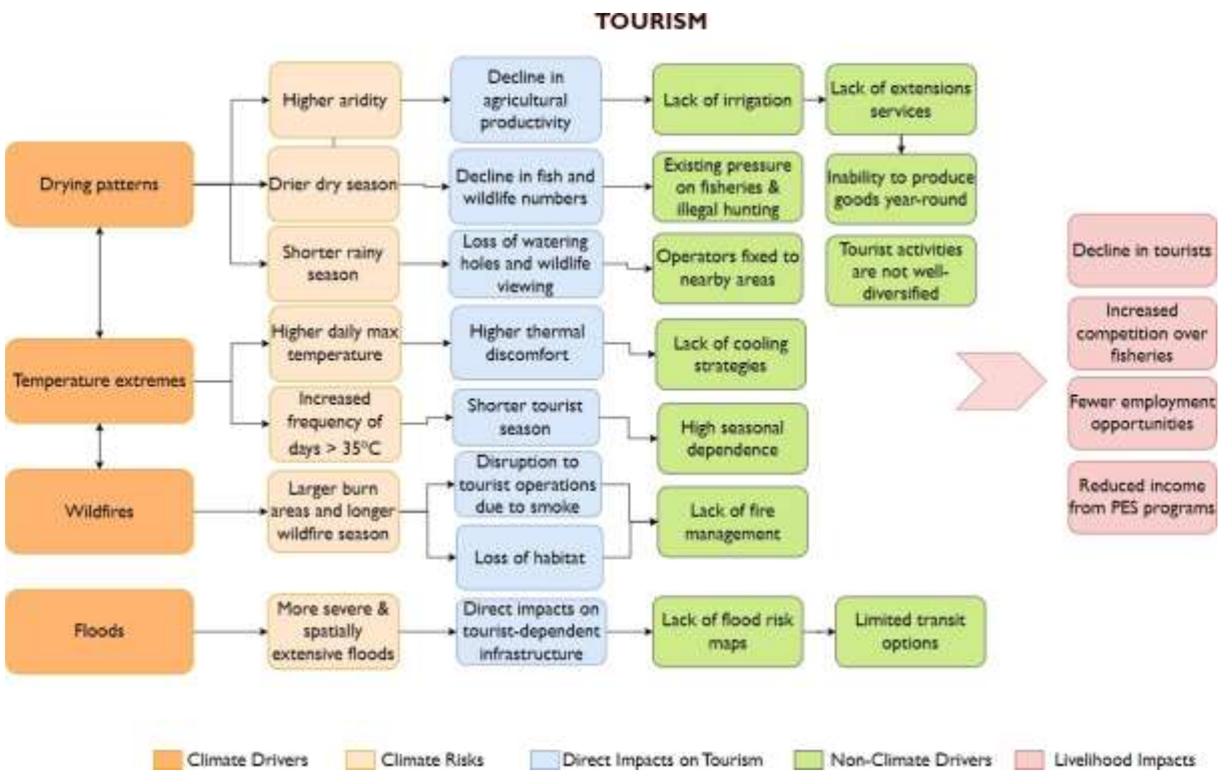
Diversifying tourist attractions in KAZA away from highly climate-sensitive activities (i.e., wildlife- or water-based attractions) and toward cultural and historical tourism offers an alternative, and more

[17] Future studies examining the heat-related impacts to the tourism sector should consider more sophisticated thermal and tourist comfort indices, combining wind speed, radiation, humidity, and air temperature, such as those defined in Bröde, et al., (2012) and Mieczkowski, (1985).
[18] Geographic locations of "tourist places" provided by WWF-Germany. It was outside the scope of this report to determine the geographic accuracy of the coordinates provided by WWF-Germany against satellite imagery, and therefore, the quantification of flood risk exposure to tourism was limited.

climate-resilient, pathway for the tourism industry. Cultural tourism, however, requires community engagement and participation, respecting the rights and dignity of local communities and their cultural heritage. The mapping of cultural and heritage assets in KAZA will be an integral part of promoting cultural tourism in the area.

Given the growing awareness of the environmental impacts associated with tourism, there are also opportunities to facilitate carbon offset payments directly into local, community-based PES programs that generate carbon credits. Meanwhile, participating eco-lodges can help raise awareness of the development challenges and ongoing programs in the area. The KAZA Secretariat can play an active role in training and capacity building for alternative community-based tourism efforts that focus on cultural, historical, and ecotourism.

Figure 25. Tourism impact chain.



NON-TIMBER FOREST PRODUCTS

Most residents of the KAZA TFCA live in rural areas and take advantage of nearby natural resources for conversion into food, fiber, food, or products for sale. NTFPs are key inputs into households' subsistence needs, often providing more than just food, but also medical care, fuel, construction materials, and important cultural value. Most households use NTFPs to complement other livelihoods, which makes them a critical safety net during income loss and food shortages.

Changes in climate can influence the quality, abundance, and seasonality of these resources. As an example, wild fruit and mushroom production is highly sensitive to rainfall onset and temperature extremes. In the floodplains, the productivity of reeds and grasses are closely associated with seasonal variations between flood and dry season, such that drying patterns could affect the availability and productivity of the reedbeds, and through higher evaporation rates, shrink the shallower oxbow lakes where thatch grasses are usually abundant. And in more arid climates, such as the areas surrounding the San communities in Botswana and Namibia, drying patterns could have consequences for food security. For example, in Botswana's Western Kalahari, bushman communities rely heavily on hunting and foraging for food, livelihoods that could become more challenging as animals move in response to prolonged and increasingly severe dry season — patterns that are expected to prevail over the region in the near-term climate. The role of wildfire in the "savannisation" of areas that were previously woodlands may also have a profound effect on the abundance of NTFPs.

Climate and population changes will inevitably lead to increased pressure on these resources and to the degradation and loss of critical habitats, such as the floodplains and riparian woodland, which offer an abundance of NTFPs. As trees are cut for fuel or construction, and reeds and thatch grasses are cut for household use or baskets, these areas lose their capacity to support the growth of fruits, medicinal plants, wild vegetables, and spores for mushroom production. High charcoal use is also associated with land degradation, and KAZA will need to invest in scaling up clean cooking programs and enforcement efforts to alleviate pressure on habitat supporting NTFPs and a wide range of other provisional ecosystem services.

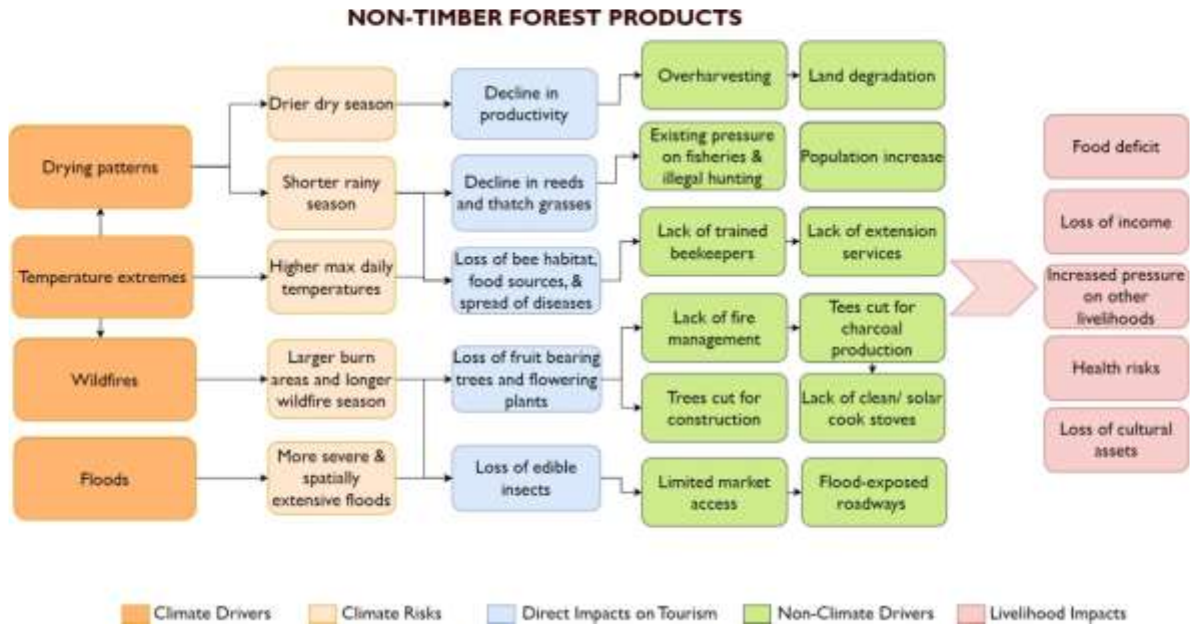
"Fruit trees have [] stopped bearing as many fruits as they used to ... Musuma, gum, boabob, bird plum, etc., ... and people have started to sell quarry stone to neighboring towns."

Female farmer
Lupane District, Zimbabwe
May 27, 2021
Report #4017999
WWF Crowd Surveys

Regional plans have promoted increased access to, and market development for NTFPs to international markets and for sale to local tourist lodges and eateries (KAZA TFCA, 2014; CRIDF, 2017). Many of these products are threatened by drying patterns and deforestation (i.e., illegal logging and charcoal production). Therefore, habitat conservation is essential to protecting high-yielding NTFPs, such as the Baobab tree, which can generate eight different products. Extended periods of drought can cause stunting and sterility in flowering plants, which are popular NTFP products and provide a food source for the burgeoning bee and honey industry.

Devil's claw is a plant that is traditionally used for medicinal purposes but is also an important source of income for many rural communities, particularly in Namibia and Botswana. Devil's claw requires specific temperature and moisture conditions for optimal growth. Oladele et al. (2007) found that growth begins to decline at temperatures above 28°C, requires at least 300 millimeters of rainfall per year and does not tolerate long periods of drought. The projected temperature and rainfall changes presented in this assessment suggest a possible decrease in the season length in which devil's claw can be harvested, and by mid-century, the suitable range for growth may shift north and eastward where slightly cooler and wetter conditions are expected to prevail (Figures 13 and 21).

Figure 26. Non-Timber Forest Products impact chain.



ADAPTATION ACTIONS

There are near- and medium-term responses to climate risks. In the near term, livelihood programming can support efforts by KAZA residents to cope with the inevitable impacts of climate change. These *coping strategies* typically precede adaptation responses and tend to be oriented to reducing exposure to climate impacts (i.e., migration or moving exposed assets like livestock) and finding alternative sources of income (i.e., supplementing farming with fishing) on a seasonal or annual basis. While these changes are often necessary, they are limited in their capacity to adapt to longer-term trends that may require what is referred to as transformational adaptation (i.e., the process of responding to underlying causes of vulnerability at the societal- and systems-level). These changes are typically adopted over much larger geographic and time scales, requiring sustained investment and programming efforts.

Accordingly, this section describes actions that can be taken to strengthen climate resilience, accompanied by specific assignments to actors within the KAZA ecosystem, including Partner States and ministries, research organizations, implementing partners, financial institutions, and local NGOs and CBOs. As a facilitator and organizing entity, the KAZA Secretariat is well positioned to advance these actions, and ultimately, help drive transformational climate adaptation within the broader KAZA landscape. It is worth mentioning that these actions must be integrated into larger plans, whether that be a climate adaptation plan or a master development plan.

<table>
<tr><th colspan="4">General Actions</th></tr>
<tr><td rowspan="3">1</td><td colspan="3">Diversify, leverage and scale adaptation finance opportunities by targeting large adaptation funds and working with accredited implementation entities to access funding sources for adaptation programming with sufficient time to build momentum and realize adaptation benefits. Such adaptation-focused funding organizations might include but are not limited to the Green Climate Fund (GCF), Global Environmental Facility (GEF), the Adaptation Fund (AF), regional concessional financing (e.g., African Development Bank (AfDB), and national banks such as the National Development Bank). For example, in 2021, Conservation International worked with the Government of Botswana to co-finance a US$ 97 million project funded largely by the GCF, aimed at restoring degraded soils and building the adaptive capacity of livestock producers across communal rangelands most vulnerable to climate change. Similarly, in 2023, the GCF-funded Mashare Climate Resilient Agriculture Centre of Excellence (MCRACE) was operationalized and helped train 411small-scale horticulture farmers within the highly climate vulnerable regions of northern Zambia, cropping practices. The KAZA Secretariat could work with implementation partners to help identify similar opportunities and package funding proposals for adaptation solutions that offer the largest co-benefits and potential for scale, while also leveraging this assessment to justify specific funding needs.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3-7 years</td><td>Long-term: >7 years</td></tr>
<tr><td>Identify international accredited entities that can unlock funding quickly and avoid the burden of management of those funds. identify viable targets of finance, project preparation partners, and suitable finance providers while conducting baseline assessments, risk and vulnerability studies, climate rationales, and establish impact metrics while engaging communities and local partners.</td><td>Diversify climate finance instruments and pursue grants or concessions while slowly building capacity to progress to more diverse portfolios with blended finance, ROI investors and private capital. Meanwhile, work towards becoming a direct access entity (DAE), able to pursue GCF and AF funding independently.</td><td>Establish a blended finance fund promoting catalytic capital with domestic, concessional, and low-ROI investors, dispersed across a wide range of projects</td></tr>
<tr><td rowspan="2">2</td><td colspan="3">Facilitate community involvement in carbon credit programs. As of early 2023, no forest-based carbon credit programs were operational within the KAZA TFCA, but there are several baseline surveys underway (e.g., potential REDD+ programs in the Miombo woodlands). In addition, several clean cook stove programs are operational (e.g., Commonland African Improved Cookstove Programme (GS 10874)). The KAZA Secretariat could help coordinate existing initiatives and leverage its relationship with Partner States to help bring oversight to the area. As a local hub of knowledge, the KAZA Secretariat could also work with one of its research partners to identify and assess the feasibility of carbon credits that could be generated through carbon sequestration within KAZA's many deltas, peatlands, and floodplains (i.e., blue carbon), while also considering the various climate futures and land use pressures that could compromise the durability of those projects.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3-7 years</td><td>Long-term: >7 years</td></tr>
</table>

	Identify viable project areas based on a combination of sequestration potential, deforestation or land use threats, and community management potential.	Engage communities and establish financial and conservation management plans. Pursue highest standard verification and pool buyers and investors.	Develop community plans and downscale the diversification strategy to help spur additional streams of income, diversifying and growing community revenues.
3	**Bolster data generation, synthesis, and last-mile delivery** by investing in early-warning systems (EWS) and climate information systems (CIS). Data are essential in designing climate information services and informing planting decisions or index insurance options. **Partner States' National Meteorological/Hydrological Services (NMHSs), climate scientists from universities and research institutions, regional and international user's organizations (e.g., agricultural extension groups or fishery associations)** under regional efforts such as the **SADC Climate Services Centre (SADC-CDC)** can help invest in building data pipelines to end users. Some prioritization may be necessary to help identify areas of critical need and investment, and ultimately determine which groups or areas may benefit most from access to climate information. The **KAZA Secretariat** can help harmonize the numerous evaluations of vulnerability; help map key natural capital assets (fish stocks, soil health, forest cover); and engage communities and households on their climate information needs and preferences to effectively deliver this information the "last-mile" to users.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Establish protocol for sharing climate and harmonizing climate information and related health, hazard, and agrometeorological services for Partner States. Evaluate suitability of these services through end-user needs assessments and identify information and usability gaps.	Deploy and scale EWS and CIS to all KAZA residents, tailor data to specific livelihoods, and provide training to residents of what the data means for them and how to use it.	Continuously adjust delivery based on user feedback, and inputs based on emerging science

<table>
<tr><td rowspan="3">4</td><td colspan="3">Improve access to affordable insurance to provide some protection against weather-related losses. Climate extremes, such as heat waves, prolonged dry periods, and floods, can all contribute to increased losses, productivity declines, and increased disease and infections that affect livelihood assets and incomes. Traditional insurance is often unworkable in more rural areas like KAZA, especially when land ownership is communal. As an alternative, a weather-based index can structure payouts based on, say, seasonal rainfall recorded from local gauges if rainfall amounts fall under an agreed-upon threshold. Such an arrangement lowers transaction costs and allows policy holders to apply for bank loans or credit that would otherwise be unavailable to them. There are several low-cost index insurance arrangements that could be devised according to climate zone, livelihood, and farm/operation size that would finally provide some protection against unmitigable losses. Increasing insurance coverage may necessitate more robust land titles and/ or asset inventories. Research institutions such as Columbia University's Financial Instruments Sector Team works with livelihood groups, national governments, and insurers to design and develop index insurance and index-based disaster risk insurance. In some cases, anticipatory insurance programs may be suitable. There is some evidence that providing anticipatory funding (i.e., before a shock) to highly exposed areas and vulnerable individuals can make post-shock responses more effective (Linnerooth-Bayer and Mechle, 2009). With this insurance mechanism, participating farmers, herders, fisherfolk collect an immediate pay-out if the forthcoming risk reaches a certain meteorological threshold, regardless of actual losses. This can be facilitated by assembling small groups with similar asset and risk exposure profiles (e.g., farmers, herders, fisherfolk, harvesters) and offering a climate- and livelihood-specific index that offers stronger social protection against increasingly frequent or severe climate shocks. The KAZA Secretariat could help facilitate discussions between these groups, communities, and legal authorities at the subnational level</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Engage potential lenders, insurers, and communities to understand asset value, risk probabilities, and affordability of associated premiums</td><td>Solicit interest from vulnerable livelihood groups with similar risk profiles and historically high losses. Determine cost-benefit ratio of different coverage options and deploy where appropriate.</td><td>Monitor usage and effectiveness</td></tr>
<tr><td rowspan="3">5</td><td colspan="3">Implement flood-smart zoning so that households, businesses, and tour operators can avoid building in flood-risk zones, invest in defenses and insurance, and design transport options and redundancies that account for the expansion of flood zones. Transport, planning, development, and housing divisions within Partner States can incorporate forward-looking flood inundation mapping into capital and development plans. Where high flood risk zones intersect with private property, Partner States' can consider use of Transfer of Development Rights (TDR) to avoid displacement, asset losses, and encourage future investments. There is a need to first facilitate this discussion among landowners, residents, local authorities, and the KAZA Secretariat acting as a data provider and convener.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Integrate spatial files provided in this report (or commission flood departments or research institutes to conduct similar analyses) to inform capital plans, zoning regulations, and flood risk reduction measures</td><td>Evaluate costs and suitable financing options (i.e., bonds, concessional financing, or other sources of domestic public resources)</td><td>Invest in nature-based flood defenses and risk reduction techniques adjacent to concentration of assets and critical transport hubs</td></tr>
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<table>
<tr><td rowspan="3">6</td><td colspan="3">Recognize communal land tenure arrangements. Financial institutions do not often recognize communal land tenure systems and will not offer products in the absence of formal land titles, which can restrict access to loans for tourism initiatives or for CBNRM efforts using communal lands. As such, local lending institutions and insurance providers must work toward incorporating and recognizing communal land arrangements into their offerings</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Create forums for dialogue between local communities and state actors to negotiate fair rules and arrangements surrounding land allocation</td><td>Codification of tenure rules and boundaries and registration of local rules to secure communal tenure and improve access to lending, insurance, and capital</td><td>Continue to socialize models of success (e.g., South Africa's Communal Land Rights Act (2004)) with local banks, insurers, and within ongoing state and community negotiations</td></tr>
<tr><td rowspan="3">7</td><td colspan="3">Support the expansion of CBNRM - or community groups with similar governance structures - to manage wildlife activities and increase community capacity to lead the management of conservation agriculture, sustainable rangeland management, aquaculture, and sustainable fisheries efforts, and to help assist with the adoption of climate-adaptive technologies. Technical partners of the KAZA Secretariat can help support the communities in need of technology, facilitation, or models for sustainable resource governance.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Evaluate suitable governance structures that align within community priorities and preferences for conservation and/ or sustainable use models. The CBNRM should also develop financial plans to ensure funding needs are met through reliable sources.</td><td>Where appropriate, establish Community Resource Boards (CRBs) where none exist and begin drafting benefit sharing agreements between the Government and CRBs from income derived from the sustainable utilization of resources</td><td>Equip community groups with the tools and knowledge to measure, monitor, and self-evaluate the financial and environmental benefits of ongoing programs</td></tr>
<tr><td rowspan="3">8</td><td colspan="3">Invest in climate education and training, raising a climate-conscious generation with the skills to start their own businesses or support the adoption of climate-smart practices in their communities. The KAZA Secretariat and its partners can help mainstream climate education and green and blue economy opportunities within local schools, universities, government agencies, and the private sector.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Create curriculum and train teachers on climate science topics and local effects, and with a focus on preparing young biologists, agripreneurs, and environmental scientists for the new blue and green economy</td><td>Host learning exchanges with farmers to better understand crop selection options, marketing, agro-processing, use of seasonal climate outlooks and EWS, insurance</td><td>Develop paid internships and job-training programs for young adults</td></tr>
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<tr><td rowspan="3">9</td><td colspan="3">Center climate in health-related programming, including through existing communicable and vector-borne disease monitoring, prevention, and treatment programs. The Animal & Human Health for the Environment And Development (AHEAD) - a program of Cornell University and the Planetary Health Alliance, the Animal Health Sub-Working Group (AHSWG), and the respective Ministries of Health should work with research institutions to incorporate current and projected climate conditions to identify emerging risk areas, both temporally and spatially. It may also be necessary to extend mental health services, food safety, and nutrition programs to respond to changing needs and livelihood losses associated with climate change.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Evaluate the role of climate factors in vector-borne and zoonotic disease patterns. Also, establish protocols for sharing climate and health information between Partner States.</td><td>Deploy EWS and seasonal forecasts tailored to human and animal health risks</td><td>Involve citizens in monitoring and data collection, including tracking changes in animal populations, behavior, and health</td></tr>
<tr><td rowspan="3">10</td><td colspan="3">Expand availability of climate adaptive technologies for agriculture. In the near-term, smallholder rainfed farming will likely continue, necessitating the adoption of new practices and technologies to withstand the projected changes in growing conditions. At the same time, there is a need to de-risk CSA adoptions and build a market for CSA that pays and/or incentivizes farmers to adopt CSA technologies and practices. One idea would be to establish a market for climate-tolerant crops that serve as inputs to other livelihoods like brewing, and in turn, selling the biproducts (after appropriate treatment) to livestock producers for feed during the dry season. This circular economy approach would rely on a network of cooperatives, intermediaries, buyers, and technology suppliers to socialize, pilot, and incentivize new, climate-adaptive technologies and products.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Where none exist, establish extension services and farmer cooperatives that work to strengthen market linkages between producers and buyers, such as small-scale fruit producers and tourist operators, and establish cross-border agreements within KAZA</td><td>Deploy cost-sharing programs across value-chain actors to finance new inputs (e.g., water harvesting technologies, drip irrigation, shade, and cover crop material)</td><td>Scale and deploy successful models and technologies throughout KAZA</td></tr>
<tr><td rowspan="2">11</td><td colspan="3">Promote clean cooking. Charcoal production for cooking fuel is a major driver of deforestation (CORB, 2017) and one of the known triggers of wildfires in KAZA (interviews with KAZA Community Working Group). Reducing pressure on woodlands could also help improve the health and availability of fruit-bearing trees. The KAZA Secretariat could help by promoting the adoption and use of clean cook stoves through subsidies, PES and carbon credit programs, and education.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
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	Identify areas of high deforestation stemming from needs for cooking fuel, initiate dialogue with communities, and identify suitable fuel alternatives	Work with donor community and Partner States in deploying subsidized fuel alternatives and clean cookstove technology to some communities	Explore clean cook stove credit opportunities and other market-based conservation incentives such as NTFP commodities
12	**Restore degraded areas**. Slash-and-burn activities for agricultural land, timber harvest, and charcoal production have had a significant impact on KAZA's woodland and riparian areas, especially the Kwando-Chobe Delta and the Okavango Delta, as well as the upper, forested reaches of the Cuando, Zambezi, and Machili rivers (WWF-Germany, 2021). These areas provide essential habitat and key ecosystems services, such as flow regulation and sediment retention. They also provide shade and water retention to help augment the impacts of extreme heat and prolonged dry periods. The regeneration of these degraded areas could also improve the supply of NTFPs. The **KAZA Secretariat** and its **research partners** can help identify and map degraded areas, assess soil quality and potential for regeneration, remove competing vegetation, and limit grazing and fire to protect soil and young trees. Such initiatives could build on practices and processes of The Southern Africa Development Community (SADC) Forestry Strategy.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Map degraded zones	Harmonize regional practices with the SADC Forestry Strategy, and implement programs targeting soil regeneration with co-benefits for wildlife, agriculture, and water quality	Pursue restrictions and zoning to protect regenerative soils and vegetation
13	**Expand Wildfire Management.** Climate change and population growth are increasing the threat of large, uncontrolled, runaway fires, which are more likely following rainy seasons. The establishment of a transboundary, TFCA-wide bush and forest fire control program could help mitigate wildfire risks with proper surveillance, response, enforcement, and education in close coordination with existing **Partner State's** wildfire programs, with guidance from the **SADC's Regional Cross-border Fire Management Programme**. The **KAZA Secretariat** can leverage wildfire trends presented in the assessment and others to identify hotspots and engage relevant stakeholders.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Develop wildfire education, prevention, surveillance, and response plans based on known and projected wildfire hotspots, as presented in this Assessment and others	Harmonize regional practices with SADC's Regional Cross-border Fire Management Programme	Expand burn bans seasonally and spatially and promote fuel reduction practices in high wildfire risk zones
	Agriculture		

<table>
<tr><td rowspan="3">14</td><td colspan="3">Expand irrigation and water-harvesting. At present, less than 1% of the KAZA TFCA is irrigated. As a result, most farmers practicing rain-fed agriculture are highly susceptible to increasingly variable rainfall patterns and increasingly severe and prolonged drying patterns. Expanding large- and small-scale irrigation would allow farmers to grow multiple crops and stabilize yields during dry periods, assuming of course that sufficient ground- and surface water resources are available. Work with large suppliers to source a combination of improved irrigation (e.g., low-volume irrigation) and water harvesting (e.g., groundwater recharge or water catchment strategies) and pumping technologies (e.g., solar-powered pumps) that could help stabilize agricultural production amidst greater rainfall variability and more reliably grow and sell high-value crops. The KAZA Secretariat could also support extension services, intermediaries, and cooperatives in education, adoption, and scaling phases, while ensuring surface and groundwater extraction strategies balance irrigation needs with river flow needs for downstream ecological functions and other water users.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Host knowledge exchange workshops, allowing farmers that successfully leverage water capture, retention, and low-volume irrigation to share their stories with others and promote "copy-cat" adoption, especially for thirstier crops such as maize</td><td>Partner with large suppliers to negotiate affordable material and installation costs, while promoting digitization programs to monitor changes in inputs and yields</td><td>Scale and deploy successful models and technologies throughout KAZA</td></tr>
<tr><td rowspan="3">15</td><td colspan="3">Target, diversify, and rotate crops. Crop suitability of key crops is changing in tandem with the climate. The planting of heat-tolerant and disease-resistant crop varieties in concert with efforts to strengthen the demand for such crops through local buyers (e.g., leafy greens, peppers, tomatoes) in the tourism sector could ease the transition to more climate-suitable crops. The growing of small grain crops such as millet, sorghum, and groundnuts, or even cotton and sunflower have been identified as heat- and water-efficient crops (Coldrey and Turpie, 2020). Agriculture extension services and cooperatives are best suited to advance the socialization and implementation phases of these adaptations.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Socialize crop alternatives and engage the entire value-chain (intermediaries, buyers, and local buyers such as tourist operators) about water-efficient crops. Host knowledge exchange programs to promote "copy-cat" and 'farmer-to-farmer" learning</td><td>Deploy cost-sharing programs across value-chain actors to finance new technologies and practices (e.g., water harvesting technologies, drip irrigation, shade, and cover crop material)</td><td>Scale and deploy successful approaches throughout KAZA</td></tr>
<tr><td>16</td><td colspan="3">Adjust planting calendar. Many farmers are already aware of the water and temperature requirements (and challenges) of growing maize in a warmer and drier climate, and yet maize remains a preferred crop (Coldrey and Turpie, 2020). In the near term and with good climate information, farmers can still grow maize ahead of a forecasted rainy season. Such planting decisions will require robust climate information and timely and accessible forecasts. Partner States' agrometeorological agencies, alongside research partners, are best suited for the evaluation and development of tools that allow farmers to confidently adjust planting schedules.</td></tr>
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	Near-term: 0 - 3 years	Mid-term: 3 - 7 years	Long-term: >7 years
	Evaluate current decision-making criteria for planting decisions and current availability of seasonal forecasts, including their role and usage in farmer-level decision-making	Help establish digitization tools to monitor planting decisions, daily climate indices, and associated yields	Circulate seasonal outlooks to farmers within KAZA, including guidance on planting calendar and crops based on the upcoming seasonal forecast
17	**Improve access to climate information**. When farmers can access climate information, they can better anticipate seasonal changes and prepare for climate shocks by allowing them to make timely decisions about crop selection and key inputs. For example, during drier seasons, farmers can substitute from the worst-affected crops (e.g., maize) to less affected crops (e.g., yams), utilize water savings, and in the event of an incoming heat wave, minimize potential for heat stress by focusing more on indoor, or less physically demanding, work. According to the World Meteorological Organization, Botswana, Namibia, and Angola provide only the most basic and essential climate services to residents (Dobardzic et al., 2020). The **KAZA Secretariat** could work with **agrometeorology departments, agricultural extension groups, and regional efforts such as the SADC Climate Services Centre (SADC-CDC)** to identify climate information needs of farmers by determining the most appropriate variables, timing, and delivery mechanisms. Extending climate services to farmers should be tailored to farmer needs, including specific climate risks to agriculture in each region, available agro-meteorology products and tools, cell phone (or radio) and signal access, agronomic and adaptation research needs, and farmer perceptions of weather and climate information to all help inform the last-mile delivery of climate information.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Conduct farmer needs assessments to understand most suitable methods and formats for accessing agrometeorological information, including relevant indicators, time horizons, and decision-points	Work with pilot sites to further tailor climate information services and measure effectiveness against comparable farms.	Socialize benefits among potential funders and formalize structure and funding for long-term climate information services
18	**Advance conservation and climate-smart agriculture (CSA**). Conservation agriculture, which looks to improve soil quality, use better quality seeds, retain more water, and better manage land, could significantly boost existing yields and equip farmers with practices and knowledge to adapt to changing climate conditions. One such example is the planting of fruit-bearing trees within crop growing areas to provide shade and retain soil. Where land and water inputs are limited, farmers will need to adopt more intensive forms of production such as shaded tunnels and drip irrigation. Some of these practices may already be in place and could benefit from an assessment of what is (and is not) working where and under what conditions. Following this diagnostic phase, successful programs may be scaled in some contexts and complemented by hands-on support and training. To better understand the training needs of conservation and CSA practices and technologies, it is recommended that a KAZA-wide skills and technology needs assessment is first conducted for those communities in the greatest need.		

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<tr><td></td><td>Near-term: 0 - 3 years</td><td>Mid-term: 3 - 7 years</td><td>Long-term: >7 years</td></tr>
<tr><td></td><td>Evaluate barriers to technological and behavioral adoption, as well as financial needs for CSA technologies and practices. Synthesize lessons from existing programs and begin targeting proven, locally relevant technologies.</td><td>Expand training and technical assistance supporting use and adoption of CSA technologies and practices, and broadening access to digital agriculture</td><td>Strengthen local agro-logistics and adoption incentives across the entire value-chain</td></tr>
<tr><td rowspan="3">19</td><td colspan="3">Reduce HWC. Wildlife-related damages on crops and predation are often associated with lack of water, as farmers, livestock, and wildlife tend to congregate during dry periods near diminishing surface water. Lack of, or competition for, forage is also commonly cited. Members of the KAZA Community Working Group cited the need for solar-powered fencing to keep wildlife out of household gardens. While such technologies could provide useful at safeguarding crops, focus should be on safeguarding natural watercourses for wildlife, including improved groundwater management to ensure adequate water supplies for both wildlife and irrigation that ultimately limits withdrawals from surface water that wildlife critically depend upon. Wildlife Dispersal Areas (WDA) and corridors are another effective strategy to limiting HWC but require first building trust and buy-in in nearby communities. Ongoing projects such as those along the Angolan side of the Kwando River led by ACADIR can help share successes and lessons learned. In early 2023, Peace Parks Foundation and KfW finished the implementation of a HWC reduction program in the Hwange-Kazume-Chobe WDA with significant year-over-year reductions in HWC. Working in the Hwange Kazuma Chobe WDA in 2021, practitioners from Africa's Coexistence Landscapes (ACL) can contribute lessons about effective policy harmonization.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3 - 7 years</td><td>Long-term: >7 years</td></tr>
<tr><td>Identify high-risk HWC zones through system dynamics to understand causes, seasonality, and opportunities for reducing HWC. Where projects are already underway, establish CBOs.</td><td>Design programming to target high-risk HWC zones and offer proven technologies (e.g., solar-powered fencing) to help reduce HWC, alongside processes for conflict and dispute resolution.</td><td>Monitor and evaluate levels of trust an engagement between communities and HWC programs, as well as wildlife tolerance and incidents of HWC in areas of intervention.</td></tr>
<tr><td rowspan="3">20</td><td colspan="3">Capitalize on traditional practices. Traditional forms of flood recessional crop production, known as molapo farming in Botswana, Zambia, and Namibia and theolonaka farming in Angola use floodwaters to irrigate crops and play an important role in maintaining food security among more rural communities. Increasingly, farmers may choose to establish vegetable gardens near seasonal floodplains, using traditional diversion channels or solar water pumps to pump water uphill to irrigate crops.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3 - 7 years</td><td>Long-term: >7 years</td></tr>
<tr><td>Identify water-smart climate practices that have been used in farming and foraging communities and help scale to areas undergoing rapid rates of drying.</td><td>Create a training program and train farmers unfamiliar with this practice through agricultural extension services</td><td>Where culturally and climatically relevant, scale and deploy successful strategies throughout the KAZA landscape</td></tr>
<tr><td colspan="4">Livestock Production</td></tr>
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<tr><td rowspan="3">21</td><td colspan="3">Mapping and zoning are a necessary perquisite to developing rangeland management plans that can be used to conserve sensitive habitat and reduce losses Flood risk maps, for example, should be developed using forward-looking flood projections (such as the ones provided in this assessment) to inform livestock owners of the expanding flood threat. Similarly, the development of erosion hazards maps, supplemented by extensive communication and outreach efforts led by trusted partners such as KAZA's Animal Health Sub-Working Group (AHSWG). Ultimately, programs could help herders avoid sensitive areas and livestock owners that participate in these knowledge sharing exercises may then become eligible to participate in PES programs that compensate for sustainable practices.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Map flood zones, sensitive riparian habitat, and erosion sensitive areas.</td><td>Launch an awareness and education campaign for herders about the risks of flooding, effective risk reduction measures, and best-practices for minimizing livestock losses</td><td>Reward farmers for participating in good grazing and flood risk reduction practices through PES programs</td></tr>
<tr><td rowspan="3">22</td><td colspan="3">Restore vegetation in communal grazing lands. The restoration and management of grazing vegetation will help restore soil fertility and reduce the need to move cattle into contact with farming areas and wildlife buffalo with infectious foot-and-mouth disease. The Green Climate Fund is already supporting the Government of Botswana and Conservation International through a project called, "Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands". Other financing opportunities could also arise through performance-based compensation programs. Using evidence-based conservation outcomes for particular species, wildlife corridors, and dispersal areas would make appropriate targets for such PES schemes. Livestock owners that successfully participate and successfully fulfill conservation or mitigation goals associated with a PES programs are then able to market their beef differently with a "green beef" certification.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Identify areas of high aridity, degraded soils, and high concentrations of permanent or seasonal livestock</td><td>Launch an awareness and education campaign for herders about best-practices and associated market-based opportunities</td><td>Strengthen financial incentives for sustainable rangeland management through certification programs</td></tr>
<tr><td rowspan="3">23</td><td colspan="3">Climate-proofing the livestock value-chain begins with ensuring markets, roadways, and processing facilities, such as slaughter slabs and meat processing plants, undergo climate risk assessments, with an emphasis on building in flood-safe areas.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Map flood zones with a focus on key assets in the meat processing value-chain, including transit and roadways, processing facilities, slaughterhouses, and cold storage facilities.</td><td>Ensure new development is building to future flood levels and existing assets are adequately upgraded with defenses</td><td>Update zoning and building codes</td></tr>
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<tr><td rowspan="3">24</td><td colspan="3">To prevent herder-farmer conflicts, it is necessary to strengthen existing governance mechanisms. For example, local mediator groups, such as CBNRM groups, could work with local leaders and stakeholders to establish a process for de-escalation and conflict resolution ahead of land-use disputes. Some communities and member states may also elect to designate land uses alongside local communities and may choose to leverage land-use designations (e.g., Land-Use Conflict Identification System) and the development of a real-time response system that tracks the movement of cattle and wildlife and enables stakeholders and mediators to engage on issues before they ignite into conflict.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Identify potential zones through system dynamics to understand causes, seasonality, reasons for escalation, and opportunities for reducing conflicts</td><td>Deploy digitization tools such as Land-Use Conflict Identification Systems to prevent conflict</td><td>Where no community-level processes exist, help train and designate conflict mediation and resolution specialists within CBNRM and other CBOs</td></tr>
<tr><td rowspan="3">25</td><td colspan="3">To maintain livestock productivity during periods of extreme heat, several cooling strategies can be promoted. One of the more effective, low-cost methods of limiting thermal heat stress of cattle is through the provision of shade, typically by guiding and allowing cattle to graze near trees. It is recommended that tree conservation and planting exercises are promoted in traditional grazing areas. Ministries of Agriculture could explore broader introductions of more heat-tolerant species with stronger resistance to parasites (e.g., Senepol and N'Dama species) given the significant increase that is expected in the number of extreme heat days, particularly within the Namibian panhandle, the upper reaches of the Angolan-Zambian border, and southward over Maun, Botswana and the Okavango Delta.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Expand tree planting efforts in communal or and/ or traditional grazing areas</td><td>Consider introduction and adoption of more heat-tolerant species</td><td>Identify opportunities to develop artificial ponds and lakes where surface- and groundwater sources are limited</td></tr>
<tr><td rowspan="3">26</td><td colspan="3">To maintain livestock health, it may be necessary to expand dip tanks to help prevent the infection and spread of parasitic infections that tend to increase during periods of extreme heat and prolonged dry periods. Groups such as AHEAD, AHSWG, and the respective Ministries of Health and Agriculture could support the siting and expansion of dip tanks.</td></tr>
<tr><th>Near-term: 0 - 3 years</th><th>Mid-term: 3 - 7 years</th><th>Long-term: >7 years</th></tr>
<tr><td>Identify areas of high need and determine site suitability based on a combination of future climate extremes, and existing infrastructure and herding corridors.</td><td>Build dip tanks</td><td>Regularly maintain existing dip tanks and expand where needed</td></tr>
<tr><th colspan="4">Fisheries</th></tr>
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<tr><td rowspan="3">27</td><td colspan="3">Fish reserves have the potential to boost food security, incomes, and reduce pressure on fisheries. Where fish stocks have been overfished and trophic levels are unstable, sustainably managed fish farms could support healthy fisheries and water quality efforts. The development of fish reserves in Namibia (e.g., Sikunga, Impalila, Mayuni, Balyerwa, Nakabolelwa, and Lusese) through the Strengthening Community Fisheries, implemented by Namibia Nature Foundation, builds on lessons from the Community Conservation Fisheries Project in KAZA, eventually aimed at scaling such models across KAZA's other inland fisheries. Much like sustainable rangeland practices for livestock owners, participating residents/ fisherfolk could become eligible for PSE as downstream beneficiaries (i.e., eco-tourist lodges and commercial fishing outfits) benefit from fish reserves.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3 - 7 years</td><td>Long-term: >7 years</td></tr>
<tr><td>Identify viable fish reserves based on ecological value and sensitivity to fishing pressure. Where projects are already underway, establish CBOs and training for residents, including job-training (e.g., guides and rangers)</td><td>Engage downstream beneficiaries in potential PES programs to compensate upstream residents managing and protecting established fish reserves</td><td>Deploy standardized tools and guidelines that can be applied across the wider KAZA landscape</td></tr>
<tr><td rowspan="3">28</td><td colspan="3">Strengthen enforcement of illegal fishing, including the ban of highly damaging monofilament nylons, or banning fishing during certain hours (i.e., ghost fishing) and months can be difficult to enforce given the limited capacity of agencies. There is some evidence that bans on monofilament fishing nets, drag netting, and commercial fishing for export could help improve the health of fisheries (Hay et al., 2020), but will require greater investment by Partner States to implement a multi-pronged approach of training, incentives, enforcement, and community stewardship.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3 - 7 years</td><td>Long-term: >7 years</td></tr>
<tr><td>Bolster accuracy and regularity of data collection to establish baselines and track improvement in fisheries, while offering training for community fish monitors</td><td>Decentralize management and monitoring such that local community representatives are resourced with the proper equipment and authority to enforce bans</td><td>Legislate the protection of threatened fish species while encouraging the fishing for underutilized, small-sized fish species, which can be promoted by local buyers and restaurants</td></tr>
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<tr><td rowspan="3">29</td><td colspan="3">Harmonize transboundary fishing regulations. Partner States have historically legislated incongruous regulation that has led to unintentional overexploitation. The KAZA Secretariat, with support from experienced CBNRM members and NGOs, could help facilitate a transboundary perspective for individual Fisheries Management Committees and Plans and help ensure fishing regulations and development take a transboundary-level approach to avoid rules that unintentionally lead to overexploitation. For example, establishing fish reserves could be promoted to reduce fishing pressure on designated river stretches and support efforts of persistence of various species in the natural water bodies. The closed fishing season, currently observed in Botswana, the Zambezi region of Namibia, and Zambia should be widely promoted to apply across the TFCA and in the river systems where regulations are not observed.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3 - 7 years</td><td>Long-term: >7 years</td></tr>
<tr><td>Evaluate existing governance structures that can effectively deliver coordinated responses involving all the partner countries, allowing for alignment and transboundary enforcement.</td><td>Embed and/ or update the SADC Protocol on Fisheries (2001) with technical guidelines and concepts from the United Nations’ Food and Agriculture Organization Code of Conduct for Responsible Fisheries (CCRF)</td><td></td></tr>
<tr><td colspan="4">Tourism</td></tr>
<tr><td rowspan="3">30</td><td colspan="3">Farming cooperatives offer an opportunity to exchange knowledge, minimize cost of investment, and connect with tourist operators to make sales and ensure farmers can meet market demands. Upscaling the operations of such cooperatives will require adoption of climate-adaptive technologies as well. For example, for farmers to reliably produce vegetables and soft greens/herbs for the tourism sector, they may need to adopt more intensive forms of production, such as shaded tunnels with low-volume irrigation, and invest in cold-storage chains as a diversification strategy to crop farming currently dominated by maize and other cereal like sorghum and millet with potential to meeting multiple and complementary objectives of income generation and securing livelihoods. CCARDSE and other research institutions could help support specific guidance and training for new technologies.</td></tr>
<tr><td>Near-term: 0 - 3 years</td><td>Mid-term: 3 - 7 years</td><td>Long-term: >7 years</td></tr>
<tr><td>Strengthen communication channels to ensure farmers understand agricultural product needs (e.g., quality, timing, type) and can effectively market directly to buyers</td><td>Increase awareness of, and promote locally grown fruits, vegetables, and herbs among tourists, chefs, and lodge owners</td><td>Expand cold-storage supply chains to promote transboundary trade within the TCFA</td></tr>
</table>

31	**Capitalize on existing Community Conservancies** to advance community-driven tourism efforts such as tourism joint-ventures. In 2021, the Gciriku community was granted joint ownership of the Sikerete Tourism Concession within Namibia's Khaudum National Park. This arrangement gives the community access to funding, private sector invest opportunities, and establishes the community as the primary beneficiary of tourism-related revenue and job creation within its boundaries. Such efforts, including **CBNRM** developments on communal land, can be readily deployed throughout KAZA's community conservancies.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Help establish forums for dialogue between local communities and state actors to negotiate fair rules and arrangements surrounding resource rights	Codification of tenure rules and boundaries and registration of local rules to secure communal tenure and improve access to lending, insurance, and capital for CBOs	Ensure all new tourist operators hire locally and/ or enter into joint-venture agreements with local communities
32	**Vector-borne and zoonotic disease monitoring**, surveillance, and prevention efforts will be critical to all sectors. In the tourist sector for example, the growing risk of malaria could affect tourist numbers. KAZA can help facilitate the planning for interventions aimed at year-round surveillance and targeted, pre-deployment of prevention efforts to mitigate potential outbreak locations. Additionally, KAZA member states can increase access to diagnostic tests, medications, and hospital facilities while providing training to healthcare workers to enhance their ability to diagnose and manage cases. Similar efforts should be deployed for dengue and cholera, given their connection to climate change.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Review existing health surveillance systems and evaluate prediction skill to ensure future viability	Deploy EWS and seasonal forecasts tailored to vector-borne and zoonotic disease	Expand capacity to investigate and respond to cases, while increasing educational outreach efforts, laboratory testing capabilities, and hiring and training of local personnel
33	**Cooling strategies** will need to be adopted by tourist operators through a combination of technological adoption (e.g., solar-powered air conditioning), behavior change (i.e., avoiding tours during the hottest part of the day), and training for staff on how to recognize and treat heat-related illness. The **KAZA Secretariat** can help operators draft their Heat Preparedness and Response Plans to tourist authorities, which documents their protocol for preventing and responding to extreme heat dangers. meanwhile, **National Occupational, Safety, and Health** ministries should begin setting minimum requirements for employers to follow, and penalties for those that fail to comply.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**

	Draft Heat Preparedness and Response Plans	Provide workers with regular breaks, and if outside, provide personal protective equipment and cold water, provide heat stroke prevention and first-aid training	Establish syndromic surveillance system to track and evaluate heat-related medical incidents. Also, establish reporting systems for workers (and tourists) to file incidents of workplace non-compliance.
34	**Diversifying tourist attractions** in KAZA away from highly climate-sensitive activities (i.e., wildlife- or water-based attractions) and toward cultural and historical tourism offers an alternative, and more climate-resilient pathway for the tourism industry. Cultural tourism, however, requires community engagement and participation, respecting the rights and dignity of local communities and their cultural heritage and will benefit from involvement and coordination between national and international organizations such as the **national tourism agencies, heritage conservation agencies, and UNESCO**. Given the growing awareness of the environmental impacts associated with tourism, there are also opportunities to facilitate carbon offset payments directly into local, community-based PES programs that generate carbon credits. Meanwhile, participating eco-lodges can help raise awareness of the development challenges and ongoing programs in the area. The **KAZA Secretariat** can also play an active role in training and capacity building for alternative community-based tourism efforts that focus on cultural, historical, and ecotourism.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Test models of cultural tourism with select sites, putting in place safeguards for cultural preservation and join-ventures with CBOs.	Expand marketing and promotion strategies to attract a wider domestic and international audience	Extend protections to sacred sites and places of special significance used for rituals, ceremonies, footpaths, natural water bodies, and flora with medicinal or spiritual properties.
Non-Timber Forest Products			
35	**Promote apiculture**. Beekeeping requires few inputs and can be bundled with other horticulture activities, helping pollinate other flowering products and generate additional income through the sale of honey. Bees are also a known deterrent of elephants, one of the more frequent and disruptive intruders in KAZA (Salerno et al., 2021). However, hives require ample water and food sources in the immediate area. Otherwise, hives may be abandoned or suffer infection. That said, centralizing operations and processing could help the industry scale. In some areas, honey harvesters could hang wooden beehives from trees to encourage forest conservation and limit pressure in sites of already high-intensity use. The KAZA Secretariat could work with beekeepers to form cooperatives, provide training on agroecology best-practices, and help establish market connections for producer groups.		
36	**Wild vegetables** are usually well-adapted to local climate variability and offer in important safety net during economic insecurity. There are reportedly hundreds of different species of wild vegetables in the wider region, and many communities have developed sustainable harvesting techniques to maintain levels of abundance and diversity. Collection can also reduce pressure on cultivated crops and be used in crop rotation practices. Local tourist operators may also be willing to pay higher prices given their unique taste profiles. Much like other NTFPs, collection can occur within areas that do not require land tenure access or rights, favoring those sub-groups that often lack access to private or protected lands.		

37	**Kalahari Melons and bi-products**. The Kalahari Melon (*Citrullus Vulgaris*), also known as Tsamma Melon, has played an essential role for people in the Kalahari for many years. In the arid, and particularly dry months of the year, these melons are an essential substitute when water is scarce. Several bi- products can also be extracted, such as oil for cooking and as a skin moisturizer. The seeds, when properly aged and dried, can be safely packaged for sale and easily exported to feed rising demand among western diets. Their ability to grow in arid conditions and germinate within a week after pollinations make them viable, and climate-suitable products for commercial harvest in a region that is otherwise sparse in agricultural products.		
38	**Expand marketplace for thatch grasses**. While thatch grasses play important ecological role for nesting birds, sequestering carbon, and providing forage for livestock and wildlife, they can also be used for handicrafts. During wet months, some grasses can grow several centimeters per week, and annual thatch grasses can reach maturity within a few months and begin a new cycle relatively quickly. Traditionally, across the deltas and wetlands of Southern Africa, most of the harvested thatch grasses were re-proposed for construction materials and basket making. The more recent emergence of local tourist handicraft markets and e-commerce platforms, provides a more lucrative marketplace for handicraft producers, with much of the potential proceeds going to woman.		
39	**Promote insects** as a food source, as they require very little water and land, are highly nutrient dense, and can survive in harsh climatic conditions, though the effects of climate change on the distribution and availability of edible insects is still relatively unknown (FAO, 2013). As protein sources, they require lower food conversation rates than other livestock and can be grown on organic waste, requiring almost no inputs in the production process. They can be made available as a high-protein food for livestock or human consumption, and with the appropriate food safety procedures, could be marketed internationally. They also provide and easily accessible source of income for women and children who are typically involved in insect collection, which can occur within areas that do not require land tenure access or rights. Though to increase the consumption of insects, which relatively low, significant investments may be required to boost cultural acceptance of insects as a source of nutrients and protein.		
	Near-term: 0 - 3 years	**Mid-term: 3 - 7 years**	**Long-term: >7 years**
	Establish regional cooperatives to support training, cost-sharing, and market opportunities for individuals and CBOs	Cooperatives can also help develop a network of domestic and international buyers through broader education about the social and environmental benefits of NTFPs through marketing and certification programs	Expand agro-logistics, including cleaning, processing, inspection, and packaging capacity for intermediaries

CONCLUSION

There is strong agreement across climate models and scenarios that the KAZA TFCA will continue to warm and dry, amplifying existing risks while also generating emergent flood and wildfire risks. Shorter and increasingly variable rainfall patterns will decrease the reliability of rainfed agriculture; drying patterns will further constrain resource harvesting, fishing and livestock grazing opportunities, while likely increasing negative human-wildlife conflicts; wildfires and floods are likely to expand into new areas some seasons, limiting the availability NTFPs, grazing and farming land, and placing more households and infrastructure at-risk; and extreme heat will invariably affect tourism, wildlife, livestock and labor productivity. Taken together, the climate changes unfolding across KAZA will have profound impacts on the livelihoods of its residents in the absence of significant investments in climate adaptation.

As the region continues to undergo social and environmental changes, it is critical that households diversify their mix of livelihoods, continuously adjusting to seasonal changes stemming from climate and socioeconomic pressures. Meanwhile, it is vital that institutions begin to incorporate climate risk information and adaptation needs into their livelihood programming. At the landscape level, actions must be integrated into larger plans, whether that be a climate adaptation plan or a master development plan. These actions should aim to improve existing livelihoods while also creating a pathway toward new sources of income that incentivize conservation and, ultimately, limit resident's exposure to climate risk.

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APPENDIX

CLIMATE MODEL UNCERTAINTY

The climate system presents an inherent unpredictability due to its internal variability that must be considered in any impact assessment. Following a common practice in the IPCC, we represent the uncertainty of the climate projections for a given estimate of projected change as the percentage of models that agree on that particular outcome. We, therefore, consider each of the 16 climate projections (Table 3) as independent plausible futures, which combined allow us to provide a probabilistic estimation of any of our results. The probabilistic estimation is expressed as percentiles, where the median or 50th percentile represents the central estimation, meaning that 50% of the models predict a higher estimate and the other 50% a lower estimate. 10th and 90th percentiles are included, and they represent the lower and higher bounds of the estimation, thus accounting for the uncertainty of the predicted value. When for example the 10th percentile of an estimated change for a future period is higher than 0, it means that more than 90% of the models agree on a future positive change.

The source of global climate model uncertainty can be generalized through four types: boundary condition, parameter, initialization, and structural (Nychka *et al*., 2008). Physical uncertainty covers both process representation and parameter uncertainty and is driven by the model's internal imperfections and inability to perfectly replicate a complex system (Nychka *et al*., 2008) and resolve spatially or temporally granular processes (Flato *et al*., 2013).

Climate models are an attempt to simulate how energy moves through the Earth's system — that is, through the atmosphere, oceans, and terrestrial systems. This is done by creating a series of physical equations which approximate the processes that drive the Earth's climate. This procedure is inherently imperfect, and the way certain elements (e.g., clouds or aerosols) affect and interact with different feedback loops is not well understood. Consequently, this simulation of physical processes adds a baseline layer of uncertainty to projections.

Initial state uncertainty is the inability of the model to perfectly replicate the state of the Earth's system at the time when the model run begins. In other words, modelers who initialize the model do not have access to the exact state of energy in the system at time zero. Although weather observations have become increasingly comprehensive globally, on both land and in the oceans, it is still difficult to accurately account for the temperature of ocean and atmosphere at all depths and heights. Even slight discrepancies in initial conditions can lead to large diversions in the simulation. This reduces the certainty of the model in the near-term — as time progresses, however, internal and external forcings begin to neutralize the initial state uncertainty, and the skill of the model begins to improve in this regard.

It is worth mentioning the uncertainty associated with scenarios. This is less about modeling imperfections, and more about an inability to accurately predict future external forcings (namely human-driven changes like greenhouse gas emissions and land-use patterns) (Flato *et al.,* 2013) This uncertainty is somewhat controlled, as all models part of the CMIP project (and those used in this assessment) conform to a handful of scenarios that represent likely changes in external forcings based, at least partially, on policy implementations. This type of uncertainty is not significant in the near term, as changes in human behavior will make little to no change on climate in that time frame due to the pipeline of warming. However, as the model runs further into the future, the scenario uncertainty rapidly increases, as changes in forcing will have significant impacts on the simulated climate.

LIMITATIONS AND SAMPLING UNCERTAINTY

Population and land-use estimates carry some uncertainty as sampling techniques may homogenize exact locations and finer spatial patterns. Additionally, some estimates may not precisely reflect today's conditions. More so, the latitude and longitude coordinates of "tourist places" provided by WWF-Germany are assumed to carry some imprecision. The estimates of flood risk facing tourist hubs are thus limited.

The wildfire weather analysis does not consider the spatial extent of burnable fuels (i.e., vegetation). Estimates are limited to the changes in wildfire weather conditions and future wildfires will in large part be shaped by the presence of burnable fuels, while wildfire severity and potential size is influenced by vegetation characteristics (e.g., load, type, continuity) as well as wind, neither of which were modeled in this assessment.

This study is limited to evaluating climate risk exposure — the extent to which climate-related risks may adversely affect current and future livelihoods; and sensitivity — the non-climate factors that contribute to vulnerability. Therefore, no direct measure of vulnerability — or the propensity or susceptibility to suffer from climate change — was evaluated. In part, this is due to lack of comprehensive household-level survey data across the KAZA TFCA that indicate the extent of assets, knowledge, resources, and other capacities to deal with climate change at a local level.

Finally, this study places greater attention on rural livelihoods to align with the *Livelihood Diversification Strategy* (KAZA Secretariat, 2023). As such, this study does not provide a comprehensive review of anticipated climate impacts across the entirety of KAZA or other, less commonly practiced livelihoods.

LIST OF CLIMATE MODELS

PROJECTION	DRIVING GLOBAL CIRCULATION MODEL	REGIONAL CIRCULATION MODEL
1	NCC- NCC-NorESM1-M Norwegian Climate Center, Norway	SMHIRCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
2	CCCma- CanESM2 Canadian Centre for Climate Modelling and Analysis, Canada	SMHIRCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
3	CCCma-CanESM2 Canadian Centre for Climate Modelling and Analysis, Canada	CCCma-CanRCM4_r2 Canadian Centre for Climate Modelling and Analysis, Canada
4	CNRM-CERFACS-CNRM-CM5 National Centre for Meteorological Research and Centre Européen de	CLMcom-CCLM4-817_v1 Climate Limited-area Modelling Community CLM-Community)

5	Recherche et de Formation Avancée en Calcul Scientifique, France	SMHI-RCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
6	CSIRO-QCCCE-CSIRO-Mk3-6-0 Commonwealth Scientific and Industrial Research Organisation; Queensland Climate Change Centre of Excellence, Australia	SMHI-RCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
7	ICHEC-EC-EARTH Irish Centre for High-End Computing, Ireland	SMHI-RCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
8	IPSL-IPSL-CM5A-MR Institut Pierre-Simon Laplace, France	SMHI-RCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
9	MIROC5 National Institute for Environmental Studies and Japan Agency for Marine Earth Science and Technology, JAPÓN	SMHIRCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
10	MOHC-HadGEM2-ES MetOffice Hadley Center, UK	KNMI-RACMO22T_v2 Royal Netherlands Meteorological Institute, Netherlands
11		CLMcom-CCLM4-8-17_v1 Climate Limited-area Modelling Community (CLM-Community)
12		SMHI-RCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
13	MPI-M-MPI-ESM-LR Max Planck Institute for Meteorology, Germany	CLMcom-KIT-CCLM5-0-15 KIT, Karlsruhe, Germany in collaboration with the CLM-Community
14		MPI-CSC-REMO2009_v1

		Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology, Germany
15		SMHI-RCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden
16	NOAA-GFDL-GFDL-ESM2M The Geophysical Fluid Dynamics Laboratory, NOAA, USA	SMHI-RCA4_v1 Swedish Meteorological and Hydrological Institute, Sweden

U.S. Agency for International Development

1300 Pennsylvania Avenue, NW

Washington, D.C. 20523

Tel.: (202) 712-0000

Fax: (202) 216-3524

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