Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands

Annex 2: Feasibility Study

Structure and Contents

Prepared by Conservation International and C4 EcoSolutions through a Project Preparation Facility (PPF) Grant from the Green Climate Fund – March 2020

Annex 2 - Feasibility Study:

This Feasibility Study is designed to support the GCF Funding Proposal by presenting additional information that contributed to the development of the FP and facilitate access to the models, data, and assumptions that led to the proposed Project approaches and targets.

The Feasibility Study documents provide analyses of the current and projected impacts of climate change on Botswana's communal rangelands and the vulnerable populations that live on these lands. The documents also provide evidence for the effectiveness and responsiveness of the Project's selected approaches to address the adaptation needs of beneficiary populations while achieving reductions in GHG emissions.

To facilitate use of this Feasibility Study by reviewers, it is divided into the following sections which are presented as independent documents with associated appendices:

Section 1: Country Profile & Climate Change Vulnerability Assessment

The Country Profile provides a brief overview of the geographic, population, land use, and socio-economic characteristics of Botswana and the Project areas. Information is also presented on land tenure issues and current management practices on communal rangelands.

The Climate Change Vulnerability Assessment is a comprehensive description of Botswana's current climatic conditions, projected climate change impacts, and an assessment of the target populations' vulnerability to these current and future impacts of climate change. Trends in precipitation, temperature, and extreme climate events are discussed in the context of rangeland ecosystems' and populations' vulnerability to climate change. The CCVA uses a combination of spatial and statistical analyses of timeseries data to determine the climate change vulnerability of the Project target areas: Bobirwa, Kgalagadi North and Ngamiland. The Climate Change Vulnerability Assessments of these regions applies the *Vulnerability = Exposure x Sensitivity – Adaptive Capacity* formula to social, livestock, and livelihood sectors in addition to rangeland ecosystems to assess vulnerabilities. Various available adaptation strategies to reduce vulnerability are also discussed.

Section 1 Appendices:

- **1.1** ENSO analysis
- **1.2** Draft Botswana GCF Country Programme
- **1.3** Government of Botswana Priority Programmatic Areas for Climate Finance
- **1.4** CCVA Site Selection
- **1.5** Climate model validation

Section 2: Options Analysis & Financial and Economic Analysis

The Options Analysis presents five primary approaches identified through literature review and consultations with stakeholders that were considered while designing the Project interventions. Descriptions of these interventions are presented along with the relative advantages and disadvantages of each.

The Financial and Economic Analysis (FEA) undertakes a detailed scenario-driven analysis of the components of the Project to determine the relative benefits of each aspect of the Project approach. The first part of the analysis consists of a financial cost-benefit analysis (CBA) which seeks to assess the feasibility of traditional, communal livestock production under different regimes of management and market access. Project beneficiaries - livestock producers in the traditional sub-sector - are the focus of this financial analysis. The second part extends the analysis to include the wider costs and benefits to society associated with livestock production under different management regimes and constitutes a broader economic analysis.

- For additional details on the FEA methodology and results, please also see Annex 3 of this Funding Proposal – *Financial and Economic Analysis in Spreadsheet format.*

Section 3: Carbon and Water Baseline Assessment

The Carbon and Water Baseline section includes detailed assessments of rangeland conditions, carbon pools / sequestration potential, and water availability in the target areas of Botswana's communal rangelands. This includes estimates of current rangeland carbon stocks and emissions sources, and describes water conditions in terms of resilience, quality, quantity and availability for the three areas targeted by the Project. The carbon pools included in this assessment include vegetative (above- and below-ground biomass) and soil organic carbon. The mitigation sources considered include livestock greenhouse gas production by enteric fermentation and soil carbon storage from ecosystem restoration. The water sources considered in this assessment include borehole water as a proxy for groundwater, and the Okavango delta. Rangeland condition is also considered given how intricately it is directly and indirectly linked with the carbon and water balances in Botswana. From this information, estimates of the mitigation potential of Project activities are presented here and in the appendices listed below.

Section 3 Appendices:

3.1 - Fieldwork Notes
3.2 - Baseline Maps
3.3 - IPCC Livestock Emissions Calculations
3.4 - Livestock Mitigation Targets
3.5 - Ecosystem Mitigation Calculations and Targets

Section 4: Project Overview and the Herding for Health Model

The Project Overview provides a discussion of the Project approach and background information from stakeholder engagement. Included is a detailed table of prior and ongoing projects in Botswana and how the proposed Project will link to these initiatives, identified information gaps, and how the project aims to address them**.** The project's theory of change is then presented with an in-depth analysis of the proposed project components, including recommendations and guidance provided by extensive stakeholder engagement throughout proposal development.

The second part of this section presents more detailed information on the key elements of the holistic Herding for Health model which is being employed by the Project. This includes description of the mechanisms employed including Conservation Agreements / Rangeland Stewardship Agreements, the value of communal management, benefits obtained from professionalizing the herding profession, how Free, Prior, and Informed Consent is embedded in the approach, information on successes from pilot activities, and critical lessons learned from implementation of this model across a variety of geographies.

Section 4 Appendices:

4.1: Livestock Production and Animal Health Management Systems in Communal Farming Areas at the Wildlife-Livestock Interface in Southern Africa - Jacques Van Rooyen PhD dissertation (Herding for Health Director)
4.2: Conservation Stewardship Programme Synthesis Report-- Integrating the Free, Prior and Informed Consent Principle in the Implementation of Conservation Agreements
4.3: Design and Implementation of Conservation Stewardship on Communal Lands
4.4: SWFF Meat Naturally Performance Evaluation Report 2019
4.5: H4H Conservation Agreements Example
4.6: Lin Cassidy - Final Report on Feasibility of Conservation Agreements in Botswana
4.7: Natural Resource Management Catalyser of Employment-South Africa
4.8: OIE PVS Evaluation Follow-Up Mission Report of Botswana Veterinary Services
4.9: Spreadsheet of beneficiary calculations
4.10: Ecoranger and Team Leader Job Descriptions
4.11: Botswana Regulatory Environment
4.12: Rangeland Toolkit development

Section 5: Market Assessment and Sustainability Plan

This final section of the Feasibility Study includes market analyses of the Botswana meat value chain including main actors, objectives of the Project, and Project approach to stimulate the demand-side of the value chain to increase economic benefits to Project beneficiaries through promotion of Commodity Based Trade (CBT). This analysis is followed by an assessment of sustainability scenarios and project approaches to ensure the continuation of activities after the project implementation period. Several studies are used as the basis for this assessment and key reports are included as appendices listed below:

Section 5 Appendices:

5.1: Exploring market opportunities for CBT of Beef from Ngamiland – 2017 Report
5.2: Meat Naturally Botswana Business Plan and Feasibility Assessment
5.3: Feasibility report – Business Value Chains to support H4H in Mapungubwe TFCA - 2019
5.4: CBT FMD Guidance Report – AHEAD Project 3rd Edition
5.5: Herder's Fund Lessons Learned 2018 Report
5.6: Gap Analysis on the Implementation of Commodity-Based Trade of Beef in Ngamiland, Botswana

Please note that the Feasibility Study does not repeat information or analysis on Environmental and Social Safeguards and Gender Inclusion for the project – this information is presented in Funding Proposal Annexes 6 and 8.

Feasibility Study - Abbreviations and Acronyms

AC	Adaptive Capacity
ACCRA	Adaptation to Climate Change in Rural Areas of Southern Africa
AHEAD	Animal and Human Health for the Environment and Development
APR	Annual Performance Report
ASSAR	Adaptation at Scale in Semi-Arid Areas
BAITs	Botswana Animal Identification System for livestock traceability
BAU	Business as usual
BCR	Benefit-cost ratios
BDF	Botswana Defence Force
BIDPA	Botswana Institute for Development Policy
BITC	Botswana Investment and Trade Centre
BMC	Botswana Meat Commission
BNBPU	Botswana National Beef Producers Union
BOBS	Botswana Bureau of Standards
BOCOBONET	Botswana Community Based Organization Network
BOCONGO	Botswana Council of NGOs
BPCT	Botswana Predator Conservation Trust
BTO	Botswana Tourism Organisation
BUAN-CICE	Botswana University of Agriculture and Natural Resources Centre for In-service and Continued Education
CA	Conservation Agreement
CBA	Cost-benefit analysis
CBFiM	Community-based Fire Management
CBO	Community-based Organisation
CBNRM	Community-based Natural Resources Management
CBT	Commodity-based Trade
CCVAs	Climate Change Vulnerability Assessments
CCV	Climate change vulnerability
CDM	Cold dressed mass
CEDA	Citizen Enterprise Development Agency
CI	Conservation International Foundation
COP	Chief of Party
CMIP5	Fifth phase of the Coupled Model Intercomparison Project
DAC	District Agricultural Coordinator

DAP	Department of Animal Production
DDC	District Development Committees
DEA	Department of Environmental Affairs
DEM	Digital Elevation Model
DFID	Department of International Development, UK Agency for International Development
DFRR	Department of Forestry and Range Resources
DVS	Department of Veterinary Services
DWNP	Department of Wildlife and National Parks
E	Exposure
EbA	Ecosystem-based Adaptation
EC	electrical conductivity
EU	European Union
Ex-ACT	FAO Ex-Ante Carbon-balance Tool
F	Fluorine
FA	Farmers association
FABB	Farm Assured Botswana Beef
FAO	Food and Agriculture Organization of the United Nations
FCB	Forest Conservation Botswana
FDI	fire danger index
FEA	Financial and Economic Analysis
FFT	Farmer Facilitator Team
FMD	Foot and Mouth Disease
GCM	general circulation models
GDP	Gross domestic product
GDSA	Gaborone Declaration on Sustainability in Africa
GE	Gross energy
GHG	Greenhouse gas
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit*
GLTFCA	Great Limpopo Transfrontier Conservation Area
Gov't	Government
H4H	Herding for Health
HACCP	Hazard Analysis Critical Control Point
HM	Holistic Management
HWC	Human-wildlife conflict
IDRC	International Development Research Centre
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change

IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
ISFI	International Savannah Fire Management Initiative
IWMI	International Water Management Institute
KCS	Kalahari Conservation Society
LEA	Local Enterprise Authority
LUCIS	Land Use Conflict Identification Strategy
MAP	mean annual precipitation
MENT	Ministry of Environment, Natural Resources Conservation and Tourism
Mgmt.	Management
MITI	Ministry of Investment, Trade and Industry
MLGRD	Ministry of Local Government and Rural Development
MoA	Ministry of Agriculture and Food Security
MOU	Memorandum of Understanding
NCCAP	National Climate Change Policy and Action Plan
NDC	Nationally Determined Contribution
NDP	National Development Plan
NDVI	Normalized Difference Vegetation Index
NEF	National Environment Fund
NGO	Non-Governmental Organisation
NIR	near infrared
NO_3	nitrate
NPP	net primary productivity
NPV	Net present value
NSO	National Strategy Office
OIE	World Organization for Animal Health
PES	Payment for Ecosystem Services
PPF	Project Preparation Facility
RCP	Representative Concentration Pathway
ROI	Return on investment
RSA	Rangeland Stewardship Agreements
S	Sensitivity
SADC	Southern African Development Community
SAREP	Southern Africa Regional Environment Programme
SAT	One of seven serotypes of Foot and Mouth Disease; there are three SAT serotypes: SAT1, SAT2, and SAT3.
SDHI	short-duration, high-intensity
SLM	Sustainable Land Management

SMHI	Swedish Meteorological and Hydrological Institute
SOP	Standard Operating Procedure
SPARC	Spatial Planning for Protected Areas in Response to Climate Change
SPI	Standardised Precipitation Index
SSP2	Shared Socioeconomic Pathway middle of the road projection
SWFF	Securing Water for Food
SWIR1	shortwave infrared 1
SWIR2	shortwave infrared 2
TAHC	Terrestrial Animal Health Code
TDS	total dissolved solids
TFCA	Transfrontier Conservation Areas
TGLP	Tribal Grazing Land Policy
TNC	Third National Communication
TTT	Train-the-Trainers
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VCI	Vegetation Condition Index
VDC	Village Development Committee
VIP	Ventilated Improved Pit latrine
WMAs	Wildlife Management Areas
WRI	World Resources Institute

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Annex 2: Feasibility Study

Section 1: Country Profile and Climate Change Vulnerability Assessment (CCVA)

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Part 1 - Country Profile: Botswana

(1) Geography

Botswana is a land-locked country in Southern Africa. The country covers 581,780 km^2, approximately the size of France or Kenya, and is bordered by South Africa to the south, Namibia to the north and west, and Zimbabwe to the northeast.

The Kalahari Desert covers approximately 70% of the country, savannah covering the rest only 2.7% being, mostly seasonal, water bodies. There is little topographical variation and the country is mostly flat with a few isolated inselbergs, geological remnants of some of the original rock formations on earth. The most prominent water feature of the country is the Okavango Delta, a seasonal floodplain with a source in the Angolan highlands to the north-west of Botswana and holds 95% of Botswana's surface water. Two-thirds of the country's soils are sandy which, due to ease of water flow transmission often lie above good aquifers. In the east and south-east, the more clay-based soils limit the number aquifers but increase surface water that is more suitable for cultivation[1] .

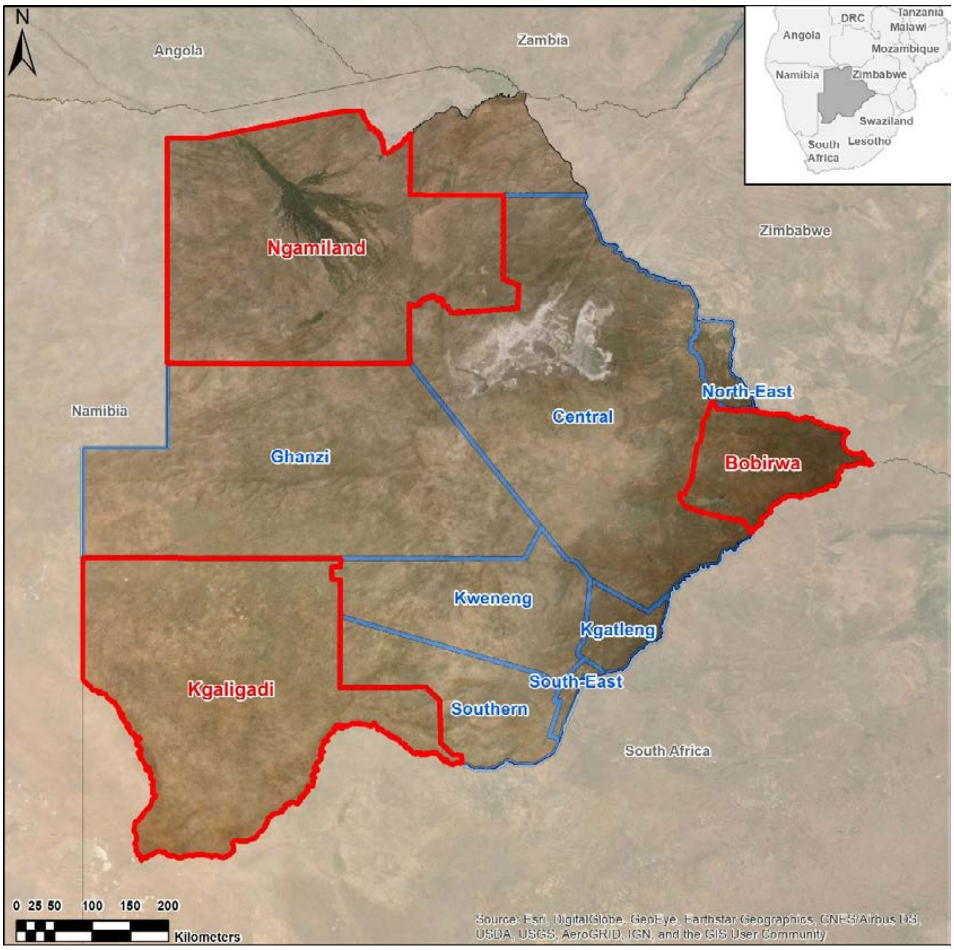

Figure 1. Location of Botswana in Southern Africa and Project Target Areas (red borders)

Within the country, the project sites represent three distinct habitats and a summary of their natural features is presented in Table 1.

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[1] Botswana National Atlas (www.atlas.gov.bw), pg. 52-53

Table 1: Size, habitat description and water availability for the three project sites.

District	Size (ha)	Habitat description	Water Availability
Ngamiland	11,181,993	Open shrub-land and sage bushveld (86%); Floodplain channels and wetland (24%) on sandy soils	Low rainfall but seasonal flooding, variation in aquifer availability is high
Kgalagadi	10,583,881	Thorn-tree dryland savannah w seasonal grassy plains on sandy soils	Low rainfall (<250mm per annum) but good aquifers
Bobirwa	2,222,922	Mixed mopane-savannah veld, with diversity of thorn and non-thorn trees, highly erodible clay soils	Poor aquifers but high surface water availability in normal climate years

(2) Population

Botswana has a small population of approximately 2.3 million people. The population density is approximately 2.6 people per km^2. The population in increasingly urbanising, from 54% of the population being in rural areas in 1991 to the 2015 where 70% live in the country's urban nodes of Gaborone and Francistown. Both of these urban areas are in the wetter regions of the country and drought is a key driver of this migration[2].

(3) Socio-economic status

Botswana has transformed itself from one of the world's poorest countries at independence in 1966, to a middle-income country with a per capita GDP of $8,120 in 2019[3]. Significant wealth from the diamond sector, good governance, prudent economic management have led to relative prosperity in the country. Yet, poverty and high levels of income inequality persist. In recent years, the percent of population living in poverty is approximately 16%. However, an estimated additional 30% of the population remains just above the poverty line and is therefore vulnerable to climate shocks. In the Project target areas, poverty levels exceed 50%. Botswana's level of income inequality, while declining, remains one of the world's highest with a Gini coefficient of 53.3[4]. There is strong dependence on the government. While unemployment remains high (approximately 18%), of those that are employed, the majority are involved in the Ipelegeng programme (see Annex 6). Ipelegeng and other government programmes that aim to provide social safety nets have not been able to overcome cyclical, often climate-induced poverty. These programmes are also increasingly unable to meet the demand related to failed crops and livestock impacts from drought[5].

While not significant in terms of GDP (2% at current prices in 2018), agriculture is the main source of livelihood for over 80% of the total population. Crop production is constrained by limited availability of arable land (0.7% of total area) and erratic rainfall which varies from 650 mm per annum in the east to 230 mm in the south-west. The main crops grown for local consumption are sorghum, corn, and millet. The sorghum and corn produced locally account for less than 20% of annual needs. Livestock farming is a particularly important component of the agricultural sector. In the livestock sector beef production is broadly divided

[2] Botswana National Atlas (www.atlas.gov.bw)
[3] International Monetary Fund. https://www.imf.org/external/datamapper/NGDPDPC@WEO/OEMDC/ADVEC/WEOWORLD/BWA
[4] World Bank. (2015) https://data.worldbank.org/indicator/SI.POV.GINI?locations=BW
[5] See Annex 6, Table 5. Between 2009 and 2016, the % of employment in Ipelegeng grew from 43- 68%.

into two groups of producers. Of the estimated 2.55 million heads of cattle, 88% is raised by mainly small communal farmers, using traditional, less efficient, husbandry techniques. The remaining 12% is owned by commercial farms, using modern husbandry and commercial practices. While export markets to the European Union are more lucrative for livestock farmers in the southern part of the country where geographic zoning maintained by veterinary fences separates wildlife and livestock (see Communal Livestock Management below for more details,) overall, the industry is characterised by low inputs and low profitability.

Botswana's manufacturing base is limited, with a share in GDP stagnating at 5-6% since the 1990s; however, the sector contributes around 11% to formal employment. The sector has a narrow range of activities, such as meat products, beer, textiles and garments, tannery and leather products, glass and information technology products such as electronics, cell phone assembly and related products.

With its rich wildlife, tourism was an obvious sector to develop as part of the economic diversification drive. The sector's total contribution to GDP stood at 10.9% in 2016. With beef and diamonds, tourism is among the major foreign exchange earners and, with travel, accounted for 8.5% of total investment and about 7% of total employment in Botswana. The services sector is the fastest growing sector. Its overall contribution to GDP (including government services) accounted for around 60% in 2018. The fastest growing sub-sectors in recent years were banking, insurance, business services, and construction.

(4) Land Tenure and Use

There are three main categories of land tenure in Botswana. *State land* is primarily conservation areas and urban areas and accounts for approximately 25% of the country's land area. *Freehold or private land* represents between 5-10%. Lastly, *tribal and communal land* is approximately 60-70%. Distribution of the land types is presented in the map in Figure 2.

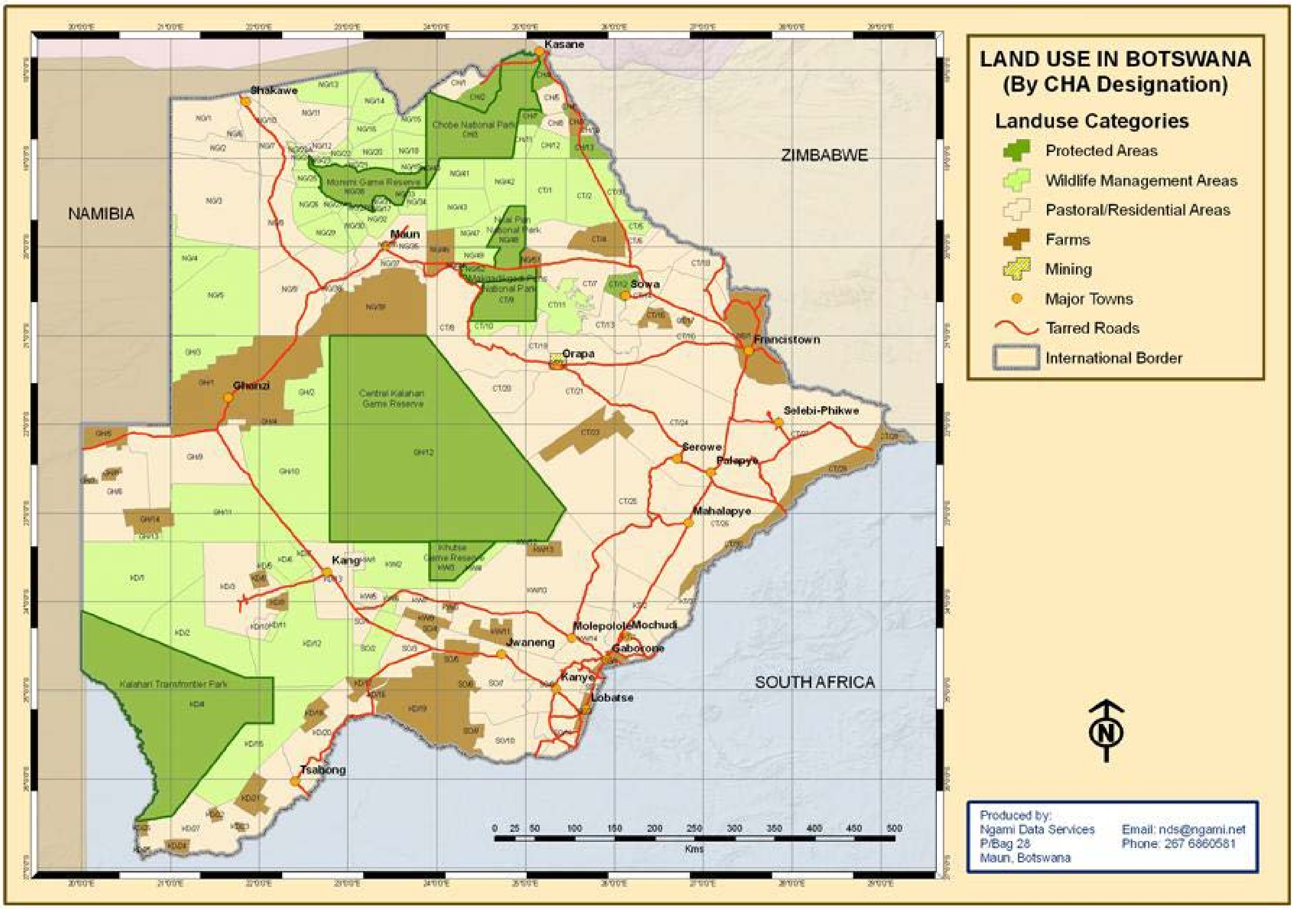

Figure 2: Map of various land use and associated tenure in Botswana.

(5) Livestock management in communal lands

Eighty percent of the non-protected land is communal land and is rangeland that is used by the Batswana with deep cultural attachments to livestock farming. Livestock populations are concentrated around natural and artificial water points and often exceed state recommended carrying capacities. The New Agricultural Policy of 1990 and the Tribal Grazing Areas Act Amendment (2019) seeks to increase private holdings within the current communal areas and expand Land Board authority over management of communal areas in an effort to halt degradation. Increased frequency of droughts is driving farmers into state lands once left for “wilderness” and the impacts on wildlife has been devastating as both predators and bushmeat species are hunted in an effort to survive[6].

Fences have been erected across communal and private rangeland as a way of meeting trade regulations requiring the separation of wildlife, particularly buffalo, and livestock. Wild buffalo populations are known carriers of Foot and Mouth Disease (FMD), a contagious zoonotic veterinary disease that does affect the productivity of livestock. Areas where buffalo co-exist with livestock are considered “infection areas” (Figure 4a). Within the infection area, different vaccination regimes and surveillance across sub-zones may allow certain areas, like the Central region in the northeast of the country (Figure 4b) to also become “FMD free”, though an outbreak of the disease in this area can lead to a rapid quarantine and trade ban being implemented.

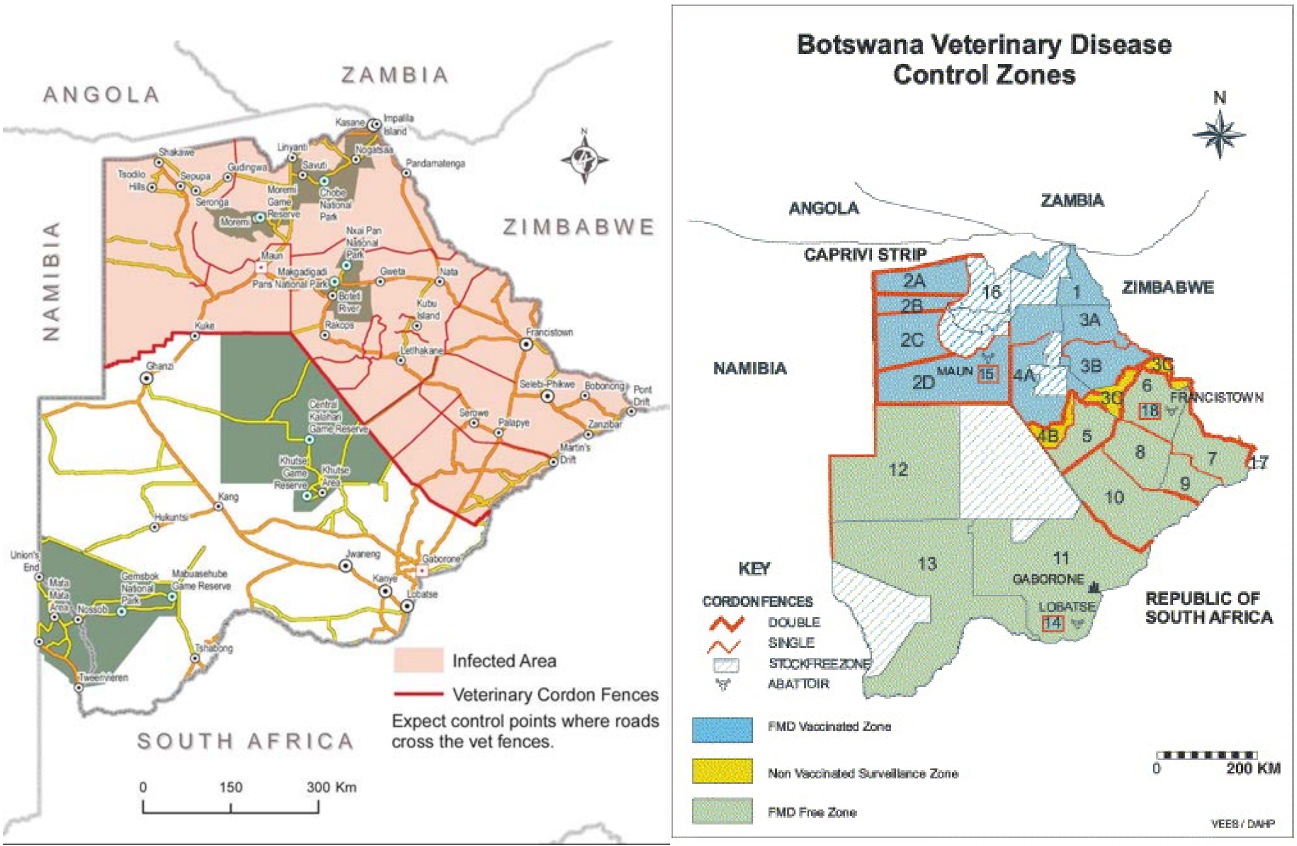

Figure 4. Geographic zones that are used by the Botswana government’s Department of Veterinary Services to manage wildlife-livestock disease risk and enforce trade barriers. 4a shows the entire potential infection zone due to high presence of buffalo in

[6] DOUGILL A.J. ET AL, 2016. LAND USE, RANGELAND DEGRADATION AND ECOLOGICAL CHANGES IN THE SOUTHERN KALAHARI, BOTSWANA. AFRICAN JOURNAL OF ECOLOGY. VOLUME 54, ISSUE 1.

the north and central regions, and 4b shows the sub-zones that are used to manage vaccination support and trade bans to address the disease risk.

Figure 5 shows the distribution of wildlife and domestic livestock resulting from the land-use management in Botswana.

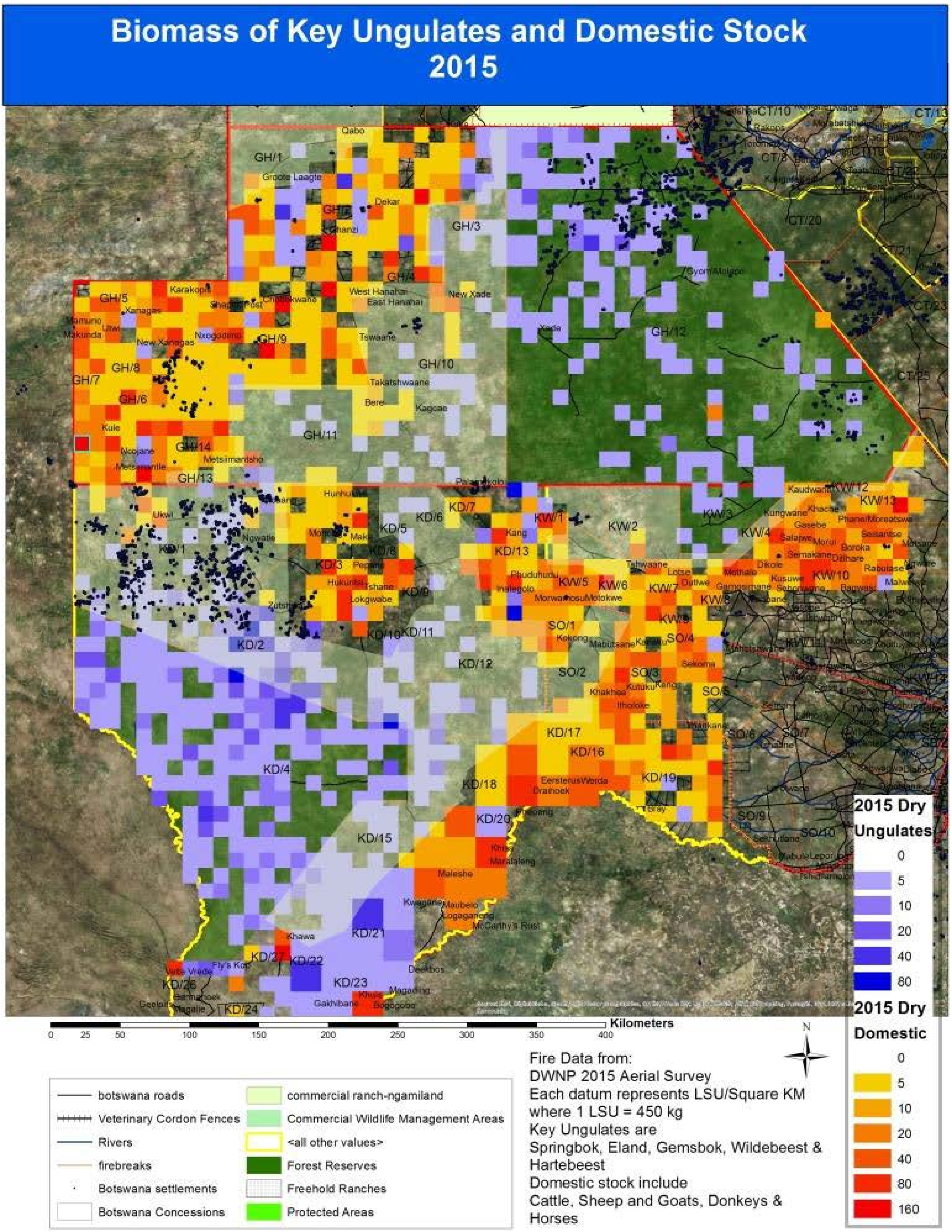

Figure 5. Biomass of ungulates and domestic livestock across Botswana in 2015. JS Perkins (2016)

Increased pressure on all rangelands across Botswana over the last decades has transformed extensive areas of productive natural pastures into dense shrub savannas dominated by *Dichrostachys cinerea* (sickle bush), *Senegalia mellifera* (black thorn) and *Vachellia tortilis* (umbrella thorn) referred to as bush encroachment. This unfortunately is currently the condition of the vegetation in the majority of the rangelands used for livestock production and has resulted in a significant reduction in the carrying capacity of the natural vegetation[7]. Efforts to reduce bush encroachment in Botswana have been minimal and ad hoc leaving a lack of understanding of rates and causes of expansion of encroachment[8].

Although tourism is creating jobs and economic growth in rural areas, the majority of the communal land population is dependent on livestock farming and trapped in a cycle of mutually reinforcing ecosystem degradation and poverty. Impacts of climate change are already exacerbating the downward cycle, and further changes projected for the area are likely to be devastating for both people and nature unless innovative solutions can be found.

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7 MOLEELE, NM ET AL, 2002. MORE WOODY PLANTS? THE STATUS OF BUSH ENCROACHMENT IN BOTSWANA'S GRAZING AREAS. JOURNAL OF ENVIRONMENTAL MANAGEMENT. VOLUME 64, ISSUE 1, PG 3-11.

[8] Kgosikama OE et al 2012. Bush encroachment in relation to rangeland management systems and environmental conditions in Kalahari ecosystem of Botswana. African Journal of Agricultural Research. Volume 7, Issue 15, pg. 2312-2319

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Part 2 - Climate Change Vulnerability Assessment (CCVA)

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Executive summary

Botswana's reliance on natural systems for livelihoods and economic activity, particularly among rural populations, increases the country's sensitivity to the impacts of a changing climate — most notably varying degrees of droughts and extreme temperatures. The purpose of this report is to characterize climate change vulnerability of three areas in Botswana, Bobirwa, Kgalagadi North and Ngamiland and to identify and understand the vulnerability of pastoral communities in these areas who urgently require support for increasing their climate resilience.

The assessment used a combination of spatial and statistical analyses of timeseries data to determine the climate change vulnerability of Bobirwa, Kgalagadi North and Ngamiland, Botswana. The Climate Change Vulnerability Assessments (CCVAs) are the combination of each of these indices using the Climate change **Vulnerability** = **Exposure** x **Sensitivity** – **Adaptive Capacity** formula to each of the social, livestock, livelihood sectors and the rangelands.

- The exposure of the areas of Botswana, the primary climate variables were used to assess the direction of change in the factors of: i) precipitation totals; ii) precipitation intensity; iii) drought potential; and iv) temperature changes (heat waves). Further specific climate exposures were applied to the analysis of livestock exposure, including: i) climate stress; ii) water supply; and iii) water demand pressure. For the livelihoods exposure analysis, the following data was applied: i) seasonal variability changes; and ii) overall exposure indices.

- The sensitivity component of the social vulnerabilities analysis included population demographic variables such as: i) gender; ii) people with disabilities; iii) household sources of fuel for heating and light; and iv) access to water and sanitation. Vegetation drought sensitivity was used for indices of livestock sensitivity, where natural sensitivity data was lacking, and other data gaps existed. Being highly reliant on natural systems, the livelihoods sensitivity index incorporated the: i) loss of normal vegetation cover; ii) depletion of biodiversity; and iii) the reduction in ecosystem services and significant loss of beneficial natural assets. Where data gaps existed when assessing the sensitivity of livelihoods, the standardised soil moisture sensitivity was used.

- The adaptive capacity indices included social vulnerabilities which included variables such as: i) access to education; ii) current levels of employment; and iii) additional vocational training. The livestock adaptive capacities used the water stress index, highlighting areas with higher resilience[9]. Data gaps were filled with the adapted livestock drought economic resilience being a measure of livestock economic susceptibility in drought conditions.

- The rangeland assessment was undertaken in a different manner. The SPARC[10] dataset was used to highlight areas of changing climatic suitability of the medium- to high-value grazing grasses. The climate exposures were derived from WorldClim bioclimatic variables, where the sensitivities are species-specific, while adaptation capacities are mostly dependent on rangeland management practices.

Rangeland ecosystems and the livestock industry are likely to be exposed to reduced rainfall and increased temperatures of ~2–6°C in Bobirwa, Kgalagadi and Ngamiland, depending on greenhouse gas concentrations (under RCP 4.5 and RCP 8.5). As a result, both rangeland plant productivity and the quality of forage plants will decline substantially due to heat and moisture stress. The heat stress will also reduce the reproductive performance of grazing livestock and increase water demand. In addition, poor nutrient supply — as evaporation affects available water sources and heat increases water needs for survival — will further exacerbate poor livestock productivity as climate change reduces both forage plant quality and quantity.

[9] Resilience is defined by the IPCC as "The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions".

[10] Spatial Planning for Protected Areas in Response to Climate Change

The vulnerability assessment indicated that pastoral communities in Kgalagadi and Ngamiland are more vulnerable to climate change relative to Bobirwa and this could be attributed to a high dependency on pastoralism and/or agriculture that relies primarily on precipitation.

- Kgalagadi pastoral communities are currently extremely sensitive to climate risks, which could be a result of high dependence on grazing livestock, which are highly exposed to recurring droughts[11].
- Ngamiland also exhibited high sensitivity to climate risks because key economic activities (agriculture and tourism) in that district are dependent on rainfall-sensitive ecosystems[12].
- Bobirwa is less sensitive to climate risks, which could be attributed to multiple factors such as high surface water availability for irrigation and diversified income activities, including employment in the mining sector. Bobirwa sub-district therefore had lower social vulnerability relative to other sites which could be linked to diversified livelihood options that included arable farming, mining and a high literacy rate of above 80%[13].

Adaptation Potential

A participatory approach and literature review were used for identification of current and future adaptation practices to build resilience among pastoral communities.

- The pastoralists in Botswana implement multiple adaptation practices to reduce the impact of climate shocks on their livestock, primarily: i) breeding climate-adapted varieties of livestock; ii) provision; and iii) improved water supply.
- The ecosystem-based adaptation practices in communal land — such as sustainable grazing management, rehabilitation of degraded land, fire management and fodder production — are not preferred partly because of insecure land tenure that does not guarantee return on investment.
- The stakeholders indicated that rangeland functionality needs to be enhanced urgently through sustainable management, rehabilitation and control of wildfires. Therefore, farmers in communal rangelands need to manage and plan the use of shared rangeland in a manner that allows land to rest and well-timed grazing pressure.
- Without fencing, herding provides an opportunity to control livestock movement to facilitate nonselective grazing and resting periods. In shared rangeland, herding requires pastoralists to work together for healthy ecosystems and enforcing the agreements.

The institutional arrangement — including policies and programmes — were reviewed to assess their potential to contribute towards a conducive adaptive environment and highlight potential barriers that hinder adaptation. Botswana has multiple policies and programmes that support resilience in communal rangelands. Relevant policies and programmes are listed below.

- The climate change policy, whilst not yet completed, promotes resilience across different sectors including pastoral communities.
- Vision 2036, National Development Plan 11 and the Community Based Natural Resource Management (CBNRM) Policy also support resilient and healthy ecosystem that ensure sustained ecological services and enable communities to maintain their livelihoods and reduce poverty.

A lack of rangeland policy and insecurity of communal rangeland, however, could deter pastoralists from investing in sustainable management and rehabilitation of their shared grazing land. Therefore, GCF funding will provide an opportunity to stimulate a shift towards planned and collective management of communal rangelands to buffer livestock and the livelihoods of poorly resourced pastoralists, as well as vulnerable groups such as women, against climatic shocks.

[11] Kgosikoma OE, N Batisani. 2014. Livestock population dynamics and pastoral communities' adaptation to rainfall variability in communal lands of Kgalagadi South, Botswana. Pastoralism: Research, Policy and Practice 4:19

[12] Kolawole OD, MR Motsholapheko, BN Ngwenya, O Thakadu, G Mmopelwa, D L Kgathi. 2016. Climate Variability and Rural Livelihoods: How Households Perceive and Adapt to Climatic Shocks in the Okavango Delta, Botswana. WEATHER, CLIMATE, AND SOCIETY, 8

[13] (Statistic Botswana 2013)

1. Introduction

In Botswana, climate change threatens sectors that are sensitive to rainfall variability — including agriculture, water, biodiversity and health. Rangelands and the livestock industry are particularly vulnerable to climate variability and change but have been the least investigated. These projected climatic changes are likely to exacerbate agricultural land degradation and will result in the agricultural productivity declining further. The rangeland-based livestock sector — characterized by low calving rates and high mortality — contributes substantially to the wellbeing of society, especially rural and poor communities, but their sustainability is being threatened by climate change. This will consequently threaten livelihoods of both men and women as agriculture employs ~1.7% of Botswana's population — with males being the majority owners of livestock; owning ~74% of cattle, 67% of sheep and ~76% of goats[14,15]. Additionally, ecosystem services provided by rangelands include provision of grazing resources, food security (e.g. mopane worms and wild fruits), energy sources (firewood) and water regulation[16]. The value of ecosystem services provided by rangelands in Botswana have not yet been quantified, but it is generally large, as it supports the livestock and tourism industries. Across Botswana, economic losses of compromised environmental goods and service associated with rangeland degradation is estimated at US$353 million[17], which indirectly demonstrates the importance of rangeland ecosystems. The rangeland annual net primary production is expected to decline as a result of limited soil moisture as well as bush encroachment. Therefore, its capacity to support the livestock industry is reduced, exacerbating poverty among livestock farmers and putting the most vulnerable groups, reliant on livestock, at increased risk. Climate change in Botswana, therefore, is likely to threaten the livelihoods of ~55,000 people employed by agricultural related industries, of which ~25% are female[18]. Additionally, the livelihoods of smallholder livestock farmers that own ~73% of an already declining national cattle population, and ~73 and 62% of the goat and sheep population, respectively[19] will be further compromised, likely exacerbating poverty. To enable proper adaptation measures, it is therefore critical to understand the impact of climate change on rangeland ecosystems and associated economic sectors.

Botswana's rangeland and livestock industry are strongly dependent on rainfall and as a result highly vulnerable to climate variability and change. The United Nations Intergovernmental Panel on Climate Change (IPCC) forecasts rising temperatures, increased temporal and spatial variation in precipitation, and more frequent extreme climate events in the future across Africa[20]. Similarly, Botswana's Third National Communication (TNC) to the UNFCCC estimated a temperature increase of 1.5–2.1°C and a 3–15% decline in rainfall by 2050 across the country[21].

This study — commissioned by the government of Botswana in partnership with Conservation International — has the objective of establishing the level of vulnerability of pastoral communities to climate change. Specifically, the study is aimed at quantifying the social, livelihoods, livestock, and rangeland vulnerabilities in Bobirwa, Kgalagadi and Ngamiland (Figure 1). This was achieved through assessment of:

- current and projected climate change scenarios for targeted areas;
- social, livelihoods vulnerability to climate change;
- impact of climate change on rangeland ecosystem and livestock sector; and

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[14] Statistics Botswana. 2014. Botswana in figures 2012/13. Available at: http://www.statsbots.org.bw/sites/default/files/documents/Botswana%20in%20Figures.pdf

[15] Statistics Botswana. 2018. Botswana Agricultural Census Report 2015. Available at: http://www.statsbots.org.bw/sites/default/files/publications/Botswana%20Agriculture%20Census%20Report%20Final%202015..pdf

[16] Mugari E, Masundire H, Bolaane M, New M, (2019) "Perceptions of ecosystem services provision performance in the face of climate change among communities in Bobirwa subdistrict, Botswana", International Journal of Climate Change Strategies and Management, 265-288

[17] Global Mechanism of the UNCCD, 2018. Country Profile of Botswana. Investing in Land Degradation Neutrality: Making the Case. An Overview of Indicators and Assessments. Bonn, Germany

[18] Statistics Botswana. 2019. Multi-topic Household Survey Report. 2015/16. Available at: http://www.statsbots.org.bw/sites/default/files/publications/Botswana%20Multi%20Topic%20Household%20Survey%20REPORT%202015%2016_0.pdf

[19] Statistics Botswana. 2018. Botswana Agricultural Census Report 2015. Available at: http://www.statsbots.org.bw/sites/default/files/publications/Botswana%20Agriculture%20Census%20Report%20Final%202015..pdf

[20] Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart, 2014: Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[Barros, V.R., C.B. Field,D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma,E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

[21] Republic of Botswana. 2019. Botswana's Third National Communication to the UNFCCC. Available at: https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/3567491_Botswana-NC3-1-BOTSWANA%20THIRD%20NATIONAL%20COMUNICATION%20FINAL%20.pdf

- adaptation practices adopted by pastoral communities.

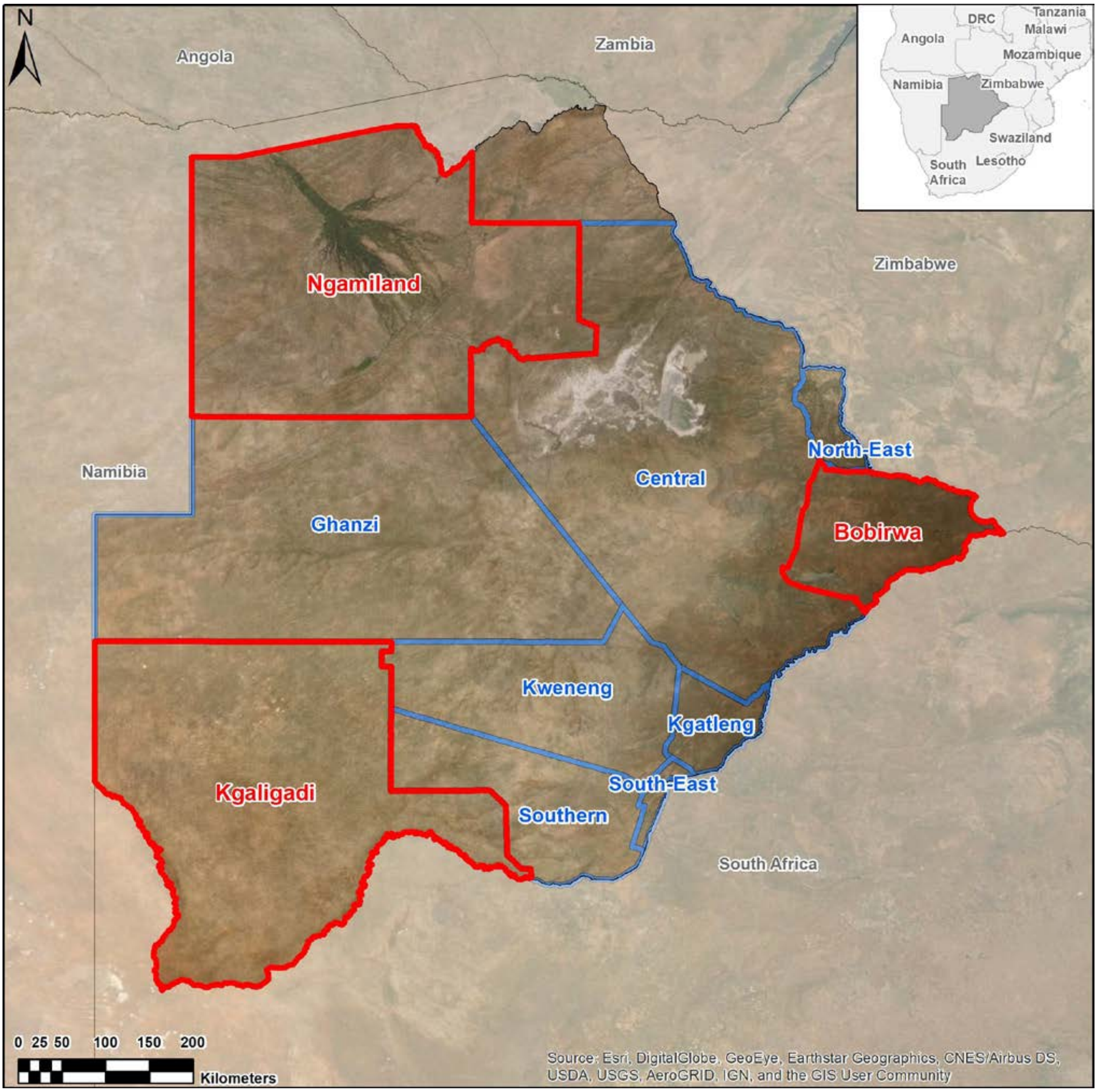


Figure 1. Project Study Areas

The report also covers the methodological approach for vulnerability assessment, current and projected climate scenarios across Botswana and implications for the rangeland and livestock industry. This is followed by analysis of social, livelihood, rangeland and livestock vulnerability. The adaptation practices and supporting environment are also reviewed to enable sustainable adaptation intervention.

2. Vulnerability assessment framework

Effective prioritisation of development action, with the intention of enhancing resilience of communities and systems to current climate variability and projected change, necessitates the determination of areas most vulnerable to that variability and change. The outcomes of this assessment seek to present the climate change vulnerability of rangelands, livelihoods, livestock and society in Botswana. Each analysis presented within the assessment will focus on a different component of the vulnerability profiles of the project's study areas. A detailed review of the vulnerability to climate variability and change is informed through assessment of the individual vulnerabilities.

The IPCC defines climate change vulnerability (CCV) as "the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes"[22]. Vulnerability is a function of the profile, magnitude and rate of climate change to which a system is exposed, as well as the sensitivity and adaptive capacity of that system[23]. Within the CCV framework, the primary components of current/projected exposure, sensitivity, merged into potential direct impacts, and adaptive capacity determine to what extent a system is vulnerable to climate change.

The methodology applied follows international best practice as outlined by the IPCC AR4 report[24]. The climate change vulnerability assessment (CCVA) assesses the following:

- The current and projected climatological exposure, which is the anticipated change and impact of climate parameters — such as occurrence of extreme precipitation events or heat waves — that may have implications for on-the-ground communities, ecosystems or livelihoods. Exposure is the degree to which a system is subject to significant climatic variations[25].
- Sensitivity is the degree to which a system can be affected, either adversely or beneficially, by climate-related stimuli, the effect of which may be direct or indirect. These indices are the attributes that influence the degree to which a system may be impacted as a result of being exposed to the changes in the climate system[26]. For instance, areas of higher population density, or people living in low lying areas, may be differentially exposed to the effects of flooding. Other attributes to be considered when assessing sensitivity include assets in exposed areas, proximity to neighbours, population by age and gender, dependency structures, and factors such as the number of people in a property.

The combination of exposure and sensitivity is a measure of the direct potential impact of climate changes (Figure 2).

Lastly, adaptive capacity is the ability of a system or community to recover from the consequences of, or adapt to, changes in baseline climate variables — including climate variability and extremes — to moderate potential damages, take advantage of opportunities, or cope with consequences[27]. These variables include: i) income and employment; ii) property ownership; iii) literacy; iv) access to, and completion of, education or training; v) access to services to overcome hazards; vi) personal and community assets; vii) access to water; viii) access to adequate sanitation; and ix) principle source of energy for cooking and lighting. These indicators will affect the potential of individuals and communities' ability to recover in both immediately (post hazard event) and in the long term.

[22] McCarthy JJ *et al*. eds. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability – Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

[23] McCarthy JJ et al. eds. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability – Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

[24] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp

[25] McCarthy JJ *et al*. eds. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability – Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

[26] McCarthy JJ et al. eds. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability – Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

[27] McCarthy JJ *et al*. eds. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability – Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

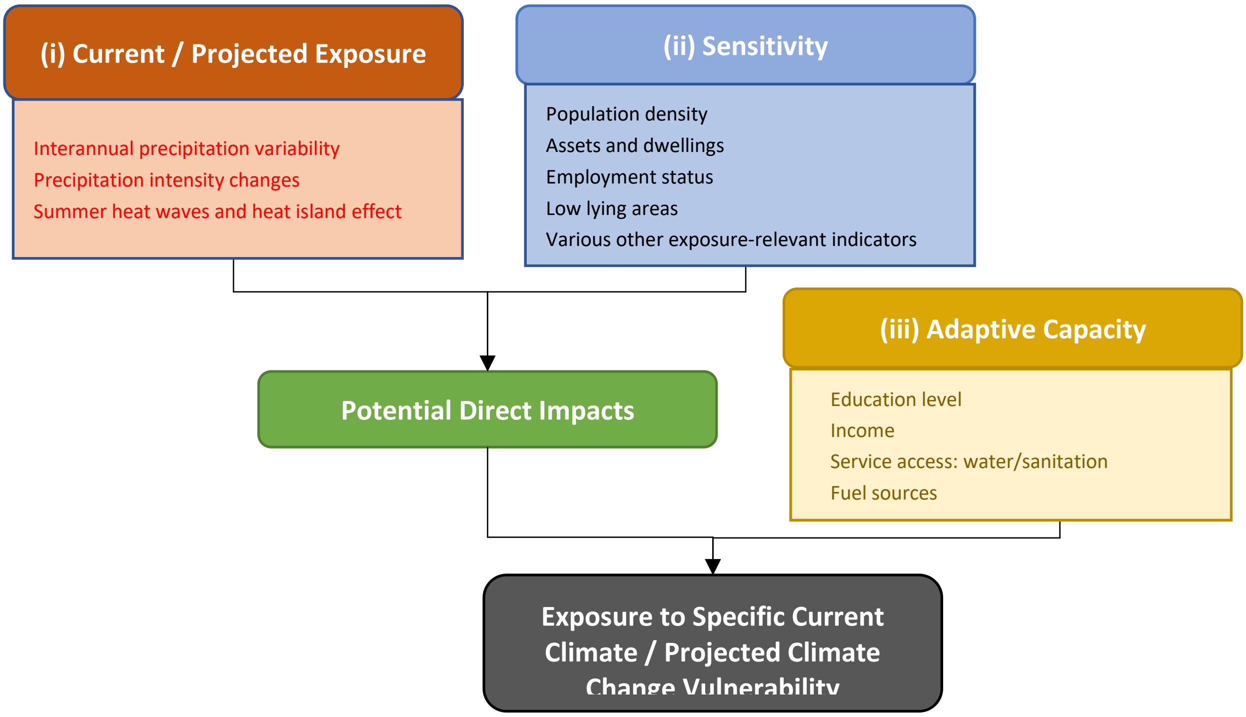


Figure 2. Climate Change Vulnerability Assessment Model

Each of the climate vulnerability assessments will have different variables used as inputs into the Climate Change Vulnerability equation, which is:

Climate Change Vulnerability (CCV) = **Exposure (E) x Sensitivity (S) – Adaptive Capacity (AC)**

The rangeland, livelihoods, livestock and social climate change vulnerability assessments were undertaken for Botswana based on the different indicators making up the exposure, sensitivity and adaptive capacity scores. The resulting CCVA scores are quantified by the Jenks natural breaks classification[28] into the seven scores encompassing a range from low, to medium, and to high vulnerability.

3. Data used for the analysis

There were different datasets used for the four different climate change vulnerability assessments (social, livelihood, livestock and rangeland assessments). Some of the primary data source had gaps in the spatial coverage due to unreported information. These data were, however, useful in the areas where coverage was complete. Secondary datasets of lower resolution were used to fill in the gaps of the primary analysis. The most complete coverage data was used for the analysis in each of the study regions. These datasets are listed below.

[28] de Smith, M.J., *et al*. 2018. Geospatial Analysis — A Comprehensive Guide, 6th edition. Available at: https://www.spatialanalysisonline.com/HTML/index.html

Table 2. Data used for analysis

<table>
<tr><th></th><th>Social assessment</th><th>Livelihood assessment</th><th>Livestock assessment</th><th>Rangeland assessment</th></tr>
<tr><td>Exposure</td><td>Cordex and WorldClim data assessing average annual precipitation decrease, change in extreme summer convective precipitation, drought potential, increase in daily maximum temperatures and intensity of heatwaves.</td><td>● FAO exposure index weighted specifically to people, livestock and croplands.
● WRI seasonal variation data* as a changed range of climate needing adaptation response.</td><td>● FAO climate stress index weighted specifically to people, livestock and cropland.
● WRI water demand/supply data* as projected impacts of water stress.</td><td rowspan="4">● Spatial Planning for Protected Areas in Response to Climate Change (SPARC) data of medium to high value grazing vs low to medium value grazing grasses.

● Analysis was done using MaxEnt (maximum entropy analysis) incorporating climate data, species sensitivities and local soil parameters.

● Climatic factors of annual mean temperature, mean diurnal range, temperature seasonality, minimum temperature of the coldest month, annual precipitation, and precipitation seasonality from WorldClim data.

● Sensitivity thresholds were done on an individual spatial basis.

● Local soil conditions assessed aridity, bulk density, clay, Depth, Ph, and silt.</td></tr>
<tr><td>Sensitivity</td><td>Subdistrict population and house census: selected indication 2011 volume 5, data from Statistics Botswana Census data was used for the social sensitivity assessment.
Variables assessed were total population in an area, population density, population at school vs left or never attended, and disabled population ratio.</td><td>● FAO natural resources sensitivity index weighted by ecosystem vitality and resource quality.
● Standardised soil moisture* as a measure of agricultural sensitivity.</td><td>● FAO water stress sensitivity index for consumed vs available water/precipitation for agriculture.
● IWMI ground water sensitivity* used as potential alternative water source for livestock.</td></tr>
<tr><td>Adaptive capacity</td><td>Subdistrict population and house census: selected indication 2011 vol 5, data from Statistics Botswana Census data was used for the social adaptive capacity.
Variables assessed were access to adequate sanitation services, access to water source by type, employment of population, principal source of fuel for cooking, literacy rate, and tertiary education.</td><td>● Rurality index as a measure of a populations dependence on natural and agricultural systems.
● Population accessibility* as a measure of proximity to service areas.</td><td>● FAO natural sensitivity index for ecological stress resulting from agriculture.
● Livestock economic drought resilience* as the noted impacts on livestock from drought.</td></tr>
<tr><td>Augmenting data[29]</td><td>Population projections were done using the Shared Socioeconomic Pathways - SSP5[30].</td><td></td><td>● FAO cattle estimated distribution dataset.</td></tr>
</table>

**data used for second round of analysis due to initial assessment data not having sufficient coverage*

[29] Data that provides further context to the assessment, such as livestock climate vulnerability framed against the cattle distribution data.

[30] Botswana has shown a willingness to prioritise adaptation activities. The low national population and low CO_2 emissions per capita suggests a likely lower mitigation activity prioritisation.

The weighting of the exposure, sensitivity and adaptive capacity indicators was done using Jenks natural breaks algorithm. This weighted classification isolates clusters of observations into discrete classes which have low internal variance and higher external variance. These classes are then assigned values of “low”, “medium”, or “high” representing best to worst case scenario for exposure and sensitivity indicators, and worst to best case for the adaptive capacity indicators. It should be noted that much of the data used in this assessment required modification to be utilised in the statistical analysis needed for these CCVAs. The varying resolution and format of the data from point, to small–large vector, and rasters of varying grid sizes means that there are hard edges to the analysis. While this is clearly not represented on-the-ground, the lack of data at applicable scale resulted in this compromise being necessary. Please apply caution when interpreting the maps, particularly at the hard edges of the grids.

3.1 Exposure indicators

Presenting climate data is often a complex task, particularly when assessing multiple variables with different units and anomalies, time scales and RCP scenarios. Analysis seeks to present the data in a way that is fully indicative, while remaining understandable and useful to decision makers. This is done by assessing changes in the variables of maximum temperature, precipitation levels and precipitation intensity individually.

3.1.1 Cordex climate data

The RCP climate analysis dataset used was the Swedish Meteorological and Hydrological Institute (SMHI) — SMHI Cordex[31] CMIP5 historical and CMIP5 IPCC AR5 projected experiments, at 0.5°x0.5° spatial resolution, and daily temporal resolution from 1951–2005 and 2006–2100.

Downscaled data has several advantages over the large scale GCMs, chief among them the increased spatial and temporal resolution. Having higher spatial resolution provides greater local context between areas of interest, while daily temporal scales allow for analysis such as extreme events or accumulation anomalies, which is not possible using monthly data. The cordex experiments seeks to downscale the GCMs used in the IPCC AR5 analysis. Understanding the computation requirements for this task, regions were allocated to different climate analysis institutes and models known to better simulate conditions in those regions. The Africa region was assigned to SMHI. They used the following models for downscaling the GCM data for the cordex analysis.

Table 3. Cordex driving models.

Historical	Projected RCP 4.5	Projected RCP 8.5
CCCma-CanESM2	CCCma-CanESM2	CCCma-CanESM2
CNRM-CERFACS-CNRM-CM5	CNRM-CERFACS-CNRM-CM5	CNRM-CERFACS-CNRM-CM5
CSIRO-QCCCE-CSIRO-Mk3-6-0	ICHEC-EC-EARTH	ICHEC-EC-EARTH
ICHEC-EC-EARTH	IPSL-IPSL-CM5A-MR	IPSL-IPSL-CM5A-MR
IPSL-IPSL-CM5A-MR	MIROC-MIROC5	MIROC-MIROC5
MIROC-MIROC5	MOHC-HadGEM2-ES	MOHC-HadGEM2-ES
MOHC-HadGEM2-ES	MPI-M-MPI-ESM-LR	MPI-M-MPI-ESM-LR
MPI-M-MPI-ESM-LR	NCC-NorESM1-M	NCC-NorESM1-M
NCC-NorESM1-M	NOAA-GFDL-GFDL-ESM2M	NOAA-GFDL-GFDL-ESM2M
NOAA-GFDL-GFDL-ESM2M		

An ensemble of downscaled GCMs used in the IPCC AR5 analysis were applied for this assessment given the lack of long-term observational data in Botswana. The downscaled ensemble dataset was established by the Swedish Meterological and Hydrological Institute. All driving GCMs that were considered robust enough for the IPCC AR5 were included in the ensemble. No local datasets or analyses offer greater spatial or temporal granularity than the downscaled GCM ensemble, including analyses provided in Botswana’s National Communications to the UNFCCC. The uncertainties of the climate models are presented using the

[31] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

inter-quartile range, indicating the degree of conformity between simulations. Although the projections would require validation for granular estimates of the absolute indices, the trends in climate variables relative to the baseline are considered robust and fit-for-purpose for the design of this project and the demonstration of climate impacts and adaptation rationale.

Model validation has been conducted using intra- and inter-annual precipitation observational station data for each of the three project areas. The results of the validation are presented in Annex 2, Section 1, Appendix 1.5 and referred to in Section B.1., paragraph 2 of the Funding Proposal. The GCMs employed in the CCVA were all shown to effectively reproduce the historical precipitation observations.

3.1.2 WorldClim data

WorldClim[32] data is a set of bias corrected, high resolution, downscaled climate models that can be used for detailed spatial analysis of an area's climate changes. This data is presented at a lower temporal resolution than the cordex data but is resolved to 1 km x 1 km making it a good spatial complement. Variables presented are minimum, maximum and average temperature, precipitation (mm), and bioclimatic variables, and follow the IPCC AR5 outputs for RCP 2.6, 4.5, 6.0, and 8.5 for the near and far futures. Table 3 presents the models used for the spatial analysis from historical, RCP 4.5 and 8.5 scenarios.

Table 4. WorldClim driving models.

ACCESS1-0	GISS-E2-R	MIROC-ESM
BCC-CSM1-1	HadGEM2-AO	MIROC5
CCSM4	HadGEM2-CC	MPI-ESM-LR
CESM1-CAM5-1-FV2	HadGEM2-ES	MRI-CGCM3
CNRM-CM5	INMCM4	NorESM1-M
GFDL-CM3	IPSL-CM5A-LR	
GFDL-ESM2G	MIROC-ESM-CHEM	

3.1.3 Food and agriculture organisation (FAO) data[33]

The FAO data used for this assessment was derived from the FAO GeoNetwork.

- Exposure Index (2010): ClimAfrica WP4 — The 'exposure index' relates to exposure that is the degree of climatic stress upon a particular unit of analysis or element at risk in 2010. The exposure is commonly defined as the combination between the density of the element at risk and a hazard. Here the elements at risk are people, livestock units and crop land and the hazards are climate change and its impacts.
- Climatic Stress Index (2010): ClimAfrica WP4 — The 'climatic stress index' symbolises the pattern in 2010 of the climatic stresses (i.e. people, livestock unit or crop land) that potentially compromise communities.

3.1.4 Spatial Planning for Protected Areas in Response to Climate Change

SPARC data[34] assesses how a species' range has shifted due to climate change in response to that species' unique climatic tolerances. These movements will cross protected area and national boundaries. As species shift, ecosystems will fragment, adjust and reassemble, affecting habitat coverage and spatial representation across protected areas.

Evaluation was done with the sample of grass species listed below.

- Medium to high value grazing for cattle

[32] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

[33] http://www.fao.org/geonetwork/srv/en/main.home#

[34] Spatial Planning for Protected Areas in Response to Climate Change (SPARC), CI-GEF and Conservation International

- *Panicum maximum*
- *Eragrostis superba*
- *Setaria incrassate*
- *Urochloa mosambicensis*
- *Schmidtia pappophoroides*
- *Tricholaena monachne*
- *Digitaria eriantha*

- Low to medium value grazing for cattle
  - *Perotis patens*
  - *Pogonarthria squarrosa*
  - *Aristida congesta*
  - *Eragrostis trichophora*
  - *Eragrostis rigidior*

3.1.5 Aqueduct data[35]

Data gaps were filled by the World Resources Institute Aqueduct Water Risk Atlas data, focussing on droughts and water stress indicators. This includes data on seasonal precipitation variability. This highlights the degree to which year-on-year precipitation variability increases the sensitivity for industries and communities reliant on seasonally stable rainfall. Water demand change from baseline and water supply change from baseline was used in combination to give an indication of water stress.

3.2 Sensitivity indicators

3.2.2 Subdistrict population and house census data

The Subdistrict population and house census — selected indication 2011, volume 5 data from Statistics Botswana Census data — was used to assess social sensitivity. Census data was classified by sensitivity types such as total population in an area, population density, population at school vs left or never attended, and disabled population ratio. Each of the variables were given a weighting of high, medium, or low based on the extent to which they contribute to the overall sensitivity scores. For example, population density scored high and would have a larger influence on an area's sensitivity than disabled population ratio, which had a weighting of low. The baseline vulnerability assessment was measured according to the current climatic conditions. Climate changes were then assessed and applied to assess the exacerbation of these vulnerabilities to future conditions.

Table 5. Application of social sensitivity variables

Sensitivity	Reason for analysis/Proxy for	Application
Total population in an area.	Requirement needs of larger population to single/ongoing hazards	Disaggregated by gender. Disaggregated by age and dependency
Population density and dependency ratios.	Sensitivity of larger population in an area to single/ongoing hazards	Projected population changes in 2050 under low development and high development scenarios
Population at left or never attended school vs those that attended school.	Sensitivity acting as a proxy for the ability to plan effectively for adaptation	Disaggregated by gender
Disabled population ratio	Sensitivity being less able to provide for own/family needs	Combined sensitivity

Population characteristics were projected using the Shared Socioeconomic Pathway middle of the road projection (SSP2)[36]. This data represents changes in social, economic, and technological trends. The middle

[35] World Resources Institute Aqueduct Water Risk Atlas https://www.wri.org/aqueduct/about

[36] SSP2 - Middle of the Road (or Dynamics as Usual, or Current Trends Continue, or Continuation, or Muddling Through).

of the road scenario used here assumes the world follows trends that do not shift markedly from historical patterns.

3.2.3 Food and agriculture organisation (FAO) data[37]

The FAO data listed below was used for this assessment was derived from the FAO GeoNetwork.

- Water Stress Sensitivity Index (ClimAfrica WP4) — The “water stress index” relates to the water sensitivity of a certain area in 2010. This potential is measured the water consumption and its relation to water availability and by the volume of rainfall available per people in crop land areas.
- Natural Resources Sensitivity Index (ClimAfrica WP4) — The “natural resources sensitivity index” relates to the ecosystem vitality and degree of conservation. Assessment done against deforestation, loss of water resources, vegetation cover and depletion of biodiversity and beneficial ecosystem services

3.2.4 Other data sources

- Standardized Soil Moisture Index Future — highlights the degree to which upper level soils vary under future projections.
- International water Management institute (IWMI) — sensitivity of ground water recourses to droughts.

3.3 Adaptive Capacity indicators

3.3.2 Subdistrict population and house Census data

The Subdistrict population and house Census: selected indication 2011 vol 5 data from Statistics Botswana Census data was used for the social sensitivity and adaptive capacity. Census data was arranged by adaptive capacity such as Access to adequate sanitation services, Access to water source by type, Access to water source by type, Employment of population, Principal source of fuel for cooking, Literacy rate, and Tertiary education. Each of the variables were given a weighting of high, medium, or low to which they contribute the overall adaptive capacity scores. For example, household employment was scored high and would have a larger influence on an area’s adaptive capacity than tertiary education scores, which had a weighting of low. The baseline vulnerability assessment was measured according to the current climatic conditions. The spatial distribution of climate change impacts was applied to the baseline vulnerability to assess the exacerbation of community’s vulnerability to future conditions.

Table 6. Application of social adaptive capacity variables.

Adaptive Capacity	Reason for analysis/proxy for	Application
Access to adequate sanitation services	Sensitivity acting as proxy for poverty index	Owned or shared Flush toilet, Ventilated Improved Pit latrine (VIP), pit latrine, or dry compost
Access to water source by type	Climate sensitive resource access	Type of water source and degree of sensitivity. Well, borehole, river/stream, dam/pan, rainwater tank or spring water
Access to water source by type	Adaptive capacity through institutional resource access	Type of water source fed though municipal services Piped indoors, piped outdoors, neighbours tap, communal tap, bowser/tanker
Employment of population	Sensitivity proxy for (in)ability to finance basic recovery and cope with shock	Disaggregated by gender
Principal source of fuel for cooking	Sensitivity of reliance on natural resources vs institutional services	Fuel type and sensitivity to resource availability

[37] http://www.fao.org/geonetwork/srv/en/main.home#

		Electricity grid, petrol, diesel, solar power, gas (LPG), bio-gas, wood, paraffin, cow dung, coal, crop waste or charcoal
Literacy rate	Adaptive capacity proxy for ability to receive early warning	Disaggregated by gender
Tertiary education	Adaptive capacity proxy for adaptation planning	Various education levels Training, apprentice, brigade, technical/ vocational, education college, IHS diploma, or university

3.3.3 Food and agriculture organisation (FAO) data[38]

The FAO data used for this assessment was derived from the FAO GeoNetwork.

- Rurality Index (2010) — ClimAfrica WP4 — The 'rurality index' represents the level of dependence of a certain region to agriculture and rural means of livelihood in 2010, and therefore the region's vulnerability to food security and other factors dependent on agriculture. A population strongly reliant on agriculture is subject to suffer larger consequences from a decrease in agricultural productivity because of climatic alteration than a population less dependent on rural livelihood means.
- Natural Sensitivity Index (ClimAfrica WP4) — The 'natural sensitivity index' relates to the ecological component of sensitivity in 2010 and it is linked to the degree of stress over the ecological systems that sustain agricultural production. The underlying indices are: i) a water stress index: ii) natural resources sensitivity index; and iii) an agriculture resources sensitivity index. Resultantly, this data is relevant to both horticulture and pastoralism.

3.3.4 Other data sources

- Global Map of Travel Time to Cities — acts similarly to the rurality data in that increase distance to city centres acts as a proxy for reliance on natural system economies.
- Economic Drought Sensitivity measures to lose in cattle stock as a result of drought.

3.4 Augmenting data

- Population projections were done using the Shared Socioeconomic Pathways — SSP5.
- FAO cattle data (cattle distribution) — Gridded Livestock of the World version 2.01. This dataset shows the global model of cattle distribution as of 2010[39].

4 Botswana Climate Change Exposure

In Botswana, anthropogenic climate change is altering ecosystems and sensitive environments beyond the normal thresholds and transforming areas across the country. Over the last 66 years there have been 21 years (or 32%) classified as Abnormally, moderately, severely, extremely, or exceptionally dry. And only 17 years (or 25%) being classified as wetter. However, from 1980 to present, 43% of years have been classified as dry compared to 14% being wetter and 43 % being near normal. Furthermore, years from 1980 to present have accounted for 97% of moderately, severely, extremely, or exceptionally dry years. The ratio of wet to dry years is 1:1.24 (1954 to present) and 1:3.06 (1980 to present) The magnitude of these dry years has increased by 72% over wet years[40]. These drought events affected ~1.3 million people[41,42] and causing ~US$ 3 million in damages[43]. Among other factors, this and increasing rates of resource depletion has led to a

[38] FAO, http://www.fao.org/geonetwork/srv/en/main.home#

[39] Robinson TP, Wint GRW, Conchedda G, Van Boeckel TP, Ercoli V, Palamara E, Cinardi G, D'Aietti L, Hay SI, and Gilbert M. (2014) Mapping the Global Distribution of Livestock. PLoS ONE 9(5): e96084. doi: 10.1371/journal.pone.0096084

[40] Standardised Precipitation-Evapotranspiration Index (SPEI), https://spei.csic.es/home.html

[41] Juana, J., *et al*. (2014). "Socioeconomic Impact of Drought in Botswana." *International Journal of Environment and Sustainable Development*, 11(1).

[42] Mogotsi, K., *et al.* (2011). The perfect drought. Constraints limiting Kalahari agropastoral communities from coping and adapting. *African Journal of Environmental and Science Technology* 5.

[43] Masih, I., S. Maskey, F. E. F. Mussá, and P. Trambauer. 2014. "A Review of Droughts on The African Continent: A Geospatial and Long-Term Perspective". *Hydrology and Earth System Sciences* 18 (9).

decrease in vegetation cover and subsequent desertification, with evidence from satellite imagery confirming this has occurred since at least the mid-1980s[44]. The United Nations Intergovernmental Panel on Climate Change (IPCC) forecast increased temperatures, increased temporal and spatial variation in precipitation, and more frequent climatic disasters in the future across Africa[45]. Botswana's TNC to the UNFCCC estimated a temperature increase of 1.5–2.1°C and a 3–15% decline in rainfall by 2050, under RCP4.5, across the country. The potential impacts of climate change on natural events such as heat waves, bush fires and increased drought intensity and frequency will alter the ecosystem stability, cause loss of habitat and threaten the related livelihood activities.

Climate change analyses of the Southern African region show a general increase in day and night-time temperatures. These increases become greater, the larger the distance from the mitigating effects of the ocean or larger water bodies. Additionally, there will be greater occurrence of heatwaves and extreme temperature days, as well as increasing variability in the precipitation profile. Some areas on the eastern coast show an increase in annual precipitation totals. Conversely, the western coast shows a decreasing precipitation trend. The central areas also exhibit a decrease in total precipitation. There are many areas that exhibit a concentration of rainfall into the main precipitation months with decreases in the intermediary shoulder season[46] rainfall. Generally, over the whole southern Africa region there is an increase in hourly maximum precipitation rate. This parameter shows an increase in most months even in areas with overall deceasing precipitation trends.

Botswana, being landlocked and not subject to large water body temperature mitigation, will experience large increases in both maximum and minimum temperatures. Day time maximum temperatures are likely to increase by ~2.0°C in the south west and ~3.4°C in the northern and eastern regions by 2050 under RCP 4.5 (Figure 3). Increased day time temperatures are closely matched by increased night-time temperatures with the average diurnal range rising by 0.1–0.2°C over most of Botswana (with the exception of the southernmost area of Kgalagadi).

The projected precipitation level over Botswana shows a general annual total volume decrease of 5 to 18 mm annually. This is greater in more northern areas where a decrease of ~32 mm is expected (Figure 3F). However, the three-month precipitation peak (Figure 3G) associated with summertime convective precipitation, exhibits an increase over most of Botswana of 4–13 mm across these three peak rainfall months. The southern area of Kgalagadi is an exception as it shows a near normal to slight decrease trend over these peak months. The coefficient of variation (Figure 3H), already high in the central to northern areas of Botswana, will increase further. This will be most evident in the central areas with an increase of up to 10%. This will further worsen the year-on-year precipitation variability.

Summarised climate change exposures are highlighted below.

Table 7. Project area climate change exposure summaries

Main measurable climate impact paths	**Measured from**	**Bobirwa**	**Ngamiland**	**Kgalagadi**
1. Percentage change in annual precipitation, change in precipitation totals and monthly standard deviation	RCP 4.5 and RCP 8.5 scenarios for 2030 and 2050, anomaly from historical 1970–2000 precipitation	Precipitation will decrease by 8–14 mm/yr but increase by up to 14 mm in peak summer months. Therefore, shoulder seasons will exhibit reduced rainfall to account for the overall decreased annual volume. Seasonal variation will increase by 7–10%.	Precipitation will decrease by 19 mm/yr but increase by up to 13 mm in peak summer months in Qangwa (west Ngamiland). Decreases are therefore mostly resigned to the shoulder seasons. Seasonal variation is set to increase by 5–10%.	Precipitation will decrease by 7–14 mm/yr but increase by up to 5 mm in peak summer months. Seasonal variation is set to increase by up to 6% annually.

[44] C. Vanderpost, S. Ringrose, D. Kgathi & W. Matheson (2007) The nature and possible causes of land cover change (1984 –1996) along a rainfall gradient in southeastern Botswana, Geocarto International, 22:3

[45] Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart, 2014: Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[Barros, V.R., C.B. Field,D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma,E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

[46] The season preceding or following the main seasons of winter and summer

2. Drought potential under Standardised Precipitation Index (SPI)	Changes in the SPI drought occurrence and magnitude for extremely dry and exceptionally dry periods lasting 2 years	Frequency of drought will increase with an increase in SPI events in the very and extremely dry statues.	Frequency of drought will increase with an increase in SPI events in the very and extremely dry statues.	Frequency of drought will increase with an increase in SPI events in the very and extremely dry statues.
3. Change in summer monthly precipitation totals and 90th percentile events	Change in extreme summer convective precipitation for peak months	There is a general trend of decreasing precipitation. Projections shows a large decrease in early onset events of October. This continues until increases in January. February and March show some variation, though there is not a clearly defined trend. The event returns show increases of intensity of ~10% for most of the return thresholds.	Monthly projected precipitation shows a decrease in the early onset events of October and to some extent in November. This is offset by monthly increases in volume in December and January. The event returns show an increase in intensity of ~7% for the 1:100-year events, 9.5% for 1:80-year events and between 10% and 13% for the remaining events.	There is a slight projected increase in volume from November to February. As with the other areas, early season sees a decrease in volume resulting in a likely delayed onset. The event returns show increases in intensities of between 10.5 to 12.5% for the larger return event.
4. Increase in daily maximum temperatures and intensity of heatwaves	Spatial anomaly for projected temperature increases and 90th change in percentile heatwave intensity	Projections show an increase of 3.1°C in the warmest months by 2050 under RCP4.5, with minimum temperatures increasing to a slightly lesser extent. The number of extreme temperature days will rise from an average of 1.2/yr to ~6 by 2100 under RCP4.5.	Projections show an increase of 3.3°C in the warmest months by 2050 under RCP4.5, with minimum temperatures increasing to a slightly lesser extent. The number of extreme temperature days will rise from an average of 1.8/yr to ~9 by 2100 under RCP4.5.	Maximum temperatures will likely increase by ~3.0°C by 2050 under RCP4.5, with minimum temperatures set to increase to a lesser degree. The number of extreme temperature days will rise from an average of 0.5/yr to ~3 by 2100 under RCP4.5.
Sum of the additionality of these hazards.	Sums all the hazards to give a cumulative total exposure	Bobirwa will experience a low to medium seasonal variability which will impact livelihood exposure. Low water supply and demand pressure will impact livestock exposure.	Small areas will experience low seasonal variability, whilst most areas will experience medium high to high seasonal variability which will impact livelihood exposure. Medium-low to medium-high water supply and demand pressure will impact livestock exposure. A small area in the far north will experience very low pressure.	Very low to low seasonal variability will influence livelihood exposure. Wide variation (very low to very high pressure) in water supply and demand pressure will impact livestock exposure.

Since the 1950s, Botswana has experienced multiple, multi-year droughts[47,48,49]. This indicates that the return period between droughts has shortened and consequently the frequency of drought events has increased over this time period[50]. Future probability of drought occurrence, including severity and duration of drought events, has been assessed using the Standard Precipitation Evapotranspiration Index (SPEI) method as part of Botswana's TNC[51]. The results indicated that even with a projected increase in annual precipitation, increasing temperatures could intensify evapotranspiration. Therefore, drought severity and duration could increase under all selected RCP scenarios. The anticipated climate impacts can be assessed though four main impact paths, shown in Table 7 below.

[47] These have occurred in the following years: 1959/60, 1961/62, 1963/64, 1964/65, 1969/70, 1972/73, 1978/79, 1981/82, 1982/83, 1983/84, 1984/85, 1985/86, 1991/92, 1993/94, 1994/95, 1995/96, 1997/98, 1998/99, 2001/02, 2004/5, 2005/06, 2007/08, 2012/13 and 2015/16.

[48] Juana, J., *et al*. (2014). "Socioeconomic Impact of Drought in Botswana." *International Journal of Environment and Sustainable Development*, 11(1).

[49] Mogotsi, K., *et al.* (2011). "The perfect drought. Constraints limiting Kalahari agropastoral communities from coping and adapting." *African Journal of Environmental and Science Technology* 5

[50] IDRC and UKaid. 2017. Background paper on Botswana's Draft Drought Management Strategy. Available at: http://www.assar.uct.ac.za/sites/default/files/image_tool/images/138/Southern_Africa/botswana/Background%20Paper%20on%20Botswana%E2%80%99s%20Draft%20Drought%20Management%20Strategy%20-%20formatted.pdf

[51] Republic of Botswana. 2019. Botswana's Third National Communication to the UNFCCC. Available at: https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/3567491_Botswana-NC3-1-BOTSWANA%20THIRD%20NATIONAL%20COMUNICATION%20FINAL%20.pdf

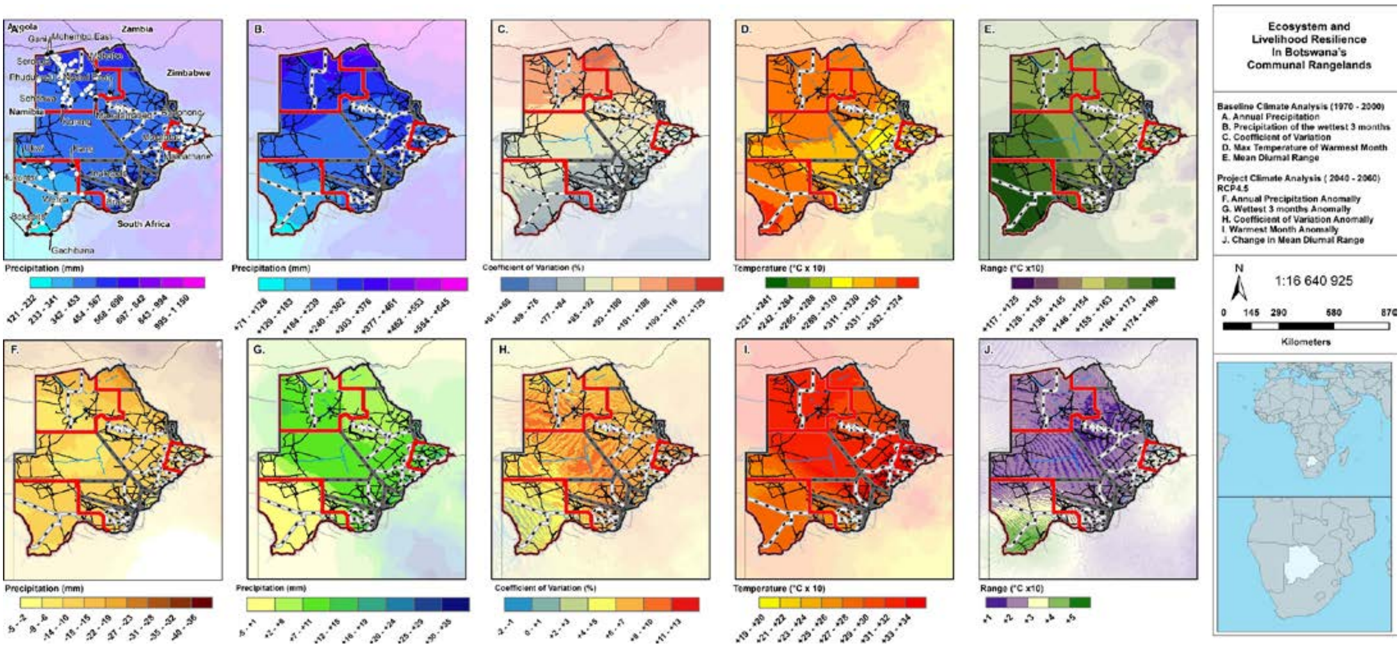


Figure 3. Principle current variables (top) and projected climate anomalies (bottom) for Botswana[52].

Table 8. Climate hazards

Main measurable climate impact paths	Measured from
1. Percentage change in annual precipitation, change in precipitation totals and monthly standard deviation	RCP 4.5 and RCP 8.5 scenarios for 2030 and 2050, anomaly from historical 1970–2000 precipitation
2. Drought potential under Standardised Precipitation Index (SPI)	Changes in the SPI drought occurrence and magnitude for extremely dry and exceptionally dry periods lasting 2 years
3. Change in summer monthly precipitation totals and 90th percentile events	Change in extreme summer convective precipitation for peak months
4. Increase in daily maximum temperatures and intensity of heatwaves	Spatial anomaly for projected temperature increases and 90th change in percentile heatwave intensity
Sum of the additionality of these hazards.	Sums all the hazards to give a cumulative total exposure

Climate change will also likely affect the characteristics of fires in Botswana. Fires occurs throughout Botswana, though they are more prevalent in the Ngamiland region than anywhere else in Botswana. The largest occurrence of fire is in the northernmost areas along the Namibian border, as well as in the Delta itself (Figure 4). The majority of these fires occur from August to October. The peak fire brightness also occurs over this time. The number of fire detections[53] over time shows a slight linear increase from 2001 to 2019, with peak activity being in 2008 and 2011. There is also a linear increase in average fire brightness[54] from 2001 to 2019, with average brightness consistently higher in more recent years than the more variable early years.

There are many complex factors that contribute to a particular fire season having a higher occurrence of fires or hotter fires than other seasons (such as point of origin and vegetation dryness, wind speed on ignition day, or the speed of extinguishing). The fire danger index (FDI) is a trusted measure utilised by wildland firefighters to call extra resources or prepare standby crews because of its strong correlation to fire intensities. FDI is calculated using scales of recent rainfall and evaporation as a measure of vegetation dryness along with current temperature, humidity and wind speed. The projections of wind speed and direction are not clearly

[52] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

[53] Pixels depicting a local fire detected via remote sensing with fire confidence greater than 50%

[54] Photon count acting as proxy for fire pixel temperature

suggesting any particular trend; however, the daily meteorological wind will have a greater impact on FDI than general climatological wind changes.

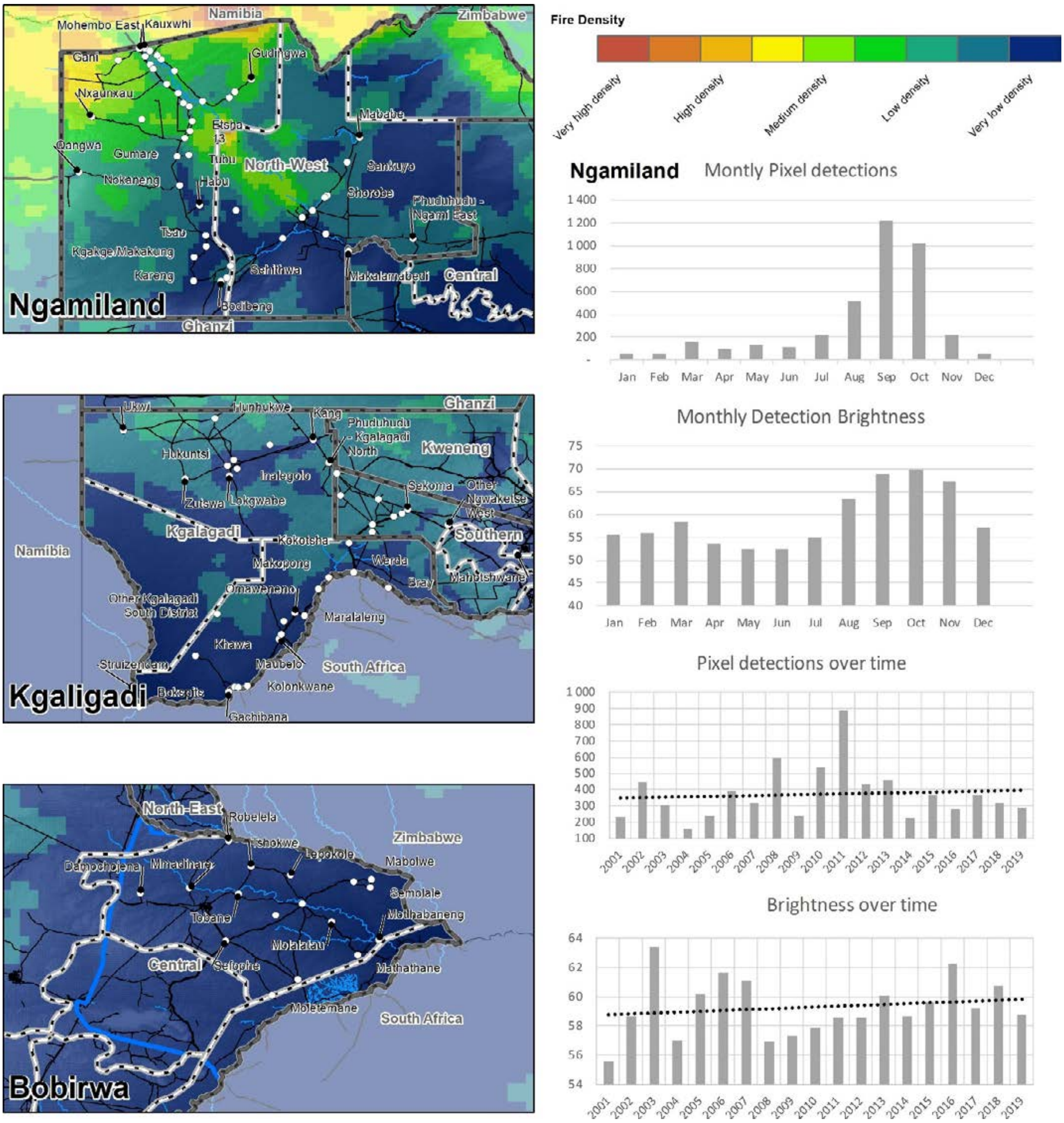


Figure 4. Fire occurrence heat map (left panel) and fire character (right panel)[55].

4.1 Climate changes in Bobirwa

Table 9. Projected Climate Change in Bobirwa

Temperature will increase: Average of 28.6°C Increase of 0.22 °C/decade, ±0.15 °C 95% confidence level
Frequency of drought will increase with an increase in SPI events in the very and extremely dry statues
Rainfall will be more uncertain, and overall precipitation may decrease. Average of 565mm/year. Decrease of 4.16mm/decade, ±14mm 95% confidence level
# of days over 30 degrees likely to increase from 85 to 178 by 2050
# of days over 40 degrees likely to increase from ~1 to 3.2 by 2050

[55] Fire Information for Resource management System (FIRMS), https://firms.modaps.eosdis.nasa.gov/

Bobirwa, on the eastern side of Botswana, has an annual baseline precipitation of 300–450 mm, with a majority of that being convectively forced rainfall occurring over the peak summer months (Figure 5 A, B, C)[56]. The seasonal variation (coefficient of variation) is moderate to high in Botswana. The local, rainfall-dependent economy will be subjected to this high precipitation variation and associated uncertainty. The anticipated precipitation changes in Bobirwa show an annual decrease of 8–14 mm. However, precipitation in the peak summer months is set to increase by up to 14 mm. Precipitation is therefore being concentrated into these months while shoulder seasons will exhibit reduced rainfall to account for the overall decreased annual volume. The seasonal variation is set to increase by 7–10%, further increasing vulnerability of the rain-reliant economy.

Bobirwa's maximum temperatures are more moderate compared to the rest of Botswana, with average maximum temperatures being ~28–33°C. The diurnal variation is also not as large compared to elsewhere in the region. Projected increased temperatures (Figure 5 I, J) show an increase of 3.1°C in the warmest months under RCP 4.5 by 2050. The minimum temperatures are also increasing, though to a slightly lesser extent than maximum temperatures. The diurnal range will increase by ~0.3°C meaning night-time temperature profile shift is similar to the higher day time temperature profile shift.

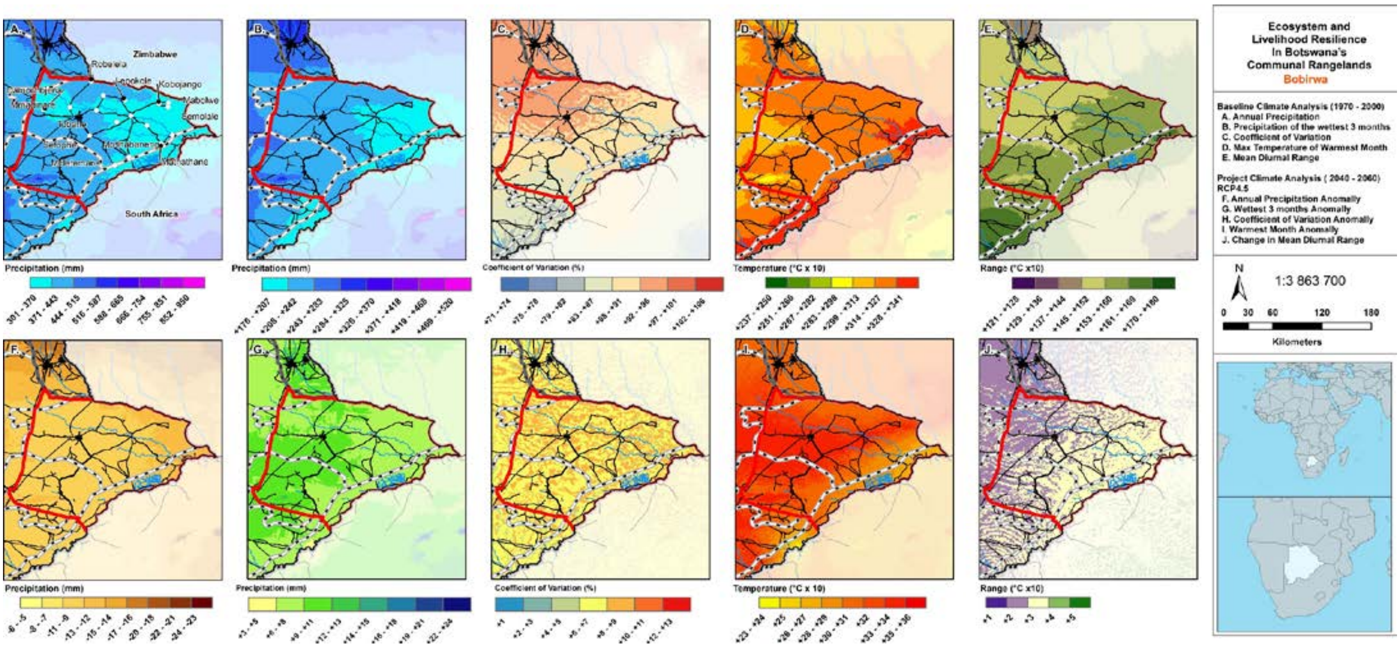


Figure 5. Current (top) and projected climate anomalies (bottom) for Bobirwa[57].

[56] Mugari E, Masundire H, Bolaane M, New M, (2019) "Perceptions of ecosystem services provision performance in the face of climate change among communities in Bobirwa subdistrict, Botswana", International Journal of Climate Change Strategies and Management, 265-288

[57] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

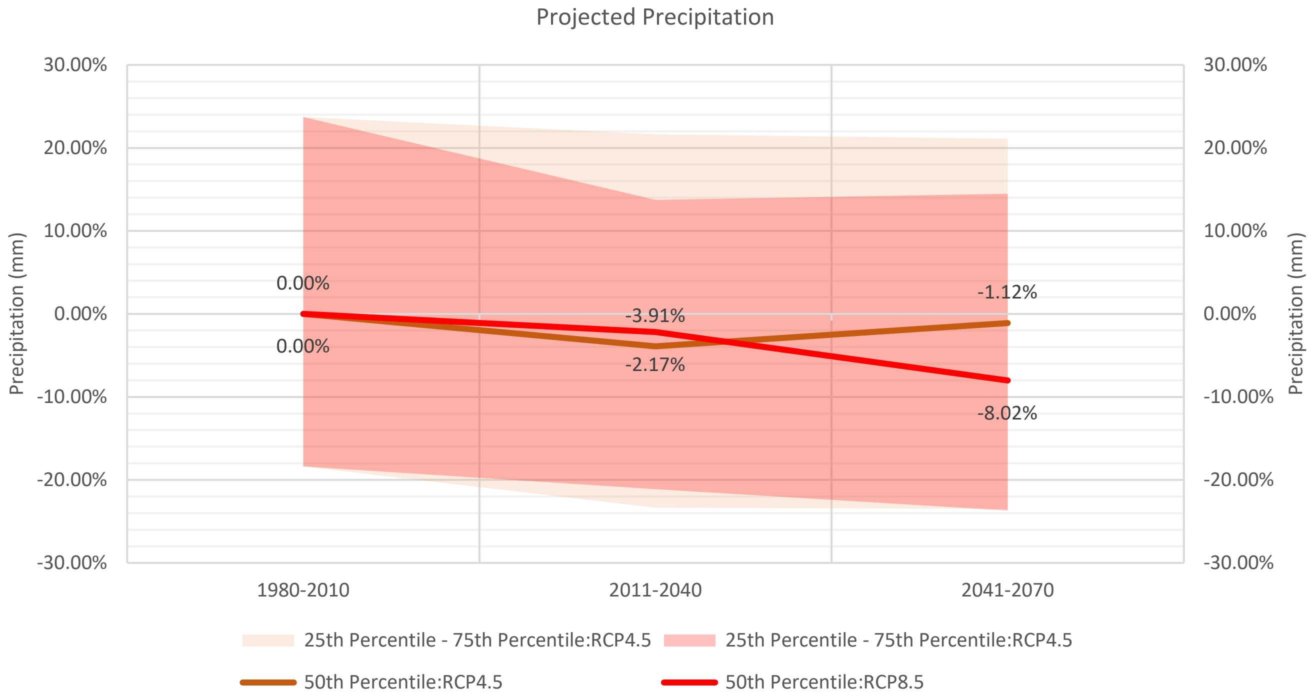


Figure 6. Long term precipitation percentage anomaly for 1980–2010 using RCP 4.5 (brown) and 8.5 (red) for Bobirwa[58].

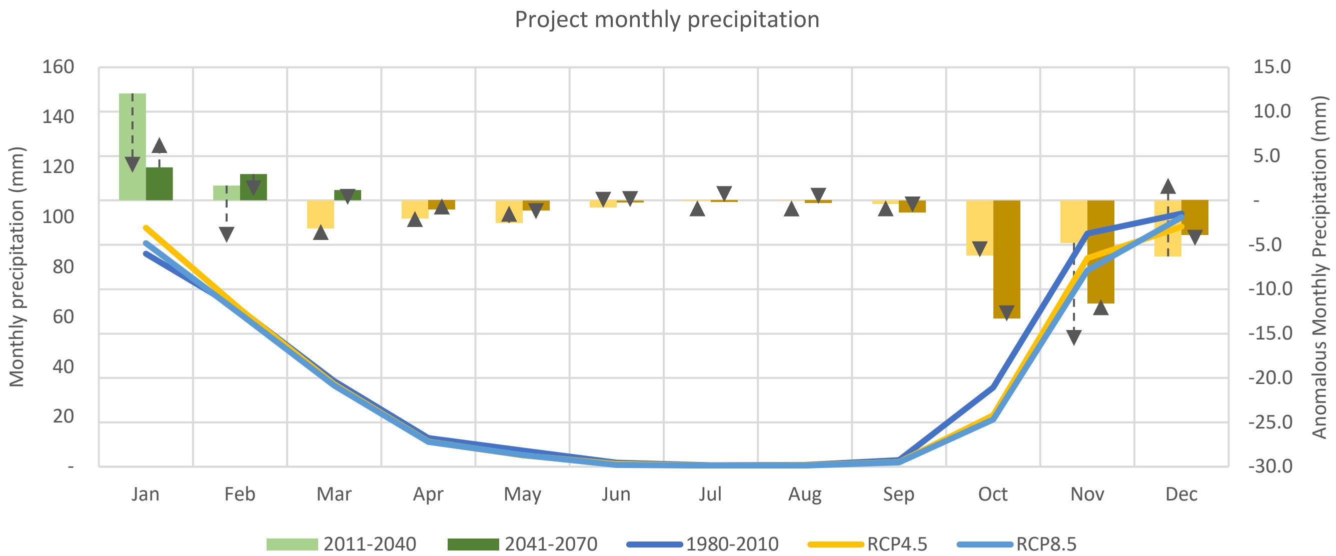
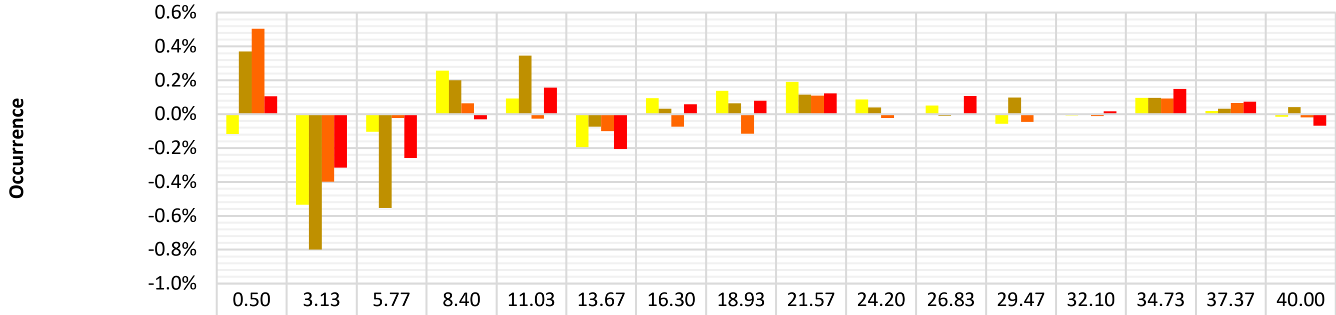


Figure 7. Monthly precipitation climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (yellow solid line) and 8.5 (brown dashed line) for Bobirwa[59].

[58] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[59] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012



	0.50	3.13	5.77	8.40	11.03	13.67	16.30	18.93	21.57	24.20	26.83	29.47	32.10	34.73	37.37	40.00
RCP4.5 - 2011-2040	-0.12%	-0.54%	-0.10%	0.26%	0.09%	-0.19%	0.10%	0.14%	0.19%	0.09%	0.05%	-0.06%	-0.01%	0.10%	0.02%	-0.02%
RCP4.5 - 2041-2070	0.37%	-0.80%	-0.55%	0.20%	0.35%	-0.07%	0.03%	0.06%	0.12%	0.04%	-0.01%	0.10%	0.00%	0.10%	0.03%	0.04%
RCP8.5 - 2011-2040	0.50%	-0.40%	-0.02%	0.06%	-0.03%	-0.10%	-0.07%	-0.11%	0.11%	-0.02%	0.00%	-0.04%	-0.01%	0.09%	0.07%	-0.02%
RCP8.5 - 2041-2070	0.11%	-0.31%	-0.26%	-0.03%	0.16%	-0.21%	0.06%	0.08%	0.12%	0.00%	0.11%	0.00%	0.02%	0.15%	0.07%	-0.07%

Bin range (mm)

Figure 8. Precipitation profile changes from observed (1980-2010) for projected (2011–2040 and 2041-2070) using RCP 4.5 (pink) and 8.5 (red) for Bobirwa[60].

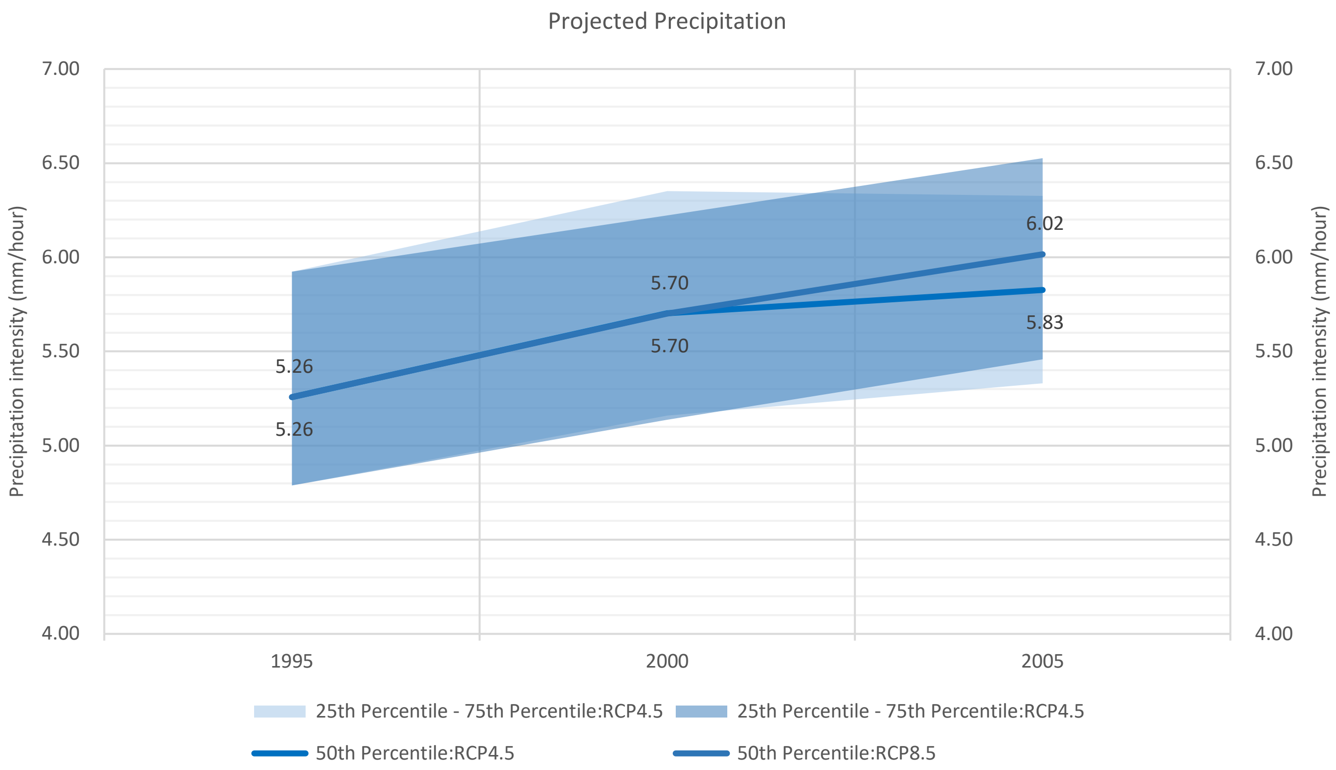


Figure 9. Long term precipitation intensity anomaly for 1980-2010 using RCP 4.5 (light blue) and 8.5 (dark blue) for Bobirwa[61].

[60] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[61] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

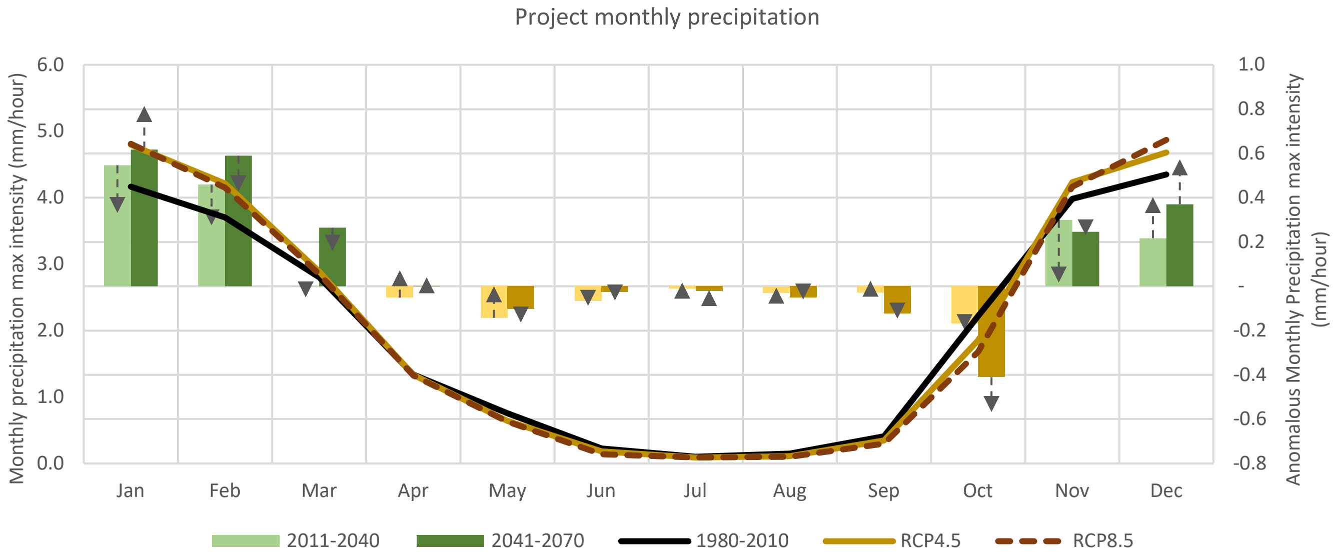
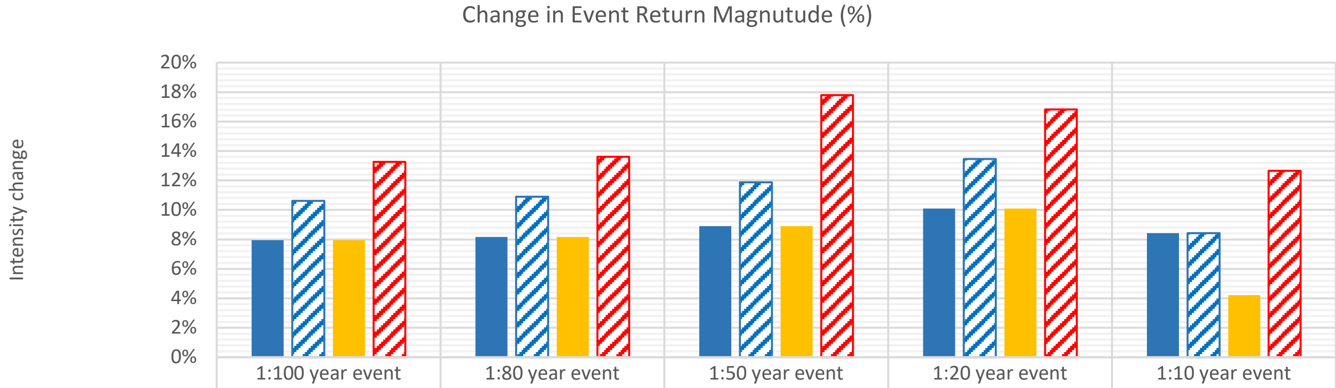


Figure 10. Monthly precipitation intensity climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (yellow solid line) and 8.5 (brown dashed line) for Bobirwa[62].



	1:100 year event	1:80 year event	1:50 year event	1:20 year event	1:10 year event
RCP4.5 - 2011-2040	7.95%	8.17%	8.90%	10.10%	8.43%
RCP4.5 - 2041-2070	10.61%	10.89%	11.86%	13.46%	8.43%
RCP8.5 - 2011-2040	7.95%	8.17%	8.90%	10.10%	4.22%
RCP8.5 - 2041-2070	13.26%	13.62%	17.80%	16.83%	12.65%

Figure 11. Change in extreme return event intensity using RCP 4.5 (blue) and 8.5 (orange) for Bobirwa[63].

Long term precipitation changes show a decrease of 1.12 and 8.0% in the mid-century (2041-2070) for RCP 4.5 and 8.5, respectively (Figure 6). This is anticipated to increase to 10–15% by 2100. There is wide variability in these annual precipitation projections with an upper range of an ~10% increase and a lower range of 30–35% decrease. This is indicative of the general trend of decreasing precipitation. The monthly projected precipitation shows a large decrease in the early onset events of October (Figure 7). This decrease is propagated further into the summer months until there are noted precipitation increases in January. February and March show some variation in total precipitation, though there is not a clearly defined trend direction.

The changes in the summer rains, for a projected warmer atmosphere, modifies the nature of the precipitation. Projections show a decrease in the occurrence of lower magnitude events (3.1–5.77 mm/day rainfall events) (Figure 8). The warmer atmosphere however is more conducive to higher volume rainfall events so there is a positive anomaly in the occurrence of larger scale events 16.3 mm/day and above. This is particularly the case under RCP 8.5. This rise in the number of larger magnitude daily events corresponds to an increase in the maximum hourly precipitation rate. Hourly intensity increases from ~5.26 mm/hour to between 5.7 and 5.83 - 6.02 in the mid-century, and up to 6.0 and 6.5 mm/hour under RCP 4.5 and 8.5, respectively by 2100 (Figure 9). While this is only a small change in peak magnitude, the intensities in leadup

[62] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[63] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

and tail of these events will also be enhanced to match the increased peak intensity. This intensity change is present (~0.5 mm/hour) from November through to March (Figure 10) despite the early onset rainfall volumes decreasing. These intensities are increased further under the RCP 8.5 scenario. This change in precipitation rate will change the magnitude of the extreme return events. The event returns show increases of intensity of between 4 and 18%for the return thresholds (Figure 11).

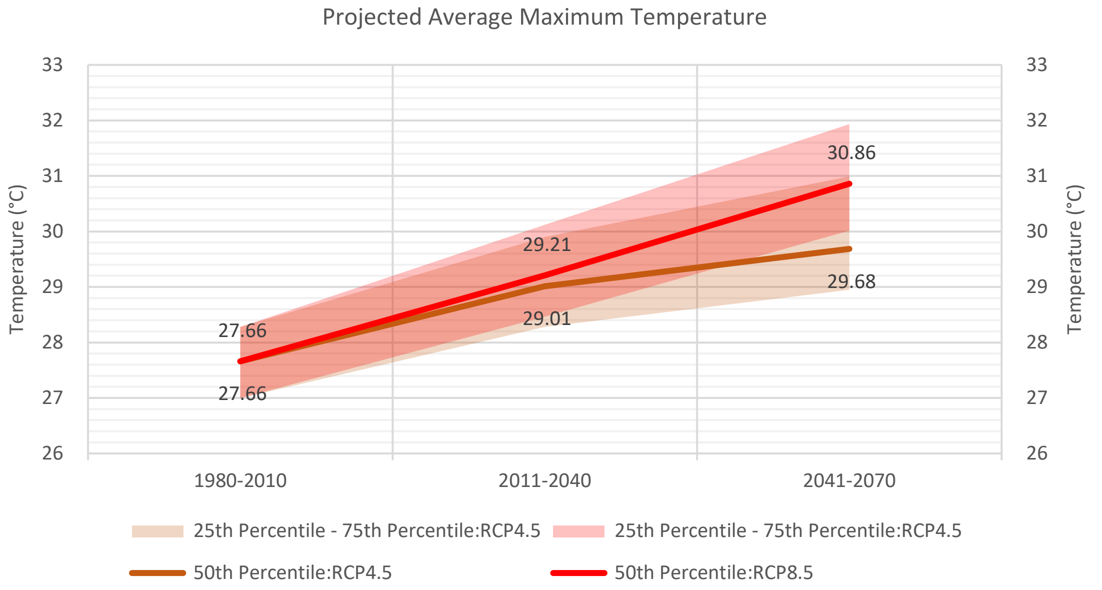


Figure 12. Long term average maximum temperature (1980-2010) and for projected (2011–2040 and 2041-2070)using RCP 4.5 (brown) and 8.5 (red) for Bobirwa[64].

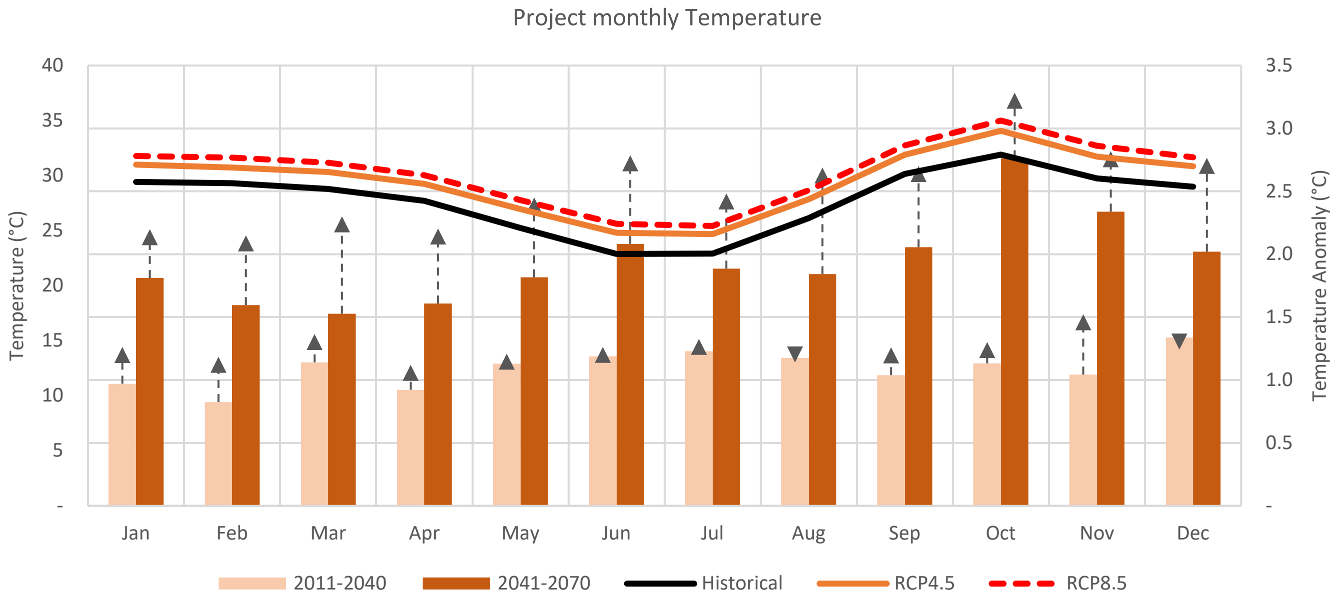


Figure 13. Monthly maximum temperature climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (brown solid line) and 8.5 (red dashed line) for Bobirwa[65].

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[64] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[65] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

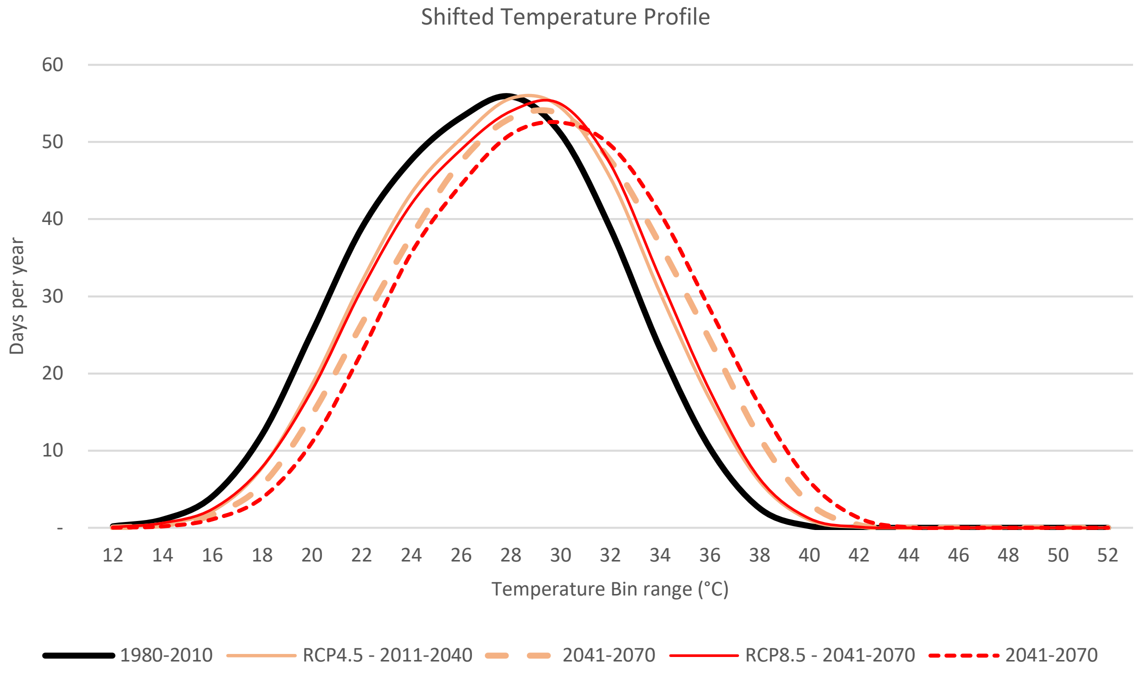


Figure 14. Temperature profile per decade from 1980 to 2090 using RCP 4.5 (left) and 8.5 (right) for Bobirwa[66].

Long term maximum temperatures are projected to increase in Bobirwa from ~27.6 to ~29.0-29.7 and 29.2-31°C under RCP 4.5 and 8.5 at the near and mid-century respectively (Figure 12). There is minimal change in the trend over time and both the mitigating and business as usual scenarios will lead to large increases in maximum average temperatures. The increasing trend is 0.25°C and 0.50°C per decade. This anomaly is greatest in October with up to 1.2-1.3°C and 2.8-3.3°C increases by 2070 under RCP 4.5 and 8.5, respectively (Figure 13). All other months show an increase of ~1°C, , and 2.2°C in 2030, and 2070, respectively for RCP 4.5. The RCP 8.5 scenario shows similar increases in 2030 and 2050 but rapidly increases thereafter. While the RCP 4.5 scenario anticipates emission stabilisation, RCP 8.5 continues without this emission reduction.

This maximum temperature increase changes the full temperature profile and temperatures are shifted towards the more extreme but previously rare events (Figure 14). This shift will increase the number of extreme temperature days (+40°C) from an average of <1 per year to ~2.5 and ~6 days per year by 2070, for RCP 4.5 and 8.5 respectively.

4.2 Climate changes in Ngamiland

Table 10. Projected Climate Change in Ngamiland

Temperature will increase: Average of 30.09°C Increase of 0.23 °C/decade, ±0.15 °C 95% confidence level
Frequency of drought will increase with an increase in SPI events in the very and extremely dry statues
Rainfall will be more uncertain, and overall precipitation may decrease. Average of 703mm/year. Decrease of 6.54mm/decade, ±20mm 95% confidence level
# of days over 30 degrees likely to increase from 98 to 219 by 2050
# of days over 40 degrees likely to increase from ~1 to 4.3 by 2050

Ngamiland, in the north of Botswana, has the highest baseline precipitation of 453–564 mm annually. The majority of this precipitation occurs as a result of convectively forced rainfall occurring over the peak summer months (Figure 15 A, B, C) with an average of 300–366 mm in these three months. Ngamiland has the highest

[66] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

seasonal variation (coefficient of variation) in Botswana with a very large degree of variability year on year in this region[67].

Precipitation volume is projected to decrease by 2050 across Botswana[68]. Projections suggest that rainfall is potential to decline across Ngamiland and gets drier in the northern part of the district by 19 mm annually (Figure 15 F)[69]. This is a low change in volume compared to the observational volume of ~396–563 mm. Additionally, when considered against the high levels of inter annual precipitation variability, this decrease is not clearly indicative of a long-term trend and may merely be a representation of the 2050 decade. However, precipitation in the peak summer months is set to increase by up to 13 mm in Qangwa, in the west of Ngamiland. Precipitation decreases are therefore mostly resigned to the shoulder seasons to account for the overall decreased annual volume. The seasonal variation is set to increase by 5–10%, further exposing the already highly variable area.

Ngamiland, is among the warmer areas in Botswana from a maximum temperature perspective with average maximum temperatures being ~33–35°C. Projected increased temperatures (Figure 15 I, J) show an increase of 3.3°C in the warmest months under RCP 4.5 by 2050. The minimum temperatures are also projected to increase, though to a slightly lesser extent than maximum temperatures. The diurnal range is projected to increase by ~0.2°C meaning night-time temperatures are closely tracking the higher day time temperatures.

[67] Kolawole OD, MR Motsholapheko, BN Ngwenya, O Thakadu, G Mmopelwa, D L Kgathi. 2016. Climate Variability and Rural Livelihoods: How Households Perceive and Adapt to Climatic Shocks in the Okavango Delta, Botswana. WEATHER, CLIMATE, AND SOCIETY, 8

[68] Republic of Botswana. 2011. Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). Available at: https://unfccc.int/resource/docs/natc/bwanc2.pdf

[69] Mayaud, J.R., *et al*. 2017. Modelled responses of the Kalahari Desert to 21st century climate and land use change. www.nature.com/scientific reports

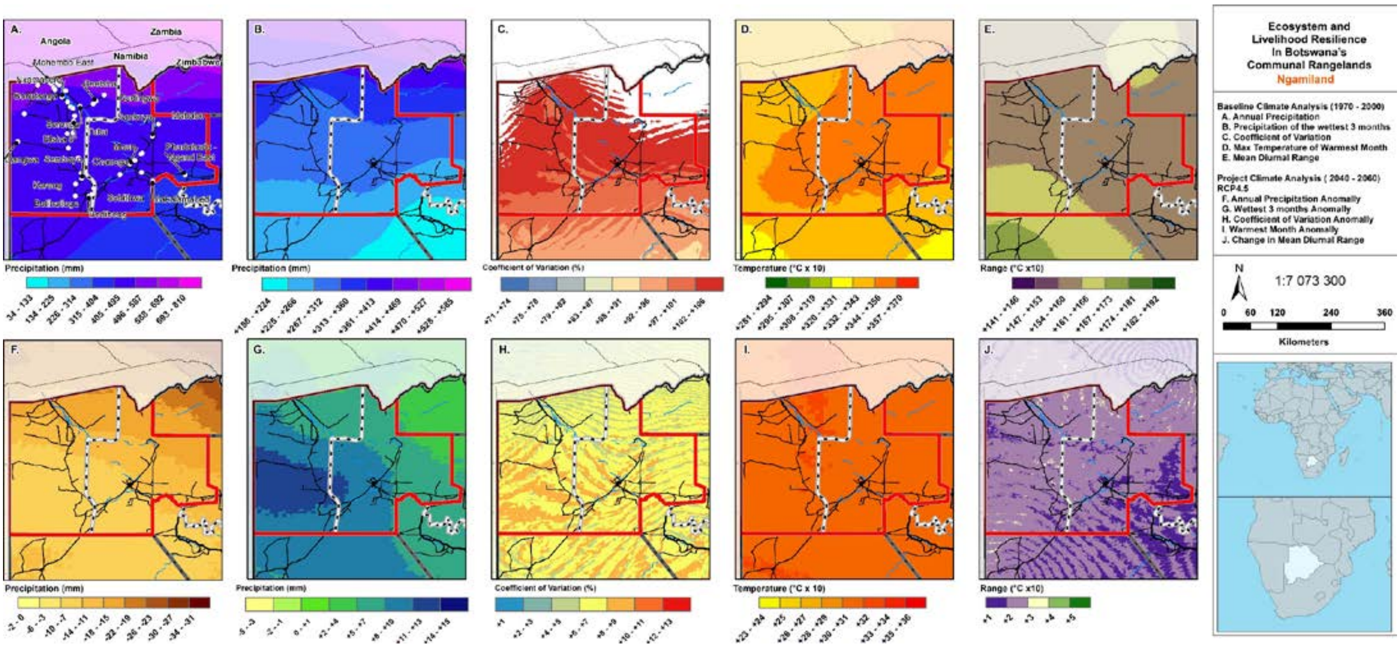


Figure 15. Current (top) and projected climate anomalies (bottom) for Ngamiland[70].

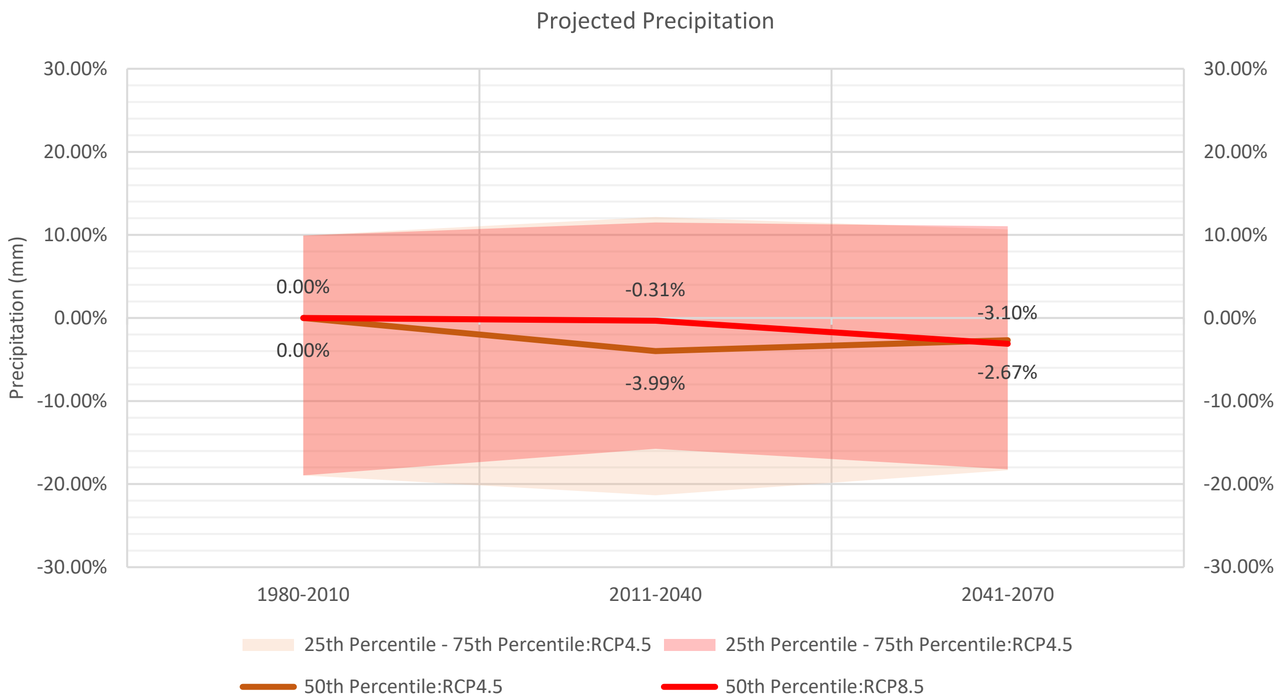


Figure 16. Long term precipitation percentage anomaly (1980-2010) and for projected (2011–2040 and 2041-2070)using RCP 4.5 (brown) and 8.5 (red) for Ngamiland[71].

[70] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

[71] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

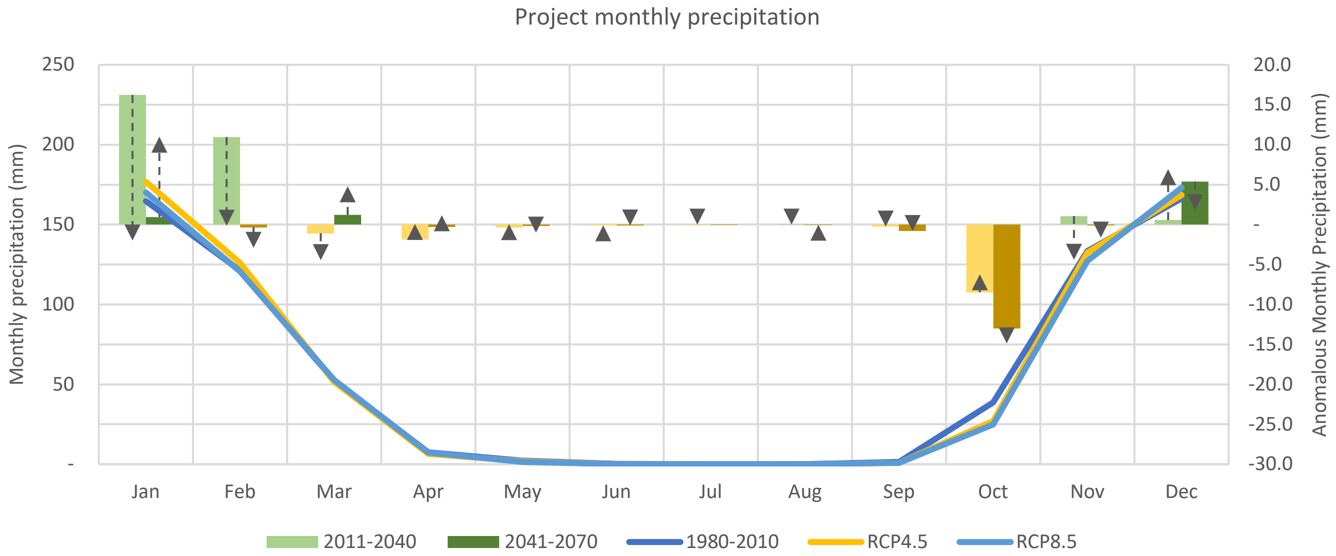
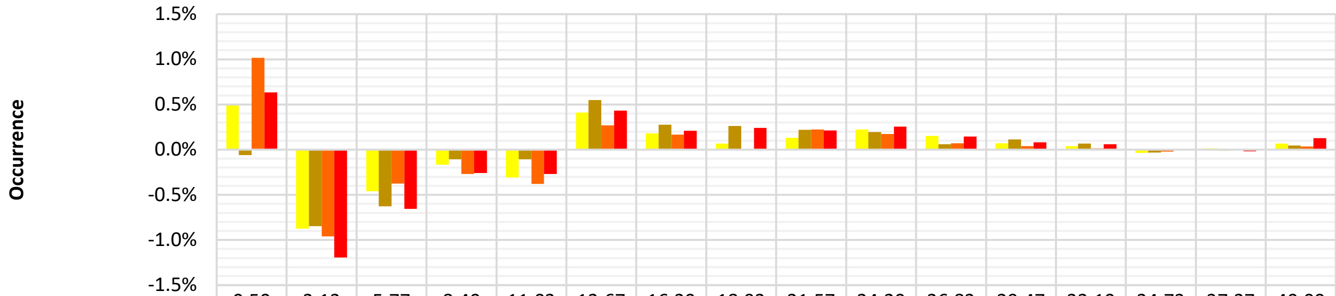


Figure 17. Monthly precipitation climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (yellow solid line) and 8.5 (brown dashed line) for Ngamiland[72].



	0.50	3.13	5.77	8.40	11.03	13.67	16.30	18.93	21.57	24.20	26.83	29.47	32.10	34.73	37.37	40.00
RCP4.5 - 2011-2040	0.49%	-0.88%	-0.46%	-0.17%	-0.31%	0.41%	0.18%	0.07%	0.13%	0.22%	0.15%	0.07%	0.04%	-0.04%	0.01%	0.07%
RCP4.5 - 2041-2070	-0.06%	-0.85%	-0.63%	-0.11%	-0.11%	0.55%	0.28%	0.26%	0.22%	0.19%	0.06%	0.11%	0.07%	-0.03%	-0.01%	0.05%
RCP8.5 - 2011-2040	1.02%	-0.96%	-0.37%	-0.27%	-0.38%	0.27%	0.17%	0.00%	0.22%	0.17%	0.07%	0.04%	0.01%	-0.02%	0.00%	0.03%
RCP8.5 - 2041-2070	0.63%	-1.20%	-0.66%	-0.26%	-0.27%	0.43%	0.21%	0.24%	0.21%	0.26%	0.14%	0.08%	0.06%	0.00%	-0.02%	0.13%

Bin range (mm)

Figure 18. Precipitation profile changes from observed (1980-2010) for projected (2011–2040 and 2041-2070)using RCP 4.5 (light blue) and 8.5 (blue) for Ngamiland[73].

[72] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[73] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

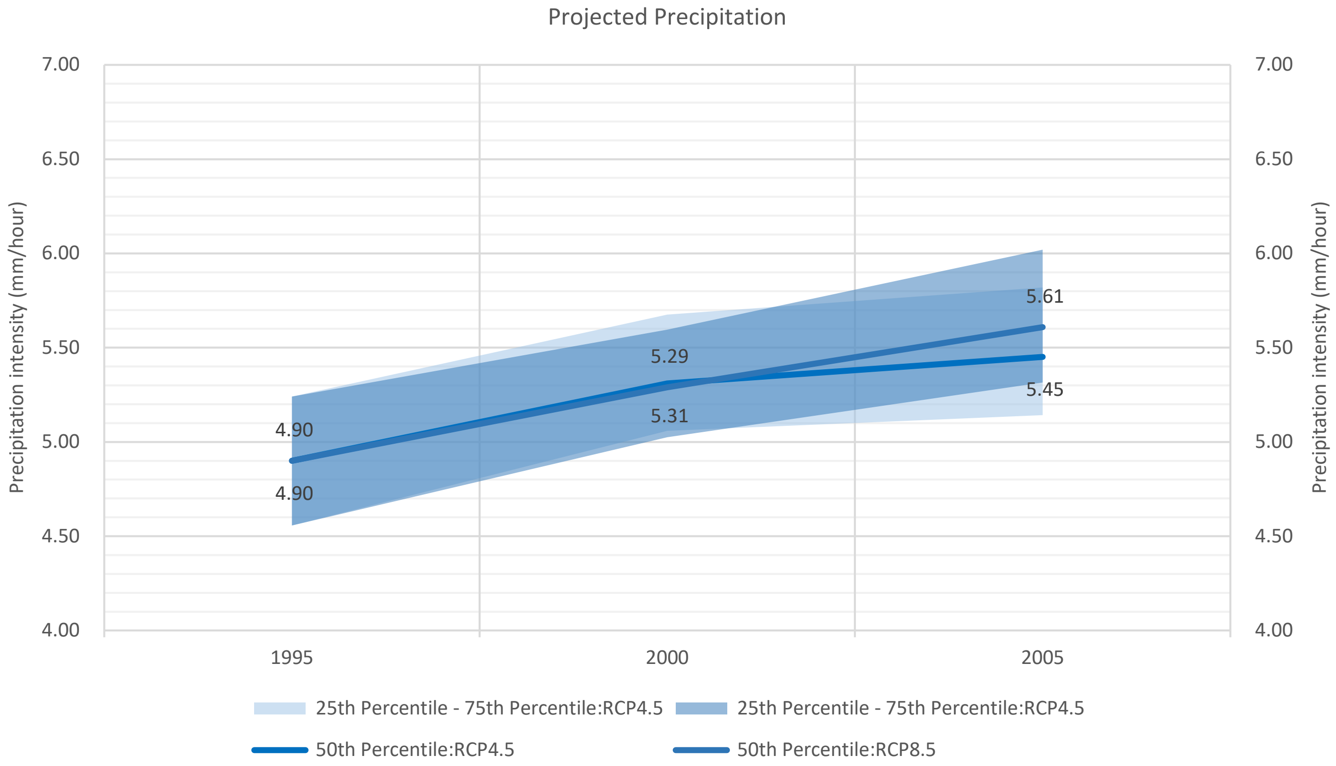


Figure 19. Long term precipitation intensity anomaly (1980-2010) and for projected (2011–2040 and 2041-2070)using RCP 4.5 (light blue) and 8.5 (dark blue) for Ngamiland[74].

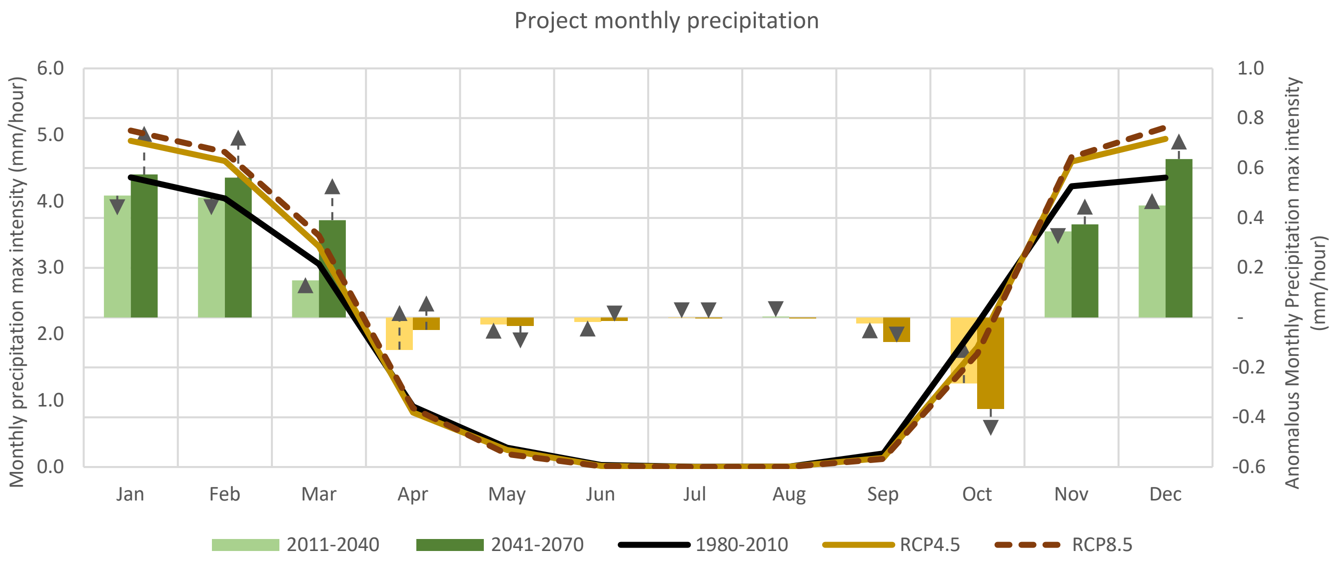
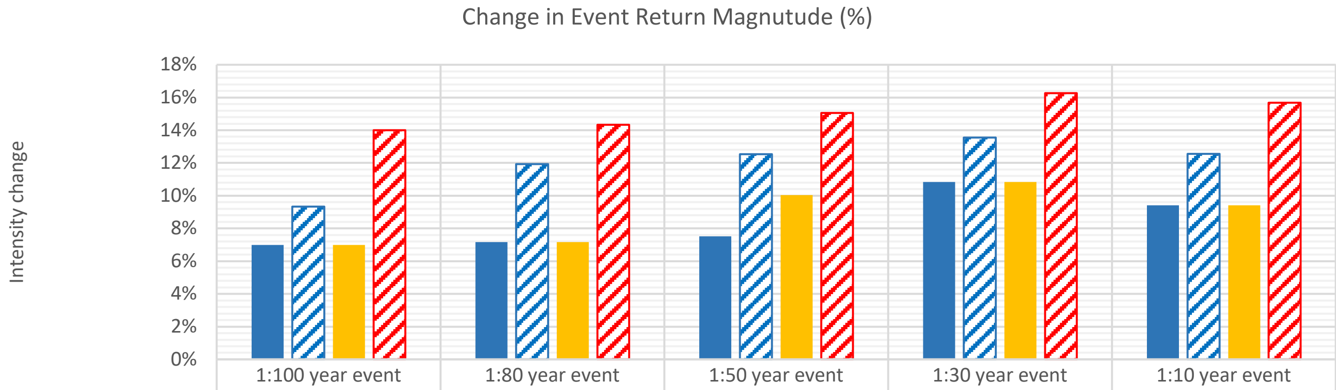


Figure 20. Monthly precipitation intensity climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (yellow solid line) and 8.5 (brown dashed line) for Ngamiland[75].

[74] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[75] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012



	1:100 year event	1:80 year event	1:50 year event	1:30 year event	1:10 year event
RCP4.5 - 2011-2040	7.00%	7.16%	7.52%	10.85%	9.41%
RCP4.5 - 2041-2070	9.33%	11.94%	12.54%	13.56%	12.55%
RCP8.5 - 2011-2040	7.00%	7.16%	10.03%	10.85%	9.41%
RCP8.5 - 2041-2070	13.99%	14.33%	15.05%	16.27%	15.68%

Figure 21. Change in extreme return event intensity using RCP 4.5 (blue) and 8.5 (orange) for Ngamiland[76].

Long term precipitation changes show a high degree of statistical variability with no definitive trend (Figure 16). Being an area of higher average total precipitation in the presence of the higher degree of interannual precipitation variability, there is a wide envelope of potential year-on-year variability (~20% either side of the mean). The monthly projected precipitation shows a decrease in the early onset events of October and to some extent in November. This is offset by monthly increases in volume in December and January (Figure 17). These monthly increases are however varied over time later in the century. The RCP 8.5 scenario shows an exemplification of the RCP 4.5 directional changes.

The changes in the summer rains changes the nature of the precipitation. Projections show a decrease in the occurrence of lower magnitude events (3.1–11.03 mm/day rainfall events) (Figure 18). The warmer atmosphere however is more conducive to higher volume events so there is a positive anomaly in the occurrence of larger scale events (13.67 mm/day and above). This shifted rainfall profile corresponds to an increase in the maximum hourly precipitation rate. Hourly intensity increases from ~4.9 mm/hour to between 5.45 and 5.61 mm/hour, under RCP 4.5 and RCP 8.5 respectively by the middle of the century (Figure 19). This is anticipated to increase to ~6mm/hour by 2100. This increase will alter the intensities in leadup and tail of these events. This intensity change is present (~0.5 mm/hour) from November through to February (Figure 20) despite the early onset rainfall volumes decreasing and wide variance in the projected summer total volumes. These intensities are further increased under the RCP 8.5 scenario. This change in precipitation rate will alter the magnitude of extreme return events. The event returns show an increase in intensity of ~7-14% for the 1:100-year events, 7.2-14.1% for 1:80-year events and between 7.75% and 16% for the remaining events (Figure 21).

[76] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

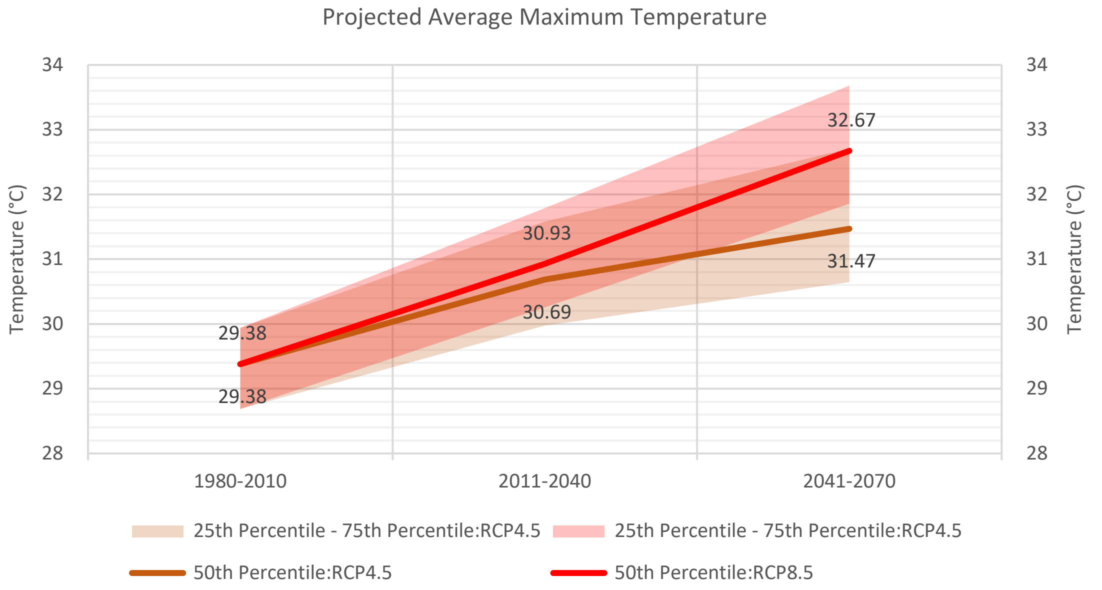


Figure 22. Long term average maximum temperature (1980-2010) and for projected (2011–2040 and 2041-2070)using RCP 4.5 (brown) and 8.5 (red) for Ngamiland[77].

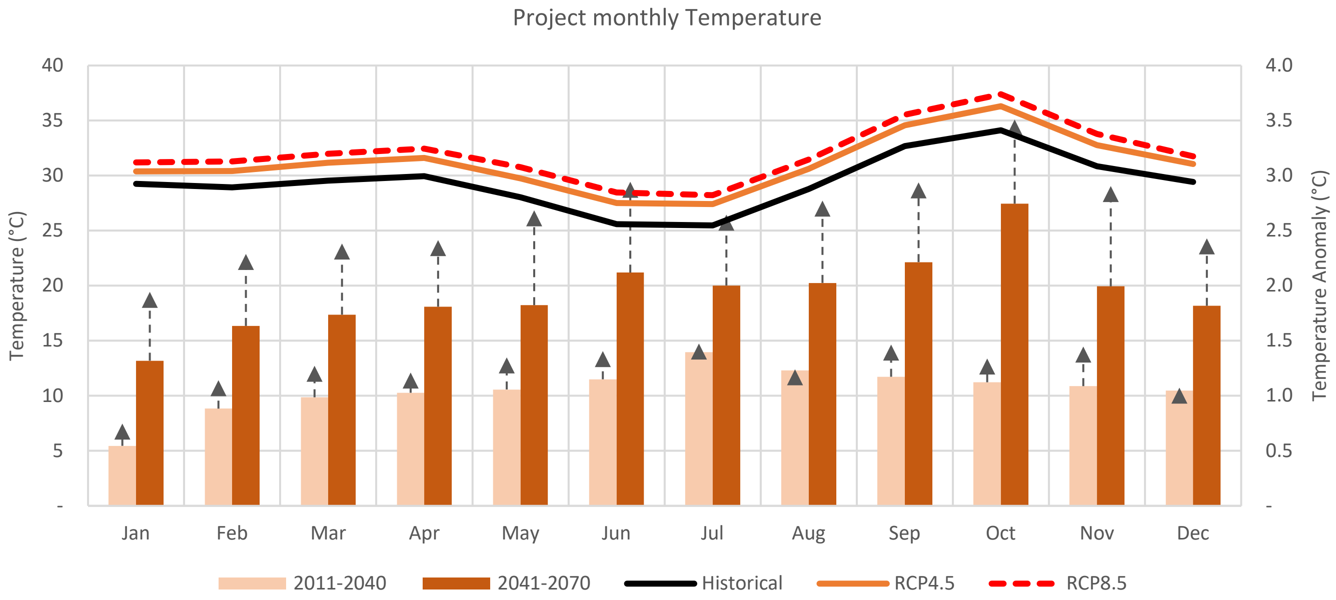


Figure 23. Monthly maximum temperature climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (brown solid line) and 8.5 (red dashed line) for Ngamiland[78].

[77] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[78] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

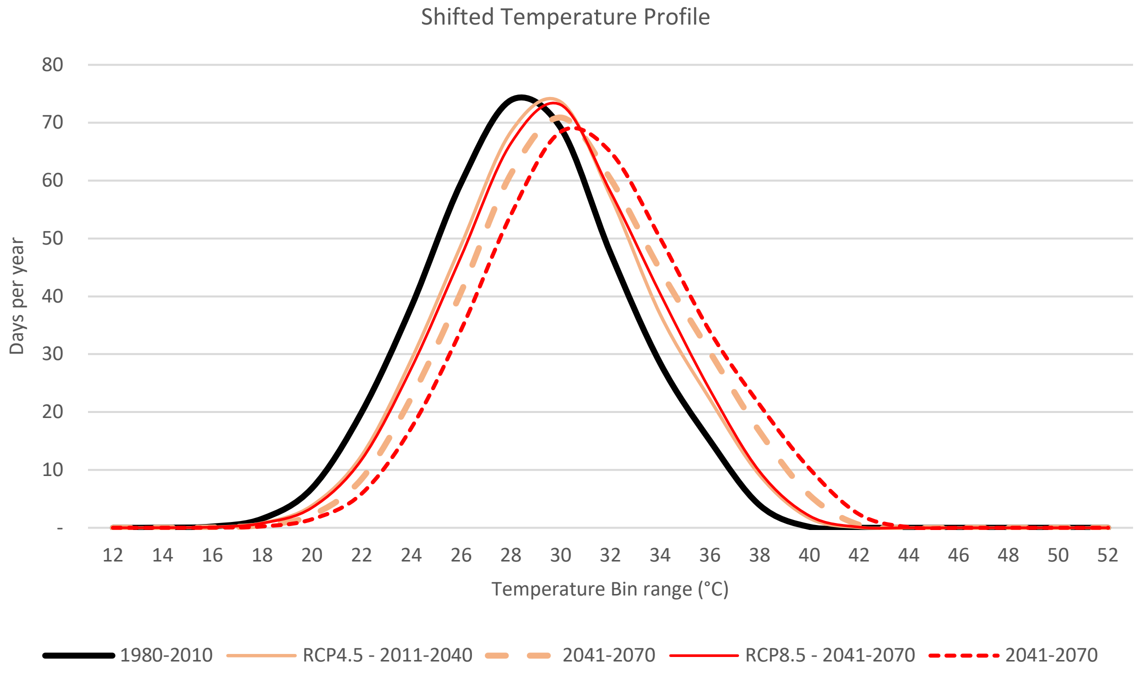


Figure 24. Temperature profile per decade from 1980 to 2090 using RCP 4.5 (left) and 8.5 (right) for Ngamiland[79].

Long term maximum temperatures are projected to increase in Ngamiland from ~29.4 to 30.7-30.9 and 31.5-32.7°C in the near and mid futures; this is anticipated to increase to 31.5°C and ~35.0°C, under RCP 4.5 and 8.5 respectively and the end of the century (Figure 22). This trend shows there is minimal change over time and both the mitigating and business as usual scenarios will lead to large increases in maximum average temperatures. This increase correlates to 0.26°C and 0.50°C increases per decade for RCP 4.5 and 8.5. This anomaly is greatest in October with up to 1.1-2.7°C and 1.3-3.5°C increases by 2040 and 2070, under RCP 4.5 and 8.5, respectively (Figure 23). All other months show this increase over time for RCP 4.5 and more so for the RCP 8.5 scenario after 2050.

This maximum temperature increase changes the full temperature profile and temperatures are shifted towards the more extreme but previously rare events (Figure 24). This shift will increase the number of extreme temperature days (+40°C) from an average of 1 per year to ~2 near future and ~6 and 10 days per year by 2070, for RCP 4.5 and 8.5 respectively.

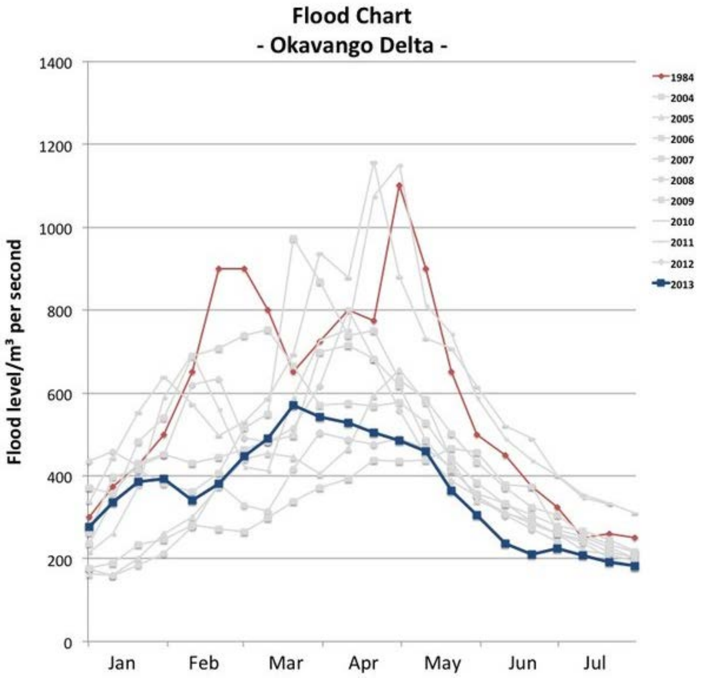
The climate projection in the Ngamiland area suggests clear increases in temperatures (both daily maximum and nightly minimum) and consequently enhanced evaporation. There is also likely greater variability in precipitation regimes with decreases in the early season. This decreased moisture availability, particularly if there was a weak flooding event leading into the fire season will also result in decreased humidity. Whether these fires are naturally occurring or anthropogenic in cause, the meteorological factors suggest an enhanced FDI, particularly in October such that if an event is triggered, the fire will be of greater severity. There will likely be an increase in the late fire season activity and/or intensity in the far north of Ngamiland and in the Delta area.

4.2.1 Okavango basin climate change analysis

Unlike Bobirwa and Kgalagadi, the Ngamiland ecosystem and its exposure to climate change extends beyond the climate within its location. The Okavango flooding, which comes from rainfall in Angola highlands, occurring each year provides much needed water to the very diverse delta ecosystem and contributes significantly to ecotourism for Ngamiland and Botswana nationally. This flood tends to arrive in the dry winter months (from April). The specific origin of this slow onset flood are the Moxico and Cuando Cubango provinces in Angola (Figure 25 left). Rainfall, temperature and evaporation in this region alters the delta flood event. The flood magnitude oscillates over the season (Figure 25 right) but also has variation in volume year-to-year. This is further complicated by the often-uncertain timing of the flood arrival in the delta. Although

[79] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

upstream water resources (mostly concentrated in Angola) are abundant in the Okavango River Basin, the mid and downstream sections of the basin are very dry. Research has elucidated that, under future climate change scenarios, the annual mean water flow for the period 2020–2050 will remain close to the present situation. For the periods 2050–2080 and 2070–2099, GCM simulations anticipated flow decreases of 23% and 26%, respectively. However, the uncertainty in the magnitude of simulated future changes remains high.



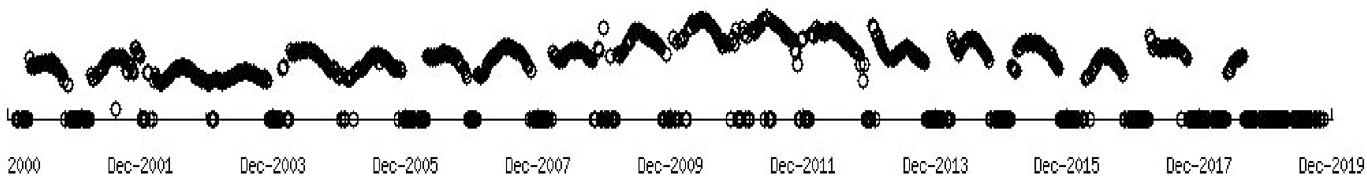


Figure 25. Okavango flood at hydrograph Mohembo 2004–2013[80] (left) and long-term flood fluctuation[81] (right).

[80] https://www.expertafrica.com/botswana/info/okavango-delta-flood/gallery

[81] Okavango Delta Monitoring and forecasting http://okavangodata.ub.bw/ori/

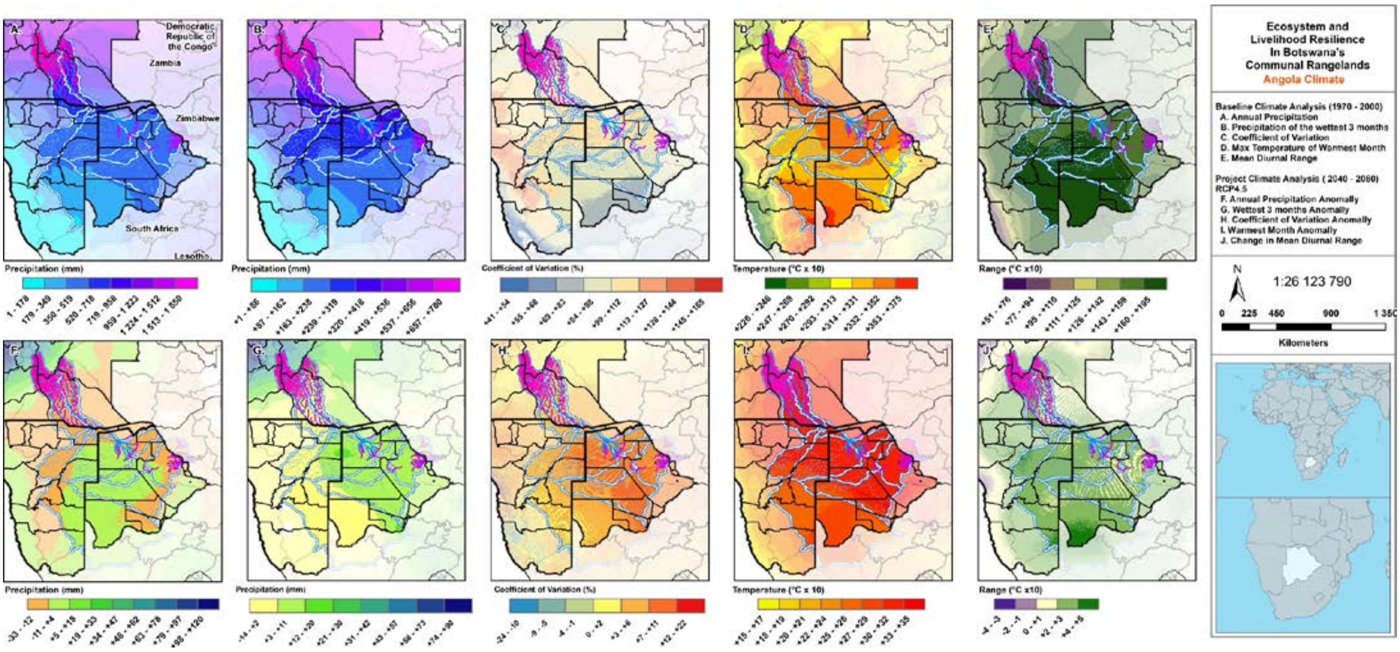


Figure 26. Okavango basin climate data current (top) and projected climate anomalies (bottom)[82].

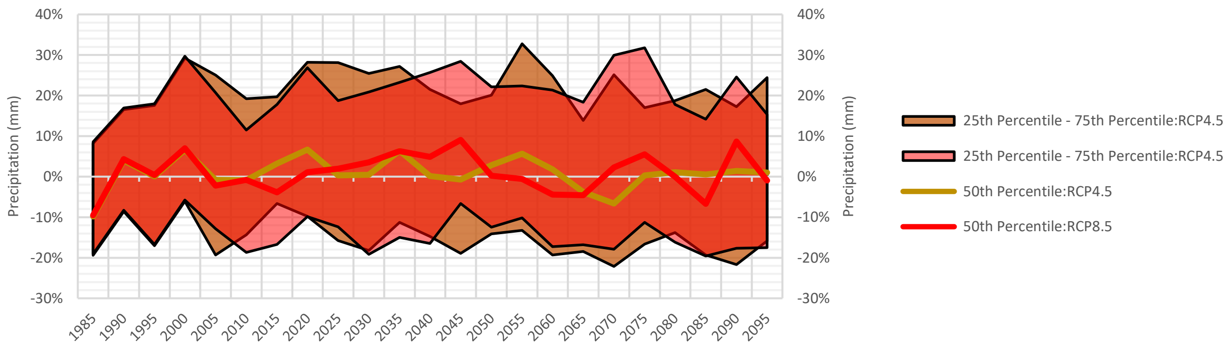


Figure 27. Long term precipitation percentage anomaly 1985–2100 using RCP 4.5 (brown) and 8.5 (red) for the delta catchment[83].

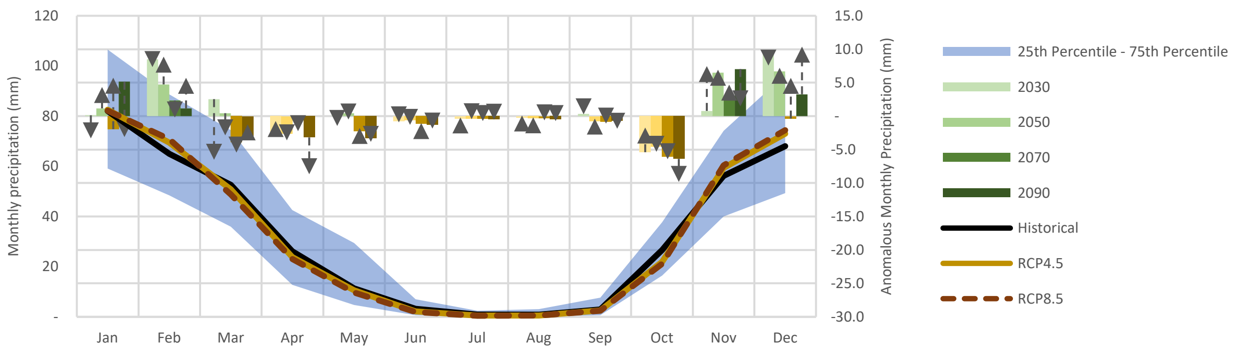


Figure 28. Monthly precipitation climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (solid yellow line) and 8.5 (brown dashed line) for the delta catchment[84].

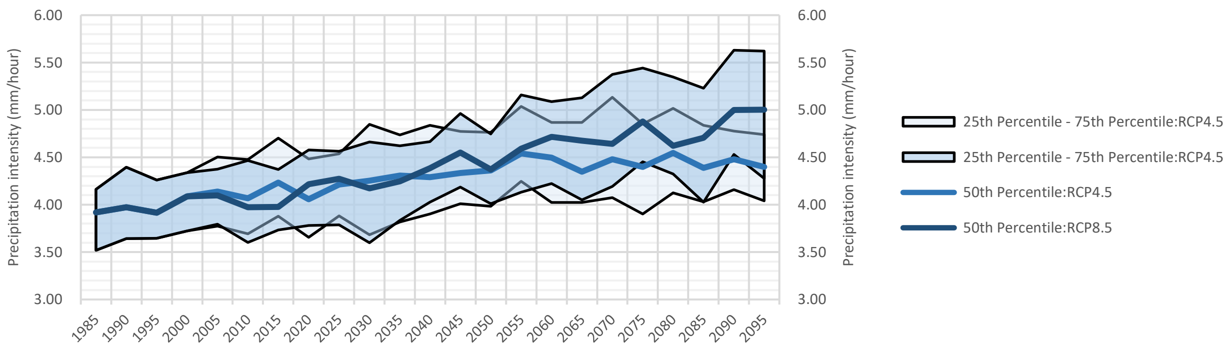
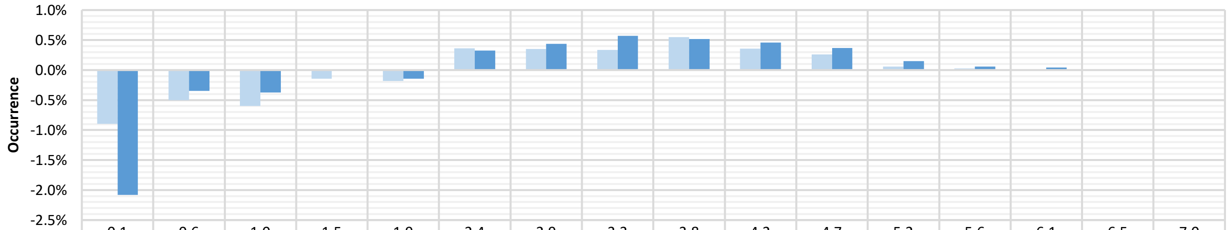


Figure 29. Long term precipitation intensity anomaly 1985–2100 using RCP 4.5 (light red) and 8.5 (dark red) for the delta catchment[85].



	0.1	0.6	1.0	1.5	1.9	2.4	2.9	3.3	3.8	4.2	4.7	5.2	5.6	6.1	6.5	7.0
rcp45	-0.89%	-0.50%	-0.60%	-0.15%	-0.18%	0.36%	0.35%	0.33%	0.55%	0.36%	0.26%	0.06%	0.02%	0.01%	0.00%	0.01%
rcp85	-2.08%	-0.35%	-0.37%	0.00%	-0.14%	0.32%	0.44%	0.57%	0.52%	0.46%	0.37%	0.15%	0.06%	0.04%	0.01%	0.01%

Figure 30. Precipitation intensity profile changes from observed (1985–2005) for projected (2030–2100) using RCP 4.5 (pink) and 8.5 (red) for the delta catchment[86].

Precipitation, temperature and evaporation in the Okavango basin plays a significant role in the nature of the delta flooding extent. The long-term projected precipitation trends do not show a particular tendency to either an increase or decrease over time, with less than a 1 mm per decade trend under the different RCP 4.5 and 8.5 scenarios. The extreme upper reaches of the basin sees a small increase of 18 mm per year, but in southern Angola (representing the upper, mid and lower reaches of the basin) as the flood event approaches the Namibian boarder, the negative anomaly is between -12 and -33mm per year (Figure 27). During the peak precipitation months, this anomaly is reduced to -8mm. It is likely that this drying trend in the upper, mid and lower reaches of the Okavango basin will offset the small increase in projected precipitation in the extreme upper catchment. The observed co-efficient of variation is quite high in the South Angola region. This is projected to increase under the RCP 4.5 2050 scenario. The precipitation will likely be more focussed into the peak season of November to February (Figure 28), with volume decreases noted in the onset month of October. This will enhance the high seasonal variation meaning the flood events may become more unpredictable. There is a general increase in maximum hourly precipitation over time (Figure 29). Hourly intensity increased from ~4 mm/hour to 4.5 and 5.0 mm/hour in 2100, under RCP 4.5 and 8.5 respectively. This increase is further noted in the intensity profile with decreased occurrence of the lower intensity events and an increase in the larger intensity events in the future (Figure 30). This shift is regardless enhanced under RCP 8.5.

[82] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

[83] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[84] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[85] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[86] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

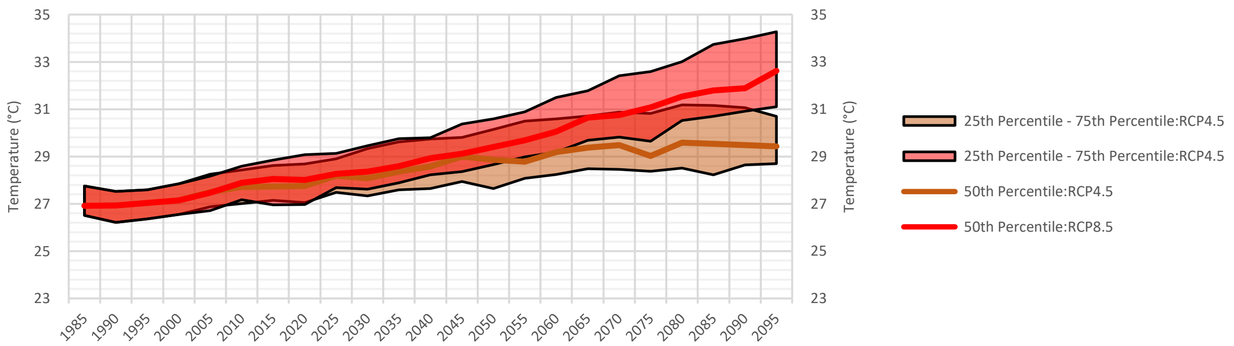


Figure 31. Long term average maximum temperature 1985–2100 using RCP 4.5 (brown) and 8.5 (red) for the delta catchment[87].

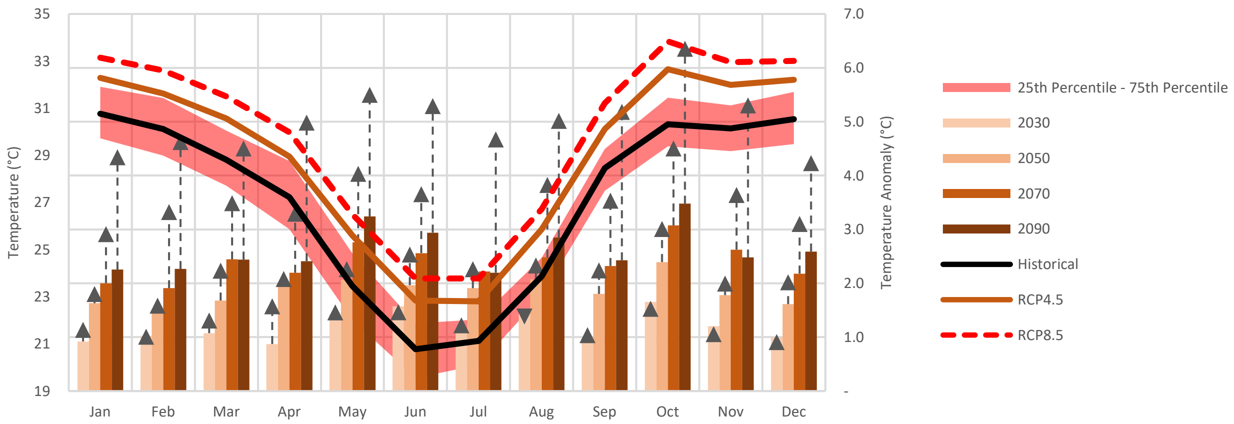


Figure 32. Monthly maximum temperature climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (brown solid line) and 8.5 (red dashed line) for the delta catchment[88].

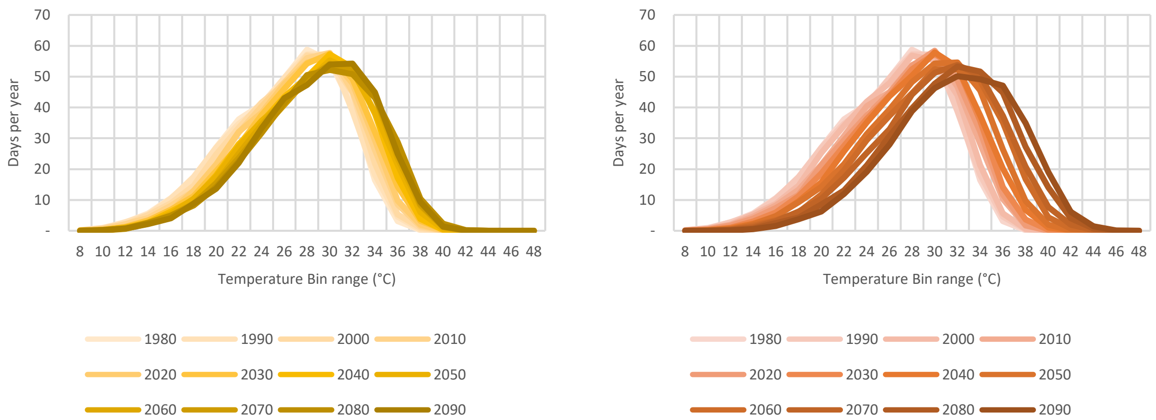


Figure 33. Temperature profile per decade from 1980 to 2090 using RCP 4.5 (left) and 8.5 (right) for the delta catchment[89].

The temperature change is more clearly increasing over time with the maximum average anomaly being ~3.3°C by 2050 under RCP 4.5 (Figure 31). This increase is further enhanced under RCP 8.5 to ~33°C by 2100. This increase occurs in every month with the largest increases being in October (Figure 32). This increase will be noted not only in the more extreme temperatures and heatwaves, but also through the full daily temperature profile — with the number of days per year with lower temperatures, decreasing over time, as the profile shifts towards higher temperatures (Figure 33). The median temperatures increase from 28°C to 30°C (RCP 4.5) and 32°C (RCP 8.5). There will be increases in the number of days above 36°C from ~3 to +20 days (RCP 4.5) and +40 days (RCP 8.5) by 2100. This increased temperature will result in an increase in evaporation of the shallow water slow moving flood.

[87] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[88] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[89] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

The increase in precipitation rate will likely increase overland flow and may result in faster moving flood events. However, there will likely be a delayed onset of the flooding. There will also be greater year-on-year precipitation variation. This coupled with the enhanced evaporation from warmer temperatures will further complicate the predictability of the flood magnitude.

4.3 Climate changes in Kgalagadi

Table 11. Projected Climate Change in Kgaligadi

Temperature will increase: Average of 28.09°C Increase of 0.28 °C/decade, ±0.17 °C 95% confidence level
Frequency of drought will increase with an increase in SPI events in the very and extremely dry statues
Rainfall will be more uncertain, and overall precipitation may decrease. Average of 474mm/year. Decrease of 6.81mm/decade, ±12mm 95% confidence level
# of days over 30 degrees likely to increase from 74.5 to 182 by 2050
# of days over 40 degrees likely to increase from ~0 to ~2.5 by 2050

Kgalagadi, in the south of Botswana, has the lowest average baseline precipitation ranging from 130 to 350 mm annually. The majority (81–243 mm) of this rainfall occurs in the warm summer months (Figure 34). Kgalagadi, with lower total precipitation, has the lowest year-on-year seasonal variability.

Precipitation volume is projected to decrease by 2050 in Kgalagadi by between 7 and 14 mm annually. The peak months show a slight increase of up to 5 mm in precipitation over the three months, as is noted in the other study areas (Figure 34 G). The low seasonal variability is also set to increase by up to 6% annually.

Maximum temperatures in Kgalagadi are the warmest in Botswana, particularly in the southernmost area which peaks at average maximum of 37.4°C. Maximum temperatures in Kgalagadi will likely increase by ~3.0°C by 2050 under RCP 4.5. The anomalous diurnal temperatures are the highest in the far south of Kgalagadi at ~0.5°C. Minimum temperatures are set to increase and track the changes in the higher day time temperatures but to a lesser degree, therefore increasing the diurnal range.

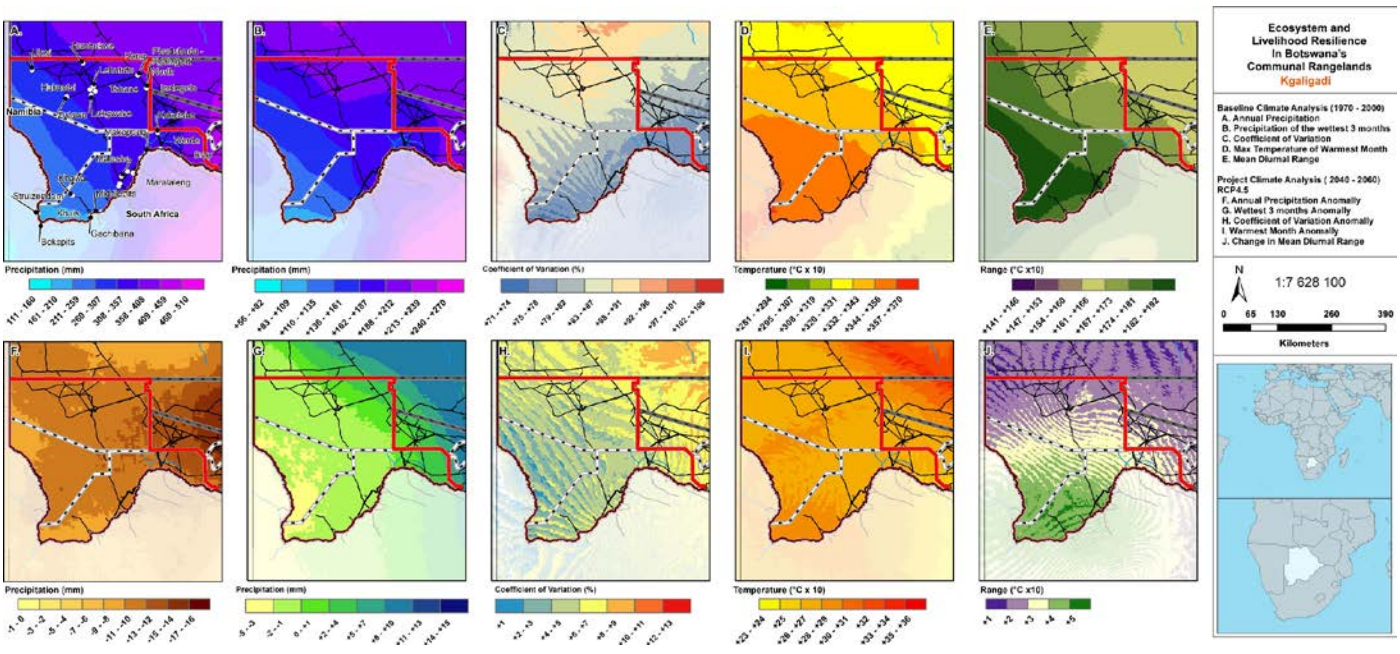


Figure 34. Current (top) and projected climate anomalies (bottom) for Kgalagadi[90].

[90] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

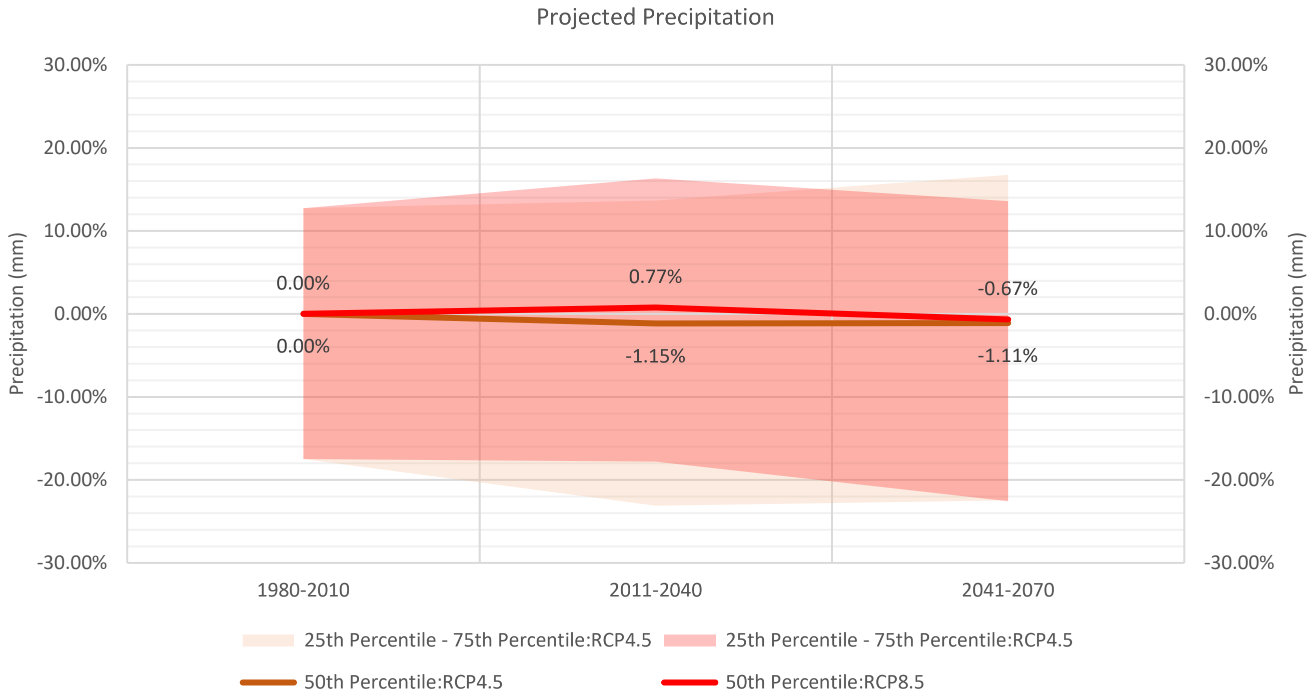


Figure 35. Long term precipitation percentage anomaly (1980-2010) and for projected (2011–2040 and 2041-2070). RCP 4.5 (orange) and 8.5 (red) for Kgalagadi[91].

[91] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

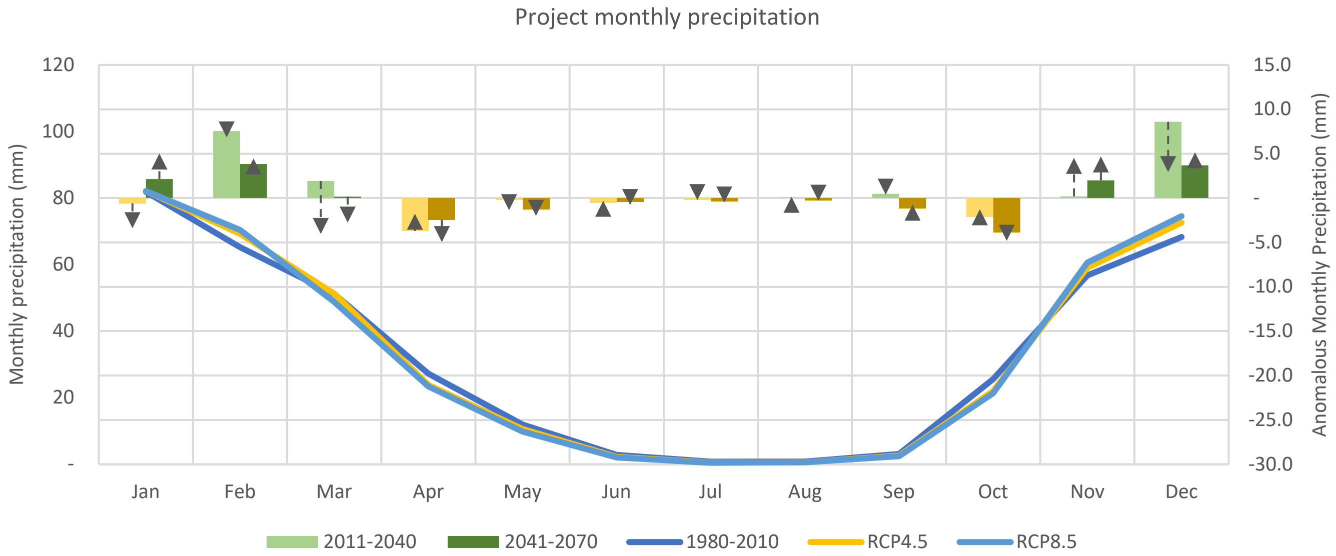
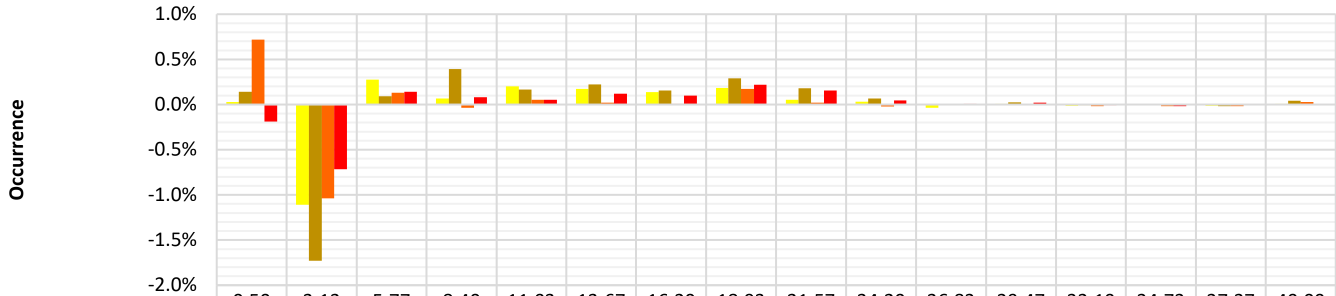


Figure 36. Monthly precipitation climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (yellow solid line) and 8.5 (brown dashed line) for Kgalagadi[92].



	0.50	3.13	5.77	8.40	11.03	13.67	16.30	18.93	21.57	24.20	26.83	29.47	32.10	34.73	37.37	40.00
RCP4.5 - 2011-2040	0.03%	-1.11%	0.27%	0.07%	0.20%	0.17%	0.14%	0.18%	0.05%	0.03%	-0.03%	0.01%	-0.02%	0.00%	-0.01%	0.01%
RCP4.5 - 2041-2070	0.14%	-1.73%	0.09%	0.39%	0.16%	0.22%	0.16%	0.29%	0.18%	0.07%	-0.01%	0.02%	-0.01%	-0.01%	-0.02%	0.04%
RCP8.5 - 2011-2040	0.72%	-1.04%	0.13%	-0.04%	0.05%	0.02%	0.01%	0.17%	0.02%	-0.02%	0.00%	0.00%	-0.02%	-0.02%	-0.02%	0.03%
RCP8.5 - 2041-2070	-0.19%	-0.71%	0.14%	0.08%	0.05%	0.12%	0.10%	0.22%	0.15%	0.05%	0.01%	0.02%	-0.01%	-0.02%	-0.01%	0.00%

Bin range (mm)

Figure 37. Precipitation profile changes from observed (1980-2010) for projected (2011–2040 and 2041-2070)using RCP 4.5 (pink) and 8.5 (red) for Kgalagadi[93].

[92] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[93] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

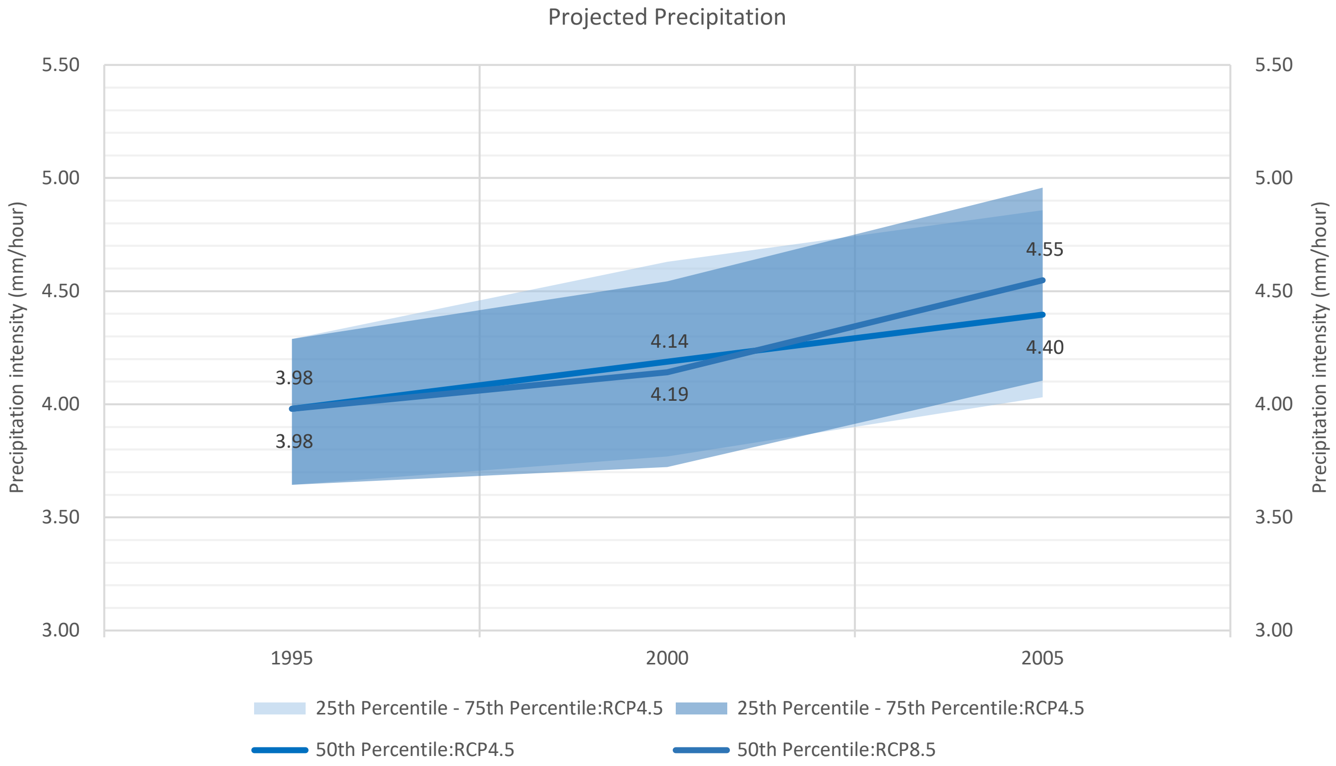


Figure 38. Long term precipitation intensity anomaly (1980-2010) and for projected (2011–2040 and 2041-2070)using RCP 4.5 (light blue) and 8.5 (dark blue) for Kgalagadi[94].

[94] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

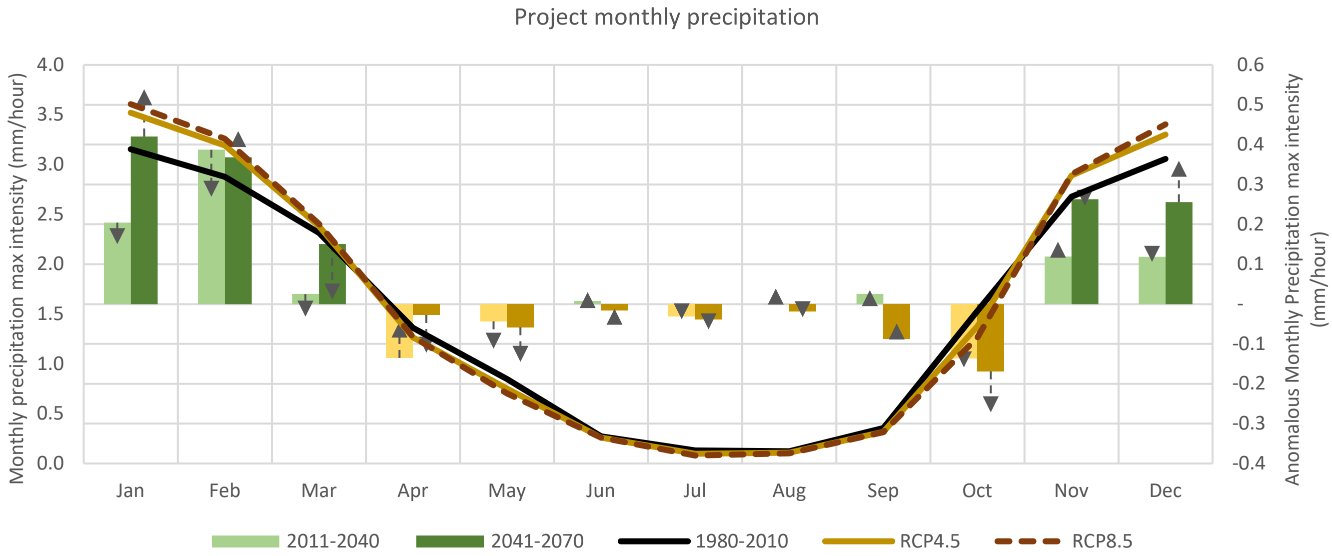
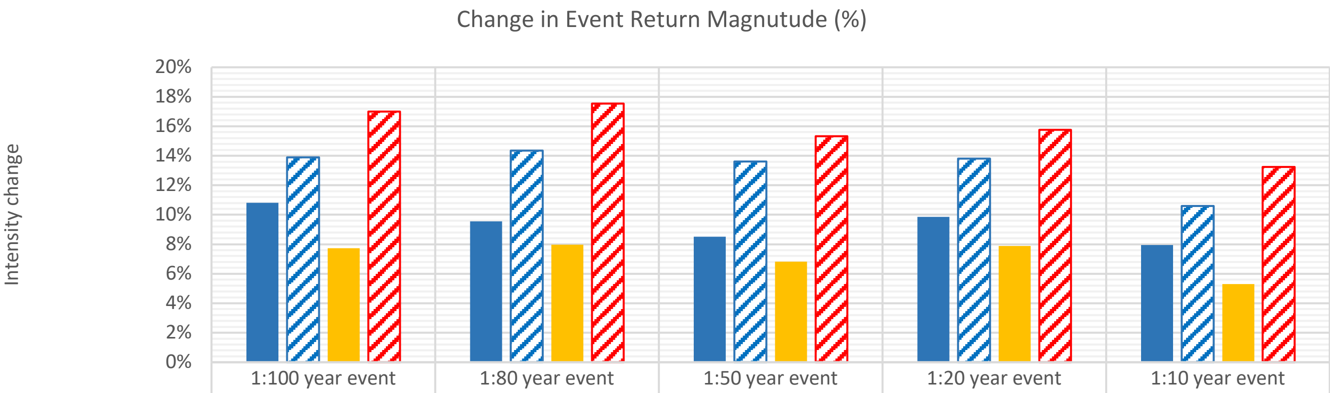


Figure 39. Monthly precipitation intensity climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (yellow solid line) and 8.5 (brown dashed line) for Kgalagadi[95].



	1:100 year event	1:80 year event	1:50 year event	1:20 year event	1:10 year event
RCP4.5 - 2011-2040	10.81%	9.56%	8.51%	9.85%	7.95%
RCP4.5 - 2041-2070	13.90%	14.35%	13.62%	13.80%	10.60%
RCP8.5 - 2011-2040	7.72%	7.97%	6.81%	7.88%	5.30%
RCP8.5 - 2041-2070	16.99%	17.53%	15.32%	15.77%	13.25%

Figure 40. Change in extreme return event intensity using RCP 4.5 (blue) and 8.5 (orange) for Kgalagadi[96].

The low projected spatial annual precipitation anomaly of -7 to -14 mm (Figure 34 F) is not consistent over a long enough period to present a definitive decreasing statistical precipitation trend (Figure 35), with the 50th percentile change being variable about the climatological mean. The small increases in the summer months are noted in the slight increased volume from November to February. As with the other areas, early season sees a decrease in volume resulting in a likely delayed onset (Figure 36).

These monthly changes also are present in the nature of the precipitation. Projections show a decrease in the occurrence of lower magnitude events of 3.13 mm/day but an increasing occurrence of the larger scale events (5.77 mm/day and above) (Figure 37). This shift to larger events increases the maximum hourly precipitation rate. Hourly intensity increases from ~4.0 mm/hour to between 4.2 and 44-4.55 mm/hour at mid-century and up to 4.5 and 5.0 mm/hour under RCP 4.5 and 8.5, respectively by the end of the century (Figure 38). This intensity change is present consistently from November through to February (Figure 39). This change in precipitation rate will change the magnitude of the extreme return events. The event returns show increases in intensities of between 7.9 to 17% for the larger return event (Figure 40).

[95] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[96] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

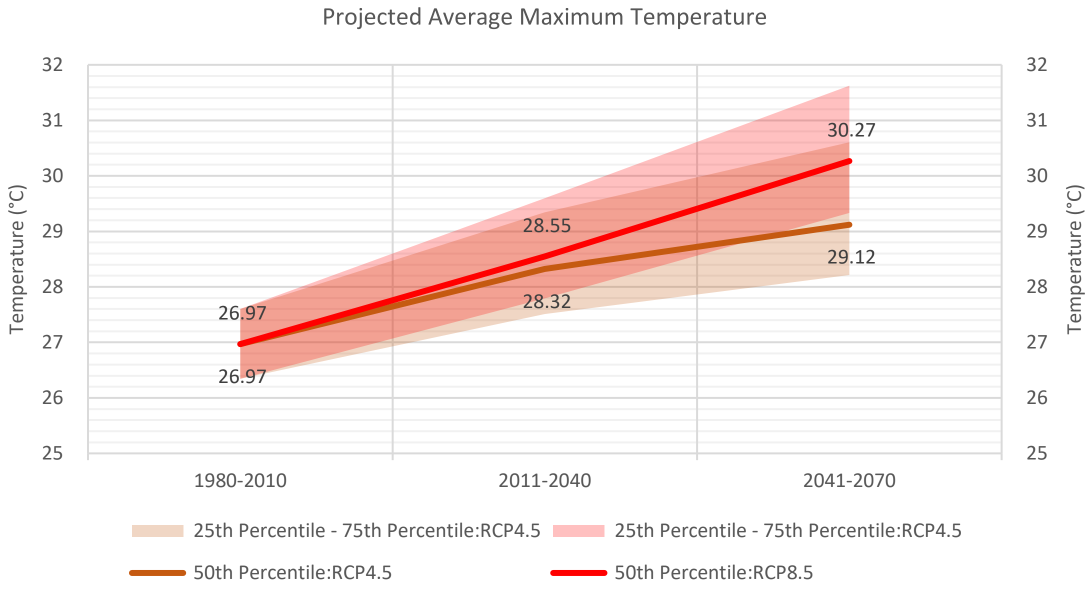


Figure 41. Long term average maximum temperature (1980-2010) and for projected (2011–2040 and 2041-2070)using RCP 4.5 (brown) and 8.5 (red) for Kgalagadi[97].

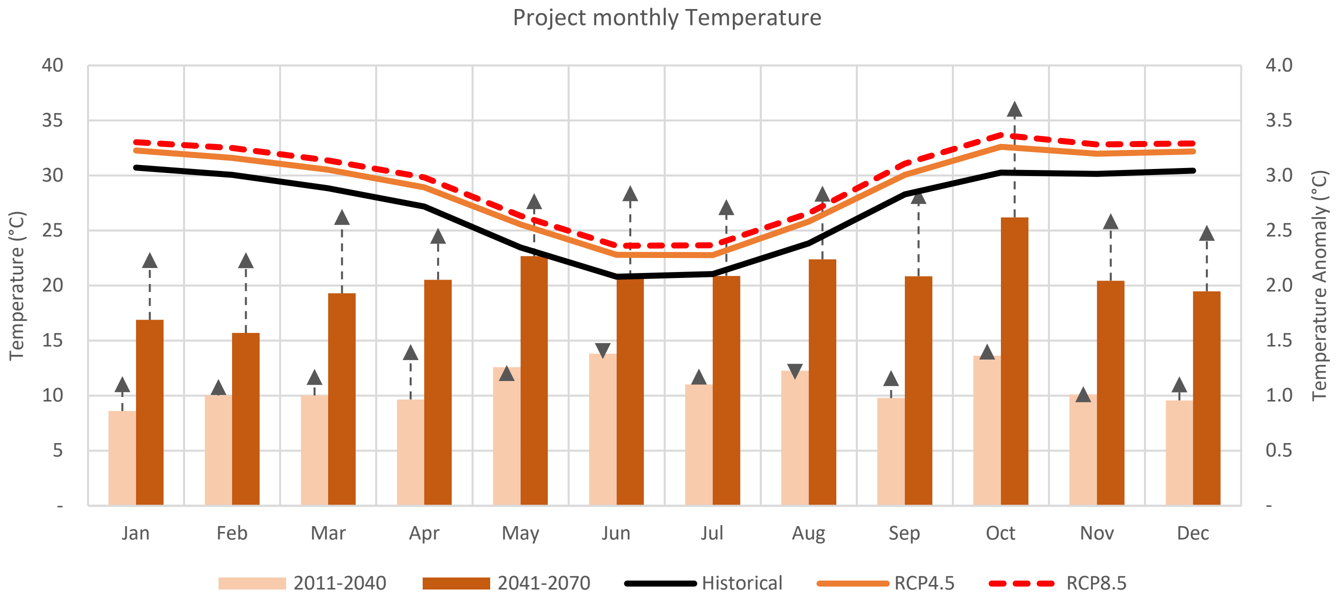


Figure 42. Monthly maximum temperature climatology (left axis) and monthly decadal anomaly (right axis) using RCP 4.5 (brown solid line) and 8.5 (red dashed line) for Kgalagadi[98].

[97] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

[98] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

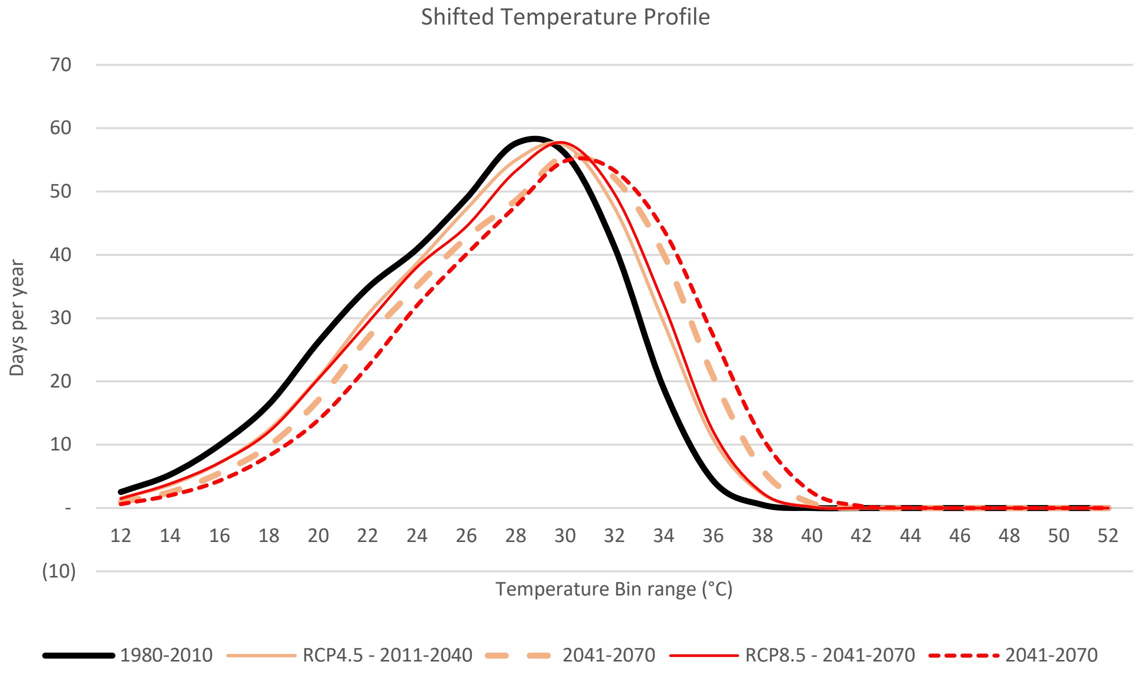


Figure 43. Temperature profile per decade from 1980 to 2090 using RCP 4.5 (left) and 8.5 (right) for Kgalagadi[99].

Long term maximum temperatures are projected to increase in Ngamiland from ~27 to 28.3-25.6 (near future) and to 29.1-30.27 (mid-century) and to 29.5°C and ~33°C (end century), under RCP 4.5 and 8.5 respectively (Figure 41). These increases occur each month but are highest in October. The anomaly is greatest in October with up to 2.6 – 3.6 °C at the mid-century and 3.4°C and 6.5°C increases by 2090 under RCP 4.5 and 8.5, respectively (Figure 42). The maximum temperature increase changes the full temperature profile and temperatures are shifted towards the more extreme but previously rare events (Figure 43). This shift will increase the number of extreme temperature days (+40°C) from < 1per year to ~3.0 by the mid-century and up to ~27 days per year, by 2100.

[99] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012

4.4 FAO and WRI exposures indices

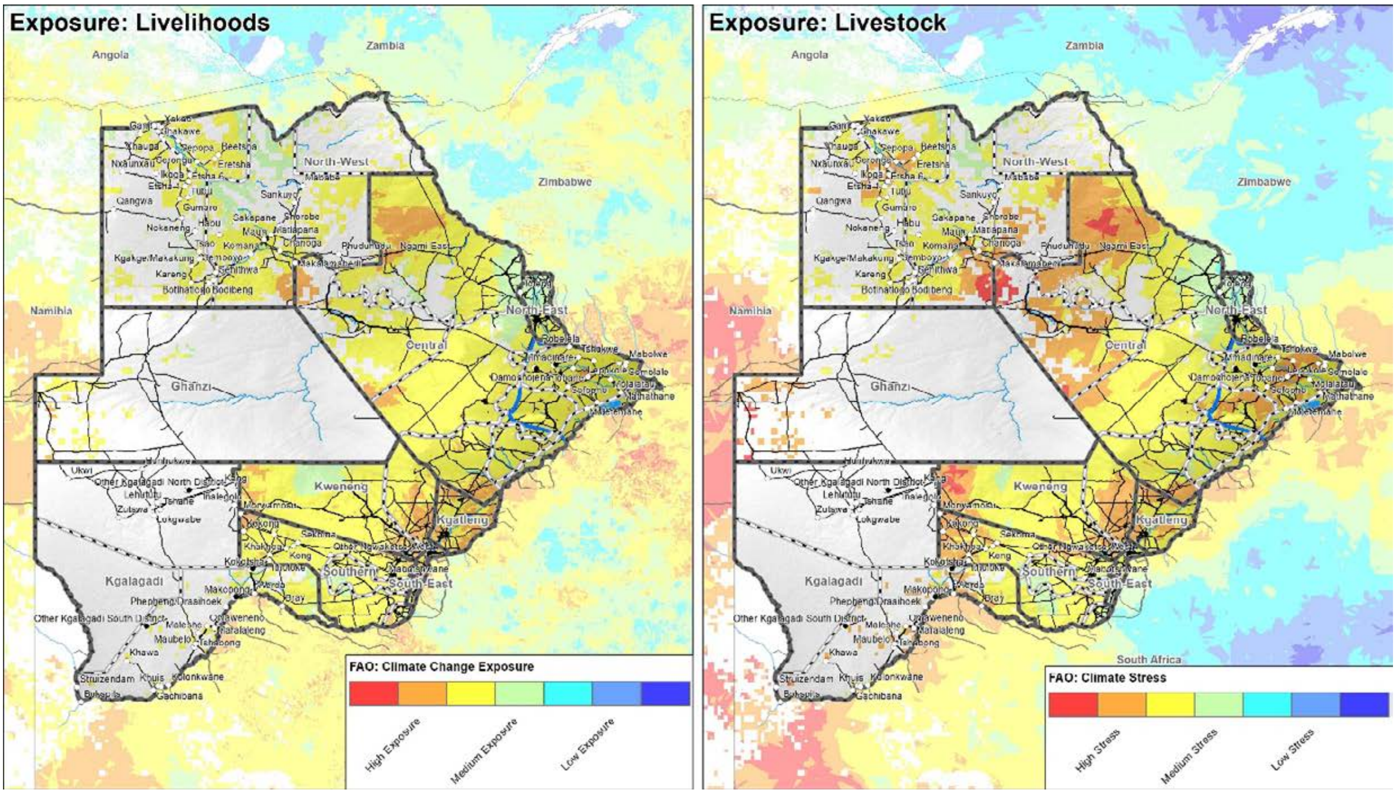


Figure 44. Livelihood and livestock custom exposures[100].

It is important to understand exposure of climate effects on livelihood strategies that are the target of the project, namely livestock farming. The FAO analysis exposure is an index (Figure 44 left) that calculates the potential commutative impact on people, livestock and agriculture by spatial density, as a result of climatic stresses. Areas of larger population, higher infrastructure density or area under agriculture will have a higher element at risk index. Livestock being more mobile are assessed by the climate stress index (Figure 44 right) and are less influenced by spatial population densities. The climate stress is predominantly precipitation exposure focussed but considers factors that have highly correlated relationships with agriculture suitability and ecosystem function. The metrics that make up the climate stress are interannual rainfall seasonal variation, probability of precipitation being 300 mm or less, reliable annual precipitation, rainfall trend coefficient and the negative years of Standardised Precipitation Index (SPI).

Noted areas of increased exposure and stress are those that correspond to the principle climate anomalies with a large driver being the increase in maximum temperature, decreased annual precipitation, and increased coefficient of variation (seasonal variation) being more prominent in the northern part of the country (RCP 4.5 2050). This data was used as an exposure component for the livelihoods and livestock primary CCVA analysis. However, where local statistics are not reported, these indices have data gaps. This data was therefore augmented with the WRI data as an alternative set of indicators.

[100] Exposure Index (2010) - ClimAfrica WP4 http://www.fao.org/geonetwork/srv/en/main.home

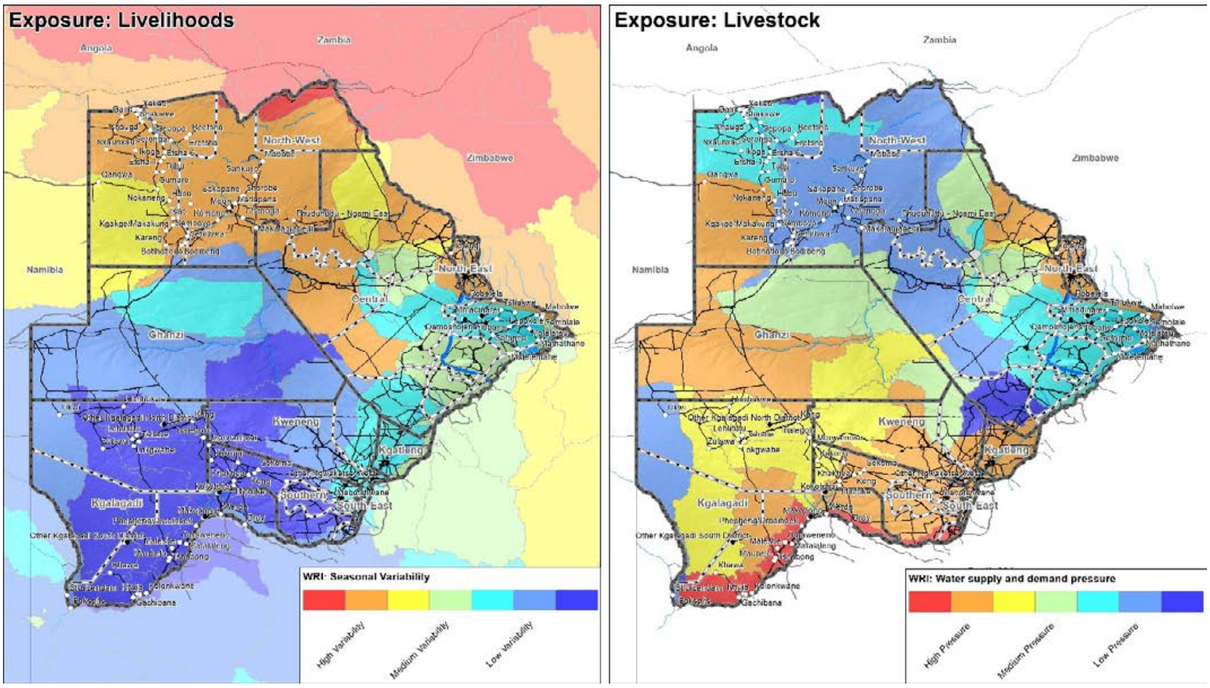


Figure 45. WRI livelihood and livestock exposures[101].

The need for alternative indicators allowed for further targeted assessment. The seasonal variability (Figure 45 left) would compromise a livelihood that relied on consistent or predictable precipitation. Areas further to the south, while having reduced annual and peak seasonal precipitation, also have smaller projected precipitation anomalies and will be less variable. The precipitation coefficient variation[102] is lower in the south under current conditions and lower under projected conditions. Livestock compete with humans for water resources and therefore increase the water supply and demand pressure exposure (Figure 45 right). Areas of lower pressure are the urban centres and the areas in the further north with increased precipitation. The more remote areas, particularly in the south corresponding to lower rainfall totals have the highest water supply and demand pressure.

5 Climate Change Vulnerability assessments

5.1 Summary of climate change vulnerability assessments

A considerable proportion of livelihoods in the rural areas of the target subdistricts are agriculturally based and therefore reliant on sufficient and reliable rainfall and water security. The projected climate changes in these areas are anticipated to further expose communities and livelihoods from a year on year variability and drought potential. In 2015, the total district populations of the target areas were approximately 150,000, 51,000 and 72,000 for Ngamiland, Kgalagadi and Central Bobonong (where Bobirwa is located), respectively. Across Botswana the total number of small-scale livestock holdings in 2015 were ~38,000, with the number of holdings for Ngamiland, Kgalagadi and Central Bobonong being approximately 9,300, 3,400 and 5,600, respectively. No information on the total area of communal rangelands and the number of villages has been included as part of the 2015 agricultural census.

The current social vulnerability of pastoral communities with target areas varies widely, with this variation resulting from differences in, inter alia, unemployment and illiteracy rates, access to sanitation, access to water sources and reliance on electricity. In Bobirwa alone, for example vulnerability scores ranged from very low to low and high to extreme. Kgalagadi North and South's current vulnerability scores were generally lower than the other study areas. Regarding future vulnerability, the cumulative impacts — with enhanced increased precipitation variability and drought severity considered as greater contributors to social exposure than more rare flooding events with more severe impacts — are higher in Kgalagadi and Bobirwa and slightly lower in Ngamiland.

[101] Aqueduct Global Maps 3.0 Data, https://www.wri.org/aqueduct/data - RCP 4.5 2040

[102] Likely (standard deviation) year-on-year precipitation range

The components of livelihood vulnerability are based largely on climate variability and ecosystem health. The resilience of livelihoods relying on ecosystem health is highly correlated to the sensitivity of soil moisture, with this being very high throughout Botswana. Bobirwa, with the middle range for precipitation, is moderately exposed to shifts in seasonal variation, but is highly sensitive to soil moisture. In Kgalagadi, vulnerability appears to be high in settlements dominated by San ethnic groups. Communities in Ngamiland whose livelihoods are heavily reliant on rainfall are most vulnerable due to a likely increase in competition for water resources.

The climate and soils in the Bobirwa environment are most suitable for medium-high and low-medium value grazing grass species. In Ngamiland, the lands around the Okavango delta and Sehithwa are well-suited for grasses of high grazing value. Outside of these regions the suitability is limited in Ngamiland. The Kgalagadi ecosystem has the lowest overall suitability for both grasses of high or low grazing value. Regarding future rangeland vulnerability, Bobirwa shows consistent decreased suitability of both medium-high and low-medium value grazing grass species. Low-medium value grazing grass species show a large decrease in suitability in Ngamiland, except for some of the north eastern areas. Kgalagadi, which already had low species suitability, sees this suitability further decrease in the future except for the furthest south areas for low-medium value grazing grass species.

Regarding livestock vulnerability, in Bobirwa current sensitivity is low to medium. However, future vulnerability will increase because of high dependence on surface water which is highly variable depending on river flows. The adaptive capacity in Bobirwa is considered low to medium. In Kgalagadi, sensitivity is medium to high and future vulnerability is low to medium in most areas. Ngamiland has a medium adaptive capacity.

5.2 Detailed climate vulnerability assessments

The following sections groups the varying indices of sensitivity and adaptive capacity under each of the vulnerability assessments for the social, livelihoods, livestock and rangeland vulnerabilities. Vulnerability assessments have been undertaken in three sub-districts across Botswana representing different ecological zones and socio-economic contexts. Specifically, the focus of these assessments was on Bobirwa, Kgalagadi North and Ngamiland subdistricts.

Bobirwa is located in the north-eastern part of Botswana. The climate of this subdistrict is characterized as semi-arid, with an annual rainfall ranging between 300-400 mm[103]. The rainfall is highly variable, and droughts occurs regularly. The soil type includes loams to sandy clay loams. The ecosystems are heavily degraded as a result of overharvesting of natural resources (such as water and rangeland grasses) and drought impacts — a trend that is likely to be exacerbated by climate change. This degradation is likely to be exacerbated by climate change. Kgalagadi district is the most arid region in Botswana — with a median annual rainfall of 284.8 mm — and soils are dominated by non-calcareous, deep Kalahari soils. Ngamiland district is also characterized by variable and unreliable rainfall that is concentrated in the summer months from November to April. The observed annual rainfall in the town of Maun is 446.8 mm and Shakawe is 462 mm. The Ngamiland soils are dominated by arenosols along NG2, Lake Ngami and the Hainaveld Farms. The vegetation in Ngamiland is dominated by tree savanna, with grass savannah along lake Ngami and Miombo savanna in the northern part.

The current climate conditions in the focus areas of Botswana have required the population to adapt to generally low rainfall totals — of 130–350, 300–450 and 453–564 mm annually for Kgalagadi, Bobirwa and Ngamiland, respectively — and warm summer months. Many of the agriculturally-based livelihoods in the communal rural areas have a strong dependency on sufficient and reliable rainfall and subsequently on water security. The projected climate changes are anticipated to further expose these communities and livelihoods from a year on year variability and drought potential.

This vulnerability assessment will look at social, rangeland, livestock and livelihood indicators to determine the most climate-vulnerable locations. In turn, this will allow for the development of effective intervention strategies to reduce vulnerability. Methods for this analysis are described in Section 2 Vulnerability

[103] Mugari E, Masundire H, Bolaane M, New M, (2019) "Perceptions of ecosystem services provision performance in the face of climate change among communities in Bobirwa subdistrict, Botswana", International Journal of Climate Change Strategies and Management, 265-288

assessment framework. Zoomed in maps of the different climate change vulnerability assessments can be found in Clustered Results appendices (page 94).

5.3 Social Vulnerability

This assessment used the population at *subdistrict level and household census: selected indication 2011* data as indicators of sensitivity and adaptive capacity to climate exposures. Projected changes in population and subsequent sensitivities and adaptive capacities used the Shared Socioeconomic Pathway middle of the road projection (SSP2). More detailed information regarding sensitivity and adaptive capacity indicators of the project areas is provided within sections 3.2 and 3.3, respectively. Sensitivity is the degree to which a climate impact will affect a community whereas the adaptive capacity is the ability of a community to recover from these impacts. The social vulnerability was calculated using the baseline sensitivity and adaptive capacity and incorporating the projected climatic exposures, as informed by the Cordex and WorldClim climate datasets.

Current vulnerability

The assessment of different pastoral communities at local scale suggested that their sensitivity, and adaptive capacity to climate change is relatively diverse and driven by multiple stressors. In Bobirwa's Central Bobonong district, there is a wide range in anticipated social vulnerabilities of the different pastoral communities. Both Damochojena and Tshokwe communities had high to extreme vulnerability scores, whereas the vulnerability of communities of both Molalatau and Robelela was very low to low. The strongest cause of the poor vulnerability score in Damochojena and Tshokwe are the high dependency ratio (+100%), particularly in the <5-year-old range and the relative unemployment rates for all genders (~26%). However, it is anticipated that women likely engage more in unpaid and unreported work resulting in higher dependency/lower adaptive capacity. In contrast, Molalatau and Robelela have lowered dependency ratios (~64%) and lower reported unemployment rates (~18%). These communities also have greater resilience as a result of having greater access to goods and services – access to sanitation, water sources and reliance on electricity for cooking and heating are higher in Molalatau and Robelela. By contrast Damochojena and Tshokwe have ~45% sanitation access, 11% private household access to water resources and 4% private household electricity access and therefore lower adaptive capacity.

Kgalagadi's north and south have a wide disparity in the sensitives and adaptive capacities but generally have lower overall vulnerability than the other study areas. Ngwaketse West, in close proximity to cross-administration-grazing areas, exhibit low vulnerability. Kang and Bokspits in the north and south districts, respectively, have low vulnerability profiles resulting from the low total unemployment rates (~7%) and lowered dependency ratios (51%), which means that the communities are less sensitive to disruption. Moreover, they have higher adaptive capacity resulting from having access to piped water within private households (~57%). Some other villages in districts do not have similar capacities. Inalegolo and Kokotsha have low access to sanitation services and only 23% private households have water access. These settlements also have high illiteracy rates and a high dependency ratio of 93%.

Ngamiland's Ngami East and Ngami West districts, in the northern area, have the largest number of villages and include the town of Maun. There are large discrepancies in the community's vulnerabilities, which is likely a result of the diverse livelihoods in the area. The vulnerability profiles are driven by differences in the dependency ratios and employment sensitivities in this area. Gudingwa and Botlhatlogo both have dependency ratios of ~135%, while Botlhatlogo has an unemployment rate of 25%. The limited adaptive capacity in these areas is driven by the high reliance on communal taps (66% of the population), rather than having private water access (10% of the population) and the limited access to formalised sanitation services (23.5% of the population). The town of Maun, having a large local population and well-developed infrastructure, has greater access to services. Water is available to ~70% of the population either within private dwellings or still on the same property. 66% of dwellings also have access to electricity as an energy source. Seronga does not have the same access to these services but has a similar sensitivity profile, with an average dependency ratio of 74% and a low unemployment rate of 16%.

The adaptive capacity in Kgalagadi is varied over the area, but villages that are clustered together do show greater capacity than more isolated villages such as Zutshwa and Ukwi, which are characterized by low adaptive capacity. The area as a whole has a tendency for higher sensitivities than Bobirwa or Ngamiland.

Populations in Kgalagadi will not gain the collective benefits of some of the other villages and will suffer from limited accessibility. In general, Bobirwa sub-district had higher adaptive capacity and lower sensitivities relative to other sites and that could be linked to diversified livelihood and therefore employment options that include farming and higher employability (literacy rate above 80% Statistic Botswana 2013). Bobirwa seems to be well-served by transport infrastructure connecting the settlements. Ngamiland is more varied in its vulnerability but areas to the south around Maun appear to have decreased sensitivity and greater capacity than those further north where several locations with very low adaptive capacity and that could be explained by high poverty levels of 46 and 33.4% in 2009/10 and 2015/16 respectively[104]. It has been reported that poverty is one of the determinants of farmers' adaptive capacity in Botswana (Kgosikoma et al 2018). The reoccurrence of Foot and Mouth disease (FMD) in Ngamiland could also be contributing to pastoralists' low adaptive capacity as access to market is continuously be disrupted during disease outbreaks and as a result livestock prices are relatively low and therefore limit earning potential of communities.

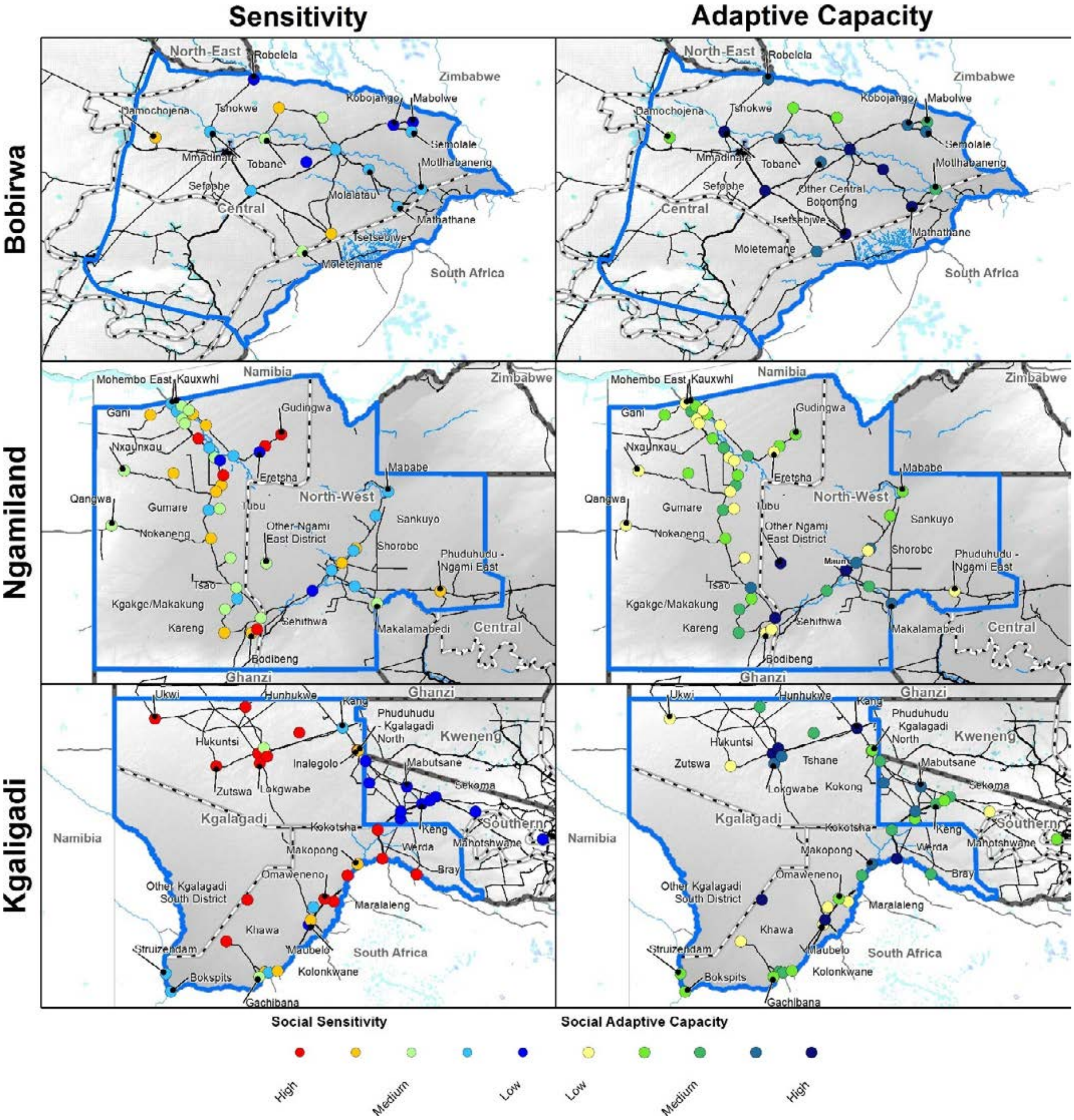


Figure 46. Current social sensitivity and adaptive capacity in the village in the study areas.

Future vulnerability

The social climate change vulnerability was calculated by reviewing the baseline social sensitivities and adaptive capacities in the presence of the spatial climate change exposures for RCP 4.5 and RCP 8.5 by 2050 and applying them to the future Shared Socioeconomic Pathway 2 population scenario[105]. In a water-

[104] Statistics Botswana, 2018

[105] SSP2 - Middle of the Road

scarce country with livelihoods often reliant on rainfed agriculture and ecosystem services (such as flood mitigation, nutrient cycling, etc), baseline and decreased precipitation — along with enhanced increased precipitation variability and drought severity — were considered greater contributors to social exposure than more rare flooding events with more severe impacts. The cumulative vulnerability is highest in Kgalagadi, this is followed by Ngamiland, with Bobirwa being the least vulnerable.

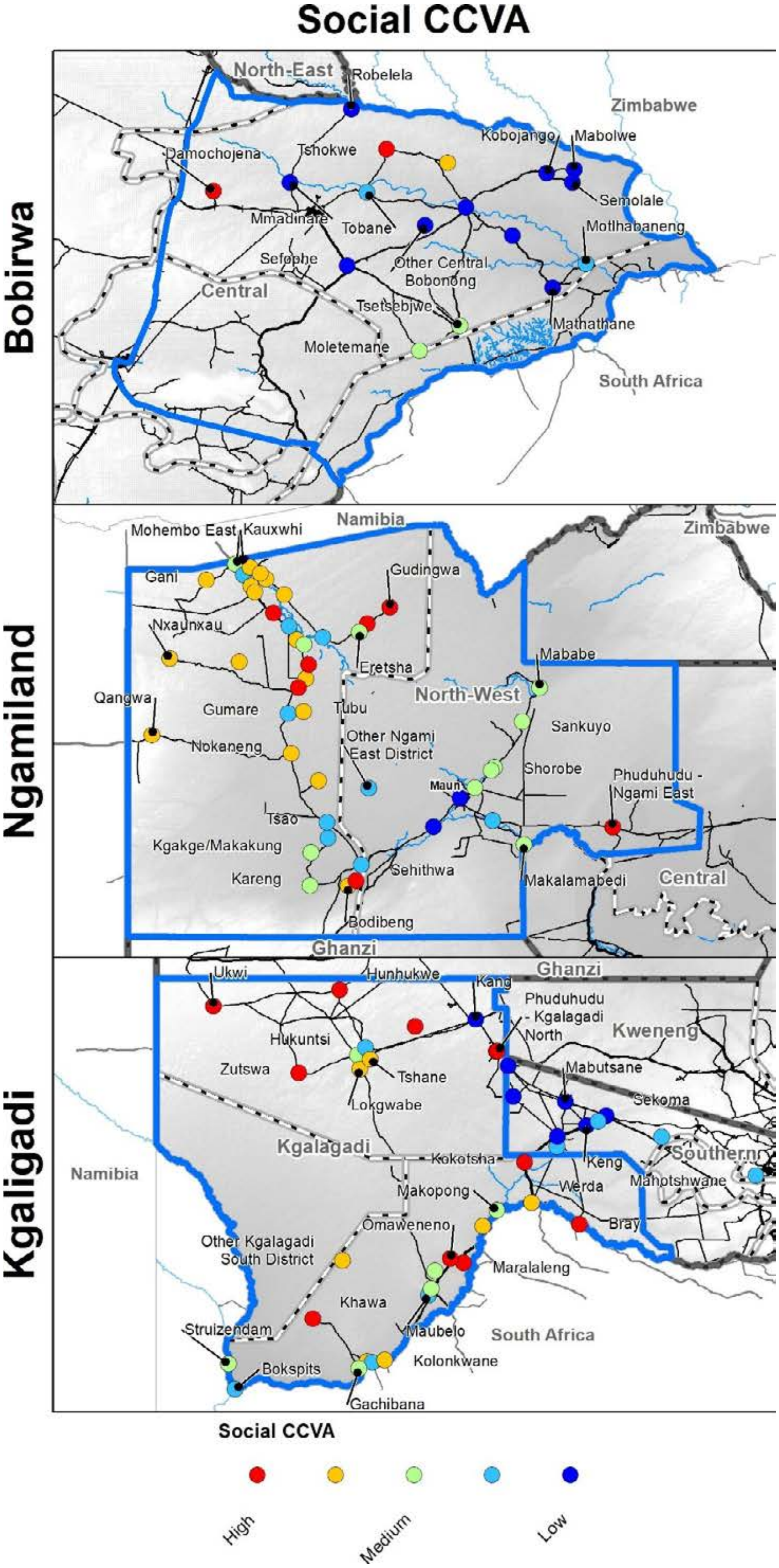


Figure 47. Projected social vulnerability across Botswana.

Table 12. Village level Social Climate Change Vulnerability assessment under RCP 4.5 2050.

Bobirwa

Village		Climate Vulnerability
Central Bobonong	Bobonong	Very low
	Damochojena	Extreme
	Kobojango	Very low
	Lepokole	Extreme
	Mabolwe	Very low
	Mathathane	Very low
	Mmadinare	Very low
	Molalatau	Low
	Moletemane	Medium
	Motlhabaneng	Low Medium
	Other Central Bobonong	Insignificant
	Robelela	Insignificant
	Sefophe	Very low
	Semolale	Low
	Tobane	Low Medium
	Tsetsebjwe	Medium High
	Tshokwe	Extreme

Kgalagadi

Village		Climate Vulnerability
Kgalagadi North District	Hukuntsi	Medium High
	Hunhukwe	Extreme
	Inalegolo	Extreme
	Kang	Very low
	Lehututu	Low Medium
	Lokgwabe	Very High
	Other Kgalagadi North District	Extreme
	Phuduhudu - Kgalagadi North	Extreme
	Tshane	Very High
	Ukwi	Extreme
	Zutswa	Extreme

Village		Climate Vulnerability
Kgalagadi South District	Bokspits	Low Medium
	Bray	Extreme
	Gachibana	Medium High
	Khawa	Extreme
	Khuis	Very High
	Kokotsha	Extreme
	Kolonkwane	Very High

	Makopong	Medium High
	Maleshe	Medium
	Maralaleng	Extreme
	Maubelo	Low Medium
	Middlepits	Low Medium
	Omaweneno	Extreme
	Other Kgalagadi South District	High
	Phepheng/Draaihoek	Extreme
	Struizendam	Medium High
	Tshabong	Medium
	Werda	High

Village		Climate Vulnerability
Ngwaketse West	Itholoke	Low
	Keng	Very low
	Khakhea	Insignificant
	Khonkhwa	Low
	Kokong	Insignificant
	Mabutsane	Insignificant
	Mahotshwane	Low Medium
	Morwamosu	Very low
	Other Ngwaketse West	Low Medium
	Sekoma	Very low

Ngamiland

Village		Climate Vulnerability
Ngami West District	Beetsha	Extreme
	Eretsha	Medium
	Etsha 1	Extreme
	Etsha 13	Extreme
	Etsha 6	High
	Gani	Extreme
	Gonutsuga	Very High
	Gudingwa	Extreme
	Gumare	Low
	Ikoga	Medium
	Kauxwhi	Very low
	Mogomotho	Very High
	Mohembo East	Extreme
	Mohembo West	Medium High
	Ngarange	Very High
	Nokaneng	High
	Nxamasere	Extreme

	Nxaunxau	High
	Other Ngami West District	Very High
	Qangwa	Very High
	Samochema	Very High
	Sekondomboro	Very High
	Sepopa	Low Medium
	Seronga	Low
	Shakawe	Low
	Tubu	Very High
	Xakao	High
	Xhauga	High

Village		Climate Vulnerability
Ngami East District	Bodibeng	Extreme
	Botlhatlogo	Extreme
	Chanoga	Low Medium
	Habu	Very High
	Kareng	Medium High
	Kgakge/Makakung	Medium High
	Komana	Very low
	Mababe	Medium
	Makalamabedi	Medium High
	Matlapana	Medium
	Maun	Very low
	Other Ngami East District	Low
	Phuduhudu - Ngami East	Extreme
	Sakapane	Medium High
	Sankuyo	Medium
	Sehithwa	Low Medium
	Semboyo	Low Medium
	Shorobe	Medium
	Toteng	High
	Tsao	Low

5.4 Livelihoods Vulnerability

The agricultural sector is the primary source of employment as it accounts for 15.2% of those employed in 2011 (Figure 48). The agricultural communal production sector engages approximately 22,243 farm labourers annually and more people are employed across the value chain in industries such as butcheries, milk processing, suppliers and the Botswana Meat Commission[106].

[106] Hellyer et al, 2015

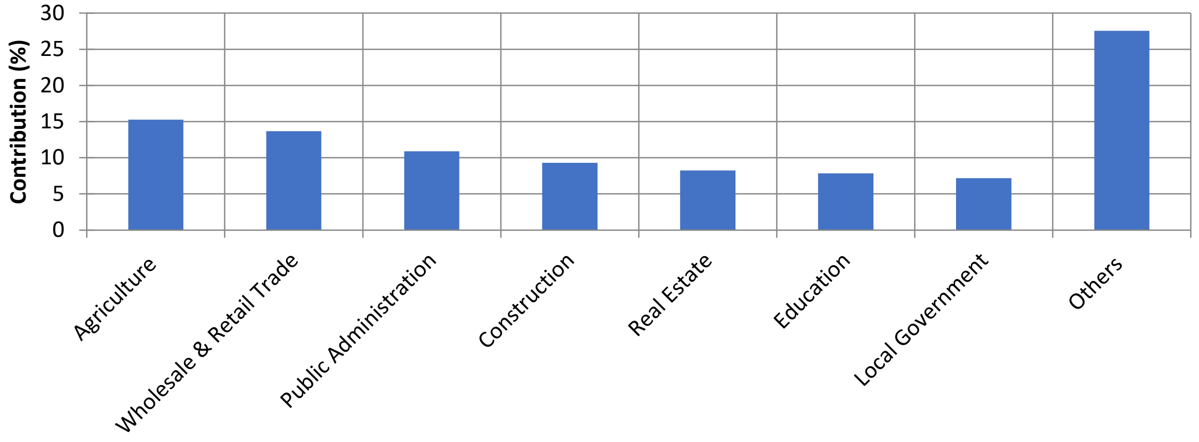


Figure 48. Employment in Botswana by different sectors in 2011 (Statistics Botswana)[107].

At the national level, the agricultural sector has been contributing an average of 2.3% to the national GDP between 2004 and 2016[108] (Figure 49) of which 65% is attributed to the livestock industry. In addition, the agricultural sector's contribution to the GDP has been constrained to primary production, rather than comprising the derived products along the value chain — where once these agricultural products are processed, they are termed investments. Nevertheless, the value added to GDP by agriculture has steadily increased from 0.95 billion Pula in 2004 to 3.4 billion Pula in 2016. Botswana's GDP is mostly driven by mining, construction, manufacturing and trade and tourism.

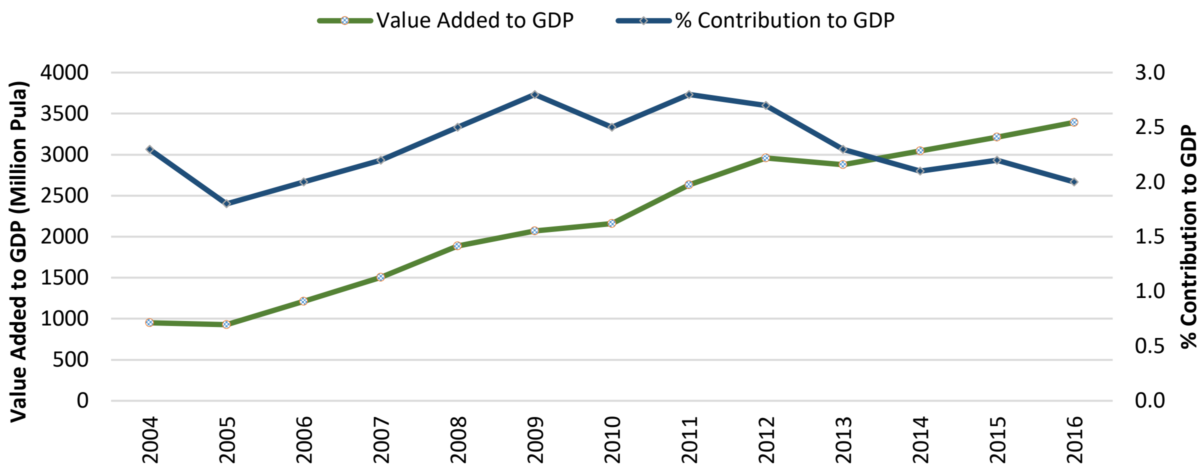


Figure 49. Agricultural contribution and value added to GDP in Botswana[109].

[107] Sectors in the 'other' category include manufacturing, hotels and restaurants, transport and communication, finance and business services, central government and private and parastatal.

[108] The contribution of the services and industry sectors to GDP in 2016 was ~32 and 57%, respectively.

[109] Statistics Botswana, 2018

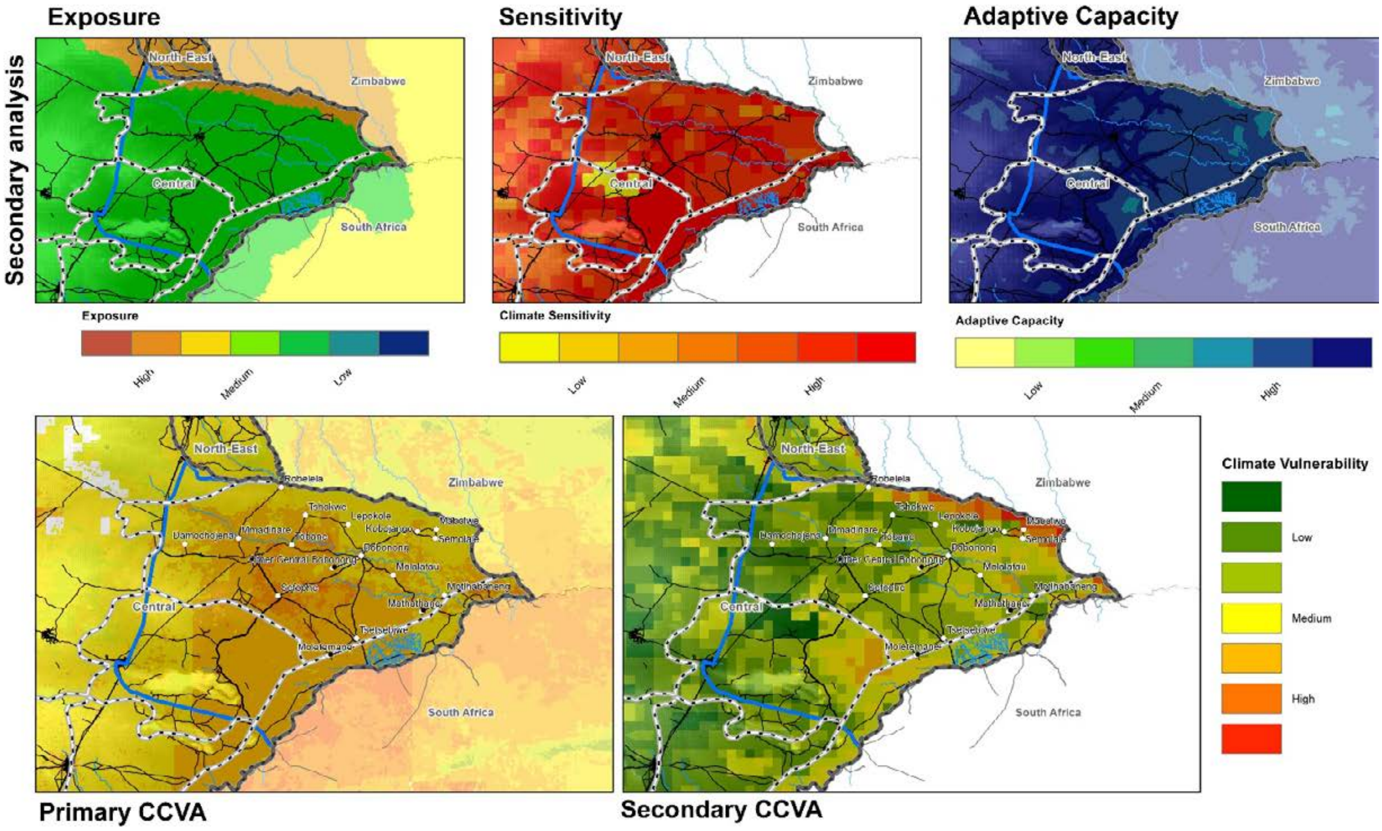


Figure 50. Components of livelihood climate vulnerability for Bobirwa

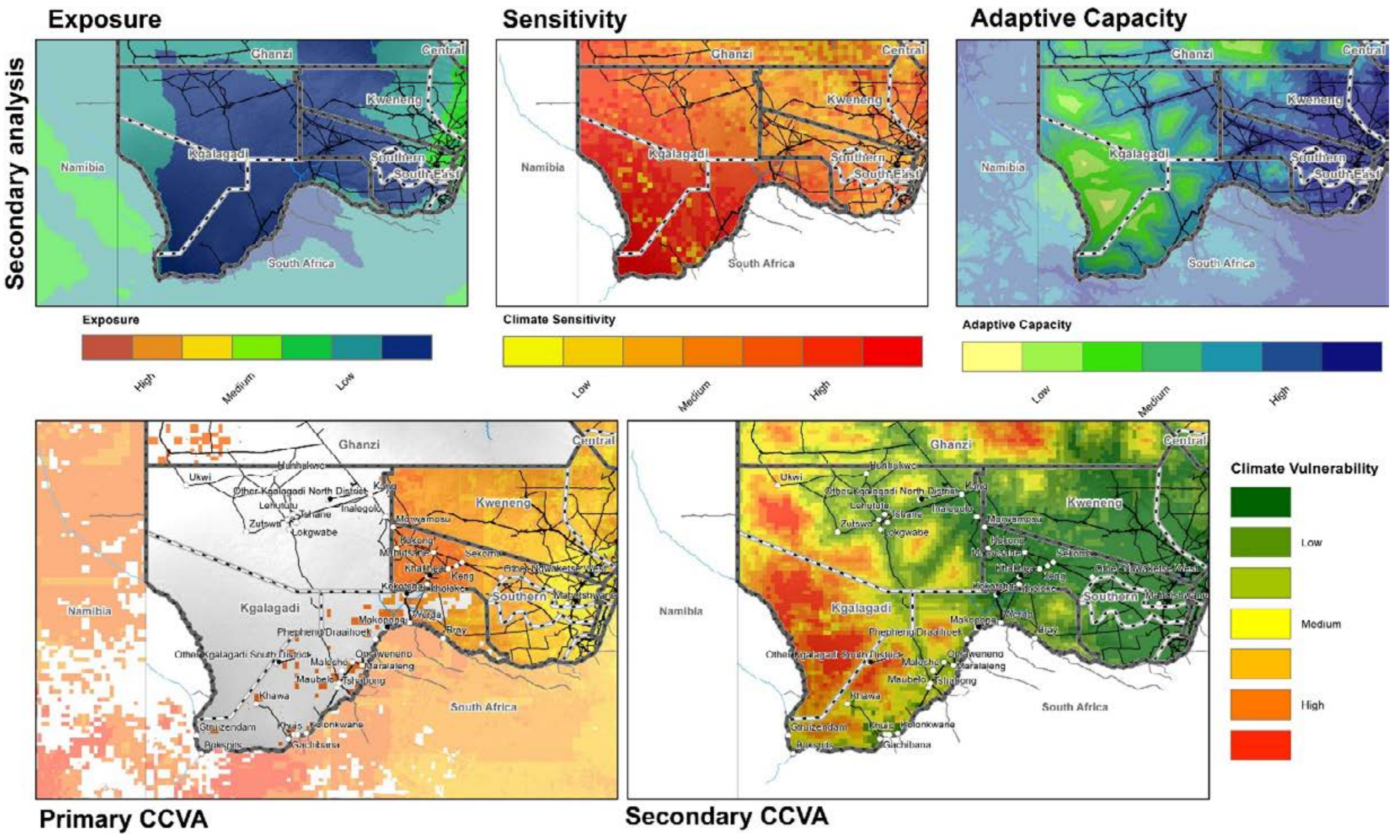


Figure 51. **Components of livelihood climate vulnerability for Kgaligadi.**

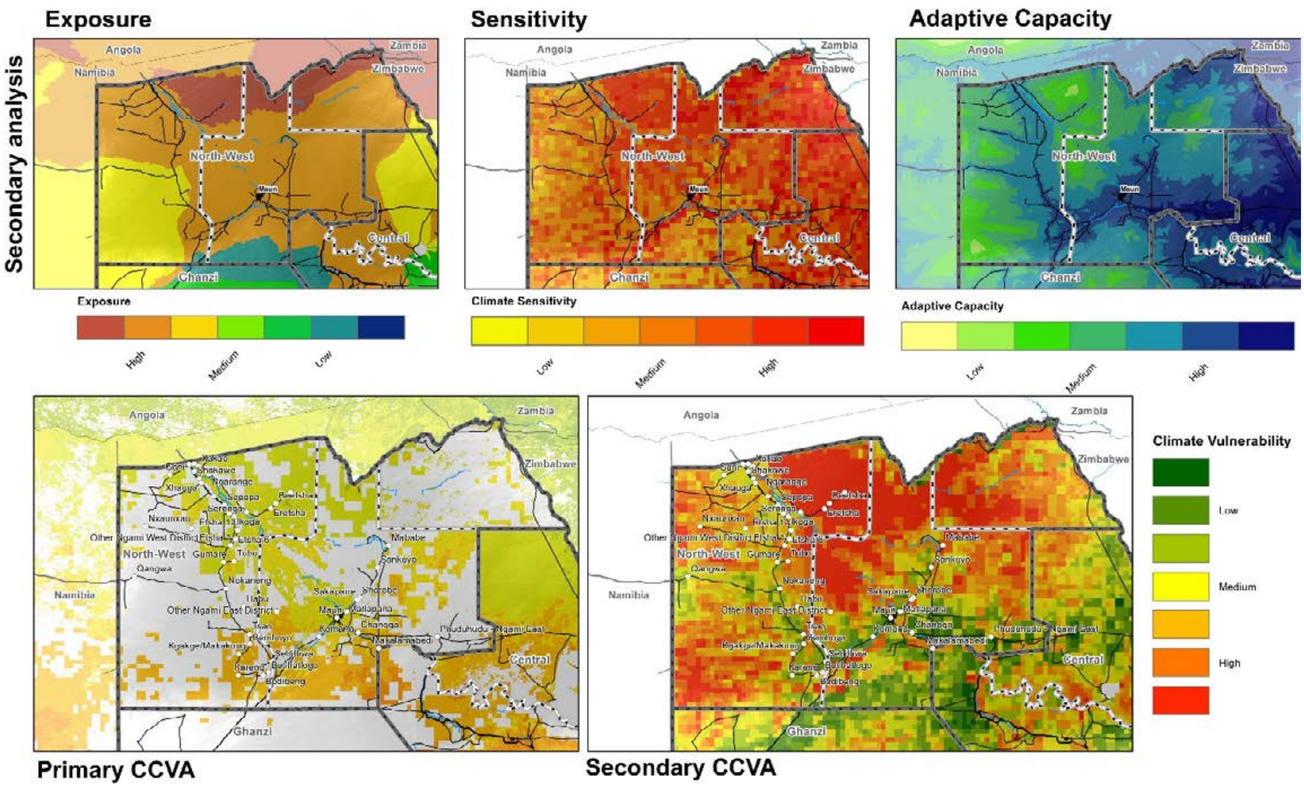


Figure 52. Components of livelihood climate vulnerability for Ngamiland.

Rural communities in Botswana tend to have livelihoods reliant on climate consistency and ecosystem health. The components of the livelihood vulnerability therefore speak to these factors. The accessibility of a region acts as a proxy for the ability to utilise diverse services and of market access of rural commodity-based trading. The further from these services the lower the livelihood capacity. The resilience of livelihoods relying on ecosystem health will be highly correlated to the sensitivity of soil moisture. High sensitivity in soil moisture index will render crops infeasible or rangelands degraded, during a drought event. The soil moisture sensitivity throughout Botswana is very high. The long dry period and the low average precipitation contribute to a rangeland ecosystem that needs to cope under very dry conditions.

Bobirwa, with the middle range for precipitation, is moderately exposed to shifts in seasonal variation, but is highly sensitive to variable soil moisture, which can be seen in severely degraded ecosystems, rangelands and a high dependency on surface water which compromises producers' ability to sustain their families[110]. The livelihood options in Bobirwa for both males and females — such as crop farming, livestock production and harvesting of NTFP such as phane[111] (mophane worms) — are dependent on natural ecosystems[112] and therefore vulnerable to climate variability, however the local access to markets[113] and various good and services does reduce this overall vulnerability (Figure 50).

Kgaligadi, with generally reduced precipitation, has lower possible seasonal variation, and communities have adapted to this lowered threshold. Kgaligadi has the lowest connectivity with much of the area being highly isolated. Goods and services are more spread out and markets are not as accessible. In Kgalagadi, vulnerability appears to be high in settlements dominated by San ethnic groups and could be because they have limited resources to buffer their livelihoods against climate shocks (Figure 51).

The ecosystems around the Okavango Delta and Sehitwa in Ngamiland are also highly exposed and therefore lead to increased vulnerability. The increases in seasonal variation will expose the livelihoods of rural communities to disruption (Figure 52). The most vulnerable groups will likely be those whose access to

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[110] Mugari E, Masundire H, Bolaane M, New M, (2019) "Perceptions of ecosystem services provision performance in the face of climate change among communities in Bobirwa subdistrict, Botswana", International Journal of Climate Change Strategies and Management, 265-288

[111] Phane harvesting is a livelihood activity mostly carried out by women. There are large number of phane harvesters in Botswana, especially in Bobirwa according to: IDRC, DFID and CARIAA. 2015. Vulnerability and Risk Assessment in Botswana's Bobirwa Sub-District: Fostering People-Centred Adaptation to Climate Change. Available at: http://www.assar.uct.ac.za/sites/default/files/image_tool/images/138/Botswana/ASSAR%20Botswana%20Vulnerability%20Risk%20Assessment.pdf

[112] Masundire, H., Morchain, D., Raditloaneng, N., Hegga, S., Ziervogel, G., Molefe, C. and Angula, M.(2016), About ASSAR Reports Vulnerability and Risk Assessment in Botswana's Bobirwa Sub-District: Fostering People-Centred Adaptation to Climate Change, Gaborone, available at:www.ub.bw/ (accessed 13 December 2017).

[113] Masunungure C and Shackleton .2018. Exploring Long-Term Livelihood and Landscape Change in Two Semi-Arid Sites in Southern Africa: Drivers and Consequences for Social–Ecological Vulnerability.

livelihood sources and food security depends on both crop farming and pastoralism, as both are influenced by soil moisture sensitivity especially during drought events. Specifically, these groups will be those whose livelihoods are reliant on regular rainfall due to high seasonal variation of rainfall in Ngamiland, particularly female-headed households.

The seasonal variation is highest in Ngamiland, this is followed by Bobirwa and Kgaligadi respectively. The higher rainfall and flooding events in Ngamiland mean that communities and ecosystems are heavily reliant on these events occurring with regularity. Should these events fail or be reduced, many livelihoods that would normally utilise these resources would be competing over fewer resources. Ngamiland accessibility follows the connections to Maun as the main hub in the region. Many of the small communities follow this infrastructure and are well connected. Though the further west and northern areas are more isolated. Further vulnerability could be attributed to poor livestock markets and limited assets to support livelihood diversification, high unemployment, high poverty levels and a high percentage of female-headed households[114].

5.5 Rangeland Vulnerability

Natural ecosystems provide a wide range of benefits to human society including provisioning services (e.g. animal and plant resources and their products), regulatory services (e.g. climate and air quality regulation), and cultural services (e.g. grassland landscapes and nomadic culture), and other supporting services (e.g. species diversity maintenance). However, ecosystems such as rangelands are overexploited, highly exposed to climatic shocks (e.g. droughts) and thus more sensitive to climate change. These changes pose a serious threat to the economic and environmental sustainability in drylands. It is therefore critical to understand the sensitivity of economies that are dependent on natural ecosystems and urgently adopt adaptive management strategy that buffer the production systems and livelihood of the affected communities[115].

Land degradation has high social and economic costs, estimated at US$353 million annually[116]. Rangelands cover large parts (76%) of Botswana’s total land area[117] and as a result are important for ecological and socio-economic sustainability. However, the rangeland’s productivity is severely compromised by degradation and high climatic variability and change. Climate variability and change — through loss of key ecosystem services such as grazing resources, firewood and non-timber products — threaten to increase poverty across Botswana, including Bobirwa[118], Ngamiland[119] and Kgalagadi[120].

Secondary data on Vegetation Condition Index (VCI) for the period 2001 to 2017 was collected from the Department of Meteorological Services. The VCI relates current decadal Normalized Difference Vegetation Index (NDVI) to its long-term minimum and maximum, normalized by the historical range of NDVI values for the same decade. It was aggregated to reflect annual variation of vegetation health in response to climatic variability at different locations across Botswana.

Rainfall variability is the major driver of rangeland productivity in drylands[121] and accounts for 63% of the variation in global terrestrial net primary productivity (NPP)[122]. The observations across Botswana suggest that rangeland ecosystems are highly exposed to drought impacts. This is reflected in high inter-annual heterogeneity in vegetation condition (Figure 53). The results suggested that Selebi-Phikwe in Bobirwa is

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[114] Sallu, S. M., C. Twyman, and L. C. Stringer. 2010. Resilient or vulnerable livelihoods? Assessing livelihood dynamics and trajectories in rural Botswana. Ecology and Society 15(4): 3

[115] (Berger et al 2019)

[116] (Global Mechanism of the UNCCD, 2018. Country Profile of Botswana. Investing in Land Degradation Neutrality: Making the Case. An Overview of Indicators and Assessments. Bonn, Germany.

[117] Asner, G.P., A.J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004.GRAZING SYSTEMS, ECOSYSTEM RESPONSES, AND GLOBAL CHANGE. Annu. Rev. Environ. Resour. 2004. 29:261–99

[118] Mugari E, Masundire H, Bolaane M, New M, (2019) "Perceptions of ecosystem services provision performance in the face of climate change among communities in Bobirwa subdistrict, Botswana", International Journal of Climate Change Strategies and Management, 265-288

[119] Kolawole OD, MR Motsholapheko, BN Ngwenya, O Thakadu, G Mmopelwa, D L Kgathi. 2016. Climate Variability and Rural Livelihoods: How Households Perceive and Adapt to Climatic Shocks in the Okavango Delta, Botswana. WEATHER, CLIMATE, AND SOCIETY, 8

[120] Kgosikoma OE, Batisani N. 2014. Livestock population dynamics and pastoral communities’ adaptation to rainfall variability in communal lands of Kgalagadi South, Botswana. Pastoralism: Research, Policy and Practice 4:19

[121] Mphinyane WN, Tacheba G, Mangope S, Makore J.2008. Influence of stocking rate on herbage production, steers live mass gain and carcass price on semi-arid sweet bushveld in Southern Botswana. African journal of agricultural research 3(2):84-90

[122] Pan S, Tian H, Dangal SR.S., Outang Z, Lu C., Yang J, Tao B, Ren W, Banger K, Yang Q, Zhang B. 2015. Impacts of climate variability and extremes on global net primary production in the first decade of the 21st century. J. Geogr. Sci. 25(9): 1027-1044

relatively more exposed to drought than other sites. Rangeland conditions in Maun and Selebi-Phikwe have been on a consistent downwards trends from 2010 to 2017, leading to reduced capacity of rangeland to provide ecological services. More importantly, multiple drought years have the potential to exacerbate land degradation and erode adaptive capacity of the farming community. The lag time of these impacts to be noted in the NDVI record may mean that vegetation condition could be worse than reflected[123].

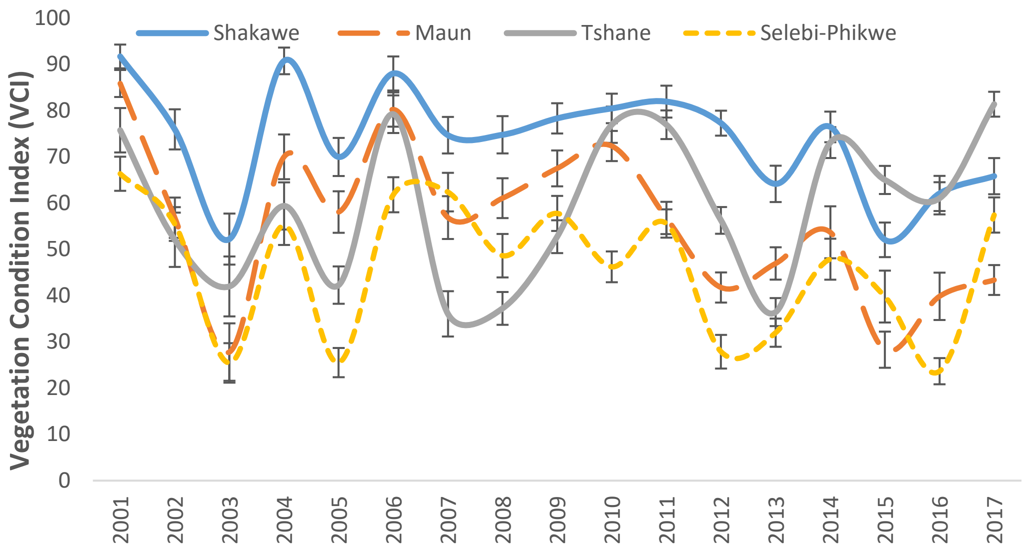

Figure 53. Vegetation Condition Index across the different locations in Botswana.

Current vulnerability

The main grasses in these rangelands of Botswana were categorised into low- to medium-value grazing and medium- to high-value grazing for livestock utilisation. The suitability of these species was assessed under current climate parameters as well as projected changed future climate parameters to highlight the potential vulnerability of these grassland ecosystems. This was done using the SPARC data[124] which assesses how a species' range under current and may be shifted due to future climate change in response to that species' unique climatic tolerances. The factors that contributed to the species' suitability are listed below.

- Annual Mean Temperature
- Mean Diurnal Range
- Temperature Seasonality
- Minimum Temperature of Coldest Month
- Annual Precipitation
- Precipitation Seasonality (Coefficient of Variation)

Soil characteristics influencing suitability of species are listed below.

- Aridity
- Bulk density
- Clay
- Depth
- Ph
- Silt

The factors that contribute to the suitability for both the medium-high and low-medium value grazing species are similar. The largest climatic factor is temperature seasonality contributing ~35%. The next highest is the precipitation seasonality, with ~15%. These species are highly reliant on stable seasonal climates (Figure

[123] Quiring SM, Ganesh S. 2010. Evaluating the utility of the Vegetation Condition Index (VCI) for monitoring meteorological drought in Texas. Agricultural and Forest Meteorology. Agricultural and Forest Meteorology; 150; 330-339

[124] Spatial Planning for Protected Areas in Response to Climate Change (SPARC), CI-GEF and Conservation International

54). Previous analysis suggests that both the current and projected future precipitation will be more variable. This therefore reduces the current and future suitability of both these species.

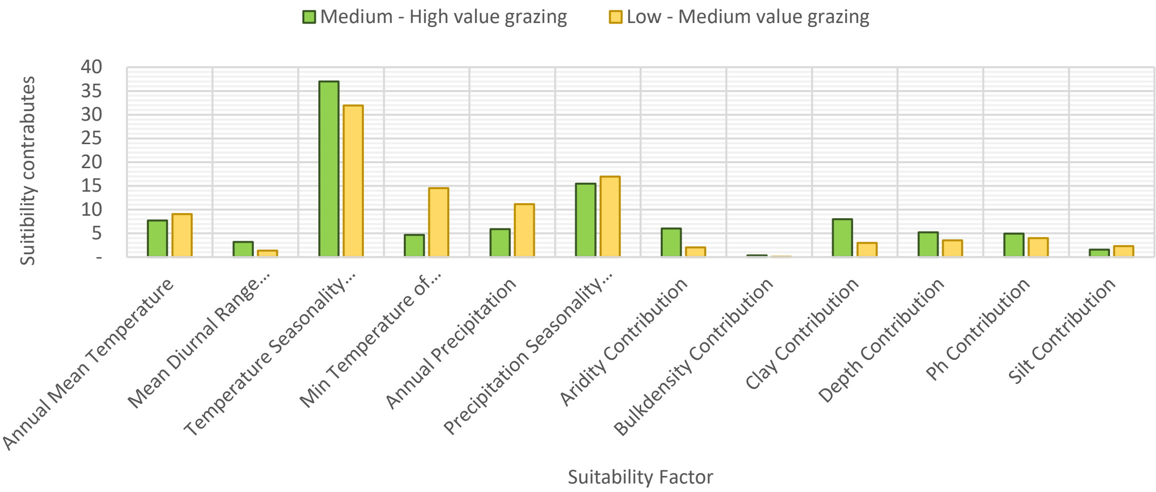

Figure 54. Grass species contributing suitability factors.

The climate and soils in the Bobirwa environment are most suitable for medium-high and low-medium value grazing grass species. This could be attributed to high soil fertility and moisture in high veld areas. However, low cover of palatable grasses such as *Schmidtia pappophoroides* and *Panicum maximum* and attributed this to land degradation in Bobirwa. In Ngamiland, the lands around the Okavango delta and Sehithwa were also well-suited for grasses of high grazing value. Outside of these regions the suitability is limited in Ngamiland. The Kgalagadi ecosystem has the lowest overall suitability for both grasses of high or low grazing value and that because soil moisture and fertility are limiting.

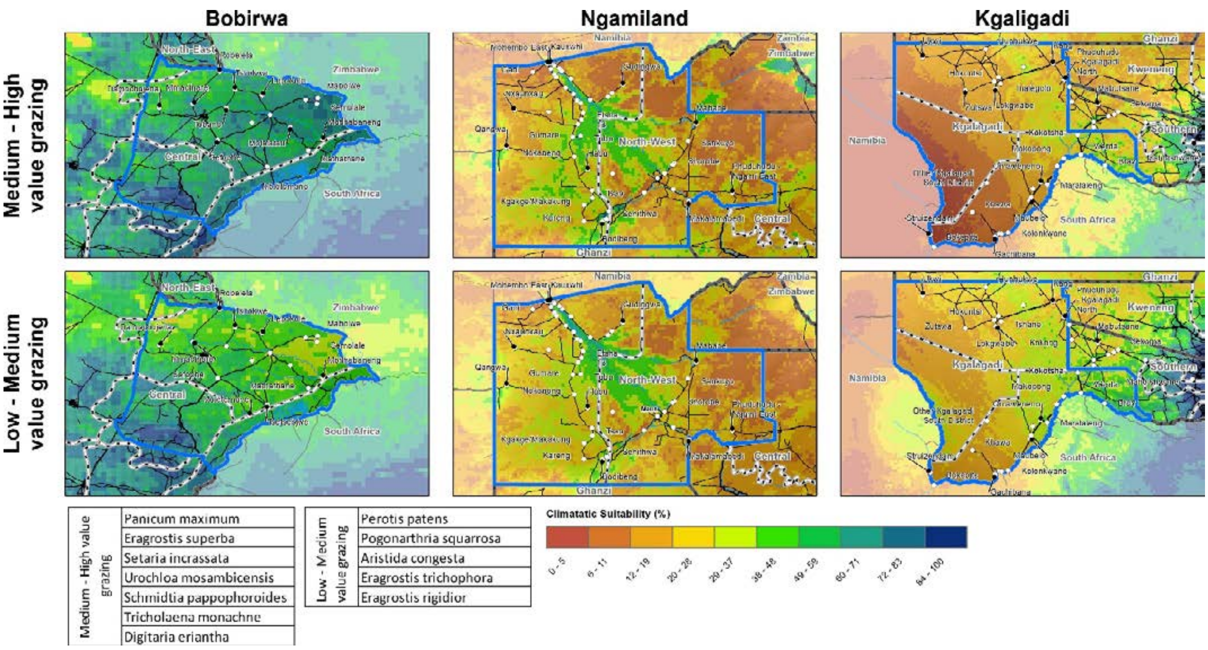

Figure 55. Current environmental suitability of different grass species across Botswana.

Future vulnerability

Future vulnerability of rangeland grazing species — which pastoralist communities are dependent upon to support livestock herds — has been determined by assessing the climatic suitability of these species under future climate change, namely using RCP8.5. The projected climate changes indicate more extreme day and night-time temperatures, decreasing precipitation and large variability in the rainfall reliability, particularly in the first part of the season. These climate changes will alter the suitability of the species by 2070 (RCP 8.5). Bobirwa shows consistent decreased suitability of both medium-high and low-medium value grazing grass species (Figure 55). While this does not necessarily mean that will change under RCP8.5 because of factors such as climate shocks and competition from climate-change tolerant species.

These species may also be outcompeted in this region by species suited to the modified climate parameters. Low-medium value grazing grass species show a large decrease in suitability in Ngamiland, with the exception of some of the north eastern areas. These same areas will likely be more climatologically suitable to some of the medium-high value grazing grass species. Elsewhere however, species suitability is decreased. Kgalagadi, which already had low species suitability, sees this suitability further decrease in the future with the exception of the furthest south areas for low-medium value grazing grass species.

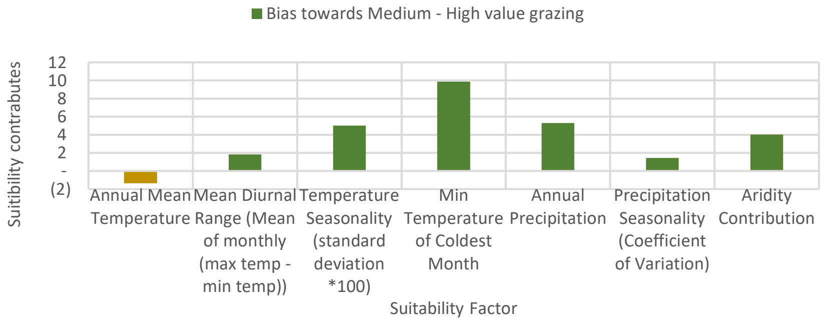

Figure 56. Suitability factors favouring medium-high over low-medium value grazing species.

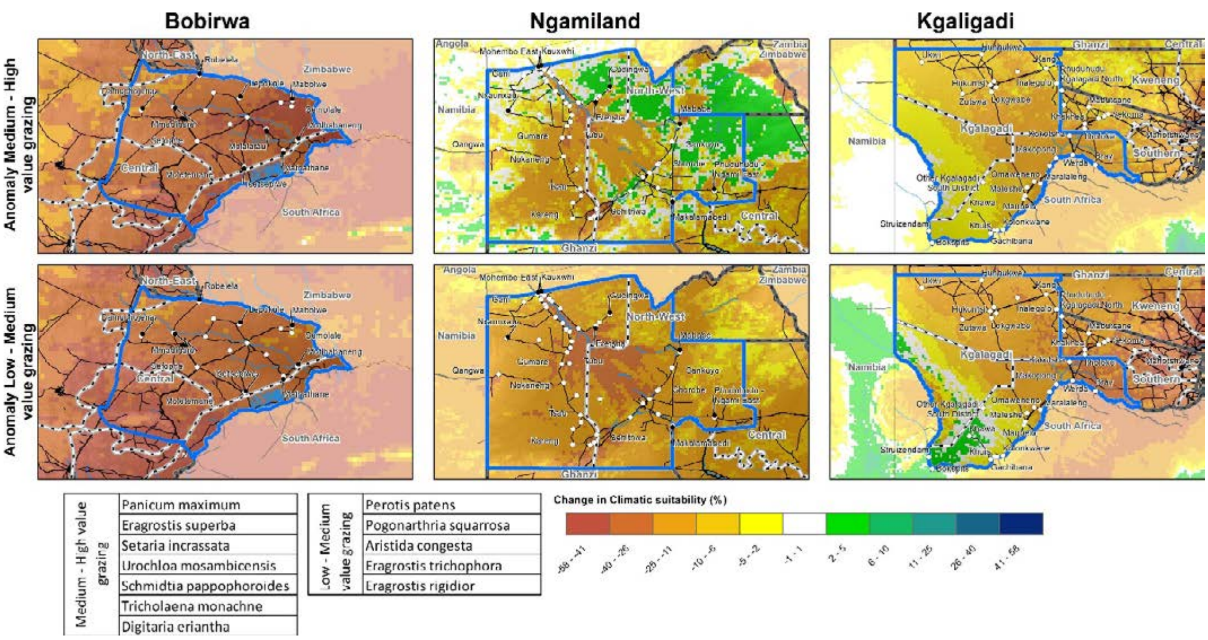

Figure 57. Future changes in rangeland herbaceous composition under RCP 8.5 2070 scenario.

Despite changes in suitability of these various species, medium-high and low-medium value grazing grasses may also compete within an area. The climate factors of minimum temperature of coldest month, annual precipitation, and precipitation seasonality (coefficient of variation) are projected to become less stable and may therefore ultimately reduce the suitability of species more reliant on these climate factors.

Low–medium value grazing species have a minor climatological suitability bias (Figure 56) meaning changes in climatic factors will shift suitability away from these species more so than the medium-high value species. Medium-high value species are also more reliant on soil characteristics such as clay, soil depth and Ph. Therefore, land-use practices would have an influence on the suitability of these species.

5.6 Livestock Vulnerability

The rangeland-based livestock industry is critical for national development — particularly in rural areas — as it provides multiple services to society[125]. At household level, livestock serves as a food source. Grazing beef cattle provide protein in the form of meat and milk to balance diets and therefore contribute significantly towards eliminating hunger and malnourishment, especially among vulnerable groups such as children. Farmers also earn an income from livestock sales and a revenue of ~US$1.4 million, US$0.7 million and US$2.7 million was raised from cattle sale in Bobirwa, Kgalagadi North and Ngamiland West, respectively in 2015[126]. The percentage of pastoralist income that cattle sales represent is not published as part of Botswana's agricultural censuses and is likely to vary widely, owing to multiple factors that differ on an individual basis. This includes the composition of pastoralists' herds, their access to markets and access to alternative income sources. The 2011 census, however, states that across Botswana "for those that received income from agricultural activities (21.5% of the population), cattle (9.6%) and goats or sheep (5.4%) sales were the highest recorded income earners, followed by sales of maize, melons and/or sweet-reed and mophane worms each at 2.8%. In the project area districts for which information was available, dependency on the sale of cattle in Kgalagadi North was 21.3% (the second highest in the country). Kgalagadi South had the highest proportion of households receiving income from the sale of goats and sheep at 17.6%, followed by Kgalagadi North at 14.3% and Central Bobonong at 9.4%.

The analysis of livestock population (2004–2017) indicated that the highest mean cattle population is in the districts of Ngamiland West (51,747), then Bobirwa (46,128) and least at Kgalagadi (26,815). Cattle ownership is skewed in favour of male farmers as indicated by 70, 75 and 83% male ownership in Bobirwa, Ngamiland West and Kgalagadi North, respectively. This could be partly associated with the traditional culture of male children engaging in livestock farming and often inheriting the family business. The cattle population coefficient of variation, ranging from 44 to 88%, which indicates instability and risk involved in this livestock farming in dryland ecosystems.

The analysis of goat population indicated that production is also dominated by men, but the herd size is highly variable, as indicated by coefficient variation (37–66 %), which indicated the high risk-return trade-off. For the period of 2004 to 2017, Bobirwa had the largest mean goat population of 59,296, while Kgalagadi North and Ngamiland West had an average population of 19,301 and 26,655 respectively. The male producers owned 66, 71 and 78% of goat herd in each of those areas respectively and were therefore more empowered than women (as with cattle production).

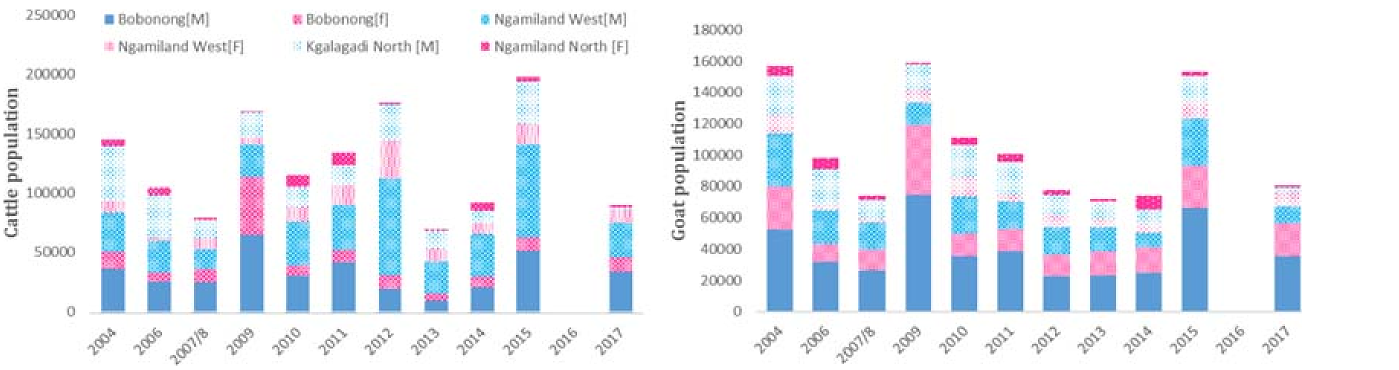

Figure 58. Gendered cattle (left) and goat (right) population in the districts of Bobonong, Kgalagadi North and Ngamiland West.

The livestock production system in Botswana is extensive and largely dependent on rangeland. Smallholder livestock farmers in communal land hold 85–90% of the national cattle herd[127] and support 36% of the national population[128]. Cattle and goats are the most kept livestock species and are continuously grazed in shared rangelands around meraka (cattle posts) and homesteads. The livestock populations tend to be influenced by climatic conditions[129] and tend to decline during drought shocks (Figure 58), as they strongly rely on natural rangelands for nutritional supply.

[125] Vision 2036 Presidential Task Team Secretariat, *Vision 2036 Achieving Prosperity For All* (Statistics Botswana, 2016), http://www.statsbots.org.bw/sites/default/files/special_documents/Vision 2036_0.pdf.

[126] Statistics Botswana, 2018

[127] Dizyee K, D Baker, K.M. Rich. 2017. A quantitative value chain analysis of policy options for the beef sector in Botswana. Agricultural Systems 156; 13–24

[128] Seleka T.B, P.G Kebadile. 2015. Export Competitiveness of Botswana's Beef Industry. BIDPA Working Paper 42

[129] Kgosikoma OE, N Batisani. 2014. Livestock population dynamics and pastoral communities' adaptation to rainfall variability in communal lands of Kgalagadi South, Botswana. Pastoralism: Research, Policy and Practice 4:19

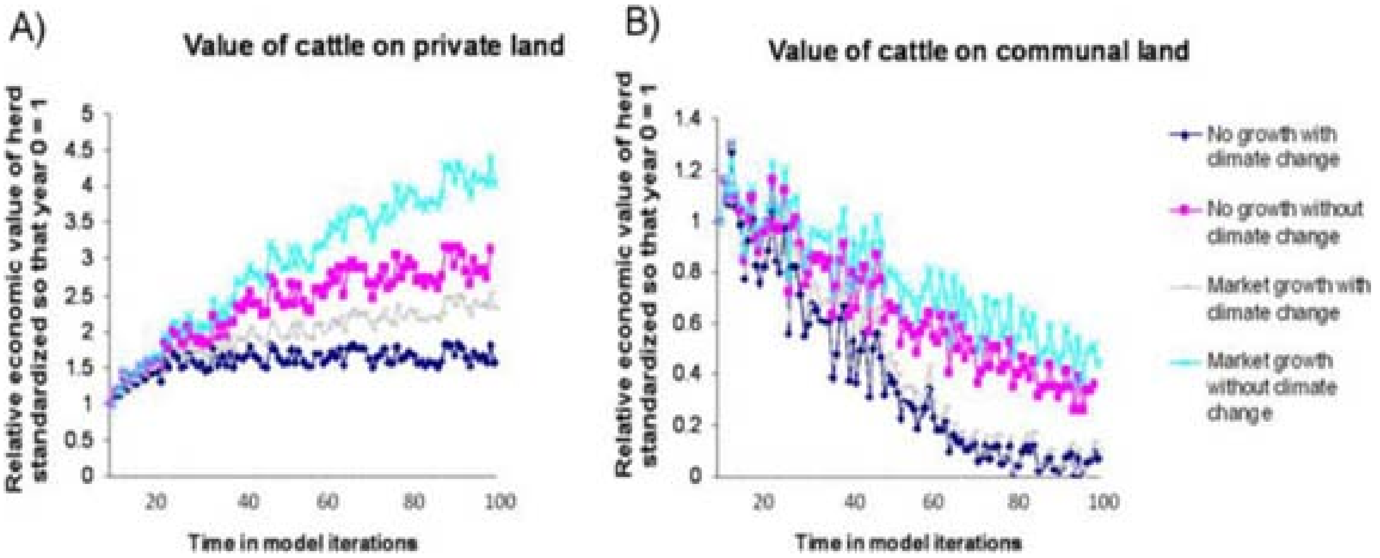

Figure 59. Cattle value on A) private land and B) communal land across southern Botswana in response to climate change, rangeland degradation and market growth[130]. Model iterations are in years.

Communal rangeland-based livestock sector contribution to national economic development may diminish due to changing climate. The reduced rangeland and livestock productivity projected under changing climate will have an adverse impact on the profitability of the industry. The simulation using dynamic models indicates that production of cattle in communal grazing land is highly vulnerable to climate change relative to that in private land (ranching) (Figure 59)[131]. This could be partially attributed to the fact that producers in ranches manage their stocking rates better than those in communal land and so far there is evidence to suggest high stocking density leads to more severe feed gaps and sensitivity to climate change than less densely stocked farms[132]. In this context, farmers in Ngamiland and other foot and mouth prone areas are significantly more vulnerable as their cattle herd continues to grow and degrade rangeland as a result of limited access to external markets[133]. It is therefore evident that climate change will lead to decline in cattle value in both production systems, and this could be linked to lower cattle productivity because of heat stress and reduced rangeland carrying capacity as a result of declining rainfall and increasing bush encroachment under changing climate. Taking into consideration the importance of rangeland-based livestock sector in the livelihood of society and economy, it is therefore essential to manage climate risks to reduce its potential impacts.

The temperature increase is consistent across all sites and compares well with projected temperatures increase of between 1.5 and 3.5°C across Botswana[134]. It is estimated that for every degree of temperature, evaporation increases by 5%, resulting in future enhanced evaporation from water bodies — particularly wide, shallow dams or watering holes — as well as heightened evapotranspiration from vegetation and soils potentially exacerbating water scarcity. Shifts in rainfall distribution, an increasing frequency of extreme weather events and consequent increased heat stress and reduced water-availability are expected to adversely affect livestock production and productivity[135]. Low and erratic rainfall, coupled with high evapotranspiration rates, are major limiting factors for primary livestock productivity. This, coupled with drought, reduces not only water availability for livestock but also the rangeland species they feed on as potential evapotranspiration increases with higher air temperatures[136]. Rangeland vegetation consequently

[130] Dougill, A. J., E. D. G. Fraser, and M. S. Reed. 2010. Anticipating vulnerability to climate change in dryland pastoral systems: using dynamic systems models for the Kalahari. Ecology and Society 15(2): 17

[131] Dougill, A. J., E. D. G. Fraser, and M. S. Reed. 2010. Anticipating vulnerability to climate change in dryland pastoral systems: using dynamic systems models for the Kalahari. Ecology and Society 15(2): 17

[132] Descheemaeker K, M Zijlstra, P Masikati, O Crespo, S Homann-Kee Tui.2017. Effects of climate change and adaptation on the livestock component of mixed farming systems: A modelling study from semi-arid Zimbabwe. Agricultural Systems

[133] Kolawole OD, MR Motsholapheko, BN Ngwenya, O Thakadu, G Mmopelwa, D L Kgathi. 2016. Climate Variability and Rural Livelihoods: How Households Perceive and Adapt to Climatic Shocks in the Okavango Delta, Botswana. WEATHER, CLIMATE, AND SOCIETY, 8

[134] Zhou P.P., T Simbini, G Ramokgotlwane, T.S Thomas, S Hachigonta, L.M Sibanda, 2013. Botswana. In Southern African Agriculture and Climate Change: A comprehensive analysis. Chapter 3 Pp. 41-70. Washington, D.C.: International Food Policy Research Institute (IFPRI)

[135] FAO climate-smart agriculture sourcebook: climate-smart livestock production. Available at: http://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b2-livestock/chapter-b2-1/en/

[136] Dai, A., *et al*. 2004. A global dataset of palmer drought severity index for 1870–2002: Relationship with soil moisture and effects of surface warming. J. Hydrometeorol., 5, 1117–1130.

dries out as greater rates of evapotranspiration reduces soil moisture availability, and limits vegetative growth. Moreover, current climate change and variability has exacerbated poor livestock productivity by making dry season feed shortage a more prominent problem in arid and semi-arid rangelands[137,138].

Table 13. Livestock climate thresholds.

Product	Preferred climatic conditions	Future climate impact
Cattle (Beef/Dairy)	Beef cows thrive at an ambient temperature range of about 15°C to 25°C. The water needs of cows is reliant on the temperature. Above 35°C the water requirement is triple that of 15°C to 25°C.	Though cattle are very resilient, the increased temperatures will likely increase heat stress of the cattle and also increase the amount of water they consume. Additionally, voluntary intake of food will likely decrease as ambient temperatures increase, with severe heat stress considerably lowering appetite and therefore likely reducing productivity.
Broilers	The recommended temperatures for poultry vary with age. Week 1 - 30°C, week 2 - 26°C, week 3 - 22°C, week 4 - 20°C The ideal relative humidity for poultry is approximately 60%.	Increased future temperatures will often exceed these thresholds and animal heat stress may occur.
Eggs	Chickens lay eggs best at temperature of 11°C to 26°C. Below 11°C many chicken types do not lay eggs. Above 28°C production and quality of eggs decrease. Relative humidity of more than 75% will decrease egg production.	Increased future temperatures will often exceed 28°C and therefore production and egg quality will deteriorate unless there is sufficient ventilation. High humidity may occur due to enhanced evaporation on hot days though heat stress is more likely to decrease production.
Goats	Goats tend to be more resilient to climate changes, particularly higher temperatures. In more extreme temperatures they will need an adequate source of water.	Goats are most sensitive to cold and wet conditions. The increase in average temperature will reduce this sensitivity, thought anomalously cold night-time temperatures during the rainy season may render goats more vulnerable.

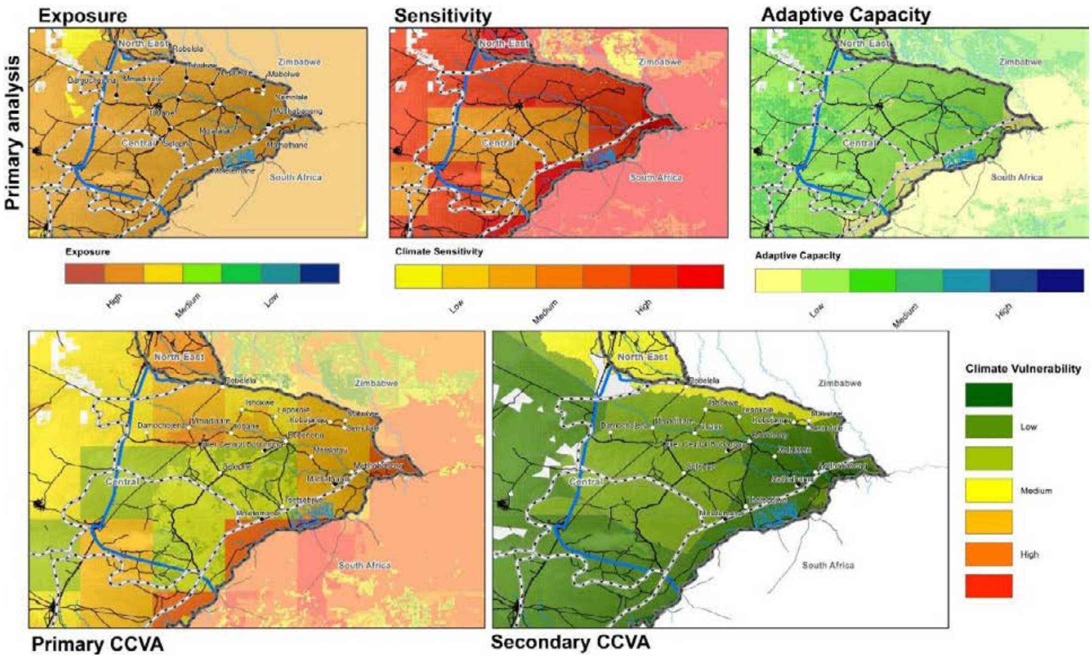

Figure 60. Components of livestock climate vulnerability for Bobirwa.

[137] Lohmann, D., *et al*. 2012. "Shifting thresholds and changing degradation patterns: climate change effects on the simulated long-term response of a semi-arid savanna to grazing." Journal of Applied Ecology, 49(4), 814-823.

[138] Martin, R., *et al.* 2014. "How much climate change can pastoral livelihoods tolerate? Modelling rangeland use and evaluating risk." Global Environmental Change, 24, 183-192.

During the consultative discussions, the pastoral communities confirmed that recurring rainfall anomalies threatens the sustainability of their livestock production and livelihoods. The future precipitation (2040–2060) is expected to decline by at least 8 to 16 mm, even when using the moderate emission pathway (RCP 4.5). This downward future trend in precipitation has also been demonstrated in work by other researchers[139,140]. The rainfall is also likely to be more unreliable in the future, as indicated by increased coefficient of variation. These climate changes noted by the communities will become more severe in the future and will have both direct and indirect implications for communal livestock. Bobirwa (Figure 60), in the east of the country see medium to high exposure for people, livestock and crop lands.

Sensitivity analysis in Bobirwa used the water available to agriculture and livestock. The anticipated sensitivity is low to medium resulting in lower overall competition between sectors for access to water resources. This lower sensitivity to climate risks could be attributed to multiple factors such as high surface water availability for irrigation and diversified employment activities where water-use is less intensive. However, small-scale livestock without the diversification of activities would be highly sensitive to drought and drying of ponds in these extreme events[141]. With the high anticipated exposure changes, the future vulnerability will increase because of high dependence on surface water which is highly variable depending on river flows. The adaptive capacity in Bobirwa was assessed through the resolve of natural ecological systems focusing on livestock and agriculture sustainability. The adaptive capacity is considered low to medium. The large number of cattle in this area will place additional stress on these natural systems.

The projections indicated that livestock environment is likely to be more unfavourable in Bobirwa (Figure 60) particularly in the south, western and northern parts of the district. Nonetheless, this district is likely to have more cattle population in the future and loss of this assets due to climate change will lead to increased poverty. This will likely force pastoralists to seek alternative livelihoods such as employment in urban areas or harvesting of increased volumes of non-timber forest products (for example, mophane worms and firewood). This could potentially disrupt family life through migrations and exacerbate land degradation. Additionally, with expanding livestock populations and decreasing rangeland and water availability, resource competition is likely to increase between farmers. The combination of increasing poverty and competition for dwindling resources may increase the likelihood of conflict among pastoralists. Previous research has indicated that Ngamiland, for example, is characterised by this with land use competition, conflicts and environmental problems cited as some of the most common issues faced by pastoralists[142,143]. Moreover, surveys conducted in Bobirwa have shown that men, as the primary holders of livestock, are particularly distressed by water and livestock feed shortages. This is because livestock is reared for both income and consumption, so reduced productivity leads to a reduced ability to provide and subsequently an increase in the likelihood of behaviours such as alcohol abuse, criminal activities and family breakdown. Social issues of water scarcity extend also to women and their children as it is often the responsibility of the female household members to ensure water is available for household use[144]. The projected increase in temperatures and reduced rainfall are likely to have adverse impact on livestock as shown in Table 12.

[139] Zhou P.P., T Simbini, G Ramokgotlwane, T.S Thomas, S Hachigonta, L.M Sibanda, 2013. Botswana. In Southern African Agriculture and Climate Change: A comprehensive analysis. Chapter 3 Pp. 41-70. Washington, D.C.: International Food Policy Research Institute (IFPRI)

[140] Shongwe ME, GJ Van Oldenborgh, BJJM Van Den Hurk, B De Boer, CAS Coelho, MK Van Aalst. 2009. Projected changes in mean and extreme precipitation in Africa under global warming. Part I: Southern Africa. Journal of Climate 22: 3819-3837

[141] Masundire, H., Morchain, D., Raditloaneng, N., Hegga, S., Ziervogel, G., Molefe, C. and Angula, M.(2016), About ASSAR Reports Vulnerability and Risk Assessment in Botswana's Bobirwa Sub-District: Fostering People-Centred Adaptation to Climate Change, Gaborone, available at:www.ub.bw/ (accessed 13 December 2017).

[142] Basupi, L.V., *et al*. 2017. "Using participatory mapping and a participatory geographic information system in pastoral land use investigation: Impacts of rangeland policy in Botswana." Land Use Policy 64.

[143] Basupi, L.V., *et* al. 2017. "Historical perspectives on pastoralism and land tenure transformation in Ngamiland, Botswana: What are the policy and institutional lessons?" Pastoralism 7, 24.

[144] Nitya, R., *et al*. 2019. "Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia," Climate and Development, 11:1.

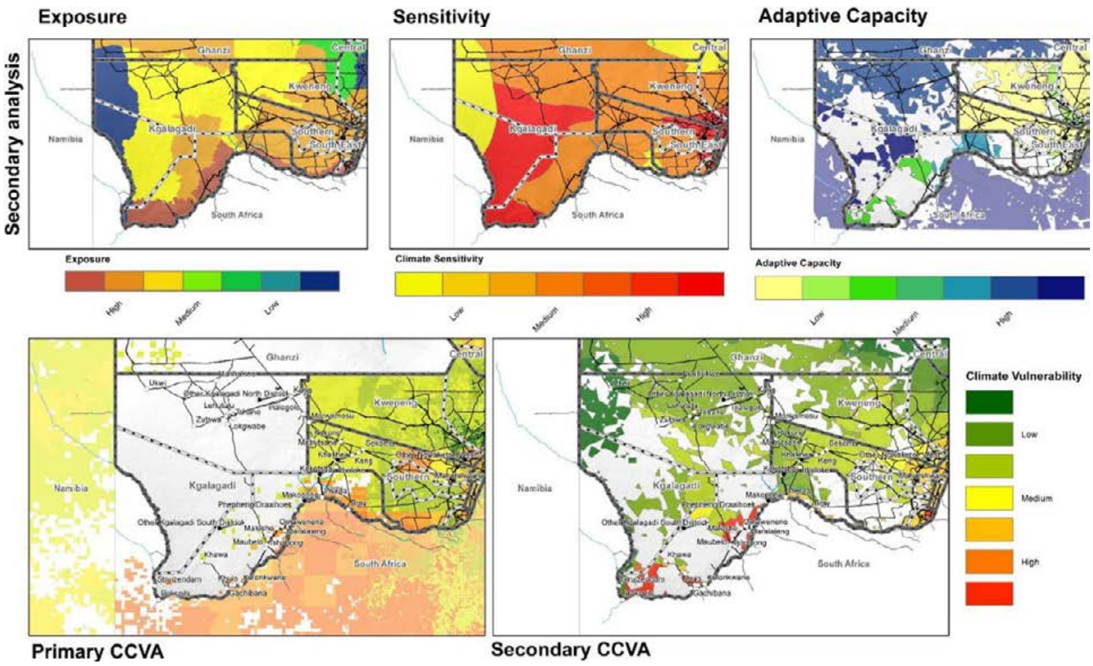

Figure 61. Components of livestock climate vulnerability for Kgaligadi.

Kgalagadi communities (Figure 61), in the south of the country, are currently extremely exposed to climatic changes. The anticipated decreased precipitation is very high proportional to the low annual precipitation totals. Kgalagadi is currently characterized by low annual rainfall ranging between 212 mm in the southwest and 317 mm in the north of the district. The coefficient of variation is very high indicating high rainfall uncertainty including all rangeland ecosystem[145] and livestock production system as there highly correlated[146]. The annual rainfall is projected to decline by at most 15 mm under changing climate (RCP 4.5) and similar pattern had been reported at Tshane[147].

Kgalagadi has a high concentration of boreholes which provides some relief for livestock but are often of high salinity. The sensitivity in water supply, given the low precipitation in this region comes from groundwater as a viable potential alternative. The low rate of groundwater replenishment means that the sensitivity is medium to high in this area. The adaptive capacity in Kgalagadi is based on the economic impact to livestock associated with largescale drought in the region. The lower proportion of commercial cattle in the region does however show lower economic impact from drought. The impacts of substance farmers, of which there are fewer, will still be high because of high dependence on communal grazed livestock system, which are highly exposed to recurring droughts[148].

The high exposure and sensitivity in Kgalagadi suggest future livestock suitability will decrease per livestock unit. However, the reduced number of cattle in the area will lower the rangeland impacts of these cattle. The future vulnerability is low to medium and high in some further south areas. This vulnerability is highly dependent on the lowered number of cattle in the area. With high exposure and sensitivity, increasing the cattle density will rapidly increase the climate vulnerability of the area. Moreover, an increase in cattle density will likely exacerbate both the direct and indirect consequences of climate change on livestock suitability — with increasing temperatures and frequency and intensity of heatwaves and droughts leading to, *inter alia*, a higher incidence of heat stress, increased pathogen transmission and a reduction in grazing and water resources[149]. In 2015/16, a period during which there was drought, cattle experienced the highest mortality of all livestock in Botswana, with Kgalagadi being the second most affected district with 2,698 cattle deaths (~21% of all cattle deaths during this period)[150].

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[145] (Mphiayne et al 2008)

[146] Kgosikoma OE, N Batisani. 2014. Livestock population dynamics and pastoral communities' adaptation to rainfall variability in communal lands of Kgalagadi South, Botswana. Pastoralism: Research, Policy and Practice 4:19

[147] Jerome R. Mayaud, Richard M. Bailey & Giles F. S. Wiggs. 2017. Modelled responses of the Kalahari Desert to 21st century climate and land use change. www.nature.com/scientific reports

[148] Kgosikoma OE, N Batisani. 2014. Livestock population dynamics and pastoral communities' adaptation to rainfall variability in communal lands of Kgalagadi South, Botswana. Pastoralism: Research, Policy and Practice 4:19

[149] Lacetera, N. 2019. "Impact of climate change on animal health and welfare." *Animal Frontiers, 9 (1).*

[150] Statistics Botswana. 2018. Botswana Environment Statistics. Natural Disasters Digest 2017. Available at: http://statsbots.org.bw/sites/default/files/publications/Botswana%20Environment%20Natural%20Disaster%20Digest_2017.pdf

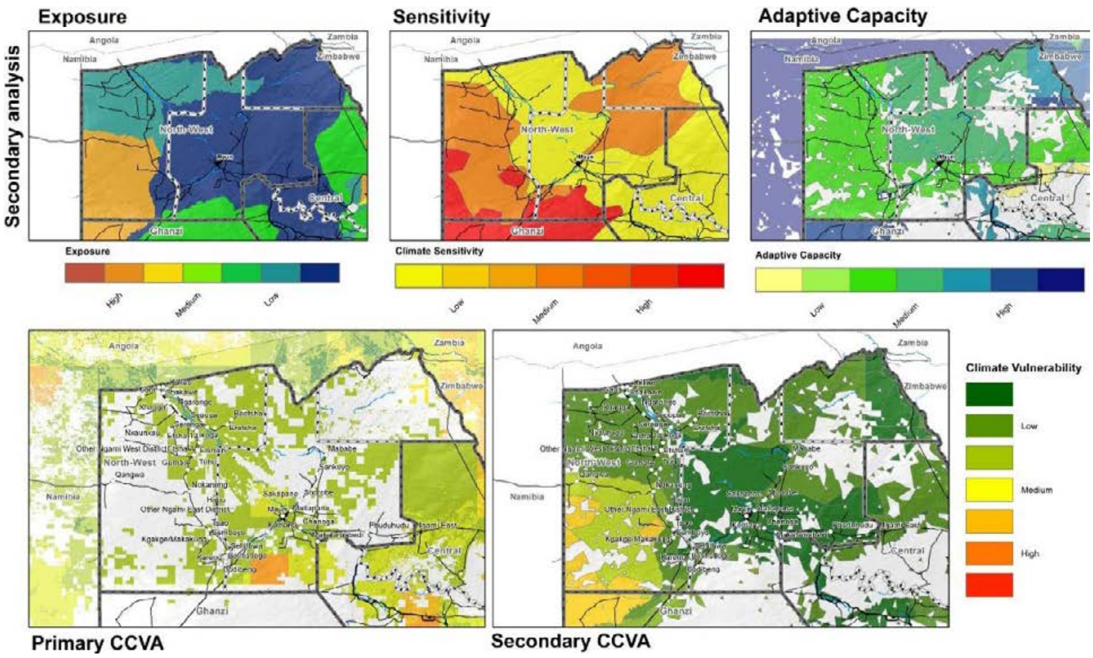

Figure 62. Components of livestock climate vulnerability for Ngamiland.

Ngamiland, in the northern delta region of the country, has the highest average precipitation in the country as well as being subject to the annual Okavango flooding event and as such has a lower exposure of future water stress. Sensitivity is based on ground water reliability. With the higher annual average precipitation and the flood inundation, from a purely water volume perspective, this area has decreased potential ground water stress. The sensitivity in the southern area of Ngamiland is also driven by the high cattle densities in this area resulting in land degradation and ecosystem pressure.

The adaptive capacity of the region is medium - mostly a result of key variable economic activities of agriculture and tourism. Both of these activities are highly rainfall-sensitive with ecosystems responding to an extreme extent to seasonal changes[151]. Smallholder livestock, not benefiting from the economic activity from tourism around the delta, would still be exposed to these changes.

Given the higher total precipitation in the area and the various economic activities, this area as a whole will likely have the highest overall resilience to future climate changes. However, in the event of precipitation failing and floods being of reduced magnitude, the small-scale livestock farmers will need to find water and rangeland resources for their cattle and compete in the area of the country with the highest average cattle density. In a water scares country, the climate change vulnerability is driven primarily by the shifted exposures of surface and ground water resources, the sensitivity of natural resources and the livestock density competing for resources.

Kgaligadi is the most climate exposed and sensitive region, but the low cattle density reduces the pressure on the region. This area would be functioning at its current threshold and further climate shocks would likely compromise the livestock resilience. Bobirwa with its medium levels of precipitation is more resilient to extreme climate shocks that Kgaligadi, however the greater density of cattle will place greater pressure on the ecosystem. Ngamiland diversity in economic activities and the highest total precipitation will have lower climate vulnerability, though in years of reduced rainfall and flood events, livestock will be forced to move further into the delta region for the resources needed by their cattle.

5.7 Impact chain

The climate change on the ground are manifest though a culmination of multiple interrelated long-term climate forcing and meteorological feedback mechanisms. Assessing changes in a single variable will therefore give

[151] Kolawole OD, MR Motsholapheko, BN Ngwenya, O Thakadu, G Mmopelwa, D L Kgathi. 2016. Climate Variability and Rural Livelihoods: How Households Perceive and Adapt to Climatic Shocks in the Okavango Delta, Botswana. WEATHER, CLIMATE, AND SOCIETY, 8

a siloed view of the impacts to communities and eco-systems that operative in a complex interdependency balance. Vulnerability should consider numerous variables with the ramifications of anomalies contextualised against impacts on the different aspects of communities and ecosystems.

Table 14. Climate change impact pathways.

		Anticipated Climate changes			**Average Precipitation change**	**Extreme Summer Precipitation Events**	**Rainfall variability, Drought, Onset shifts, Ground water changes**	**Increase in Extreme temperatures and Heatwaves**	
		Direct impacts	Longer Dry Spell	Less Rain	Flooding Events	Late Rainfall Onset	More Variable Precipitation	Heat Stress	Drying of Vegetation
Downstream effects	**Indirect Impacts**	Physical damage and costs for recovery and reconstruction	water insecurity		livestock enhanced metabolism needing more feed	crop climate thresholds breached	Ecosystem climate thresholds breached	soil drying	Increase in FDI
		Road infrastructure additional investment	prioritisation of water use	Compromised Water Supply and Sanitation	Heat induced premature deaths	agricultural shock	Degradation of soil and water quality	Changes in winter and summer tourism demand	Labour force productivity loss
		public expenditures			Disruption to Farming/ cropping system	Animal and crop pests increase		Disruption to local economy	
				Agriculture livelihoods compromised - Crop	Agriculture livelihoods compromised - Livestock	Pressure placed on natural resources to remain sustainable	Competing land uses	Non-compliance with local environmental limits	
				Agricultural Market Shock - Pricing compromise	Demand and investments shift	Loss of production - losses of workers due to heat and humidity	Decreased competitiveness from weakened profit margins		
Upstream effects			Changing livelihoods	Competing priorities	Labour Rights and Decent Work	service provision	Climate migrations		
			Sector resilience	Areas economic profile	Governance	Distribution of wealth			
		Risk of Child not attending school	Risk of Child labour	Employment risk and lacking bargaining power	Risk of sector wage below poverty guidelines	Risk of inflexibility for labour by sector	Risk of weakened legal system	Risk of weakened gender equality	Risk of limitation to Freedom of association

Sectors Environment (dark green), Agriculture (orange), Water Supply and Sanitation (blue), Manufacturing and Trade (grey), Catastrophe Management (pink), Tourism (purple)

6 Climate change risk management in the communal livestock system

Adaptation is a complex and interactive risk management strategy based on individual circumstances[152]. As a result, stakeholder participation is a vital component of the assessment of adaptation measures because not all adaptation practices are necessarily suitable for all farmers. Therefore, there is a need to critically assess adaptation measures, with the inclusion of social and gender considerations and economic and environmental sustainability, to avoid maladaptation. Sustainable adaptation to climate change is critical in ensuring food security, reducing poverty, and enabling the conservation of natural resources.

[152] Eriksen S and Brown K. 2011. Sustainable adaptation to climate change. Climate and Development, 3: 3-6

A participatory approach was used to gain insights into pastoral communities' perspective of adaptation practices. The group discussions — with pastoral communities and diverse stakeholders including representatives from extension services, farmer associations, village development committees and local government — were used to elucidate the adaptation practices being used to reduce the impact of climate-related hazards (for example, drought) on livestock. The stakeholders in Ngamiland and Bobirwa prioritised the adaptation practices by each selecting the main three measures in place in these areas. Additionally, a literature review was used to complement the group discussions and identify alternative adaptation practices used in the livestock industry in arid environments.

6.1 Current and alternative pastoral adaptation practices in Botswana

In Botswana, pastoralists who have had to respond to climate-related hazards, in particular drought, have been using a variety of adaptation practices to reduce impacts on their livestock and livelihoods. A matrix of adaptation practices that have been adopted to reduce specific climate sensitivity in their production systems are shown in Table 14. Such practices provide an opportunity to leverage on the process of building resilience against climate change.

Table 15. Adaptation practices identified by pastoralists across Botswana[153].

Adaptation strategy	Practices	Male respondents	Female respondents	Bobirwa	Kgalagadi North	Ngamiland
Ecosystem-based Adaptation	Sustainable grazing management	7	5			■
	Rehabilitation of degraded land		1	■		■
	Fire management					■
	Fodder production	23	4	■	■	■
Livestock based	Breeding for adapted breeds					
	Supplementation	16	14	■	■	■
	Improve water supply	4	2	■	■	■
	Disease surveillance and vaccinations	3	3			
	Destocking through market	10	10	■	■	■
	Mobility	3	2	■	■	
	Mixed farming (multi – species)					
Livelihood diversification	Migration			■		
	Government social programmes			■		

6.2 Ecosystem based adaptation

Climate change and high, continuous grazing pressure contribute towards declining rangeland productivity[154] and therefore it is critical to sustain ecosystems' ability to provide ecological services under changing climate. A healthy rangeland ecosystem is a result of balanced grazing and resting periods, to allow herbaceous

[153] Blue coloured boxes indicate the non-ranked practice of an adaptation strategy in an area — i.e. sustainable grazing management is practiced in Ngamiland but not Kglagadi North or Bobirwa. Where numbers of respondents are provided, they indicate the quantity of survey participants who have stated their preferred adaptation strategy, where this information is available (Maun, Gumare and Bobonong).

[154] Dangal, S. R. S., H. Tian, C. Lu, S. Pan, N. Pederson, and A. Hessl. 2016. Synergistic effects of climate change and grazing on net primary production of Mongolian grasslands. Ecosphere 7(5): e01274. 10.1002/ecs2.1274

species to recover[155]. The current communal rangeland management does not allow the exclusion of livestock and the resting and recovering of plant species leading to loss of palatable grass species. Ecosystem based adaptation therefore could be achieved through:

6.2.1 Sustainable grazing management

The rangeland needs to be grazed at an appropriate intensity and then allowed to sufficiently rest and restore its integrity[156]. The abundance of healthy perennial and palatable grasses enables the ecosystem to efficiently utilize the available moisture and produce sufficient biomass needed to support livestock during dry periods. Importantly, grazing regimes need to be controlled to fully utilize both poor and palatable grasses, without selecting only desirable grasses and compromising their competitive vigour.

6.2.2 Rehabilitation of degraded rangelands

The literature review and stakeholders' views indicated that rangelands are highly degraded[157] and therefore the rehabilitation of degraded rangeland could significantly improve its carrying capacity. Restoration of rangeland ecosystems reduce their sensitivity to climate shocks and therefore improve their capacity to sustain the national herd through climatic shocks. This could be achieved through:

- control of bush encroachment — e.g. Senegalia (acacia) mellifera, Terminalia sericea — and invasive plants (Cenchrus biflorus and Prosopis species);
- establishment of perennial and palatable grasses (e.g. Cenchrus cilirias); and
- adherence to conservative rangeland stocking rates that will result in abundance of standing hay during dry seasons.

6.2.3 Fire management

Bush fires frequency and intensity are projected to increase under changing climate[158]. The intensity of bushfires relates to the amount and types of fuel loads[159] and, in the context of Botswana, the risk of high intensity bushfires is high following wet years. Properly managed bushfires could be used to regulate bush encroachment. However, most bushfires are unplanned and unmanaged and therefore destroy the rangeland's capacity to provide ecological services.

The current fire management system in Botswana is centralized around the Government and is not well coordinated to ensure an efficient response mechanism. As a result, bushfire management strategies should be inclusive of local communities, motivated by conservation of standing hay and ecological sustainability of their grazing lands[160]. Improved bush fire management contributes towards bush encroachment management and therefore protects the ecosystem integrity and climate change resilience of pastoralism. It is for this reason, that the government of Botswana — in partnership with the Australian government — have been building capacity for preventing, managing and fighting bushfires to reduce the economic, social and environmental costs of bushfires.

6.2.4 Fodder production

The use of drought tolerant fodder crops such as Lablab and forage sorghum could be either produced solely or intercropped with other crops, especially during good years. Forage-legume intercropping could improve

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[155] Mudongo EI, Fynn RWS, Bonyongo MC. 2016. Role of Herbivore Impact and Subsequent Timing and Extent of Recovery Periods in Rangelands. Rangeland Ecology & Management

[156] Mudongo EI, Fynn RWS, Bonyongo MC. 2016. Role of Herbivore Impact and Subsequent Timing and Extent of Recovery Periods in Rangelands. Rangeland Ecology & Management

[157] Bai Z.G, D.L Dent, L Olsso, M.E Schaepman. 2008. Proxy global assessment of land degradation: Review Article. Soil Use and Management, 24, 223–234

[158] Dube, O.P. 2013. Challenges of wildland fire management in Botswana: Towards a community inclusive fire management approach. Weather and Climate Extremes, 1:26–41

[159] Douglas, GB and He Y. 2019.Design Bushfire Selection for Bushfire Protection in Adaptation to Global Warming. Frontiers in Mechanical Engineering

[160] Dube, O.P. 2013. Challenges of wildland fire management in Botswana: Towards a community inclusive fire management approach. Weather and Climate Extremes, 1:26–41

productivity, resource use efficiency and resilience of the system under climate change[161]. Agroforestry (e.g. planting/intercropping with Cajanas) could also contribute positively towards carbon sequestration[162]. Bobirwa district has reasonable surface and underground water to support irrigated fodder production. Recycled water could also be used to irrigate fodder crops.

6.3 Livestock based adaptation

6.3.1 Breeding for adapted breeds

It is essential to breed livestock that could be productive under future climate conditions[163]. The local breeds (e.g. Tswana cattle and goats) have the capacity to: i) manage a higher threshold than the 30°C ambient temperature; ii) walk long distances in search of grazing resources; and iii) digest poor grasses[164]. The adaptive traits of local breeds could be utilized to cross with exotic breeds to increase resilience and to sustain productivity. The Government of Botswana — through the Department of Agricultural Research — has already developed a composite cattle breed, known as Mosi, as an adaptation measure to climate risks, by smallholder farmers. However, during the consultative meeting, the pastoral community did not mention the breeding aspects as part of adaptation, and this could be a result of insufficient of awareness of climate change adaptation practices among local communities.

6.3.2 Supplementation

To address shortages of forage, strategic additional feed should be provided to sustain the livestock to reduce mortality — particularly those with calves. The correct supplementary feed needs to be supplied at critical stages to manage costs and provide required nutrients. For example, animals exposed to dry but sufficient grazing need to be provided with a protein source, which could be economically achieved through use of urea-molasses blocks. In case of dry and limited grazing resources both protein and energy need to be provided. Crop residues should be promoted to ensure that animals remain in reasonable condition until the next wet season.

6.3.3 Improved water supply

The sustainable management and provision of water resources is key to adaptation practices — particularly in drylands with limited surface water such as Botswana — and therefore central to pastoralists and their livelihood sustainability[165]. The increased temperature caused by climate change will result in increased demand for water, from livestock, for thermoregulation. As a result, the cost of pumping water is likely to increase considerably — by more than 20% under a changing climate[166]. It may, therefore, be prudent to encourage the sustainable abstraction of water resources from aquifers and potentially use clean energy — such as solar and wind energy — to pump water for the livestock sector. This may help to reduce the ongoing financial costs associated with abstraction, without increasing carbon emissions. In addition, rainwater-harvesting technologies may be introduced to provide water supply for the livestock industry during periods of reduced water availability, for example, during droughts. Feasibility studies, however, would need to be conducted before they are deemed an appropriate adaptation solution to improve water supply and management to pastoralist communities in the project areas. Moreover, this will help to ensure these measures are locally appropriate, can be implemented alongside effective and sustainable management frameworks and are financially viable, as clean energy solutions often require a large capital outlay.

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[161] Hassen A, Talore DG, Tesfamariam EH, Friend MA, Mpanza TDE. 2017. Potential use of forage-legume intercropping technologies to adapt to climate-change impacts on mixed crop-livestock systems in Africa: a review. Regional Environmental Change

[162] Bayala J, Sanou J, Teklehaimanot Z, Kalinganire A, Ouedraogo SJ (2014) Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. Current Opinion in Environmental Sustainability, 6:28–34

[163] Scholtz MM, A Maiwashe, FWC Neser, A Theunissen, WJ Olivier, MC Mokolobate, J Hendriks. 2013. Livestock breeding for sustainability to mitigate global warming, with the emphasis on developing countries. South African Journal of Animal Science, 43 (No. 3)

[164] Archer Van Garderen ERM. 2011. (Re) Considering Cattle Farming in Southern Africa under a Changing Climate. American Meteorological Society

[165] Basupi LV, Quinn CH and Dougill AJ. 2017. Historical perspectives on pastoralism and land tenure transformation in Ngamiland, Botswana: What are the policy and institutional lessons? Research, Policy and Practice (2017) 7:24

[166] Masike S, and P Urich. 2008. Vulnerability of traditional beef sector to drought and the challenges of climate change: The case of Kgatleng District, Botswana. Journal of Geography and Regional Planning Vol. 1(1), pp. 012-018

6.3.4 Disease surveillance and vaccinations

Higher or lower temperatures may increase the rate of development of pathogens or parasites that increase disease outbreaks. Anthrax, blackleg and foot and mouth diseases are some of the diseases of concern as their outbreak could result in loss of income for smallholder farmers. The farming community in Ngamiland and Bobirwa indicated that there have been several outbreaks of ticks, and other parasites, after wet years which leads to increased mortality. Regular surveillance and treatment of livestock diseases is therefore essential to maintaining livestock productivity and reducing mortality.

6.3.5 Market-based adaptation (Destocking)

The shift in production and marketing strategies by livestock producers — in interaction with traders — could reduce their vulnerability to climate shocks[167]. The pastoralists indicated that there are high livestock populations in their grazing land and therefore there is an opportunity to systematically control livestock population through improved and coordinated market access. The farmers need to supply old and unproductive livestock to the market timeously to avoid driving prices down due to oversupply. In Kgalagadi North and Ngamiland in particular, more cattle are lost through natural death than slaughter at market. This may partly be explained by a failure to dispose of stock through efficient timing of market entry. Consequently, this may lead to overgrazing and increase vulnerability to climate shocks. However, a favourable market price is also needed to motivate producers to sell. A lack of motivation for small-scale producers in Botswana to sell their livestock is evidenced by off-take rates in communal areas being lower than the commercial off-take rates, despite pastoralists holding ~80% of all cattle[168]. This is of note for ensuring livelihood sustainability as market participation in agriculture is considered one of the most important contributory factors to poverty reduction in developing countries[169]. In Botswana, however, the market off-take rate of cattle through formal markets remains relatively low at 8.26% compared to 15.79% from commercial farming. This may be attributed to a number of factors including a lack of availability of market surplus — with pastoralists preferring to slaughter cattle for consumption as opposed to income during periods of low productivity — and the generation of income from alternative income sources, such as the selling of small stock[170]. Institutional constraints and high transactional costs associated with selling cattle to formal markets are also often barriers to market access for pastoralists[171]. Specific examples of this include differential access to assets and information asymmetries for commercial vs communal livestock holders[172]. When faced with these barriers, smaller scale producers receive fewer benefits from trade, thereby choosing not to participate in markets and this can consequently result in low off-take rates[173].

6.3.6 Livestock mobility

Traditionally, pastoral farmers grazed different grazing land during wet and dry periods, which provided an opportunity to restore its condition. However, some of the reserved grazing land has been privatized and the total area of communal land has been reduced. In Kgalagadi North, the pastoralists indicated that they seasonally graze away from water-points and use wild citron melons (Tsamma/kgengwe) as water sources. These melons are drought tolerant and also have high protein content (22 %)[174] which complements native grasses during dry periods. Meanwhile in Bobirwa, the pastoralists tend to move their livestock along the Motlotse and Shashe rivers in search of water and grazing resources. The Ovaherero and Ovambanderu in

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Ngamiland also herded their livestock following seasonal transhumant patterns between areas around the delta in the dry season and sandveld grasslands in the wet season[175].

6.3.7 Mixed farming

Pastoralists keep multiple livestock species to build resilience in their production systems. The farmers also indicated that they are switching from cattle to goat production, which is considered more resilient to climate shocks. The selected species need to have complementary diets (grazers vs browsers) to ensure that all grazing resources are fully exploited. In addition, markets for alternative livestock species need to be well developed to encourage farmers to trade. In Botswana, the government has provided small stock to resource poor farmers to boost their potential to sustain their livelihoods and resilience to climate shocks.

6.4 Livelihood diversification

Livestock producers are broadening their livelihood options, with some migrating to urban centres in search of employment to support their families. In Ngamiland, some pastoralists are now dependent on social programmes to sustain their families and need support to recover economically. A number of livelihood diversification options are available to pastoralists, many of which have been successfully adopted in other areas of Botswana, including the Okavango Delta[176]. These options include cultural and community-based tourism, — where the education and demonstration of traditional lifestyles and practices may be viewed as a tourism product — the collection and production of veld products, formal (wage-based) employment, self-employment such as trading, the production of feed/fodder development from bush encroachers such as *Senegalia (acacia) mellifera* (which is abundant in Kgalagadi North) and the production of artisanal and craft products[177][178]. Many of these strategies could offer alternative sources of income for vulnerable groups including female-headed households for whom agriculture is not an option. Vulnerable groups could also be trained and supported in other value chains such as bee keeping and fodder production. Additionally, the adoption of climate-resilient horticulture of crops with a high export value, such as vanilla, presents another possible strategy for livelihood diversification that is more closely associated with agriculture[179]. These livelihood-diversification options, however, would need to undergo an analysis of feasibility to ensure they are appropriate to the project areas and target communities.

6.4.1 Way forward in resilience building

The livestock industry in Botswana is strongly dependent on rangelands, which is poorly managed in communal land. As a result, ecosystem-based adaptation is a cornerstone of building resilience among communal pastoralists of Botswana. As illustrated in Figure 63, ecosystem-based adaptation is a process that is responsive to the state of rangelands and requires flexibility to achieve the desired rangeland condition. The highly encroached rangelands (2400 woody plants/ha)[180] need to be thinned to allow the herbaceous layer to re-establish. Similarly, a climax rangeland needs to be optimally grazed and then allowed to rest and recover from herbivory.

In communally grazed rangelands, the exclusion of grazing animals to allow for the recovery (rest) or establishment of an herbaceous layer (reseeding) is a challenging task, as there are no institutions to enforce the rules. Therefore, pastoral communities need to be supported to organise and work collectively to sustainably manage their grazing resources. Herding is then used as a tool to control livestock movement and monitor rangeland condition. Herding/holistic rangeland management as concepts therefore provide an opportunity to improve rangeland sustainability and livestock husbandry. This will, in turn, build rangeland

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[180] (Rogues et al 2001)

and livestock resilience in dryland ecosystems while the livelihoods of pastoral communities will also be improved. There is an urgent need to reintroduce herding as a tool to control livestock.

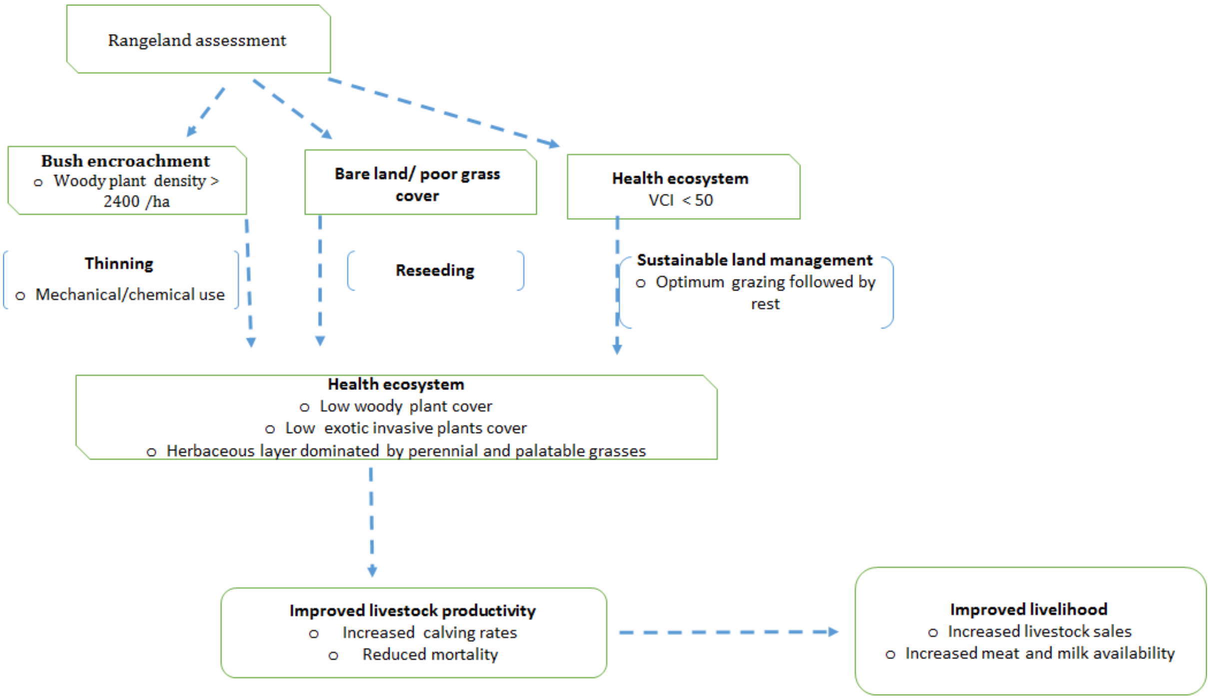

Figure 63. Ecosystem-based adaptation

6.4.2 Barriers to adaptation across Botswana

The stakeholder's knowledge on current livestock related adaptation practices is a prerequisite for developing a sustainable adaptation strategy and provides an opportunity that the project can leverage to address key barriers. There are multiple factors that make it difficult for pastoral communities to adopt practices that could enhance the resilience of their production systems.

Adaptation practices	Barriers	Recommendation
Ecosystem based adaptation	• Lack of institutions that promote sustainable management of ecosystems • Botswana has no rangeland management policy • Limited knowledge/experience on rangeland rehabilitation • Fodder production value chain are not well developed, and seeds are not readily available locally.	• Advocate for supportive policies such as CBNRM and sustainable rangeland management policy to ensure that communal rangelands are sustainably grazed. The land tenure should protect community's investment in SLM practices • Scale up proven rehabilitation practices in the Southern Africa (Department of Agricultural Research recommends use of *Cenchrus ciliaris* for rehabilitation) • To ensure EbA measures are effective they should be mainstreamed into both existing policy frameworks. This will ensure interventions are sustainable and scalable and can effect change beyond the project areas. To achieve this there should be support for EbA and local decision making in higher-level planning and policy processes. • As part of a larger adaptation strategy, EbA should become an integral part of key policies and implementation frameworks for sustainable development, agriculture, land use, poverty reduction, natural resource

		management and climate change adaptation. ● Local and national government actors should be actively engaged from the start to secure buy-in and promote support for implementation and wider mainstreaming. ● EbA approaches should include a monitoring and reviewing component that allows learning and adapting based on lessons learnt from on-the-ground implementation.
Livestock based adaptation	• Poor market access, particularly in Bobirwa and Ngamiland, as a result of FMD outbreaks. Low prices also a concern for farmers. • Cultural beliefs that associate large herd size with high social status. • Financial constraints limit smallholder farmers' capacity to supplement • Shrinking of communal land reduces the feasibility of mobility as an adaptation strategy.	● Commodity based trade could unlock market access ● Building farmers' capacity for sustainable rangeland and livestock management ● Local fodder production should be promoted ● Policy interventions could promote institutional upgrades such as improved structure and function of support services covering *inter alia* research, marketing, credit and extension, and training ● Additional policy interventions to address a major barrier to market access could be the formulation of strategies to provide animal health programmes aimed at limiting the impact of disease on production, namely by protecting livestock from major epizootic diseases through quarantines and veterinary care.

7 Institutional constraints and opportunities in climate resilience building among pastoral communities

The Botswanan Government has multiple policies that acknowledge climate change risks and promote resilience among pastoral communities. As a result, there is a paradigm shift towards integrated planning and management of climate change risks under NDP 11 which will create a conducive environment for different stakeholders (institutions) to work together to sustainably adapt across sectors. However, there are still some policies and programmes that compromise the adaptive capacity of pastoral communities in communal land and need to be addressed urgently.

Pastoral communities, additionally, are not always aware of policies and programmes in place which may affect communal grazing lands and consequently their livelihoods. For example, research in Ngamiland has found that, previously, village-level representatives from Village Development Committees (VDCs) did not know of the existence of any Integrated Land Use Plans for the District. Moreover, survey respondents argued that policy making processes remain top-down and communities tend to be aware of only basic services or information, which are acquired through one-off, village-level consultation meetings or via state radio. Communities are consulted only after the policy process and agenda has been discussed and agreed at central government level by policy-makers who often do not understand the impacts of policy implementation. This is evidenced by survey respondents who stressed implementation challenges are often brought about by centralised policy-making processes, which do not take into consideration the spatial heterogeneity of different pastoral landscapes. Pastoralists in Ngamiland are of the view that policy-makers tend to treat the country as a homogenous landscape, such that the same policy instrument can be applied throughout the country. Consequently, it may be put forward that VDCs are disenfranchised with current methods of policy-making and implementation related to livestock and land use management. This likely prevents complete and committed uptake and implementation of centrally formulated policies. Despite this, Village Courts and associated traditional institutions, such as VDCs and Farmer's Committees, still offer potential for community mobilisation and involvement in sustainable land management activities. The policy and government institutional framework for management of communal lands, however, has yet to take full advantage of these traditional institutions. Relevant stakeholders argue that the power of these structures has declined, and they are now used for one-off consultations by authorities. This may lead to the issue of legal pluralism mainly because traditional pastoral institutions are not thoroughly integrated into policy. Where they are mentioned, such as in the District Integrated Land Use Plan and Okavango Delta Management Plan, an overall framework on how to effectively integrate traditional institutions, pastoralist rights, and their knowledge of the environment is absent[181]. Resultantly, this offers an opportunity to ensure the integration of traditional institutions in future livestock and land use management and planning.

7.1 Policies and drafts

Despite steady improvements in the capacity of Local Government structures since Botswana's independence, challenges remain regarding their ability to perform their roles and discharge their functions. This is a result of insufficient capacity building such that the autonomy of Local Governments is limited and so they remain unable to perform many essential functions without assistance from Central Government ministries. Moreover, Central Government possesses a dominant role not only in the formulation of policies and development plans but also their subsequent implementation. This problem is exacerbated by Local Government structures lacking extensive independent revenue sources and their development expenditures consequently being met by Central Government. This is evidenced by Central Government providing ~97% of the recurrent expenditure of rural councils and ~80% of that of urban councils. Despite, therefore, being autonomous statutory bodies, Local Government essentially operates as decentralised agencies of the Ministry of Local Government[182,183]. Additionally, some policies and programmes such as the Tribal Grazing Land Policy have not undergone review to enable responsive measures or refinement.

There is potential, however, for strengthening the capacity of Local Government structures — including District Climate Change Committees, as outlined under Section 7.2 — to implement and monitor polices and management plans. This is especially true for VDCs as they are often more familiar with local contexts and individual nuances among villages and communities. In this way, VDCs may be viewed as a potentially effective tool for ensuring centrally formulated plans are locally-appropriate and can be modified to suit unique challenges amongst target communities. Moreover, they may be seen by community members as more informed and aware of challenges faced at a local scale and resultantly more sensitive to their needs, including those of vulnerable groups. To ensure effective implementation of policies and plans by VDCs and/or District Climate Change Committees, however, training programmes would likely need to be conducted to build their capacity for implementation and monitoring[184].

7.1.1 Botswana Climate Change Policy and Action Plan (draft)

The national climate change policy and action plan (NCCAP) aims to make the ecosystems and livestock sectors more resilient to climate change through a coherent approach that will enhance the preparedness at all levels of governance and improve rangeland integrity by the year 2030. This NCCAP seeks to ensure that the Botswana livestock value chain actors' takes necessary steps to reduce vulnerability to climate change and adopt a low carbon development pathway with multiple potential benefits such as:

- Improving adaptive capacity of communities through improved access to information and services.
- Sustaining the livelihoods of livestock producers, especially the poor and other disadvantaged groups in rural areas.
- Conservation of rangeland ecosystems and promotion of sustainable utilization.
- Efforts to improve climate resilience that can further low-carbon development strategy.

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[184] Ibid.

7.1.2 National Development Plan 11 (NDP 11: 2017–2023)

The National Development Plan 11 indicate that climate change threatens the sustainability of agricultural sectors, including livestock. Therefore, it is critical to strengthen the resilience of economic sectors, communities and institutions to facilitate sustainable responses to climate shocks. However, the government acknowledges that lack of financial resources could be a barrier towards preparing and responding to climate risks appropriately. NDP 11 promotes key components of ecosystem-based adaptation, which includes:

- preparedness for disaster management include drought.
- sustainable environment through improved natural resource management and governance, including of rangeland.

7.1.3 Vision 2036

The national vision acknowledges the threat of climate change and promotes mainstreaming climate change vulnerability assessments, adaptation and mitigation into our development planning. This project will therefore contribute towards achieving this vision through piloting of some adaptation and mitigation measures — appropriate for smallholder livestock farmers — and successful practices, scaled up nationally.

7.1.4 Climate Smart Agricultural Programme (2015–2025)

The National Climate Smart Agricultural Programme specifically targets building resilience, and associated mitigation co-benefits, in the agricultural sector. The intended outcomes of the programme include the conservation of natural resources and rehabilitation of degraded land, which is consistent with the concept of ecosystem-based adaptation. The proposed resilience building project among smallholder livestock farmers is therefore well aligned with the national response to climate change.

7.1.5 Tribal Grazing Land Policy (TGLP)

The TGLP was formulated to curb rangeland degradation through privatization of communal land into ranches. The policy is not favourable for smallholder farmers in communal land because it leads to shrinking of communal land and degradation due to increased grazing pressure. The situation is further exacerbated by the fact that those allocated ranches enjoy dual grazing rights as they continue to have access to communal resources. The policy has contributed to increased vulnerability of smallholder farmers in communal land because mobility is now limited and what used to be reserved grazing resources are now privately owned by someone else.

7.1.6 Proposed Drought Management Strategy for Botswana

This strategy proposes a more proactive and integrated approach to drought management over the short-, medium- and long-term. The strategy consists of five priority objectives i) Strengthen institutional and technical capacities for Drought risk reduction and climate change adaptation in Botswana and enhance coordination mechanisms; ii) Promote and enhance early warning systems for pro-active drought risk reduction and climate change adaptation; iii) Enhance knowledge management and innovation in support of drought risk management and climate change adaptation; iv) Reduce vulnerabilities to drought by improving technical options and implementing Community Based Drought Risk Management and Climate Change Adaptation measures; and v) Strengthen effective preparedness and response capacities and integration of drought risk reduction and climate change adaptation and interventions.

7.1.7 National Policy on Agricultural Development

The national policy on Agricultural Development does not address climate change directly, but some of its components are compatible with climate smart agriculture. The policy highlights the Government of Botswana’s commitment to sustainability, efficient resource use and environmentally compatible production systems and programmes. The policy is currently being reviewed and this proposed project could contribute significantly towards providing supporting evidence on climate resilient practices that could be scaled up nationally.

7.1.8 Community Based Natural Resources Management Policy

This policy aims to support rural development through provision of incentives for communities' participation in conservation activities that result in sustainable development and poverty reduction. So far, the concept of CBNRM has been widely applied in wildlife management in Botswana and has not been extended to rangeland management. The experience from implementation of CBNRM in wildlife management is essential to formulate effective community-based organizations (CBOs) responsible for sustainable rangeland management. The proposed project therefore has an opportunity to initiate community-based rangeland management in communal grazing land and promote livestock management practices that could buffer pastoral communities from the impact of climate change and also promote carbon sequestration. The project could build on community-based rangeland assessment work initiated by Indigenous Vegetation Project and their manuals used to build capacity among herders or livestock owners.

7.1.9 National Disaster Risk Reduction Strategy (2013–2018)

The proposed project is also guided by the National Disaster Risk Reduction Strategy, which aims to build community resilience against the threats and effects of disaster. The increased frequency of droughts, wildfires, climate change and the depletion of natural resources are some of the risks identified by the strategy. Through the proposed project, the livestock farming communities on communal lands will be supported to improve their resilience to climate change risks and therefore directly address components of the National Disaster Risk Reduction Strategy.

7.1.10 Livestock Management and Infrastructure Development (LIMID)

This programme seeks to promote livestock management improvement and conservation and efficient utilization of rangeland resources through development of infrastructure such as water reticulation to control grazing pressure, borehole drilling and equipment and promote fodder production. The programme provides a platform to subsidize a shift from diesel water pumps to solar energy and offsets the emissions from enteric fermentation. The Government of Botswana has committed to reduce greenhouse gases by 15 % by 2030[185] and shifting to solar energy will contribute strongly towards meeting this goal. The Botswanan government already provide financial support to farmers through this programme and the project needs to advocate for low carbon development and, where possible, provide additional financial resources so that more farmers are supported.

7.2 Government arrangements and capacity to address climate change

Several institutional arrangements exist which have been established to address climate change in Botswana. These have been outlined in the draft climate change response policy and a summary of the most relevant organisations is given below[186]. As these structures are yet to be established, their capacity to address climate change and implement related policies and plans is yet to be determined.

Responsible for climate change policy and planning at a national level will be the National Climate Change Unit. Yet to be established, their responsibilities will include implementation, monitoring and compliance relating to climate change response measures. Serving as an advisory body to the Botswanan government will be the National Climate Change Committee. This Committee will be formed of members with technical expertise on climate change and will advise on matters relating to both national and international responsibilities and obligations, as well as the implementation of response measures. At District and village levels, District Climate Change Committees will be established to support the implementation of climate change adaptation measures. This committee will additionally be responsible for integrating climate change considerations into district development plans and assist in building climate resilient development planning

[185] (INDC 2015)

[186] Republic of Botswana and UNDP. 2019. Botswana Climate Change Response Policy. Draft Version 2. Available at: https://info.undp.org/docs/pdc/Documents/BWA/DRAFT%20CLIMATE%20CHANGE%20RESPONSE%20POLICY%20%20version%202%20(2).doc

at local levels. The committee will be accountable to district councils and indirectly linked and supported by the National Climate Change Unit on resource mobilisation, capacity building and education and awareness[187].

8 Conclusion

Climate change in the rural communal livestock areas are currently, and will in future be, subject to further climate stressors. Being an arid country, water availability though rainfall is primarily for the source of climate exposure. However increased temperatures and increased drought frequency/intensity combine to negatively affect the rangeland ecosystem capacity to provide ecological services compromising local rural livelihoods.

The pastoral communities' low adaptive capacity and high sensitivity to climate change leads to their vulnerability to climate change. There are currently multiple adaptation practices adopted by pastoral communities and which need to be enhanced to build resilience against climate change. The application of community based natural resource management would enhance the ecological resilience of rangelands. Alternatively, diversification away from climate reliant livelihoods to alternative livelihoods, such as commodity-based trade or cultural tourism, would alleviate some exposure, but there are limited opportunities in many of these communities to move beyond agricultural livelihoods. Further resilience could be achieved through community-based Rangeland Stewardship programs promoting ecosystem services and climate smart rangeland and livestock management practices. Providing veterinary capacity to cope with potential disease vector increases as a result of future water and heat stresses would help secure livestock investments.

Legislation such as the NCCAP and NDP seek to support and protect rural livelihoods, but currently poor enforcement and financial resources are a limiting factor in responding to climate risks. The enhancement of the rural communal livestock livelihood will contribute to the Vision 2036 plan to build resilience in the sector.

[187] Ibid.

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Seleka T.B, P.G Kebadile. 2015. Export Competitiveness of Botswana's Beef Industry. BIDPA Working Paper 42.

Shongwe ME, GJ Van Oldenborgh, BJJM Van Den Hurk, B De Boer, CAS Coelho, MK Van Aalst. 2009. Projected changes in mean and extreme precipitation in Africa under global warming. Part I: Southern Africa. Journal of Climate 22: 3819-3837.

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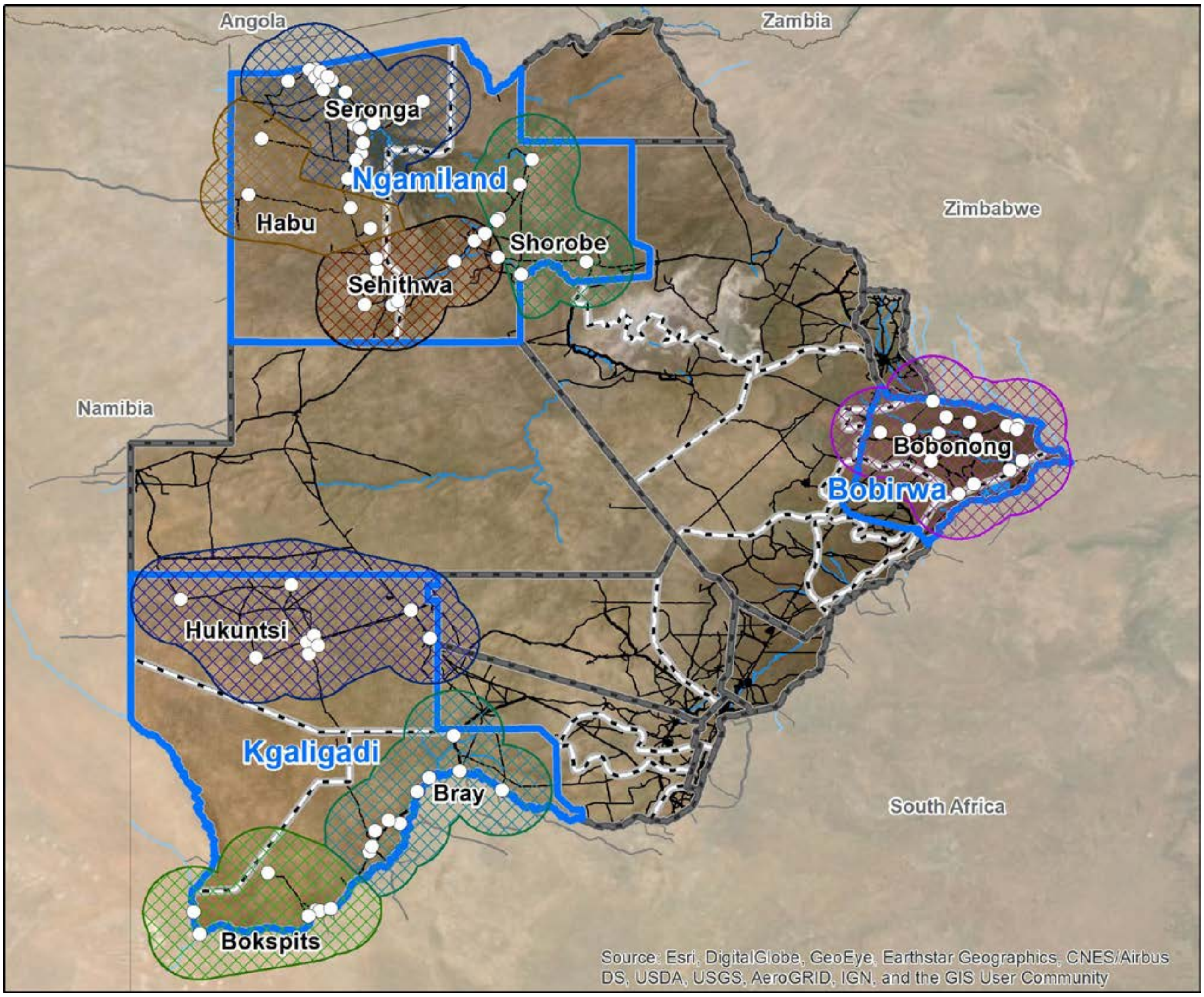
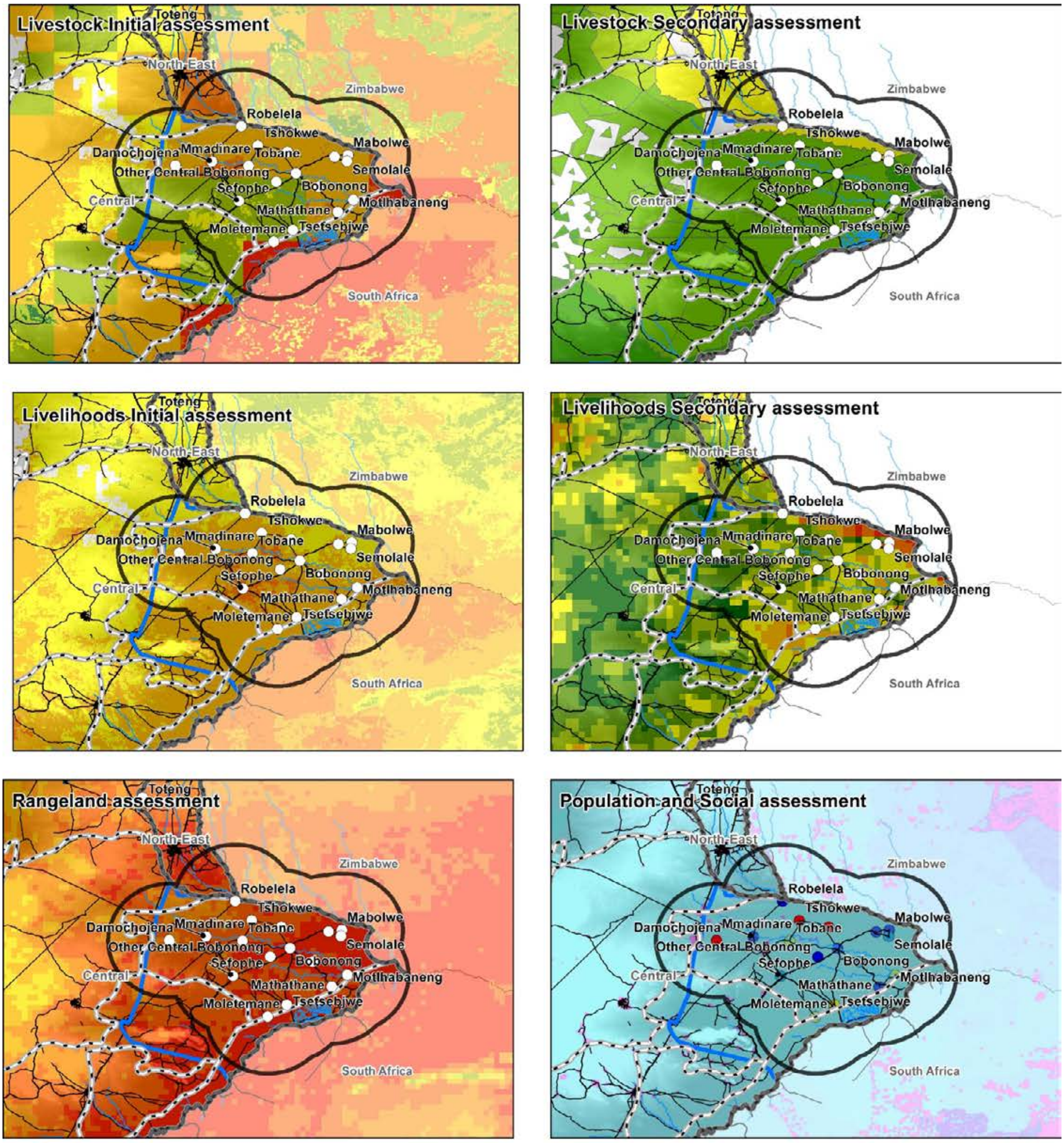
10 Appendixes

10.1 Appendixes: Cluster Locations



10.1.1 CCVAs Bobirwa – Vulnerability Assessment



Assessments are the output of the CCVA equation and are relative rankings ranks.
Data that went into each assessment as ia follows

Livestock initial assessment
Projected Climate Stress, Natural vegetation Sensitivity, Water Resilience

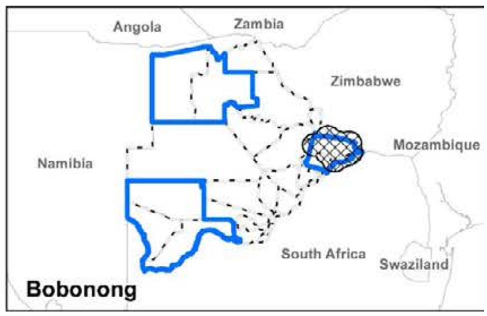
Livestock Secondary assessment
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

Livelihoods initial assessment
Projected Climate exposure, Natural resource sensitivity, Rurality Index

Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios



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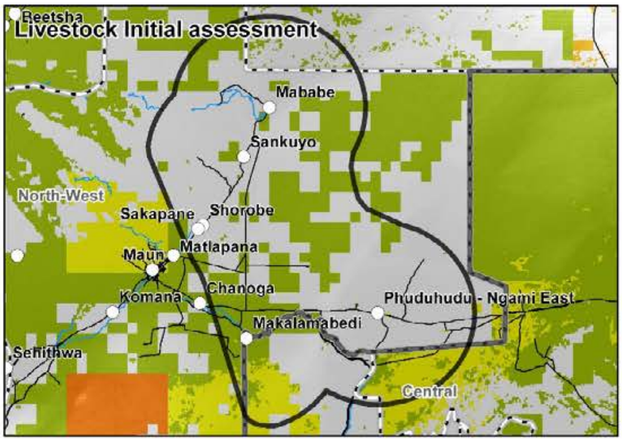
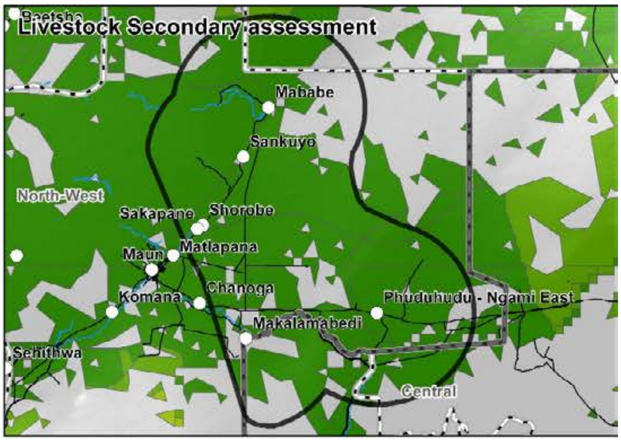
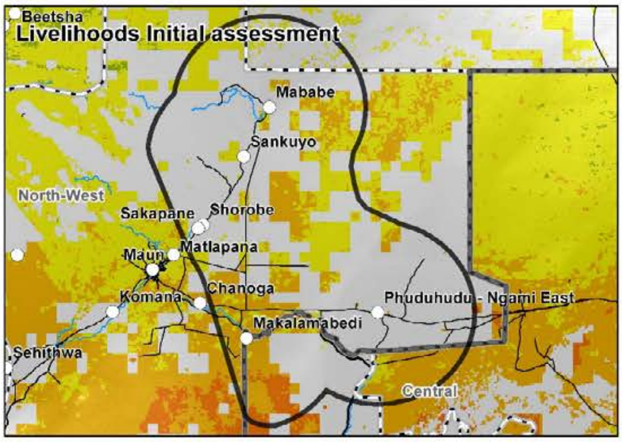
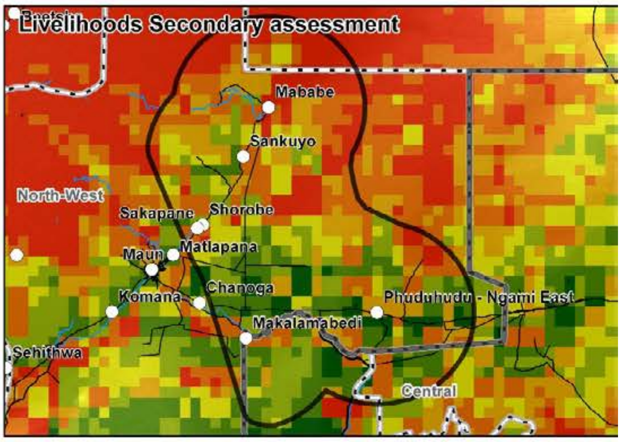
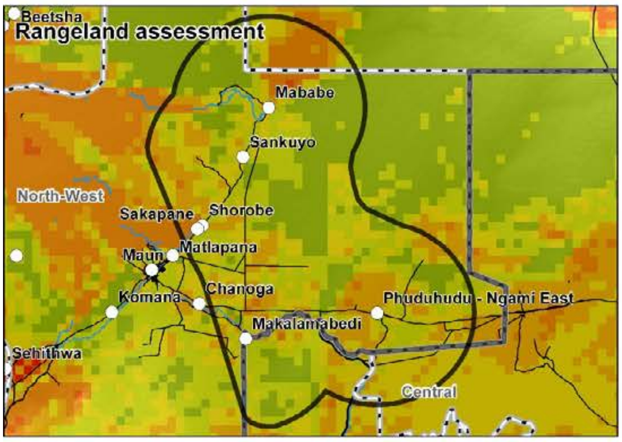
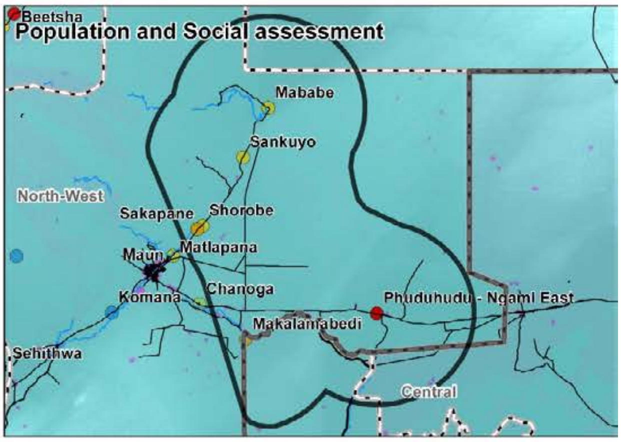


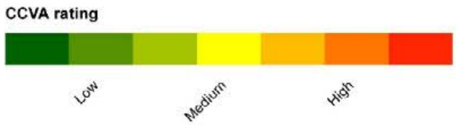












Assessments are the output of the CCVA equation and are relative rankings ranks.
Data that went into each assessment as ia follows

Livestock initial assessment
Projected Climate Stress, Natural vegetation Sensitivity, Water Resilience

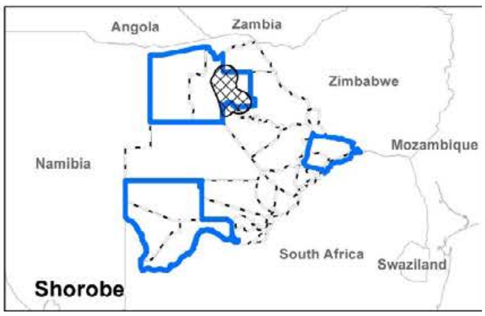
Livestock Secondary assessment
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

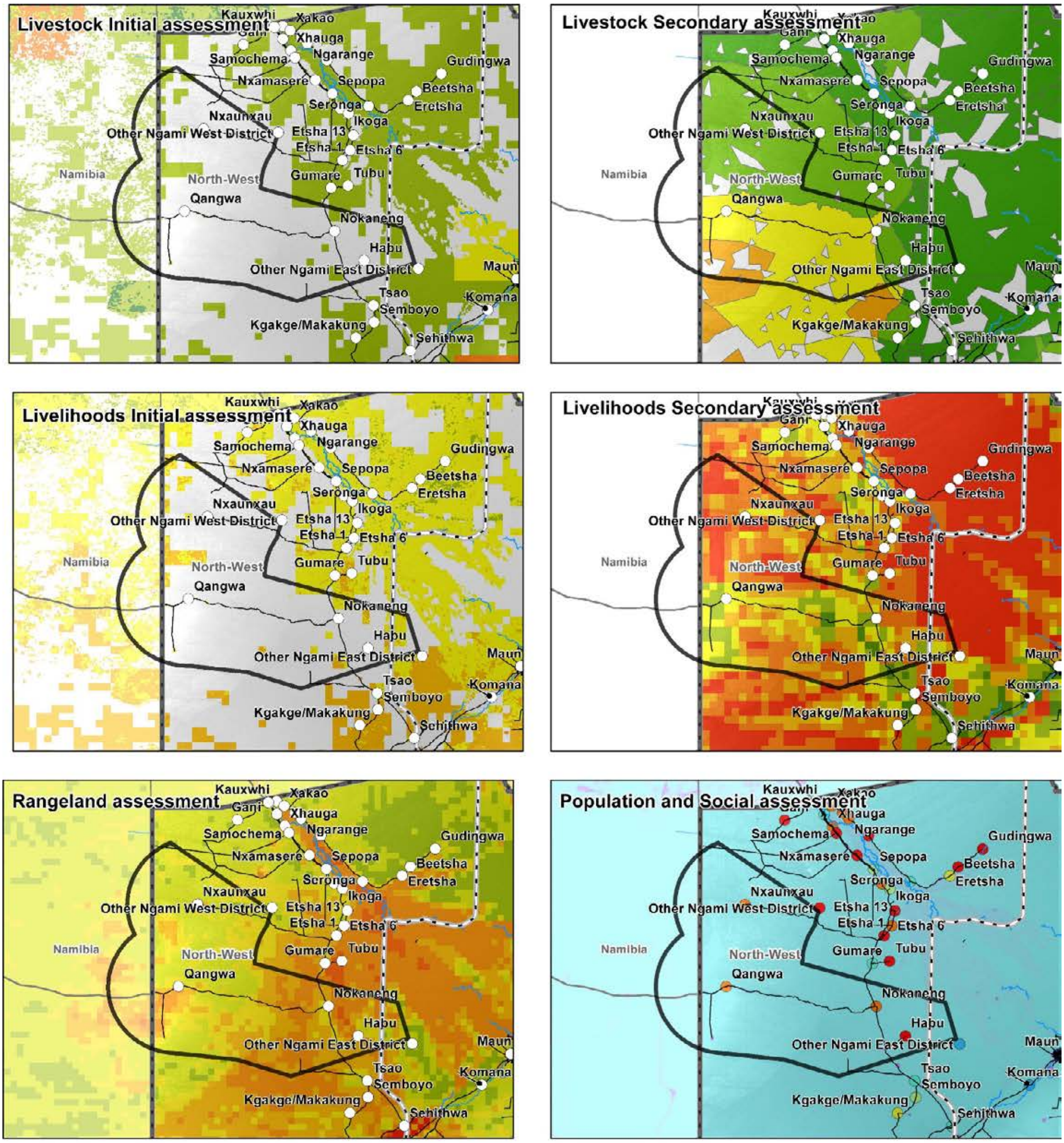
Livelihoods initial assessment
Projected Climate exposure, Natural resource sensitivity, Rurality Index

Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios





CCVA rating

Assessments are the output of the CCVA equation and are relative rankings ranks.
Data that went into each assessment as ia follows

Livestock initial assessment
Projected Climate Stress, Natural vegetation Sensitivity, Water Resilience

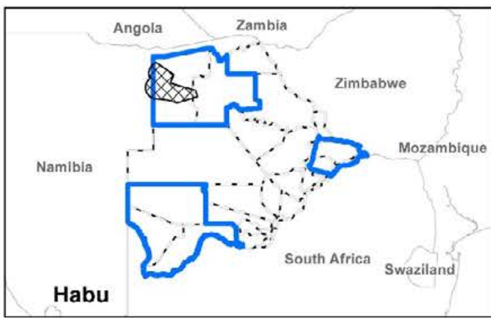
Livestock Secondary assessment
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

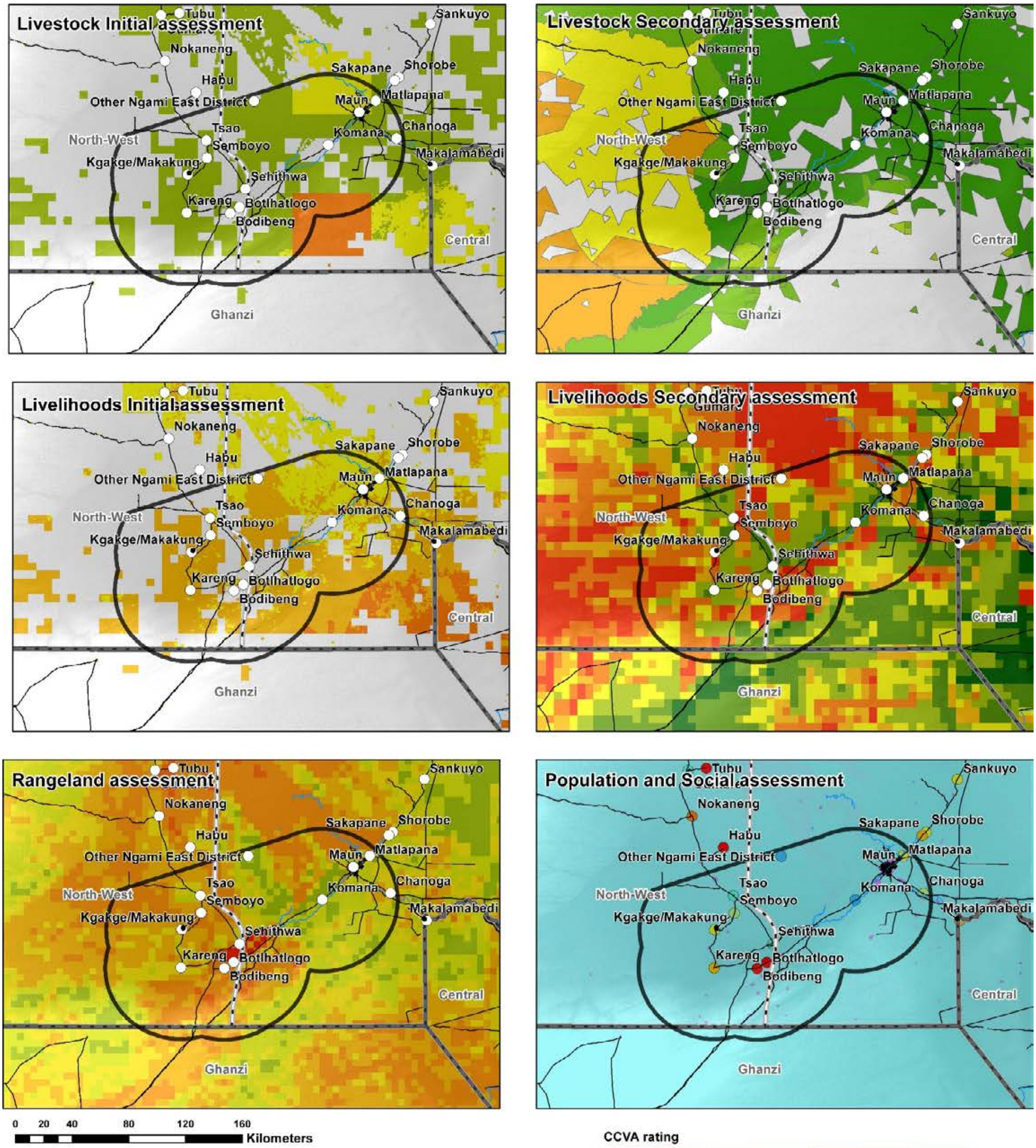
Livelihoods initial assessment
Projected Climate exposure, Natural resource sensitivity, Rurality Index

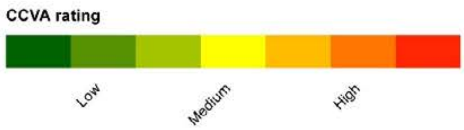
Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios







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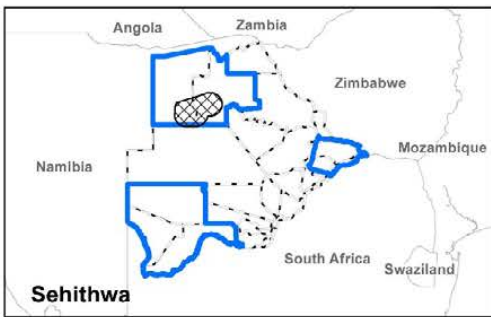
Livestock Secondary assessment
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

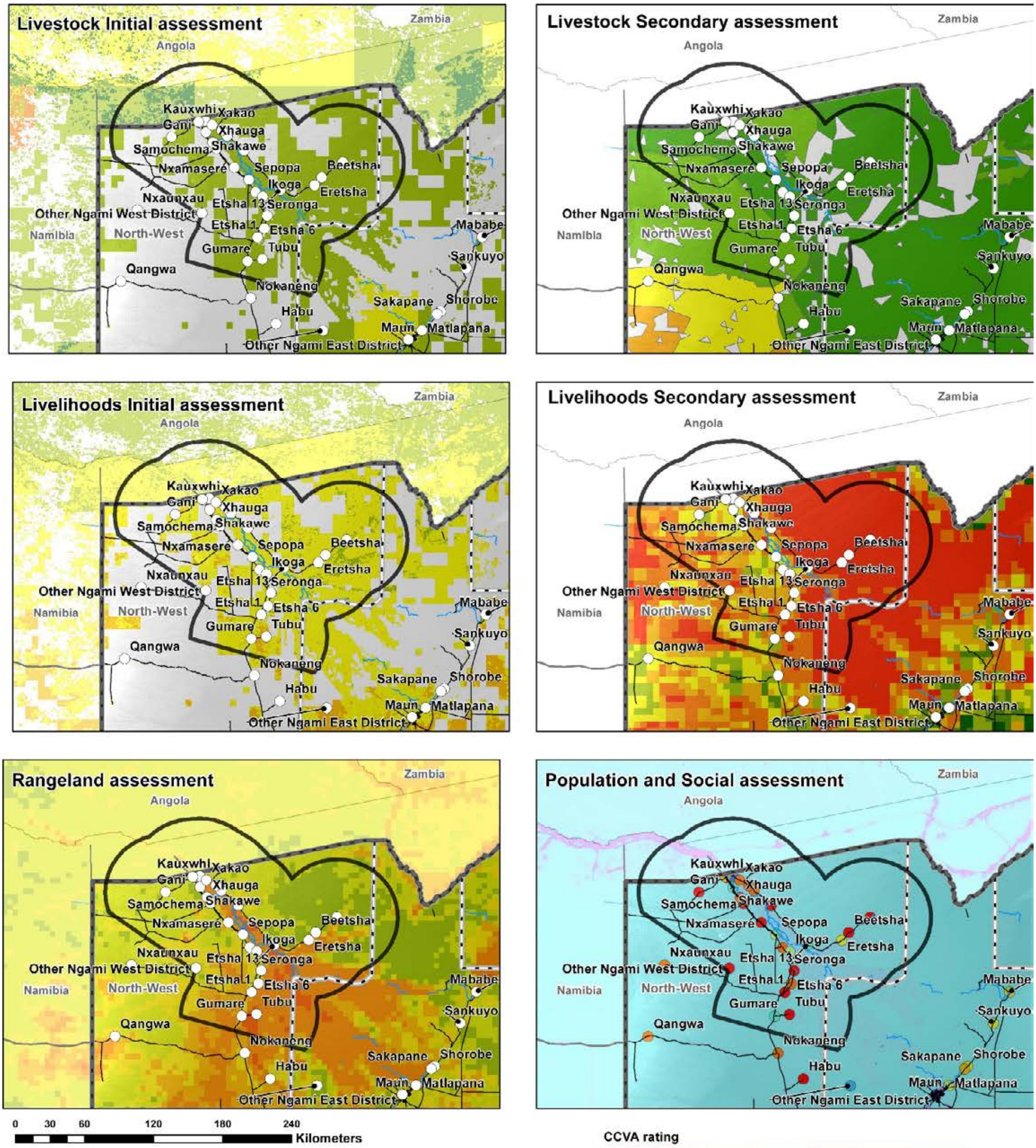
Livelihoods initial assessment
Projected Climate exposure, Natural resource sensitivity, Rurality Index

Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios





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Rangeland
SPARK High value grazing grasses climatic suitability

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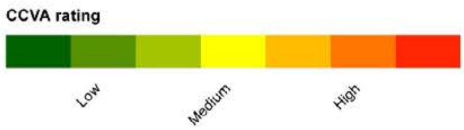
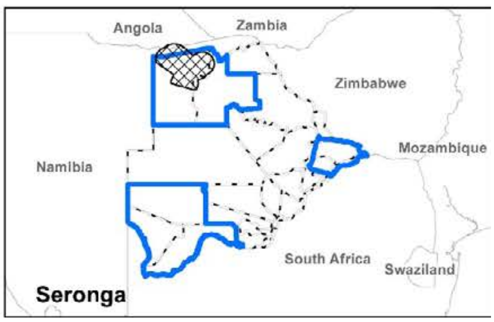
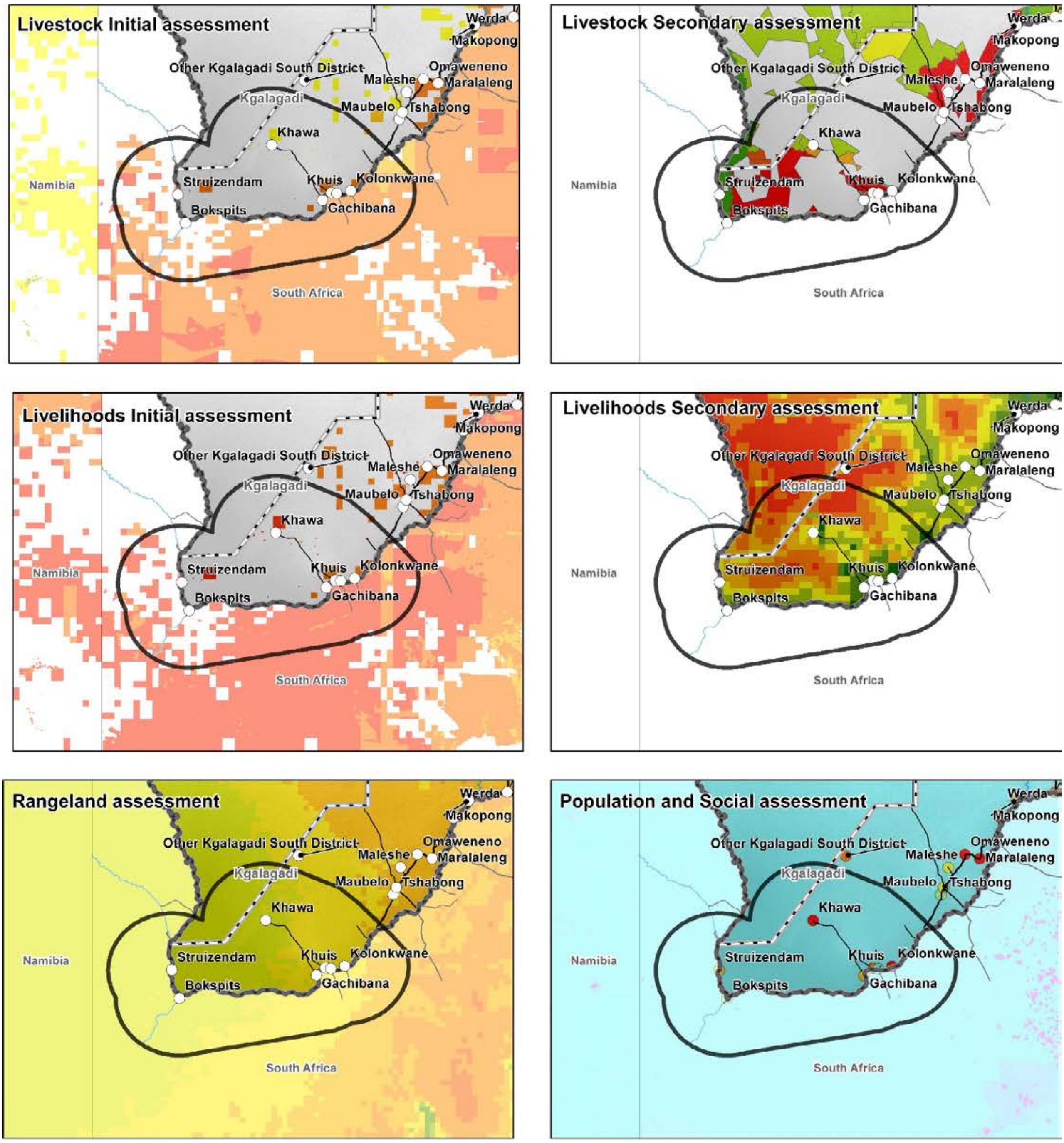
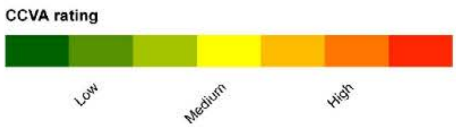




10.1.3 CCVAs Kgalagadi - Vulnerability Assessment





Assessments are the output of the CCVA equation and are relative rankings ranks.
Data that went into each assessment as ia follows

Livestock initial assessment
Projected Climate Stress, Natural vegetation Sensitivity, Water Resilience

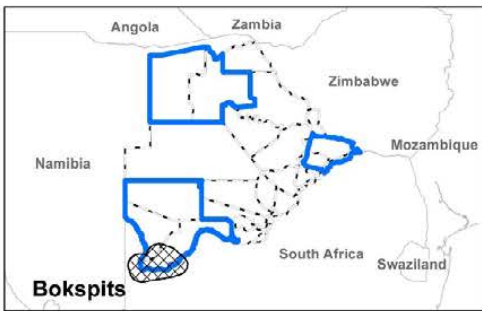
Livestock Secondary assessment
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

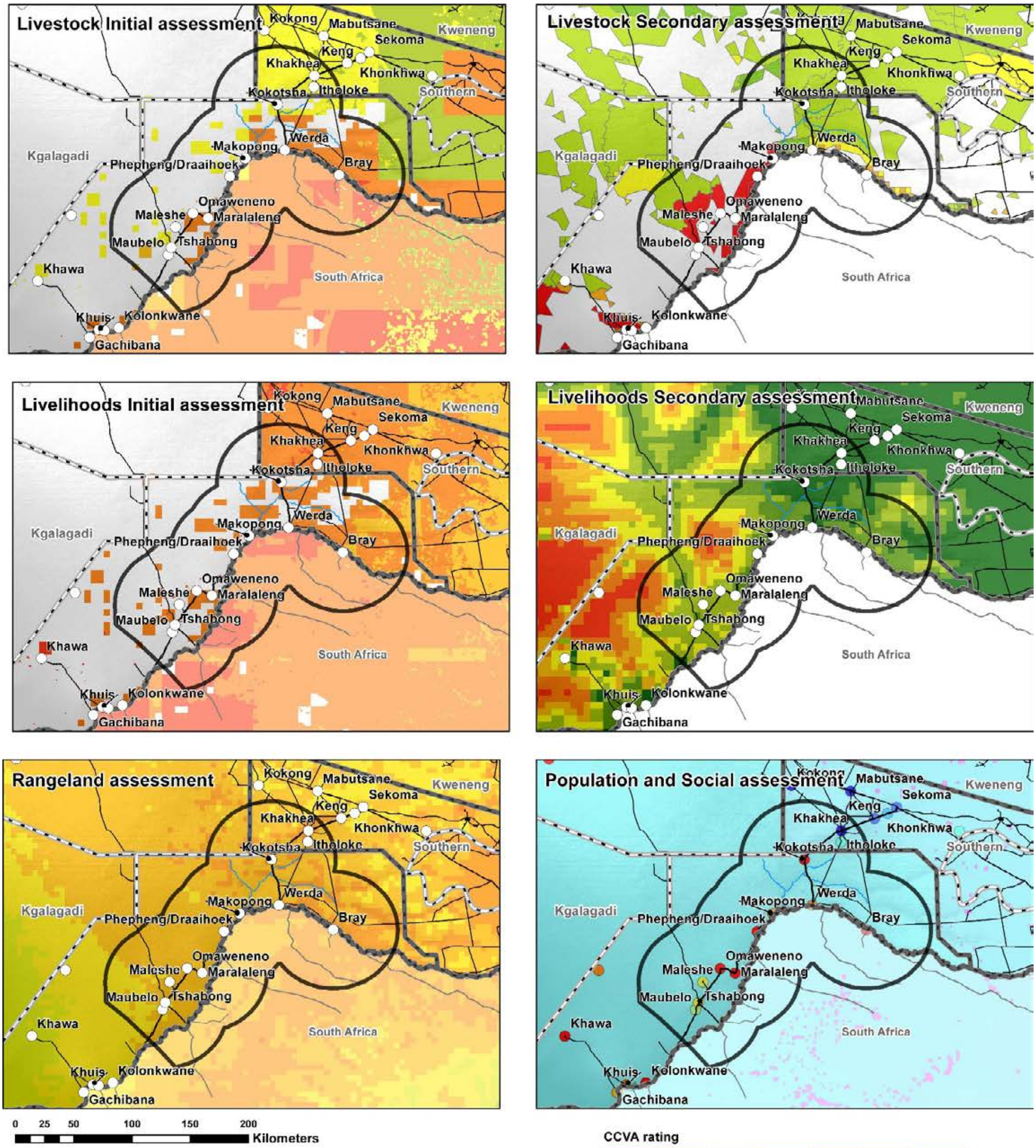
Livelihoods initial assessment
Projected Climate exposure, Natural resource sensitivity, Rurality Index

Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios





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Livestock initial assessment
Projected Climate Stress, Natural vegetation Sensitivity, Water Resilience

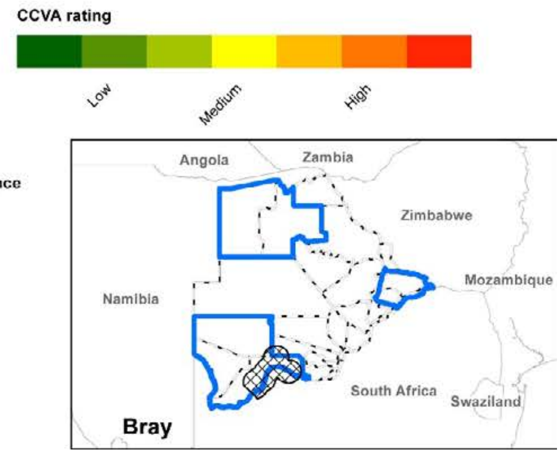
Livestock Secondary assessment
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

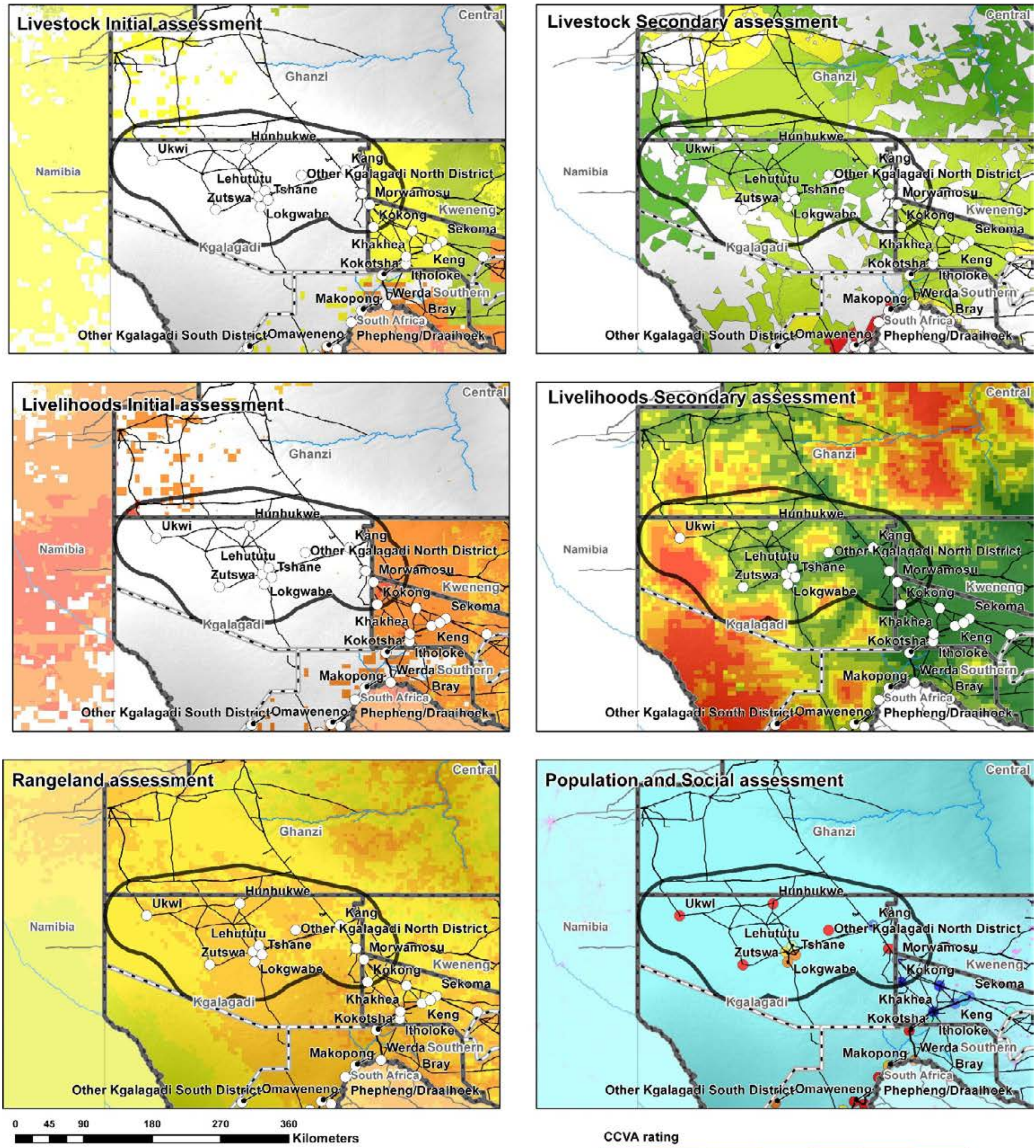
Livelihoods initial assessment
Projected Climate exposure, Natural resource sensitivity, Rurality Index

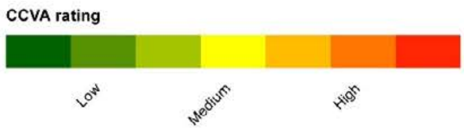
Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios







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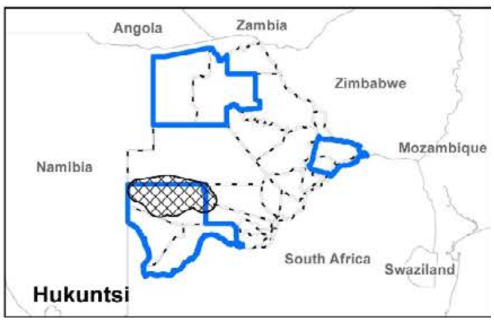
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

Livelihoods initial assessment
Projected Climate exposure, Natural resource sensitivity, Rurality Index

Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios



Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands

Annex 2 - Feasibility Study

Section 2: Options Analysis & Financial and Economic Analysis

Prepared by Conservation International and C4 EcoSolutions through a Project Preparation Facility (PPF) Grant from the Green Climate Fund – March 2020

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1. Options Analysis

Based on literature reviews and consultations of stakeholders involved in communal land management, five key strategies are available to contribute to the Project Objectives[1]. These are described below and assessed against the current scenario (no project) in Table 1.1.

Increased privatisation and fencing: The current Tribal Grazing Lands Act seeks to curb land degradation through the privatisation of communal land into group ranches. Privatisation and fencing are the preferred mechanisms to achieve the Acts' intended outcomes — to reduce overgrazing practices and protect grazing reserves for the most vulnerable existing and future generations. The Acts' intended outcomes have not been realised[2]. Fenced group ranches allocated to "commercial farmers" have led to shrinking communal land and limited mobility for smallholder farmers, as previously accessible communal grazing resources are privately owned by someone else. Because of the low and seasonal productivity of Botswana's communal rangelands, it is impossible to allocate productive plots to each citizen. Biodiversity impacts of increasing fencing are known to affect communal farmers and wildlife by interfering with their seasonal movements and blocking access to water in dry years. Increasing private land in Botswana's communal areas, while it may benefit a few, will continue to fragment ecosystems and relegate the most vulnerable communities to a diminishing quantity and quality of land. Resultantly, fencing and privatisation has become a controversial and emotive issue in the country, as well as being an expensive and potentially maladaptive practice. However, there is a potential to integrate privatised areas into broader communal livestock management strategies, capitalising on infrastructure on these ranches, to build greater climate resilience for both larger commercial and communal farmers.

Increasing investment into land and livestock management in communal rangelands: There are several regional models where ecosystem resilience, and thus the climate change risk, has been tackled by governments through significant investment in land rehabilitation. Two important models are the South African Natural Resource Management Programme[3] and Ethiopia's Land Rehabilitation efforts. In both countries, huge investments have delivered significant reductions in vulnerability through improved food and water security[4] and reduction of fire risk[5]. Efforts are sustained through continued national budget investments that effectively transfer funding from economic activity in the country into areas that are more vulnerable. Given Botswana's relative wealth and existing investment in its job creation programme, Ipelegeng, and an ability to draw on established practice developed by these other programmes over the last 20-30 years, there is an opportunity for this option to support vulnerable peoples and land in Botswana's communal rangelands. Based on farmer consultation, inclusion of supplementation of fodder during extreme droughts is likely to always be a requirement and fodder gardens/reserve banks are considered an integral part of this option. The potential introduction of Rangeland Stewardship Agreements (RSA) would introduce rangeland and livestock management practices that could simultaneously sequester carbon and enable the co-existence of communal livestock

[1] A full summary of adaptation options currently used in the target regions is provided in Section 1, Part II of the Feasibility Assessment. These five key strategies were selected from the list based on 1) current policy frameworks; 2) response numbers from stakeholders regarding preferred adaptation strategies.

[2] Frimpong, K. A Review of the Tribal Grazing Land Policy in Botswana. Pula: Botswana Journal of Africa Studies, Volume 9, Issue 1. Accessed at http://digital.lib.msu.edu/projects/africanjournals/. See Annex 6 for additional information and references.

[3] See https://www.environment.gov.za/projectsprogrammes#workingfor for more info on South Africa and

[4] Wuletawu Abera et al, Characterizing and evaluating the impacts of national land restoration initiatives on ecosystem services in Ethiopia, *Land Degradation & Development* (2019). DOI: 10.1002/ldr.3424

[5] van Wilgen B.W. 2009 The evolution of fire and invasive alien plant management practices in fynbos. South African Journal of Science. Volume 105. Pp.335-342.

and wildlife. The RSA would allow wildlife movement to be controlled in appropriate areas, minimising contact between livestock and wildlife.

Increased investments into increasing market access: The shift in production and marketing strategies by livestock producers — in interaction with traders — could reduce their vulnerability to climate shocks[6]. The farmers consulted in the project preparation process indicated that there are high livestock populations in their grazing land and therefore there is an opportunity to systematically control livestock population and build climate change resilience through improved and coordinated market access. The farmers need to supply old and unproductive livestock to the market in a timely manner to avoid driving prices down due to oversupply during drought periods and to avoid loss of cattle through starvation. A favourable market price is needed to motivate producers to sell as market participation in agriculture is considered one of the most important contributory factors to poverty reduction in developing countries[7]. In Botswana, however, the market off-take rate of cattle through formal markets remains relatively low at ~8% compared to ~16% from commercial farming. Institutional constraints and high transactional costs associated with selling cattle to formal markets are often barriers to market access for pastoralists[8]. When faced with these barriers, smaller scale producers receive few benefits from trade, and are unable to participate in markets[9]. This is particularly true for farmers in the Ngamiland and Bobirwa communal lands where geographic zoning for Foot and Mouth Disease (FMD) can prevent trade completely.

Investments that would address these barriers and facilitate improved market access for small-scale livestock farmers and pastoralists would have considerable benefits in terms of enhanced livelihoods. The focus on livestock-product value chains could allow these beneficiaries to diversify and increase their incomes, particularly in marginal wildlife areas where other economic activities such as ecotourism are not yet viable and there is currently no opportunity to sell or manage commercial livestock because of FMD legislation. Livestock-product value chains include, *inter alia,* natural fodder development, restoration enterprises, veterinary enterprises, hides, skins, wool and beef. The AHEAD initiative in Ngamiland, led by the Ministry of Agriculture with Cornell University, has recently developed a comprehensive analysis of what is required to enable new trade from FMD zones in Botswana that can guide market development investments[10]. These steps are the basis of what is considered a requirement for this option (see Section 5 of this report for more details).

Promotion of wildlife-based alternative livelihood options: Botswana has a vibrant tourism sector that has grown by 3–6% per annum over the last decade and contributes approximately US$2 billion *per annum* to the country's national economy. This represents ~13% of total Gross Domestic Product (GDP) in Botswana, primarily as a result of international travels involved in recreational tourism[11]. Despite these impressive statistics, Botswana's approach to the promotion

[6] Gautier D, Locatelli B, Corniaux C, Alary V. 2016. Global changes, livestock and vulnerability: the social construction of markets as an adaptive strategy. The Geographical Journal, Vol. 182, 153–164, doi: 10.1111/geoj.12115

[7] Ehui S., *et al*. 2009. Policy options for improving market participation and sales of smallholder livestock producers: A case of Ethiopia. Draft prepared for presentation at the 27th Conference of the International Association of Agricultural Economists (IAAE), 16-22 August 2009, Beijing, China.

[8] Kirsten, J.F. 2002. Livestock marketing in northern communal areas of Namibia (livestock producer marketing strategies and informal trade in live animals, meat, hides and skin). Northern Regions Livestock Development Project (NOLIDEP). Windhoek, Namibia.

[9] Mahabile, M. 2013. Measuring transaction costs in marketing cattle in Southern Botswana: A Case Study. Botsw. J. Agric. Appl. Sci. 9(2).

[10] Atkinson, SJ, M. Penrith, and N Ramsen (eds) 2019. Gap Analysis on the Implementation of Commodity-based Trade of Beef in Ngamiland. Available at http//www.wcsahead.org.za/kaza.

[11] Knoema. N.d. Botswana – Contribution of travel and tourism to GDP as share of GDP. [online] Available: https://knoema.com/atlas/Botswana/topics/Tourism/Travel-and-Tourism-Total-Contribution-to-GDP/Contribution-of-travel-and-

of high-end, low volume tourism has limited benefits for marginalised populations in rural areas, and some experts estimate that 70% of revenue generated from high-end tourism leaves Botswana through foreign operators[12].

Despite the limited economic benefits from high-end tourism, communities have benefited historically from Community-based Natural Resource Management policies that allowed the establishment of hunting concessions in marginal wildlife areas[13]. It is likely that the recent lifting of the temporary hunting ban will enhance opportunities for tourism development in more communal areas adjacent to wildlife areas. Game farming has been suggested for several areas in Ngamiland and the Kgalagadi where community structures are in place and attitudes towards protected areas are positive. However, the current reality is that game cannot be introduced successfully into the communal rangeland areas in their currently degraded state without significant infrastructure, expertise, and fencing — as natural instinct will motivate wildlife movement out of degraded habitats. Conservation managers are also concerned that additional fencing for any new game farming, livestock, or tourism effort will negatively impact wildlife dispersal areas that will become even more important under climate change. In the future, once communal rangeland habitats have been restored to an equal condition to nearby wildlife management areas, a shift to game stocking represents a lucrative livelihood option that can and should be encouraged.

Climate change is also negatively impacting ecotourism, particularly as a result of climate-related loss of livestock in grazing areas adjacent to wildlife populations. This has driven increases in poaching for local consumption, as well as lethal predator management by communities through the use of traps and poisons. Moreover, livestock presence in wilderness and migratory corridors has also increased as communal farmers seek fodder and water sources. The recent Covid-19 pandemic, and associated travel bans, have highlighted that a strategy that is solely dependent on foreign visitors is insufficient for building consistent resilience for vulnerable people in communal rangelands.

Table 1.1 Summary of Options Analysis.

Option Description	Potential for Application	Advantages	Drawbacks
1. No change		No investment required	Increased vulnerability of people and ecosystems as detailed in FA Section 1.
2. Expand fencing and privatization of communal lands	Low-Medium	No behaviour or policy change required; fencing is an established approach.	Expense, lack of effectiveness at improving resilience for most vulnerable people, potential for strong community pushback, impact on wildlife and small producer mobility and dry season reserves.

tourism-to-GDP-percent-of-GDP#:~:text=In%202018%2C%20contribution%20of%20travel,average%20annual%20rate%20of%204.42%25.

[12] Moswete, Naomi & Dube, Opha Pauline. (2013). Wildlife-based Tourism and Climate: Potential Opportunities and Challenges for Botswana. pp 395 - 416.

[13] Arntzen, J.W.; Molokomme, D.L.; Terry, E.M.; Moleele, N.; Tshosa, O.; Mazambani, D. Main findings the review of community based natural resources management (CBNRM) in Botswana. In Occasional Paper N0.14; IUCN/SNV CBNRM Support Programme: Gaborone, Botswana, 2003.

3. Deploy investments into land regeneration	Medium - High	Re-deploys existing government investment into direct climate change resilience for people and the landscapes they live in. Reduces the number of livestock deaths in drought periods, reduces GHG emissions and increases communal rangelands as a carbon sink. Improves resilience for most vulnerable households that do not have surplus animals to sell by improving condition of animals that contribute to household nutritional security.	May be insufficient in the face of long-term climate change, especially in more marginal or drier lands such as the Kgalagadi where active restoration may not produce results for 10+ years.
4. Deploy investments into building new market access for livestock farmers	Medium	Enhanced sustainability beyond government budget cycles, income generated can be invested at the household level to increase resilience in the short- and long-term.	Likely to be insufficient to build resilience to longer or consecutive drought periods if the fodder base is degraded. Investments into new market technologies are costly and un-tested which limits investment opportunities for the private sector
5. Deploy investments into development of tourism ventures	Medium	Creates income generation and employment opportunities that can enhance resilience for households with working-age individuals. Tourism employment can continue to provide income during times of extreme drought.	Tourism flows are subject to external global market volatility that is likely to increase with future climate change.

Based on the above analysis, the proposed project has been designed to accommodate and/or enable all options as a blended approach to build resilience in Botswana’s communal rangelands. The integration of private ranches into village grazing areas is enabled by the Rangelands Stewardship Agreement process and opportunities to develop cultural or natural tourism enterprises is enabled by an output dedicated to alternative livelihood development that contributes to the sustainable livestock production value chain (see Section 5 for more details). However, because of the opportunity to optimise GCF investment into reducing climate risks for most vulnerable populations, the Project’s focus is on developing a blend of Options 3 and 4. The economic and financial analysis of pursuit of such an integrated project design is provided in the next segment of this Section.

2. Economic and Financial Analysis

Executive Summary

Botswana's traditional livestock production sub-sector has been identified as an area with considerable potential for improvement. Traditional livestock holdings account for ~97% of all livestock holdings across the country and make up ~90% of the total national herd[14].

Poverty levels and vulnerability are likely to increase as climate change contributes to increased degradation of Botswana's communal rangelands. The combined impact of increased drought frequency, higher temperatures and reduced precipitation will be most strongly felt by smallholders who are dependent on communally shared rangelands[15]. The vast majority of the country's low-income population is dependent on the country's communal land, particularly indigenous communities and female headed households (see Gender Assessment and GAP). More than 55% of all communally owned livestock is owned by individuals 65+ years of age, who have fewer alternative livelihood options.

It is widely acknowledged that interventions in both the supply-side and demand-side of the traditional livestock production sub-sector have potential to result in poverty alleviation[16]. It has also been highlighted that climate change is likely to have a disproportionately large impact on this sub-sector, given the sensitivity of rangeland systems to variations in rainfall and temperature, as well as the limited levels of resilience which characterizes communities that depend on livestock production for their livelihoods[17]. Existing research therefore suggests that there are substantial risks to those operating in Botswana's traditional livestock production sub-sector and that these risks are likely to be amplified under climate change.

The following report provides an economic and financial analysis of the GCF funding proposal entitled *Ecosystem and livelihoods resiliency: climate change risk reduction through ecosystem-based adaptation in Botswana's communal grazing lands* (hereafter referred to as the project). The project's main area of focus is the traditional livestock production sub-sector in three areas of Botswana, namely Bobirwa, Kgalagadi and Ngamiland.

Project description

The project is based on the successful model of the Herding for Health programme, a joint initiative of Conservation International and Peace Parks Foundation, which uses herding and livestock management to regenerate Africa's rangeland ecosystems and enhance climate change resilience of the communities dependent on them. The Herding for Health Model is based on executing rangeland stewardship agreements with affected communities that agree to site-specific good practice defined by scientific and traditional knowledge. In most cases, much of the conservation agreement involves collective grazing and/or corralling that is implemented by communities and professional herders called "Ecorangers". Restoration and wildlife protection elements of the agreement can be further incentivized by additional livestock production and

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14 including cattle sheep and goats

15 Zhou P.P., T Simbini, G Ramokgotlwane, T.S Thomas, S. Hachigonta, L.M Sibanda. 2013. Botswana. In Southern African Agriculture and Climate Change: A comprehensive analysis. Chapter 3 Pp. 41-70. Washington, D.C.: International Food Policy Research Institute (IFPRI).

16 Engelen, Anton van, Malope, Patrick, et al., *Botswana Agrifood Value Chain Project Beef Value Chain Study*, 2013; Seleka and Kebakile, *Export Competitiveness of Botswana's Beef Industry*; Dizyee, Kanar, Baker, Derek, & Rich, Karl M., "A Quantitative Value Chain Analysis of Policy Options for the Beef Sector in Botswana," *Agricultural Systems* 156, no. October 2016 (2017): 13–24, https://doi.org/10.1016/j.agsy.2017.05.007.

17 See the Feasibility Assessment, Section 1, Climate Vulnerability Assessment

training support and sustained through access to markets for their livestock products. Key market readiness interventions (legal requirements and market systems) are a critical component that ensures income flow to participating farmers that leads to self-sustaining impact and replication.

Project costs and financing

The project's indicative costs show that project components will be implemented through a combination of grant financing from GCF and the Government of Botswana. The total indicative cost is US$ 97.6 million. Of this, US$ 54.0 million–55% of the total– represents funding that will be redirected from the Ipelegeng extended public-works programme, with the aim of achieving improved effectiveness with regards to the socio-economic impact associated with this expenditure.

Considering only direct project beneficiaries, the project's cost per beneficiary is estimated at US$ 395 including co-finance ($149 for GCF funding only). These costs have been found to be comparable to similar projects elsewhere, and it is useful to consider project costs in relation to the costs associated with drought relief programmes. This is the topic of Section 2.3. The project's cost per hectare is $8.64 (see paragraph 250 of the Funding Proposal).

Net benefits associated with the project

Net benefits associated with project implementation are shown in Table 2.16. The per-beneficiary net benefits associated with each of the scenarios is positive relative to the 'without project' scenario. The combination of improved livestock management and improved market access results in the highest net benefits relative to the no project scenario across all timeframes. The net benefit of this scenario relative to the without project scenario is US$273 per-beneficiary over the 20-year period considered.

Table i. Net benefits to livestock production beneficiaries under with project scenarios relative to the without project scenario (US$)

Scenario	Per-beneficiary net benefit relative to the without project scenario (US$)		
	4 years	8 years	20 years
Scenario 2. Improved land and livestock management	46	72	63
Scenario 3. Improved market access	53	80	128
Scenario 4. Improved land and livestock management & improved market access	89	195	273

These findings demonstrate that the project's design reflects the need to address multiple barriers simultaneously if paradigm shift is to be achieved. The performance of Scenario 4 in relation to the performance of Scenarios 2 and 3 demonstrates a high degree of complementarity between the project components.

Another finding, applicable across all scenarios considered, shows the extent to which traditional livestock producers are affected by a drought event. Under the model, aggregate revenues drop below costs and losses are incurred by farmers. These losses are amplified with the implementation of Component 2 because of the labor costs involved. As mentioned in Section 2.5, the modelled drought represents a highly conservative depiction of the climatic conditions that livestock producers are likely to face in the coming years. The CBA demonstrates the timeframes required for livestock producers' revenue to recover in the wake of drought events. Therefore, in the anticipated context of multiple, consecutive drought events this finding highlights the risks faced by livestock producers who may experience compounding impacts of multiple drought events. In the face of intensifying climate change, with increasingly more frequent and more severe droughts expected, building resilience in the traditional livestock production sub-sector will be critical to ensuring that it continues to support rural livelihoods.

The financial cost benefit analysis further reveals that without the promotion of climate-sensitive enterprise development and value-chain investments to sustain transformational change, there are insufficient incentives available for livestock producers to invest in rangeland and livestock health. The analysis suggests that under current conditions, investment in sustainable rangeland management is not viable for livestock producers in the traditional sector. This supports the need for intervention in the areas of institutions, capacity as well as in markets to adequately shift incentive structures facing livestock producing households. Adjusted incentives would be likely to catalyze investments in livestock and rangeland stewardship, leading to further adoption and upscaling.

Economic impacts on the broader population in the project areas

The importance of considering a broader range of actors than just livestock producers is highlighted by the annual cost of land degradation in Botswana, which is estimated at US$ 353 million, equivalent to 3.2% of the country's GDP18. Given that a central aim of the proposed project will be to address the drivers of rangeland degradation, it follows that the benefits to those parts of Botswana's economy which are reliant on healthy rangeland ecosystems will be considerable. The stakeholders who are likely to benefit, in addition to traditional livestock producers, include value-chain actors, commercial livestock producers, tourism operators and associated employees.

In addressing Rangeland degradation, reform of communal grazing land-use is likely to provide higher returns than reform of other land uses. Rangeland ecosystems are utilized for four types of land use in Botswana including communal grazing, private cattle ranching, game ranching and Wildlife Management Areas (WMAs). Research conducted in the Kgalagadi District has revealed that communal grazing provides the widest range of ecosystem services as compared with other land uses19. Furthermore, the authors of this research note current communal grazing practices are not sustainable.

Degraded rangelands have been shown to exhibit lower levels of plant diversity and are therefore far less likely to support livelihoods to the extent that healthy rangelands can. An improvement in rangeland condition is thus likely to result in considerable benefits to rural households who rely on these systems for harvesting timber and non-timber products. This benefit can be viewed as an added layer of resilience in the face of intensifying climate change.

An improvement in rangeland condition is likely to result in improved water provision and regulation in the project catchments[20]. The value of these ecosystem services has not been established in monetary terms, but it is likely to be substantial.

18 Munaz et al., "Country Profile: Botswana. Investing in Land Degradation Neutrality: Making the Case."
19 Favretto, N, Stringer, L C, et al., "Assessing the Socio-Economic and Environmental Dimensions of Land Degradation: A Case Study of Botswana's Kalahari," 2014, 1–28, http://www.see.leeds.ac.uk/research/sri/eld/.
20 See Feasibility Assessment, Section 3: Carbon and Water Baseline Assessment for additional details

Scope for the growth of Botswana's nature-based tourism provides a unique opportunity to grow and diversify the economy while ensuring that nature can continue to provide society with broader ecosystem services such as water regulation and carbon sequestration[21,22]. Growth of Botswana's nature-based tourism sector can be both driven by a paradigm shift in rangeland livestock production and as feedback into improving the resilience of communities where communal grazing is practiced.

Due to the significant portion of the populations that are involved in livestock farming in the Project areas, there are other likely economic resilience effects. Improved management of communal cattle and land is likely to reduce disease transmission to herds grazing on adjacent private lands by straying cattle who break private fences to get to private fodder and water reserves in drought times. Market access opportunities enabled by the project will also result in increased cash flows through the local economic hubs in the Project Areas, stimulating greater resilience throughout the regional economy.

The Project aims to work with StatsBotswana to identify positive and negative spillovers and interference (i.e., effects in and outside targeted populations and borders) to measure reduce or increase net impacts[23]. Indicators directly associated to the channels and mechanisms by which spillovers operate will be monitored through the Impact Monitoring efforts of the project (See Annex 11). As suggested by Pfaff and Robalino (2017)[24] some of these channels are input reallocation; market prices; learning; nonpecuniary motivations; and ecological-physical links. This will require identifying the mechanistic relationship through which the project components affect the outcome and explaining the process of change from an initial stage leading to an intermediate or final stage (the outcome). For example, in the presence of leakage of slippage a farmer who faces restrictions on resource use can lead to continued unsustainable grazing and land clearing in other land parcels (input reallocation). This in turn would lead to increases in measurement of land degradation above-baseline. By not considering this spillover effect the program will show no impact or negative impact. Similar spillovers arise from cash transfers in the form of incentive payments that increase the capacity of a participant in the project to buy goods and use those to work in areas outside the program potentially leading to no project effect at the landscape level. Our proposed impact evaluation plan will assess the mechanisms whereby causal effects arise when interference and spillover effects are present.

Climate Change mitigation

Improvements in livestock and rangeland condition has been shown to result in agro-ecological systems that regulate carbon, methane and other greenhouse gasses more effectively than in degraded systems. Through the simulation of different rangeland management scenarios, the impact of the project's activities was modelled and estimates of carbon-balance impacts were generated for enteritic fermentation and soil. At a 10% discount rate, the present value of mitigation benefits associated with the project has been estimated at US$9.3 million over the 8-year project period, ramping up to US$24.9 million over 20 years.

Given that the total cost of the project is US$97.6 million, and that the project should result in the mitigation of around 21.5 million tCO_2e, the cost of mitigation is estimated at US$4.54 per tCO2e.

21 The World Bank, "Botswana: Systematic Country Diagnostic," 2015, http://documents.worldbank.org/curated/en/489431468012950282/pdf/95304-REPLACEMENT-SCD-P150575-PUBLIC-Botswana-Systematic-Country-Diagnostic-Report.pdf.
22 World Bank Group, "Supporting Sustainable Livelihoods through Wildlife Tourism" (Washington D.C., 2018), https://openknowledge.worldbank.org/handle/10986/29417.
23 Van der Weele, T. (2015). Explanation in causal inference: methods for mediation and interaction. Oxford: Oxford Univ. Pr.
24 Pfaff, A., & Robalino, J. (2017). Spillovers from conservation programs. Annual Review of Resource Economics, 9, 299-315.

Furthermore, the project intends to leverage US$54 million in government funding towards climate resilience and mitigation.

Macroeconomic impacts

The project has the potential to result in improved macro-economic performance and stability for Botswana as a whole. Much of the beef produced is expected to meet the needs of the domestic market and, in doing so, there exists potential to target the particularly high-end segment of this domestic market, which could result in import substitution.

Partial economic CBA

A partial economic CBA was carried out, using all of the costs and benefits accruing to livestock producers modelled under the financial CBA. In addition to these costs and benefits, all project costs were included in the economic analysis. Finally, the economic analysis includes some of the some of the benefits that would accrue to society more broadly under the 'with project' scenarios. The additional benefits considered include the indirect impact of improved productivity in the livestock sector, as well as the benefits associated with the project's climate change mitigation outcomes. The results of the economic CBA, outlined in Table ii, show that the 'with project' scenario has a net present value of US$19.7 million relative to the 'without project' scenario over the 8-year project timeframe and US$291 million over a 20-year period.

Table ii. Results of the economic cost-benefit analysis

Scenario	PV - costs (US$)	PV - benefits (US$)	NPV (US$)			BCR
			4 years	8 years	20 years	
Without project	11 689 497	28 460 442	12 045 288	12 469 142	16 770 945	2.43
Improved land and livestock management	78 315 900	344 110 207	29 848 903	74 052 021	265 794 306	4.39
Improved market access	11 875 800	48 443 299	14 863 567	22 151 255	36 567 499	4.08
Improved land and livestock management & improved market access	97 580 470	405 309 148	31 760 606	89 375 942	307 728 679	4.15
With project relative to without project			**19 715 318**	**76 906 800**	**290 957 733**	

Cost-effectiveness and upscaling potential

A partnership with Ipelegeng would result in the stimulation of economic development through skills development in the livestock production sector, which would be critical to improving the country's export competitiveness. This would reduce in positive socio-economic outcomes across the country in terms of an improved resilience of communities who are particularly vulnerable to climate change, and in contributing to the development of a key economic sector in which there exists considerable potential for increased value addition[25].

25 Seleka and Kebakile, *Export Competitiveness of Botswana's Beef Industry*. BIDPA

Replication of the Project model in other regions of the country will be possible through Botswana's standing budgetary priority to support job creation nationwide. The co-finance contribution to this project represents only 10% of the total programme budget per annum and if proven successful, could be scaled significantly for other regions of the country.

For replication in other nations, over the last 15 years, the number of African countries implementing major social protection programmes for poor and vulnerable people has tripled, with internal and external (primarily World Bank) financing[26]. This trend is likely to continue, particularly in response to COVID-19 economic slowdowns. Through GDSA, AFR100, and other forums, additional countries will be exposed to lessons from this Botswana project and be able to integrate the rangeland restoration model into their own efforts.

Potential for replication and upscaling

Replication of the Project model in other regions of the country will be possible through Botswana's standing budgetary priority to support job creation nationwide. The co-finance contribution to this project represents only 10% of the total programme budget per annum and if proven successful, could be scaled significantly for other regions of the country.

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26 Cristilla, C. and R. Tebaldi, 2016. Social Protection in Africa: an Inventory of Non-contributory Programmes. www.ipc-undp.org

27 Cristilla, C. and R. Tebaldi, 2016. Social Protection in Africa: an Inventory of Non-contributory Programmes. www.ipc-undp.org

2.1. Introduction

Agriculture is an important economic sector in Botswana. Despite contributing only 2–3% of the country's Gross Domestic Product (GDP), the sector constitutes ~70% of rural livelihoods[28]. Rural households, which comprise ~40% of the total population of the country, depend on the agricultural sector for employment, food security and income generation[29]. Within the sector, ~85% of Botswana's agricultural output is derived from livestock production[30]. In addition to supporting livelihoods, livestock play a central role in the cultural practices of the Batswana people[31].

Botswana's livestock production sector has experienced stagnation over at least the past 20 years, both in terms of real livestock value added and in terms of livestock's contribution to agricultural value added overall, the latter having declined substantially since 1994. Despite this stagnation, Botswana's livestock sector has continued to maintain a strong degree of export competitiveness, especially relative to other Southern Africa Development Community (SADC) member states[32].

The traditional livestock production sub-sector has been identified as an area with considerable potential for improvement. Traditional livestock holdings account for ~97% of all livestock holdings across the country and make up ~90% of the total national herd[33]. It is widely acknowledged that interventions in both the supply-side and demand-side of the traditional livestock production sub-sector have potential to generate economic activity and alleviate poverty [34].

Poverty levels and vulnerability are likely to increase as climate change contributes to increased degradation of Botswana's communal rangelands. The combined impact of increased drought frequency, higher temperatures and reduced precipitation will be most strongly felt by smallholders who are dependent on communally shared rangelands[35]. The vast majority of the country's low-income population is dependent on the country's communal land, particularly indigenous communities and female headed households (see Gender Assessment and GAP). More than 55% of all communally owned livestock is owned by individuals 65+ years of age, who have fewer alternative livelihood options.

In addition to the opportunity costs associated with stagnation, livestock management practices in Botswana result in externalities on society more broadly. The livestock production system is characterized by feedback mechanisms whereby increased levels of rangeland degradation lead to increasingly low levels of productivity in the traditional livestock production sub-sector, and *vice versa*[36]. Through a reduction in rangeland productivity for livestock production, as well as a variety of other ecosystem services, the national, annual cost of rangeland degradation has been

[28] World Bank 2019. Botswana Country Profile; Government of Botswana. 2012. Agriculture and Food Security Policy Brief: Reflecting on the challenges of attaining a Green Economy for Botswana.
[29] *Ibid*
[30] United States Department of Agriculture Foreign Agricultural Service, 2015. Botswana: Agricultural Economic Fact Sheet.
[31] Such as for *lobola*, which is a type of dowry payment made as an aspect of a traditional marriage.
[32] Seleka, Tebogo Bruce & Kebakile, Pinkie G., *Export Competitiveness of Botswana's Beef Industry*, *SSRN Electronic Journal*, 2016, https://doi.org/10.2139/ssrn.2819998.
[33] including cattle sheep and goats
[34] Engelen, Anton van, Malope, Patrick, et al., *Botswana Agrifood Value Chain Project Beef Value Chain Study*, 2013; Seleka and Kebakile, *Export Competitiveness of Botswana's Beef Industry*; Dizyee, Kanar, Baker, Derek, & Rich, Karl M., "A Quantitative Value Chain Analysis of Policy Options for the Beef Sector in Botswana," *Agricultural Systems* 156, no. October 2016 (2017): 13–24, https://doi.org/10.1016/j.agsy.2017.05.007.
[35] Zhou P.P., T Simbini, G Ramokgotlwane, T.S Thomas, S. Hachigonta, L.M Sibanda. 2013. Botswana. In Southern African Agriculture and Climate Change: A comprehensive analysis. Chapter 3 Pp. 41-70. Washington, D.C.: International Food Policy Research Institute (IFPRI).
[36] See Feasibility Assessment, Section 3: Carbon and Water Baseline Assessment Report

estimated at US$ 353 million — equivalent to 3.2% of the country's GDP[37]. The magnitude of these losses is likely to intensify under climate change.

The following report provides a financial and economic analysis of the GCF funding proposal entitled *Ecosystem and livelihoods resiliency: climate change risk reduction through ecosystem-based adaptation in Botswana's communal grazing lands* (hereafter referred to as the project). The project's main area of focus is the traditional livestock production sub-sector in three areas of Botswana, namely Bobirwa, Kgalagadi and Ngamiland.

The report provides an overview of project costs and financing, followed by a financial cost-benefit analysis of the project's intended impacts on livestock producers in the traditional sub-sector. The report then presents a broader, qualitative analysis of the economic impacts on other beneficiaries in the project area. This is followed by a discussion of the project's potential macroeconomic impacts. The final section considers the project's cost-effectiveness.

The report is structured as follows:

- Section 2.2 presents the project description;
- Section 2.3 provides project costs and financing;
- Section 2.4 outlines the scenarios used in the financial cost-benefit analysis;
- Section 2.5 provides key assumptions, parameters, and limitations;
- Section 2.6 presents the findings of the financial cost-benefit analysis;
- Section 2.7 analyses economic impacts on value-chain actors and other beneficiaries in the project areas;
- Section 2.9 considers macroeconomic impacts;
- Section 2.11 presents a discussion around cost-effectiveness; and
- Section 2.12 concludes the economic and financial analysis.

2.2. Project description

The project is based on the successful model of the Herding for Health programme, a joint initiative of Conservation International and Peace Parks Foundation, which uses herding and livestock management to regenerate Africa's rangeland ecosystems and enhance climate change resilience of the communities dependent on them. The Herding for Health Model is based on executing rangeland stewardship agreements with affected communities that agree to site-specific good practice defined by scientific and traditional knowledge. In most cases, much of the conservation agreement involves collective grazing and/or corralling that is implemented by communities and professional herders called "Ecorangers". Restoration and wildlife protection elements of the agreement can be further incentivized by additional livestock production and training support and sustained through access to markets for their livestock products. Key market readiness interventions (legal requirements and market systems) are a critical component that ensures income flow to participating farmers that leads to self-sustaining impact and replication.

2.2.1. <u>Components and outputs</u>

The project is comprised of three components as outlined in Table 2.1. The first component is focused on strengthening institutions and support systems for climate-responsive planning and management. The second component is to reduce GHG emissions and negative livelihood impacts through new job deployment in rangeland rehabilitation, improved livestock management, and climate impact monitoring. The third component seeks to promote climate-sensitive enterprise development and value-chain investments to sustain transformational change.

[37] Munaz, Pablo, Ali, Mian, et al., "Country Profile: Botswana. Investing in Land Degradation Neutrality: Making the Case," 2018.

Table 2.1 Project components and outputs

Component 1: Strengthening institutions and support systems for climate-responsive planning and management.	Output 1.1: New structures and systems for climate responsive planning and implementation by communal populations are operationalized
	Output 1.2: New job creation programme and veterinary approach for climate responsiveness are adopted by national departments.
	Output 1.3: New rangeland management curricula developed and operationalised to expand skills for restoration and regenerative grazing
	Output 1.4: New rangeland monitoring system is operationalised, embedded, and utilized in market, carbon monitoring, and policy systems
	Output 1.5: Improved government policy initiatives on climate change actions and needs, enabling adaptive management
Component 2: Reducing GHG emissions and negative livelihood impacts through new job deployment in rangeland rehabilitation, improved livestock management, and climate impact monitoring.	Output 2.1: Job creation and social safety net programmes resourced by the Government are used to deploy restoration teams for climate-resilient land and livestock management in target Project Areas
	Output 2.2: Rehabilitation of ecosystems and improved management of land, soil, and livestock implemented to increase ecosystem productivity, reduce vulnerability of beneficiary populations, and reduce GHG emissions on 4.6 million hectares of climate-vulnerable communal rangelands
Component 3: Promoting climate-sensitive enterprise development and value-chain investments to sustain transformational change	Output 3.1: Market readiness trainings, enterprise development support, supply chain facilitation, and local level funds build the enabling conditions for improved low-emission livestock value chains
	Output 3.2: Selected financiers and value-chain players are aware and supported to incentivize rangeland stewardship and adopt carbon-optimization practices and technologies

2.2.2. Beneficiary numbers

The beneficiary numbers for the project have been revised to include 80% (effectiveness rate) of the total district populations. The indirect beneficiaries will be the entire population of Botswana, which will benefit from national level policy interventions and climate information development and distribution. The monitoring and evaluation system will include annual assessments of these factors and new indicators will be included at the Impact and Activity Level to ensure beneficiation is measurable.

Livestock production beneficiaries constitute the most direct form of beneficiary and include all members of livestock producing households within the traditional livestock production sector. These constitute 57% of the population living within the project area. Benefits to livestock production beneficiaries are discussed in Section 2.6. Economic impact beneficiaries include those participating in other parts of the livestock production and value-addition process, including those working in abattoirs and processing facilities. This category also includes those who would benefit from the project because of improvements in rangeland resources, which would allow for increased levels of harvesting and nutrition, enhanced water security and quality, as well as better disease containment. The latter would result in benefits to the commercial livestock producers as well as wildlife-dependent sectors such as tourism. Reduced degradation levels would also have the potential to generate increased revenues from tourism through offering an improved tourist experience. The beneficiaries associated with these impacts are all considered under the title economic impact beneficiaries in Table 2.2. These benefits have not been quantitatively appraised as part of this analysis, but a qualitative discussion is provided in Section 2.7.

Table 2.2 Beneficiary populations within the project areas

Project area	Livestock production beneficiaries		Economic impact beneficiaries		Total beneficiaries within project area		Total population within project area	
	Number	% of total pop.	Number	% of total pop.	Number	% of total pop.	Number	% of total pop.
Bobirwa	36,009	48%	14,457	19%	50,466	67%	75,018	100%
Kgalagadi	28,162	48%	11,307	19%	39,469	67%	58,671	100%
Ngamiland	112,333	64%	45,100	26%	157,433	90%	175,520	100%
Areas combined	**176,504**	**57%**	**70,864**	**23%**	**247,367**	**80%**	**309,209**	**100%**

2.3. Project costs and financing

The project's indicative cost is outlined in Table 2.3, which shows that project components will be implemented through a combination of grant financing from GCF and the Government of Botswana. The total indicative cost is US$ 97.6 million. Of this, US$ 54.0 million–55% of the total–represents funding that will be redirected from the Ipelegeng extended public-works programme, with the aim of achieving improved effectiveness with regards to the socio-economic impact associated with this expenditure. This is further discussed in Section 2.11 of this report.

Table 2.3 Financing by component

Component	Output	Indicative cost million USD ($)	GCF financing		Co-financing		
			Amount million USD ($)	Financial Instrument	Amount million USD ($)	Financial Instrument	Name of Institutions
Component 1: Strengthening institutions and support systems for climate-responsive planning and management.	Output 1.1: New structures and systems for climate responsive planning and implementation by communal populations are operationalized	6.1	5.1	Grants	1.0	Grants	CI
	Output 1.2: New job creation programme and veterinary approach for climate responsiveness are adopted by national departments.	4.6	3.8	Grants	0.7	Grants	CI
	Output 1.3: New rangeland management curricula developed and operationalised to expand skills for restoration and regenerative grazing	2.6	2.2	Grants	0.4	Grants	CI
	Output 1.4: New rangeland monitoring system is operationalised, embedded, and utilized in market, carbon monitoring, and policy systems	2.5	2.1	Grants	0.5	Grants	CI
	Output 1.5: Improved government policy initiatives on climate change actions and needs, enabling adaptive management	0.7	0.6	Grants	0.1	Grants	CI
Component 2: Reducing GHG emissions and negative livelihood impacts through new job deployment in rangeland rehabilitation, improved livestock management, and climate impact monitoring.	Output 2.1: Job creation and social safety net programmes resourced by the Government are used to deploy restoration teams for climate-resilient land and livestock management in target Project Areas	51.9	0.4	Grants	51.5	Grants	Government of Botswana; CI
	Output 2.2: Rehabilitation of ecosystems and improved management of land, soil, and livestock implemented to increase ecosystem productivity, reduce vulnerability of beneficiary populations, and reduce GHG emissions on 4.6 million hectares of climate-vulnerable communal rangelands	16.8	16.7	Grants	3.1	Grants	CI
Component 3: Promoting climate-sensitive enterprise development and value-	Output 3.1: Market readiness trainings, enterprise development support, supply chain facilitation, and local level funds build the enabling conditions for improved low-emission livestock value chains	3.7	3.1	Grants	0.6	Grants	CI

chain investments to sustain transformational change	Output 3.2: Selected financiers and value-chain players are aware and supported to incentivize rangeland stewardship and adopt carbon-optimization practices and technologies	1.1	0.9	Grants	0.2	Grants	CI
Independent Evaluations		0.1	0.1	Grants	0.02	Grants	CI
Project Management Costs		4.6	1.7	Grants	2.9	Grants	Government of Botswana; CI
Indicative total cost (USD)		**97.6**	**36.8**		**60.1**		

2.3.1. Cost per beneficiary

Considering only direct project beneficiaries, the cost per beneficiary (including co-finance) is estimated at US$ 395. The remainder of this section presents project cost benchmarking data from similar projects, with some discussion around the cost-effectiveness of projects aimed at improved natural resource management.

2.3.2. Comparisons with similar projects in Africa and elsewhere

Two programmes in Africa that are most similar to what is being proposed in this initiative are the Ethiopian Productive Safety Net Programme (EPSNP) and the South African Natural Resource Management Programme. The ESPNP was funded by the World Bank at a cost of $315 per beneficiary for the first five years starting in 2007. Of these beneficiaries, 70% indicated that they developed additional income generating opportunities as a result of the programme (the bulk of which are agricultural in nature given the focus on restoring pastoral and croplands) which provides good evidence of building household resilience.

Ethiopia continues to spend $900 million per annum on the programme in support of 10 million beneficiaries on 60,000 km2 at a cost of $90 per beneficiary now that infrastructure systems are in place to support, greater economies of scale. At a national scale, Ethiopia is now using the programme's carbon sequestration benefits to support their NDCs and attract carbon finance for sustainability[38].

South Africa's Natural Resource Management (NRM) programmes are also an example of a national job creation for restoration programme. The initiative which is reviewed in Annex 2 Section 4 Appendix 4.7 shows the investment the government makes annually to their land restoration programme, the return on the investment, and the potential to increase the scale of the programme for further job creation and ecosystem benefits. Key employment and cost data for the programmes is outlined in Table 2.4.

[38] Dominic Woolf, Dawit Solomon & Johannes Lehmann (2018) Land restoration in food security programmes: synergies with climate change mitigation, Climate Policy, 18:10, 1260-1270, DOI: 10.1080/14693062.2018.1427537

Table 2.4 Employment and expenditure in South Africa's Natural Resource Management Programme

Fiscal year 2009/10	Number of FTE*	Wages earned (000 US$)**	Budget (000 US$)**	Achievements
Working for Water	7 422	22 475	64 214	More than 2 million ha have been cleared since 1995.
Working for Land	348	1 308	3 737	1 700 ha have been restored.
Working for Wetland	1 514	3 319	9 482	516 wetlands have been rehabilitated between 2004 and 2010.
Working on Fire	2 012	5 429	15 510	The programme fought 1 628 fires in 2010, made 20 332km of fire belts, prescribed burning on 78 771 ha, manual fuel reduction on 343 ha, and covered 368 734 ha of fire-suppression (i.e. 14% of the fire area).
Total	**11 297**	**32 530**	**92 944**	

Source: Department of Water Affairs and the Department of Environment Affairs, unpublished data.

* FTE – Full-time equivalent; while the actual number of people employed by the respective programmes is much higher than the numbers reported here, we calculate an FTE as the number of person-days of work created by the programmes, divided by 230 days in a work year. The total number of people employed is much higher than the FTE number because few work for an entire year.

** All figures have been converted from Rand to US Dollar at a R/$ exchange rate of 7.5.

In addition to the programmes outlined above, there is also the Working on Ecosystems Programme, which evolved from some of the Conservation International engagement that focuses on shifting interventions from a short-term wage to a longer-term development opportunity[39]. Personal communication with the senior manager for the programme provided an estimate of a per annum investment of roughly $8700 per year for three years ($26,100) per beneficiary (NRM currently employs 100,000 per annum) with an estimated 55% "graduating" from the system into formal ecosystem-based economic activities after the investment.

Australia also has an indigenous rangers' "Working for Country" programme that has been in place since 2007 because of its success in transforming the lives of the most marginalized while also generating land management benefits[40]. In March 2020, Australia just announced a further $102 Million in support for 840 full-time ranger posts, and thousands of part-time land management jobs over the next six years.

[39] https://www.environment.gov.za/projectsprogrammes/workingfor_ecosystems
[40] https://www.niaa.gov.au/indigenous-affairs/environment/indigenous-rangers-working-country

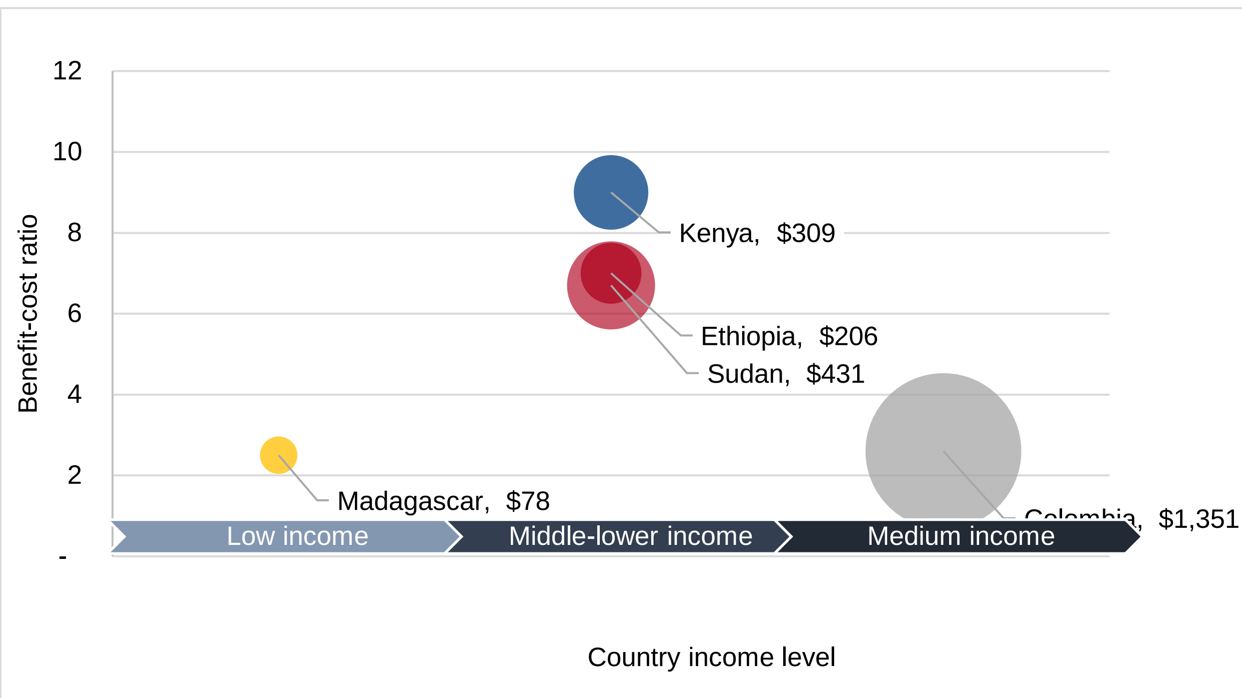
2.3.3. Comparisons with Early Warning-Early Action Programmes

The project can be viewed in the context of the cost per beneficiary for a proactive action versus emergency funding for drought response. Kenya and Ethiopia have shown the economic investment in early action to be $580-$1,357 per beneficiary, but when compared to costs for emergency relief the savings are substantial (see Table 2.5).

Table 2.5 Cost Estimates for Drought Responses in Horn of Africa, discounted over 20 years[41]

Location	Beneficiaries	Emergency	Early Action	Saving	Saving Per Capita
Wajir, Kenya	367,000	US$ 606 mil	US$214 mil	US$ 392 mil	US$ 1,068
Southern Ethiopia	2,800,000	US$ 3,800 mil	US$734 mil	US$ 3,066 mil	US$ 1,095

Net benefits of early warning-early action response to drought are further illustrated in Figure 2.1, which shows the net-benefits to targeted livestock producing households generated through FAO-led early warning-early action responses. Although these are arguably less sustainable in the long run, the benefits to households demonstrate the importance of action to avoid the costs associated with drought, most often incurred by the most vulnerable populations[42].



[41] Bailey, Rob. 2012. Famine Early Warning and Early Action: The Cost of Delay. London: Chatham House. http://www.fao.org/fileadmin/user_upload/drought/docs/0712pr_bailey.pdf
[42] See Section 5 of Annex 6 for the social and economic baselines of the Project Areas

Figure 2.1 Average net benefit to households and benefit-cost ratios for a selection of FAO EW-EA interventions targeting livestock-producing households before and during times of drought[43]

The anticipated net gains to livestock producers resulting from the project are presented in the following sections, which constitute a financial cost benefit analysis of the proposed project components, the implications of which are discussed in Section 2.6.6.

Cost per hectare: The cost per hectare is $8.64 (see paragraph 250 of the Funding Proposal).

Disaggregated cost per beneficiary per project area: Due to the site-specific variations and the different restoration technique investments that may be selected by communities, it is not possible to calculate an exact cost per beneficiary per region at this time. Based on implementation across three similar sites in South Africa, the cost per beneficiary is higher in low-density population areas where transport costs are high relative to the number of people benefiting. Low population density areas also are the most challenging implementation areas as they have more limited economic activity, slower rangeland recovery timeframes and smaller local demand for goods and services. Based on these factors, it is likely that Kgalagadi will have the highest cost per beneficiary. Despite higher costs, the targeted areas are home to the most vulnerable populations, and rich indigenous cultures where some of the best lessons on practices that maintain ecological integrity under extreme climate stress can be learned.

The following section will outline the scenarios considered in the financial cost benefit analysis. Following this will be a breakdown of key assumptions, parameters used in, and limitations of, the financial cost-benefit analysis presented in Section 2.6.

2.4. Outline of scenarios used in the analysis

For the financial analysis, four scenarios were outlined to investigate the interplay between the project components. A description of each is provided as hereafter, followed by a discussion of the study's key assumptions, parameters and limitations.

2.4.1. Scenario 1: Without Project

This scenario is characterized by a continuation of the *status quo*. A lack of intervention in the traditional livestock production sub-sector implies continued low levels of land and livestock management. The Botswana Meat Commission (BMC) continues as a parastatal and holds a monopsony over beef exports. Current regulations around the management of foot and mouth disease (FMD) persist and no trade opportunities exist in geographic zones within the Project Areas designated as Red Zones. Other restrictions to market access faced by traditional livestock producers from limited veterinary requirement and traceability compliance are also maintained and producers also receive a relatively low price per kilogram for sales. A lack of fodder reserves and limited access to markets implies that under drought conditions, traditional livestock producers are left vulnerable and without the necessary coping strategies.

2.4.2. Scenario 2: Improved land and livestock management

Under this scenario, Component 2 of the project is implemented. Active management of land and livestock is enacted through the training and deployment of Ecorangers. The condition of

[43] FAO, "Horn of Africa Impact of Early Warning Early Action: Protecting Pastoralist Livelihoods Ahead of Drought"; FAO, "The Sudan Impact of Early Warning Early Action: Protecting Agropastoralist Livelihoods Ahead of Drought" (Rome, 2018); FAO, "Colombia Impact of Early Warning Early Action: Boosting Food Security and Social Cohesion on the Frontline of a Migration Crisis" (Rome, 2019); FAO, "Madagascar Impact of Early Warning Early Action: Protecting Farming Livelihoods from Drought and Food Insecurity" (Rome, 2019).

rangeland ecosystems improves gradually along with the condition of livestock, with a 2% increase in the average cold dressed mass (CDM) of cattle beginning from Year 3 . Under drought conditions, livestock producers can utilise fodder reserves to mitigate against losses in the number of livestock as well as losses in the average weight of livestock. Reduced need for movement into conservation areas reduces negative impacts on conservation areas. Due to restricted market access, however, livestock producers are unable to sell stock to reduce pressure on rangeland ecosystems. Limited market access, combined with low levels of bargaining power for producers, maintains low market prices for livestock products.

2.4.3. Scenario 3: Improved market access

Scenario 3 considers the implementation of Component 3. Under this scenario, value-chain transformation leads to improved market access for farmers in the traditional livestock production sector. The introduction of mobile abattoirs and commodity-based-trade results in producers receiving a higher price per kilogram than under Scenarios 1 and 2. Producers are also able to sell their stock during times of drought, reducing pressure on rangeland ecosystems; however, a lack of active land and livestock management implies that the condition of livestock does not improve over time. In addition, fodder reserves remain limited and unavailable as a coping strategy during times of drought.

2.4.4. Scenario 4: Improved land and livestock management and improved market access

The fourth scenario considers the joint implementation of Components 2 and 3. This results in both improved land and livestock management as well as improved market access for producers. During times of drought, producers are able to sell part of their herd to ensure that pressure on rangeland ecosystems is reduced. The remaining herd is sustained with fodder reserves built up through improved land management. Overall, resilience is enhanced to a greater degree than in any of the other scenarios considered. This scenario integrates the recommendations and feasibility assumptions of the proposed project.

2.5. Assumptions, parameters and limitations

Many of the complexities which characterize the coupled ecological and economic systems associated with livestock production have been omitted from the model. Where possible, these complexities have been simplified and incorporated in a conservative manner. Ultimately the model is intended to show the financial costs and benefits facing livestock producers in the traditional sub-sector under the scenarios outlined above. The following assumptions and parameters were used to accomplish this whilst maintaining a balance between simplicity and realism.

2.5.1. Climate change and drought

Expected impacts from climate change were handled in a conservative manner by assuming that over the 20-year period a single drought would occur. In the model, the drought occurs in years 6 and 7, with years 8 and 9 constituting a recovery period[44]. It is probable, in reality, that the drought frequency and severity will be greater than assumed under this model[45]. In addition, the compounding impacts of consecutive drought events that would result under more extreme climate scenarios are not considered in this model. The drought impacts predicted by this analysis are therefore expected to underestimate the probable impacts.

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[44] Note that in the Without Project Scenario, cattle weight does not return to levels allowing for sales to commence until Year 11

[45] See Feasibility Assessment, Section 1: Climate Vulnerability Assessment Report

2.5.2. Cattle population and condition

Cattle populations were modelled using the baseline data presented in the Botswana Agricultural Census Report of 2015 (see Table 2.6). Populations were assumed to be a function of sales, births, deaths, losses and eradication and were assumed to remain stable outside of drought conditions. Given that the population fell slightly between 2015 and 2016, a balancing factor was incorporated to maintain this assumption.

Table 2.6. Baseline cattle population, sales, births, deaths, losses and eradication in the traditional sector[46].

Project area	Cattle population	Sales		Births		Deaths, losses and eradication	
		No.	%	No.	%	No.	%
Bobirwa	62 768	3 716	5.9%	16 332	26.0%	6 035	9.6%
Kgalagadi	69 402	5 000	7.2%	20 414	29.4%	10 801	15.6%
Ngamiland	190 187	12 283	6.5%	50 170	26.4%	30 362	16.0%

The drought which was incorporated into the model was assumed to affect cattle populations in the manner outlined in Figure 2.2. The guiding assumptions employed to develop these curves are based on research which demonstrates the varying degrees to which drought impacts secondary producer populations, including livestock and other herbivores, under differing management regimes[47]. The key assumptions are outlined here:

Under Scenario 1, livestock numbers fall the most, take the longest to recover, and do not fully recover to their pre-drought levels. This is because livestock producers in this scenario do not have access to fodder reserves (livestock have limited supplementary feed and mortality is therefore higher) and do not have access to markets (they cannot sell livestock at the onset of drought to reduce pressure on rangeland ecosystems).

Under Scenario 2, livestock numbers are less impacted by the drought than under Scenario 1, due to the availability of fodder reserves.

Under Scenario 3, livestock producers can sell stock at the onset of drought. Populations therefore fall initially due to increased sales but recover quicker than in Scenario 1 as the remaining cattle left on rangelands are more likely to survive under drought conditions.

Under Scenario 4, livestock producers sell their stock at the onset of drought and have fodder reserves available for the cattle remaining. The result is that numbers fall initially due to the drought but recover faster than in any of the other scenarios because of the two-tiered approach to adaptation.

[46] Statistics Botswana, "Botswana Agricultural Census Report 2015" (Gaborone, Botswana, 2018).
[47] See Feasibility Assessment, Section 3: Carbon and Water Baseline Assessment for additional details

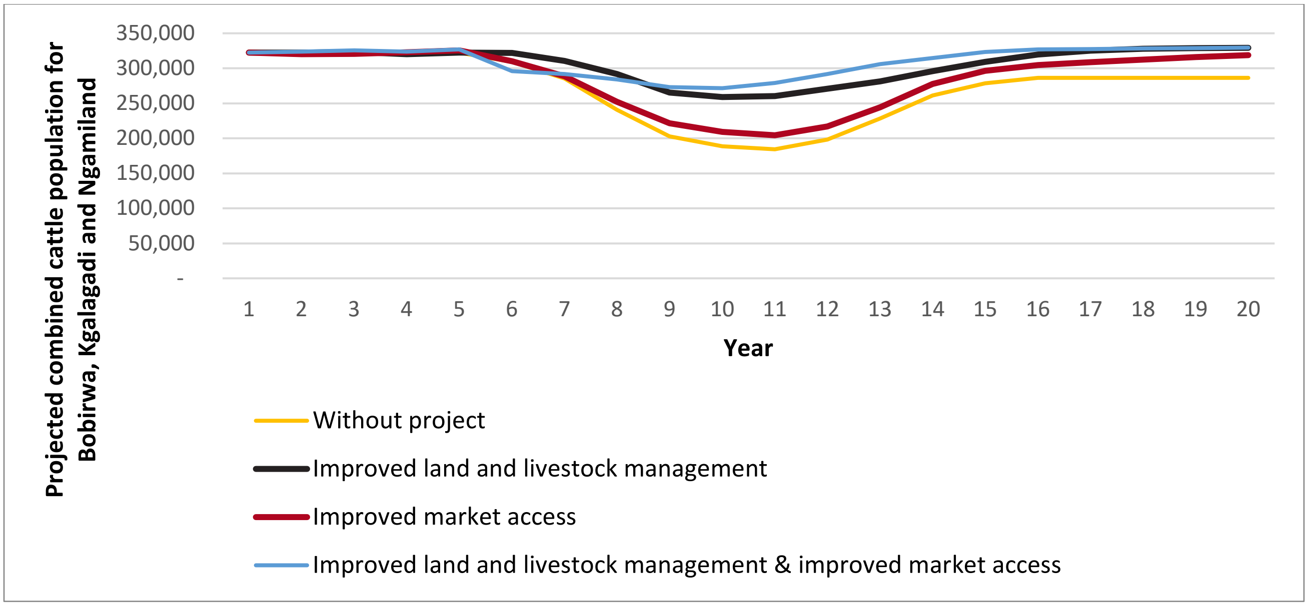

Figure 2.2 Estimated impact of drought on cattle populations under the four scenarios[48].

The condition of the cattle sold by livestock producers was assumed to vary as outlined in Figure 2.3, which shows the assumed average cold dressed mass (CDM) of the livestock, sold over the course of the period considered, and the effect of drought on CDM under the four scenarios. The changes in CDM shown are a direct result of changes in livestock condition due to the drought. The reasons for the differences across scenarios are therefore the same as the reasons for the differences in the changes to livestock populations outlined above.

[48] Statistics Botswana, "Botswana Agricultural Census Report 2015" (Gaborone, Botswana, 2018).

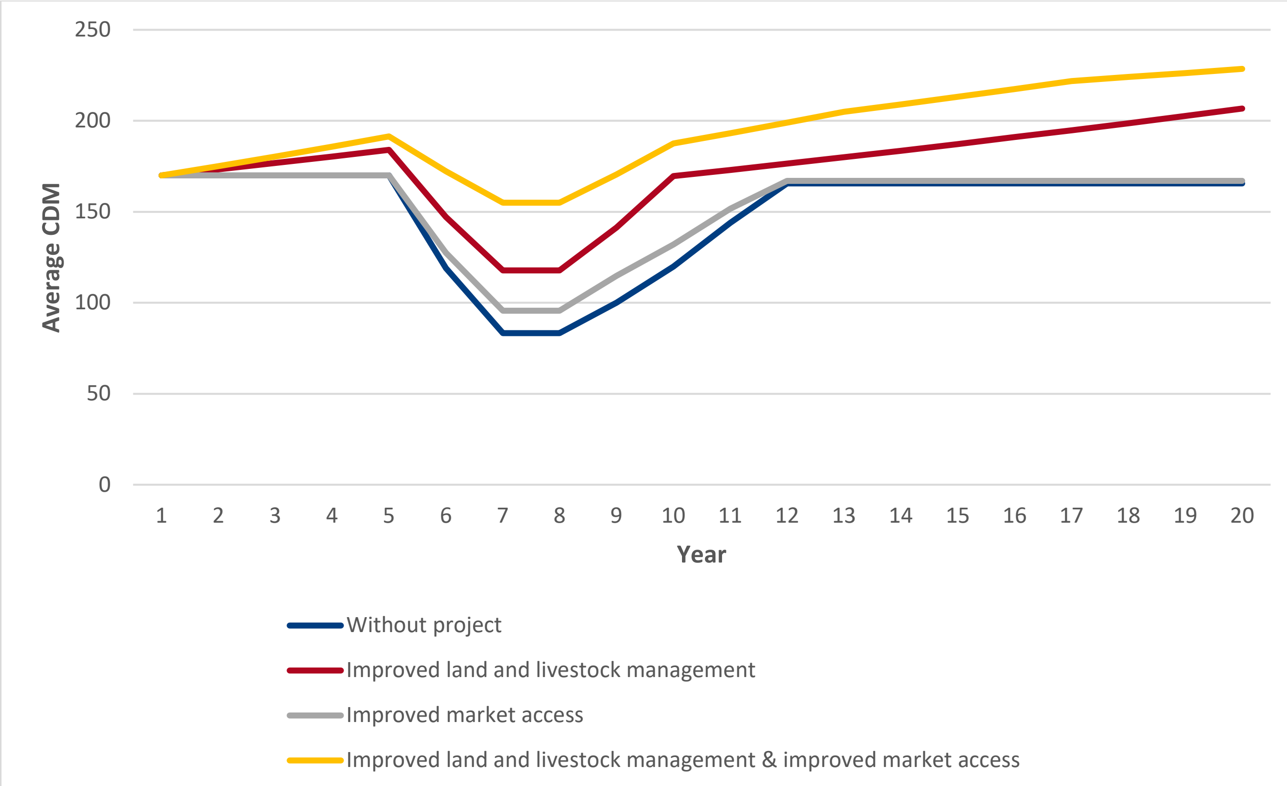

Figure 2.3 Estimated impact of drought on the average CDM of livestock sold under the four scenarios[49,50]

2.5.3. Market prices

Along with population numbers and CDM, the price received per kilogram is an important parameter in determining the revenues received by livestock producers. Price per kilogram was assumed to vary according to CDM as outlined in Table 2.7Table 2.7.

In Scenarios 1 and 2 (i.e. no market intervention), the average price received is set at zero when CDM is below 160 kg (given that abattoirs do not accept animals for slaughter below this threshold), US$ 0.99 between 160 kg and 180 kg (the average price estimated based on sales to BMC, Ngamiland Abattoirs and local butcheries[51]), and US$ 1.85 where CDM is greater than 180 kg (based on current BMC prices[52]).

In scenarios 3 and 4 (with the introduction of mobile abattoirs and commodity-based trade), producers are able to sell at a relatively low rate of US$ 0.99 per kg even when CDM is lower than 160 kg[53]. When CDM is between 160 and 180 kg, the price increases to US$ 1.72, which reflects the premium price paid in the domestic market[54]. When CDM is between 180 and 220 kg, the price is US$ 1.85 (based on current BMC prices[55]). Above 220 kg, the quality is assumed to

[49] van Engelen et al., *Botswana Agrifood Value Chain Project Beef Value Chain Study*.
[50] Feasibility Assessment, Section 3: Carbon and Water Baseline Assessment
[51] Conservation South Africa, “Meat Naturally Pty Business Plan for Botswana,” 2018; Bing, Mark, MNarshall, Clive, & Masedi, Mokadi, “EXPLORING MARKET OPPORTUNITIES FOR COMMODITY-BASED TRADE (CBT) OF BEEF FROM NGAMILAND , BOTSWANA : Towards Harmonization of the Livestock and Wildlife Sectors,” 2017. (see Feasibility Assessment, Section 6)
[52] See https://bmc.bw/revision-of-bmc-cold-dressed-masscdm-prices-post-drought-subsidy/
[53] Conservation South Africa, “Meat Naturally Pty Business Plan for Botswana”; Bing, MNarshall, and Masedi, “EXPLORING MARKET OPPORTUNITIES FOR COMMODITY-BASED TRADE (CBT) OF BEEF FROM NGAMILAND , BOTSWANA : Towards Harmonization of the Livestock and Wildlife Sectors.” (see Feasibility Assessment, Section 6)
[54] Conservation South Africa, “Meat Naturally Pty Business Plan for Botswana.” (Feasibility Assessment Section 6)
[55] See https://bmc.bw/revision-of-bmc-cold-dressed-masscdm-prices-post-drought-subsidy/

be suitable for export and the lower end of BMC export prices has been used as an assumption here[56]. Given that in the model, the CDM is only estimated to reach a level higher than 220 kg in year 17 of the project, this allows ample time for the market interventions that are intended to enable exports to occur.

Table 2.7. Assumed price per kg received by livestock producers under the scenarios considered.

CDM (kg)	Price (US$/kg) Scenarios 1 and 2	Price (US$/kg) Scenarios 3 and 4
<160	0	0.99
160–180	0.99	1.72
180–220	1.85	1.85
>220	1.85	2.41

2.5.4. Input costs

Transport costs were assumed to be US$ 33.72 per head under Scenarios 1 and 2, and US$ 11.24 under Scenarios 2 and 4. This assumption is based on the observation that given current market setup, transport costs facing producers are three times higher than they could reasonably be[57]. This assumption is conservative given that the mobile abattoirs would likely reduce transport costs faced by livestock producers to an even greater degree than was considered by the research utilized.

Labor costs were assumed to be US$ 0.61 per head per annum under Scenarios 1 and 3. This reflects the low amount which is spent on herding under the current system whereby transient, migratory herders are employed on an ad-hoc basis[58]. Under Scenarios 2 and 4, the labor costs were taken from the project budget which outlines projected spending on training and employment of Ecorangers. The labor costs associated with Scenario 4 are outlined in Table 2.8, reflecting full implementation of project components. The labor costs associated with Scenario 2 were assumed to be 70% of those associated with Scenario 4, given that labor costs for the purposes of compliance monitoring, record-keeping and management of quarantine sites would not be incurred directly by livestock producers.

Table 2.8. Labor costs associated with Scenario 4.

Total labor costs per annum	Bobirwa (US$)	Kgalagadi (US$)	Ngamiland (US$)
Years 1-2	221,221	146,846	666,815
Years 3-5	663,662	440,537	2,000,444
Years 6-20	1,548,544	1,027,921	4,667,703

[56] See https://bmc.bw/revision-of-bmc-cold-dressed-masscdm-prices-post-drought-subsidy/
[57] Bing, MNarshall, and Masedi, "EXPLORING MARKET OPPORTUNITIES FOR COMMODITY-BASED TRADE (CBT) OF BEEF FROM NGAMILAND , BOTSWANA : Towards Harmonization of the Livestock and Wildlife Sectors." (Feasibility Assessment, Section 6)
[58] van Engelen et al., *Botswana Agrifood Value Chain Project Beef Value Chain Study*.

A final category of general input costs was also included. These were estimated to be US$ 2.31 per head per annum under Scenarios 1 and 3, and US$ 4.62 per head per annum under Scenarios 2 and 4[59]. Input costs were assumed to double with improved land and livestock management.

2.5.5. Timeframe and discount rate

The scenarios outlined in Section 2.4 were used in conjunction with the assumptions above to model the impacts of the interventions proposed over a 20-year period. While the project is seeking grant finance over a period of eight years, a longer timeframe is needed for the appraisal, given the time profile of costs and benefits, which is characteristic of EbA interventions. Typically, these interventions entail costs in early years, with benefits taking many years to materialize, but lasting potentially into perpetuity[60]. A timeframe of analysis less than 20-years would therefore capture a disproportionate share of costs while not counting a large enough portion of benefits.

For the reasons outlined above, the choice of discount rate is important in the cost-benefit of EbA interventions. With more benefits occurring disproportionately in later years, a high discount rate has the potential to produce bias against EbA interventions and in favor of those that provide more immediate returns. A conservative discount rate of 10% was used for the CBA, obtained from the African Development Bank Socio Economic Database[61].

2.6. Financial impacts on direct project beneficiaries

Results of the cost benefit analysis (CBA) are presented below for each of the scenarios considered. The figures provide a visual representation of the costs and benefits over time for all project areas combined. The tables provide a summary of the net present values (NPVs) and cost-benefit ratios, estimated for each of the three study areas, under the different scenarios.

2.6.1. Scenario 1: Without Project

Under the Without Project Scenario, benefits exceed costs by a marginal amount until the onset of the drought in year 6. At this point the average CDM of livestock falls to below 160 kg and sales terminate. Revenue drops to zero over the next 6 years until livestock condition has recovered to the point that CDM exceeds 160 kg (Figure 2.4). Cattle populations and conditions do not fully recover following the drought and net benefits post-drought are resultantly lower than pre-drought levels.

[59] Reflecting estimations of the average input costs faced currently by livestock producers, which seem to consist of highly variable, ad-hoc spending on supplementary feeding, operation and maintenance of boreholes, those vaccines which are not provided by government such as Pasteurella and Botulism, and fines in the event that livestock cause vehicle accidents.

[60] Asian Development Bank, 2017. Guidelines for the economic analysis of projects, pg. 53. www.adb.org; openaccess.adb.org; Emerton, L. 2017. Valuing the Benefits, Costs and Impacts of Ecosystem-based Adaptation Measures: A sourcebook of methods for decision-making. GiZ, Frankfurt, Germany.

[61] AFDB. 2009. African Development Bank Socio Economic Database. Available: https://dataportal.opendataforafrica.org/nbyenxf/afdb-socio-economic-database-1960-2021

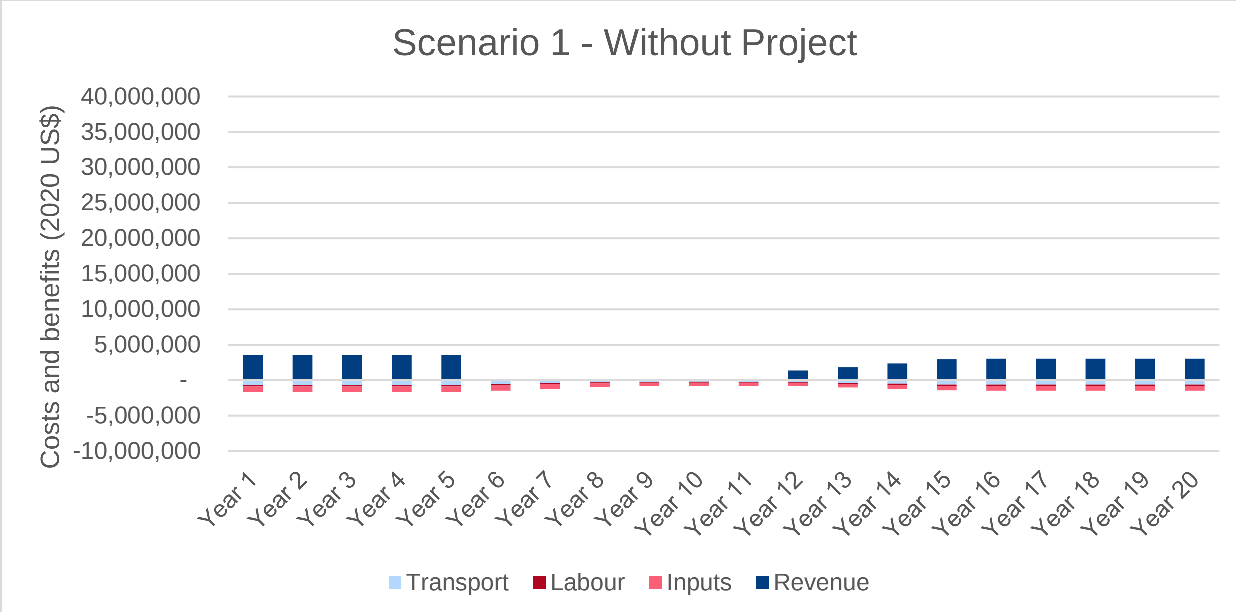

Figure 2.4 Costs and benefits associated with the Without Project scenario (Y-axis scale is standard across scenarios).

The net-present value of the costs and benefits estimated for the Without Project Scenario range from US$ 1.1 million for Bobirwa to US$ 3.9 million for Ngamiland (Table 2.9). Kgalagadi has the highest benefit-cost ratio under this scenario, reflecting the area's relatively favorable cattle population dynamics as evidenced in the national cattle census. Per beneficiary NPVs demonstrate how low profits are expected to be in the traditional livestock production sub-sector. Across all project sites, the NPV per beneficiary over the 20-year period considered is US$ 38, which amounts to an average of US$ 1.90 per year.

Table 2.9. Net present values (NPVs) and benefit-cost ratios (BCRs) associated with the Without Project scenario.

Without project	NPV (US$)			BCR	Livestock production beneficiaries	NPV per livestock prod. ben. (US$) 20-year
	4 years	8 years	20 years			
Bobirwa	1,004,155	820,423	1,106,036	1.47	36,009	31
Kgalagadi	1,490,459	1,353,880	1,781,562	1.68	28,162	63
Ngamiland	3,479,184	3,034,049	3,879,743	1.58	112,333	35
Areas combined	**5,973,798**	**5,208,352**	**6,767,340**	**1.58**	**176,504**	**38**

The Without Project Scenario results in marginally positive net benefits for livestock producers which are compromised during times of drought. This calls into question the feasibility of relying on livestock production as a means of supporting livelihoods under conditions of intensifying climate change.

2.6.2. Scenario 2: Improved land and livestock management

Under improved land and livestock management, livestock producers see increasing returns to investments in the initial years of the programme. There is a marked increase in revenue in years 4 and 5, when cattle condition improves sufficiently such that CDM exceeds 180 kg (the current threshold for BMC's increased price per kg). With the onset of drought in year 6, however, the condition of cattle falls to below the 160 kg CDM threshold and sales terminate (Figure 2.5). Following the drought, the condition of cattle improves faster than under Scenario 1 and producers are able to generate revenue by year 10. Revenues then increase rapidly and begin levelling off towards the end of the period considered, as cattle reach optimal conditions.

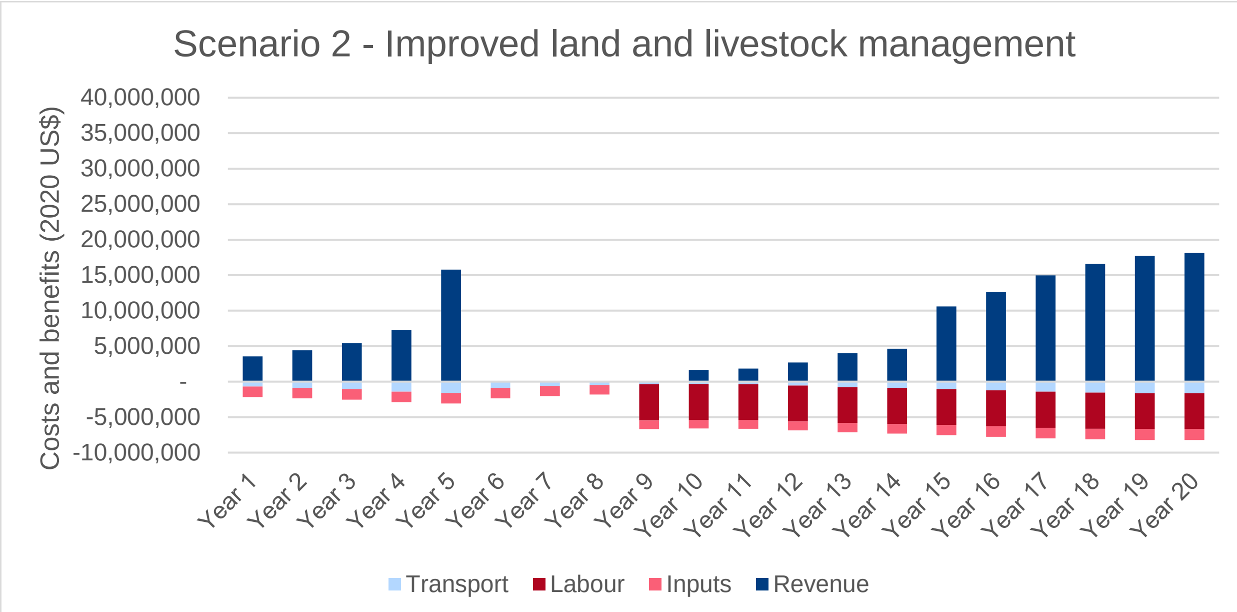

Figure 2.5 Costs and benefits associated with the improved land and livestock management scenario.

The net present values associated with Scenario 2 are marginally positive for all project sites (Table 2.10). Across all the areas considered, the NPV per livestock production beneficiary under Scenario 2 is US$ 63.

Table 2.10. Net present values and benefit-cost ratios associated with the improved land and livestock management scenario.

Improved land and livestock management	NPV (US$)			BCR	Livestock production beneficiaries	NPV per livestock prod. ben. (US$) 20-year
	4 years	8 years	20 years			
Bobirwa	1,343,489	2,105,609	1,190,056	1.16	36,009	33
Kgalagadi	2,026,435	3,202,144	4,438,197	1.66	28,162	158
Ngamiland	4,700,577	7,410,468	725,247	1.03	112,333	6
Areas combined	**8,070,502**	**12,718,221**	**11,074,207**	**1.31**	**176,504**	**63**

The financial analysis of Scenario 2 has revealed that improving land and livestock management would result in improved livestock production and a marginal increase in the direct revenue that this sector provides to rural households. Through the assurance of a marginally more reliable income source, the component would improve the resilience of livestock producers to increased rainfall variability under Climate Change.

2.6.3. Scenario 3: Improved market access

In Scenario 3, associated with improved market access, livestock producers see increased returns from cattle production relative to Scenario 1 (Figure 2.6). This is attributable to an increase in the price per kilogram received by producers. Producers are also able to respond to the drought event by selling cattle early, consequently reducing the pressure on the rangeland ecosystems that support the remaining cattle. Even when the condition of livestock deteriorates to below 160 kg CDM, producers are able to sell stock, albeit at a reduced rate due to losses in quality.

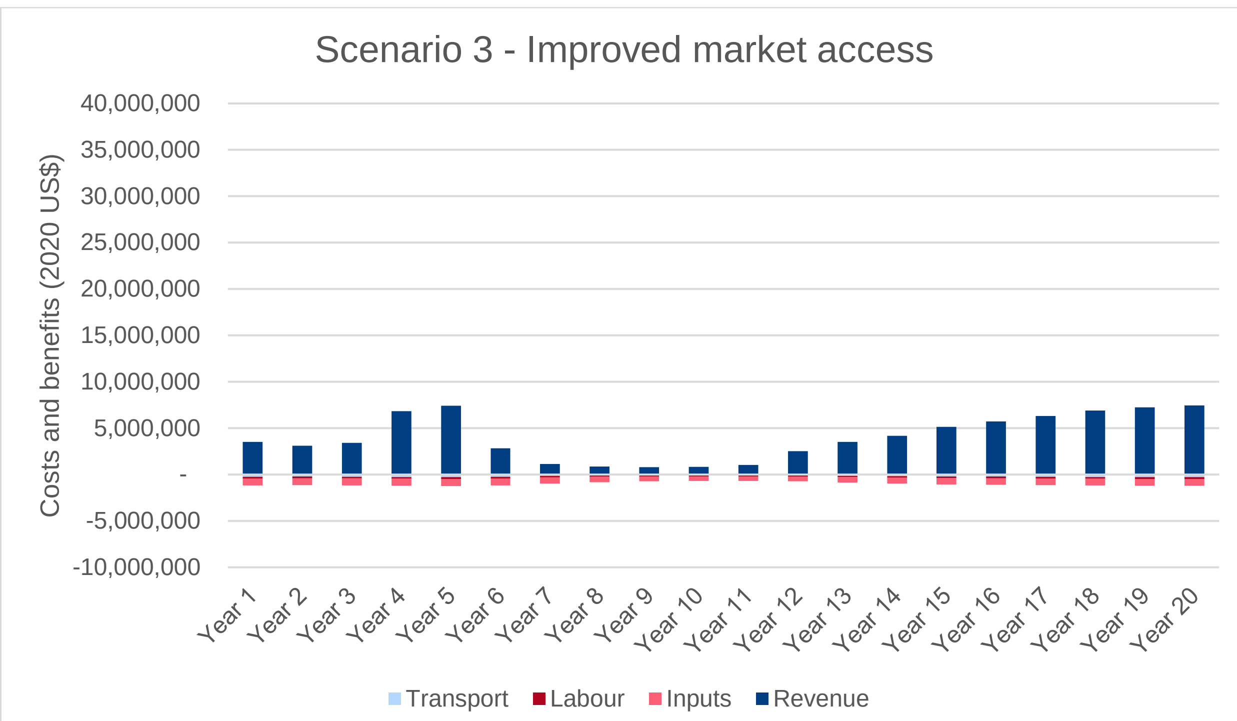

Figure 2.6 Costs and benefits associated with the improved market access scenario (Y-axis scale is standard across scenarios).

The NPVs associated with Scenario 3 range from US$ 4.6 million for Bobirwa to US$ 10.1 million for Kgalagadi (see Table 2.11). Given the relatively low input costs, high BCRs are seen across each of the areas, ranging from 2.6 for Ngamiland to 5.7 for Kgalagadi. Across all areas considered, the NPV per direct beneficiary is US$ 128 over the 20-year period.

Table 2.11. Net present values and benefit-cost ratios associated with the improved market access scenario.

Improved market access	NPV (US$)			BCR	Livestock production beneficiaries	NPV per livestock prod. ben. (US$) 20-year
	4 years	8 years	20 years			
Bobirwa	1,834,229	2,812,993	4,550,506	3.50	36,009	126
Kgalagadi	3,667,081	5,935,158	10,047,515	5.65	28,162	357
Ngamiland	3,814,911	5,435,339	7,928,820	2.62	112,333	71
Areas combined	**9,316,221**	**14,183,490**	**22,526,841**	**3.53**	**176,504**	**128**

Financial analysis of the improved market access scenario suggests that market interventions can substantially improve the returns seen by livestock producers. If implemented in isolation, this component would have a positive impact on revenues relative to the without project scenario.

2.6.4. Scenario 4: Improved land and livestock management and improved market access

Under successful implementation of Project Components 2 and 3, the combined impacts of improved land and livestock management and improved market access result in increased revenue, such that the net benefits associated with Scenario 4 increase rapidly (see Figure 2.7). The impact of the drought is mitigated both through sales facilitated by market access and the use of fodder reserves facilitated by improved land management. Net benefits during drought years, however, remain negative due to the higher input costs associated with the project. Revenue increases rapidly post-drought and by year 16 there is an increase in the price per kg received by producers given that the average CDM of their livestock has increased beyond 220 kg.

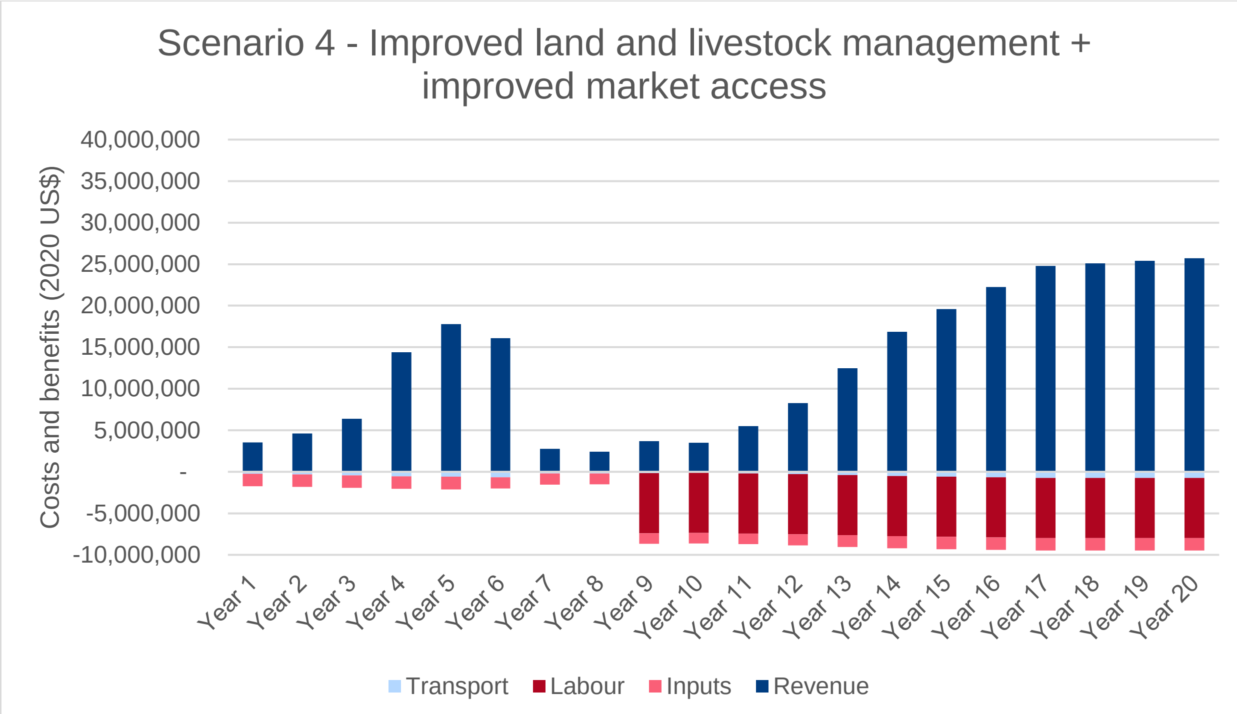

Figure 2.7 Costs and benefits associated with the improved land and livestock management and improved market access scenario.

The NPVs associated with Scenario 4 (with project) are higher than the preceding scenarios, ranging from US$ 3 million for Bobirwa to US$ 14.8 million for Ngamiland (see Table 2.12). BCRs are also favorable, ranging from 1.4 for Bobirwa to 2.5 for Kgalagadi. It should be noted that the BCRs for this scenario are lower than those for Scenario 3 because of the higher costs associated with Scenario 4. NPVs are, however, higher under Scenario 4 than under Scenario 3. The average per-beneficiary NPV generated under this scenario is US$ 273, which translates to US$ 22.75 per year.

Table 2.12. Net present values and benefit-cost ratios associated with the improved land and livestock management and improved market access scenario.

Improved land and livestock management & improved market access	NPV (US$)			BCR	Livestock production beneficiaries	NPV per livestock prod. ben. (US$) 20-year
	4 years	8 years	20 years			
Bobirwa	1,362,789	1,803,005	3,070,058	1.26	36,009	85
Kgalagadi	2,969,470	5,588,027	10,986,448	2.17	28,162	390
Ngamiland	5,186,587	7,731,528	14,764,056	1.40	112,333	131
Areas combined	**15,767,998**	**34,485,455**	**48,183,458**	**2.25**	**176,504**	**273**

Projected financial performance under the combined implementation of project Components 2 and 3 indicates that this scenario will result in the highest returns to livestock producers, as compared to a business-as-usual scenario and implementation of either Component 2 or 3.

2.6.5. Sensitivity analysis

Three variations of sensitivity analysis were carried out to test the robustness of the results under more conservative outcomes than were considered in the base case presented above. These include changes in assumptions related to the magnitude of the costs facing livestock producers, changes to the anticipated degree of benefits from improved productivity and revenues, as well as changes to the discount rate used.

A 40% increase in the present value of costs

The first form of sensitivity analysis checked what the result of a 40% increase in the present value of costs would be. The outcomes are presented in Table 2.13. For the Without Project Scenario, all project areas maintain marginally positive NPVs. For Scenario 2, only the net benefits associated with Kgalagadi are positive (as opposed to the base case in which only Ngamiland was negative). Other than this change, the results are largely similar to those in the base case except that NPVs are lower across all scenarios. The For the 'with project' scenario, the NPV was found to switch to negative at a 230% increase in costs.

Table 2.13. Sensitivity analysis 1: A 40% increase in the present value of costs (20-year period).

Without project	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	3,266,492	3,439,244	172,752	1.05
Kgalagadi	3,652,773	4,390,685	737,912	1.20
Ngamiland	9,446,032	10,626,908	1,180,876	1.13
Areas combined	**16,365,296**	**18,456,837**	**2,091,541**	**1.13**

Improved land and livestock management	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	10,107,052	8,409,379	- 1,697,673	0.83
Kgalagadi	9,410,361	11,159,883	1,749,522	1.19
Ngamiland	37,503,787	27,513,667	- 9,990,121	0.73
Areas combined	**50,412,210**	**47,082,929**	**- 3,329,281**	**0.93**

Improved market access	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	2,547,597	6,370,218	3,822,621	2.50
Kgalagadi	3,027,091	12,209,723	9,182,631	4.03
Ngamiland	6,869,978	12,835,947	5,965,969	1.87
Areas combined	**12,444,666**	**31,415,888**	**18,971,222**	**2.52**

Improved land and livestock management & improved market access	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	16,800,412	15,070,353	- 1,730,059	0.90

Kgalagadi	13,165,499	20,390,376	7,224,877	1.55
Ngamiland	51,164,642	51,310,229	145,587	1.00
Areas combined	**54,022,500**	**86,770,958**	**32,748,459**	**1.61**

A 40% decrease in the present value of benefits

A 40% reduction in the present value of benefits generates results as presented in Table 2.14. Under the 'without project' scenario, only Kgalagadi maintains a positive NPV and it is low at US$ 25,000. Scenario 2 results in less-than-favorable outcomes for all project areas. Under Scenario 3, NPVs remain positive. Under Scenario 4 the NPV for Bobirwa and Ngamiland are both negative. Bobirwa's NPV switches to negative under a decrease in benefits of ~21%, while Ngamiland's NPV switches at ~29%.

Table 2.14. Sensitivity analysis 2: A 40% decrease in the present value of benefits (20-year period).

Without project	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	2,333,208	2,063,546	- 269,662	0.88
Kgalagadi	2,609,123	2,634,411	25,288	1.01
Ngamiland	6,747,165	6,376,145	- 371,021	0.95
Areas combined	**11,689,497**	**11,074,102**	**-615,395**	**0.95**

Improved land and livestock management	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	7,219,323	5,045,627	- 2,173,696	0.70
Kgalagadi	6,721,686	6,695,930	- 25,756	1.00
Ngamiland	26,788,420	16,508,200	- 10,280,220	0.62
Areas combined	**36,008,721**	**28,249,757**	**- 7,758,964**	**0.78**

Improved market access	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	1,819,712	3,822,131	2,002,419	2.10
Kgalagadi	2,162,208	7,325,834	5,163,626	3.39
Ngamiland	4,907,127	7,701,568	2,794,441	1.57
Areas combined	**8,889,047**	**18,849,533**	**9,960,486**	**2.12**

Improved land and livestock management & improved market access	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	12,000,294	9,042,212	- 2,958,083	0.75
Kgalagadi	9,403,928	12,234,226	2,830,298	1.30
Ngamiland	36,546,173	30,786,138	- 5,760,035	0.84
Areas combined	**38,587,500**	**52,062,575**	**13,475,075**	**1.35**

Use of a 20% discount rate

Switching to a 20% discount rate changes very little in the results. The reason for this can be found in the distribution of costs and benefits over time. The figures shown throughout this section reveal that costs and benefits are relatively homogenous over time compared to a project where, for example, most of the costs are incurred early on while most of the benefits accrue in later years. The findings of the financial analysis are therefore robust to the use of different discount rates, as is shown in Table 2.15.

Table 2.15. Sensitivity analysis 3: Use of a 20% discount rate (20-year period).

Without project	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	1,370,566	2,143,181	772,615	1.56
Kgalagadi	1,580,811	2,822,440	1,241,629	1.79
Ngamiland	4,114,626	6,894,563	2,779,937	1.68
Areas combined	**7,066,004**	**11,860,184**	**4,794,180**	**1.68**

Improved land and livestock management	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	3,283,555	4,314,112	1,030,557	1.31
Kgalagadi	3,299,932	5,759,565	2,459,633	1.75
Ngamiland	10,489,277	14,196,764	3,707,488	1.35
Areas combined	**16,692,721**	**24,270,441**	**7,577,720**	**1.45**

Improved market access	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	1,054,952	3,557,799	2,502,848	3.37
Kgalagadi	1,264,345	6,585,118	5,320,774	5.21
Ngamiland	2,938,535	7,660,723	4,722,187	2.61
Areas combined	**5,257,831**	**17,803,640**	**12,545,809**	**3.39**

Improved land and livestock management & improved market access	PV - costs (US$)	PV - benefits (US$)	NPV (US$)	BCR
Bobirwa	5,901,038	7,370,906	1,469,867	1.25
Kgalagadi	4,733,175	9,926,453	5,193,278	2.10
Ngamiland	17,954,690	24,781,527	6,826,836	1.38
Areas combined	**16,333,724**	**42,078,885**	**25,745,161**	**2.58**

The sensitivity analysis has revealed that sustaining project benefits will be crucial for successful outcomes, and that a reduction in the magnitude of benefits available to livestock producers is likely to be a strong determinant of successful implementation, with Kgalagadi being more resilient than Bobirwa and Ngamiland in this regard.

2.6.6. Implications of the financial analysis

Overall, the financial CBA suggests that the success of the project will be dependent on the effective implementation of both project Components 2 and 3. This is further discussed in the following sub-section, followed by the study's implications for understanding the financial implications of drought on livestock producers.

Net benefits associated with the project

Net benefits associated with project implementation are shown in Table 2.16. The per-beneficiary net benefits associated with each of the scenarios is positive relative to the 'without project' scenario. The combination of improved livestock management and improved market access results in the highest net benefits relative to the no project scenario across all timeframes. The net benefit of this scenario relative to the without project scenario is US$235 per-beneficiary over the 20-year period considered.

Table 2.16 Net benefits to livestock production beneficiaries under with project scenarios relative to the without project scenario (US$)

Scenario	Per-beneficiary net benefit relative to the without project scenario (US$)		
	4 years	8 years	20 years
Scenario 2. Improved land and livestock management	46	72	63
Scenario 3. Improved market access	53	80	128
Scenario 4. Improved land and livestock management & improved market access	89	195	273

The above result is in line with the findings of the Beef Value Chain study conducted by the FAO, which demonstrate that under the present market conditions, it is not financially viable for communal livestock farmers to make the investments necessary to improve the health of livestock and rangelands. Their findings further highlight that in the absence of market intervention, incentives exist for communal livestock producers to increase their stock levels to the detriment of the agro-ecological systems which support them[62].

Financial impact of drought on livestock producers

Another finding, applicable across all scenarios considered, is the extent to which traditional livestock producers are affected by a drought event. Under the model, aggregate revenues drop below costs and losses are incurred by farmers. These losses are amplified with the implementation of Component 2 because of the labor costs involved. As mentioned in Section 2.5, the modelled drought represents a highly conservative depiction of the climatic conditions that livestock producers are likely to face in the coming years. The CBA demonstrates the

[62] van Engelen et al., *Botswana Agrifood Value Chain Project Beef Value Chain Study*.

timeframes required for livestock producers' revenue to recover in the wake of drought events. Therefore, in the anticipated context of multiple, consecutive drought events this finding highlights the risks faced by livestock producers who may experience compounding impacts of multiple drought events. In the face of intensifying climate change, with increasingly more frequent and more severe droughts expected, building resilience in the traditional livestock production sub-sector will be critical to ensuring that it continues to support rural livelihoods.

The analysis presented here suggests that the project will lead to net benefits for livestock producing households in the project area, as well as enhanced adaptive capacity in the context of increasing rainfall variability and drought. The following section will expand the analysis to include the broader population of the area, including value-chain actors and their dependents, commercial livestock farmers and actors in the nature-based tourism sub-sector.

2.7. Economic impacts on the broader population in the project areas

The importance of considering a broader range of actors than just livestock producers is highlighted by the annual cost of land degradation in Botswana, which is estimated at US$ 353 million, equivalent to 3.2% of the country's GDP[63]. Given that a central aim of the proposed project will be to address the drivers of rangeland degradation, it follows that the benefits to those parts of Botswana's economy which are reliant on healthy rangeland ecosystems will be considerable. The stakeholders who are likely to benefit, in addition to traditional livestock producers, include value-chain actors, commercial livestock producers, tourism operators and associated employees.

In addressing rangeland degradation, reform of communal grazing land use is likely to provide higher returns than reform of other land uses. Rangeland ecosystems are utilized for four types of land use in Botswana including communal grazing, private cattle ranching, game ranching and Wildlife Management Areas (WMAs). Research conducted in the Kgalagadi District has revealed that communal grazing provides the widest range of ecosystem services as compared with other land uses[64]. Furthermore, the authors of this research note current communal grazing practices are not sustainable.

The following sub-sections outline the economic benefits that are likely to result from the project insofar as it addresses the drivers of rangeland degradation under communal grazing land use.

2.7.1. Rangeland resources

The direct use-value of forest and rangeland resources, including both timber and non-timber products in Gweta, Lerala, Palla Road, Tsetseng, Chobokwane and Kumakwane was estimated at approximately BWP 39.8 million (US$ 3.9 million) in 2017[65]. At the household level, these critical sources of income are rarely accounted for. One study estimated the direct use value of plant resources in three villages adjacent to the Okavango Delta, finding that the value of this form of resource utilization was approximately US$ 1,434 per household per year, slightly above the average financial household income of US$ 1,416 per year[66].

[63] Munaz et al., "Country Profile: Botswana. Investing in Land Degradation Neutrality: Making the Case."
[64] Favretto, N, Stringer, L C, et al., "Assessing the Socio-Economic and Environmental Dimensions of Land Degradation: A Case Study of Botswana's Kalahari," 2014, 1–28, http://www.see.leeds.ac.uk/research/sri/eld/.
[65] Centre for Applied Research, "2016 Review of Community Based Natural Resources Management in Botswana : Report Prepared for SAREP by Centre for Applied Research," 2016, 43.
[66] Mmopelwa, G, Blignaut, J N, & Hassan, R, "Direct Use Values of Selected Vegetation Resources in the Okavango Delta Wetland," *SAJEMS* 12, no. 2 (2009): 242–55.

Degraded rangelands have been shown to exhibit lower levels of plant diversity and are therefore far less likely to support livelihoods to the extent that healthy rangelands can. An improvement in rangeland condition is thus likely to result in considerable benefits to rural households who rely on these systems for harvesting timber and non-timber products. This benefit can be viewed as an added layer of resilience in the face of intensifying climate change.

2.7.2. Water security

Water security is an issue of strategic importance for Botswana. As a result of climate change, Botswana is expected to experience a reduction in rainfall and increased frequency of drought events[67]. The link between healthy ecosystems and water provision is well established[68]. In terms of the economic importance of water provision and water regulation, however, few studies have estimated the values associated with these ecosystem services in Botswana — although one such study estimated the value associated with the groundwater recharge service provided by the Makgadikgadi wetland system at BWP 8.6 million per year (US$ 1.3 million in 2010 terms)[69].

An improvement in rangeland condition is likely to result in improved water provision and regulation in the project catchments[70]. The value of these ecosystem services has not been established in monetary terms, but it is likely to be substantial.

2.7.3. Nature-based tourism

Approximately 11.6% of Botswana's GDP is generated through tourism-related activity. This figure is 1.2% higher than the global average of 10.4%. Travel and tourism indirectly support 72,000 jobs in Botswana, and this is expected to increase to 102,000 by 2028[71]. Nature-based tourism is considered to be the most important sub-sector within the country's overall tourism sector ,and this sector is particularly critical to the economy of the Ngamiland Project area As with agriculture, this sub-sector is heavily reliant on well-functioning ecosystems.

Through Botswana's Community-based Natural Resource Management (CBNRM) Programme, communities are able to benefit from the utilization of natural resources in the areas where they live. The revenue generated by the 53 active Community-based Organizations (CBOs) through this utilization was estimated at BWP 26.8 million (US$ 2.5 million) in 2016, having increased by 21% since 2012[72]. It is recognized that there is scope for increased benefits to communities under this programme[73] and reduced human-wildlife conflict in the Project areas is likely to increase such opportunities

Scope for the growth of Botswana's nature-based tourism provides a unique opportunity to grow and diversify the economy while ensuring that nature can continue to provide society with broader

[67] See Feasibility Assessment, Section 1: Climate Vulnerability Assessment Report
[68] A. Reichhuber, N. Gerber, A. Mirzabaev, M. Svoboda, A. López Santos, V. Graw, R. Stefanski, J. Davies & A. Vuković, M.A. Fernández, García, C. Fiati, X. Jia., *The Land-Drought Nexus* (Bonn, Germany: United Nations Convention to Combat Desertification, 2019).
[69] Setlhogile, Tshepo, Arntzen, Jaap, et al., "Economic Valuation of Selected Direct and Indirect Use Values of the Makgadikgadi Wetland System, Botswana" (University of Zimbabwe, 2011), https://doi.org/10.1016/j.pce.2011.08.008.
[70] See Annex 4: Carbon and Water Baseline Assessment for additional details
[71] World Travel and Tourism Council, "Economic Impact 2018: Botswana," 2018, https://www.wttc.org/-/media/files/reports/economic-impact-research/countries-2018/botswana2018.pdf.
[72] Centre for Applied Research, "2016 Review of Community Based Natural Resources Management in Botswana : Report Prepared for SAREP by Centre for Applied Research."
[73] Ministry of Environment, Natural Resources Conservation and Tourism (MENT). 2018. Biodiversity Finance Initiative (BIOFIN) – Botswana: Biodiversity Finance Plan. Report written by Hugo Van Zyl. MENT and United Nations Development Programme, Gaborone, Botswana.

ecosystem services such as water regulation and carbon sequestration[74,75]. Growth of Botswana's nature-based tourism sector can be both driven by a paradigm shift in rangeland livestock production and as feedback into improving the resilience of communities where communal grazing is practiced. For example, stakeholder consultations indicated that at the village-level, this Project would likely increase the number of opportunities for improved co-existence between farming and tourism activities through the spatial planning and land-use agreements

2.7.4. Regional economic impacts

Finally, due to the significant portion of the populations that are involved in livestock farming in the Project areas, there are other likely economic resilience effects. Improved management of communal cattle and land is likely to reduce disease transmission to herds grazing on adjacent private lands by straying cattle who break private fences to get to private fodder and water reserves in drought times. Market access opportunities enabled by the project will also result in increased cash flows through the local economic hubs in the Project Areas, stimulating greater resilience throughout the regional economy.

The Project aims to work with StatsBotswana to identify positive and negative spillovers and interference (i.e., effects in and outside targeted populations and borders) to measure reduce or increase net impacts[76]. Indicators directly associated to the channels and mechanisms by which spillovers operate will be monitored through the Impact Monitoring efforts of the project (See Annex 11). As suggested by Pfaff and Robalino (2017)[77] some of these channels are input reallocation; market prices; learning; nonpecuniary motivations; and ecological-physical links. This will require identifying the mechanistic relationship through which the project components affect the outcome and explaining the process of change from an initial stage leading to an intermediate or final stage (the outcome). For example, in the presence of leakage of slippage a farmer who faces restrictions on resource use can lead to continued unsustainable grazing and land clearing in other land parcels (input reallocation). This in turn would lead to increases in measurement of land degradation above-baseline. By not considering this spillover effect the program will show no impact or negative impact. Similar spillovers arise from cash transfers in the form of incentive payments that increase the capacity of a participant in the project to buy goods and use those to work in areas outside the program potentially leading to no project effect at the landscape level. Our proposed impact evaluation plan will assess the mechanisms whereby causal effects arise when interference and spillover effects are present.

2.8. Climate Change mitigation

Improvements in livestock and rangeland condition has been shown to result in agro-ecological systems that regulate carbon, methane and other greenhouse gasses more effectively than in degraded systems. Through the simulation of different rangeland management scenarios, the impact of the project's activities was modelled and estimates of carbon-balance impacts were generated for enteritic fermentation and soil, shown in Table 2.17.

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[74] The World Bank, "Botswana: Systematic Country Diagnostic," 2015, http://documents.worldbank.org/curated/en/489431468012950282/pdf/95304-REPLACEMENT-SCD-P150575-PUBLIC-Botswana-Systematic-Country-Diagnostic-Report.pdf.

[75] World Bank Group, "Supporting Sustainable Livelihoods through Wildlife Tourism" (Washington D.C., 2018), https://openknowledge.worldbank.org/handle/10986/29417.

[76] Van der Weele, T. (2015). Explanation in causal inference: methods for mediation and interaction. Oxford: Oxford Univ. Pr.

[77] Pfaff, A., & Robalino, J. (2017). Spillovers from conservation programs. Annual Review of Resource Economics, 9, 299-315.

Table 2.17 Mitigation benefits estimated under project implementation (tCO_2e)[78]

Project Area	Source	4-year	8-year	10-year	20-year
Bobirwa	Enteric fermentation	16,744	77,114	114,570	371,758
	Soil carbon stocks	98,270	601,275	932,701	2,731,092
	Total	115,014	678,389	1,047,270	3,102,851
Ngamiland	Enteric fermentation	61,394	282,752	420,089	1,363,114
	Soil carbon stocks	360,324	2,204,675	3,419,902	10,014,006
	Total	421,718	2,487,427	3,839,992	11,377,120
Kgalagadi	Enteric fermentation	37,953	174,792	259,692	842,653
	Soil carbon stocks	222,746	1,362,890	2,114,121	6,190,476
	Total	260,698	1,537,682	2,373,813	7,033,129
Grand Total		**797,430**	**4,703,498**	**7,261,075**	**21,513,100**

The figures above were annualized by taking the mean quantity of carbon mitigated per year for each of the periods, except for the first four-year period, during which mitigation was assumed to begin in year two and ramp up consecutively until just below the annualized amount estimated in year 5. Current literature shows that the social cost of carbon is estimated to be between US$80 and US$100[79]. As of 2019, carbon pricing initiatives used a range of between US$1–US$127/tCO2e, with 51% of emissions covered priced below US$10/tCO2e[80]. A conservative estimate of US$5/tCO2e was used as a shadow price to estimate the value associated with the project's mitigation outcomes, outlined in Section 2.10.

The projects goals in terms of mitigating greenhouse gas emissions and leveraging government funding to do so are outlined in Table Table 2.18. Given that the total cost of the project is US$97.6 million, and that the project should result in the mitigation of around 21.5 million tCO_2e, the cost of mitigation is estimated at US$4.54 per tCO2e.

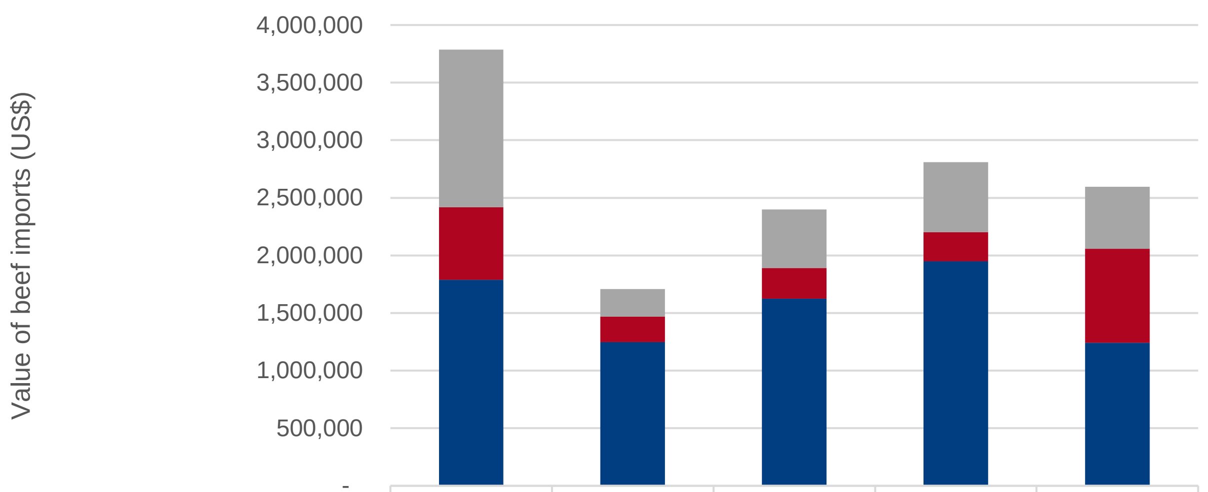
Botswana's Intended Nationally Determined Contribution (INDC) to global mitigation targets has been set at 1,246,050 tCO_2e by 2030. Should the project go ahead, it is likely to result in the mitigation of 587,973 tCO_2e by 2030, representing 47.2% of the country's national commitment.

2.9. Macroeconomic impacts

The project has the potential to result in improved macro-economic performance and stability for Botswana as a whole. Much of the beef produced is expected to meet the needs of the domestic market and, in doing so, there exists potential to target the particularly high-end segment of this domestic market, which could result in import substitution.

In 2018, Botswana imported in excess of US$ 2.5 million worth of beef (see Figure 2.8), in part to meet the needs of high-end tourism establishments. If the beef produced by traditional livestock farmers meets the expectations of this market segment (it is likely that a premium label such as Meat Naturally would help with this), there may be potential for this beef to act as a substitute for the beef that is currently being imported. This would lead to improvements in Botswana's balance of payments.

[78] See Feasibility Assessment, Section 3: Carbon and Water Baseline Assessment for additional details
[79] Paper from Aaron
[80] WB report



	2014	2015	2016	2017	2018
Meat of bovine animals, frozen	1,369,000	239,000	507,000	610,000	537,000
Meat of bovine animals, fresh or chilled	628,000	224,000	266,000	252,000	817,000
Live bovine animals	1,789,000	1,246,000	1,625,000	1,949,000	1,242,000

Figure 2.8 Value of Botswana's beef imports, 2014–2018[81].

In addition to meeting the needs of the domestic market, there is potential for achieving increased exports, especially in the latter years of project implementation. Globally, demand for beef has grown by approximately 14% between 2015 and 2018 (Figure 2.9). It should, however, be noted that the global beef industry is characterized by strong competition. Achieving a competitive advantage will require either a high level of cost-efficiency or the targeting of niche markets, such as those associated with ecolabelling.

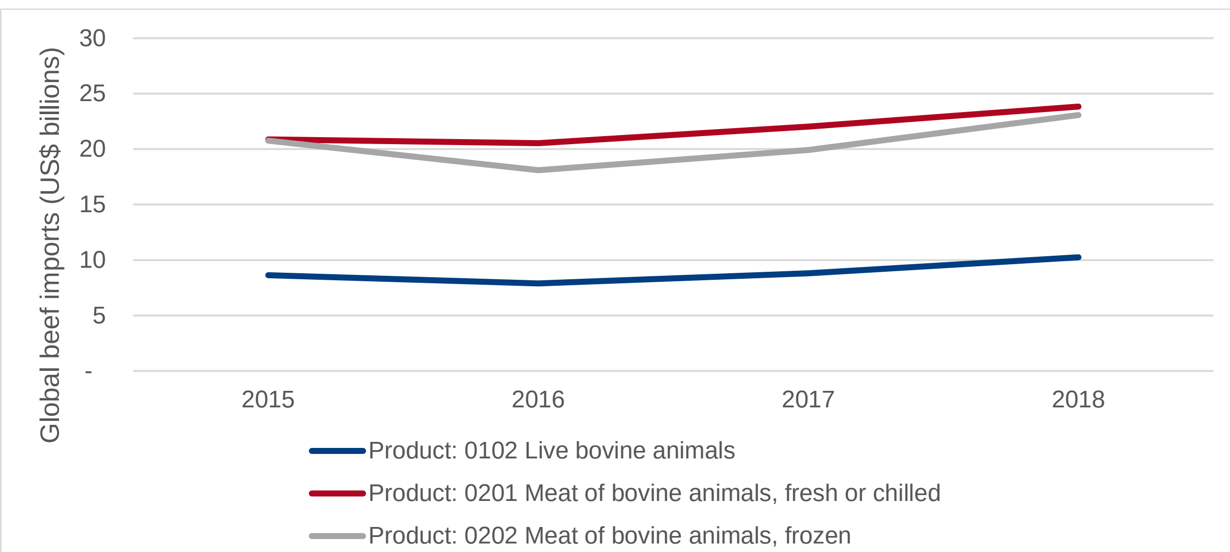


Figure 2.9 Value of global beef imports, 2014–2018[82].

[81] http://www.intracen.org/itc/market-info-tools/statistics-import-product-country/
[82] http://www.intracen.org/itc/market-info-tools/statistics-import-product-country/

Diversifying Botswana's export portfolio would constitute an achievement of national strategic importance. In the World Bank's Systematic Country Diagnostic, Botswana's reliance on diamonds for generation of government revenue and foreign earnings is highlighted as a key challenge facing the country's economy (Figure 2.10). The World Bank authors go on to recommend the Botswana prioritize diversification through the growth of employment-intensive sectors. This strategy is reflected in national planning imperatives as reflected in Annex 6 of this Funding Proposal.

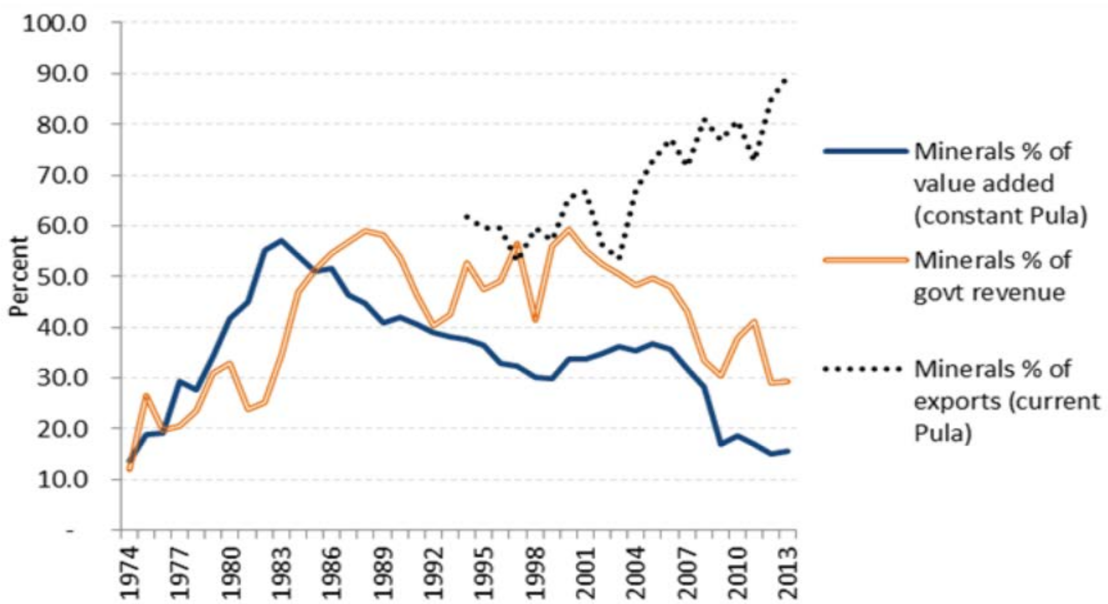


Figure 2.10 Botswana's reliance on minerals 1974–2013[83].

2.10. *Partial economic CBA*

A partial economic CBA was carried out, using all of the costs and benefits accruing to livestock producers modelled under the financial CBA. In addition to these costs and benefits, all project costs were included in the economic analysis. Finally, the economic analysis includes some of the some of the benefits that would accrue to society more broadly under the 'with project' scenarios. The additional benefits considered include the indirect impact of improved productivity in the livestock sector, as well as the benefits associated with the project's climate change mitigation outcomes.

Indirect economic impacts were estimated by applying a multiplier to the direct benefits resulting under the project CBA. Multipliers provide a way of estimating the economy-wide impacts of increased output generated from economic activity in any given sector. Investments in agricultural projects can support the growth of rural economies through linkages between the agricultural sector and other sectors, which are responsible for indirect economics impacts. Multipliers reflect the structure of a given economy, therefore providing a way of estimating the magnitude of the indirect impacts of increased economic activity in any given sector.

[83] The World Bank, "Botswana: Systematic Country Diagnostic."

Table 3.1 outlines several output multipliers for the agriculture sector, which have been estimated for selected African countries. The lowest recorded multiplier was 1.28, for a study of two communal areas in KwaZula-Natal, South Africa. This indicates that a US$1 increase in agricultural incomes will lead to a US$0.28 increase in incomes outside of the agricultural sector in the local economies of the areas studied. The highest multiplier estimated was 1.83, for Senegal. The average of all multipliers included in the table is 1.54.

Table 2.18 Agricultural multipliers from studies reviewed

Authors	Year	Place	Agricultural multiplier
Hendriks and Lyne[84]	2010	Communal areas, KwaZulu-Natal, South Africa	1.28
Haggblade et al.[85]	1991	Rural Sierra Leone	1.35
Delgado et al.[86]	1994	Burkina Faso	1.31
Delgado et al.	1994	Niger	1.77
Delgado et al.	1994	Senegal	1.83
Delgado et al.	1994	Zambia	1.41
Block and Timmer[87]	1994	Kenya	1.64
Bautista and Thomas[88]	1998	Zimbabwe	1.62
Block[89]	1999	Ethiopia	1.54
Pfunzo[90]	2017	Limpopo, South Africa	1.67
Average			**1.54**

Based on the above review of relevant studies, we estimated that an increase of US$1 in income resulting from the project would result in a further US$0.54 in indirect spending in the economy. This is the factor which was used to estimate the EIRR associated with the project (presented in Appendix 1). It should, however, be noted that there are some co-benefits which are not likely to be reflected in this estimation technique. The multiplier approach assumes that the structure of an economy will remain relatively stable with the intervention being considered. The project being considered, however, aims to generate a paradigm-shift in both the demand side and supply side of the livestock production sector. The resulting economic restructuring could lead to more substantial indirect and induced impacts on Botswana's economy through a restructuring of markets, resulting in a broad array of benefits discussed in Section 2.7. The EIRR estimated can

[84] Hendriks, SL. Lyne, MC. (2010) Agricultural growth multipliers for two communal areas of KwaZulu-Natal. Development Southern Africa, 20:3, 423-444, DOI: 10.1080/0376835032000108211

[85] Haggblade, S. Hammer, J. Hazell, P. (1991) Modelling Agricultural Growth Multipliers. American Journal of Agricultural Economics. May 1991.

[86] Delgado, C. Hazell, P. Hopkins, J. Kelly, V. (1994) Promoting intersectoral growth linkages in rural Africa through agricultural policy and technological reform. American Journal of Agricultural Economics, 76.

[87] Block, S. Timmer, CP. (1994) Agriculture and economic growth: Conceptual issues and the Keynesian experience. CAER Discussion Paper No. 27.

[88] Bautista, RM. Thomas, M. (1998) Agricultural growth linkages in Zimbabwe: Income and equity effects. Trade and Macroeconomics Division Discussion Paper No. 31. International Food Policy Research Institute.

[89] Block, SA. (1999) Agriculture and economic growth in Ethiopia: growth multipliers from a four-sector simulation model. Agricultural Economics, 20.

[90] Pfunzo, R. (2017) Agricultural contribution to economic growth and development in rural Limpopo Province: A SAM multiplier analysis. MSc Thesis, Faculty of AgricSciences, Stellenbosch University.

therefore be considered a conservative estimate in terms of its inclusion of indirect economic impacts.

The project's climate change mitigation benefits were estimated through the use of a conservative estimate for the shadow price of carbon, as is outlined in Section 2.8. Applying an estimate of US$5/tCO2e, it was inferred that the project benefits in terms of Climate Change mitigation have a net value of US$9.3 million over the 8-year project period and US$24.9 million over the 20-year period.

The results of the economic CBA, outlined in Table 2.20, show that the 'with project' scenario has a net present value of US$19.7 million relative to the 'without project' scenario over the 8-year project timeframe and US$291 million over a 20-year period.

Table 2.19 Results of the economic cost-benefit analysis

Scenario	PV - costs (US$)	PV - benefits (US$)	NPV (US$)			BCR
			4 years	8 years	20 years	
Without project	11 689 497	28 460 442	12 045 288	12 469 142	16 770 945	2.43
Improved land and livestock management	78 315 900	344 110 207	29 848 903	74 052 021	265 794 306	4.39
Improved market access	11 875 800	48 443 299	14 863 567	22 151 255	36 567 499	4.08
Improved land and livestock management & improved market access	97 580 470	405 309 148	31 760 606	89 375 942	307 728 679	4.15
With project relative to without project			**19 715 318**	**76 906 800**	**290 957 733**	

2.11. Cost-effectiveness and upscaling potential

This section discusses the cost-effectiveness of the investment in terms of leveraging and redirecting existing public spending to achieve socio-economic objectives and build resilience more effectively. The section also provides some discussion around the potential for replication and upscaling.

One of the project's intended goals is to leverage government investment in adaptation through the Ipelegeng Programme. Ipelegeng is Botswana's Public Works Programme, launched in 2008 and intended to reduce poverty and develop skills through the creation of meaningful employment under various initiatives. Botswana's currently spends US$65 million per annum on the Ipelegeng, which has been in place for the last three decades.

The programme has received mixed reviews and while it has served one of its intended purposes, in acting as a social safety net used by vulnerable communities, its success as a vehicle for socio-economic development has been called into question[91]. One of the recommendations proposed

[91] Nthomang, Keitseope, "Botswana' s Ipelegeng Programme Design and Implementation : Reduction or Perpetuation / Entrenchment of Poverty ?," Asian Journal of Social Science Studies 3, no. 3 (2018): 27–38, https://doi.org/10.20849/ajsss.v3i3.445; UNICEF, "FINAL REPORT FOR THE REVIEW OF IPELEGENG PROGRAMME," 2012; Jongman, Kgomotso, "Sustainable Livelihood and Poverty Eradication in Botswana" 7, no. 4 (2018): 1317–24; Seleka, TB, Lekobane, KR. Targeting Effectiveness of Social Transfer Programs in Botswana: Means-tested versus Categorical and Self-selected Instruments. Social development issues, 42(1): 12-30.

by reviewers of the programme is that the initiatives should be redesigned in a way that allows participants to gain experience and skills that will allow them to participate in the country's economy. It has also been noted that the programme has had especially limited success in rural areas.

Given high unemployment levels, government revenue projections, and the known high cost of emergency relief (as discussed in Section 2.3.3), the government is likely to sustain the programme in the project areas and replicate it in other communal area regions of the country as part of the ongoing investment in the institutional infrastructure for Ipelegeng that is already in place.

A partnership with Ipelegeng would result in the stimulation of economic development through skills development in the livestock production sector, which would be critical to improving the country's export competitiveness. This would reduce in positive socio-economic outcomes across the country in terms of an improved resilience of communities who are particularly vulnerable to climate change, and in contributing to the development of a key economic sector in which there exists considerable potential for increased value addition[92].

Replication of the Project model in other regions of the country will be possible through Botswana's standing budgetary priority to support job creation nationwide. The co-finance contribution to this project represents only 10% of the total programme budget per annum and if proven successful, could be scaled significantly for other regions of the country.

For replication in other nations, over the last 15 years, the number of African countries implementing major social protection programmes for poor and vulnerable people has tripled, with internal and external (primarily World Bank) financing[93]. This trend is likely to continue, particularly in response to COVID-19 economic slowdowns. Through GDSA, AFR100, and other forums, additional countries will be exposed to lessons from this Botswana project and be able to integrate the rangeland restoration model into their own efforts.

2.12. Conclusion

Botswana's traditional livestock sector is characterized by low financial returns, high levels of vulnerability and an institutionalized restriction of incentives that would otherwise allow for market correction. This analysis suggests that the successful implementation of proposed project components could provide the nature and degree of intervention required to remove existing barriers to a paradigm shift in the traditional livestock production sub-sector. This paradigm shift would entail a transition away from the current traditional livestock production model, which delivers sub-optimal outcomes in terms of livestock productivity as well as broader ecosystem services, towards a more sustainable model capable of generating improved returns and resilience under healthier ecosystems.

The financial cost benefit analysis presented here demonstrates that the project has the potential to improve revenue generation in the livestock production sector, with direct impacts on livestock producing households in the form of increased income and enhanced resilience to drought conditions, which are anticipated to intensify with climate change.

The financial cost benefit analysis further reveals that without the promotion of climate-sensitive enterprise development and value-chain investments to sustain transformational change, there

[92] Seleka and Kebakile, *Export Competitiveness of Botswana's Beef Industry*. BIDPA
[93] Cristilla, C. and R. Tebaldi, 2016. Social Protection in Africa: an Inventory of Non-contributory Programmes. www.ipc-undp.org

are insufficient incentives available for livestock producers to invest in rangeland and livestock health. The analysis suggests that under current conditions, investment in sustainable rangeland management is not viable for livestock producers in the traditional sector. This supports the need for intervention in the areas of institutions, capacity as well as in markets to adequately shift incentive structures facing livestock producing households. Adjusted incentives would be likely to catalyze investments in livestock and rangeland stewardship, leading to further adoption and upscaling.

The project would also benefit other stakeholders in the project areas. Increased livestock productivity would generate indirect economic activity for value-chain actors, commercial livestock producers, tourism operators and associated employees. Macroeconomic benefits such as import substitution and export diversification would also possible following implementation. Other co-benefits would result from the restoration of degraded rangelands, including enhanced delivery of ecosystem services. At a 10% discount rate, the present value of mitigation benefits associated with the project has been estimated at US$9.3 million over the 8-year project period, ramping up to US$24.9 million over 20 years.

Through redirecting government spending on public works, the project provides potential to provide a more efficient vehicle for investment of public funding, through a more targeted focus on critical skills development and economic growth. In terms of achieving mitigation objectives, successful implementation of the project would allow Botswana to meet just under half of its INDCs by 2030. Given that the co-finance component represents only 10% of Botswana's expanded public works programme, and considering the recent move to commit fiscal resources to public works programmes in other African countries, particularly in the wake of the economic fallout from COVID-19, this project demonstrates strong potential for replication and upscaling.

3. Appendix 1. Financial and economic internal rate of return for the project

A project's internal rate of return (IRR) reflects the discount rate at which the net present value (NPV) associated with the project, over the given timeframe, is equal to zero. In broad terms, the IRR can be said to provide a measure of the return on investment offered by a project. Projects with higher IRRs are therefore preferable to those with lower IRRs in cases where they are also characterised by a sufficiently high NPV, and satisfy other relevant project objectives, for instance related to budget constraints and cash positivity. Minimum IRR thresholds may also be used by investment institutions for as one of the criteria used in determining when an investment is viable.

The financial internal rate of return (FIRR) was estimated using the results generated by the financial cost-benefit analysis (CBA) presented in Section 2.6. The economic internal rate of return (EIRR) was estimated using the results of the economic CBA outlined in Section 2.10.

The FIRRs and EIRRs associated with the project scenarios are outlined in Table 3.2 for the 8-year project timeframe as well as for a 20-year timeframe. Those fields marked with an asterisk represent instances where the IRR was not able to be estimated. For projects with fluctuating annualised net benefits, research has shown that the IRR is a less reliable metric, with the potential to produce theoretically inconsistent or contradictory results[94]. In some cases, an IRR

[94]Magni, AM. 2011. Average Internal Rate of Return and investment decisions: a new perspective. The Engineering Economist, 55(2); Karpov, V. Shevchenko-Perepelkina, V. 2015, Analysis of fundamental contradictions of efficiency in the cash flow of projects. Socio-economic research bulletin, 2015: 4(59). Available: https://core.ac.uk/download/pdf/147040413.pdf

may be undefined. Given that the IRR represents the discount rate at which the present value of all future costs and benefits is equal to zero, two possible reasons for this include the following.

- Where there is no discount rate that would result in an NPV of zero (or where this discount rate is infinite)
- Where there are multiple discount rates that would result in an NPV of zero

For those instances where an IRR was returned, a cautious interpretation is hereby attempted in ascertaining that the benefits to livestock producing households under the project are exceptionally high (with a return of ~1409%), and the benefits to the economy are also high (~186% return over the 8-year period and ~187% over the 20-year periods). These results should be interpreted with caution, however, as it is not clear that the IRR is useful as a measure for analysis of projects characterised by uneven cash flows over time.

Table 3.1 Financial and economic internal rates of return for the scenarios considered

Timeframes and scenarios	Financial IRR	Economic IRR
8-year period		
Improved land and livestock management	164%	328%
Improved market access	#NUM!	#NUM!
Improved land and livestock management & improved market access	**1409%**	**186%**
20-year period		
Improved land and livestock management	164%	328%
Improved market access	#NUM!	#NUM!
Improved land and livestock management & improved market access	**1409%**	**187%**

The analysis presented here, estimating the internal rates of return associated with the financial and economic outcomes of the project, suggests that the project is likely to result in favorable outcomes, but reveals that caution should be used when interpreting the project's IRRs. Section 2.7 discusses the approach that will be used to measure the full impact of the project during implementation. This approach will provide a more detailed and robust assessment of project outcomes, allowing for adaptive management to be utilized, and generating valuable information which can be used to inform upscaling.

Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands

Annex 2 - Feasibility Study

Section 3: Carbon and Water Baseline Assessment

Prepared by Conservation International and C4 EcoSolutions through a Project Preparation Facility (PPF) Grant from the Green Climate Fund – March 2020

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1. EXECUTIVE SUMMARY

Climate change is negatively impacting the livelihoods of communal livestock farmers in Botswana. The resilience of the rangelands to droughts has declined, which impacts the productivity of the ecosystem and threatens the livelihoods of the people of Botswana. Inefficient livestock production leads to unprofitable operations, more vulnerable livelihoods and a greater methane emissions intensity of the livestock sector.

Degraded rangelands provide fewer ecosystem services than functional rangelands. Increases in the fractional bare ground cover amplify the rate soil erosion, which leads to a loss of soil nutrients, greater siltation of rivers and reservoirs, increased surface water runoff, reduced soil water infiltration, and reduced aquifer recharge. This results in greater water stress to humans and livestock. Increases in the rate of bush encroachment degradation reduce the availability of high-quality forage, resulting in the degradation of the remaining grazing lands and further exacerbating the cycle of degradation.

Restoring degraded rangelands, and avoiding further degradation, has multiple carbon and water benefits. Direct benefits include carbon sequestration from greater soil carbon storage and emissions reduction from avoided soil carbon losses. Indirect benefits include emissions reduction from livestock enteric fermentation, greater resilience of rangelands to drought and enhanced livelihoods of the traditional livestock sector.

The proposed Green Climate Fund (GCF) project will restore and conserve rangelands in three project areas of Botswana to enhance the resilience of communal livestock farmers and mitigate greenhouse gas emissions. The three project areas, Bobirwa, Ngamiland and Kgalagadi, and the project activities to be implemented to achieve these outcomes are described in the project Funding Proposal and Feasibility Study. The purpose of this assessment is to quantify the baseline carbon stocks, emissions sources, and water benefits of the proposed project.

The estimated greenhouse gas mitigation and drought resilience potentials presented in this assessment are not predictions of the expected project impacts. Conservative assumptions have explicitly been made to determine realistic targets relative to business-as-usual (BAU). In many cases, this includes a considerable under-estimate of the BAU scenario. For example, it is assumed that feed digestibility, livestock methane conversion and the livestock feeding situation will remain constant under BAU relative to the baseline. In reality, it is expected that each of these factors will contribute to greater enteric fermentation emissions intensity under BAU as a result of climate change impacts on rangeland degradation. In line with the assessment objectives, this assumption results in a more conservative emissions reduction and removal target but explicitly does not reflect the expected scenario under BAU based on the best available evidence.

Key baseline characteristics of the three project areas are summarised in Table 1, as determined by this assessment. The projected mitigation potential across multiple impact periods are presented in Figure 1 under three mitigation assumptions. The conservative mitigation potential defines the project target, which is summarised in Table 2 and Table 3. The annual mitigation target by 2030 estimated under this assessment (534,658 tCO_2e/yr) amounts to almost half of Botswana's Intended Nationally Determined Contribution target (1,246,050 tCO_2e/yr)[1]. Full details of the assumptions and methodologies are provided in Section 4. Enhanced resilience of communal livestock farmers to the effects of a single drought is expected to reduce livestock losses

[1] Government of Botswana, "Botswana Intended Nationally Determined Contribution (INDC)," 2015, http://www4.unfccc.int/ndcregistry/PublishedDocuments/Nigeria First/Approved Nigeria's INDC_271115.pdf.

by a third and increase the revenue for the most vulnerable households by an order of magnitude over a 20-year period.

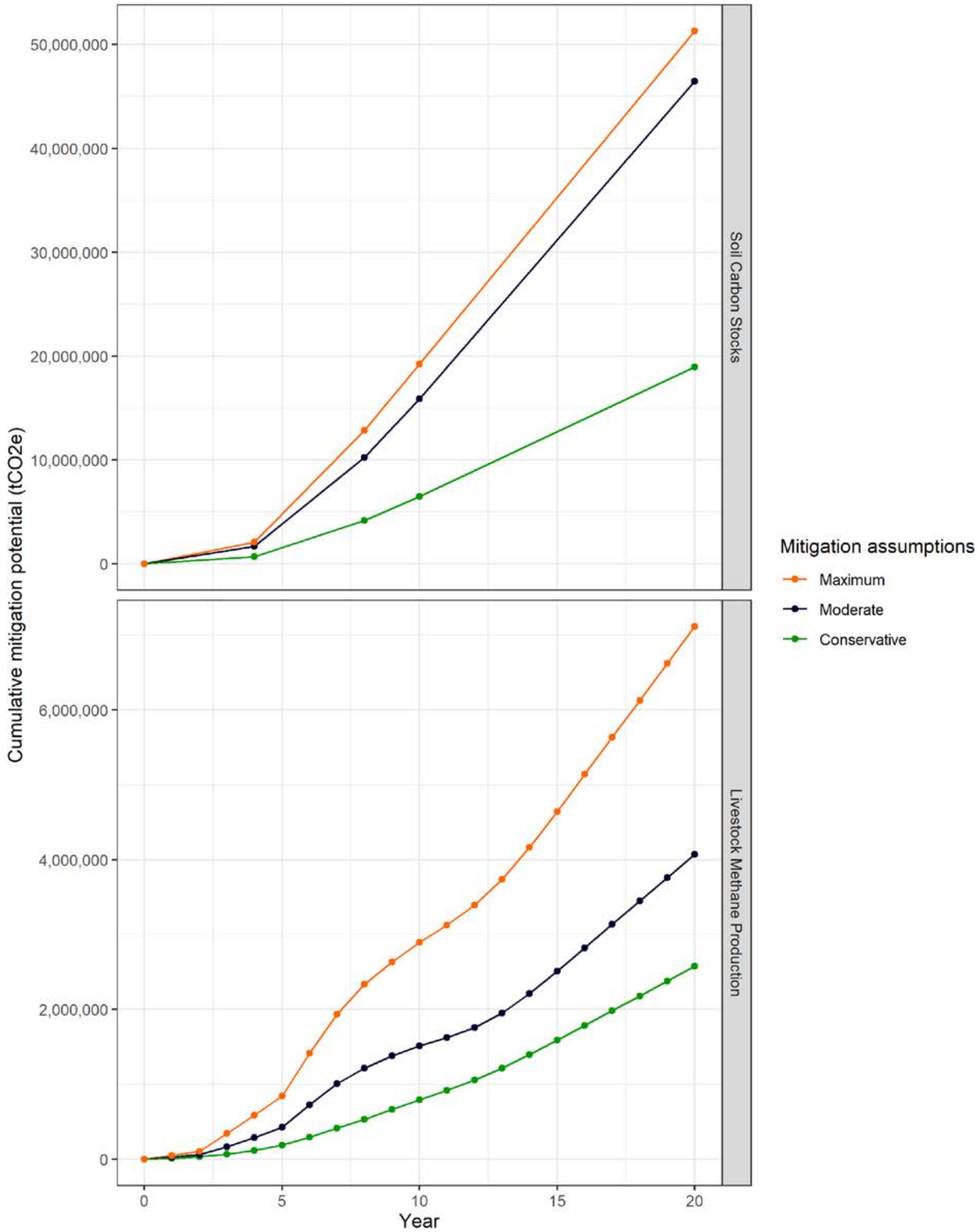

Figure 1. Cumulative mitigation potential (tCO2e) from the primary sources under three mitigation impact assumption scenarios.

Table 1. Baseline rangeland characteristics of Bobirwa, Ngamiland and Kgalagadi, as quantified in this assessment.

Variable	Unit	Bobirwa	Ngamiland	Kgalagadi
Area	ha	2,222,992	11,181,993	10,583,881
Woody cover	%	55.9	48.4	25.5
Bare ground[2]	%	43.3	57.6	89.3
Vegetative Carbon	tCO_2e/ha	309.0	267.5	140.9
Soil Carbon	tCO_2e/ha in 0-15 cm	4,044	4,470	2,143
Livestock density	head/1,000 ha	28.2	17.0	6.6
Livestock Emissions	tCO_2e/yr	130,648	385,364	143,161

Table 2. Conservative projected mitigation potential under multiple impact periods.

Impact period	Sites	Area (ha)	Livestock	Cumulative mitigation (tCO_2e)	Annual mitigation (tCO_2e/yr)
4-year	44	1,200,000	136,380	797,430	199,358
8-year	83	3,671,154	257,262	4,703,498	587,937
10-year	103	4,555,769	319,253	7,261,075	726,107
20-year	104	4,600,000	322,353	21,513,100	1,075,655

Table 3. Cumulative mitigation potential (tCO2e) under multiple impact periods across three project areas and two sources of mitigation.

Project Area	Source	4-year	8-year	10-year	20-year
Bobirwa	Enteric fermentation	16,744	77,114	114,570	371,758
	Soil carbon stocks	98,270	601,275	932,701	2,731,092
	Total	115,014	678,389	1,047,270	3,102,851
Ngamiland	Enteric fermentation	61,394	282,752	420,089	1,363,114
	Soil carbon stocks	360,324	2,204,675	3,419,902	10,014,006
	Total	421,718	2,487,427	3,839,992	11,377,120
Kgalagadi	Enteric fermentation	37,953	174,792	259,692	842,653
	Soil carbon stocks	222,746	1,362,890	2,114,121	6,190,476
	Total	260,698	1,537,682	2,373,813	7,033,129
Grand Total		**797,430**	**4,703,498**	**7,261,075**	**21,513,100**

[2] Bare ground and woody cover are estimated using separate models and therefore exceed 100% in some cases. It is likely that the bare ground estimation for Kgalagadi is overestimated, for example.

2. INTRODUCTION

The purpose of this baseline study on carbon and water is to estimate the current rangeland carbon stocks and emissions sources, and to characterize the water benefits in terms of resilience, quality, quantity and availability for Botswana, and particularly the three areas targeted for the Green Climate Fund (GCF) project, Bobirwa, Ngamiland and Kgalagadi. Details on the project activities, theory of change, and target area and site selection criteria are detailed in the project Funding Proposal and Feasibility Study. The carbon pools that are included in this assessment include vegetative (above- and below-ground biomass) and soil organic carbon. The mitigation sources considered include reduced livestock greenhouse gas production by enteric fermentation and increased soil carbon storage from ecosystem restoration. The water sources considered in this assessment include borehole water, as a proxy for groundwater, and the Okavango delta. Rangeland condition is also considered given how intricately it is linked with the carbon and water balances in Botswana, directly and indirectly.

Rangelands in Botswana are changing. The drivers of that change are varied, interacting and often complex. The communal rangelands are becoming increasingly degraded in the form of bare ground and bush encroachment degradation, as defined by the Government of Botswana[3]. Bush encroachment degradation includes the densification of woody plants in savannas (historically a mosaic of trees and grasses) as well as the invasion of woody plants into grasslands (historically free of trees or with scarce and isolated woody cover)[4]. Bare ground degradation includes the reduction or loss of biological or economic productivity following a reduction of vegetative cover and subsequent processes[5]. Rangeland degradation results in a loss of carbon stored in the ecosystem, most notably from the soil carbon pool, because of greater rates of soil erosion and reduced rates of soil carbon accumulation due to a reduction in vegetative productivity[6,7]. There are also various implications of rangeland degradation on water resources and the resilience of the rangelands to drought[8,9,10,11]. Increased rates of soil erosion and decreased soil carbon content reduces the soil water holding capacity, reduces the groundwater recharge rate, increases the rate of siltation, and reduces the quality of water resources above and below ground.

Degradation events, processes and states differ in their definition based on the context. For the purposes of this study, several key definitions are provided. Desertification is defined as a process of land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Land degradation is defined as a reduction or loss, in arid, semi-arid and dry sub-humid areas of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes

[3] Government of Botswana, "Botswana National Action Programme to Combat Desertification" (Gaborone, Botswana, 2006), www.envirobotswana.gov.bw.

[4] Tim G O'Connor, James R Puttick, and M Timm Hoffman, "Bush Encroachment in Southern Africa: Changes and Causes," *African Journal of Range and Forage Science* 32, no. 2 (2014): 67–88, https://doi.org/10.2989/10220119.2014.939996.

[5] Government of Botswana, "Botswana National Action Programme to Combat Desertification."

[6] C. J. Barrow, *Land Degradation: Development and Breakdown of Terrestrial Environments.* (Cambridge, UK: Cambridge University Press, 1991).

[7] A. Warren and C. Agnew, "An Assessment of Desertification and Land Degradation in Arid and Semi-Arid Areas," *International Institute for Environment and Development, Drylands Programme, Paper 2* (London, UK, 1988).

[8] A.J. Mills and R. de Wet, "Quantifying a Sponge: The Additional Water in Restored Thicket," *South African Journal of Science* 115, no. 5–6 (2019), https://doi.org/10.17159/sajs.2019/a0309.

[9] Bradford P. Wilcox and Thomas L. Thurow, "Emerging Issues in Rangeland Ecohydrology: Vegetation Change and the Water Cycle," *Rangeland Ecology and Management* 59, no. 2 (2006): 220–24, https://doi.org/10.2111/05-090R1.1.

[10] Bridget R. Scanlon et al., "Impact of Land Use and Land Cover Change on Groundwater Recharge and Quality in the Southwestern US," *Global Change Biology* 11, no. 10 (2005): 1577–93, https://doi.org/10.1111/j.1365-2486.2005.01026.x.

[11] Ammar Rafiei Emam et al., "Estimation of Groundwater Recharge and Its Relation to Land Degradation: Case Study of a Semi-Arid River Basin in Iran," *Environmental Earth Sciences* 74, no. 9 (November 1, 2015): 6791–6803, https://doi.org/10.1007/s12665-015-4674-2.

arising from human activities. Rangeland degradation is land degradation, as defined above, that occurs within rangelands. The Government of Botswana distinguishes between bare ground degradation, also referred to as soil degradation, which is land degradation that includes an increase in the fractional bare ground and loss of topsoil to erosion processes and bush encroachment degradation, which is land degradation that includes the densification of woody species.

Avoiding degradation, and restoring rangelands, has direct greenhouse gas mitigation benefits. The declining soil carbon stocks following degradation are lost as emissions into the atmosphere, in addition to the reduced rate of sequestration of atmospheric carbon in the soil carbon pool. In the context of Botswana, the reduced forage digestibility on degraded rangelands has implications for the emissions of the substantial livestock sector[12]. Poor forage digestibility from degraded rangelands results in increased methane emissions intensity through enteric fermentation by ruminants such as cattle, goats, and sheep. Avoiding the degradation of, and restoring, rangelands increases the abundance of palatable, digestible grass species, as well as grass cover[13]. Emission reduction benefits are therefore achieved by sequestering carbon into the soil, mitigating the further loss of soil carbon and avoiding livestock methane emissions, which have a heating effect 26 times greater than carbon dioxide over a 100-year period.

The factors that determine the incidence and severity of degradation include the biophysical, such as climate and soil, and the anthropogenic, such as management and land use. These biophysical and anthropogenic factors interact and contribute to determining the rangeland condition. Distinguishing between short-term variability of rangeland condition and long-term permanent changes can be challenging. Climatic variables, such as precipitation, have a disproportionate and often immediate effect on arid and semi-arid rangelands, such as in Botswana, compared with those in mesic conditions[14]. Greater aridity results in greater sensitivity of vegetation, livestock, and wildlife to water availability, which can often result in short-term, dramatic changes to the landscape between the wet and dry seasons or after extended drought periods[15]. These changes are worth distinguishing from the long-term, directional degradation trends because arid ecosystems have evolved to adapt to some degree of variability in precipitation and can make a full recovery from infrequent droughts. A case study of the 1980s drought in Botswana provides evidence of this; by some accounts, the extent of the rangeland categorised as being in very or extremely poor condition reduced from 40% in the height of the 1980s drought to only 3% by the mid-1990s[16]. Long-term, directional changes occur when thresholds of these variables that determine rangeland condition are crossed, resulting in an alternative stable state[17,18,19].

Bare ground and bush encroachment degradation have both been exacerbated by the impacts of climate change, including increased ambient temperatures, more frequent and intense droughts,

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[12] Andreas Wilkes et al., "Measurement, Reporting and Verification of Greenhouse Gas Emissions from Livestock: Current Practices and Opportunities for Improvement," 2017, https://cgspace.cgiar.org/handle/10568/80890.

[13] W. N. Mphinyane and N. F.G. Rethman, "Livestock Utilisation of Grass Species at Different Distances from Water on Both Traditional Cattle Post and Ranch Management Systems in Botswana," *African Journal of Range and Forage Science* 23, no. 2 (2006): 147–51, https://doi.org/10.2989/10220110609485897.

[14] Mahesh Sankaran, Jayashree Ratnam, and Niall P. Hanan, "Tree-Grass Coexistence in Savannas Revisited - Insights from an Examination of Assumptions and Mechanisms Invoked in Existing Models," *Ecology Letters* 6 (2004): 480–90, https://doi.org/10.1111/j.1461-0248.2004.00596.x.

[15] C. Vanderpost et al., "Satellite Based Long-Term Assessment of Rangeland Condition in Semi-Arid Areas: An Example from Botswana," *Journal of Arid Environments* 75, no. 4 (2011): 383–89, https://doi.org/10.1016/j.jaridenv.2010.11.002.

[16] Ibid.

[17] Lindsey Gillson, "Testing Non-Equilibrium Theories in Savannas: 1400 Years of Vegetation Change in Tsavo National Park, Kenya," *Ecological Complexity* 1, no. 4 (2004): 281–98, https://doi.org/10.1016/j.ecocom.2004.06.001.

[18] Steven I Higgins et al., "Fire, Resprouting and Variability: A Recipe for Grass-Tree Coexistence in Savanna," *Journal of Ecology* 88 (2000): 213–29.

[19] Glenn R Moncrieff et al., "Increasing Atmospheric CO2 Overrides the Historical Legacy of Multiple Stable Biome States in Africa," *New Phytologist* 201 (2013): 908–15.

shifts in the precipitation season and duration, and increased atmospheric CO_2 concentrations. The degradation of communal rangelands: i) reduces the available forage quality and quantity; ii) increases the methane production per livestock unit; iii) decreases the soil water holding capacity and infiltration; iv) increases surface water runoff, resulting in further soil erosion and evaporative water loss; v) decreases the groundwater quantity and quality; vi) reduces the total ecosystem carbon stock; vii) reduces the capacity of the ecosystem to support wildlife or livestock; and viii) results in further degradation. These impacts, feedbacks and their primary drivers are discussed in some more detail below.

3. DRIVERS OF RANGELAND DEGRADATION

3.1 Precipitation

Precipitation is one of the primary factors that determine the productivity and structure of rangelands, particularly in arid and semi-arid environments (<650 mm/yr)[20], such as those in Botswana. Maximum woody cover can reliably be predicted at a global or regional spatial scale based solely on the mean annual precipitation (MAP)[21]. The MAP for Botswana varies from ~650 mm/yr in the north to ~250 mm/yr in the south. There are many factors other than MAP that influence the woody cover of a specific site (between 0% and the maximum potential). The cover of woody plants relative to the herbaceous layer is ultimately determined by the relative competition between trees and grasses. The competitive balance between the two changes depending on the context but, in general, grasses can outcompete tree seedlings when soil moisture is reduced (in more arid conditions) by smothering seedlings and limiting their germination or recruitment to maturity. In more mesic conditions, however, trees can make better use of the increased soil moisture and higher water table than grasses can, which provides a competitive advantage to the establishment and encroachment of woody plants. The mean annual precipitation in Botswana has not significantly increased over the last 100 years[22]. Thus, changes to mean annual precipitation is unlikely to initiate the encroachment of woody plants.

In contrast to the total precipitation amount, the inter- and intra-annual variation in precipitation has a noticeable, direct impact on the cover of herbaceous and woody cover[23]. Botswana has a highly seasonal precipitation regime with wet summers (October to April) and dry winters (May to September). The country has also experienced regular inter-annual droughts in the last few decades, with abnormally low precipitation in one or more years of each decade since at least the 1960s and a notable multi-year drought occurring between 1982 and 1987[24]. This variability is correlated to variability in soil moisture and consequently the competitiveness between grasses and trees[25]. The temporal nature of this variation results in complex interactions with disturbance

[20] Mahesh Sankaran et al., “Determinants of Woody Cover in African Savannas,” *Nature* 438, no. 7069 (2005): 846–49, https://doi.org/10.1038/nature04070.

[21] O’Connor, Puttick, and Hoffman, “Bush Encroachment in Southern Africa: Changes and Causes”; Sankaran et al., “Determinants of Woody Cover in African Savannas.”

[22] See Feasibility Assessment, Section 1: Climate Vulnerability Assessment Report

[23] Todd M P Robinson et al., “Seasonal, Not Annual Precipitation Drives Community Productivity across Ecosystems,” *Oikos* 122 (2013): 727–38, https://doi.org/10.1111/j.1600-0706.2012.20655.x.

[24] Government of Botswana, “Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) Ministry of Environment, Wildlife and Tourism” (Gaborone, Botswana, 2011), https://unfccc.int/resource/docs/natc/bwanc2.pdf.

[25] Kailiang Yu, Michael Vijay Saha, and Paolo D Odorico, “The Effects of Interannual Rainfall Variability on Tree–Grass Composition along Kalahari Rainfall Gradient,” *Ecosystems* 20, no. 5 (2017): 975–88, https://doi.org/10.1007/s10021-016-0086-8.

(such as fire and herbivory). The time of year that a site is rested from grazing could, for example, result in a virtuous cycle of improved forage quality and quantity, increased nutrient inputs from herbivores, increased competitiveness of grasses compared with trees and the containment of bush encroachment; or it could result in a vicious cycle of decreasing grass basal cover, increased bare ground exposure, increased erosion, increased loss of topsoils and their nutrients, leading to further degradation. Arid and semi-arid rangelands are more susceptible to the effects of variation in precipitation than are mesic rangelands, which makes them additionally sensitive to the interaction between precipitation and land management practices. Satellite-based observations in Botswana[26] have shown that greater inter-annual variability in precipitation favours trees over grasses. This leads to bush encroachment degradation and reduced forage production, which is expected to increase with projected increases in precipitation variability[27].

3.2 Atmospheric CO_2 concentration

The global densification and invasion of woody species across multiple biomes, continents, land-use histories and practices have largely been attributed to the observed increase in atmospheric CO_2 concentration[28,29]. Theoretical and experimental data have provided evidence for the predominance of increasing atmospheric CO_2 concentration as a causal factor in the accelerating rate of bush encroachment[30]. The mechanisms by which atmospheric CO_2 concentration affect the relative competition of trees and grasses are well understood[31,32,33], but the encroachment of woody plants in Southern Africa (first detected as early as the 1860s[34,35]) also predates the considerable increase in atmospheric CO_2 concentration that has occurred as a result of anthropogenic greenhouse gas emissions, thus it is likely that CO_2, alone, does not account for all observed bush encroachment degradation[36,37,38].

Increased atmospheric CO_2 concentrations impact vegetation structure and rangeland condition by altering the effectiveness of plant biochemical strategies. The composition of Southern African rangelands is mostly C_3 and C_4 plants. The distinction between these plants is based on their photosynthetic pathways; as the atmospheric O_2:CO_2 ratio increased, billions of years ago, the risk of photorespiration also increased. C_4 plants, consequently, evolved an additional step to their C_3

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26 Ibid.

27 See Section 1: Climate Vulnerability Assessment Report

28 Barney S. Kgope, William John Bond, and Guy F. Midgley, "Growth Responses of African Savanna Trees Implicate Atmospheric [CO2] as a Driver of Past and Current Changes in Savanna Tree Cover," *Austral Ecology* 35, no. 4 (2010): 451–63, https://doi.org/10.1111/j.1442-9993.2009.02046.x.

29 Moncrieff et al., "Increasing Atmospheric CO2 Overrides the Historical Legacy of Multiple Stable Biome States in Africa."

30 Aisling P. Devine et al., "Determinants of Woody Encroachment and Cover in African Savannas," *Oecologia* 183, no. 4 (2017): 939–51, https://doi.org/10.1007/s00442-017-3807-6; Steven I. Higgins and Simon Scheiter, "Atmospheric CO2 Forces Abrupt Vegetation Shifts Locally, but Not Globally," *Nature* 488, no. 7410 (2012): 209–12, https://doi.org/10.1038/nature11238; Kgope, Bond, and Midgley, "Growth Responses of African Savanna Trees Implicate Atmospheric [CO2] as a Driver of Past and Current Changes in Savanna Tree Cover."

31 Ruth M. Doherty et al., "Implications of Future Climate and Atmospheric CO2 Content for Regional Biogeochemistry, Biogeography and Ecosystem Services across East Africa," *Global Change Biology* 16, no. 2 (2010): 617–40, https://doi.org/10.1111/j.1365-2486.2009.01997.x.

32 Wolfgang Cramer et al., "Global Response of Terrestrial Ecosystem Structure and Function to CO2 and Climate Change: Results from Six Dynamic Global Vegetation Models," *Global Change Biology* 7, no. 4 (2001): 357–73, https://doi.org/10.1046/j.1365-2486.2001.00383.x.

33 James R. Ehleringer, Thure E. Cerling, and Brent R. Helliker, "C4 Photosynthesis, Atmospheric CO2, and Climate," *Oecologia* 112, no. 3 (1997): 285–99, https://doi.org/10.1007/s004420050311.

34 Nancy Jacobs, "Grasslands and Thickets: Bush Encroachment and Herding in the Kalahari Thornveld," *Environment and History* 6, no. 3 (2000): 289–316, http://www.jstor.org/stable/20723144.

35 O'Connor, Puttick, and Hoffman, "Bush Encroachment in Southern Africa: Changes and Causes."

36 O W van Auken, "Causes and Consequences of Woody Plant Encroachment into Western North American Grasslands," *Journal of Environmental Management* 90, no. 10 (2009): 2931–42, https://doi.org/10.1016/j.jenvman.2009.04.023.

37 D A Balfour and J J Midgley, "A Demographic Perspective on Bush Encroachment by Acacia Karroo in Hluhluwe-Imfolozi Park, South Africa," *African Journal of Range and Forage Science* 25, no. 3 (2008): 147–51, https://doi.org/10.2989/AJRF.2008.25.3.7.604.

38 S.R. Archer, DS Schimel, and EA Holland, "Mechanisms of Shrubland Expansion: Land Use, Climate or CO2?," *Climatic Change* 29 (1995): 91–99.

pathway that concentrates the assimilation of CO_2, rather than O_2. The C_4 photosynthetic pathway increases the energy requirements per unit of carbohydrate produced from photosynthesis, but the efficiency of reduced photorespiration has historically been greater than the additional cost. The competitive advantage of C_4 compared with C_3 plants has, however, been declining with increasing temperatures and with increasing atmospheric CO_2 concentrations[39].

As the relative abundance of C_4 grasses declines and C_3 trees and grasses increase, the grazing potential of the rangelands in Botswana decreases. Most, if not all, trees in Botswana adopt C_3 pathways, but grasses employ that of either C_3 or C_4[40]. The differences between C_3 or C_4 grasses are readily apparent in their physiology and morphology[41]. C_4 grasses are generally more palatable and digestible forage species with greater nutritional value than C_3 plants[42,43,44,45], which has implications for livestock productivity, carrying capacity, fodder reserves and post-grazing recovery of rangelands[46]. If this decline is not accompanied by a reduction in the number of livestock per hectare or a shift in management practice, then widespread overgrazing will result (see Grazing Management below).

Trees further outcompete grasses under elevated atmospheric CO_2 concentrations because they are able to make better use of the available atmospheric carbon[47,48]. Tree seedlings can enhance their water use efficiency more readily than grasses can by reducing their stomatal aperture and density under elevated CO_2 conditions, because of differences in their leaf structure. This allows trees to capture more CO_2 per molecule of water lost through transpiration, improving their resilience to drought and limited water availability and promoting greater seedling survivorship[49]. This strategy also allows for greater leaf retention by trees into the dry winter months, further augmenting their growth rate[50]. In addition, the abundance of CO_2 allows trees to allocate more resources to browser defence strategies — such as increased tannin production — and to the growth of woody structures, including deep tap root systems, which can further enhance the water resilience of trees relative to grasses.

3.3 Temperature

[39] David Ward, "A Resource Ratio Model of the Effects of Changes in CO2 on Woody Plant Invasion," *Plant Ecology* 209, no. 1 (2010): 147–52, https://doi.org/10.1007/s11258-010-9731-z.

[40] Rowan F. Sage, "A Portrait of the C4 Photosynthetic Family on the 50th Anniversary of Its Discovery: Species Number, Evolutionary Lineages, and Hall of Fame," *Journal of Experimental Botany* 68, no. 2 (2017): e11–28, https://doi.org/10.1093/jxb/erx005.

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[43] G M Lodge and R D B Whalley, "Seasonal Variations in the Herbage Mass, Crude Protein and in-Vitro Digestibility of Native Perennial Grasses on the North-West Slopes of New South Wales.," *The Rangeland Journal* 5, no. 1 (1983): 20–27, https://doi.org/10.1071/RJ9830020.

[44] Raymond V. Barbehenn et al., "C3 Grasses Have Higher Nutritional Quality than C4 Grasses under Ambient and Elevated Atmospheric CO2," *Global Change Biology* 10, no. 9 (2004): 1565–75, https://doi.org/10.1111/j.1365-2486.2004.00833.x.

[45] G. R. McPherson, "Seasonal Herbivory Effects on Herbaceous Plant Communities of the Edwards Plateau," *Texas Journal of Science* 36 (1989): 59–70.

[46] E. A. Mikhailova et al., "Botanical Composition, Soil and Forage Quality under Different Management Regimes in Russian Grasslands," *Agriculture, Ecosystems and Environment* 80, no. 3 (2000): 213–26, https://doi.org/10.1016/S0167-8809(00)00148-1.

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[48] Doherty et al., "Implications of Future Climate and Atmospheric CO2 Content for Regional Biogeochemistry, Biogeography and Ecosystem Services across East Africa."

[49] Jon Lloyd and Graham D. Farquhar, "Effects of Rising Temperatures and [CO2] on the Physiology of Tropical Forest Trees," *Philosophical Transactions of the Royal Society B: Biological Sciences* 363, no. 1498 (2008): 1811–17, https://doi.org/10.1098/rstb.2007.0032.

[50] R J Scholes and S R Archer, "Tree-Grass Interactions in Savannas," *Annual Review of Ecology and Systematics* 28 (1997): 517–44.

The effect of temperature on rangelands can be direct and indirect. The establishment and proliferation of trees are, in part, dependent on temperature. Certain species of Southern African trees are limited by the number of frost days per year that seedlings can endure[51]. Likewise, the growth rate of trees is generally slower under cooler temperatures, which reduces the likelihood of seedling recruitment[52]. As the number of frost days in Botswana, which typically occurred between June and August[53], declines because of global heating[54], the limitation imposed on these species is alleviated. This enables the proliferation, densification, and encroachment of trees. Conversely, increasing temperature has the potential to provide some alleviation to the grass layer from high grazing pressures. Cattle can experience a degree of heat stress when temperatures exceed 32°C, especially those breeds that are not adapted to the Southern African climate. Under these conditions, critical functions and behaviours of cattle slow down or cease, including grazing[55]. This can be further exacerbated by the effect of increased exposure to parasites and diseases, especially vector-borne diseases, which may limit productivity[56].

The livestock density in Botswana has not been decreasing at the rate that rangeland degradation is occurring. Reduced grazing exertion that is occurring as a result of climate change (increasing frequency of days where temperatures exceed 32°C) results in further concentration of grazing activity on degraded lands near to water access points. As the number of water access points has increased, this concentration of grazing pressure has further intensified across a greater total area of the rangelands. In addition to the degradation cycles described above and the resulting loss of ecosystem carbon stocks, the reduced forage quality and digestibility leads to greater livestock methane emission intensity from enteric fermentation compared with livestock that are able to graze on more digestible, high-quality forage[57].

3.4 Soil properties

Vegetation structure is often dependent on several soil properties, including texture, depth, and nutrient concentrations. These properties can directly enable or inhibit the encroachment of woody plants because grasses and trees have differing physiological strategies and, therefore, soil nutrient requirements[58].

The effect of soils on the competition between trees and grasses is complex[59]. There are numerous, interacting effects of different soil properties that can enable or inhibit the resilience of

[51] Julia L Wakeling, Michael D Cramer, and William J Bond, "The Savanna-Grassland 'Treeline': Why Don't Savanna Trees Occur in Upland Grasslands?," *Journal of Ecology* 100 (2012): 381–91, https://doi.org/10.1111/j.1365-2745.2011.01921.x.

[52] Ibid.

[53] J Andringa, "The Climate of Botswana in Histograms," *Botswana Notes and Records* 16 (1984): 117–25, http://journals.co.za/docserver/fulltext/botnotes/16/1/748.pdf?expires=1512601715&id=id&accname=guest&checksum=C606DC53AD270E341F433DF0D3E11203.

[54] Government of Botswana, "Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) Ministry of Environment, Wildlife and Tourism."

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[57] Wilkes et al., "Measurement, Reporting and Verification of Greenhouse Gas Emissions from Livestock: Current Practices and Opportunities for Improvement."

[58] Anthony J. Mills et al., "Effects of Anabolic and Catabolic Nutrients on Woody Plant Encroachment after Long-Term Experimental Fertilization in a South African Savanna," *PLoS ONE* 12, no. 6 (2017): 1–24.

[59] W.S. Harpole et al., "Nutrient Co-Limitation of Primary Producer Communities," *Ecology Letters* 14 (2011): 852–62, https://doi.org/10.1111/j.1461-0248.2011.01651.x.

rangelands to degradation[60]. The ability of encroaching tree species to outcompete grasses, for example, is determined, in part, by soil nutrient concentrations and texture[61,62].

Soil texture can determine how resilient a landscape is to erosion and bare ground degradation. Sandy soils, such as those that characterize the majority of Botswana, are often more sensitive to the effects of bare ground degradation as erosion of the shallow topsoil exposes a subsoil horizon that is often unsuitable to the production of palatable fodder, leading to bush encroachment[63].

3.5 Fire

Rangeland vegetation in sub-Saharan and Southern Africa is adapted to disturbance and defoliation, specifically by fire[64,65]. The present distribution and structure of these rangelands cannot be explained without the consideration of fire, particularly in relation to competition between trees and grasses[66]. There is evidence from the paleoecological record for the incidence of fire in Southern Africa dating back thousands of years[67]. In arid and semi-arid rangelands, such as in Botswana, the fire frequency and intensity are reduced relative to more mesic rangelands, which can support the accumulation of a sufficient grass fuel load[68]. Although infrequent, the role of fire has been critical to the maintenance of open savannas and optimal grazing potential in arid and semi-arid rangelands[69]. If poorly managed, however, fire suppression can lead to the deterioration of forage quality and a reduced rate of forage production. This can result in runaway fires that often cause considerable damage to large, desirable tree species as well as erosion, negative impacts on human settlements and loss of life[70].

The importance of well-managed fire to the maintenance of functioning rangelands was a novel concept to the colonial settlers of Southern Africa. As a result, the indigenous practice of grasslands burning was considered a negative activity and fire suppression was the common practice until the early- to mid-1900s in Botswana[71]. The removal of prescribed fire from rangeland

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[60] Anthony J. Mills et al., "Constraint on Woody Cover in Relation to Nutrient Content of Soils in Western Southern Africa," *Oikos* 122, no. 1 (2013): 136–48, https://doi.org/10.1111/j.1600-0706.2012.20417.x.

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[68] N.M. Tainton, *Veld Management in South Africa* (Pietermaritzburg: University of Natal Press, 1999).

[69] Winston Trollope et al., "The Long-Term Effect of Fire and Grazing by Wildlife on Range Condition in Moist and Arid Savannas in the Kruger National Park" 0119, no. March 2016 (2014), https://doi.org/10.2989/10220119.2014.884511.

[70] Navashni Govender, Winston S W Trollope, and Brian W Van Wilgen, "The Effect of Fire Season, Fire Frequency, Rainfall and Management of Fire Intensity in Savanna Vegetation in South Africa," *Journal of Applied Ecology* 43 (2006): 748–58, https://doi.org/10.1111/j.1365-2664.2006.01184.x.

[71] O'Connor, Puttick, and Hoffman, "Bush Encroachment in Southern Africa: Changes and Causes."

ecosystem interactions generally results in the proliferation of woody plants and damaging wildfires. In a burning experiment in semi-arid Namibian savanna, a single burn resulted in the mortality of 99% of seedlings compared with the average mortality of 34% in the unburnt control plots[72]. Conversely, the application of frequent burning can also result in an increase in woody plants if the grass fuel load is not allowed to accumulate to approximately 4 t/ha, below which it is ineffective in inhibiting the growth and establishment of woody plants[73,74]. The optimal season and frequency of rangeland burning are determined in part by the rainfall regime, soil type, slope and the intensity of other forms of disturbance such as herbivory[75,76,77].

3.6 Herbivore management

Large herbivores provide a form of disturbance and defoliation that rangeland ecosystems in Southern Africa have adapted to over millennia[78]. Perennial grasses are well adapted to disturbance from grazing; following defoliation, reserve nutrients stored in the roots and basal parts are utilised for recovery. This results in some die back of the below-ground biomass, proportional to the amount of regrowth and recovery required. Once sufficient above-ground material has accumulated to photosynthesise again, energy is produced and the root system recovers, expanding and replenishing reserve nutrients[79]. This offers an explanation for the greater productivity and carbon sequestration potential of rangelands that experience appropriate disturbance compared with those in which disturbance is excluded[80,81]. The mismanagement of grazers can, however, lead to widespread degradation, as is the case for fire[82,83]. Mismanagement commonly includes species- or area-selective overgrazing.

Area-selective overgrazing commonly occurs when the grazing lands are not allowed sufficient rest periods to recover from disturbance. The amount of rest required will vary depending on the climate, season, soil, topography, baseline grass species composition and vegetation structure, severity of disturbance, and the grazing strategy of the herbivores. This form of overgrazing leads to: i) the abundance of pioneer and annual grass species that have little forage value; ii) the reduction of grass basal cover; iii) destabilisation of the topsoil; iv) increased erosion; v) the loss

[72] D. F. Joubert, G. N. Smit, and M. T. Hoffman, "The Role of Fire in Preventing Transitions from a Grass Dominated State to a Bush Thickened State in Arid Savannas," *Journal of Arid Environments* 87 (2012): 1–7, https://doi.org/10.1016/j.jaridenv.2012.06.012; O'Connor, Puttick, and Hoffman, "Bush Encroachment in Southern Africa: Changes and Causes."

[73] Govender, Trollope, and Van Wilgen, "The Effect of Fire Season, Fire Frequency, Rainfall and Management of Fire Intensity in Savanna Vegetation in South Africa."

[74] Van Oudtshoorn, *Veld Management: Principles and Practices*.

[75] Dirk Lohmann et al., "Prescribed Fire as a Tool for Managing Shrub Encroachment in Semi-Arid Savanna Rangelands," *Journal of Arid Environments* 107 (2014): 49–56, https://doi.org/10.1016/j.jaridenv.2014.04.003.

[76] Van Oudtshoorn, *Veld Management: Principles and Practices*.

[77] C D Morris, N M Tainton, and M B Hardy, "Plant Species Dynamics in the Southern Tall Grassveld under Grazing, Resting and Fire," *Journal of the Grassland Society of Southern Africa* 9, no. 2 (1992): 90–95, https://doi.org/10.1080/02566702.1992.9648305.

[78] Gareth P. Hempson et al., "Ecology of Grazing Lawns in Africa," *Biological Reviews* 90, no. 3 (2015): 979–94, https://doi.org/10.1111/brv.12145.

[79] Van Oudtshoorn, *Veld Management: Principles and Practices*.

[80] Maria U. Johansson and Anders Granström, "Fuel, Fire and Cattle in African Highlands: Traditional Management Maintains a Mosaic Heathland Landscape," *Journal of Applied Ecology* 51, no. 5 (2014): 1396–1405, https://doi.org/10.1111/1365-2664.12291.

[81] Sally E. Koerner et al., "Plant Community Response to Loss of Large Herbivores Differs between North American and South African Savanna Grasslands.," *Ecology* 95, no. 4 (2014): 808–16, https://doi.org/10.1890/13-1828.1.

[82] Kerstin Wiegand, David Ward, and David Saltz, "Multi-Scale Patterns and Bush Encroachment in an Arid Savanna with a Shallow Soil Layer," *Journal of Vegetation Science* 16 (2005): 311–20.

[83] Kerstin Wiegand, David Saltz, and David Ward, "A Patch-Dynamics Approach to Savanna Dynamics and Woody Plant Encroachment - Insights from an Arid Savanna," *Perspectives in Plant Ecology, Evolution and Systematics* 7, no. 4 (2006): 229–42, https://doi.org/10.1016/j.ppees.2005.10.001.

of nutrients and important microbial and fungal diversity in the topsoil; and vi) further bare ground degradation. Bush encroachment can accompany bare ground degradation from overgrazing as the herbaceous layer is unable to outcompete tree seedlings for resources[84]. Area-specific under-grazing is less common in arid rangelands than in semi-arid and mesic rangelands but can lead to similar outcomes as overgrazing. If the herbaceous layer is allowed to reach a climax state, the palatable grass species can be replaced by fibrous, undesirable species or else become moribund, shade out competing grasses, reduce the basal cover and lead to the same cycle of degradation as described for overgrazing[85,86,87,88].

Species-selective overgrazing occurs when herbivores preferentially and consistently graze the palatable species while avoiding those that are less palatable. This is often independent of herbivore density and commonly occurs in the absence of active livestock management or when migratory patterns, and therefore periods of rest, are disrupted[89]. This form of overgrazing leads to: i) the reduced competitiveness of nutritious, sub-climax grass species; ii) the greater abundance of unpalatable, pioneer and climax grass species and other unpalatable plants; iii) a reduction in carrying capacity; iv) the reduction of grass basal cover; v) destabilisation of the topsoil; vi) increased erosion; vii) the loss of nutrients and important microbial and fungal diversity in the topsoil; and vii) further bare ground and bush encroachment degradation. Importantly, species-selective overgrazing can occur regardless of whether the herbivore density is below the rangeland carrying capacity[90]. Historically, this form of overgrazing was likely infrequent, despite lower herbivore numbers, due to wild grazers forming mobile aggregations to avoid predation and migrating long distances between and within the seasons[91], which allows for sufficient rest and recovery from disturbance. Where overgrazing may have occurred, the reduced forage value of overgrazed areas would have resulted in reduced grazing intensity and subsequent disturbance, thereby limiting the negative degradation cycles that are presently observed.

4. BASELINE CARBON ASSESSMENT

4.1 Vegetative carbon pool

Botswana is characterised predominantly by shrub savanna and grasslands (Figure 2). Detailed national vegetation classification has most recently been conducted and reported by Bekker and De Wit[92]. The south-west of the country, including Kgalagadi, is classified as a sandveld region characterized by *Senegalia* (formerly *Acacia*) *mellifera, Vachellia (*formerly *Acacia*) *luederitzii and Boscia albitrunca* woody species. Frequent pans are evident in the northern and central regions of Kgalagadi, fringed by dense savanna shrublands. South of the shrublands, grasslands and bare ground is common with various *Sporobulus spp*., *Panicum spp*. and *Eragrostis spp*. of grass dominating. Bobirwa and the east of the country is classified as a hardveld region with vegetation ranging from shrub savanna to tree savanna, typically with taller and denser vegetation than the sandveld. The soils characteristic of the hardveld have a greater proportion of clay and nutrient

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[84] Edmund C February and Joel R Lewis, "Tree Seedling Establishment among C4 Grasses," *PeerJ* 4 (2016), https://doi.org/10.7287/peerj.preprints.2080v1.

[85] Brian H Walker et al., "Stability of Semi-Arid Savanna Grazing Systems," *Journal of Ecology* 69, no. 2 (1981): 473–98.

[86] Gillson, "Testing Non-Equilibrium Theories in Savannas: 1400 Years of Vegetation Change in Tsavo National Park, Kenya."

[87] Van Oudtshoorn, *Veld Management: Principles and Practices*.

[88] G C Stuart-Hill, "The Response of Forage Plants to Defoliation: Trees and Shrubs," in *Veld Management in South Africa*, ed. Neil M Tainton (Pietermaritzburg: University of Natal Press, 1999), 109–16.

[89] Van Oudtshoorn, *Veld Management: Principles and Practices*.

[90] Ibid.

[91] GL Smuts, "Interrelations between Predators, Prey, and Their Environment," *BioScience* 28, no. 5 (1978): 316–20.

[92] Bekker, R. P., & De Wit, P. V. "Contribution to the vegetation classification of Botswana." (1991)

content than the sandveld region. The tree species common in this region include *Peltophorum africanum*, *Vachellia tortillis* and *Terminalia sericea*. The north-west of the country around the Okavango Delta, including Ngamiland, has numerous distinct vegetation associations. West of the Delta, between Lake Ngami and the Caprivi Strip, sandy soils derived from the dune system dominate with dense shrub savannas of *Terminalia sericea*, *Loncocarpus nelsii* and *Vachellia erioloba* woody species. The shores of Lake Ngami, however, consist of a forbland of *Sesbania spp.* and *Asclepias fruiticosa*. Along the Okavango Delta and the Panhandle, north of Lake Ngami, a 5–15 km wide zone of *Colophospermum mopane* extends. East of the mopane-line, the fossil delta floodplain is typically associated with *Combretum imberbe* and *Vachellia erioloba* species. The Okavango River (Panhandle zone) and Delta, are characterised by a mosaic of permanent swamps (with hydrophytic grasses, sedges and aquatic species), fossil alluvium (savannas), and floodplains (mostly grasslands). North-east of the delta, three broad systems can be distinguished, a clay-rich central depression, a sandy terrace in the east and a beach ridge in the west. The center is covered by a shrub savanna of *Vachellia tortillis* surrounded by shrublands and woodlands with *Colophospermum mopane, Vachellia erioloba, Senegalia nigrescens* and *Lonchocarpus capassa.* The eastern terrace is associated with a dense shrub savanna of *Colophospermum mopane* and *Combretum spp*. and the western beach ridge is covered by a sandveld savanna with *Terminalia sericea, Loncocarpus nelsii* and *Vachellia erioloba* dominating.

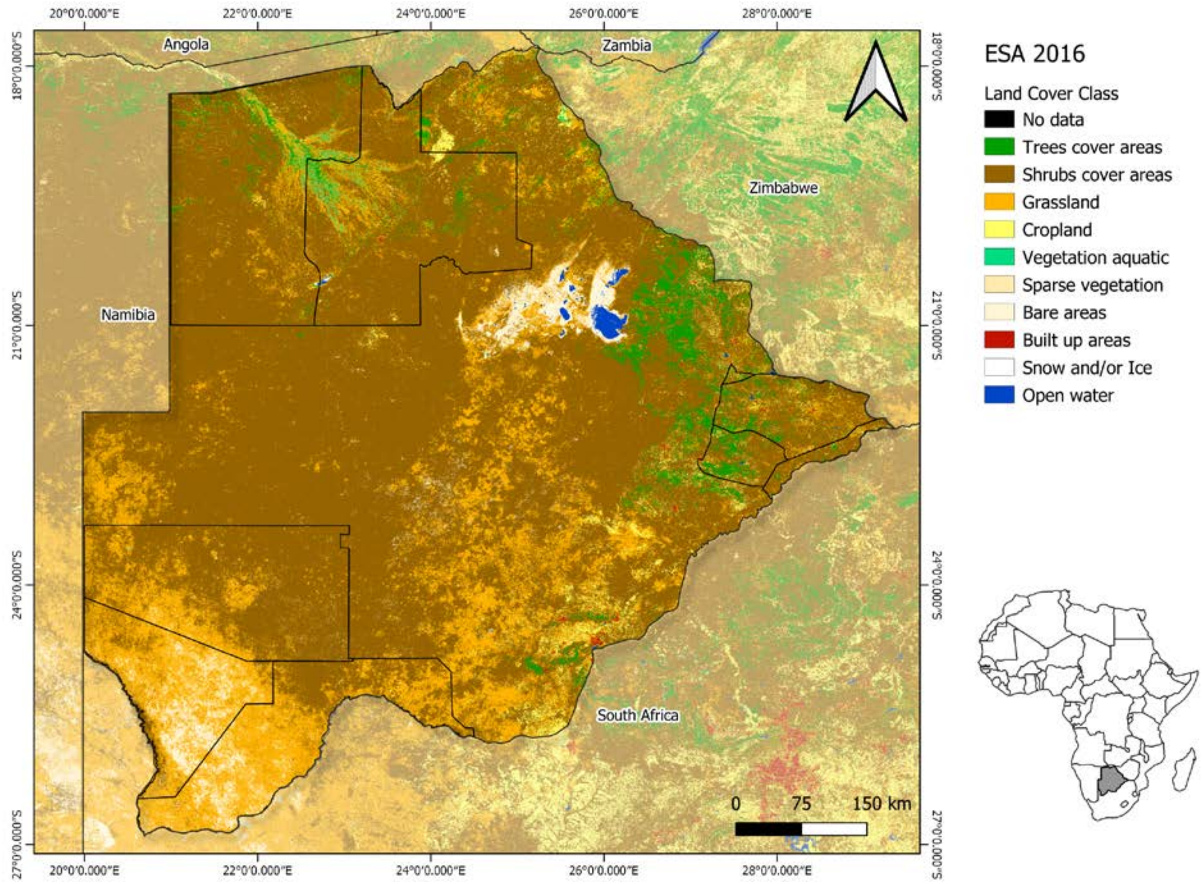

Figure 2. Land cover classes based on the European Space Agency (ESA) 2016 classification for Africa.

The above- and below-ground biomass carbon pools for Botswana were estimated using a combination of field surveys, remote sensing, and machine learning tools[93,94] after-which they were validated based on the national carbon inventories as reported in the country's Third National Communication and Biennial Update Report to the UNFCCC. In the rangelands of Botswana, the components of the vegetative carbon pool include stems, branches, leaves, litter and root biomass of trees, shrubs and grass.

The approach to estimating the vegetative carbon for Botswana is, in part, based on the method described by the South African National Terrestrial Carbon Sinks Assessment (NTCSA)[95,] particularly as described for the grassland and savanna biomes. The per hectare woody (tree and shrub) vegetative carbon was calculated for arid, semi-arid and mesic savannas in South Africa (Table 1), excluding that of leaves and roots[96]. The total annual biomass production, as calculated by FAO[97], was used to validate the vegetative carbon estimate and to determine variability of this estimate. The total biomass production expresses the total amount of dry matter produced over the year. It is calculated in approximately 10-day increments at 250 m resolution and summarised as an annual total. This allows for an estimate of the total gross biomass production rather than the net change in biomass following defoliation.

In order to account for leaf and root biomass, the NTCSA proposes a 35% expansion factor be applied to the aboveground biomass carbon estimate, which can be considered conservative as root biomass alone can often account for more than half the total biomass pool[98,99].

Aboveground grass biomass is not accumulated and maintained as a permanent carbon pool, given the defoliation that occurs by fire and herbivory. Fluctuation in phytomass occurs seasonally with the majority of growth occurring in the wetter summer months. Continuous grazing and high stocking, particularly of cattle, under the baseline scenario in combination with the extended dry season results in the loss of almost all the available aboveground phytomass by the end of winter. Under well-managed grazing systems, some inter-annual accumulation of grass biomass should occur with burning often prescribed once it exceeds 4 tDW/ha. For perennial grass species, the root:shoot ratio is approximately 2:1, on average[100]. Despite aboveground defoliation occurring, the below ground carbon stocks therefore accumulate with each successive growth season. Field work across the three project areas conducted in July 2019 (mid-winter) demonstrated that the available aboveground grass biomass was almost entirely below the minimum threshold for a disc pasture meter to quantify (<1 tDW/ha). Land that was protected from grazing for parts of the year in Bobirwa and Ngamiland had 1.48–2.13 tDW/ha of phytomass, but where rare. There were some remote areas in Ngamiland and northern Kgalagadi, more than 10 km from the nearest village or cattle post, that had phytomass up to 3.75 tDW/ha. Conservatively, it can be assumed that the average baseline phytomass in Bobirwa and Ngamiland is approximately 1.5 tDW/ha and in

93 Tomislav Hengl and Robert A. Macmillan, *Predictive Soil Mapping with R* (Wageningen, Netherlands: OpenGeoHub foundation, 2019), https://soilmapper.org/.

94 Z. S. Venter, M. D. Cramer, and H. J. Hawkins, "Drivers of Woody Plant Encroachment over Africa," *Nature Communications* 9, no. 1 (2018): 1–7, https://doi.org/10.1038/s41467-018-04616-8.

95 Department of Environmental Affairs, "National Terrestrial Carbon Sinks Assessment" (Pretoria, South Africa, 2015).

96 C. M. Shackleton and R. J. Scholes, "Above Ground Woody Community Attributes, Biomass and Carbon Stocks along a Rainfall Gradient in the Savannas of the Central Lowveld, South Africa," *South African Journal of Botany* 77, no. 1 (2011): 184–92, https://doi.org/10.1016/j.sajb.2010.07.014.

97 FAO, "Portal to Monitor Water Productivity through Open Access of Remotely Sensed Derived Data (WaPOR). Version 2.0," 2019, https://wapor.apps.fao.org/catalog/WAPOR_2/1/L1_TBP_A.

98 A. J. Mills et al., "Ecosystem Carbon Storage under Different Land Uses in Three Semi-Arid Shrublands and a Mesic Grassland in South Africa," *South African Journal of Plant and Soil* 22, no. 3 (2005): 183–90, https://doi.org/10.1080/02571862.2005.10634705.

99 T. G. O'Connor, "Influence of Land Use on Phytomass Accumulation in Highland Sourveld Grassland in the Southern Drakensberg, South Africa," *African Journal of Range and Forage Science*, 2008, https://doi.org/10.2989/AJRFS.2008.25.1.3.381.

100 Ibid.

Kgalagadi is approximately 1 tDW/ha, accounting for the seasonal variation that occurs. It is likely that the impacts of climate change will result in a decrease of these averages but that improved land and livestock management, particularly the introduction of planned grazing and rest, will increase the average phytomass. For the purposes of carbon accounting, the phytomass carbon pool is conservatively excluded.

The relationship between remotely sensed vegetation index, leaf area index and measured dry biomass has been shown for the Kalahari and Karoo[101], which is broadly and conservatively representative of Botswana's vegetation structure and climate. The field survey woody cover observations were used to validate and ground-truth the remote sensing-based estimates and to train a spectral unmixing model that classifies the fractional cover using Landsat 8 Tier 1 surface reflectance bands at 30 m resolution[102].

The vegetation cover across all three project areas varies spatially (Figure 2) and temporally (Figure 3). The spatial variation as a function of distance from populated communities demonstrates a direct anthropogenic impact on vegetation cover. In most cases, this results in an increase in the average EVI value up to 10 km from the centre of the community, beyond which there is minimal variation in the vegetation index. The temporal variation in vegetation cover demonstrates the overriding impact of climate variability on the rangeland condition.

The dependence of the rangeland productivity on climatic variables is additionally demonstrated by the temporal variation in the annual total biomass production (Figure 4). The pattern of temporal variability is replicated almost perfectly across all three project areas, indicating that it is in response to drivers that effect the productivity of the entire country, not discrete or area-specific management land use practices.

[101] L. Gerber, "Development of a Ground Truthing Method for Determination of Rangeland Biomass Using Canopy Reflectance Properties," *African Journal of Range and Forage Science* 17, no. 1–3 (2000): 93–100, https://doi.org/10.2989/10220110009485744.

[102] USGS, "Landsat 8 Tier 1 Surface Reflectance," 2019, https://www.usgs.gov.

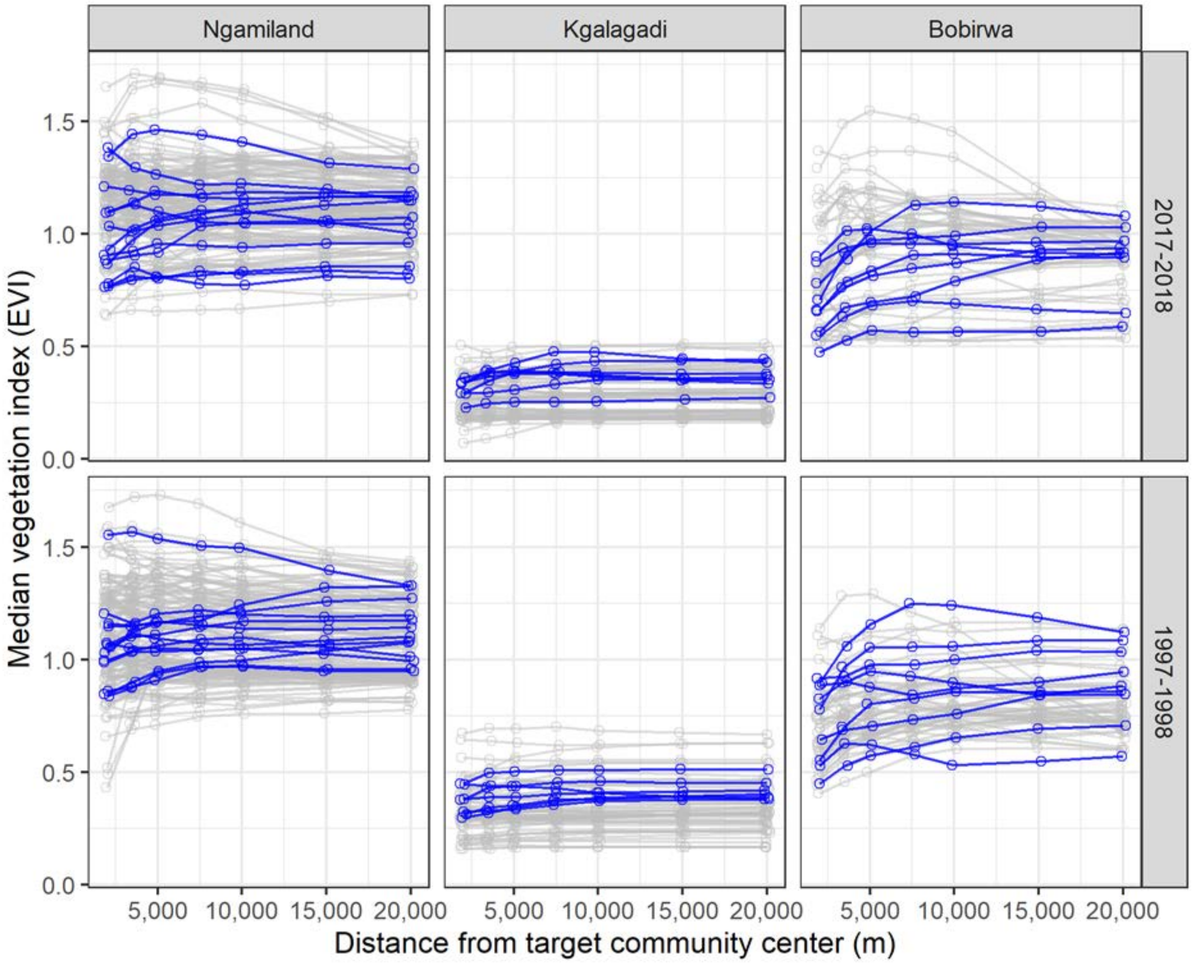

Figure 3. Spatial variation of vegetation with increasing distance from a populated community in the wet season (December to March) for two epochs, 1997-1998 and 2017-2018. Blue lines represent communities targeted as priorities for intervention and grey lines represent the remaining communities in the project area.

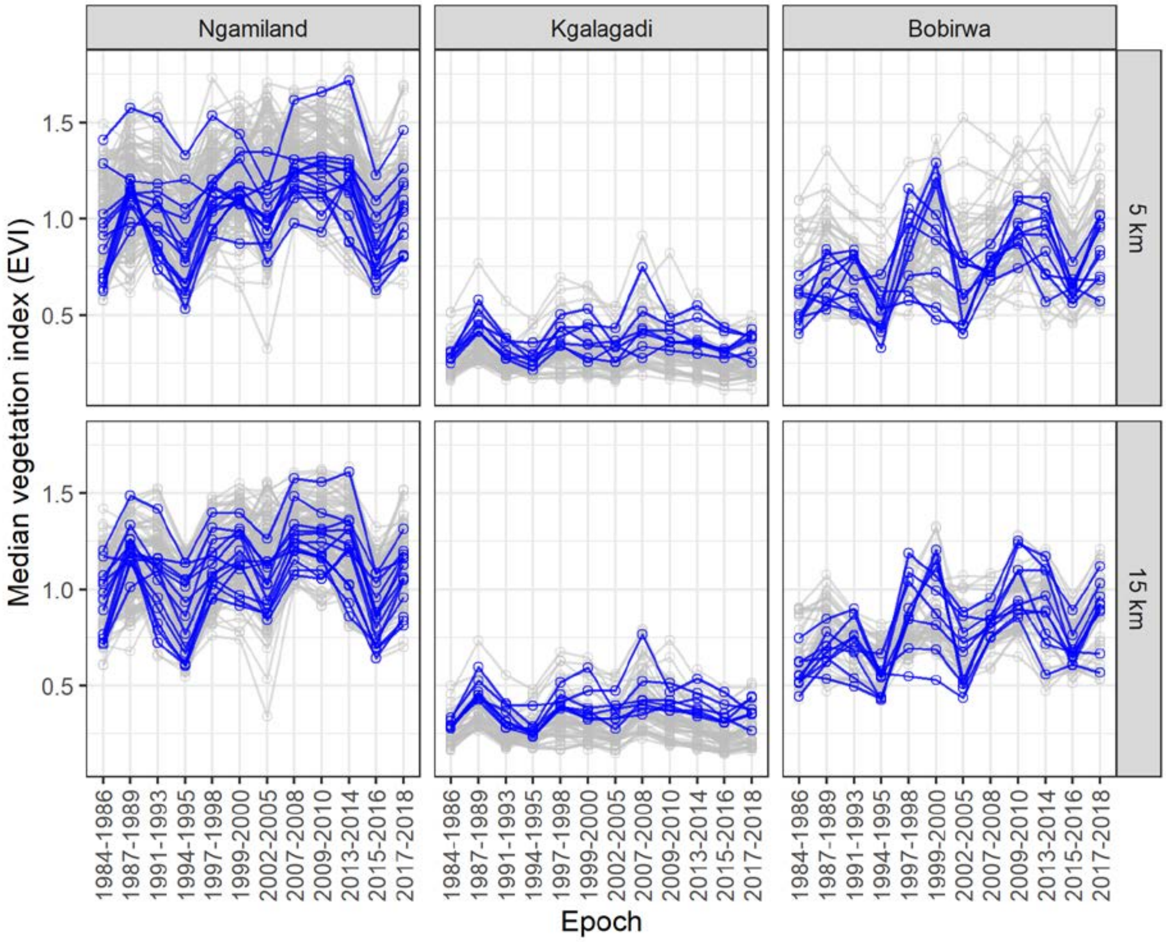

Figure 4. Temporal variation of vegetation by epoch between 1984 and 2018 in the wet season (December to March) within two radii from populated communities, 5 and 15 km. Blue lines represent communities targeted as priorities for intervention and grey lines represent the remaining communities in the project area.

Table 4. Vegetative carbon pool estimate based on the woody cover[103], biomass density[104], carbon content and ratio of above- to below-ground biomass[105]. The FAO total biomass production (TBP)[106] is included for context.

Project area	Woody cover (%)	AG Biomass (tDM/ha)	AG Biomass (tC/ha)	AG and BG Biomass (tC/ha)	FAO TBP (tDM/ha/yr)	FAO TBP (tC/ha/yr)
Bobirwa	55.9	130.0	62.4	84.2	8.3	9.3
Ngamiland	48.4	112.6	54.0	72.9	9.5	10.6
Kgalagadi	25.5	59.3	28.5	38.4	2.8	3.1

[103] Venter, Cramer, and Hawkins, "Drivers of Woody Plant Encroachment over Africa."

[104] Shackleton and Scholes, "Above Ground Woody Community Attributes, Biomass and Carbon Stocks along a Rainfall Gradient in the Savannas of the Central Lowveld, South Africa."

[105] Department of Environmental Affairs, "National Terrestrial Carbon Sinks Assessment."

[106] FAO, "Portal to Monitor Water Productivity through Open Access of Remotely Sensed Derived Data (WaPOR). Version 2.0."

Table 5. Woody area, dry biomass, carbon content and carbon density of woody species in arid, semi-arid and mesic savannas in South Africa[107].

Climate	Woody species	Woody area (m^2 ha^{-1})	Biomass (t ha^{-1})	Carbon (t ha^{-1})	Carbon density (t m^{-2})
Arid	*Acacia exuvialis*	0.047	0.033	0.02	0.34
	Acacia nigrescens	1.211	5.407	2.60	2.14
	Albizia harveyii	0.889	1.962	0.94	1.06
	Combretum apiculatum	2.058	3.683	1.77	0.86
	Combretum hereroense	0.242	0.41	0.20	0.81
	Commiphora schimperii	0.048	0.014	0.01	0.14
	Dichrostachys cinerea	0.58	0.5	0.24	0.41
	Grewia bicolor	0.467	0.366	0.18	0.38
	Grewia flava	0.248	0.177	0.08	0.34
	Grewia flavescens	0.044	0.026	0.01	0.28
	Lannea stuhlmanniana	0.307	0.991	0.48	1.55
	Ormocarpum trichocarpum	0.253	0.185	0.09	0.35
	Peltophorum africanum	0.23	0.427	0.20	0.89
	Sclerocarya birrea	1.271	4.672	2.24	1.76
	Other	2.00	4.14	1.99	0.99
	Total	**9.89**	**22.99**	**11.04**	**1.12**
Semi-arid	*Acacia swazica*	0.227	0.152	0.07	0.32
	Albizia harveyii	0.298	0.494	0.24	0.80
	Combretum collinum	1.037	3.18	1.53	1.47
	Dichrostachys cinerea	0.911	0.863	0.41	0.45
	Diospyros mespiliformis	0.447	1.669	0.80	1.79
	Euclea natalensis	0.11	0.079	0.04	0.34
	Maytenus senegalensis	0.098	0.058	0.03	0.28
	Philenoptera violacea	0.519	2.137	1.03	1.98
	Sclerocarya birrea	1.348	6.223	2.99	2.22
	Strychnos madagascariensis	0.667	1.404	0.67	1.01
	Terminalia sericea	1.462	2.135	1.02	0.70
	Other	1.51	1.82	0.87	0.58
	Total	**8.63**	**20.21**	**9.70**	**1.12**
Mesic	*Annona senegalensis*	0.371	0.33	0.16	0.43
	Antidesma venosum	0.441	0.712	0.34	0.77
	Combretum collinum	1.053	3.006	1.44	1.37
	Dichrostachys cinerea	0.689	0.521	0.25	0.36
	Dombeya rotundifolia	0.073	0.065	0.03	0.43
	Euclea natalensis	0.025	0.008	0.00	0.15
	Faurea saligna	2.193	8.91	4.28	1.95
	Heteropyxis natalensis	0.262	0.756	0.36	1.39

[107] Shackleton and Scholes, "Above Ground Woody Community Attributes, Biomass and Carbon Stocks along a Rainfall Gradient in the Savannas of the Central Lowveld, South Africa."

	Ochna sp	0.01	0.002	0.00	0.10
	Parinari curatellifolia	0.775	1.433	0.69	0.89
	Pavetta schumanianna	0.093	0.063	0.03	0.33
	Pterocarpus angolensis	2.574	9.291	4.46	1.73
	Pterocarpus rotundifolius	0.359	0.925	0.44	1.24
	Sclerocarya birrea	1.222	5.227	2.51	2.05
	Strychnos madagascariensis	0.513	0.992	0.48	0.93
	Terminalia sericea	1.783	5.665	2.72	1.53
	Other	1.62	3.57	1.71	1.06
	Total	**14.05**	**41.47**	**19.91**	**1.42**

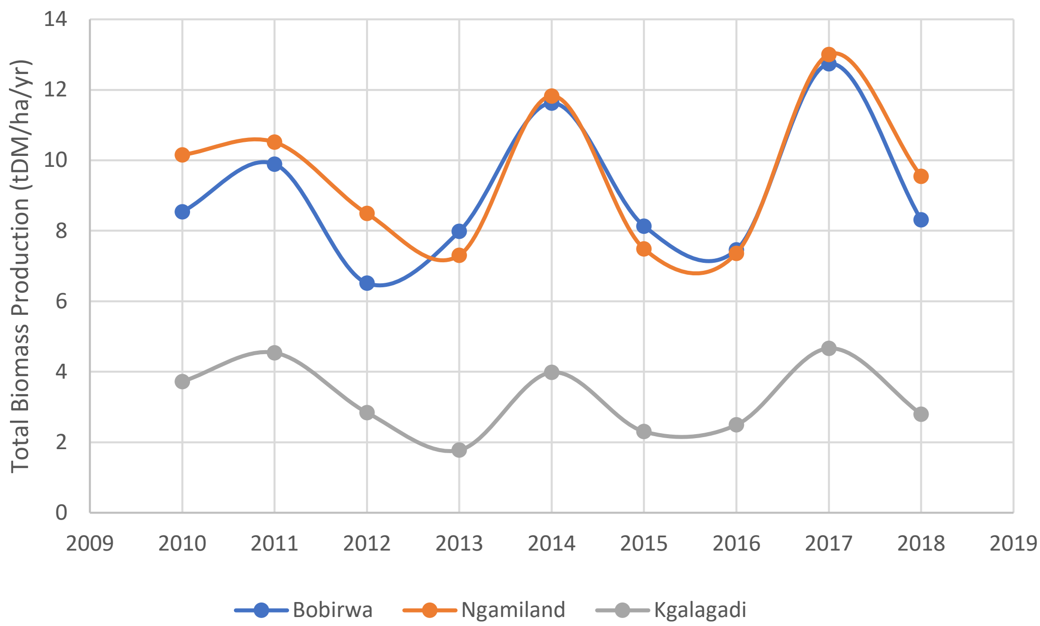

Figure 5. Temporal variability of the annual total biomass production[108] by project area.

[108] Ibid.

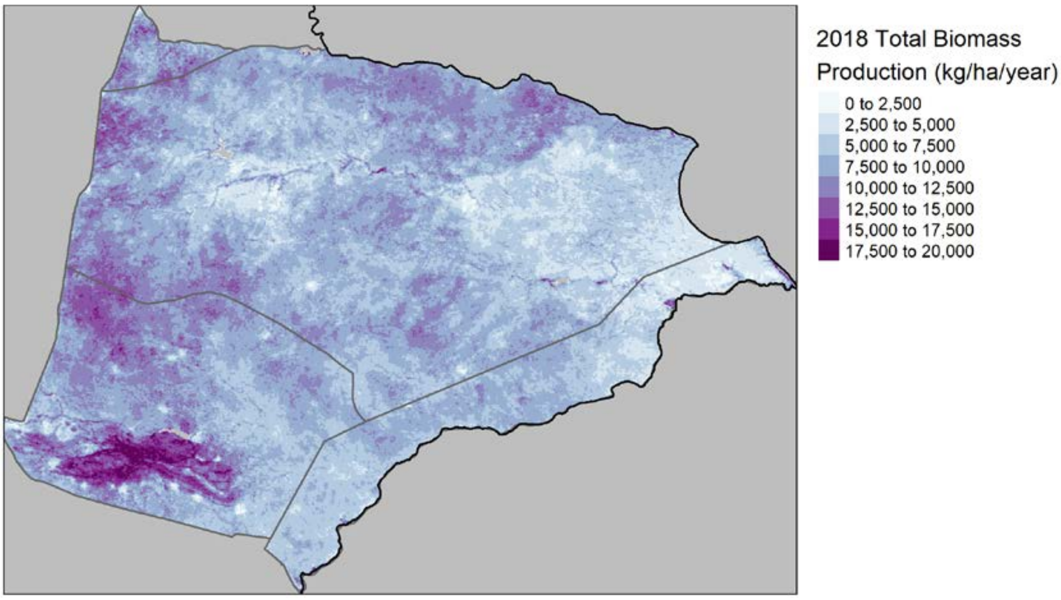

Figure 6. Total biomass production[109] in 2018 for the Bobirwa project area.

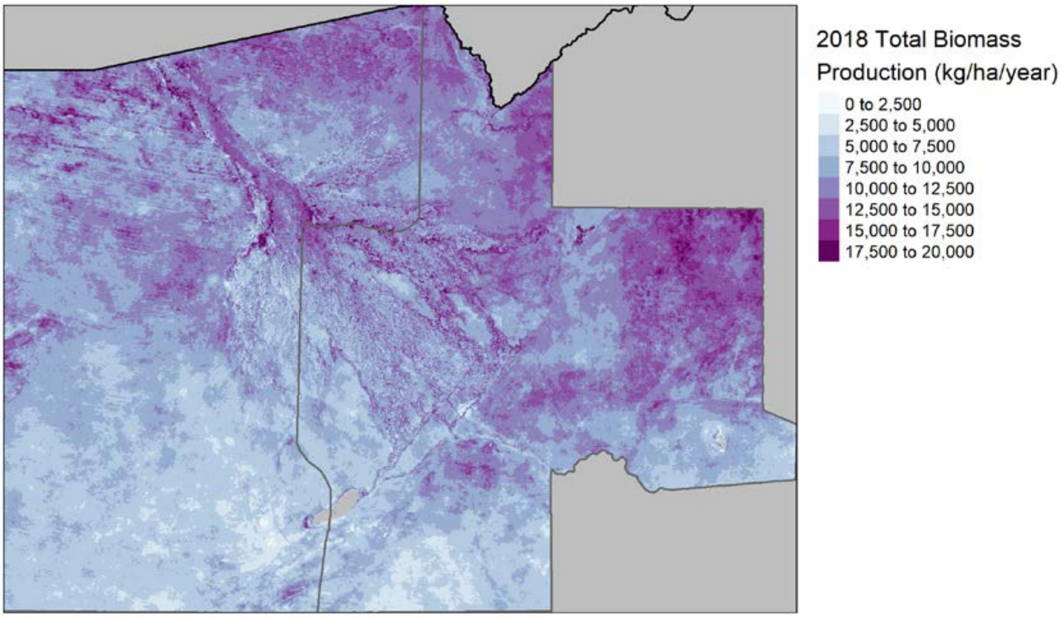

Figure 7. Total biomass production[110] in 2018 for the Ngamiland project area.

[109] Ibid.

[110] Ibid.

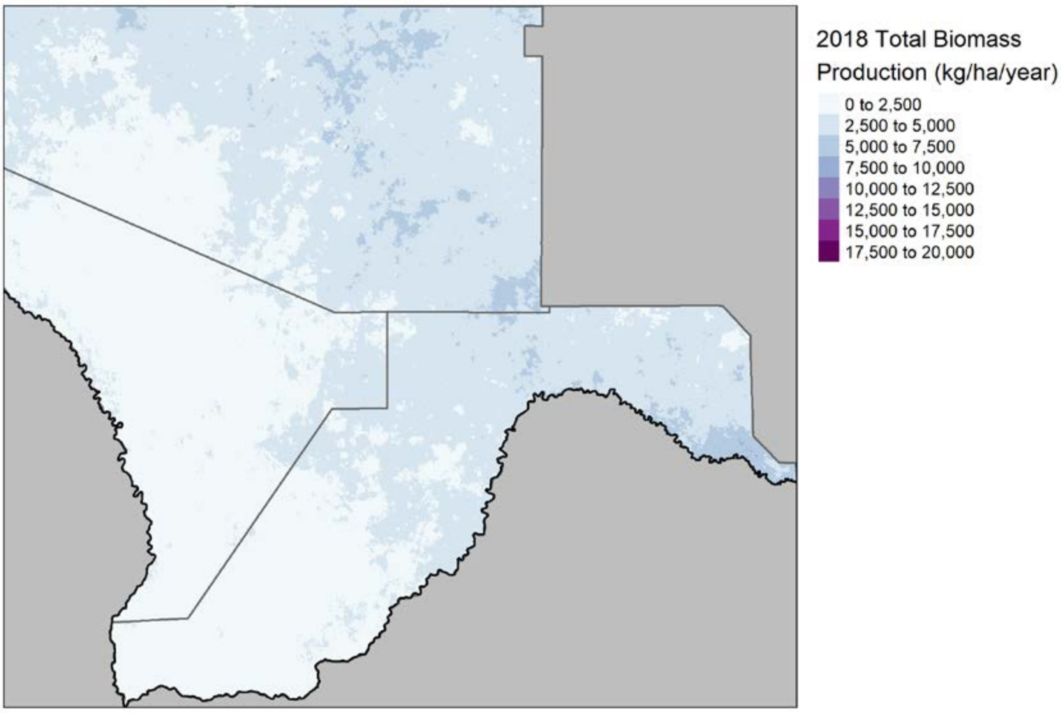

Figure 8. Total biomass production[111] in 2018 for the Kgalagadi project area.

111 Ibid.

4.2 Soil organic carbon pool

Soil organic carbon in Southern African rangelands can account for 12 to 20 times the carbon stored in above- and below-ground biomass[112,113]. The contribution of the herbaceous layer in rangeland carbon storage is largely a function of root accumulation and, subsequently, the accumulation of soil organic carbon[114]. The South African National Terrestrial Carbon Sinks Assessment estimates that the soil organic carbon in grasslands and savannas can vary between 2.3 and 14.6 tC m^{-2} with a mean of 10.1 and 5.4 tC m^{-2}, respectively[115].

Recent advances in predictive soil mapping using remote sensing and machine learning tools[116] allow for soil carbon stocks to be more reliably estimated at a national extent. The assessment of soil organic carbon for Botswana was, in part, based on the approach taken by Hengl et al.[117]. A random forest prediction model was used to estimate the distribution and total soil organic carbon stocks. To train the model, publicly available soil carbon data from the Africa Soil Profiles Database[118] was used, supplemented by soil samples collected at field survey points (Appendix 3.2).

The covariates applied to the model (Appendix 3.5) include all 19 WorldClim bioclimatic variables[119], digital elevation model (DEM) and six DEM-derived variables[120], landform classes[121], lithological units[122], soil class and texture[123], surface and sub-surface soil moisture in wet and dry seasons[124,125], and 2014 to 2018 wet and dry season mean Landsat 8 Tier 1 surface reflectance ultra-blue, blue, green, red, near infrared (NIR), shortwave infrared 1 (SWIR1) and shortwave infrared 2 (SWIR2) bands[126].

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[112] Department of Environmental Affairs, "National Terrestrial Carbon Sinks Assessment."

[113] Timm Tennigkeit and Andreas Wilkes, "Carbon Finance in Rangelands: An Assessment of Potential in Communal Rangelands" (Kunming, China, 2008).

[114] O'Connor, "Influence of Land Use on Phytomass Accumulation in Highland Sourveld Grassland in the Southern Drakensberg, South Africa."

[115] Department of Environmental Affairs, "National Terrestrial Carbon Sinks Assessment."

[116] Hengl and Macmillan, *Predictive Soil Mapping with R*; Sushil Lamichhane, Lalit Kumar, and Brian Wilson, "Digital Soil Mapping Algorithms and Covariates for Soil Organic Carbon Mapping and Their Implications: A Review," *Geoderma*, no. January (2019): 1–19, https://doi.org/10.1016/j.geoderma.2019.05.031.

[117] *SoilGrids250m: Global Gridded Soil Information Based on Machine Learning*, *PLoS ONE*, vol. 12, 2017, https://doi.org/10.1371/journal.pone.0169748.

[118] J Leenaars et al., "Africa Soil Profiles Database," *GlobalSoilMap*, 2014, 51–57, https://doi.org/10.1201/b16500-13.

[119] Stephen E. Fick and Robert J. Hijmans, "WorldClim 2: New 1-Km Spatial Resolution Climate Surfaces for Global Land Areas," *International Journal of Climatology* 37, no. 12 (2017): 4302–15, https://doi.org/10.1002/joc.5086.

[120] A Jarvis et al., "Hole-Filled Seamless SRTM Data V4," International Centre for Tropical Agriculture (CIAT), 2008, http://srtm.csi.cgiar.org.

[121] David M. Theobald et al., "Ecologically-Relevant Maps of Landforms and Physiographic Diversity for Climate Adaptation Planning," *PLoS ONE* 10, no. 12 (2015): 1–17, https://doi.org/10.1371/journal.pone.0143619.

[122] R Sayre et al., "A New Map of Standardized Terrestrial Ecosystems of Africa" (Washington DC, 2013), http://www.aag.org/cs/publications/special/map_african_ecosystems.

[123] Hengl et al., *SoilGrids250m: Global Gridded Soil Information Based on Machine Learning*.

[124] NASA, "Global Soil Moisture Data," 2019.

[125] Nazmus Sazib, Iliana Mladenova, and John Bolten, "Leveraging the Google Earth Engine for Drought Assessment Using Global Soil Moisture Data," *Remote Sensing* 10, no. 8 (2018), https://doi.org/10.3390/rs10081265.

[126] USGS, "Landsat 8 Tier 1 Surface Reflectance."

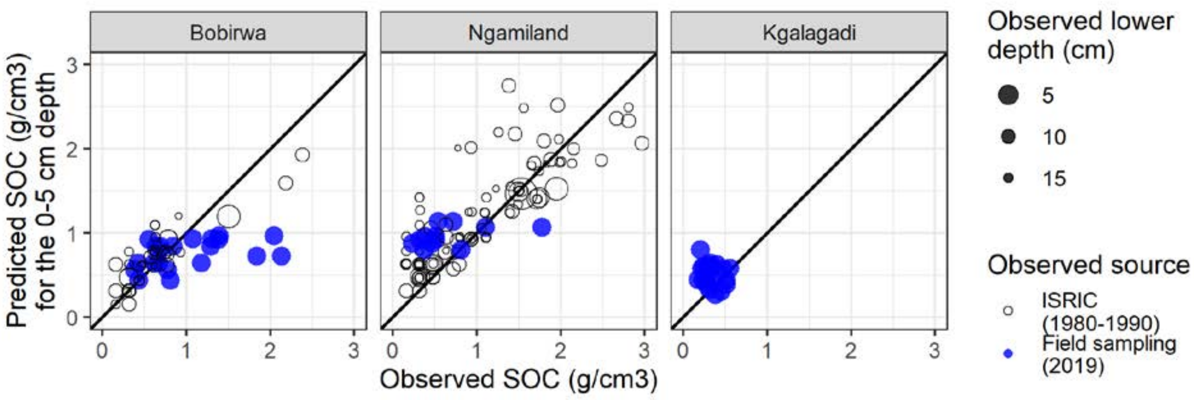

Figure 9. Soil organic carbon model prediction for the 0–5 cm depth compared with that of the 2019 field sampling observations (blue points) and the 1980–1990 observations from the ISRIC database[127] (open points).

Table 6. Average soil organic carbon density (gC/cm³) across five depth increments and in total up to 100 cm in Bobirwa, Ngamiland and Kgalagadi.

	SOC (gC/cm³)					
Project area	**0-5 cm**	**5-15 cm**	**15-30 cm**	**30-60 cm**	**60-100 cm**	**0-100 cm**
Bobirwa	0.89	0.66	0.57	0.37	0.24	0.55
Ngamiland	0.99	0.72	0.62	0.41	0.32	0.61
Kgalagadi	0.48	0.34	0.30	0.20	0.11	0.29

Table 7. Average soil organic carbon stocks (tC/ha) across five depth increments and in total up to 100 cm in Bobirwa, Ngamiland and Kgalagadi.

	SOC (tC/ha)					
Project area	**0-5 cm**	**5-15 cm**	**15-30 cm**	**30-60 cm**	**60-100 cm**	**0-100 cm**
Bobirwa	446	656	853	1117	976	**4048**
Ngamiland	497	721	932	1233	1285	**4668**
Kgalagadi	239	345	456	614	439	**2094**

[127] J.A. Dijkshoorn and V.V. Engelen, "Soil and Terain Database for Southern Africa (SOTERSAF)," 2003, https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/3571c1f3-159d-442c-b324-0af53d03f12e.

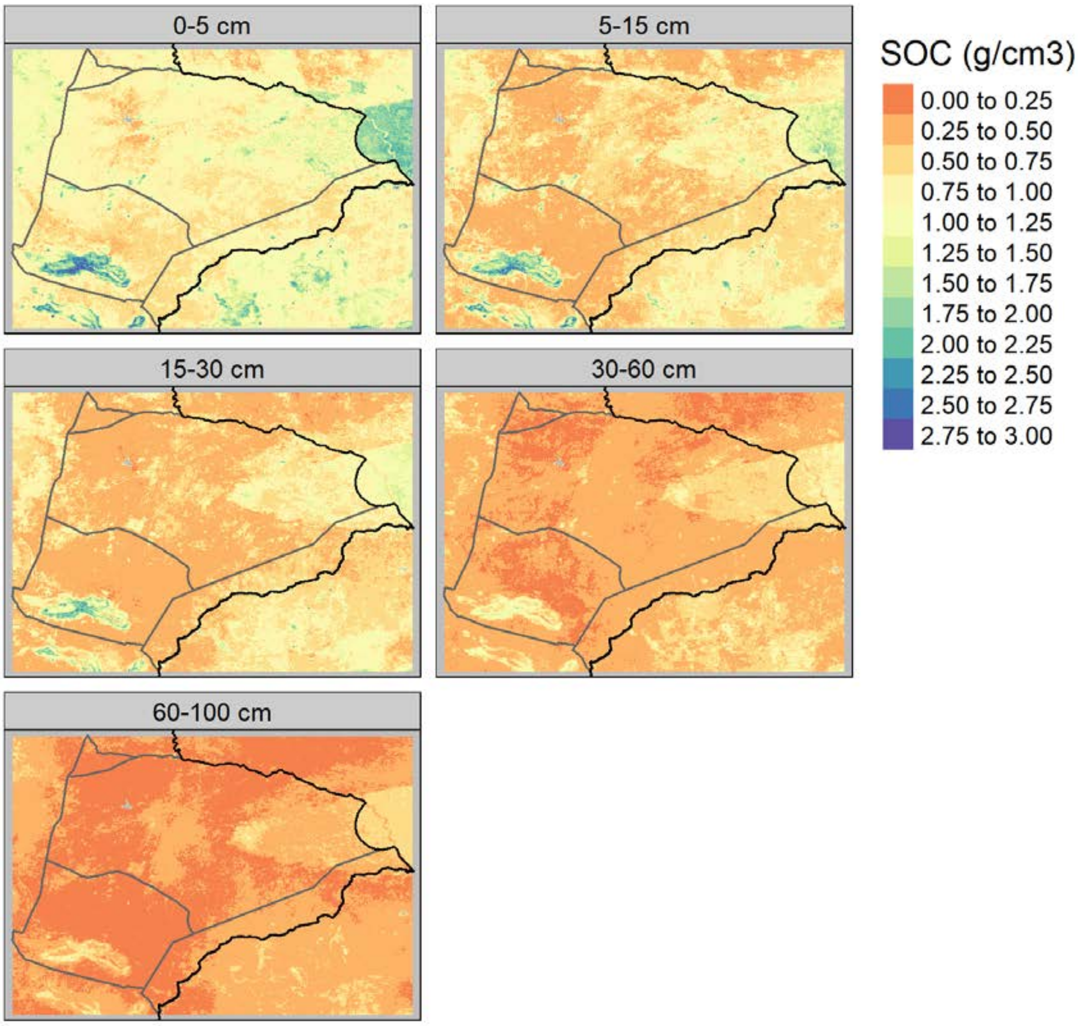

Figure 10. Modelled soil organic carbon density (gC/cm^3) for the Bobirwa project area across five depth increments.

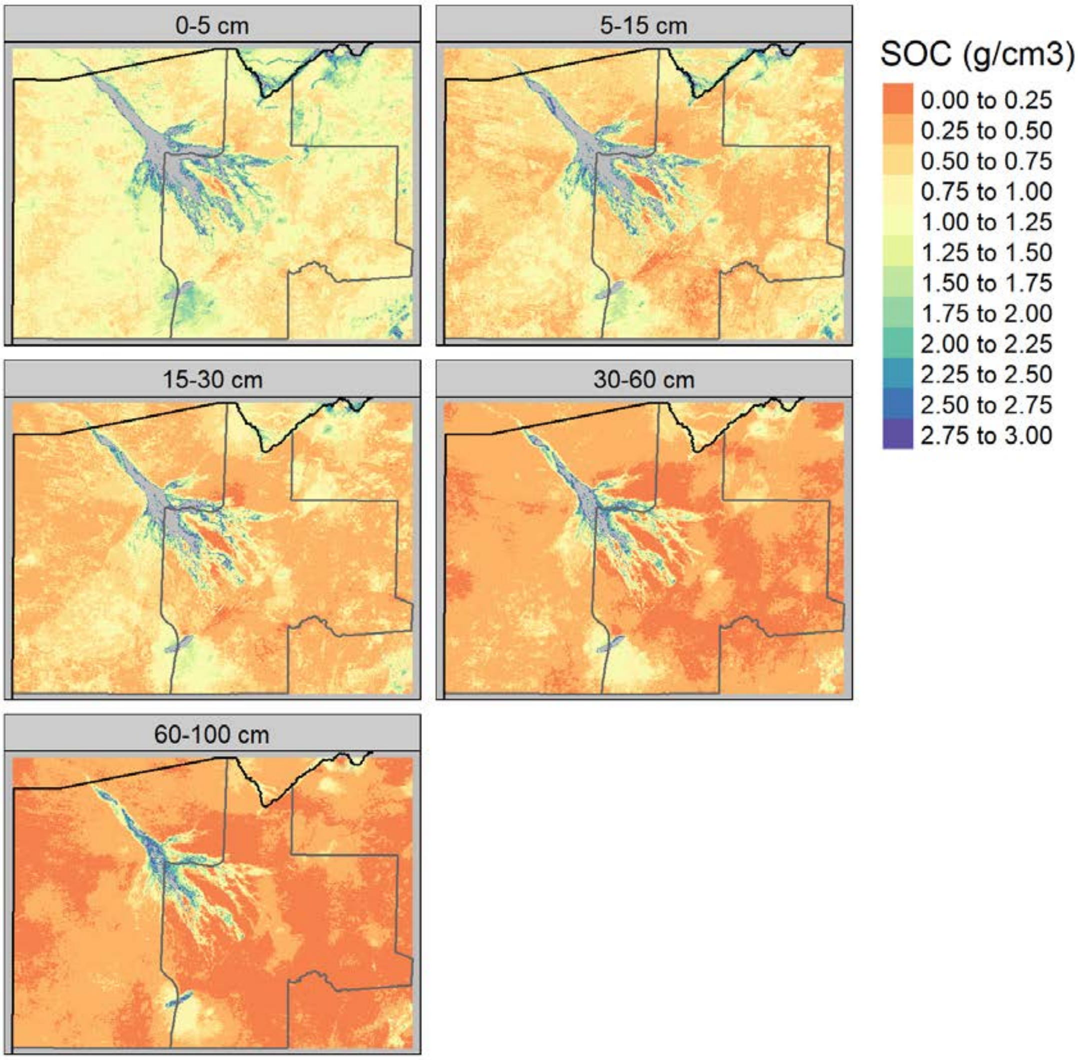

Figure 11. Modelled soil organic carbon density (gC/cm^3) for the Ngamiland project area across five depth increments.

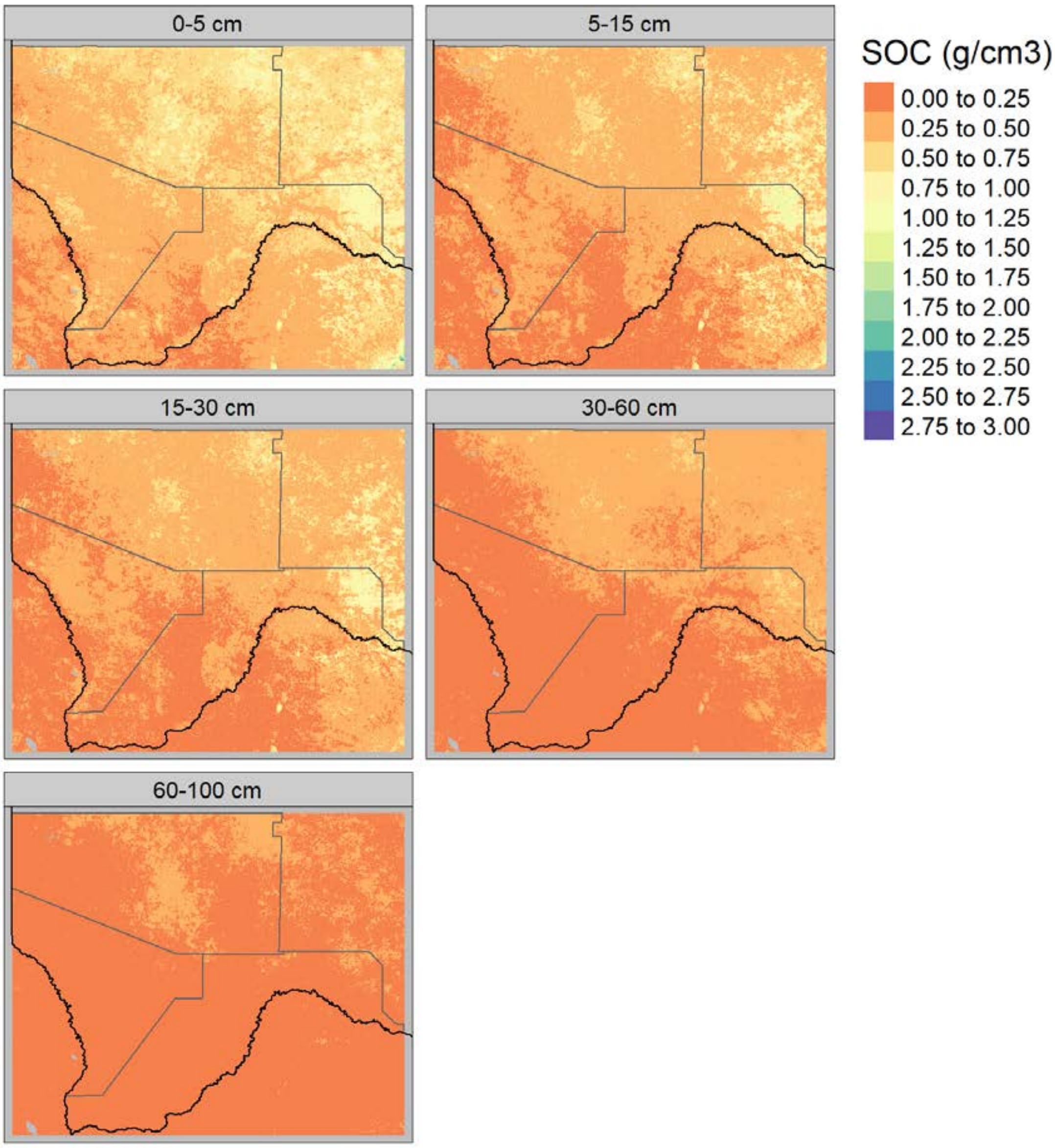

Figure 12. Modelled soil organic carbon density (gC/cm^3) for the Kgalagadi project area across five depth increments.

4.3 Emissions from livestock enteric fermentation

The majority of the livestock sector in Botswana is extensive, with 78% of the cattle population held in traditional holdings[128] in which extensive management is predominant. Village and cattle post grazing areas account for over three-quarters of the national grazing area and up to 85% in the Ngamiland District[129]. Within commercial livestock holdings, extensive ranching is also the primary management modality; only 15% of commercial cattle sales, for example, are from feedlots[130].

The direct greenhouse gas contribution of the livestock sector, in the case of ruminants such as cattle, sheep and goats, is from enteric fermentation and manure management[131], accounting for approximately half (39% and 10% respectively) of the total livestock emissions globally[132]. The production, processing, and transport of livestock feed accounts for approximately 90% of the remaining emissions, none of which is applicable in extensive grazing systems such as is predominant in Botswana. Similarly, manure management is not a consequential contributor to greenhouse gas emissions in extensive, compared with intensive, systems[133]. For this assessment, therefore, only enteric fermentation is considered in the livestock emissions estimate.

Emissions intensity from enteric fermentation is directly related to production efficiency. Methane is a by-product of the digestive process from microbial fermentation in the rumen. The conversion of carbohydrates into methane represents a loss of energy from the production system, reducing the amount of energy assimilated by the animal for maintenance and growth[134]. Poor grazing fodder quality and low grass species diversity increases the amount of enteric fermentation per unit intake, reduces production efficiency and increases the overall emissions intensity[135]. Poor animal health, overstocking and herd structures with a greater proportion of old and unproductive livestock likewise increases the emissions intensity of the sector[136]. To estimate the baseline greenhouse gas emissions from enteric fermentation, the IPCC Tier 2 livestock emissions inventory[137] was applied.

The Botswana GHG Inventories for Biennial Update Report[1], First Biennial Update Report[2] and Third National Communication[3] to the UNFCCC have all based their accounting of the emissions from the livestock sector on the IPCC Tier 1 approach. The objective of updating the national inventory to the Tier 2 approach has been recommitted in each report. This study therefore represents a positive development that can serve as a foundation for the updated national livestock emissions inventory. Notably, the default cattle methane emissions factor from enteric fermentation applied under Botswana's Tier 1 inventory (32–38 kgCH_4/head/year) represents the

128 Statistics Botswana, "Botswana Agricultural Census Report 2015" (Gaborone, Botswana, 2018), http://www.statsbots.org.bw/sites/default/files/Botswana Agriculture Census Report Final 2015..pdf.

129 Department of Environmental Affairs, "Natural Resource Accounting of Botswana's Livestock Sector" (Gaborone, Botswana, 2007).

130 Statistics Botswana, "Botswana Agricultural Census Report 2015."

131 Giampiero Grossi et al., "Livestock and Climate Change: Impact of Livestock on Climate and Mitigation Strategies," *Animal Frontiers* 9, no. 1 (2019): 69–76, https://doi.org/10.1093/af/vfy034.

132 P.J. Gerber et al., *Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities*, *Most*, vol. 14 (Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2013), https://doi.org/10.1016/j.anifeedsci.2011.04.074.

133 GRA and SAI, "Reducing Greenhouse Gas Emissions from Livestock: Best Practice and Emerging Options," 2015, https://ccacoalition.org/es/resources/reducing-greenhouse-gas-emissions-livestock-best-practice-and-emerging-options.

134 Gerber et al., *Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities*.

135 N. Wrage et al., "Phytodiversity of Temperate Permanent Grasslands: Ecosystem Services for Agriculture and Livestock Management for Diversity Conservation," *Biodiversity and Conservation* 20, no. 14 (2011): 3317–39, https://doi.org/10.1007/s10531-011-0145-6.

136 Mario Herrero et al., "Greenhouse Gas Mitigation Potentials in the Livestock Sector," *Nature Climate Change* 6, no. 5 (2016): 452–61, https://doi.org/10.1038/nclimate2925.

137 IPCC, "Chapter 10: Emissions from Livestock and Manure Management," in *Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use*, 2006, https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

commercialized sector for all of Africa and the Middle East and the IPCC guidelines recommend the Tier 2 method for countries with large livestock populations, such as Botswana. It is expected that the poor fodder quality available to livestock on communal land and significant energy requirements to acquire feed over large grazing areas compared with the commercial sector considerably increases the livestock emissions intensity. This is reflected in the greater baseline annual methane emission rate per head of cattle under the Tier 2 inventory (80–83 kgCH_4/head/year).

The Tier 2 approach to estimating livestock emissions has several additional benefits compared with the Tier 1 approach currently adopted by Botswana[138]. The Tier 2 approach estimates the emissions from livestock with greater precision; it better reflects the local livestock production context; it allows for mitigation opportunities within the livestock sector to be identified and quantified and, most importantly for this assessment, it is sensitive to the differences in emissions intensity following changes to the production efficiency[139].

The baseline livestock emissions from enteric fermentation were estimated using the livestock subcategories provided in the 2015 Agricultural Census (Table 9)[140]. The census distinguishes between the cattle population in each sub-district of Botswana by three breed subcategories (Tswana, exotic, and crosses) and seven demographic subcategories (bulls, oxen, cows, tollies, heifers, male calves, and female calves). The assumptions about the productivity of each subcategory were determined and validated by local expert opinion, in consultation with the Department of Agricultural Production. The assumptions about the feed digestibility and feeding situation were likewise determined and validated by local expert opinion, in consultation with the Department of Animal Production (Table 8). The full inventory is provided in Appendix 3.3.

Feed digestibility is defined as the proportion of the gross energy (GE) in the feed that is not excreted. For ruminants, common ranges of feed digestibility are 45-55% for crop by-products; 55-75% for good pastures, preserved forages and grain supplemented forage-based diets; and 75-85% for grain-based diets fed in feedlots. Conservatively, the baseline feed digestibility for communal livestock in Botswana is assumed to be 45%.

The extent to which feed is converted to methane (CH_4) depends on several interacting feed and livestock factors. The worse the average feed digestibility and livestock health, the greater the proportion of feed energy that is converted to methane rather than assimilated by the livestock. The default methane conversion factors for non-feedlot cattle range from 5.5% to 7.5%. Feedlot-fed cattle, by comparison, have default factors ranging from 2.0% to 4.0%. Conservatively, the baseline methane conversion factor for communal livestock in Botswana is assumed to be 7.5%.

An activity coefficient is applied, depending on the feeding situation, to account for the variability in the net maintenance energy requirements. Three feeding situations are defined with an activity coefficient for each, but the IPCC inventory recommends interpolating a realistic coefficient that is applicable to the feeding situation in question. The definitions include: i) large grazing areas (0.36), where significant energy is expended to acquire feed; ii) pastures (0.17), where livestock are confined in areas with sufficient forage so modest energy expense is required; and iii) stalls (0.00), where livestock expend very little or no energy to acquire feed. Conservatively, the baseline feeding situation for communal livestock in Botswana is assumed to be large grazing areas (coefficient of 0.36).

[138] Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Third National Communication to the United Nations Framework Convention on Climate Change" (Gaborone, Botswana, 2019).

[139] Andreas Wilkes and Suzanne van Dijk, "Tier 2 Inventory Approaches in the Livestock Sector: A Collection of Agricultural Greenhouse Gas Inventory Practices," 2018.

[140] Statistics Botswana, "Botswana Agricultural Census Report 2015."

Table 8. Baseline gross energy (GE) and methane emission factors from enteric fermentation (EF) for the traditional sector cattle subcategories defined by the Botswana Agricultural Census Report[141] as estimated by the IPCC Tier 2 emissions inventory[142].

Subcategory	GE (MJ/head/day)			EF ($kgCH_4$/head/yr)		
	Tswana	Crosses	Exotic	Tswana	Crosses	Exotic
Bulls	165.45	177.70	189.69	81.38	87.42	93.31
Oxen	165.45	177.70	189.69	81.38	87.42	93.31
Cows	188.57	202.55	216.21	92.76	99.64	106.35
Tollies	163.54	176.99	190.27	80.45	87.07	93.60
Heifers	170.27	184.46	198.49	83.76	90.74	97.64
Male Calves	95.36	103.45	111.45	46.91	50.89	54.82
Female Calves	100.51	109.17	117.75	49.44	53.70	57.92

Table 9. Baseline traditional sector cattle population and total emissions from enteric fermentation for the three project areas as estimated by the IPCC Tier 2 emissions inventory[143].

Project area	Population (head)	Emissions ($kgCH_4$/yr)	Emissions (tCO_2e/yr)
Bobirwa	62 769	5 225 923	130 648
Ngamiland	190 189	15 414 560	385 364
Kgalagadi	69 395	5 726 432	143 161

4.4 Mitigation targets

The mitigation targets for the project interventions are derived from reduced emissions from livestock enteric fermentation and from soil carbon sequestration and reduced emissions resulting from improved land and livestock management that contribute to restoring and conserving ecosystem function (Figure 13). Details on the project activities, outputs, components and the theory of change are provided in the Project Funding Proposal.

The mitigation potential has been modelled under maximum, moderate and conservative assumptions. The most conservative assumption scenarios about the rate and efficacy of implementation have been applied in estimating the mitigation targets. Specific assumptions relevant to each mitigation source are detailed in Sections 4.4.1 and 4.4.2 below. One implication of the conservative assumption, for example, is that the projected coverage of project interventions within the eight-year implementation period is approximately 20% less than the planned coverage. It is therefore likely that the projected mitigation target underestimates the probable mitigation potential. Given the irreducible complexity of ecological systems, and particularly rangeland ecosystems within highly erratic climate contexts, the conservatism of the mitigation potential is appropriate.

[141] Ibid.

[142] IPCC, "Chapter 10: Emissions from Livestock and Manure Management."

[143] Ibid.

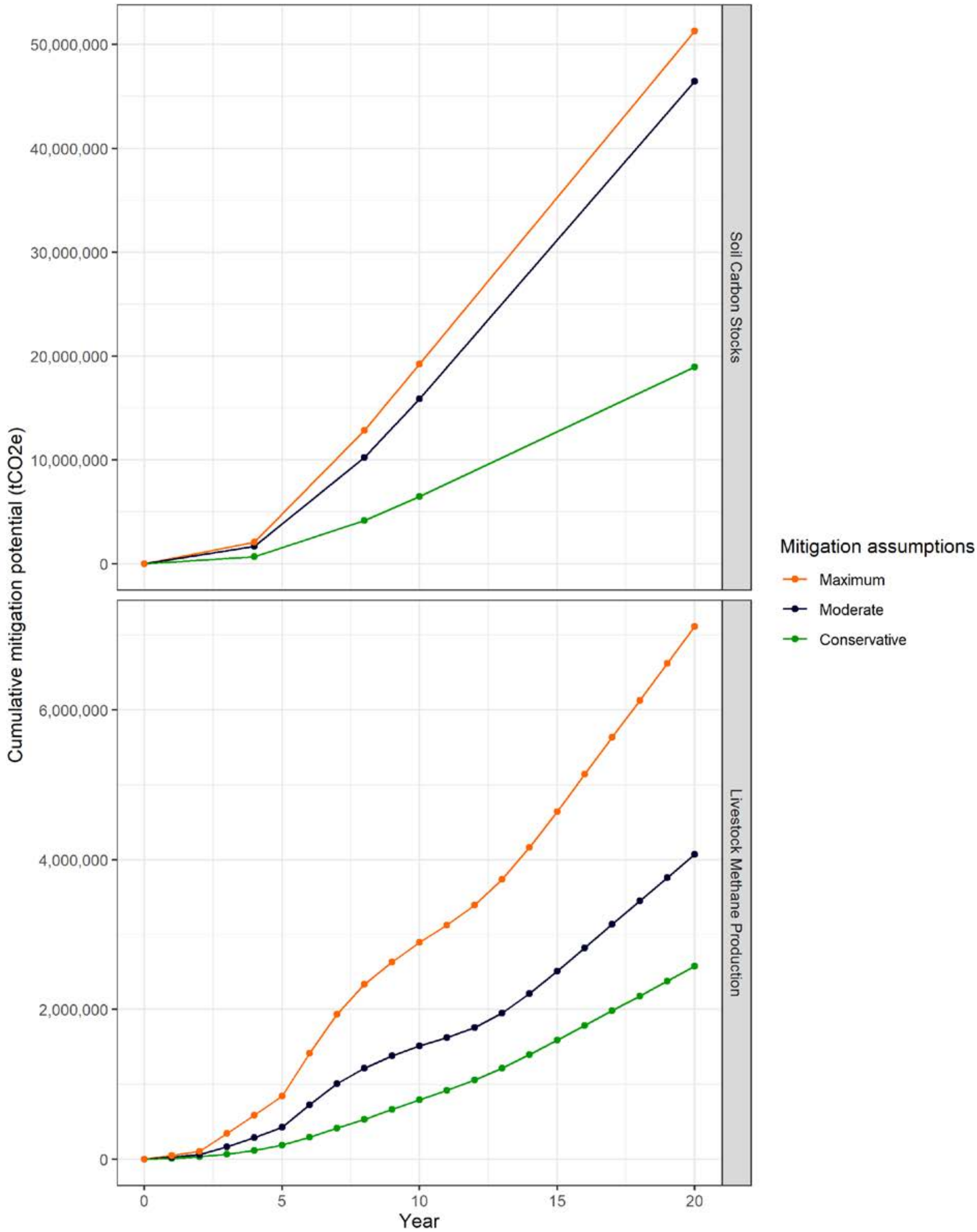

Figure 13. Cumulative mitigation potential (tCO_2e) from the primary sources under three mitigation impact assumption scenarios. Soil carbon stocks (top) includes mitigation from ecosystem restoration and reduced degradation; livestock methane production (bottom) includes emissions reduction from livestock enteric fermentation.

4.4.1 Livestock enteric fermentation

The emissions reduction target from livestock enteric fermentation was determined based on the mitigation potential resulting from an improved feed digestibility, methane conversion factor and feeding situation. The background rationale and definitions of these parameters are provided in Section 4.3. To ensure that the carbon mitigation targets are comparable to the other specialist studies conducted for this project, the input model assumptions have been standardised where feasible. The number of livestock across the 20-year projection period are assumed to be consistent with that of the Financial and Economic Analysis (FEA)[144]. The without-project scenario from the FEA assumed a greater loss in the number of livestock relative to the with-project scenarios in response to a modelled single, isolated drought event. This assumption can be considered conservative for the assessment of the mitigation potential, as fewer livestock results in reduced total greenhouse gas emissions.

Nationally, the livestock population has shown no consistent directional change from 2004–2015[145]. There has, however, been a short-term decline in the traditional sector livestock population, which has been attributed to recent drought conditions. Analogous projects implemented in South Africa with communal livestock farmers have, anecdotally, resulted in a voluntary reduction in the livestock population, which is consistent with maximizing livestock production efficiency[146]. Improved livestock and land management practices are expected to result in additional emissions reduction because of improved access to vaccinations and reduced rate of disease and parasite load. To ensure the mitigation targets are conservative, these expectations and their associated emissions reduction are not considered in the model assumptions.

A study on the direct methane emissions of South African dairy and beef cattle[147] found that the IPCC Tier 1 methane emissions factors significantly under-estimate the emissions within a Southern African context. The average emissions intensity estimated using the conservative assumptions of this assessment where at the lower bound of the estimates reported by Du Toit et al.[148], which ranged from 83–113 kgCH4/head/year for mature beef cattle. Given that the natural pastures and rangelands within South Africa experience are, on average, more mesic and generally support more palatable species than occurs within traditional livestock production systems in Botswana, these estimates can be considered conservative.

In the arid, poorly-managed, traditional livestock systems that this project is targeting, the forage quality (and therefore feed digestibility) is extremely poor and well below the regional average for comparable systems. With the greater intensity, frequency and duration of droughts that are expected in Botswana due to climate change, the feed digestibility in the absence of improved land and livestock management practices are expected to decline further. This is expected to be further exacerbated by a greater incidence of incidence of alien plant invasions, bush encroachment, and veld degradation that has already been observed and is expected to worsen due to climate change.

Although it is reasonable to expect the average feed digestibility to be reduced below 45% (as validated by the Botswana Department of Animal Production), this assessment, conservatively compared the with-project scenario to that of the baseline scenario, not the without-project scenario, to estimate the emission reductions. The feed digestibility values applied are therefore

[144] See Financial and Economic Analysis

[145] Statistics Botswana, "Botswana Agricultural Census Report 2015."

[146] Peace Parks Foundation, "Herding 4 Health," 2020, https://www.peaceparks.org/h4h/.

[147] Du Toit, C.J.L.; Meissner, H.H.; van Niekerk, W.A. (2013) Direct methane and nitrous oxide emissions of South African dairy and beef cattle. *South African Journal of Animal Science*. 43 (3). 320-339

[148] Ibid

consistent with the IPCC defaults, which can be considered conservative. Further background information supporting the feed digestibility estimates are provided in Section 4.3.

The methane conversion factor (Ym) is impacted by several interacting parameters, including feed quality, cattle breed, genetic pools and herd composition. The Ym factors from the 2006 guidelines (6.5 ± 1.0) were applied to this assessment. The 2019 Refinement of the 2006 IPCC Guidelines notes on page 10.44 that "It is possible for a country's national herd, or for parts of the national herd, to have production levels that are inconsistent with the feed quality bounds that are defined by the categories in Table 10.12. In these cases, it is good practice to develop their own country-specific Ym factors, and they should also use their information on animal diets to validate their choice of Ym against methane yield equations recommended in Niu et al. (2018)."

The nature of traditional livestock production in Botswana, particularly for the segment that this project is targeting, is that minimal, if any, land and livestock inputs are invested in improving beef production or livestock health. Because of limited market access and other historical, socioeconomic and cultural factors, the proportion of bulls and older cattle is greater than would be typical under a commercial system and there is often very poor genetic diversity, as reflected by the prevalence of genetically-linked diseases in communal herds. The methane yield equations developed by Niu et al. (2018) were based on data from commercial systems in Europe, USA and Australia where Ym ranged from 2.7 to 9.8. The Ym factors applied under this assessment (7.5 and 6.5), therefore, likely underestimates the potential improvements in the methane conversion factor following the introduction of improved land and livestock management practices.

Three comparative scenario assumptions about the rate at which the project can scale across the three project areas and the efficacy of implementation have been made. These relate to the maximum, moderate and conservative mitigation potential models with the latter defining the mitigation target. The conservative model assumes, for example, that the efficacy of the project implementation in its first year at a given site starts at 10% and increases incrementally to a maximum efficacy of 80% by the fourth implementation year. The sites that are included after the project period (after year eight of project implementation) are assumed to not exceed 50% efficacy. By contrast, the maximum mitigation potential model assumes an efficacy of 70% to 90% over the same period. With the increasing climate change impact on Botswana's rangeland ecosystems (see Section 2, it is expected that the emissions intensity per livestock head will increase. Following the recent droughts, for example, the average available feed digestibility has been observed to be as low as 30%, considerably worse than the minimum IPCC default of 45%. The maximum mitigation potential model assumes the baseline emissions intensity of 2.05 will increase to 3.11 tCO2e/head/year. The conservative mitigation potential model, however, assumes that the emissions intensity remains constant.

Under all model scenarios, only the emissions reduction achieved within the project areas are conservatively considered in the model, despite maximising the annual emissions reduction within the first decade and the likelihood of expanding the implementation beyond the project areas once the enabling environment has been provided and the benefits demonstrated.

Over the eight-year project implementation period, the cumulative conservative emissions reduction is projected to total 534,658 tCO_2e (66,832 tCO_2e/yr). This is expected to increase substantially to more than 2.5 million tCO_2e (128,876 tCO_2e/yr) over the full 20-year capitalisation period (Table 10). These mitigation benefits are expected to be further enhanced by the additional emissions reduction co-benefits described above and by the scaling of climate-resilient land and livestock management practices beyond the project areas.

The emissions reduction targets for the eight-year project implementation period were compared with that of the FAO Ex-Ante Carbon-balance Tool (Ex-ACT)[149] result for the same number of livestock, over the same period. The emissions reduction from enteric fermentation under the project implementation scenario has been conservatively assumed to be 70% that of the projected reduction calculated using the IPCC Tier 2 inventory. In total, the mitigation potential estimated using the Ex-ACT tool is 678,556 tCO_2e (84,819 tCO_2e/yr), approximately 27% more optimistic than the conservative emissions reduction target.

Table 10. Conservative number of sites, livestock and mitigation targets over 4-, 8-, 10-, and 20-year impact periods from reduced emissions intensity through livestock enteric fermentation.

Impact period	Sites	Livestock (without project)	Livestock (with project)	Cumulative mitigation (tCO_2e)	Annual mitigation (tCO_2e/yr)
4-year	44	136,382	137,064	**116,090**	**29,023**
8-year	83	192,025	226,717	**534,658**	**66,832**
10-year	103	186,972	268,991	**794,351**	**79,435**
20-year	104	286,254	329,526	**2,577,525**	**128,876**

The Botswana GHG Inventories for Biennial Update Report[1], First Biennial Update Report[2] and Third National Communication[3] to the UNFCCC have all based their accounting of the emissions from the livestock sector on the IPCC Tier 1 approach. The objective of updating the national inventory to the Tier 2 approach has been recommitted in each report. This study therefore represents a positive development that can serve as a foundation for the updated national livestock emissions inventory. Notably, the default cattle methane emissions factor from enteric fermentation applied under Botswana's Tier 1 inventory (32–38 $kgCH_4$/head/year) represents the commercialized sector for all of Africa and the Middle East and the IPCC guidelines recommend the Tier 2 method for countries with large livestock populations, such as Botswana. It is expected that the poor fodder quality available to livestock on communal land and significant energy requirements to acquire feed over large grazing areas compared with the commercial sector considerably increases the livestock emissions intensity. This is reflected in the greater baseline annual methane emission rate per head of cattle under the Tier 2 inventory (80–83 $kgCH_4$/head/year).

4.4.2 Restored ecosystem function

Ecosystem restoration and avoided degradation from improved rangeland and livestock management, results in improved ecosystem function, a reduction of bare ground cover and improvements in forage productivity. These improvements are expected to result in mitigation within the soil carbon pool. To quantify the sequestration potential, the FAO Ex-Ante Carbon-balance Tool (Ex-ACT)[150] was applied, with conservative assumptions about the proportion of successful restoration and conservation outcomes across the project areas (Table 11).

As for the mitigation target from reduced livestock enteric fermentation, multiple assumptions about the mitigation potential from ecosystem restoration have been modelled. These assumptions relate to the maximum, moderate and conservative mitigation potentials with the latter defining the mitigation target. The assumptions that define the conservatism of the mitigation potential relate to the implementation rate and efficacy achieved over the project implementation period. Where

[149] FAO, "Ex-Ante Carbon Balance Tool (Ex-ACT). Version 8.5.4.," accessed November 13, 2019, http://www.fao.org/tc/exact/ex-act-home/en/.

[150] Ibid.

the assumptions approximate the expected rate or efficacy of the project, they are assumed to be moderate. These moderate assumptions include the IPCC Tier 1 default differences in soil carbon stocks for the geographic, climate, soil and moisture regime of Botswana; and the implementation of project activities at all target sites within the implementation period.

To measure the impacts of grazing and restoration management on emissions reduction, the following indicators will be gathered:

- "**Grazing intensity", informed by**:
    - **Biomass** (kg/ha) from disc pasture meter, remote sensing models and satellite-based products such as FAO WaPOR.
    - **Basal cover** from long-term rangeland condition monitoring (Appendix 11.1), remote sensing models and satellite-based products such as fractional bare ground.
-
- **Lignin and cellulose content, informed by**
    - **Grass species composition** from long-term rangeland condition monitoring (Appendix 11.1) for Project sites. Reference sites will also be measured for mid-term and final impact evaluation reports. Remote sensing models will also be utilized (e.g., Ramoelo et al. 2015)[151]

- **Livestock numbers and weight**
    - For Project sites, livestock numbers will be gathered and updated monthly by Ecorangers and captured in the Rangeland Stewardship Information Portal with trend analysis by the Graduate Monitors and referenced against the Stats Botswana Annual Agricultural Survey Report. Average weight trends per village herd will be integrated into reports on wet and dry season vaccinations. This will be compared to reference site estimates from MoA veterinary records as without the RSA it will be impossible to get similar detail on livestock where farmers are not participating in active communal management (e.g. BAU/status quo).

- **Feed digestibility**
    - **Grass species composition** (as described above)
    - **Biomass** (as described above)
    - **Manure evaluation augmented by fecal nitrogen analysis.** Ecorangers to undertake sampling of dung viscosity as an indicator for feed digestibility that can then be translated into an estimate for emissions reductions. The exact methodology may vary per Area and season due to climate/habitat factors. This information will be reviewed and augmented with chemical analyses carried out by the MoA Nutrition specialist.

- **Activity coefficient**
    - Qualitative categorization of the average energy expended (distance walked per day) to acquire enough grazing material. This can be monitored based on the number of livestock within controlled herds as captured in the Rangeland Stewardship Information Portal with input from the Graduate Monitors.

[151] Ramoelo, A et al. (2015) Monitoring grass nutrients and biomass as indicators of rangeland quality and quantity using random forest modelling and WorldView-2 data. *International Journal of Applied Earth Observation and Geoinformation*. 43. 43–54. http://dx.doi.org/10.1016/j.jag.2014.12.010

- **Methane conversion factor**
    - This is based on feed digestibility (described above), herd structure (number and age of males/females), and livestock health indicators (vaccinations, fertility rate, death rate) that can be monitored based on the Rangeland Stewardship Information Portal with input from the Graduate Monitors.

CI will use these indicators as model parameters for the SNAP biogeochemical model[152] to estimate the emissions reductions (ER) from the project's livestock and rangeland management activities. This modelled approach quantifies the ER in a manner consistent with VCS VM0032[153].

Relative differences in the soil carbon stocks determine the mitigation potential from project interventions. The default IPCC Tier 1 soil carbon stocks for moderately- and non-degraded grassland systems are 36% and 43% greater than for severely degraded systems on sandy-dominant soils in dry, warm temperate African climates. To account for the lag in soil carbon accumulation following improved management practices and improved ecosystem function, the relative differences were conservatively reduced by more than half to only 15% and 20% for moderately- and non-degraded systems, respectively, compared with the default for severely degraded systems.

Table 11. Baseline and final degradation states under different ecosystem restoration and conservation scenarios with and without project activities.

Scenario	Baseline degradation	Final degradation	
		Without project	With project
Maximum restoration	Severe	No change	Non-degraded
Moderate restoration	Severe	No change	Moderate
Moderate restoration	Moderate	No change	Non-degraded
Successful conservation	Moderate	Severe	Non-degraded
Moderate conservation	Moderate	Severe	Moderate
No effect	All	No change	No change

Adjustments to the target implementation rate are required to account for the conservative assumptions used for estimating the mitigation potential. The project target coverage of improved management practices over the eight-year implementation period is 4,600,000 ha. For the conservative Ex-ACT model, as for the livestock enteric fermentation model, it is assumed that full coverage is only achieved in year 11. The model, therefore, assumes that the entire project duration until year 11 is the implementation phase and the remaining duration is the capitalisation phase, where applicable. The project implementation area is also scaled to reflect this difference in the projected implementation rate (Table 12).

[152] Ritchie, M (2014) Plant compensation to grazing and soil dynamics in a tropical grassland. PeerJ 2:e233; DOI 10.7717/peerj.233

[153] https://verra.org/methodology/vm0032-methodology-for-the-adoption-of-sustainable-grasslands-through-adjustment-of-fire-and-grazing-v1-0/

Table 12. Conservative number of sites, area under improved management and mitigation targets over 4-, 8-, 10-, and 20-year impact periods from improved rangeland condition or avoided degradation.

Impact period	Sites	Area (ha)	Cumulative mitigation (tCO_2e)	Annual mitigation (tCO_2e/yr)
4-year	44	1,200,000	**681,340**	**170,335**
8-year	83	3,671,154	**4,168,840**	**521,105**
10-year	103	4,555,769	**6,466,724**	**646,672**
20-year	104	4,600,000	**18,935,574**	**946,779**

The baseline vegetation biomass and above-ground carbon stocks have been estimated and are presented in Section 4.1. For the purposes of ex-ante emission reduction (ER) accounting, however, changes to the above-ground biomass carbon pools are excluded as they are expected to be de minimis. Two considerations, in particular, for this exclusion are highlighted below in relation to: i) the nature of the proposed activities; and ii) the changes to above-ground biomass carbon stocks following bush thinning.

As outlined in Table 11 of the FP (pg. 39), bush thinning is defined by this project as a restoration tool involving the pruning of lower branches (<1.5 m) where woody densification prevents livestock access to the grazing land. This differs from other approaches to addressing bush encroachment, such as the felling and clearing of all trees within a woodland or savanna in order to create an artificial grassland or grazing lawn. Such a practice would be maladaptive in the context of an extensive grazing system in Botswana that is expected to experience exacerbated heat waves and heat stress due to climate change.

The woody cover, even where intense bush encroachment has occurred, is not fully removed in order to maintain the canopy for shade, for soil protection, and for habitat niche diversity that improves the grazing quality and resilience of the ecosystem. The woody material that is pruned (small branches and leaves) is not removed from the landscape or used to make wood fuels such as charcoal under this project, as is often the practice elsewhere. It is used for brush packing in erosion gullies, on bare ground (see images in Annex 2, Section 4 pg 30-31), and to create physical barriers that reduce over-utilization of cattle paths that can cause erosion. Depending on the species, the thinned material may also be chipped and included as bulk material in dry season fodder supplementation, which further supports the restoration outcomes by reducing dry season overgrazing and soil erosion, stimulating new grass establishment, and reducing overall grazing pressure. These approaches also avoid the exportation of nutrients and carbon out of the landscape, which would occur if the woody material were removed. Bush thinning is expected to vary across the project area depending on the site-specific baseline conditions and project requirements. The average amount of bush encroached woody material that thinned is expected to be <1 tDM/ha.

Management of the spread of Invasive Alien Plants (IAPs) includes hand pulling of small saplings (<50 mm) and the use of manual hand tools to remove IAPs from riparian areas will also be conducted. The complete eradication of IAPs is not planned under the proposed project as they provide important ecosystem services such as shade and dry season fodder material, despite the negative impact that they often have on rangeland productivity, water balance, and drought resilience.

The assumption that there will be no rangeland land cover type conversions, for example from woodlands or savannas to grasslands, is therefore met under the interventions proposed by this project (Output 2.2., Activity 2.2.2.). An example of the desired end-state vegetation structure post-bush thinning is provided below, for reference.

Figure 14. Example of the desired end-state vegetation structure post-bush thinning.

The changes to above-ground biomass carbon stocks following bush thinning are not limited to the pruning of branches. Herbaceous (grass) above-ground biomass production is stimulated by bush thinning, observed to have led to the accumulation of 0.5–2 tDM/ha[154], with associated benefits to soil carbon stocks, drought resilience and livestock production. The total woody vegetation in Botswana has also been shown to be greater where bush encroachment intensity is lowest[155]. This counter-intuitive observation has been attributed to the complex interactions of herbivore intensity and selectivity, fire frequency and severity, soil nutrients and interspecific competition of encroaching and non-encroaching trees (particularly for water resources).

As a result of the uncertain directionality in the above-ground biomass stocks following bush thinning, IAP management and other restoration activities, the AGB carbon pool was conservatively assumed to be de minimis and excluded from the emission reduction (ER) estimates.

As part of Project M&E, the above-ground vegetation dynamics will be monitored for the purposes of evaluating the rangeland condition to inform management decisions, implementation success and to evaluate project impacts. Herbaceous biomass production will be measured using a disc pasture meter and changes to woody cover and vegetation structure will be measured using fixed-point wheel spoke repeat photographs, line-point intercept transects and remote sensing products. All the measurements will be captured in the Rangeland Stewardship Information Portal with trend analyses conducted by the Graduate Monitors. These data are not intended to be used to claim any ER benefits from changes in the above-ground carbon stocks as a result of the conservative de minimis assumption.

[154] Smit GN (2005) Tree thinning as an option to increase herbaceous yield of an encroached semi-arid savanna in South Africa. *BMC Ecology* 5: 4. DOI 10.1186/1472-6785-5-4

[155] Moleele, N.M.; Ringrose, S.; Matheson, W.; Vanderpost, C., (2002). More woody plants? The status of bush encroachment in Botswana's grazing areas. *J. Environ. Manage*., 64 (1): 3-11

5. **BASELINE WATER ASSESSMENT**

5.1 Introduction

Water scarcity presents a major environmental and development challenge in Botswana[156], which is exacerbated by its high susceptibility to droughts[157]. National water demand is already exceeding the sustainable yield, largely resulting from increases in rural water requirements attributed to climate change[158,159]. Groundwater abstraction (for mining, agriculture and industry) is restricted to less than 23 million m^3/yr, however, these limits are often exceeded and their enforcement are challenging in rural areas with poor access and unreliable monitoring[160]. The Botswana Integrated Water Resources and Water Efficiency Plan[161] recognises that water resources are ecological, economic and social goods that need to be managed accordingly, that water management is the responsibility of government, private sector and civil society, and that the most effective management approach requires local-level action and responsibility. The draft GCF Country Programme for Botswana recognises that a critical lack of baseline data is one of the primary challenges that the country faces; extensive reliance on the local and regional literature as well as primary analyses based on the available data have been used to mitigate these data gaps for this assessment.

Water availability varies considerably across Botswana[162]. Mean annual rainfall ranges from less than 250 mm in the southwest of the country to more than 650 mm in the northeast. Groundwater resources are estimated at 100 billion m^3 and annual surface run-off at ~700 million m^3/yr[163]. Official estimates of the rate of aquifer recharge differ between 96–1600 million m^3/yr, depending on the source, with the most recent estimate from the Department of Water Affairs being on the lower end of this range[164]. The majority of groundwater resources are, however, contained in confined aquifer systems that were recharged under paleoclimatic conditions, referred to as fossil water, and do not experience modern recharge[165]. The majority of surface run-off is unable to be captured in part because of insufficient storage, topography, high rates of evapotranspiration and high spatio-temporal variability of run-off[166,167]. The surface water storage capacity of the country is recognised as one of the most limited in the region[168]. This is further complicated by the fact that Botswana is heavily dependent on transboundary water sources, including groundwater aquifers

156 Energy & Water Resources Department of Water Affairs - Ministry of Minerals, "Botswana Integrated Water Resources Management & Water Efficiency Plan," vol. 1 (Gaborone, Botswana, 2013).

157 Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Biennial Update Report (BUR) to the United Nations Framework Convention on Climate Change."

158 A. J.E. Du Plessis and K. M. Rowntree, "Water Resources in Botswana with Particular Reference to the Savanna Regions," *South African Geographical Journal* 85, no. 1 (2003): 42–49, https://doi.org/10.1080/03736245.2003.9713783.

159 Dianne Rahm, Larry Swatuk, and Erica Matheny, "Water Resource Management in Botswana: Balancing Sustainability and Economic Development," *Environment, Development and Sustainability* 8, no. 1 (2006): 157–83, https://doi.org/10.1007/s10668-005-2491-6.

160 Tshepho Setlhogile and Ross Harvey, "Water Governance in Botswana," 2015.

161 Department of Water Affairs - Ministry of Minerals, "Botswana Integrated Water Resources Management & Water Efficiency Plan."

162 See Section 1: Climate Vulnerability Assessment Report

163 Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Third National Communication to the United Nations Framework Convention on Climate Change."

164 Ibid.

165 Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Biennial Update Report (BUR) to the United Nations Framework Convention on Climate Change."

166 Department of Water Affairs - Ministry of Minerals, "Botswana Integrated Water Resources Management & Water Efficiency Plan."

167 Du Plessis and Rowntree, "Water Resources in Botswana with Particular Reference to the Savanna Regions."

168 Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Third National Communication to the United Nations Framework Convention on Climate Change."

and rivers[169]. Surface water sources in the country, with the exception of the Okavango Delta, experience periodic drying as a result of the spatiotemporal variation in water run-off, which is being exacerbated by climate change impacts[170]. Despite ~90% of water supply in urban areas coming from surface water, the majority (~65%) of Botswana's total water supply is sourced from groundwater[171]. In addition to national water resources, Botswana receives an annual water quota of up to 7.3 million m^3/yr from Molatedi Dam in South Africa[172]. The water sources of greatest direct importance to the traditional livestock sector are the Okavango Delta and groundwater aquifers. Both water sources are discussed below, followed by an assessment of drought impacts on the livestock sector.

5.2 Okavango Delta

The Okavango Delta is the end of the endorheic Okavango River Basin[173] and is located in the Ngamiland District. It varies three-fold in its coverage, from 4,000–12,000 km^2, based on upstream annual precipitation volumes[174,175]. The water inputs from the Delta contribute a substantial proportion of the total surface water resources of Botswana, particularly in the northern region (Figure 14). The integrity of the country's and the livestock sector's water security dependent on the Delta is therefore vulnerable to the impacts of climate and water use changes in Angola and Namibia[176]. Water resources in the Delta are reliant on flooding events, or pulses, which are characterised by a large degree of variability in amount from year-to-year and in magnitude between the seasons[177].

Observations of the flooding rates in the Delta since 1984 show a drying trend over time (Figure 15). The total volume of water entering the Delta has decreased as well as the magnitude of the wet season pulse. This has implications for the surrounding vegetation and ecology, which varies in its structure and function depending on the extent, distribution, frequency and duration of inundation[178,179].

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[169] Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Third National Communication to the United Nations Framework Convention on Climate Change."

[170] Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Biennial Update Report (BUR) to the United Nations Framework Convention on Climate Change."

[171] Du Plessis and Rowntree, "Water Resources in Botswana with Particular Reference to the Savanna Regions."

[172] WAVES - The World Bank, "Accounting for Water in Botswana," 2014.

[173] There basin allows no outflow to external water bodies, such as rivers or oceans, and terminates within Botswana.

[174] Rahm, Swatuk, and Matheny, "Water Resource Management in Botswana: Balancing Sustainability and Economic Development."

[175] See Section 1: Climate Vulnerability Assessment Report

[176] Department of Water Affairs - Ministry of Minerals, "Botswana Integrated Water Resources Management & Water Efficiency Plan."

[177] See Section 1: Climate Vulnerability Assessment Report

[178] Susan Ringrose, "Characterisation of Riparian Woodlands and Their Potential Water Loss in the Distal Okavango Delta, Botswana," *Applied Geography* 23, no. 4 (2003): 281–302, https://doi.org/10.1016/j.apgeog.2003.08.006.

[179] Michael Murray-Hudson, Piotr Wolski, and Susan Ringrose, "Scenarios of the Impact of Local and Upstream Changes in Climate and Water Use on Hydro-Ecology in the Okavango Delta, Botswana," *Journal of Hydrology* 331, no. 1–2 (2006): 73–84, https://doi.org/10.1016/j.jhydrol.2006.04.041.

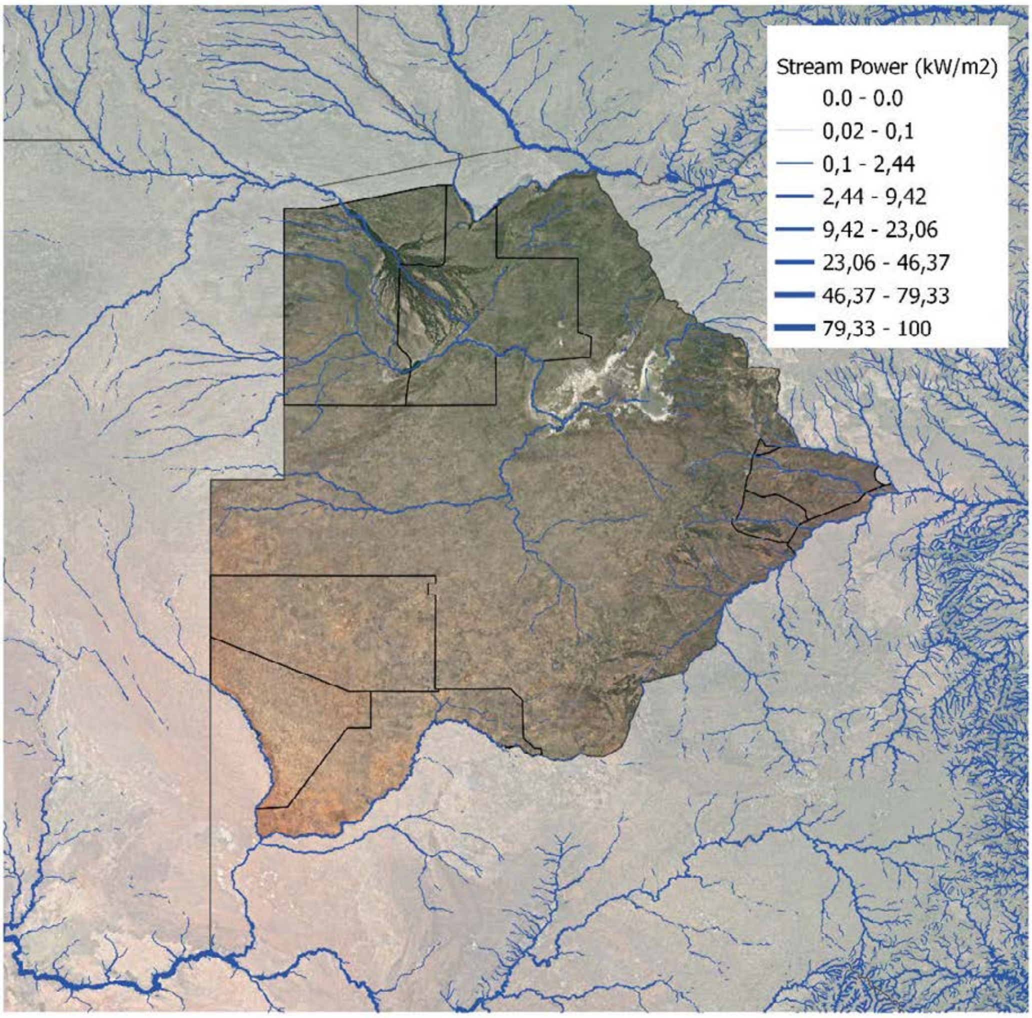

Figure 14. Stream power (kW/m^2) of rivers in and around Botswana[180] as a proxy for water inputs.

[180] Camille Ouellet Dallaire et al., "A Multidisciplinary Framework to Derive Global River Reach Classifications at High Spatial Resolution," *Environmental Research Letters* 14, no. 2 (2019), https://doi.org/10.1088/1748-9326/aad8e9.

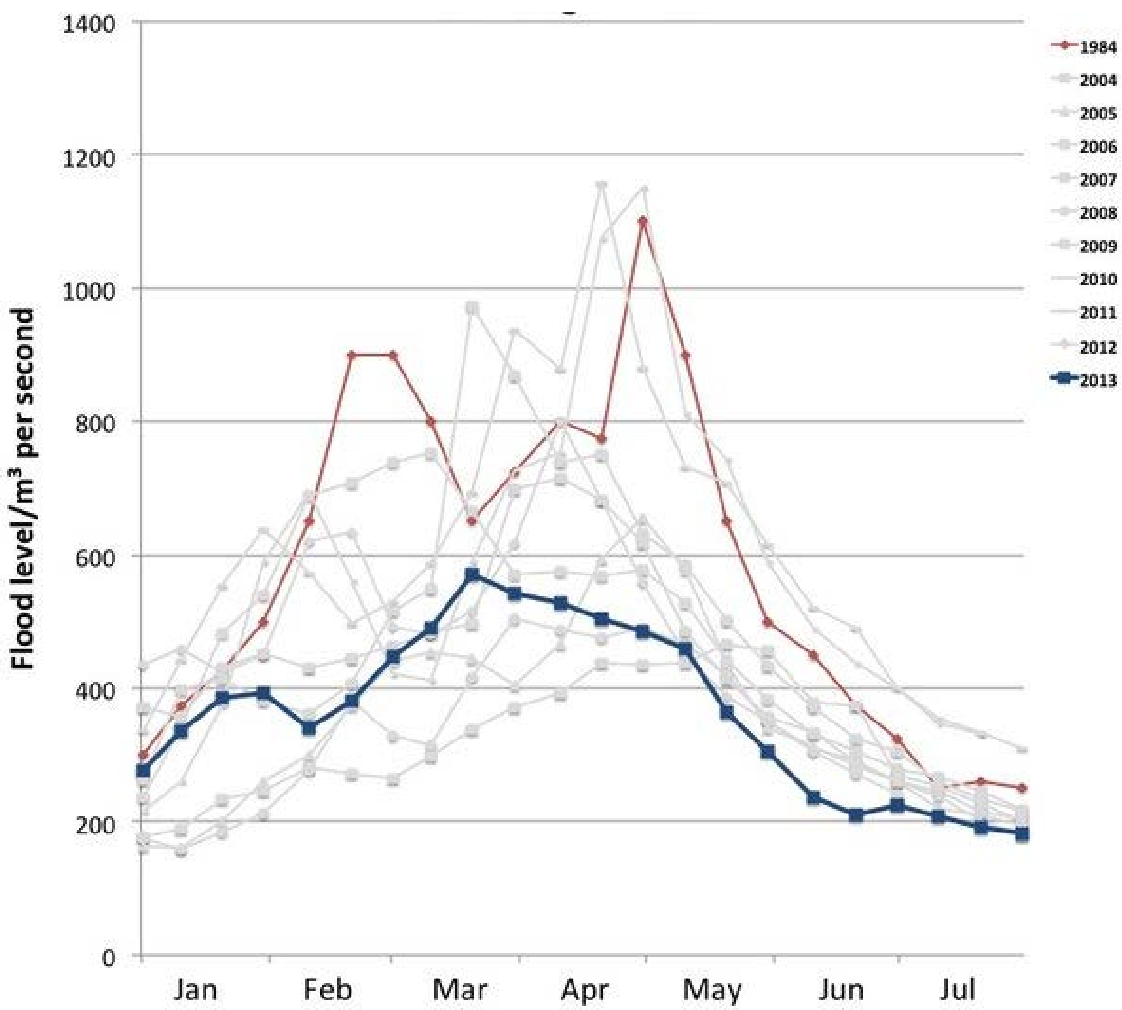

Figure 15. Historical flood fluctuation data for the Okavango Delta from 1984 to 2013 during the inundation season (January to July).[181]

Murray-Hudson et al.[182] modelled the relative contribution of different upper-catchment development — for example dam construction, water abstraction and deforestation — and climate change scenarios on the water flow volumes into the Okavango Delta. Complementary studies on these impacts by Andersson et al.[183] found that the impacts of climate change are considerably greater than the development scenarios. Under every climate change scenario applied to the flow model projections, the total flow volumes and peak monthly flows were reduced relative to the baseline (Figure 16). These projections incorporate changes in precipitation and temperature, however holding either one constant still resulted in reduced flow volumes. The contribution of precipitation seems to have a greater impact on flow volumes relative to that of temperature. Differences between the optimistic (A2) and more extreme (B2) global emissions scenarios had little impact on the results, indicating that the drying of the Delta due to climate change is inevitable. Under the baseline scenario, half of the monthly flow into the Delta equalled or exceeded 400 million m^3, but under the climate change scenarios, this is projected to decrease by more than 60% to approximately 150 million m^3/month.

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181 Okavango Delta Monitoring and forecasting http://okavangodata.ub.bw/ori/

182 Murray-Hudson, Wolski, and Ringrose, "Scenarios of the Impact of Local and Upstream Changes in Climate and Water Use on Hydro-Ecology in the Okavango Delta, Botswana."

183 Lotta Andersson et al., "Impact of Climate Change and Development Scenarios on Flow Patterns in the Okavango River," *Journal of Hydrology* 331, no. 1–2 (2006): 43–57, https://doi.org/10.1016/j.jhydrol.2006.04.039.

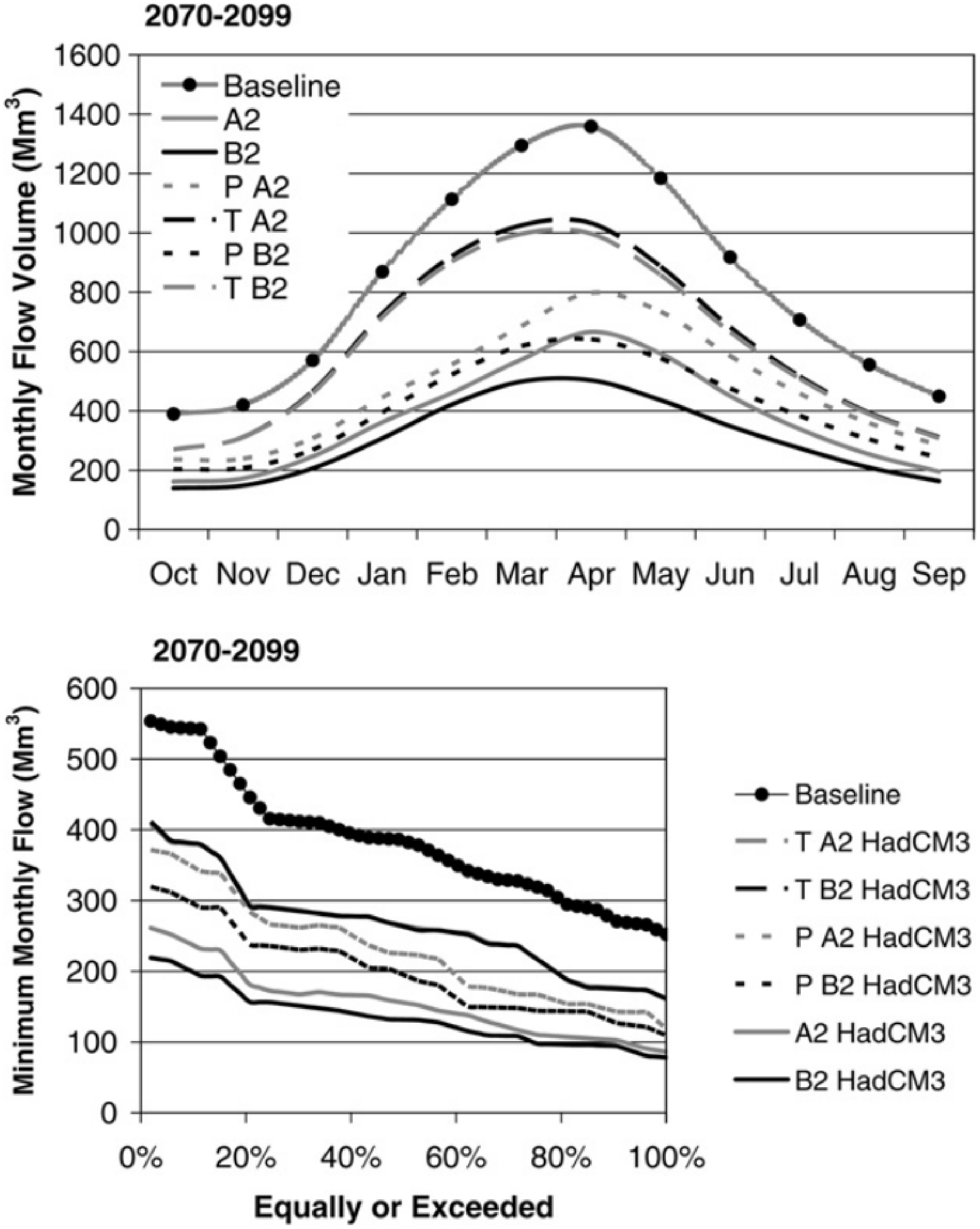

Figure 16. Projected (2070–2099) mean monthly flow volume (top) and frequency of minimum monthly flow volumes (bottom) into Botswana from the Okavango River Basin under HadCM3 climate models driven by the optimistic A2 (grey) and more extreme B2 (black) greenhouse gas emission scenarios. Both the combined impact of predicted precipitation and temperature changes (solid lines) and the impact of only precipitation (dotted lines) or only temperature (dashed lines) changes are shown relative to the baseline (points).[184]

5.3 Groundwater

[184] Ibid.

The rural livelihoods in Botswana, including the livestock sector, are dependent on groundwater abstraction[185]. The majority of the livestock sector, including commercial and traditional producers, are self-suppliers of water, with an almost ubiquitous reliance on individual boreholes[186]. The trend of increasing demand for water can be partly attributed to socioeconomic development, but is also largely a result of climate change impacts from increases in temperature, evapotranspiration, variability in precipitation, frequency and intensity of meteorological droughts and water stress on rangeland ecosystems and on the rural population[187]. There is considerable uncertainty about the rate of aquifer recharge at a national level and for each individual aquifer, but it is expected that, where modern recharge is occurring, the recharge rate will be reduced as a result of climate change[188]. The majority of groundwater resources are, however, reportedly contained in confined aquifer systems that were recharged under paleoclimatic conditions, referred to as fossil water, and do not experience modern recharge[189]. These aquifers are at risk of depletion with ongoing abstraction and limited to no recharge. The major aquifer formations for Botswana are shown in Figure 17.

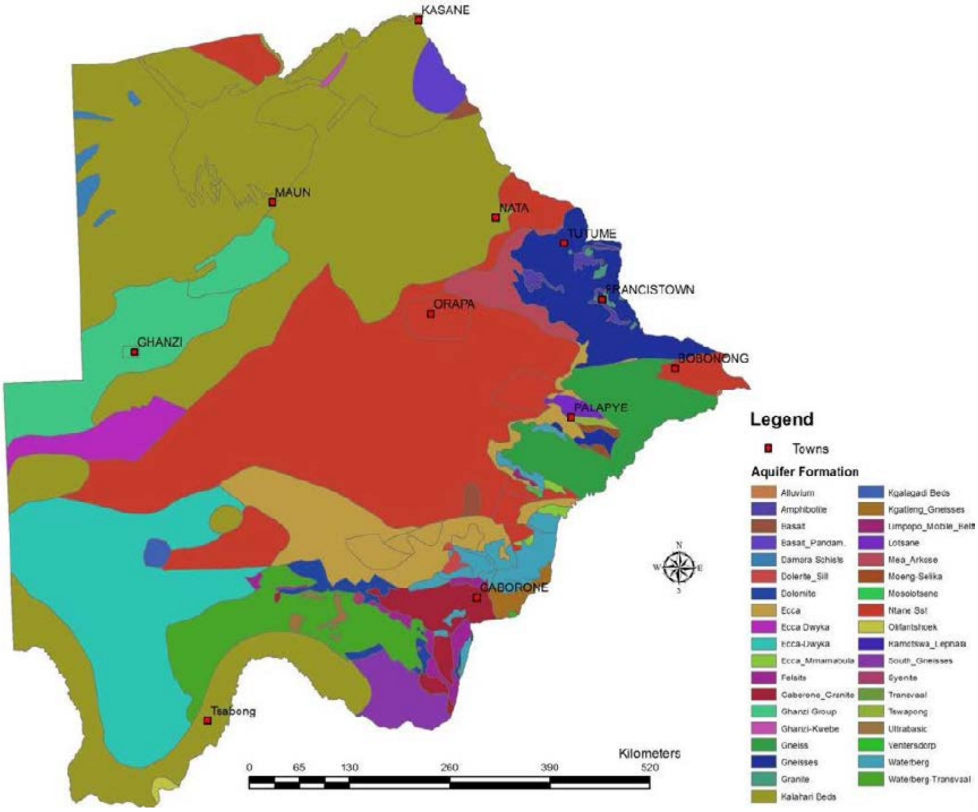

Figure 17. Aquifer formations and distributions for Botswana**[190]**.

[185] Setlhogile and Harvey, "Water Governance in Botswana."

[186] Energy & Water Resources Department of Water Affairs - Ministry of Minerals, "Botswana Integrated Water Resources Management & Water Efficiency Plan," vol. 1 (Gaborone, Botswana, 2013).

[187] See Section 1: Climate Vulnerability Assessment Report

[188] Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Third National Communication to the United Nations Framework Convention on Climate Change."

[189] Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Biennial Update Report (BUR) to the United Nations Framework Convention on Climate Change."

[190] Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Third National Communication to the United Nations Framework Convention on Climate Change."

The availability of borehole water has a direct impact on the rangeland ecology by altering the migratory patterns and behaviour of wildlife and free-roaming livestock[191]. These changes, in turn, impact the availability and condition of rangeland resources by concentrating herbivory pressure around water access points and by facilitating the expansion of human activity and settlements into wildlife corridors, disrupting wildlife migration and the connectivity of wildlife management areas. Fragmentation of the rangelands has numerous cascading impacts that ultimately lead to further ecosystem degradation[192].

Technological improvements in borehole drilling have increased their affordability and availability in Botswana over the last 50 years. The boreholes that are being drilled across the three project areas are therefore abstracting water from deeper aquifers than has been the case historically (Figure 18) and the rate of drilling has been accelerating since the 1970s (Figure 19 to Figure 22). The quality of borehole water, as represented by the electrical conductivity (EC), fluorine (F), nitrate (NO_3), and total dissolved solids (TDS), differs across Botswana (Figure 23) and within each project area (Figure 24 to Figure 26).

Despite the increase in the number of boreholes drilled in the last five decades, they are plagued by high abstraction costs, low yields and poor water quality[193]. According to the World Health Organisation[194], TDS concentrations >1,200 mg/L are unacceptable for human consumption. The FAO recommends EC levels <500 mS/m for livestock, further stating that EC >1,600 mS/m cannot be recommended under any conditions, with a decline in animal condition expected[195]. In Botswana, TDS in borehole water are commonly >1,000 mg/L throughout the country and >10,000 mg/L in Kgalagadi and parts of Ngamiland (Figure 23). EC in borehole water is commonly >1,000 mS/m, particularly in Kgalagadi (Figure 23). The quality of available water can, in general, therefore be concluded to be below acceptable standards for livestock production.

Differences in the distribution of borehole depths are evident between the three project areas, with the shallowest boreholes on average located in Ngamiland and Bobirwa (mean depth <100 m) and the deepest boreholes in Kgalagadi (mean depth >100 m).

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[191] Jeremy S. Perkins, "'Only Connect': Restoring Resilience in the Kalahari Ecosystem," *Journal of Environmental Management* 249, no. December 2018 (2019): 109420, https://doi.org/10.1016/j.jenvman.2019.109420.

[192] Ibid.

[193] Ministry of Environment Natural Resources Conservation and Tourism, "Botswana's Biennial Update Report (BUR) to the United Nations Framework Convention on Climate Change."

[194] https://www.who.int/water_sanitation_health/dwq/chemicals/tds.pdf

[195] http://www.fao.org/3/t0234e/T0234E07.htm

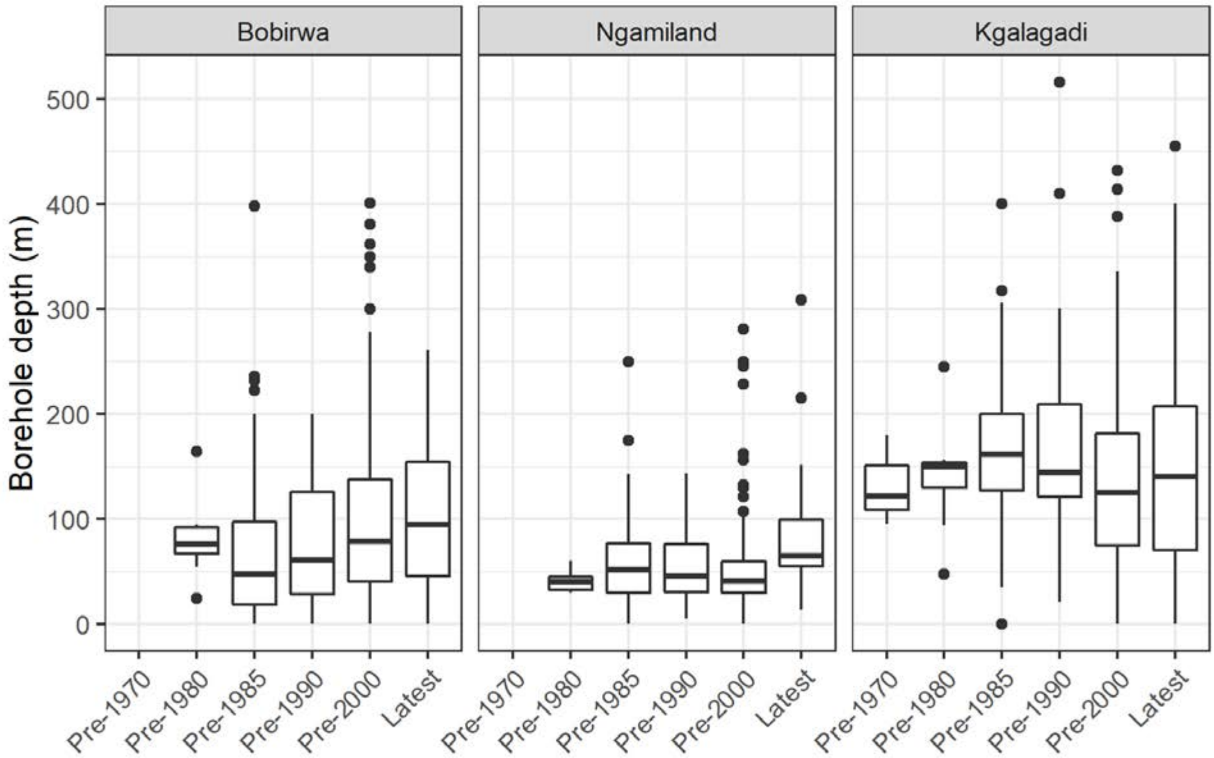

Figure 18. Borehole depth (m) over time, separated into six epochs, across the three project areas. Data source: Botswana Department of Water Affairs

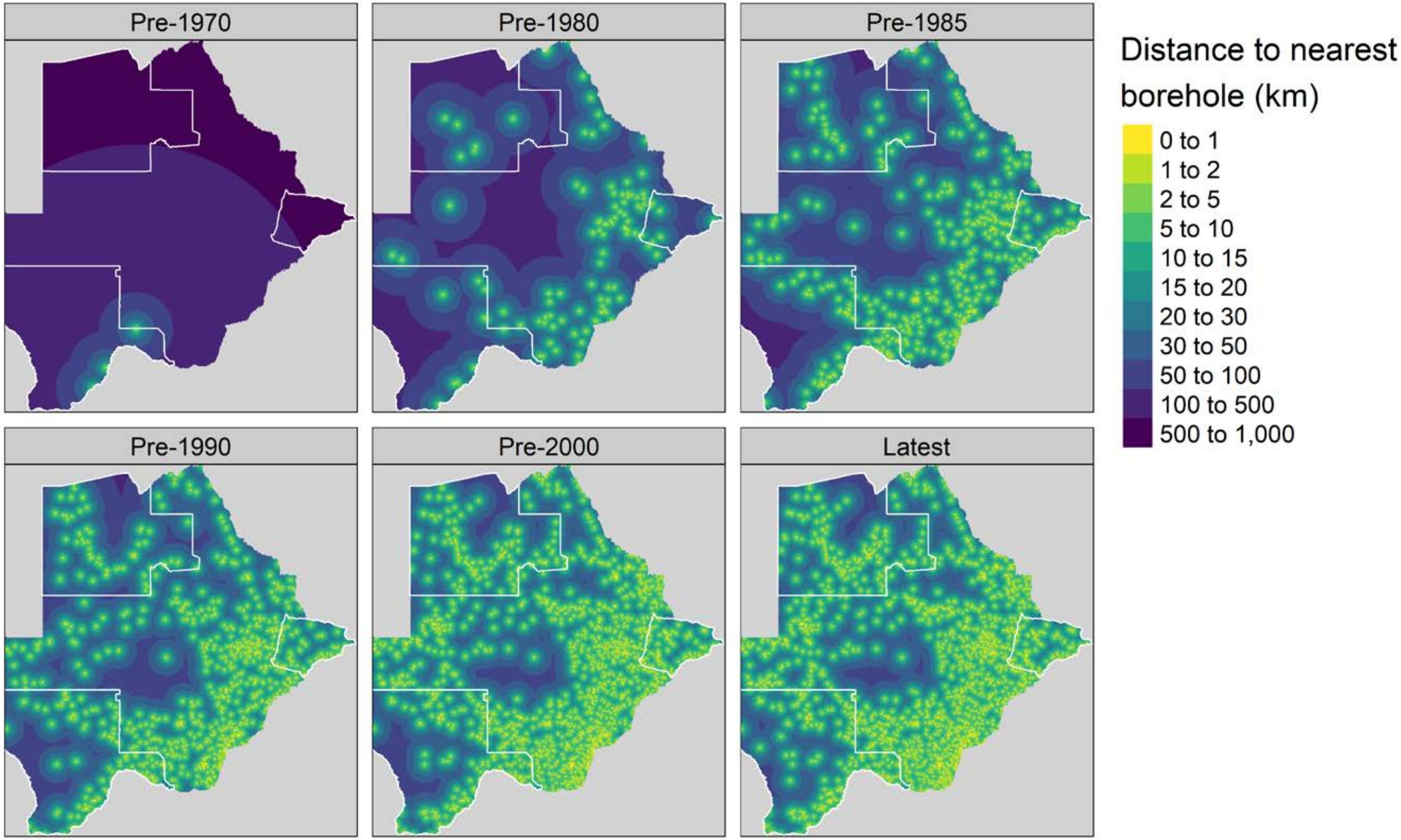

Figure 19. Distance to nearest registered borehole in Botswana over time, separated into six epochs. Data source: Botswana Department of Water Affairs

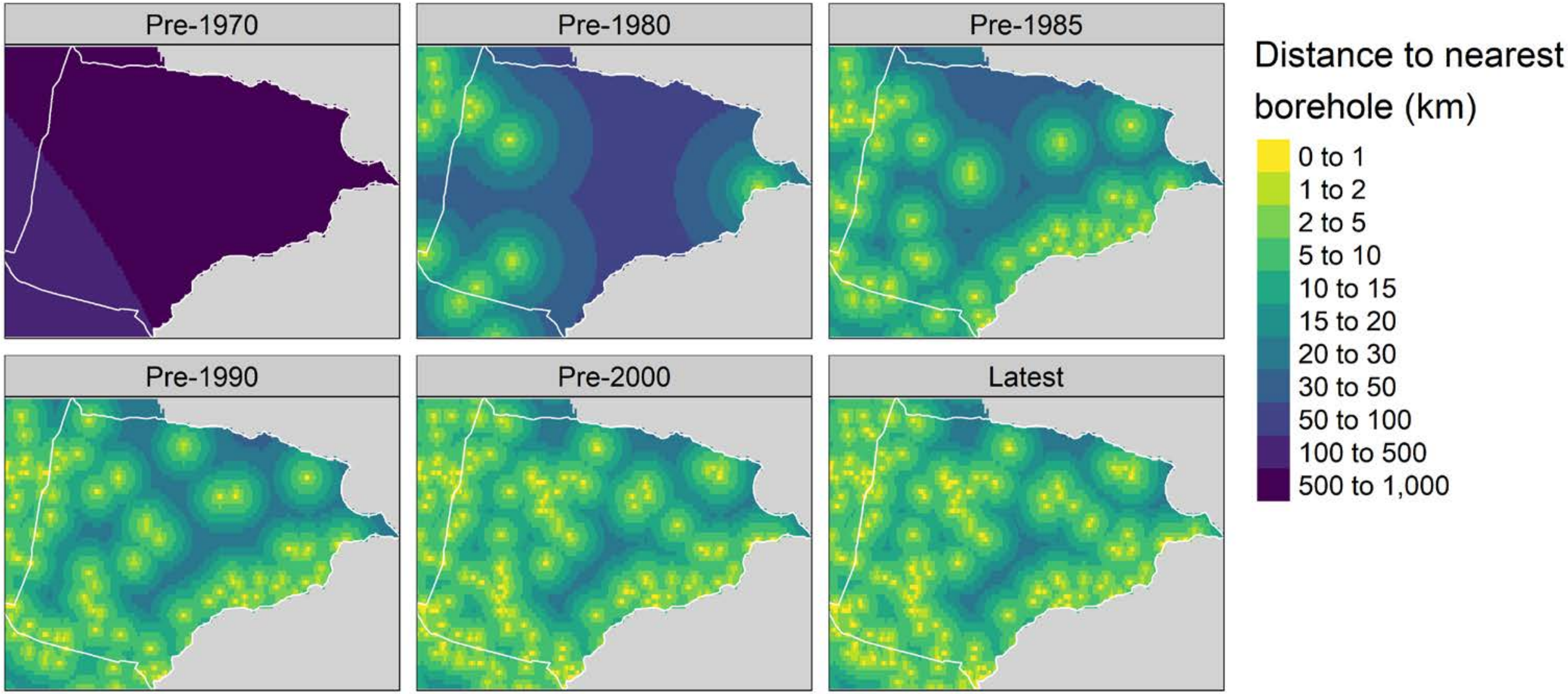

Figure 20. Distance to nearest registered borehole in Bobirwa over time, separated into six epochs. Data source: Botswana Department of Water Affairs

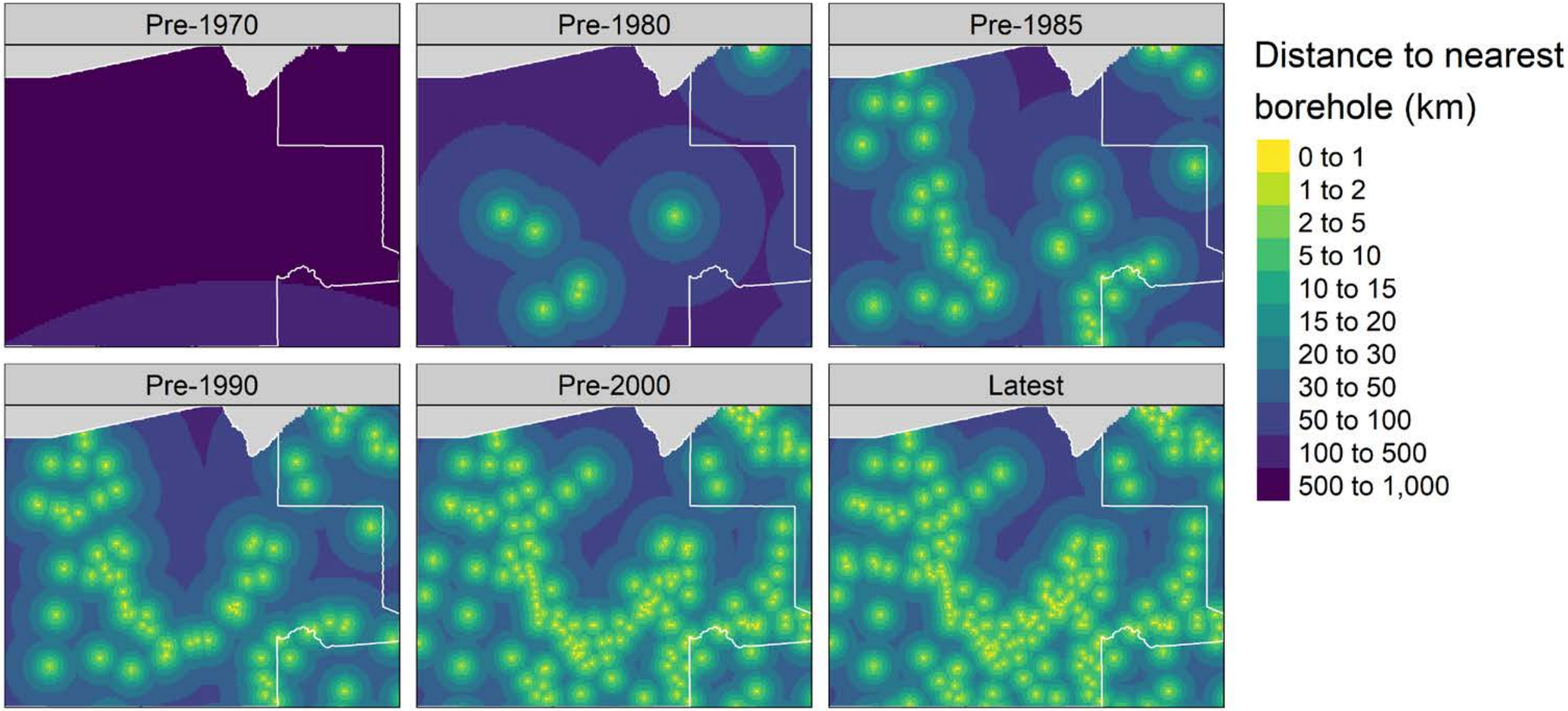

Figure 21. Distance to nearest registered borehole in Ngamiland over time, separated into six epochs. Data source: Botswana Department of Water Affairs

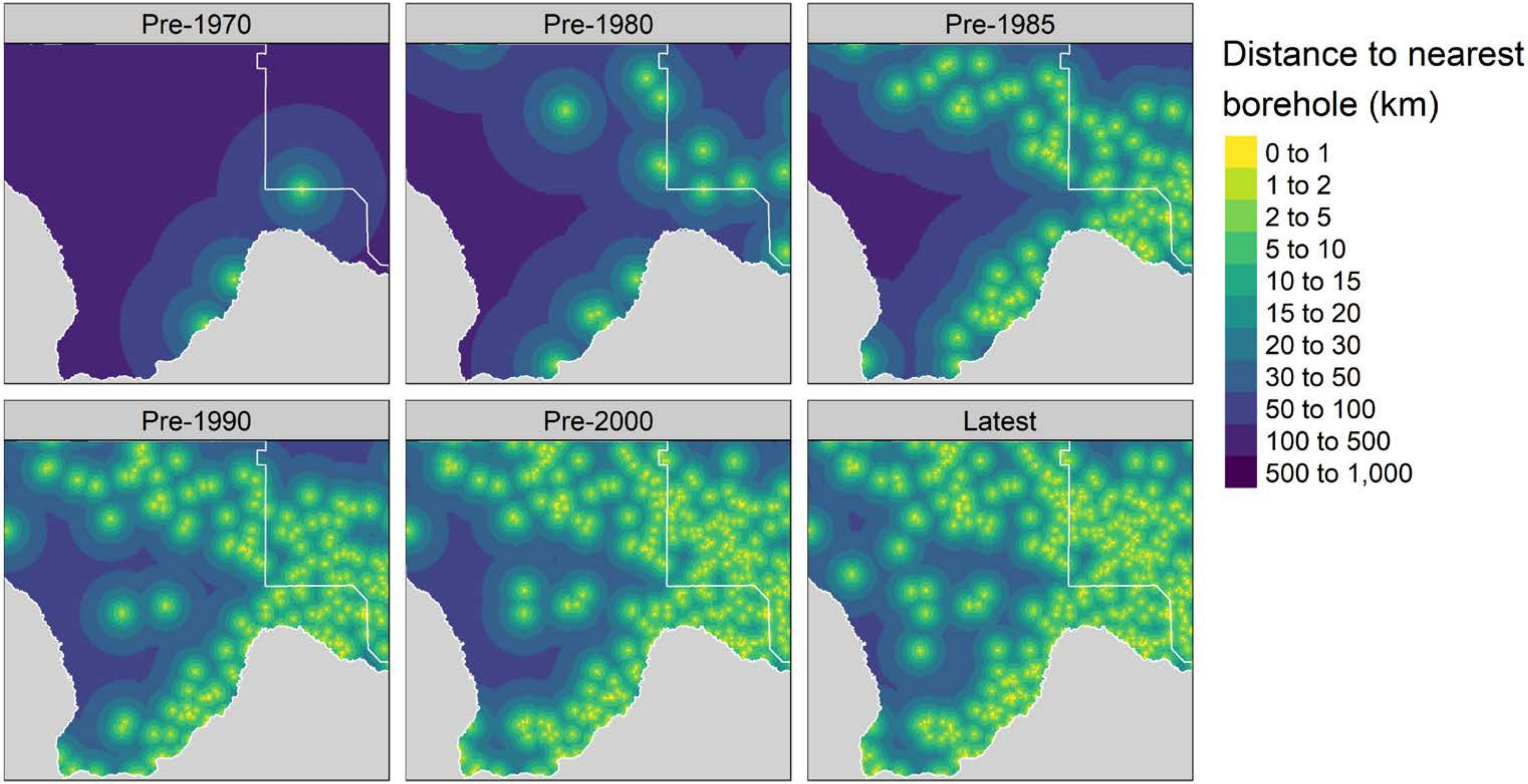

Figure 22. Distance to nearest registered borehole in Kgalagadi over time, separated into six epochs. Data source: Botswana Department of Water Affairs

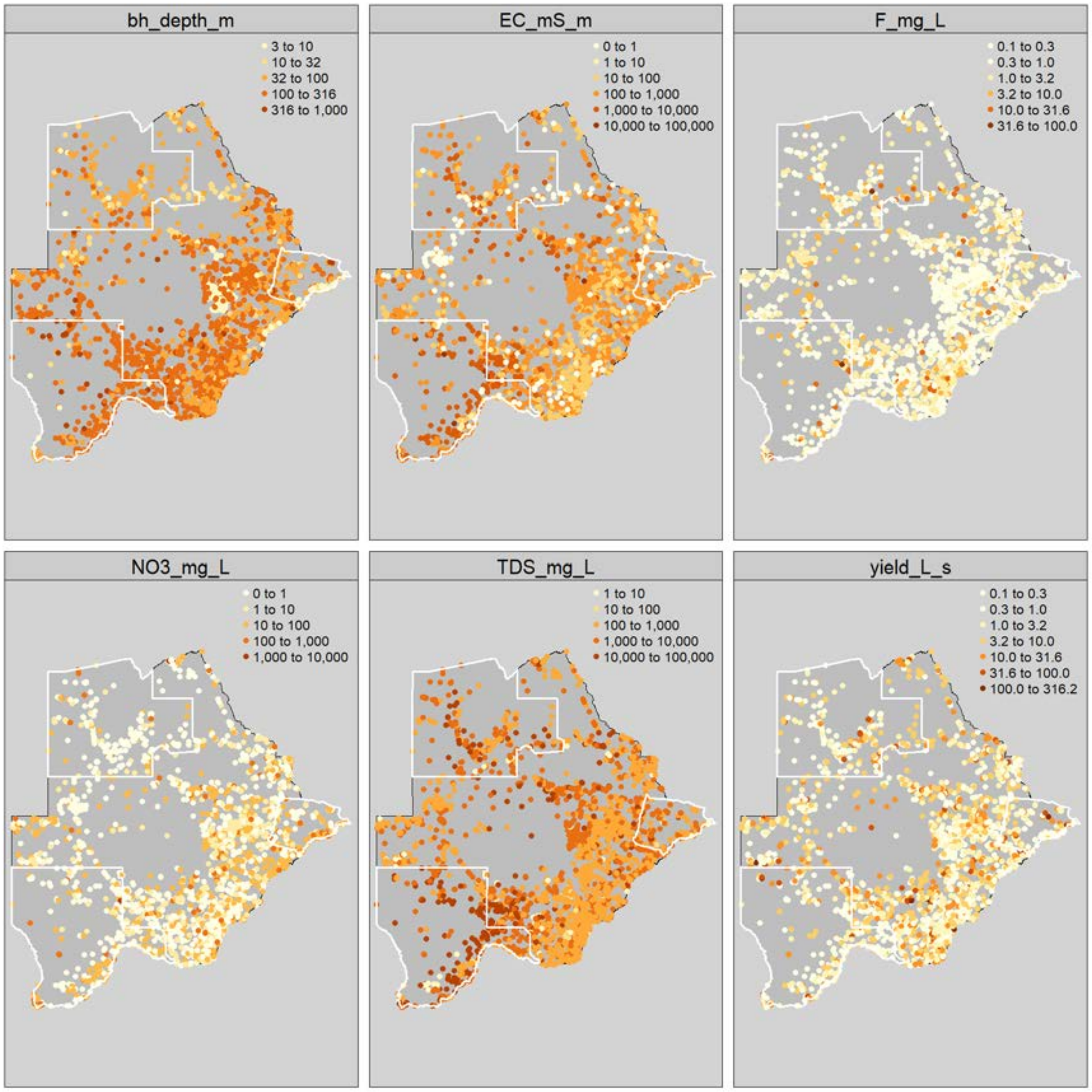

Figure 23. Borehole water depth (top left), yield (bottom right), and quality (EC (top middle), F (top right), NO_3 (bottom left) and TDS (bottom middle)) in Botswana. Data source: Botswana Department of Water Affairs

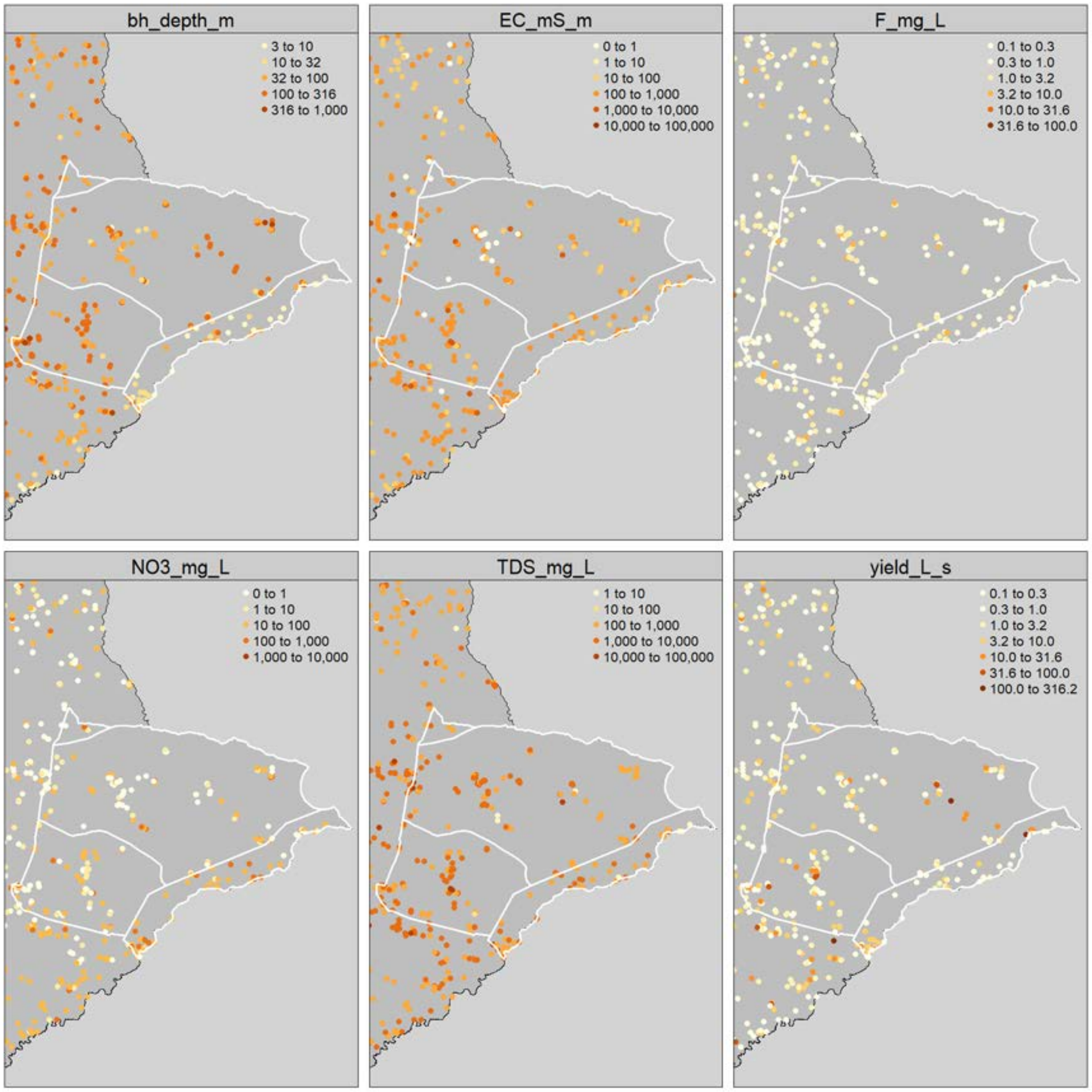

Figure 24. Borehole water depth, yield, and quality (EC, F, NO_3, TDS) in Bobirwa. Data source: Botswana Department of Water Affairs

Figure 25. Borehole water depth, yield, and quality (EC, F, NO_3, TDS) in Ngamiland. Data source: Botswana Department of Water Affairs

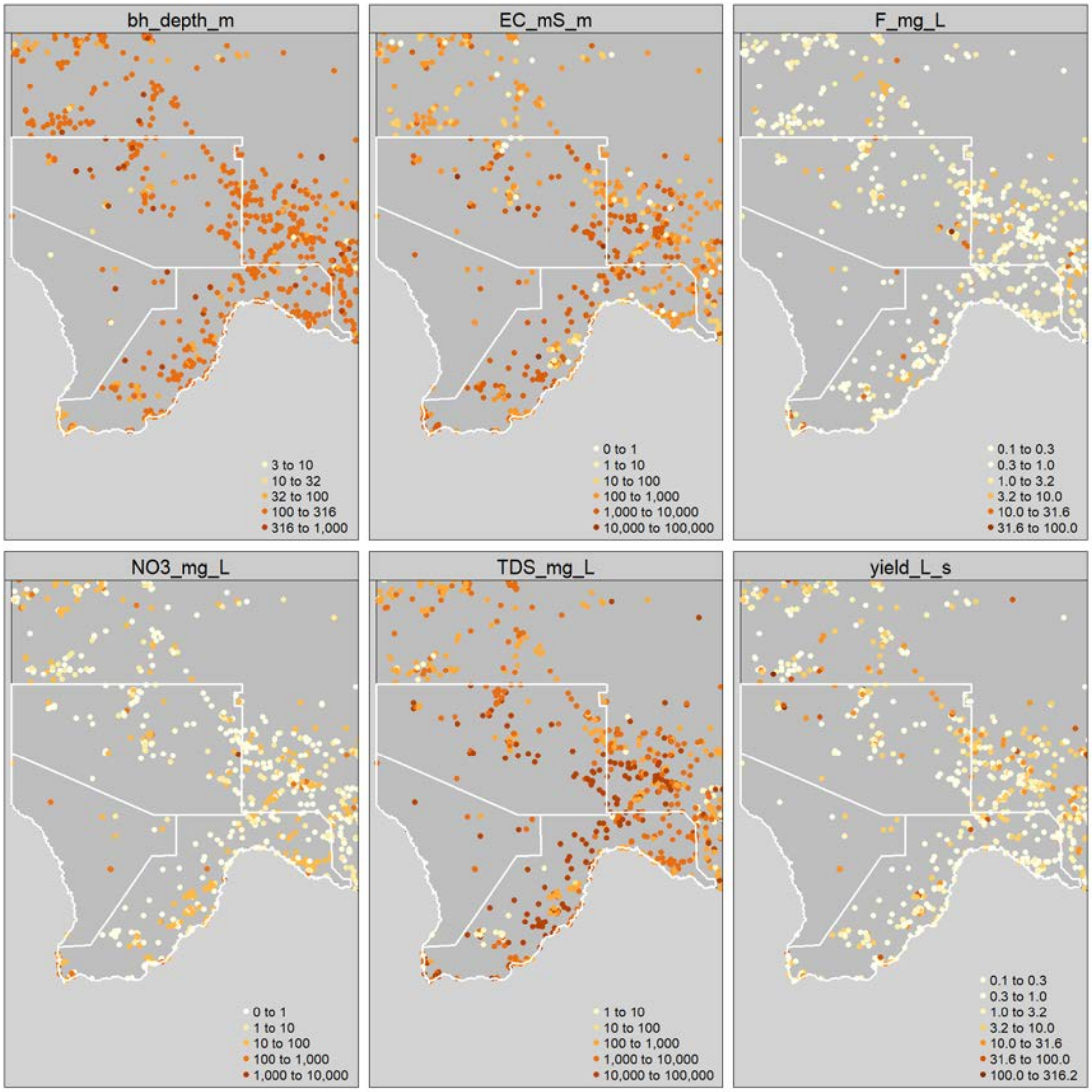

Figure 26. Borehole water depth, yield, and quality (EC, F, NO_3, TDS) in Kgalagadi. Data source: Botswana Department of Water Affairs

5.4 Drought impacts

1. Meteorological droughts are natural phenomena that occur when precipitation is significantly below the average levels[196]. Drought characteristics such as severity, duration, intensity and return interval can vary considerably (Figure 27), with concomitant differences in the impact of a given drought event. A Climpact[197] analysis of the historical and projected standardised precipitation-evapotranspiration index (SPEI) shows that meteorological droughts are expected to worsen in Botswana across every characteristic under even the most optimistic climate change scenarios (Figure 28 to Figure 32)[198]. This will reduce the resilience of rangeland ecosystems to the impacts of grazing and fire, likely resulting in accelerated degradation cycles under current management regimes. Rural "last-mile" communities are likely to be disproportionately impacted by these changes due to their limited baseline adaptive capacity, access to drought relief programmes or alternative livelihoods.

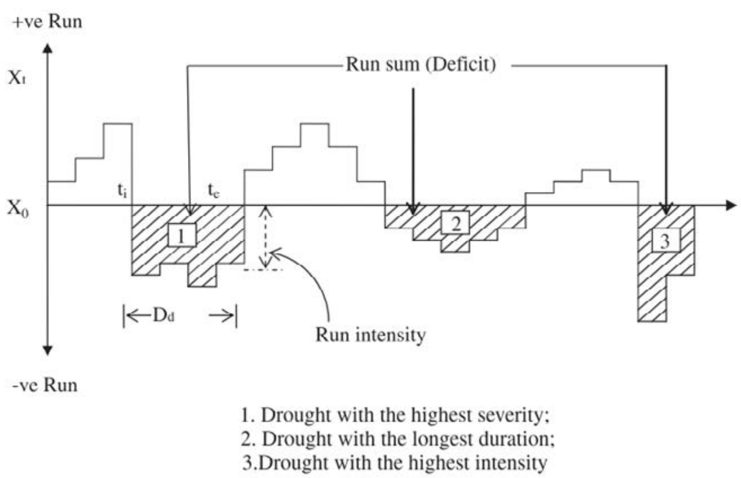

Figure 27. Meteorological drought characteristics[199].

Severe drought impacts are already evident in many rangeland systems across the country. One or more abnormally low precipitation years relative to the long-term mean have been recorded in each decade since the 1960s, with a notable multi-year drought occurring between 1982 and 1987[200]. At the height of the mid-1980s drought, the national extent of rangelands categorised as being in very to extremely poor condition reached 40%, compared with the baseline extent of approximately 3%[201]. Compared with the spatial variability in precipitation amount and variability across the country, severe meteorological droughts occur at sub-national scales more regularly than major national droughts such as that of the 1980s[202].

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[196] UNEP, *Geo Year Book 2006: An Overview of Our Changing Environment* (Nairobi, Kenya: United Nations Environment Programme, 2006).

[197] https://climpact-sci.org/

[198] See Section 1: Climate Vulnerability Assessment Report

[199] Ashok K. Mishra and Vijay P. Singh, "A Review of Drought Concepts," *Journal of Hydrology* 391, no. 1–2 (2010): 202–16, https://doi.org/10.1016/j.jhydrol.2010.07.012.

[200] Government of Botswana, "Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) Ministry of Environment, Wildlife and Tourism."

[201] Vanderpost et al., "Satellite Based Long-Term Assessment of Rangeland Condition in Semi-Arid Areas: An Example from Botswana."

[202] See Section 1: Climate Vulnerability Assessment Report

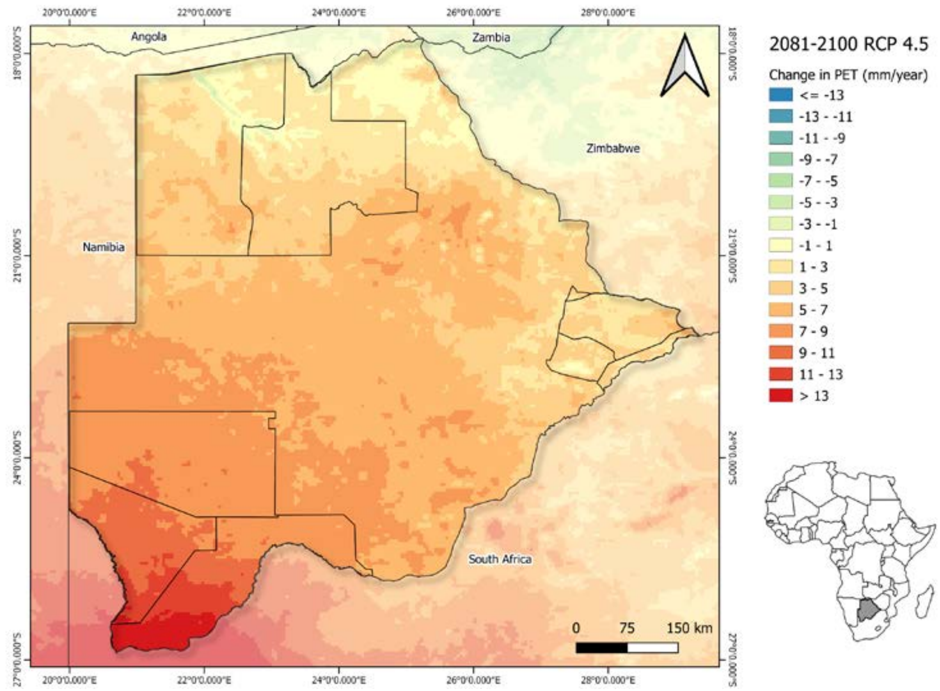


Figure 28. Projected change in average potential evapotranspiration (PET) for the period 2081–2100 under RCP 4.5 emission scenario using an ensemble of six GCMs.

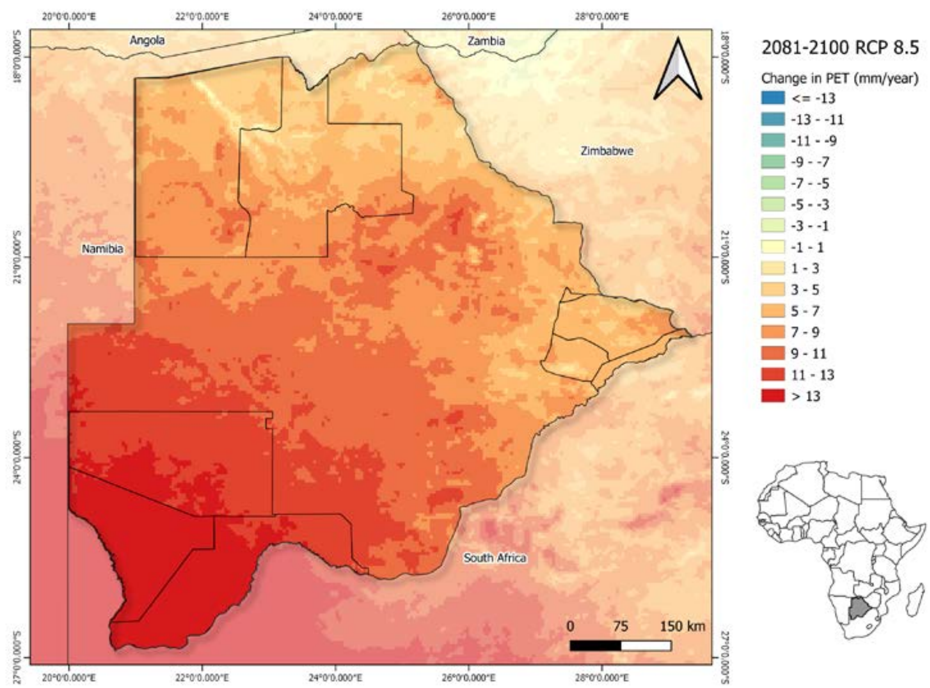


Figure 29. Projected change in average potential evapotranspiration (PET) for the period 2081–2100 under RCP 8.5 emission scenario using an ensemble of six GCMs.

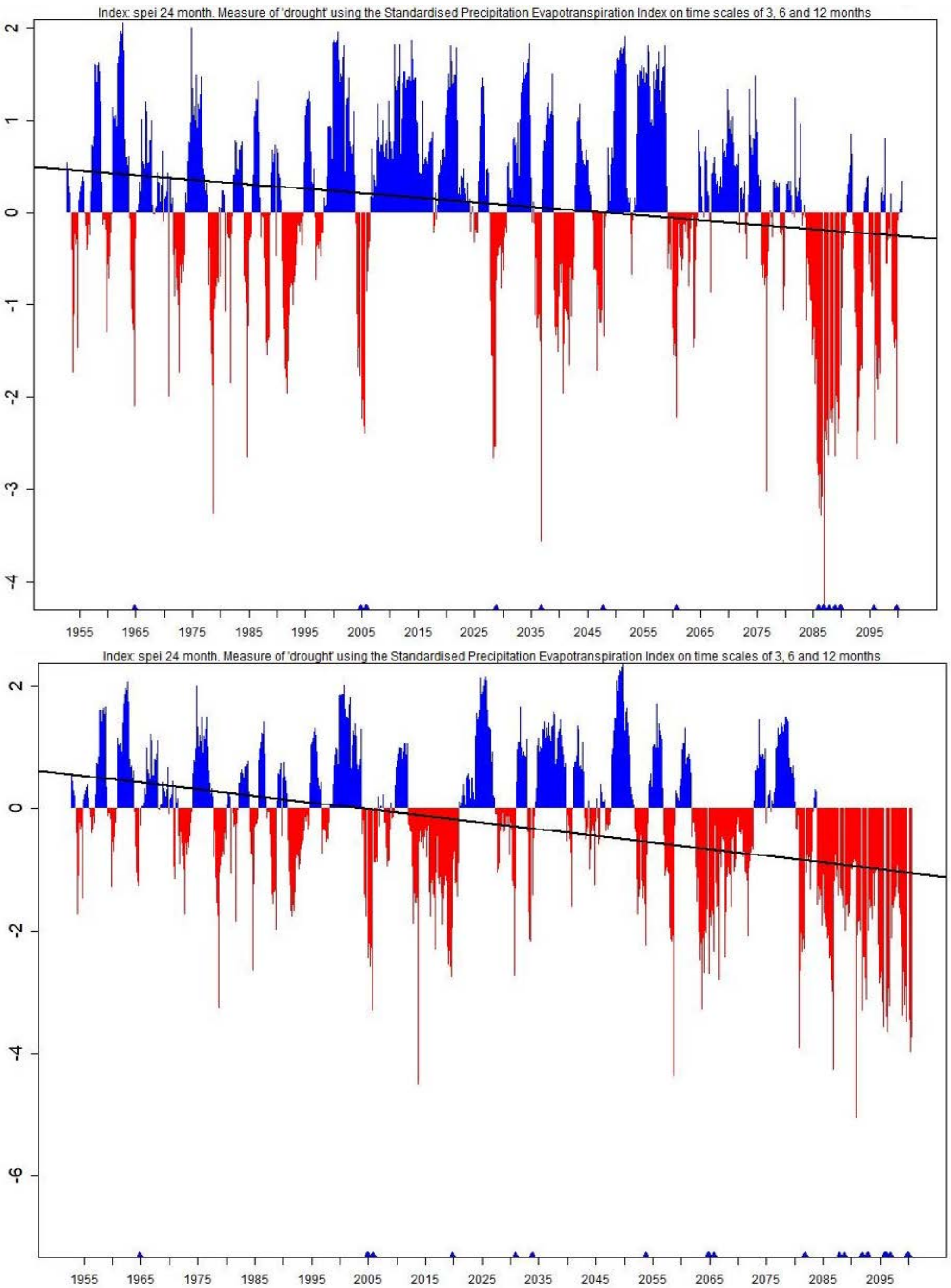
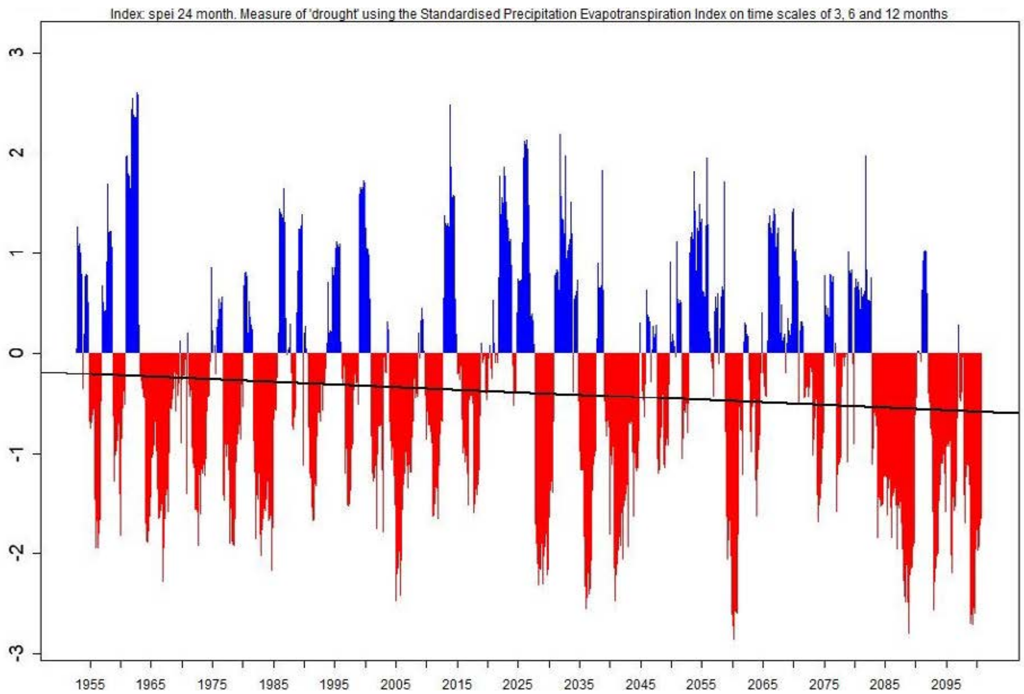


Figure 30. Standardised Precipitation-Evapotranspiration Index (SPEI) from 1951 to 2100 for Bobirwa, Botswana under RCP 4.5 (top) and RCP 8.5 (bottom) emissions scenarios using the median of 10 GCMs.



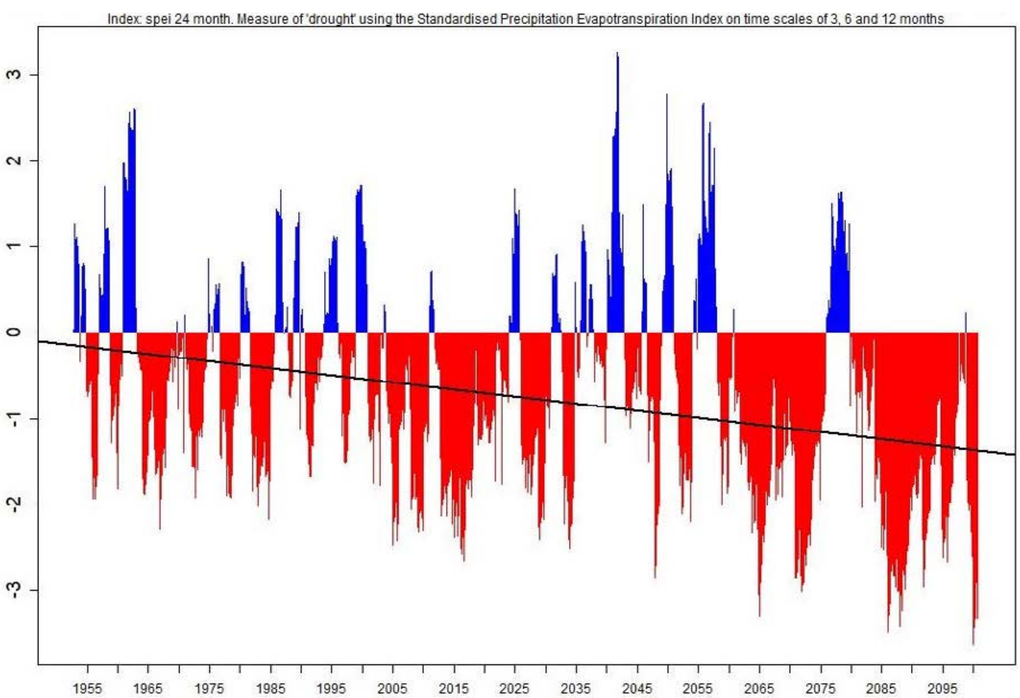


Figure 31. Standardised Precipitation-Evapotranspiration Index (SPEI) from 1951 to 2100 for Ngamiland, Botswana under RCP 4.5 (top) and RCP 8.5 (bottom) emissions scenarios using the median of 10 GCMs.

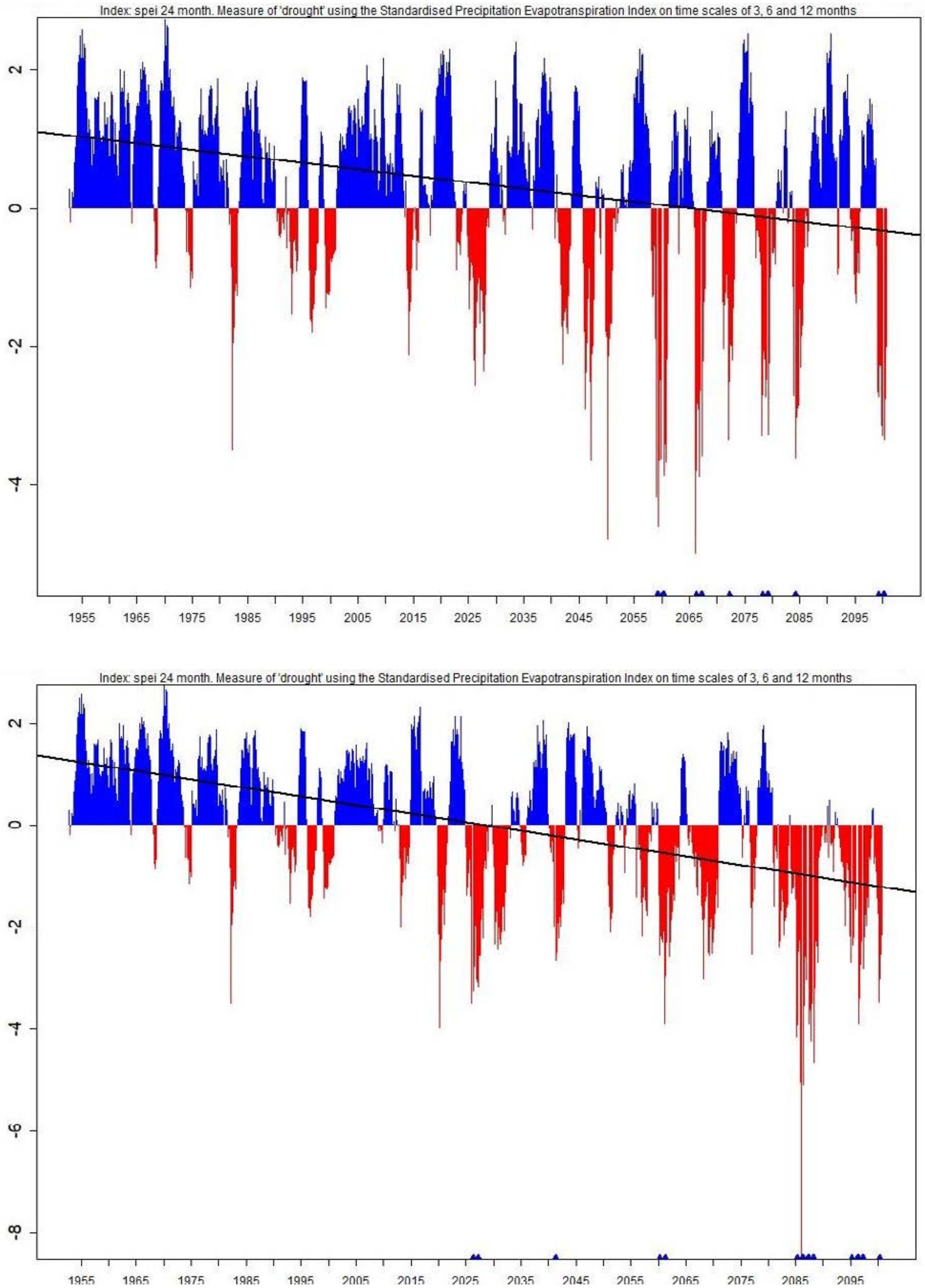


Figure 32. Standardised Precipitation-Evapotranspiration Index (SPEI) from 1951 to 2100 for Kgalagadi, Botswana under RCP 4.5 (top) and RCP 8.5 (bottom) emissions scenarios using the median of 10 GCMs.

Irrespective of the incidence of local meteorological droughts, hydrological droughts can occur when there is a period with inadequate surface or sub-surface water resources for established uses[203]. For example, the Okavango Delta is a critical surface water source that has been drying as a result of upstream climate, land use and development changes rather than just as result of local precipitation deficits. Likewise, hydrological inputs from the many transboundary rivers and groundwater aquifers can be reduced despite average precipitation being received locally. In addition to impacting available potable water, hydrological droughts can result in reduced soil moisture availability, streamflow, ecosystem function, forage production and number of water access points, as well as increased human-wildlife conflict and incidence and spread of diseases or pests between wildlife and livestock populations.

In the same way that meteorological and hydrological droughts are related but can occur independently of one another, the occurrence and severity of agricultural droughts are not solely dependent on hydrology. Rangeland condition determines the sensitivity of the communal livestock sector to agricultural droughts, following meteorological or hydrological drought events. Agricultural droughts are commonly defined based on the soil moisture deficit in the root zone, which impacts the supply of moisture to vegetation[204]. If soil moisture is still available during a meteorological or hydrological drought, then the impact on ecosystem and agricultural health remains limited. Soil moisture availability is not dependent only on the hydrology (water supply), but also on the evapotranspiration (water demand) to which a given system is exposed. An assessment of the number and duration of heatwaves[205] in the three project areas between 1951 and 2100 indicate that they are both expected to intensify under RCP 4.5 and RCP 8.5 emissions scenarios.

To avoid crop failures, soil moisture can be maintained through climate-resilient agricultural practices, but these agricultural interventions are not technically feasible or ecologically viable in an extensive rangeland context dependent on ecological processes for livestock fodder production. To avoid rangeland degradation, improved land and livestock management practices are required (Figure 35)[206,207]. The improvement in rangeland productivity is aligned with enhanced resilience to the impacts of drought. As described in *Section 3: Drivers of rangeland degradation*, the management interventions that lead to virtuous cycles such as greater forage production, increased grass species diversity, reduced bare ground degradation, reduced bush encroachment degradation and improved ecosystem function[208,209]. Detailed descriptions of the climate-resilient land and livestock management practices being implemented under this project are provided in Output 2.2[210]. The economic benefits of improved management practices, therefore, include avoided losses to climate impacts such as drought in addition to improved livestock production (Figure 35).

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[203] UNCCD, "Drought Impact and Vulnerability Assessment: A Rapid Review of Practices and Policy Recommendations" (Bonn, Germany, 2019).

[204] UNCCD, "Drought Resilience, Adaptation and Management Policy Framework: Supporting Technical Guidelines" (Bonn, Germany, 2019).

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[210] See Section E of the Funding Proposal

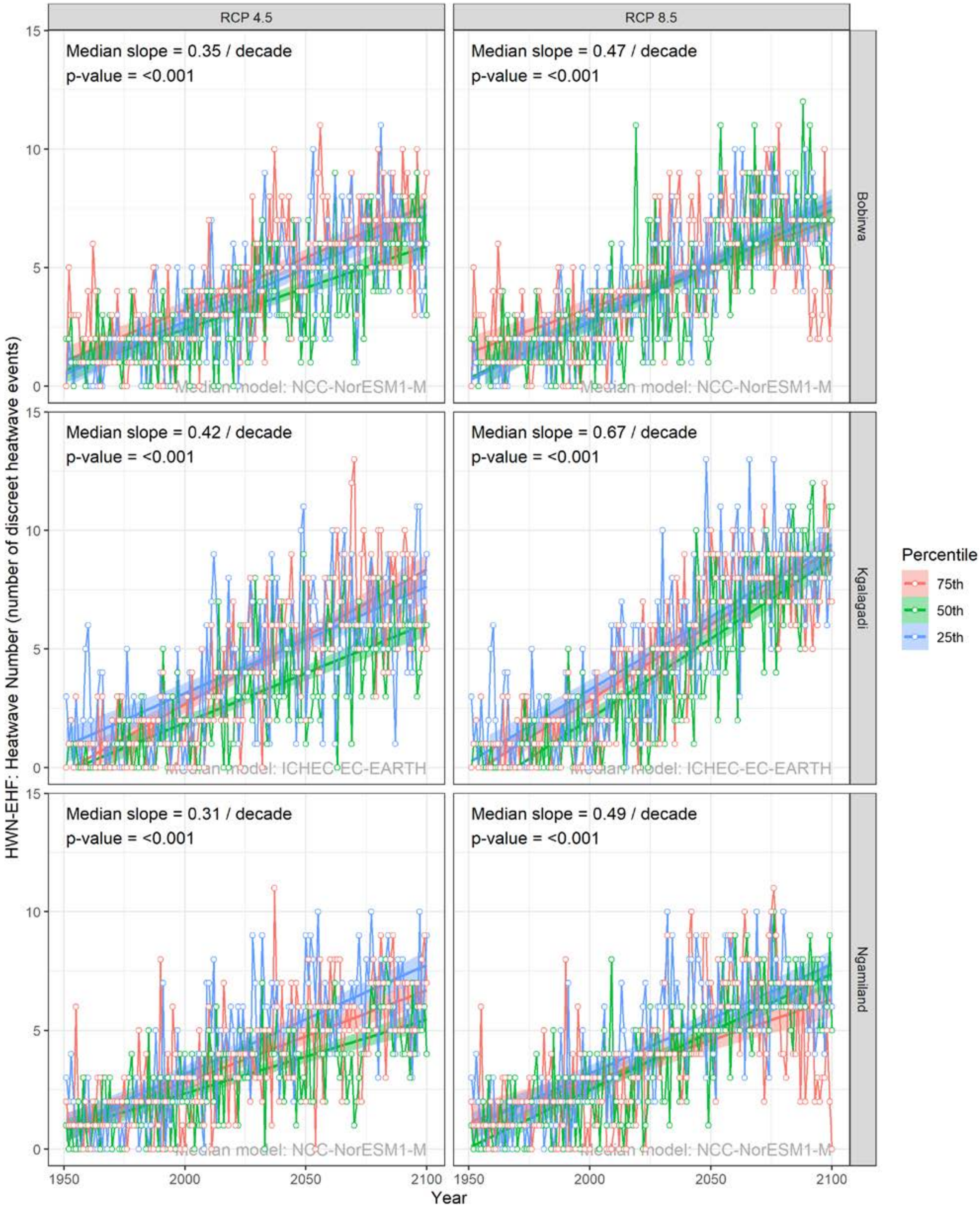

Figure 33. Number of discrete heatwave events per month in Bobirwa (top), Kgalagadi (middle) and Ngamiland (bottom) under RCP 4.5 (left) and RCP 8.5 (right) emission scenarios between 1951 and 2100.

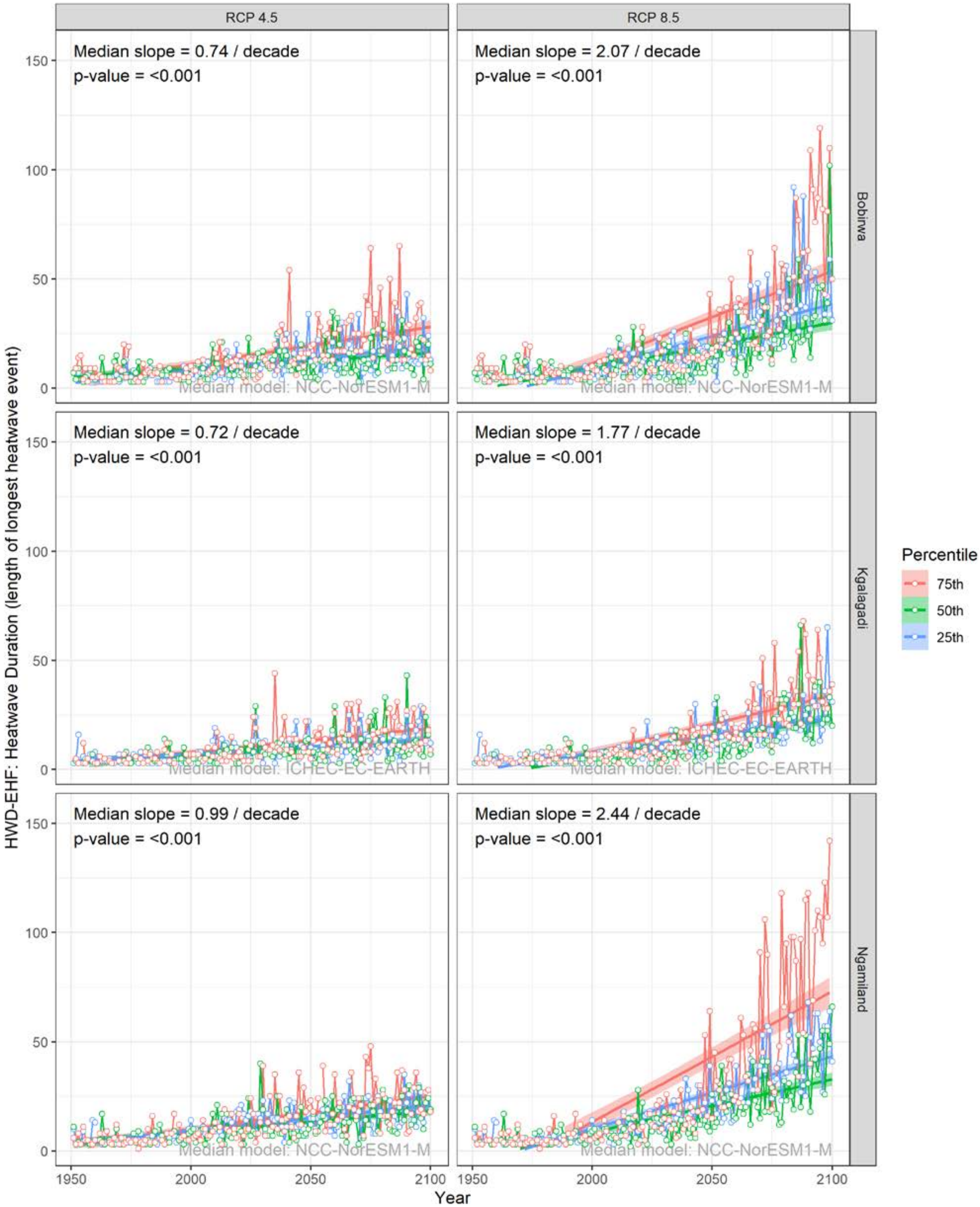

Figure 34. Duration (days) of longest heatwave events per month in Bobirwa (top), Kgalagadi (middle) and Ngamiland (bottom) under RCP 4.5 (left) and RCP 8.5 (right) emission scenarios between 1951 and 2100.

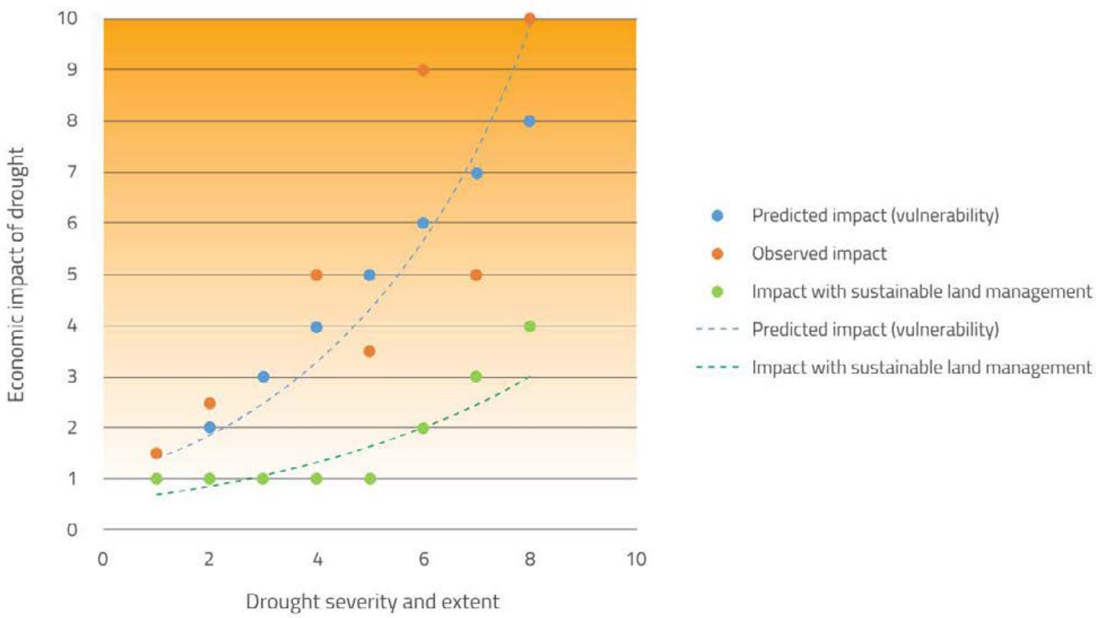

Figure 35. Illustrative representation of drought impact with and without sustainable land management interventions[211].

The greater the severity, duration, intensity and frequency of drought events, the more serious the impacts would be on the livestock sector under the business-as-usual scenario, relative to the project scenario[212]. Despite the conformity in climate models about the directionality of these drought characteristics, no climate model can forecast the precise sequence or incidence of droughts. To quantify the costs and benefits of the project implementation scenario relative to business-as-usual, the impacts of drought on the communal livestock sector has been modelled[213]. Simplified and conservative assumptions have been made in order to avoid the irreducible uncertainty and ecological complexity associated with the projections[214], as described below.

The probability of wildlife-livestock contact during a drought is greater, thereby increasing the risk of disease outbreaks. African buffalo, for example, are understood to act as a host population for Foot and Mouth Disease (FMD) in Botswana[215]. Rangeland resources are constrained during drought events, including access to surface water points. A reduction in the number of water access points for wildlife and livestock increases the probability that the remaining sources, artificial or otherwise, will be visited by both populations under the business-as-usual scenario. Regulations around local transport and sale of livestock as well as international meat exports to premium markets are responsive to the risk of disease outbreaks such as FMD[216]. The risk of

[211] UNCCD, "Drought Impact and Vulnerability Assessment: A Rapid Review of Practices and Policy Recommendations."

[212] Ibid.

[213] See Financial and Economic Analysis

[214] Seth J. Wenger and Julian D. Olden, "Assessing Transferability of Ecological Models: An Underappreciated Aspect of Statistical Validation," *Methods in Ecology and Evolution* 3, no. 2 (2012): 260–67, https://doi.org/10.1111/j.2041-210X.2011.00170.x.

[215] Genevieve V. Weaver et al., "Foot and Mouth Disease: A Look from the Wild Side," *Journal of Wildlife Diseases* 49, no. 4 (2013): 759–85, https://doi.org/10.7589/2012-11-276.

[216] Sunita Menoin, "Foot-and-Mouth Disease Already Having 'Devastating' Impact on Trade," Business Day, 2019, https://www.businesslive.co.za/bd/national/2019-01-14-foot-and-mouth-disease-already-having-devastating-impact-on-trade/.

disease outbreaks is reduced when livestock are professionally herded or under improved management practices, including regular vaccinations. The model predictions, therefore, can be considered conservative by excluding the potential regulatory or market responses to drought events.

Consecutive drought events compound the impacts on rangelands and the livestock sector. Where forage production is reduced, reserve areas and undesirable forage species are utilised, often with less efficiency than in non-drought periods. There is a lag period following a drought in which the forage production and reserves accumulate back up to baseline conditions. If the return interval

between drought periods is too short for full rangeland recovery to occur, then there would be little to no buffering of the drought impacts. This leads to greater impacts on the livestock sector following the second drought relative to the first. The model predictions, therefore, can be considered conservative by excluding interactions with prior or subsequent drought events.

The baseline rangeland condition is unlikely to support the existing communal sector stocking rate. As a result of climate-related drivers described in *Section 3: Drivers of rangeland degradation*, the carrying capacity of rangelands in Botswana have been reduced, leading to increased rangeland degradation and the loss of forage reserves. The case of two game reserves in South Africa (Klaserie Private Nature Reserve and Kruger National Park) offers an example of the implications that differences in the rangeland condition can have in the event of a drought. As a result of the land, water and wildlife management practice used, Klaserie supported more herbivores than the ecosystem could sustainably support, resulting in the homogenisation of the landscape and leaving no areas of reserve forage. Conversely, the limited artificial water point provision and lower wildlife density in Kruger resulted in a more heterogeneous landscape with spatiotemporal variability in the recovery period and grazing pressure exerted on the rangelands. Following the 1982–1983 drought, moderate herbivore mortality (20–30%) occurred at Kruger while losses in Klaserie amounted to 70–90% of the population. The model predictions, therefore, can be considered conservative by assuming that the baseline traditional livestock population are in equilibrium with the rangelands (Table 13), which maintain some ecological integrity and buffer to the impacts of drought.

The Financial and Economic Analysis models the impact of droughts on four scenarios, namely: i) business-as-usual (BAU); ii) improved land and livestock management; iii) improved market access; and iv) the combination of the second and third scenarios.

Figure 36 presents the first and fourth scenario as the business-as-usual and proposed project scenario, respectively.

Table 13. Baseline cattle population, sales, births, deaths, losses and eradication in the traditional sector[217].

Project area	Population	Sales	Births	Deaths, losses and eradication
Bobirwa	62,768	3,716	16,332	6,035
Kgalagadi	69,402	5,000	20,414	10,801
Ngamiland	190,187	12,283	50,170	30,362

[217] Statistics Botswana, “Botswana Agricultural Census Report 2015.”

As described above, there is a lag between the start of a meteorological drought, the impacts on rangeland condition and livestock births, deaths, losses and sales. The output of the presented conceptual model (

Figure 36) are the impacts on the livestock population following a single drought, resulting from the changes in births, deaths, losses and sales. A consequence of the assumption that the livestock population is in equilibrium is that the baseline birth, death, loss and sale rates remain constant in the absence of external impacts, such as project interventions or a drought. Relative to the baseline, the BAU scenario experiences no changes until the onset of the meteorological drought.

Following a single year of reduced precipitation, the rate of livestock death, loss and eradication under BAU increases by 15% and accelerate further to a 60% increase by the third drought year. This increase is a result of drought-induced starvation, increased predation, greater disease and pest burdens, increased migration in search of better grazing land and water, which leads to more road accidents, and the eradication of livestock suffering from or at extreme risk of infectious diseases. Following the drought period, the rate livestock death, loss and eradication stabilise and starts recovering back to the baseline rate over approximately the same duration as the drought period.

The number of births during the drought period reduces under BAU as livestock condition starts deteriorating, therefore reducing the fertility and weaning rates. The decline relative to the baseline rate is tempered to a degree by the concomitant decline in the total population number. Following the drought period, however, the availability of grazing forage increases before the livestock numbers return to baseline levels, improving the fertility and weaning success. Once the livestock population stabilises from the increased number of births and declining death, loss and eradication rate, the births stabilise back to the baseline rate.

Livestock sales are impacted by the incidence of drought primarily in two ways: i) a reduction caused by an oversupply of meat from the commercial sector; and ii) a further reduction as livestock condition deteriorates. Commercial farmers with greater market access and who receive early warnings of droughts increase their livestock sales as the drought period begins in order to reduce stocking rates and to subsidise the loss of income during the height of the drought. This is exacerbated by commercial livestock that would ordinarily be exported to premium international markets being sold on the local discount markets as their condition and quality deteriorates.

Under the project scenario, increased production from improved land and livestock management is projected to increase the number of births and reduce the rate of livestock death, loss and eradication relative to the baseline prior to the onset of the drought period. This is attributed to: i) reduced disease and pest burdens from improved vaccination programmes, rotational grazing practices and reduced contact with wildlife populations; ii) reduced predation because of corralling at night and the presence of professional Ecorangers; iii) supplementary fodder provision from bush clearing; iv) increased forage production and forage reserves following the recovery afforded to the rangelands in the rest camps; and v) reduced livestock theft because of the aggregation of all free-roaming cattle into actively managed herds.

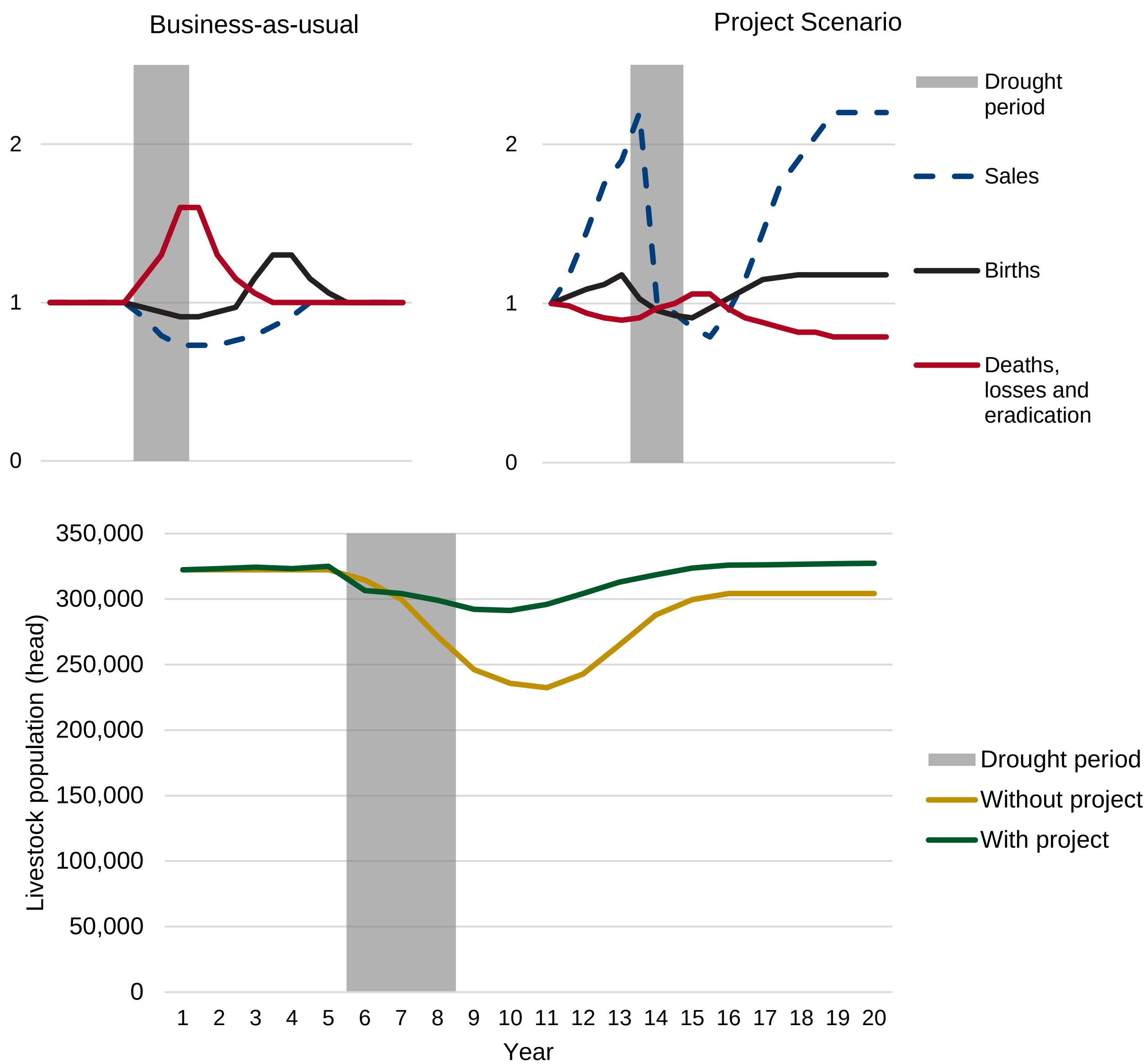

Figure 36. Indicative livestock population (bottom) and relative sales, births, deaths, losses and eradication in response to a single drought event over a 20-year period under business-as-usual (top left) and the project scenario (top right)[218].

Livestock sales are projected to rise in proportion to the increased births and avoided deaths, losses and eradication. This is facilitated by improved market access, which increases the incentive to meet the demand from premium local and export markets, almost doubling the number of sales, relative to the baseline. Greater market access enhances the adaptive capacity of communal farmers to respond to the onset or projection of droughts. In the first year of the drought period, enhanced access to markets allow communal farmers to employ the same strategies as their commercial counterparts — reducing the number of livestock by accelerating

[218] See Financial and Economic Analysis

the number of sales and lessening the grazing pressure on the rangelands during the drought period.

The increase in livestock losses and reduction in births is tempered under the project scenario relative to BAU. This is achieved by the combination of reduced livestock numbers during the height of the drought, greater forage reserves from improved land and livestock management leading up to the drought and the reduced livestock-wildlife contact from active herding by Ecorangers. Livestock sales are still considerably reduced during the height of the drought, but reverts back to pre-drought levels faster than is projected to occur under BAU.

Based on the described model assumptions, the communal livestock sector is projected to be considerably more resilient to drought impacts under the project scenario than under BAU. Livestock losses are projected to be only 10% under the project scenario, compared with 28% under BAU. The economic analysis found that the net present value of the project scenario would be an order of magnitude greater than under BAU.

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Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands

Annex 2 - Feasibility Study

Section 4: Project Approach and the Herding for Health Model

Prepared by Conservation International and C4 EcoSolutions through a Project Preparation Facility (PPF) Grant from the Green Climate Fund – V.2 September 2020

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1. PROJECT BACKGROUND

Climate change and lack of investments in land and livestock management has led to extreme degradation of natural resources in Botswana's communal lands. Eighty percent of the non-protected area land is commonage land that is rangeland and used by Botswana peoples with deep cultural attachments with livestock farming. The country low and variable rainfall, poor soils, exposure to regular droughts and proximity to wildlife make agriculture impossible in most areas[1] and current fence-based management practices are ill-suited for promoting mobility required for wildlife and livestock in the face of increased climate variability and stress and lead to degradation that increases land and livestock GHG emissions. Increased pressure on land over the last decades has transformed extensive areas of productive natural pastures into dense shrub savannas dominated by *Dichrostachys cinerea* (sickle bush), *Senegalia mellifera* (black thorn) and *Vachellia tortilis* (umbrella thorn) referred to as bush encroachment. Increased frequency of droughts is driving farmers into areas once left for "wilderness" and the impacts on wildlife have been devastating as both predators and bushmeat species are hunted in order to survive. While efforts to expand ecotourism in the country are increasing, natural heterogeneity; socio-political issues; and, in some communities, lack of interest limit the ability of tourism to support all vulnerable communities,[2] the majority of the communal land is trapped in a cycle of mutually reinforcing ecosystem degradation and poverty. Impacts of climate change are already exacerbating the downward cycle, and further changes projected for the area are likely to be devastating for both people and nature unless innovative solutions can be found.

The idea for the proposed GCF Project started at a Gaborone Declaration for Sustainability in Africa meeting in November 2016. The former focal point, Tsalano Kedikiliwe asked that GDSA engage Botswana stakeholders to develop a concept for the Green Climate Fund based on a presentation of the Herding for Health model that Conservation International was deploying in Southern Africa. The GDSA staff member at the time, Tiego Mpho, and Dr Olaotswe Kgosikama were contracted to develop the concept and CI provided technical support based on its Southern African experience. The concept was endorsed by the former director of Botswana's Office of the President Poverty Eradication Unit who saw the programme as an opportunity to alleviate poverty and transform the lives of the most destitute in communal areas—poor farmers, female headed households with limited livestock knowledge, and herders. Once the GCF approved the concept, CI invested in an independent assessment of feasibility of the use of conservation agreements in Botswana (Appendix 4.16) and simultaneously prepared a request for GCF project preparation funding in 2018 to inform the design of a full proposal with the Ministry of Environment, Natural Resources, and Tourism (MENT). However, by the time of the PPF approval, there was a new NDA and it was felt the project should relocate from MENT to the Ministry of Agriculture and Food Security (MoA). Conservation International launched an extensive preparation and consultation process with and on behalf of the new lead organisation, the MoA in June 2019 (Figure 1).

[1] Seleka, Tebogo Bruce. (1999). The Performance of Botswana's Traditional Arable Agriculture: Growth Rates and the Impact of the Accelerated Rainfed Arable Programme (ARAP). Agricultural Economics. 20. 121-133.

[2] Mbaiwa, Joseph. (2015). Ecotourism in Botswana: 30 years later. Journal of Ecotourism. 14. 1-19.

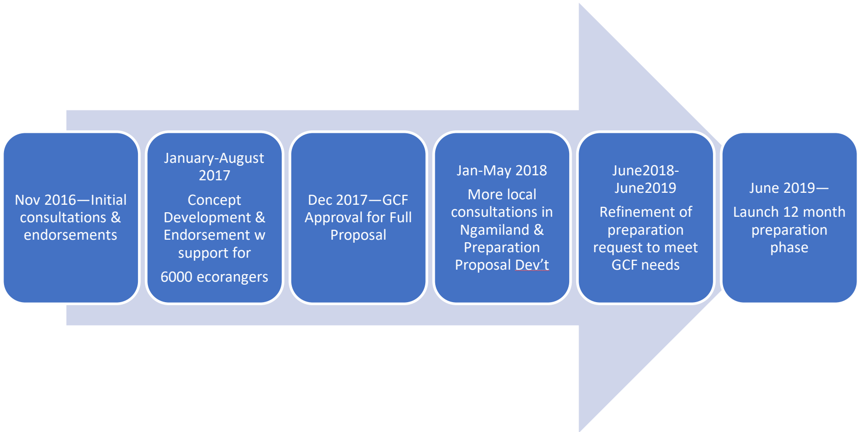

Figure 1. Project development process

Analysis of Prior and Ongoing Projects in Botswana:

The Project preparation phase enabled extensive consultation and review of past project documentation to ensure lessons from similar or complementary initiatives were embedded in the project design. A summary of the key projects and their links to the proposed GCF project is provided below:

Project Name	Human-Wildlife Co-existence Forum Northern Botswana
Funder	GEF- World Bank
Timeframe	November 2009 – January 2016
Amount of Financing	$5.5 million
Objectives/Impact Achieved (for historic project	Goal: Decrease in human-wildlife conflict, particularly for elephant and crop farmers and lions and livestock farmers Impact: As summarized in the project final report, “Weather influences prevented reduction in conflict with either species and increases in conflict with lion increased during the last three years of the project”. Increased employment in the tourism sector was substantial and included previously excluded tribes. However, this did not translate in a reduction in negative wildlife impacts or farming household livelihood improvement
Linkage/Relevance to Current Project Proposal	The project will adopt and integrate low cost HWC deterrents such as kraaling, the use of chilli pepper, noise and light techniques within the grazing management processes implemented by ecorangers. More importantly, the project will benefit from the awareness of HWC issues across the tourism sector in Ngamiland to generate support and demand for “wildlife-friendly livestock products” and associated industries.

Project Name	Southern Africa Regional Environment Programme (SAREP)
Funder	USAID
Timeframe	June 2010 - December 2016
Amount of Financing	$4.1 million over three countries

Objectives/Impact Achieved (for historic project	Goal: To protect the environment and improve livelihoods in the Okavango River Basin Impact: 42 CBNRM plans completed; LUCIS System for Land Use Conflict Decision Making; Improved water supply for 30,348 people;
Linkage/Relevance to Current Project Proposal	The Project will utilize information generated in the Ngamiland Land Use Plan and Strategic Environmental Assessment developed under this project to inform land-use plans for Rangeland Stewardship Agreements. It will also build on and integrate with the LUCIS system as part of the Rangeland Stewardship Information Portal. (Note: LUCIS was adopted in Ngamiland as an outcome of this project and the GEF-UNDP SLM project in Kgalagadi and Ghanzi are now also conducting training in these regions on the system).

Project Name	ASSAR Adaptation at Scale in Semi-Arid Areas: Botswana Country Study, with a particular focus on Bobirwa
Funder	IDRC and DFID--Collaborative Adaptation Research Initiative in Africa and Asia
Timeframe	December 2014 – November 2018
Amount of Financing	N/A
Objectives/Impact Achieved (for historic project	Goal: Generating multi-scale, interdisciplinary research that improves understanding of barriers and enablers of effective climate adaptation to inform policy and practice. Impact: Consolidation of climate data and participatory research on vulnerability of communities and adaptation strategies of community strategies and government
Linkage/Relevance to Current Project Proposal	Research and community facilitators from the ASSAR team led the PPF stakeholder engagement process with the CI-PPF team to ensure the project was seen as a natural follow-up intervention to the research conducted and the views expressed by the local communities regarding their needs. Insights from resulting papers and discussions the the ASSAR team were profoundly influenced the Projects proposed governance, timeframe, engagement process, and focus of empowering rangeland stewards (Ecorangers, Farmers, Mentor Farmer Champions, Local District Officials) at the forefront of the project implementation plan.

Project Name	Ngamiland Sustainable Land Management Project: Mainstreaming SLM in Rangeland Areas of Ngamiland- District Landscapes for Improved Livelihoods
Funder	GEF-UNDP
Timeframe	May 2015 – Sept 2019
Amount of Financing	$US 2,683,254

Objectives/Impact Achieved (for historic project	Goal: Effective range management in over 1 million hectares improves range condition and flow of ecosystem services to support the livelihoods of local communities in Ngamiland Impact: 120,000ha of improved grazing management; 760,000 under improved fire management surveillance.
Linkage/Relevance to Current Project Proposal	Linking of DFRR and DAP staff; Upscaling and deploying training modules on benefits of regenerative grazing practices, bush fodder, and community-based fire management within and through the Rangeland Stewardship Agreement development process and Ecoranger Training.

Project Name	Gap Analysis for the Implementation of Commodity-based Trade in Ngamiland
Funder	Animal and Human Health for the Environment and Development (AHEAD) and the Rockefeller Foundation
Timeframe	2016-2019
Amount of Financing	N/A
Objectives/Impact Achieved (for historic project	Goal: To improve understanding and build capacity to address challenges at the interface of wildlife health, livestock health, and human health and livelihoods in Ngamiland. Impact: Significant farmer and local official awareness of Commodity-based Trade regulations
Linkage/Relevance to Current Project Proposal	The Project responds directly to all recommendations of this project. Specifically, it will utilize the Herding for Health approach and use Ecorangers and grazing support packages to implement the AHEAD Guidelines on Commodity-Based Trade Approaches for Managing Foot and Mouth Disease Risk in Beef in Southern Africa. It will also contribute technological and human resource capacity to support expanded effectiveness of BAITS and CBT and embed climate considerations in all protocols developed.

Project Name	Support Programme to the Economic Partnership Agreement (EPA) Implementation in Botswana
Funder	European Development Fund
Timeframe	2020-2025
Amount of Financing	Euro 6 Million
Objectives/Impact Achieved (for historic project	To increase the capacity of public and private sector to contribute to increasing exports from SADC to EU.
Linkage/Relevance to Current Project Proposal	The Project will benefit from infrastructure and training investments targeting the livestock sector for this project. Although the EU project implementation will target green-zones areas that are outside of the Project Areas, as a result of the PPF for this project, the project also

	includes opportunities for CBT value chain support in broader policy and export market development activities.

Project Name	Managing the human-wildlife interface to sustain the flow of agro-ecosystem services and prevent illegal wildlife trafficking in the Kgalagadi and Ghanzi Drylands
Funder	GEF-UNDP
Timeframe	May 2017 – December 2023
Amount of Financing	$US 5.98 million
Objectives/Impact Achieved (for historic project)	Goal: To promote an integrated landscape approach to managing Kgalagadi and Ghanzi drylands for ecosystem resilience, improved livelihoods and reduced conflicts between land uses (biodiversity conservation, economic and livelihood activities).
Linkage/Relevance to Current Project Proposal	The Project team is working with the NGOs involved in the project implementation in order to support the use of these GEF-UNDP project Funds to integrate Herding for Health approaches into their engagements with the goal of identifying and developing demonstration sites for the GCF Project to use in its implementation. Learning sites are a key focus of the GCF project and given the similar objectives of the GEF, as in Ngamiland, new H4H demonstration sites can be in place to inform the development of locally-specific Ecoranger and Restoration curriculum.

Project Name	Herding for Health—Adaptation to Climate Change in Rural Areas of Southern Africa (ACCRA)
Funder	GIZ
Timeframe	December 2018- June 2020
Amount of Financing	$250,000
Objectives/Impact Achieved (for historic project)	Goal: To develop a better understanding of the feasibility of Herding for Health approach to improve climate change resilience in Southern Africa rural areas, particularly high-biodiversity rangelands.
Linkage/Relevance to Current Project Proposal	Climate vulnerability assessments of other areas and the creation of the regional learning network platform for SADC for Herding for Health will be an asset and a vehicle for sharing lessons for this project. The leader of this project, the CI Herding for Health Director, will also oversee the Chief of Party for this GCF project.

Project Name	Botswana Programme: International Savannah Fire Management Initiative
Funder	Australian Aid
Timeframe	2019-2024
Amount of Financing	N/A

Objectives/Impact Achieved (for historic project)	To build capacity for community-based fire risk reduction and management. The project specifically draws on indigenous knowledge of the Basarwa people to develop its approach and support implementation.
Linkage/Relevance to Current Project Proposal	The PPF team and ISFI agreed to combine knowledge in the design of the Rangeland Stewardship Agreements and training of local communities. Ecorangers will be provided with training and grazing management will be used to support strategic fire breaks as identified in the ISFI programme in the Kgalagadi and Ngamiland.

Project Name	Technical Support for Land Degradation Assessment, Monitoring and Development of Restoration Strategy
Funder	Botswana Gov't-FAO
Timeframe	2020
Amount of Financing	N/A
Objectives/Impact Achieved (for historic project)	Goal: To address land degradation in a holistic manner by establishing baseline information upon which appropriate intervention would be based in managing and monitoring the dynamics of land degradation.
Linkage/Relevance to Current Project Proposal	This project will develop tools and strategies for ensuring land degradation information is available and able to be used by all decision-makers. This information will be a critical component of the project and aligned to support the project with the Dept of Forestry and Range Resources.

Additionally, CI has two separate funding programmes that are being implemented by the Herding for Health Programme and its local partners in Southern and Eastern Africa, including Botswana, that will complement the proposed GCF Project:

1) The EU has provided funding to CI and other beneficiary partners working in the region to support Commodity Based Trade implementation in Northern Botswana - by working towards compliance with CBT standards and prerequisite programs that foster linkage to new markets, rangeland restoration and wildlife-livestock coexistence in communal farming areas at two pilot sites in Ngamiland, Botswana. The EU-funded project addresses specifically the market access enabling environment gaps detailed in Annex 2, Appendix 5.6 (policies, quarantine facilities, slaughtering and processing capacities to meet CBT standards.) The GCF Project will benefit from this parallel project, specifically the infrastructure and training investments targeting the livestock sector and the opportunity for CBT value chain support in broader policy and export market development activities as well as its target to increase the capacity of both the public and private sector to contribute to increasing exports from the SADC region to the EU. It is the EU project's focus to build capacity for farmers to tap into immediate markets for their grass-fed meat.

2) An AFD-funded project that will support capacity for value-chain development, including support for Meat Naturally Botswana to develop farmer-owned infrastructure that run business operations across the red meat value chain (natural fodder production, transport, slaughter, processing, and

small community butcheries, see Figure 1 below) that can service local tourism facilities as well as local communities. Details are provided below:

Project Name	Support Programme to the Economic Partnership Agreement (EPA) Implementation in Botswana
Funder	European Development Fund
Timeframe	2020-2025
Amount of Financing	Euro 6 Million
Objectives/Impact Achieved (for historic project	To increase the capacity of public and private sector to contribute to increasing exports from SADC to EU.
Linkage/Relevance to Current Project Proposal	The Project will benefit from infrastructure and training investments targeting the livestock sector for this project. Although the EU project implementation will target green-zones areas that are outside of the Project Areas, as a result of the PPF for this project, the project also includes opportunities for CBT value chain support in broader policy and export market development activities.
Specific private sector engagement and market activities	CI received a sub-grant amount of $500,000 for specific mobilisation activities for CBT, including protocol development, mobile quarantine testing of new guidelines for on-farm quarantine from DVS.

Project Name	Pro-nature Enterprises for the People of Southern Africa
Funder	AFD
Timeframe	July 2020- June 2025
Amount of Financing	Euro R5 million
Objectives/Impact Achieved (for historic project)	Goal: Conserve and restore 1 million hectares of critical habitats in trans-frontier conservation areas through incentive based sustainable livestock systems (rangelands restoration); Directly benefit at least 30,000 people (more than half of them women) through nature-friendly livestock, fisheries and tourism related enterprises.
Linkage/Relevance to Current Project Proposal	Collaboration on development of conservation agreement tools and best practices for Herding for Health. The leader of this project,

	the CI Herding for Health Director, will also oversee the Chief of Party for this GCF project.
Specific private sector engagement and market activities	An amount of Euro 1,050,000 will be invested in value-chain enterprise development, primarily through impact investment into meat and other livestock product businesses.

2. PROJECT OVERVIEW

This project provides an opportunity to replicate the approach to address impacts of climate change on vulnerable communal farmers at a national scale. The aim of the Project is to transform current government investment in job creation for vulnerable people into more than just an income development safety net - into something that also builds greater resilience for key agricultural livelihoods for greater community and national resilience to climate shocks.

Specifically, the project aims to move Botswana to a climate resilient, low-emission sustainable development paradigm where:

- The government of Botswana's commitments to the SDGs, UNFCCC, and GDSA translate into aligned programmes and policies that empower community-level governance structures to develop and enforce climate-smart communal grazing and water management strategies;

- Marginalised rural people are trained and employed as restoration workers and Ecorangers (professional herders) to draw on indigenous knowledge systems and utilize new technologies that restore and maintain rangeland ecosystem function and livestock health;

- Farmers and their communities experience fewer losses of their economic assets to climate stresses and benefit from new land and livestock management practices; and

- Adaptive capacity is sustained through livestock value-chains based on compliance with community-level Rangeland Stewardship Agreements that embed commodity-based trade requirements and respond to increased demand for low-emissions, wildlife-friendly beef.

The theory of change diagram (Figure 2) illustrates how the Project will achieve its goals to reduce climate vulnerability and reduce emissions from rangeland degradation and livestock production in Botswana's communal rangelands through enabling and monitoring gender equitable governance, supporting climate-smart livestock farming, and developing sustainable value chains. This section focuses on the Project components and outputs and their ability to overcome the barriers to the desired outcomes articulated.

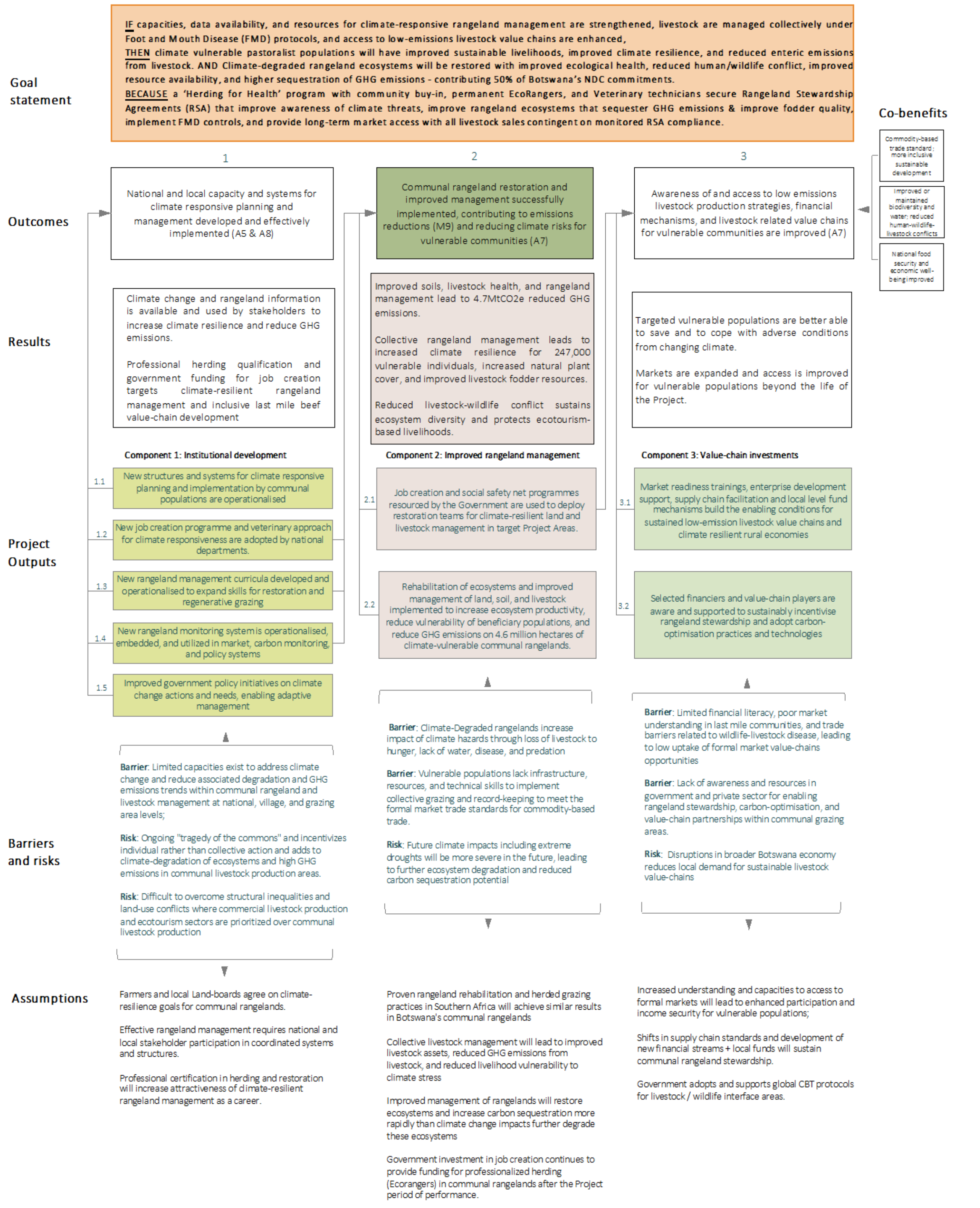

Figure 2. Project Theory of Change

3. PROJECT COMPONENTS AND KEY RECOMMENDATIONS

3.1 Component 1 – Strengthening institutions and support systems for climate responsive planning and management

Conservation International's 2018 commissioned review of relevant national policies and programmes, and consultation with stakeholders, revealed limited sectoral coordination, lack of mandated local management structures, overextended veterinary outreach, and an absence of integrated information systems to inform climate responsive planning on communal lands. (see Cassidy, 2018 - Appendix 4.6) These factors were found to compromise effectiveness of natural resource management and livelihood development on communal lands, exacerbating vulnerability to increased climate shocks. To address these shortcomings, the activities within this component aim to enable communities to make and enact climate-smart decisions about their land and livestock management. Similarly, ensuring policy-makers are aware and using information from the Project to create an enabling environment is critical and provides an opportunity for the Project to influence national and regional stakeholders facing similar challenges of degraded rangelands, high unemployment, and increasing human-wildlife conflicts.

The following factors are assessed and described in more detail below and in this Section's appendices:

- **Stakeholder Map**
- **Viability of Conservation Agreements as implementation tool for EbA**
- **Viability of improved government job creation programme**
- **Viability for improved veterinary services to be climate responsive and enable Commodity-based Trade**
- **Viability of an inter-institutional web-based monitoring platform**
- **Viability for embedding Project approach in policy**

Stakeholder Map

The main stakeholders relevant to the Project can be classified in four broad groups: national government; civil society organizations; parastatals supporting the private sector; and the private sector. Traditional leadership and leadership structures, such as the *kgotlas,* are also crucial stakeholders and their role is described in detail in Appendix 4.6 of this Section as well as the Funding Proposal Annex 6 – ESIA and Environment and Social Management Plan.

Government Ministries and Departments consulted include the following:

i) *Ministry of Agricultural Development and Food Security* (MoA) being the main partner for the project through its Department of Technical Services, Department of Animal Production (DAP), the Department of Veterinary Services (DVS) and the Department of Extension Services Coordination. These departments have representation based within each of the sub-districts targeted by the project. They host farmer training, dipping and vaccination days, and conduct veterinary checks for possible disease outbreaks;

ii) *Ministry of Environment, Natural resources conservation and Tourism* (MENT) through its Department of Forestry and Range Resources and Department of Environmental Services where climate change response and reporting sits;

iii) *Ministry of Local Government and Rural Development* through its Department of Rural Development who are responsible for coordination of drought management and other local response strategies across national ministries, and Department of Local Government and Development Planning who administer the Ipelegeng Programme.

iv) *Ministry of Lands, Water, and Sanitation* who oversee land use planning and development of national water infrastructure, including water use permits and a network of national boreholes.

v.) *Ministry of Investment, Trade and Industry (MITI)* which is tasked with monitoring and coordinating the execution of the EPA Implementation Plan, while also overseeing parastatals such as CEDA;

vi*) Ministry of Nationality, Immigration and Gender Affairs* through the Department of Gender Affairs and the national gender satellite offices in the target districts tasked with implementing gender equity policies and programmes.

Parastatals supporting agricultural development in Botswana:

i) The Botswana Investment and Trade Centre (BITC) with its mandate to promote export and investment, and to be instrumental in the implementation of the EPA;

ii) The Local Enterprise Authority (LEA) which plays a lead role in developing the leather value chain and which, more broadly, provides support to local SMMEs, offering them services encompassing training, mentoring, incubation, marketing and technology support;

iii) The Citizen Entrepreneurial Development Agency (CEDA) which complements the two other organisations by facilitating access to finance, albeit mainly for enterprises targeting the domestic market for the time being;

iv) The Botswana University of Agriculture and Natural Resources Centre for In-service and Continued Education (BUAN-CICE) who is mandated to provided adult skills development programmes that enhance agricultural productivity;

v) The Botswana Meat Commission (BMC), expected to play a key role in the reform and liberalisation of the livestock export sector and whose monopoly and low performances are seen as major obstacles constraining the development of the beef value chain; and

vi) The Botswana Bureau of Standards (BOBS) which offers technical services in areas such as standardisation, testing of goods, certification of products, industrial & trade metrology, quality management systems, and environmental management systems.

Civil society groups include national NGOs, CBOs, Farmers Associations, and other support structures[3]. Each Project Area has a unique and extensive set of civil society stakeholders and a full list and capacity assessment will be generated as part of the inception report to ensure current realities are reflected (see Ngamiland civil society capacity assessment in Appendix 4.6 pg. 25 for an example of the mapping that is proposed for the Area Inception Report stakeholder map baseline format.) Key umbrella civil society entities that have been engaged and are able to facilitate communication flow for the project include:

Botswana National Beef Producers Union (BNBPU) is an umbrella body representing beef farmers across the country.

[3] Private sector support is described in Component 3 and in Annex 2, Section 5 Market Feasibility.

Botswana Community Based Organization Network (BOCOBONET) is an umbrella body representing community-based organizations, particularly engaged in building capacity of community trusts engaged in community-based natural resource management.

Botswana Council of NGOs (BOCONGO) is an umbrella body who aims to facilitate a coordinated approach to the implementation of the national development plans and priorities as well as enhancing communication and partnerships between government and civil society organizations.

In addition to the organisations described above, several key structures are important for actions relevant to the Project goals. These are described in Table 1. Figure 3 then shows the interactions between players and process as relevant to the Project.

Table 1: Overview of key stakeholder coordination structures relevant to the Project.

Relevant Structures for the Project Implementation
Kgotlas are the traditional court or public meeting chaired by the chief of villages in Botswana. The kgotlas are the primary structure for project engagement, and the forum where all project information, negotiation of Rangeland Stewardship Agreements, and annual RSA feedback sessions will be held. Farmer Facilitator Teams and Area Managers will start all community-level engagements through this structure (see full proposal Annex 6 ESMP)
Village Development Committees (VDCs) are the mandated vehicle of local government to coordinate development and land use. Within the project region, there is a growing strength and relevance of the VDCs in fulfilling this role (see full proposal Annex 6 ESIA), but capacity and functionality of these structures vary dramatically across the region. In areas where prior climate investments have provided information on climate change, e.g. through the ASSAR programme in Bobirwa and the SLM programme in Ngamiland, the impact of climate change is more considered. Women are often represented in these structures but do not always have a strong voice with regards to livestock farming matters in this forum. However, there is still an urgent need to empower these structures with capacity, tools, and incentives to understand and facilitate development and land-use that is climate resilient and responsive in a way that is gender equitable.
Land Boards are responsible for granting management rights on communal lands. They recognize borehole allocations and endorse rights of Community Trusts in CBNRM areas for the development of tourism activities. They can allocate rights to any legal entity many communities in the project areas are in the process of registering Community Trusts or have legal Farmers Associations. Some communal lands are managed by “syndicates” the are not legal entities but can take a case to a Land Board to ensure other farmers are prevented from “trespassing” on their land. Target communities are unlikely to have a “one-size-fits-all” legal model, but as long as Land Boards and VDCs work together on a common set of criteria for implementation, the most appropriate existing or new legal entity can be established and mandated to promote behavior change in communal land and livestock management to implement climate resilient alternatives.
District Development Committees (DDCs) are the district level coordination structure for all activities in the area. They chaired by the District Commissioner as part of the Ministry of Local Government and the district representatives of the various departments, eg the District Agricultural Coordinator (DAC) report their activities in at regular DDC meetings.
District Councils are the local government administration in a District and consists of appointed and elected members. There duties include provision of primary education

infrastructure, public health and sanitation, waste management, tertiary and secondary roads and other areas such as social welfare and community development, remote area development and maintenance of public facilities
Regional Extension Coordination Committee consists of Directors of Extension Departments and mandated to oversee and ensure coordination and integration of extension services from national to village level for the purpose of providing a seamless quality service to communities. The committee receives reports, exchanges information, monitors and evaluates rural development programmes and implementation, for policy advice and direction.
National Strategy Office is an official structure mandated to drive implementation and monitor performance of the National Development Plan. It also is tasked with strategic alignment and development of new approaches for diversification of Botswana's economy. In this latter role, it is leading the development of a grassfed beef development programme as part of the Beef Cluster Strategy.
National Parliament is the structure where national legislation is developed, reviewed, and approved. It consists of the President and the National Assembly of 57 elected officials. A 15-member House of Chiefs (Ntlo ya Dikgosi) acts as an advisory body on tribal matters and on alterations to the constitution. Parliamentary approval will be required to enable new operational conditions for the proposed Ipelegeng Rangeland Stewardship programme for Ecorangers and Rangeland Restoration workers.[4]

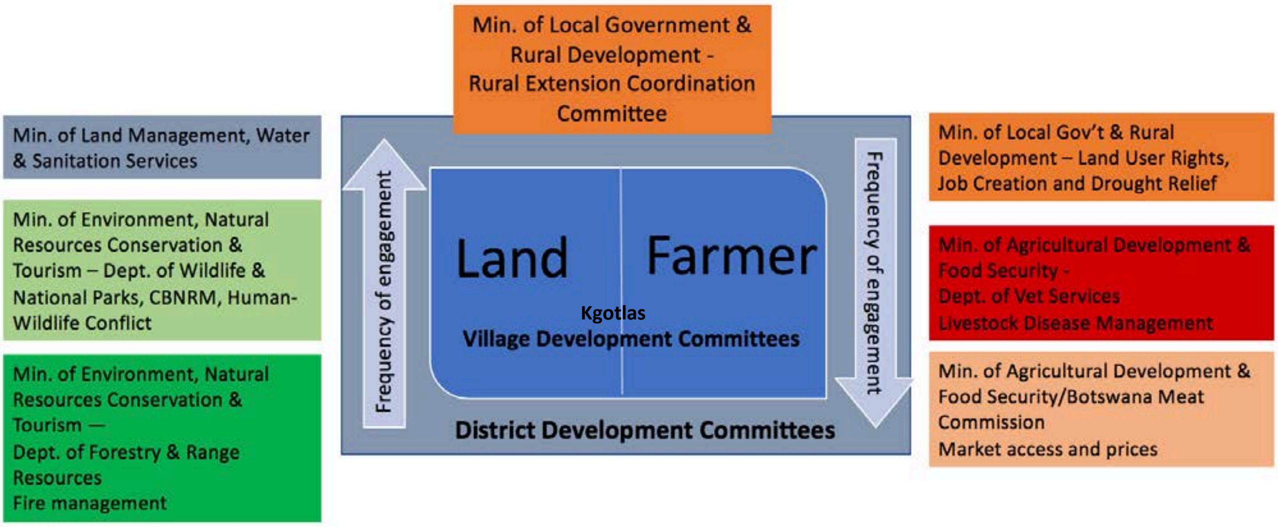

Figure 3: Four ministries and six departments play a direct role in land and livestock management in communal lands. Farmers and land most directly engage with land decisions at kgotla and VDC meetings. Officials are coordinated through District Development Committees at the local level and through the Department Directors at the Regional Extension Coordination Committee.

The advantage of using the Village Development Committee as the level of governance for the Project is described in the ESIA / ESMP in Annexure 6. In brief, it is the most local level of governance recognized by the State with a mandate to coordinate development activities and funding. As such, VDCs are the vehicle that determines the "public works" that will be prioritized for the government's Ipelegeng Programme and make all applications to the government Livestock Management and Infrastructure Development (LIMID) programme. Village Development Committees also have legislated guidelines for selection and equitable representation and therefore are a natural vehicle to embed the project activities to avoid duplication and enhance sustainability. However, the

[4] This is a process for which there are several precedents. The special constables of the Police Service, Wildlife Rangers in the Ministry of Environment and Tourism are recent examples of specific conditions for Ipelegeng deployment in these positions.

effectiveness (and representativity) of the VDCs in the project sites ranges greatly and stakeholders expressed a desire for the Project to strengthen these structures as a common feature across all Village as one of the key deliverables in Output 1.1.

3.2 Viability of Conservation Agreements as Implementation Tool for EbA

A full assessment of conservation agreement tool for deployment in Botswana is provided in Appendix 4.6. This study was carried out on the assumption that a GCF project would be implemented with the Ministry of Environment, Natural resource conservation, and Tourism (MENT) and therefore particularly looks at conservation agreements within the context of Community-based Natural Resource Management Programme of that Ministry. During the Project Preparation Process, this opportunity was explored but both the Ministerial stakeholders in MENT and MoA and the target beneficiaries themselves, expressed a desire to rather adopt "Rangeland Stewardship Agreement" as the name of the tool for the project purpose of restoring health rangelands for the purpose of sustainable land use as opposed to traditional understandings of "conservation". Nevertheless, the viability assessment remains valid and consultations under the PPF process confirmed these findings and augmented understanding of how agreements can be used to support gender and social equitable EbA in Botswana (see Annex 6-ESMP and Annex 8-GAP of the full proposal). Key recommendations from a Cassidy (2018) and the proposed project response are provided in Table 2.

Table 2: Recommended actions based on feasibility assessment of conservation agreement deployment in Botswana and the proposed project activity to address the recommendation.

Key Recommendation	Project Response
Consider a 'soft' piloting stage, where case-by-case interventions are tested for different issues and with different partners before launching any high-profile programme.	Use a three-phased project implementation plan, starting with foundational phase that focuses on development of key demonstration sites within 9 village grazing area clusters. Work through project partners who have established respect and trust with a target community and add the Rangeland Stewardship approach into their existing programmes with a strong learning focus. Invest in learning process and testing at these sites, build into adjacent and ready replication sites, and then utilize final learning for amplification to all target sites.
Conservation agreements in Botswana should focus on rangeland management, predator co-existence and sustainable resources harvesting.	Focus of RSAs will be on rangeland restoration and sustainable use actions as opposed to establishment of conservation zones. The process will be designed to complement CBNRM zoning and utilize LUCIS principles for areas where there is land-user conflicts.
Conservation agreements should address environmental issues directly relating to current livelihood strategies and practices, and as identified by communities as such.	The RSA will be driven by community engagement and participatory mapping of priority areas for intervention and focus on livelihood strategies, primarily livestock, but also livestock impacts on cropping and tourism.
Identify which NGOs are working with which communities, and ensure open dialogue and communication among all supporting	At inception, each Area Manager will engage all local associations and do an open call for project partners. Those that are interested will complete a capacity assessment and join a

agencies to maximise synergies and successful support to communities.	network of Implementing Partners to facilitate lessons sharing and synergies across the project partners.
Incentives should be strongly aligned with responsibilities as they relate to specific resource user groups at sub-village level.	While conservation agreements normally allow an open-ended negotiation of incentives, this will not be possible within a single project. As such, a set of potential incentives linked specifically to animal health benefits and grazing management support will be offered to enable deployment of the desired rangeland stewardship actions.

3.3 Viability of improved government job creation for EbA

The project approach of transforming the Ipelegeng job creation programme to fulfil basic rangeland restoration and herding functions is based primarily on Conservation International's experience as an implementing agent of the national Natural Resource Management Programme of South Africa. The details of the overarching government investment case-study shows the triple benefit of employment, environment, and social upliftment that can be achieved with a targeted programme aimed at restoring areas where people derive key ecosystem services (Appendix 4.7).[5] This model, while not without challenges, has delivered positive impacts for recipients and their communities. A review conducted by the Botswana Institute for Development Policy Analysis (BIDPA) of Ipelegeng also found that the programme played an important role as a social safety net, and particularly for women. However, there were 17 areas for improvement. Table 3 presents the reports recommendations and how the project can respond and or support delivery of an Ipelegeng programme response to improve the programme as an EbA project opportunity.

Table 3: Recommended actions based on Final Report of Ipelegeng Programme Review (2012) and the proposed project activity to address the recommendation.

Key Recommendation (BIDPA)	Project Response
Recommendation 1: Ipelegeng objectives must be revised and be aligned to the national objective of poverty eradication. Such an alignment should portray the programme only as a part of a process that seeks to achieve poverty eradication since on its own it cannot achieve that. Such an objective should therefore place emphasis on coordinating and linking the programme with other government programmes with the view to draw maximum synergies with such programmes.	The project will enable subsidized trial of new approach to link Ipelegeng to National Climate Change Response Strategy working with Ministry of Agriculture. The project will generate policy briefs on lessons learned and opportunities for policy alignment for MLGRD and MoA. (Output 1.4)
Recommendation 2: Ipelegeng must be redesigned to be result-based to introduce flexible working schedules where beneficiaries will be assigned work and will work at their own time and pace and be paid on work done instead of time spent at work. Such a change should be done with the view to enable participants to get involved in other productive	The project will test the deployment of a monitoring system which can store evidence of labour records relative to evidence of productive task that can be scaled as relevant to the broader Ipelegeng Programme. (Output 1.3)

[5] Thierry Giordano, James Blignaut and Christo Marais (2012) Natural resource management — an employment catalyst: The case of South Africa. Development Bank of Southern Africa. Development Planning Working Paper Series. No.33.

activities in the spirit of recommendation 12 below. Piece rate and task- based remuneration system as well as flexi-time should be introduced where feasible.	
Recommendation 3: Ipelegeng must introduce a well-structured capacity building component that arms participants with production skills as well as survival skills. Such skills will assist the participants to graduate to better paying jobs	The project will develop and deploy a well-structured, formalized capacity-building programme under BUAN-CICE. Short course deployment of training for restoration workers will build skills while Ecoranger formal curriculum will result in certificate/diploma and formal graduation into a job in high demand (herding.) This will assist Ipelegeng recipients within the project to graduate to better paying jobs. (Output 2.1, activities 2.1.1 and 2.1.2)
Recommendation 4: A strong and clear Communication, Education and Public Awareness Strategy for Ipelegeng must be designed. Such a strategy should place emphasis on ensuring that the programme objectives are clearly known and understood by all stakeholders. The need for participants to graduate must form a central core for such a strategy.	The Project will work with Ipelegeng and the MoA to reach out to commercial farming sector to advertise and promote the new ecorangers and the value they can bring to a private farming operation. (Output 3.2, Activity 3.2.1)
Recommendation 5: A cost benefit analysis of using a single national Ipelegeng wage rate to achieve self-selection must be undertaken with the view to establish whether different regional factors can be taken into account and hence vary the wage rate regionally.	The project can support investigations into various implementation costs across three districts and share this through new regional coordinators and a national Rangeland Stewardship Coordinator secondment position (Output 1.2, Activity 1.2.1) with cost-benefit analysis as key part of the impact evaluation (Output 2.2, Activity 2.2.3)
Recommendation 6: The Ministry of Local Government should investigate the reasons for Remote areas having displayed very different results from the rest of the groups regarding Ipelegeng Issues. Based on the outcome of this investigation the Ministry will determine if a special Ipelegeng Programme targeting Remote area should be designed and implemented.	The Project will pilot a Rangeland Stewardship Ipelegeng Programme under Ministry of Agriculture in rural areas, including RAD communities. The Project human resource infrastructure can be used to conduct such an investigation. (Output 1.2 and Output 2.1)
Recommendation 7: The IP project selection should be based on the following key criteria: i) a genuine bottom - up consultative process where community's wishes on Ipelegeng projects to be implemented; ii) headed to the environment, natural resource endowment and skills base for the concerned areas; and iii) high quality projects with second round employment generation effects and the crowding-in effect on the private sector	The Project uses a bottom up approach formalized in a Rangeland Stewardship agreement between a Village Grazing Area, the Land Board, and Ministry of Agriculture to ensure the desired outcomes of Ipelegeng resources through are spatially explicit and community driven. The Project also promote natural resource management linked to the development of herding skills. Finally the project deployment of Ipelegeng resources will enable Commodity-based Trade requirements

	for beef from red zone areas with regards to record-keeping and animal movements and will therefore enable private sector investment where it has not been possible in the past. (Output 1.1, Output 2.2, and Output 3.1)
Recommendation 8: Ipelegeng should be redesigned to take on board gender, age, health status and different group specific issues. Such a re-design would look, for example, at the needs of women in terms of their mothering and nursing roles as well as their household responsibilities. Consideration should be given to providing relevant facilities that are complementary to women's responsibilities. Work schedules would also have to consider minimizing the participation costs that both gender groups face. Use of piece-rate and task based payment must be explored where feasible.	The Project has a specific Gender Action Plan which includes support for child care to enable participation in the Rangeland Stewardship Ipelegeng programme. This initiative can be used as a test for the broader Ipelegeng programme on how this can be considered and financed in the future. (See Annex 8 Gender Action Plan)
Recommendation 9: Ipelegeng should review and upgrade its Health and Safety guidelines.	The Project will specifically develop new Standard Operating Procedures, including Health and Safety, and embed them in the training curriculum for participants. Again, this is something the broader Ipelegeng Programme can piggy-back on in order to respond to this recommendation. (Output 1.2)
Recommendation 10: Government must undertake a cost benefit analysis of engaging the Private Sector and Civil Society Organisations to supervise the design and implementation of some Ipelegeng projects.	The Project will utilize civil society intermediaries for implementation and can thus again provide an opportunity to investigate tangible cost/benefits of such an approach. (Output 2.2, Activity 2.2.1)
Recommendation 11*:* New comprehensive guidelines for the programme should be formulated in consultation with all stakeholders, including Ipelegeng beneficiaries	The Project will has provided for 1.5 year development of a Rangeland Stewardship Ipelegeng programme with the view of designing Standard Operating Procedures. This timeframe and the human resource support can contribute to such a consultative process (Output 1.2)
Recommendation 12: Re-design Ipelegeng in a manner that enhances complementarity between this programme and other programmes and other Economic Activities. In a properly designed Ipelegeng, Agriculture should not compete with Ipelegeng for labour. Proper time scheduling for Ipelegeng should make it possible for labour to be shared between economic activities and these sectors.	The Project will pilot a model where Ipelegeng and MoA work together to support the aims of personal and economic development (Output 1.2)
Recommendation 13: Government should consider involving the private sector in the funding and execution of the IP. Not only will	Again, the Project can provide a more flexible platform for testing some of these approaches, particularly in developing value-chain

this reduce the burden on the fiscus but it will also enhance the quality and usefulness of project activity selection and implementation. For example, in urban areas partnership with the private sector to run kindergartens or play schools might be attractive to the industrial sector. Such moves will no doubt crowd -in the private sector while at the same time lessening pressure on the fiscus.	opportunities linked to the rangeland restoration and improved livestock management. For example, Botswana Meat Company or Meat Naturally Botswana could be interested in taking on additional Ipelegeng beneficiaries and investing in skills development in meat processing with the view to hiring them knowing that a red-meat value chain is an area is more reliable to climate and disease shocks (Output 3.1 and 3.2).
Recommendation 14: Re-locate the Ipelegeng function to the Department of Community Development at district level. This will enable the Programme to be properly staffed with permanent staff that will provide institutional memory, capacity building in both programme planning, design and execution. This will also make it possible to establish a Monitoring and Evaluation function in the programme.	The Rangeland Stewardship Information Portal will include a labour database engine (see figure below) that Ipelegeng can use for monitoring in the longer term. New district level staff will be hired as part of the project and can transition into government function anytime during or after the project if/when Ipelegeng is able to take over the Monitoring and Evaluation function.
Recommendation 15: The Ministry of Local Government should draw a Strategic Plan as well as an Operational Plan for the programme. The process of drawing such a plan will assist IP management understand why some of the best practice PWP requirements are necessary and how they can be operationalized through programme design and implementation	The Project pilot can contribute to lessons for the development of this strategy.
Recommendation 16: All line ministries and departments responsible for poverty eradication should have included in their budgets Ipelegeng votes. That will not only improve the coordination of IP activities but it will also increase the departments' commitment and accountability for IP implementation.	The Project pilot can generate new opportunities for alignment with MoA poverty eradication projects such as LIMID and drought relief initiatives.
Recommendation 17: As a strategic, nationally important project, the Ipelegeng budget must be drawn along standard district lines and not along constituency boundaries as is currently the case. This will reduce the unnecessary expenses incurred is some regions.	The Project pilot can contribute to lessons for the development of this strategy.

3.4 *Viability for improved veterinary services to be climate responsive and enable Commodity-based Trade*

The Animal and Human Health for the Environment and Development (AHEAD) and the Rockefeller Foundation initiative to conduct a comprehensive study into the gaps in implementation capacity to enable commodity-based trade in Ngamiland provides a detailed assessment of the feasibility for MoA Department of Veterinary Services to support Commodity-based Trade through improved and proactive veterinary management, particularly in the country's large communal lands where wildlife and livestock co-exist. The full report is available at (http://www.wcs-ahead.org/kaza/rpt-cbt-gap-analysis-ngamiland-final-190912.pdf) and the DVS is currently engaged in a process to determine how they will implement these recommendations as well as those of a recent OIE Evaluation Report (Appendix 4.8). The head of the Department was consulted as well as District DVS staff extensively and the project contribution and full workplan will be detailed in Year 1 of the project based on the progress made while the GCF application is under review. The potential for the project to accelerate planned actions for delivery is substantial, particularly through embedding the DVS in the Farmer Facilitation Team outreach efforts as well as new resources for delivery (Output 1.2) The department's commitment to implementation of the AHEAD report recommendations and the alignment the project can bring with projected climate change risks will optimise short and long-term delivery potential. Importantly, the H4H model formed part of the recommendations put forward in the report and in so doing the implementation of H4H is considered an essential step towards enabling farmers and local stakeholders to implement CBT and associated activities put forward in the report. A letter of support and commitment to uptake both financial and equipment resources provided for in the GCF project is included as Annexure 25.

3.5 Viability of an inter-institution web-based monitoring platform for Rangeland Stewardship

Information accessibility is one of the greatest challenges for adaptive management planning and impact measurement. Increasingly, open access platforms that are based on remote sensing data and allow for user-based input analysis are providing the greatest functionality that can meet the needs of a wide-range of user groups (e.g. http://trends.earth/docs/en/ and https://www.globalforestwatch.org/). Botswana has an existing database on livestock ownership, health, and loss records (https://www.gov.bw/animal-husbandry/user-application-botswana-animal-identification-and-traceability-system-baits) that will be able to be better deployed with communal land farmers though the project. Additionally, Botswana is working with the FAO on a new Degradation Map database that will use remote sensing functions, and on a new Early Warning System for drought, and there is a recommendation of new remote monitoring system for Ipelegeng task-based employment. With new technologies that focus on interface development across these dedicated system, web-based portals with cel-phone/tablet based apps can tremendously increase accessibility and integration of data for generation of new insights to inform decision-making.

Within the Herding for Health programme, several systems are currently being piloted using Pasture Map (https://pasturemap.com/), Peace Parks Foundation tailor-made system, and Meat Naturally Earthtrends based Rangeland Explorer. Additionally, through this PPF, the project team was made aware of efforts by the South African, Australian, and Ethiopian governments to upgrade their own integrated monitoring systems to display level of job creation investment to environmental and social returns. This project will have an opportunity in the first two-years to draw on this expertise and contract the development of a locally appropriate system. Due to the radical speed of change in technology availability and based on the recommendation of Director of the South African Natural Resource Management Programme, the project should build in opportunities to adjust to more appropriate systems over time. Additionally, the project should ensure that upgrades and maintenance are not an in-house government function as this creates a situation where incentives to maintain the status quo may prevent necessary and/or available improvements. Meat value-chain players have expressed a willingness to contribute sales data into such a system in exchange for information on social and environmental compliance that can help access niche markets for "sustainable" meat. (Figure 4.)

Figure 4: Integrated Monitoring system that speaks to Policy and Market Needs

A schematic of identified needs and potential inputs and outputs for the project Rangeland Stewardship Information Portal is provided in Figure 5. In addition to remote sensing, it is recommended that all RSAs be uploaded and that all data captured for a particular village grazing area be linked to a single shape file of the total grazing area and to the BAITS livestock ownership details over time. In this way the RSA actions, government employment and training investment, and impacts can be traced back to the management action in the agreement. Government departments involved in reporting for the National Development Plan and UNFCCC targets expressed desire to use such a system to also inform their reporting. CI proposes to work with StatsBotswana to increase understanding of how the mitigation and adaptation actions of the Project also contribute to key economic indicators in the Project Areas.

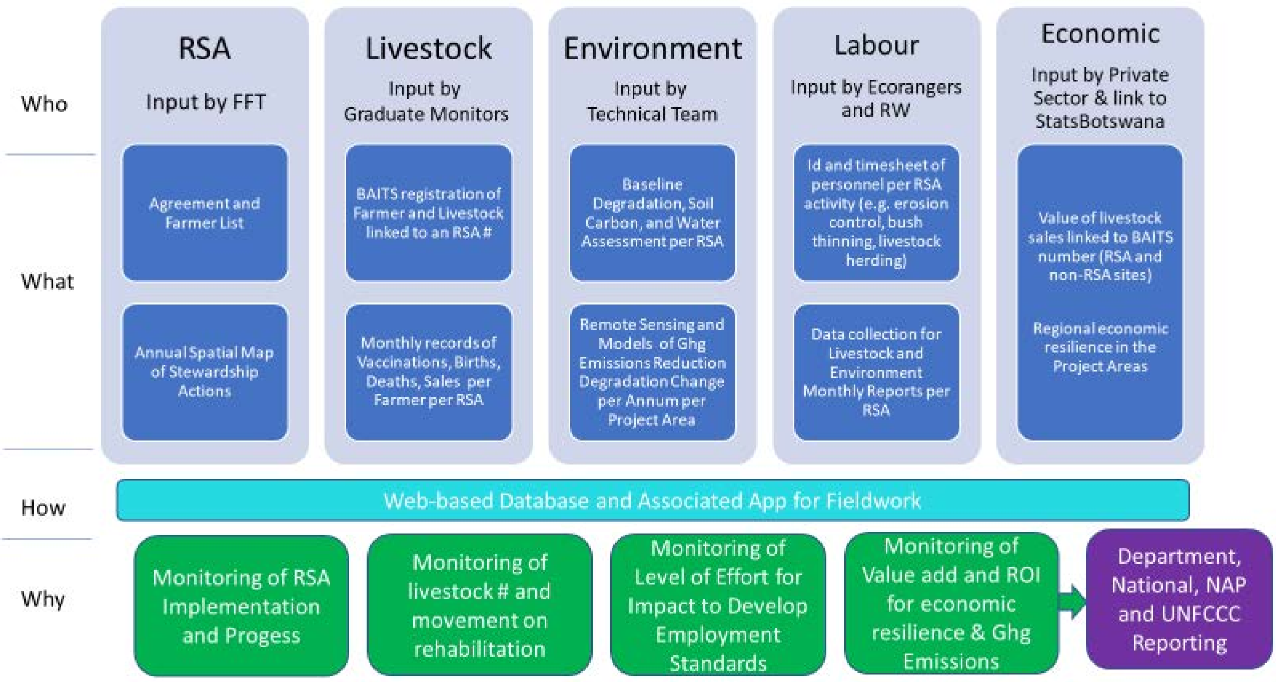

Figure 5: Initial diagram of the Rangeland Stewardship Information Portal based on inputs from stakeholders.

3.6 Viability of embedding lessons into policy

Botswana's policy environment is complex (See Annex 6 of the Full proposal) and direct policy development is outside of the project's control. That being said, there are numerous opportunities to ensure policymakers are aware of the project approach, its lessons, and potential policy recommendations for building resilience to climate change. Consultations recommended the project focus on ensuring the project is represented in forums related to the National Climate Change Response Strategy. Additionally, it was acknowledged that Conservation International, as host of the Secretariat for the Gaborone Declaration for Sustainability in Africa (http://www.gaboronedeclaration.com/) and the Herding for Health Initiative, are uniquely positioned to bring the lessons from the initiative into key regional policy platforms. To capitalise on this opportunity, it is recommended that CI include dedicated resources for policy engagement activities and host consecutive learning sessions for policy makers where understanding and uptake of lessons from the project can be facilitated. CI will also monitor progress in agricultural and trade policies, particularly those relating to regulations for commodity-based trade and red meat retail and export to determine if the Project is positively influencing these areas of enabling environment that will be critical to sustainability and amplification. Fortunately, the newly elected government of 2019 continues to indicate their support and enthusiasm for the Project and its approach to improving the environmental, social, and economic contribution of the Ipelegeng social grant programme and as a means of delivering climate change mitigation and adaption outcomes.

4. COMPONENT 2 – REDUCING GHG EMISSIONS AND NEGATIVE LIVELIHOOD IMPACTS THROUGH RANGELAND REHABILITATION AND IMPROVED LIVESTOCK MANAGEMENT

The purpose of this component is to build climate change resilience and low carbon livestock production in Botswana's communal rangelands to produce key paradigm shifts. The Project uses the H4H model (see section 4) to deliver sustainable rangeland stewardship and climate-smart livestock production across the Project target areas. Based on previously documented and Project-gathered science, the approach can engage and improve the livelihoods of communal livestock farmers by creating opportunities to use livestock and professional herders for the regeneration of landscapes and reduce human-wildlife conflict. Specialist herders, called Ecorangers, are trained to implement livestock management practices that align with ecological needs and meet trade standard compliance. The success of this programme depends on executing Rangelands Stewardship Agreements with affected communities that agree to site-specific good practices, incentivized by additional livestock production and training support and sustained through access to new markets for their livestock. Investments by the government and the Green Climate Fund into this component will provide the tools and capacity to overcome barriers to collective management for climate resilience, contributing to the GCF's Project Outcomes: Improved management of land or forest areas contributing to emissions reduction (M9), and Strengthened adaptive capacity and reduced exposure to climate risks (A7).

4.1 Ensuring equitable access to employment and training opportunities that bring dignity and resilience at an individual level for 6000 Ecorangers, Restoration Workers, and Graduate Monitors

In 2016, the Office of the President Poverty Eradication unit suggested that the employment investment co-finance for a pilot should be at least 10% of the total Ipelegeng employment numbers in order to test implementation and transformation of the programme at scale. She felt this would be important for demonstration purposes across the three target areas. At the time, Ipelegeng was employing 60,000 people per month and as a result, the project team presented a target of 6000 individuals for involvement in the project via employment. At the same time in the concept development, she expressed that given the fact that the majority of Ipelegeng beneficiaries are women[6], a majority of beneficiaries should be women and a target of 60% of all individuals supported via the co-finance allowances was set (3,600). These targets provided the boundaries for consultations on how to ensure equitable employment opportunities with government, VDC, traditional authorities, farmers, and broader communities (see Full proposal Annexes 6,7, and 8).

There were significant concerns about women being Ecorangers both from their own safety, but also additional household responsibilities point of view. For this reason, it is recommended that the project include a category of Restoration Workers, which can consist of individuals who need to work from home or, at least return home at night, and can be paid for task-based activities such as sewing of restoration mats, filling of erosion gullies, thinning of bush encroachment, or ponding of sheet erosion. Additionally, based on feedback provided at a meeting with the National Strategy Office (see Annex 7 for meeting records), a category to provide more opportunity for youth engagement should be created for environmental and social monitoring and other record-keeping required for BAITS and enabling Commodity-based Trade.

Given these recommendations, the Project targets of employment beneficiaries is 5,500 Ecorangers and Restoration Workers and 500 Graduate monitors. The detailed breakdown between Ecorangers and Restoration workers will necessarily be dependent on the activities identified within the RSA and monitoring of annual plans will be required to ensure the Project reaches the overall target. Across the total of 6000, the Project should work to ensure an equitable distribution based on vulnerability is achieved for 3,600 women and 2,400 men over the Project period (see Appendix 4.9 for the spreadsheet of beneficiary calculations)

The selection process for employment beneficiaries should be based on lessons learned from implementation by H4H projects and general good practice for benefit sharing (see Benefit Sharing at Scale: Good Practices for Results-based Land Use Programmes for a compilation by the World Bank, available at http://documents.worldbank.org/curated/en/824641572985831195/pdf/Benefit-Sharing-at-Scale-Good-Practices-for-Results-Based-Land-Use-Programs.pdf) The project will also need to comply with Standard Operating Procedures for the Ipelegeng programme with regards to selection. Conservation International's process for combining regulation with community-driven processes in South Africa is provided in Table 4 as example.

Table 4: Example of Beneficiary Selection Process for Ipelegeng Employment Opportunities

Employment Beneficiary Selection
1) Through the RSA development process, determine the total desired positions (# of Ecorangers, # of Restoration Workers, # of Graduate monitors) for a village based on herd size, state and type of degradation, level of farmer self-organisation and capacity, and the potential 3 year grazing plan.

[6] The 2012 BIDPA review calculates that 80% of Ipelegeng beneficiaries are women.

2)	Confirm that the number is reasonable based on the overall available budget/employment quota for the area that has been approved by National Ipelegeng Programme.
3)	In a community meeting, Project staff provide the detail on the government requirements for the role (% women, % youth, % indigenous people, representing most vulnerable households, only one beneficiary per household, etc) and the Job Descriptions (see examples Ecorangers and Team leaders in Appendix 4.10). They also provide details on the recruitment process which will include practical test of key skills and attitudes. The community is then left to develop the “short-list” for interviewing.
4)	Mentor farmers and the project team then design and implement an interview process which includes 4-8 exercises that are practical in nature and set up in stations so that the applicant goes through the various exercises over the interview period…fixing a fence, handling an animal (usually a small stock or a dog to test for natural approach to animals), entering data into a phone, etc.) Reluctant farmers or champion farmers who are respected by others in the community are often invited to oversee a test within the interview or the overall process.
5)	The Project staff conduct the interview and then identity their selected list and at least three alternates and present these back to the community leadership structure for confirmation.
6)	Formal medical checks are then completed and if they pass, they are appointed for the 3 year period. Should someone drop out of the programme, alternates have first option to apply. Once alternates are used, a full open process is used to select new positions and additional alternates.

4.2 Estimating implementation rates, improved livestock feeding systems, total grazing area covered by the project, and associated carbon emissions reduction

The total number of hectares in the Project areas is just under 240,000,000 and over the project period, it was assumed that the project would be implemented on approximately 20% of the land area that is communal grazing land (46,000km^2).

Nationally, the herd is approximately 2 million animals. Within Botswana legislation, a herd of >400 animals is considered commercial, though this is loosely applicable in reality with some private farmers having fewer than this but being granted private land. CI is trying to obtain updated information (as the agricultural statistics are from 2015), but using the ratios between communal and commercial operations, CI estimates that only 30% of the country’s animals are in herds >400 animals that have a structure for breeding and commercial production. Seventy percent would therefore be in inefficient herd structures with a higher proportion of older, unproductive animals >5 years of age. Stakeholder consultations indicated this was generally the case is all three target areas. Thus, there is significant opportunities to reduce emissions through herd structure transition and negotiated removal of unproductive animals as well as management strategies through the RSA.

Using these estimates and the detailed assumptions provided in Section 3 of this Feasibility Study, the following Project targets were determined:

Project Area	Source	4-year	8-year	10-year	20-year
Bobirwa	Enteric fermentation	16,744	77,114	114,570	371,758
	Soil carbon stocks	98,270	601,275	932,701	2,731,092
	Total	115,014	678,389	1,047,270	3,102,851
Ngamiland	Enteric fermentation	61,394	282,752	420,089	1,363,114
	Soil carbon stocks	360,324	2,204,675	3,419,902	10,014,006
	Total	421,718	2,487,427	3,839,992	11,377,120
Kgalagadi	Enteric fermentation	37,953	174,792	259,692	842,653
	Soil carbon stocks	222,746	1,362,890	2,114,121	6,190,476
	Total	260,698	1,537,682	2,373,813	7,033,129
Grand Total		**797,430**	**4,703,498**	**7,261,075**	**21,513,100**

4.3 Restoration and Regenerative Grazing Methods

Restoration techniques will be developed and implemented through Rangeland Stewardship agreements to address the site specific challenges for each of the 104 Village Grazing Areas. The plan for where and how (e.g. paid Ipelegeng work, Ecoranger work, or Farmer Volunteer contribution days) will be co-developed between farmers and scientific experts through consultations at initiation of site selection and formalized via the Rangeland Stewardship agreement. (Note: CI projects an 80% success rate by the end of the project duration, either due to community dynamics, climate issues—e.g. extended drought, or market failures).

Site specific interventions will lead to increased productivity, less run-off, increased biodiversity, increased infiltration, and increased sequestration. Identified techniques are described below:

Restoration Technique	Climate Induced Degradation Impact	Description	Ngamiland	Kgalagadi	Bobirwa
Ponding	Bare ground/sheet erosion	This method involves making hollows for water collection across the soil surface and can be cut by hand using a pick and shovel. This method is suitable for capped areas that are not too extensive in size. The excavated soil is piled from a	X	X	X

		low berm on the down-slope.			
Restoration mats	Bare ground/sheet erosion	Mats of loose-tied wood shavings held together with natural twines are secured into areas of heavy compaction and sheet erosion. Animals are prevented from grazing in the area and re-seeding is facilitated through broadcast seeding of natural species or left for natural re-seeding if a source areas is available. Animals are strategically herded onto the mats over time to expedite regrowth and natural ecosystem functioning.	X		X
Restoration boxes	Bare ground/sheet erosion/Ecologically devastated areas	Designed for arid systems where ecology is based on patch dynamics and broadcast; and where livestock based seeding fails to create nurse-plant effects that enable natural regeneration. Also critical in areas where regenerating seedlings require extra		X	

		protection from wind. Will be created with enterprise development beneficiaries.			
Livestock bioturbation	Bare ground/sheet erosion	Use of ecorangers to implement herding techniques that move cattle in a circle on bare patches to break hard-pan soil crusts and concentrate nutrients from livestock waste and dung that enable seed and water infiltration for grass regeneration.	X		X
Natural material weirs	Minor gully erosion	Biomass is also used for assisting with stabilizing erosion nickpoints, incised footpaths and small gullies, to assist with sediment accumulation. Small contour lines and log steps are anchored with sharpened droppers selected form the felled biomass of bush-thinning efforts.	X	X	X
Stone weirs and restoration mats	Major gully erosion	In areas of more severe erosion, a combination of restoration	X	X	X

		mats and stone weirs can be used to slow water flow and catalyse vegetation regeneration.			
Livestock Herding/ Coralling/Feeding for Re-seeding	Unpalatable species dominance/increase	Use of ecorangers to manage seasonal timing of grazing and rest periods to enable propagation of palatable grass seeds and to negatively affect life cycles of early growing unpalatable species.	X		X
Livestock Herding/ Coralling	Wetland/Riparian degradation	Use of ecorangers to manage geographic zones for grazing and water infrastructure to avoid degradation and allow for regeneration of wetland and riparian areas	X		X
Bush-thinning and hand-pulling	Bush encroachment (unnatural spread of native species)	Bush-thinning involves removal of lower branches of encroaching species. This maintains the canopy for shade and soil protection, but enables animal movement into the area to break up dense vegetation and creating usable grazing areas. Thinned	X	X	X

		material is strategically placed to facilitate regeneration or used in the creation of bush-fodder for supplementary livestock feeding in a more digestible form based on the chemistry of the bush species.			
Physical removal on best practice techniques for the IAP (South Africa IAP removal norms and standards)	Invasive alien plant (IAP) spread	**Manual cutting** using hand tools (loppers, bush knives, axes and bowsaws). **Hand pulling** of small growth <50mm where possible (using gloves and small anchor pullers /tree poppers) to remove roots, avoiding use of herbicides	X	X	X
Strategic fire breaks		Brush-thinning through manual techniques and strategic grazing, particularly concentrating small stock, to graze strategic fire breaks based on prevailing winds to prevent runaway fires.	X	X	X

The project will follow known cost effective and cost efficient protocols. Based on prior experience and lessons learned, the current Project proposes to use the following tested methodologies to improve rangeland condition, ecosystem function and combat soil erosion in the priority areas.

Stone gabions: These structures are built by packing stones through a cross section of an erosion gully. Little or no technical skills and no construction material need to be provided and thus makes it an attractive method. Gabions are constructed by packing rocks (dry packing) at a cross section of a gully. The gabion must be well keyed into the gully sides to prevent run-off water from eating around the structure while the middle of the structure should be depressed to concentrate the bulk of the overflow into mid-channel. The gabion should be lower in the middle to concentrate the overflow of water in to mid-gully. The placement of stone gabions is critical to ensure maximum effectiveness and thus the head of the gully is treated first, rather than the gully itself. The distance between these stone gabion structures is the factor of the availability of rocks and the slope of the area.

Micro-catchments / Ponding / Hollows: This method involves making hollows for water collection across the soil surface and can be cut by hand using a pick and shovel. This method is suitable for capped areas that are not too extensive in size. The excavated soil is piled from a low berm on the down-slope. Hollows can be approximately 2 meters apart in rows 1 meter apart. These micro-catchments/ hollows result in the following:

- Hollows, or small dams, which break through impervious soil capping and in which run-off water collects during rainstorms, resulting in infiltration rather than run-off.
- The cumulative and erosive run-off on degraded rangeland can be slowed down and much of it held back, by means of an extensive network of hollows.
- Silt and organic material transported by run-off water collects in the hollows and is permanently retained in them and not lost to the area.
- Wind-blown seeds, humus, animal droppings and dry plant material also collect in hollows. After rains, seeds germinate in the moist soil of the hollows and are protected as they grow by the accumulated plant debris.
- A network of hollows covering a degraded area results in numerous protected plant establishment sites - helping to transform and improve the soil moisture and microclimate of the area. Effective rehabilitation becomes possible under the more favorable microclimatic conditions in the hollows. Hollows also provide some protection from the effects of wind erosion.

Re-sloping: This method is generally used where severe gullies occur and aims to use infertile and dead soil to fill the gully and hence expose soil that still contains organic and biotic matter as well as adjusting the slope of the gully wall from a previously almost vertical slope to a more acceptable slope for plants to establish themselves. This method should be used with care as inappropriate application can lead to more disturbance than rehabilitation.

Seeding and planting for rehabilitation: Once erosion has been stabilized a protective vegetation cover must be established. The choice of species to seed or plant will depend on the specific location of the area relative to the type of vegetation and the bioregion of that area. Grass is always a good option because it is fast growing, relatively easy to establish, and binds the soil very well. The primary objective should be to establish a protective vegetation cover; thereafter other objectives can be attempted. Grass and shrub species seeds can be sustainably harvested from the immediate surroundings that are in a good ecological condition and boast high biodiversity. Seeds can be sown into lightly loosened soil that is preferably covered with a layer of mulch or brush. The soil must be loosened, as the plants will not germinate on a hard, sealed surface – making micro-catchments an ideal place to sow these seeds. Indigenous shrubs can easily be established from seed collected from the rangeland and planted into nursery plastic bags or other suitable container. Once the plants are growing well they can be planted after rain, when adequate moisture is available. The planting time is important and seedlings will be planted at the start of the active growing season of the area.

Restoration Mats: Mats of shaved bark are rolled out and pegged on bare ground with holes for bushes made around the mat. Within one month of work, evidence of seedlings is visible. It is envisaged that the GCF Project can capitalize on excellent basket-weaving skills in Botswana to make restoration mats locally as part of the Ipelegeng restoration jobs supported by government using bush-thinning material.


Brush cuts are placed on top of the mats to protect against grazing.

Impact of the restoration treatment after one year on the right half of the photo. The treatment was in a bit of an erosion gully and the river is at the tree line. As the brush decays after 1-3 years, Ecorangers can herd animals into grazing the green flush, trample seeds, and concentrate manure that leads to long-term re-establishment of healthy root:shoot ratios for perennial grasses.

Restoration boxes: In arid areas where unpalatable species dominate the ecosystem and seedlings require extra protection from wind (in addition to grazing rest) restoration boxes can be planted with native species seeds in the ratios found in natural regeneration cycles (with or without further protection from shade cloth). The edge of the box allows seedling establishment and over time, the box degrades and is covered by the vegetation. Restoration box nurseries are an enterprise development opportunity, particularly for sale back to mining companies in addition to use by farming communities on most challenging lands. See https://nurturerestoreinnovate.wordpress.com/ for more information.

Grazing management to create favourable conditions for water and seed collection and ecological regeneration: Bare patches in Ngamiland and Bobirwa from poor grazing management result in hard soil crust and the sheet erosion already starting from low water infiltration and increased surface water run-off. Bare patches increase soil temperature which reduces soil moisture and germination potential and quickly erode reducing CO2 sequestration.


Cattle herded strategically towards the bare patch to break up compacted soils.


A herd of cattle is lead onto the bare patch after which they are bunched for a few minutes and rotated gently in the same direction. The resulting hoof action breaks up the soil crust. The cattle also leave manure and urine deposits before they're led further along their grazing path. The result after four minutes of herd treatment on a bare patch in the rangeland. The hard crust is broken and manure and urine were deposited. The intensity of the treatment is judged by the size of the herd and the hardness of the crust, as well as available grazing time.

References on the recommended restoration interventions described above can be found in the following dropbox folder:

https://www.dropbox.com/sh/puf22xcqwytzxfn/AABmD5CaMCNzSQHZGRHpFEusa?dl=0

The SOP system for measuring "technical effectiveness" of the interventions for Botswana is a key element of Activity 1.2.2a, especially with regards to adaptation. An example of Quality Management support information from the South African Working for Land and Water systems is provided at the link below:

https://www.dropbox.com/sh/uzhb5r7h3vmczos/AAC2S0ZvnToAbuC46dB0NHYEa?dl=0

5. COMPONENT 3 – SUSTAINING ENHANCED ADAPTIVE CAPACITY THROUGH VALUE-CHAIN AND FINANCE POLICY TRANSFORMATION

Both government and GCF investments in rangeland stewardship for climate change resilience building are catalytic in nature. Sustaining and growing adaptive capacity requires aligning value-chain incentives and supply-chains for livestock and livestock products that are also resilient to the impacts of climate change. Price drivers and demand constraints for such products are complex[7], and promoting new supply-chain development opportunities for project beneficiaries and expanding the use of climate-smart technologies and approaches, such as Ecorangers, can ensure sustainability in the project areas as well as across the broader national value chain. This final component therefore aims to engage private sector and leverage project lessons into value-chain and finance policy transformation. In doing so, it expands the project contribution to the GCF project outcome, “Strengthened adaptive capacity and reduced exposure to climate risks (A7)” through improved incomes and value-chain participation related to the restored rangelands and improved livestock management of Component 2 and tangible benefits from “Strengthened awareness of climate threats and risk reduction processes (A8)”.

5.1 Viability of livestock value chain development and supporting enterprises in the target regions to contribute to adaptive capacity of participating beneficiaries and broader regional economy

The adaptation rationale for the Project focuses on livestock-product value chains (which may include natural fodder development, restoration enterprises, veterinary enterprises, hides, skins, and wool, as well as beef) with the goal of promoting diversified and increased incomes in marginal wildlife areas where ecotourism is not viable and yet, and as a result of the presence of wildlife, there is currently no opportunity to sell or manage commercial livestock due to FMD legislation. (See Box 1) To support increased local incomes, it is critical that the Project shift the paradigm under which Botswana implements the Commodity-based Trade Standard recently promulgated by the OIE and ensure that it is implemented in a way that builds the climate resilience of the country’s poor and most vulnerable communal farmers, and does not result in elite capture by those in the commercial beef sector. CI has and will continue to support this enabling environment in Botswana and Southern Africa more broadly through the Herding for Health initiative.

Livestock value chains are central to the adaptive capacity of Botswana rural household incomes and broader community economies. The importance of livestock resilience for household resilience is presented in the Project ESMP (Annex 6) and a case study of how the Project’s approach has benefited other farming households on communal lands is available in the independent performance evaluation report of Conservation South Africa’s original programme available at https://securingwaterforfood.org/wp-content/uploads/2020/03/SWFF_MeatNaturally_PerformanceEvaluationReport_1-30-2020.pdf.

Improved rangeland and herd health under RSAs can lead to enhanced and more resilient value-chains as well. For example, in South Africa, in a particularly degraded areas, the community agreed to remove all bulls from their herd in exchange for temporary replacement by three high quality genetic breeding bulls for a period of 2 months. This removed 53 animals in exchange for 2 who were only present on the site for 2 months to cover the cows and were then also removed and slaughtered with a promise of continued provision of better bulls for a similar covering the following year. Both the health of the ecosystem and the calving rate of the communal herd improved dramatically over the 2 year period and as the private sector partner (Meat Naturally) bore the cost and effort of securing the breeding stock (as it was in their interest to improve meat quality and increase offtake) earnings and employment were increased across the value-chain.

[7] See FS, Section 5 Market Feasibility

Box 1: What is Foot and Mouth Disease or FMD and why is it an issue?

FMD is a highly contagious veterinary disease that impacts livestock productivity but does not impact humans. The presence of FMD in most of southern Africa where hooved animals like buffalo and zebra co-exist or are adjacent to communities led to the creation of "no live-trade" zones by the global Animal Trade Regulator, the OIE, particularly around wildlife conservation areas and wildlife management areas. Communities that could not afford fencing methodologies to separate their livestock from disease exposure were simply banned access to the formal market, leaving them with reduced livelihoods and no incentive to contribute to land management or conservation goals.

However, a recent review of global trade standards from wildlife areas, called "commodity-based trade standards" (CBT), and new scientifically-defined protocols that eliminate the risk of spread for slaughtered animals have fuelled a quantum leap in local consumption and export potential of sustainable and environmentally-friendly red meat from southern Africa. Unfortunately, institutions governing production of livestock in southern Africa are outdated and communal farmer capacity to implement these protocols is non-existent.

Botswana has a long history of combatting FMD through geographic control zones that were established and maintained through fencing huge areas of the country. This approach was responsible for disastrous impacts on wildlife migrations and is incredibly expensive to maintain. Fencing has also been ineffective at preventing disease outbreaks when elephants need to move further to meet their fodder and water needs and destroy fenced areas. This has resulted in a situation where despite having a preferential trade quota for export of meat to the EU, Botswana has never been able to obtain the benefits from that agreement for its farmers as a result of outbreaks. The new CBT standard provides an opportunity to eliminate geographic zoning on where animals live, and rather examine animals in quarantine prior for a fixed period, conduct veterinary checks prior to slaughter, and test the pH levels of carcasses to ensure that no FMD is present. Given the importance of its beef industry and trade arrangements, Botswana is leading the way on making a shift to implement CBT in the country with re-training of departmental staff and farmers. However, the new technologies and skills required for traceability for CBT will create an even greater barrier for communal farmers, to not only be able to sell their animals, but also to be able to slaughter for their own consumption.

The focus of this project on the livestock product value chains aims to ensure communal farmers are not left behind as Botswana adopts CBT, and to bring an ecological sustainability system (Rangeland Stewardship Agreements) and capacity (Ecorangers) into the value chain to ensure that the pursuit of this economic development opportunity does not become maladaptive and further expose vulnerable communal farmers and the broader Botswana economy to the impacts of climate change.

5.1.1 Calculation of Beneficiaries with Improved Income Resilience

The project identifies two categories of direct beneficiaries that will derive greater income resilience beneficiation: ***farming household beneficiaries*** and **broader regional economy beneficiaries**. Within farming households, a further sub-sector breakdown is provided to indicate the source of improved income resilience: ***rangeland stewardship employment beneficiaries***, and ***value-chain participant beneficiaries***, In the absence of recent data on communal farming households, the MoA Agricultural Coordinator for each district was asked what percentage of the total population in the area owned some livestock that were likely to utilize communal grazing lands. This percentage was then applied to each district population data to calculate a "total communal farming population direct beneficiaries". However, over a project period, it is unlikely that every farming household will benefit, even indirectly, and therefore a further 80% of the potential population was taken as the Total direct farming household beneficiaries of 176,500 was reached. Similarly, it was assumed that the broader regional impact also only be to 80% of the population, so subtracting those directly involved in farming activities results in a target of 70,864 in with greater income resilience in the broader economy through reduced risk to ecotourism and other farming activities in the area.

Project Area	Projected total population per Area (extrapolation of 2015 census data)	# of VDCs	Estimate % of Pop Involved in Farming	Total Potential Farming Population Benefiting	Project Target Farming Population (80% of the Farming Population/ 57% Total Population)	Other Project Target Area Population (23% of Total Area Population)	Total Project Beneficiaries
Bobirwa	75 018	15	60%	45 011	36 009	14 457	50 466
Kgalagadi	58 671	34	60%	35 203	28 162	11 307	39 469
Ngamiland	175 520	55	80%	140 416	112 333	45 100	157 433
Total	**309 209**	**104**		**220 629**	**176 504**	**70 864**	**247 367**
80% of total pop	**247 367**			**% Women**	**45%**	**65%**	**51%**
54% women	**133 578**			**# Women**	**79 427**	**46 061**	**125 488**

Due to traditional norms, fewer women are involved in livestock farming for incomes, but there is a significant policy push in Botswana to shift this and through targeting 60% female beneficiaries for Project employment and value-chain development opportunities, it is expected that the Project can reach 45% beneficiation of the farming population. This will require proactively solicit women and apply non-discrimination principles due to the fact that in practice, livestock related work is both culturally and practically a male preserve. Most workers providing herding services are men. If the project recruits from the current crop of herders, women will continue to be side lined as job gets professionalized. If women are recruited into this job market, there is the potential risk of displacing male herders where herding has been an important source of employment for disadvantaged and vulnerable males. A balance can be struck by increasing women's participation in activities where they historically participate in significant numbers. For instancing offsetting male dominance in cattle herding by increasing female numbers in small livestock herding, fodder, and other value chain activities that will give them higher incomes. This gender balancing mitigation strategy requires accurate data on the spatial patterns of land use by women and men as well as by cattle and small livestock to enable informed planning and decision making. The ability of the project to provide economic resilience for women in the broader regional economy will be tested in partnership with StatsBotswana through project impact evaluations.

5.2 Viability for Private Sector Transformation

5.2.1 Key policies relevant to the Project private sector partners

The following key policies are relevant to if and how private sector partners will purchase meat from farmers in Rangeland Stewardship Agreements:

- *Livestock and Meat Industries Act of 2008* (http://extwprlegs1.fao.org/docs/pdf/bot6495.pdf). This Act lays out the powers of the Minister of Agriculture on developing regulations related to numerous aspects of meat production, transport, slaughter, processing and sales. It also stipulates the requirement that all facilities must be registered through an application to the Director of Animal Production.

- *Meat Inspection and Control of Red Meat Abattoirs Regulations (*http://extwprlegs1.fao.org/docs/pdf/bot91430.pdf) . These Regulations make provision for the inspection and control of red meat industries and the handling of red meat. They articulate requirements for the conditions for transportation of red meat products and their sale. The Regulations provide for the licensing of abattoirs, and processing facilities (cutting and wrapping (butcheries fall under the Fresh Produce Trade Act). They also indicate the powers of Official Veterinary Surgeons and meat inspectors, the nature of inspections and the handling of carcasses for consumption and those that are condemned. Finally, the legislation provides standards for construction and hygienic conditions of slaughterhouses and the definition of categories for their licensing. Three categories for abattoirs are defined which are used in the licensing process: High throughput : > 500 carcasses a week and >20,000 per annum; Moderate throughput: <500 carcasses a week and no more than 20,000 animals per annum; and low throughput: no more than 500 animals a year and no more than 15 per annum.

- *Commodity-based Trade Standards (2016):* International trade standards adopted by the World Organization for Animal Health (OIE) were amended to remove certain restrictions on the trading of beef derived from areas where wildlife maintain FMD viruses. These standards were revised to include incorporation of quarantine systems into risk management for deboned beef from locations not recognized as free from FMD (Article 8.8.22, Terrestrial Animal Health Code [TAHC]). Implementation of CBT approaches to managing disease risk in the context of recent OIE changes offers the potential for improving market access (to regional markets, at a minimum), and thereby livelihood-based adaptive capacity, for communal farmers in these lands.

Government, private sector and civil society organisations are already engaged in mobilizing value-chain transformation to promote livestock products from Botswana. In July 2020, new regulations that opened red meat export markets to private players beyond Botswana Meat Commission indicate the new political path with regards to red-meat value chains will be favourable for the Project. CI and RARE, have extensive expertise in developing and driving measurable behavior change campaigns that must be used to accelerate and leverage this new attitudes and expand private sector and consumer awareness and involvement in livestock product markets based on regenerative management. . See Table 6 for some examples identified in the stakeholder consultations as well as Feasibility Study Appendix 5.6 for full set of recommended actions/changes required for CBT. To be successful in value-chain transformation, the Botswana Meat Commission (BMC) must become a champion of communal rangeland meat production and climate change resilience. During the project development period, the BMC was in the middle of a process of privatization and it was impossible to determine the willingness of the entity to play this role. Their involvement is key and remains a risk to project success should they undermine other market efforts with political subsidy support.

Table 6: Activities contributing to value-chain transformation by different sectors in Botswana.

Government	The Grassfed Beef Strategy was adopted by Parliament in July 2020 as part of its national economic diversification drive. Activities to date in this process have focused engagement on the commercial beef sector value chain such as hosting learning forums, training sessions, and hosting discussions with importing countries on requirements and potential premiums for a grassfed product from Botswana. New regulations that allow for private-land quarantine were promulgated in November 2020 and DVS is working with Herding for Health to see how these need to be adapted for communal land. Additionally, he CEDA

	and Local Economic Agency are mandated to support "climate-resilient" agriculture as part of a new $40 million Covid-Recovery investment strategy and see this project as foundational to creating the understanding and skills on climate resilience in red meat production and processing.
Industry	Farm Assured Botswana Beef (FABB) has been launched as an industry standard for beef from Botswana that is "high quality, safe and can be traced to an animal that is well-cared for". The driver of FABB is excited by the project and the opportunity to include additional social and environmental standards could be used to promote climate resilience and access new markets for Botswana Beef. Meat Naturally has registered in Botswana and has completed feasibility assessments for operations in two of the three project areas, Ngamiland and Bobirwa and will start operations in the country in 2020. More information on Meat Naturally is provided in Annex 2, Section 5 Market Feasibility.
Civil Society	In Ngamiland, national conservation NGOs are increasingly promoting Wildlife-friendly beef production as part of their conservation strategies and establishing links for meat from communities adopting wildlife friendly practices to tourism operations in the Okavango Delta

6. STAFFING

The pioneering and multi-disciplinary nature of this transformative project, combined with increasing climactic variability and negative impacts, requires extensive scientific and community engagement for building adaptive management capacity. A Herding for Health initiative of this scale must have strong management, technical, extension and operational staff to be executed successfully. The management and operations team must be exceedingly strong to manage the flexible nature of the approach to respond to community and ecological needs within the fixed project delivery requirements. While CI explored the option of running the project through 15 sub-grants, due to the siloed nature of government and limited presence of NGOs/CBOs in two of the three target areas, it was determined that the most effective approach would be to hire and train area-based scientific teams as well as peer positions for each of the nine clusters. This approach will create a cadre of skilled individuals that can move into a variety of institutions that are currently under-capacitated and will require their expertise for replication of the work in Botswana's other districts. As an organization, CI is committed to building local capacity and opportunities for embedding staff into other institutions will be pursued as part of the sustainability and replication plans.

Based on a decade of implementation of a similar programme in South Africa, an initial diagramme for project implementation which blends technical and geographic expertise and responsibilities can be found in Figure 6.

The core management team should consist of the following:

Chief of Party—Responsible for the overall Project technical and operational delivery, with a specific focus on delivery of national policy and institution transformation with MoA.

Snr Director, Operations—Responsible for operational delivery, including legal compliance, human resource management, financial management, procurement, and administration.

Snr Director, Technical Support—Responsible for technical contributions and support to Rangeland Stewardship Agreements (identification and prioritisation of restoration needs and recommendations for restoration activities and effort level estimates for development of annual plans per village grazing area). Oversees scientific team and management of the Rangeland Stewardship Information Portal development and maintenance. Also responsible for all monitoring and evaluation activities.

Snr Director, Implementation—Responsible for overseeing District Directors, an Enterprise Director, and the two sub-grantee deliverables of the ecorangers curriculum and behaviour change capacity development and awareness campaign, and coordinating inputs from Technical Support with these teams. Reviews each District employment and annual plan and ensures it is in line with overall project implementation goals and budgets. Facilitates exchanges between Districts on cross-cutting issues and captures key lessons for sharing with policy platforms via the COP.

Area Directors—The three key field-based positions who oversee technical, operational, and implementation activities within a given district. They represent the COP at the landscape level with district officials and staff. They are supported by Farmer Facilitator Lead and team who oversee Ecorange and Rangeland Restoration workers, as well as administrative, procurement and financial support to ensure all operational compliance is handled as possible within the landscape. This operational capacity should grow commensurate with growth in the number of village grazing areas and Ipelegeng beneficiaries involved.

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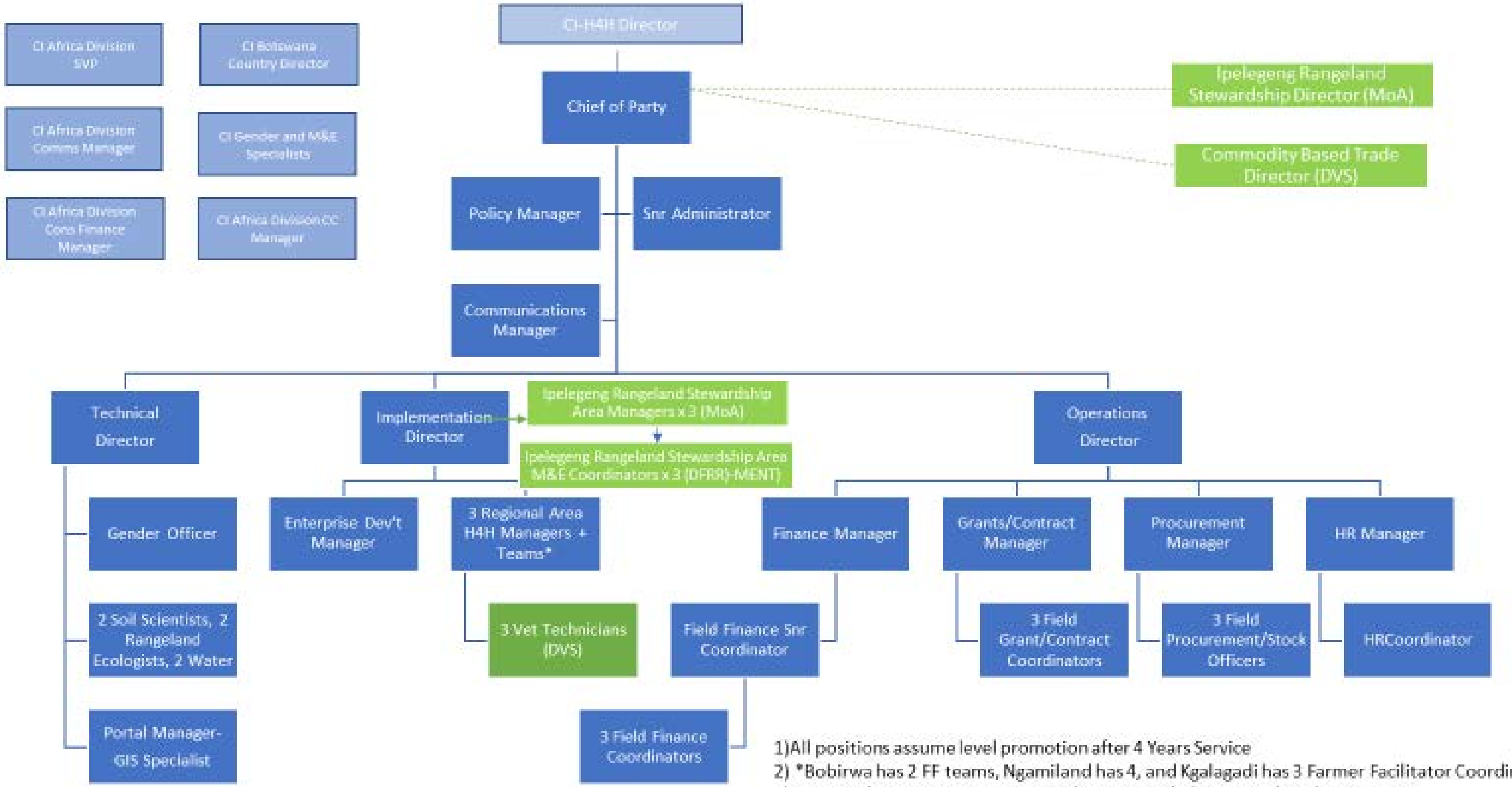
3.8 Figure 6: Indicative project staffing plan for the project.



1)All positions assume level promotion after 4 Years Service
2) *Bobirwa has 2 FF teams, Ngamiland has 4, and Kgalagadi has 3 Farmer Facilitator Coordinator
3) Green colour positions are project hires seconded to DPLGP/DVS/DFRR at govt Payband levels

7. Why Herding for Health?

Southern Africa has immense natural wealth and protects some of the last remaining populations of megafauna, including elephant, rhino, lion, and wild dog. Unfortunately, climate change and lack of investments in land and livestock management has led to extreme degradation of natural resources and increasing poaching throughout the country. Eighty percent of the non-protected land area is communal rangelands and used by African peoples with deep cultural attachments with livestock farming. Increased frequency of droughts is driving farmers into areas once left for "wilderness" and the impacts on wildlife have been devastating as both predators and bushmeat species are hunted in an effort to survive. Increased pressure on land over the last decades has transformed extensive areas of productive natural pastures into dense shrub savannas dominated by *Dichrostachys cinerea* (sickle bush), *Senegalia mellifera* (black thorn) and *Vachellia tortilis* (umbrella thorn) referred to as bush encroachment. This unfortunately is currently the condition of the vegetation in the majority of the rangelands used for livestock production and has resulted in a significant reduction in the carrying capacity of the natural vegetation. While efforts to expand ecotourism in the country are creating jobs and economic growth in rural areas, the majority of the communal land is trapped in a cycle of mutually reinforcing ecosystem degradation and poverty. Impacts of climate change are already exacerbating this downward cycle, and further changes projected for the area are likely to be devastating for both people and nature unless innovative solutions can be found (Figure 2).

Unless innovative and culturally-based climate resilient approaches are adopted by livestock farming communities, in ways that reduce the risk of rangeland degradation, disease transmission and spread, as well as human-wildlife conflict, the status quo will perpetuate vulnerabilities and increase GHG emissions by those farming communities who are unable to pursue alternative livelihoods in Botswana's rangelands. The country has low and variable rainfall, poor soils, exposure to regular droughts and proximity to wildlife make agriculture impossible in most areas[8] and tourism is unable to expand to the point where it can support all vulnerable populations—natural heterogenity; socio-political issues; and, in some communities, lack of interest being limits to tourism's reach.[9] Current fence-based management practices are ill-suited for promoting mobility required for wildlife and livestock in the face of increased climate variability and stress and lead to degradation that increases land and livestock GHG emissions.

[8] Seleka, Tebogo Bruce. (1999). The Performance of Botswana's Traditional Arable Agriculture: Growth Rates and the Impact of the Accelerated Rainfed Arable Programme (ARAP). Agricultural Economics. 20. 121-133.

[9] Mbaiwa, Joseph. (2015). Ecotourism in Botswana: 30 years later. Journal of Ecotourism. 14. 1-19.

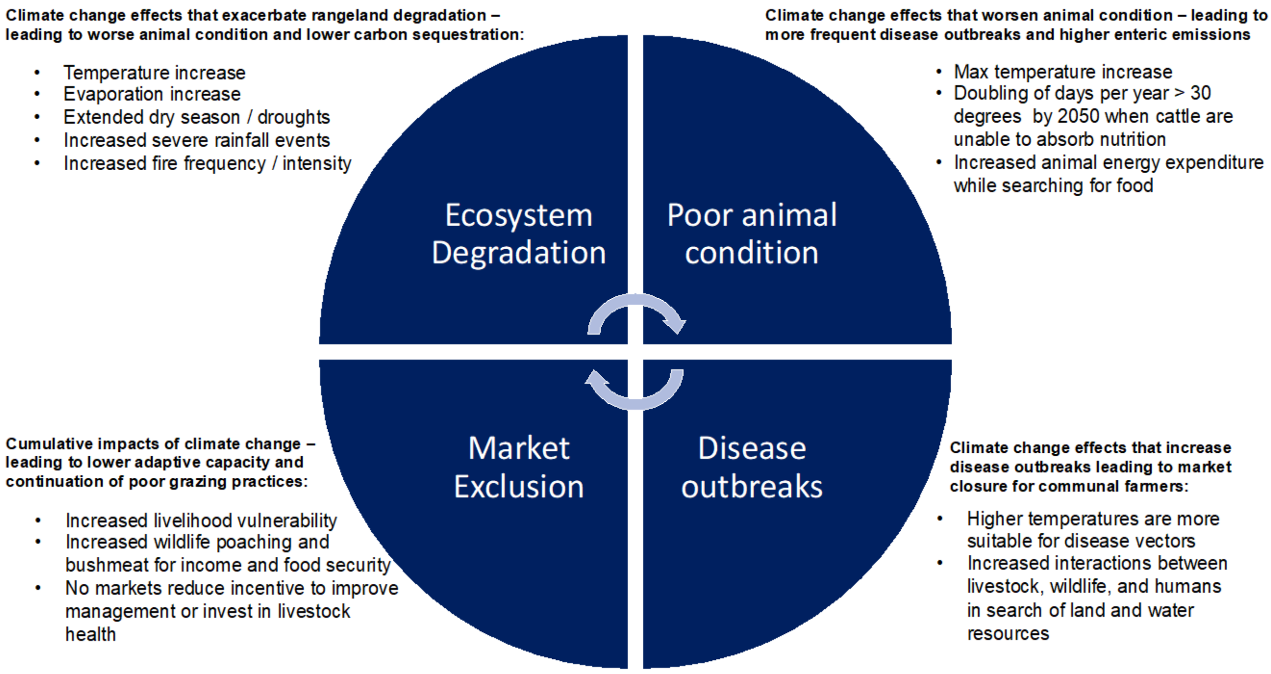


Figure 2: Depiction of the current cycle of degradation in the communal lands in Southern Africa, with various projected climate change impacts and how they relate to drivers of degradation and poverty.

8. Herding for Health, an Ecosystem-Based Adaptation Approach

The Herding for Health (H4H) Programme was developed over many years to provide a practical model for wildlife-livestock coexistence in Transfrontier Conservation Areas (TFCAs). The model is holistic and uses an integrated value chain development approach to incentivise and enable the adoption of best practices by livestock owners that are good for livestock health of rural poor, wildlife friendly, climate smart, sustainable, and unlock market access for livestock products despite restrictive disease control and market access measures in some areas. (See Appendix 4.1 of this section for a detailed overview of the science behind the H4H model). Successful implementation of variants of Herding for Health that are tailored for local context and led by various entities can be found in South Africa, Namibia, and Zimbabwe. The approach is now being rolled out across all major TFCAs in Southern Africa as a partnership initiative of Conservation International and Peace Parks Foundation (see https://www.peaceparks.org/h4h/).

Herding for Health plays a critical role in building climate change resilience through minimising wildlife-livestock climate induced risks (increase in natural resource competition, predation, and disease transmission, all of which induce tension and conflict), regenerating ecosystem health, and promoting sustainable land use and livelihood improvement.

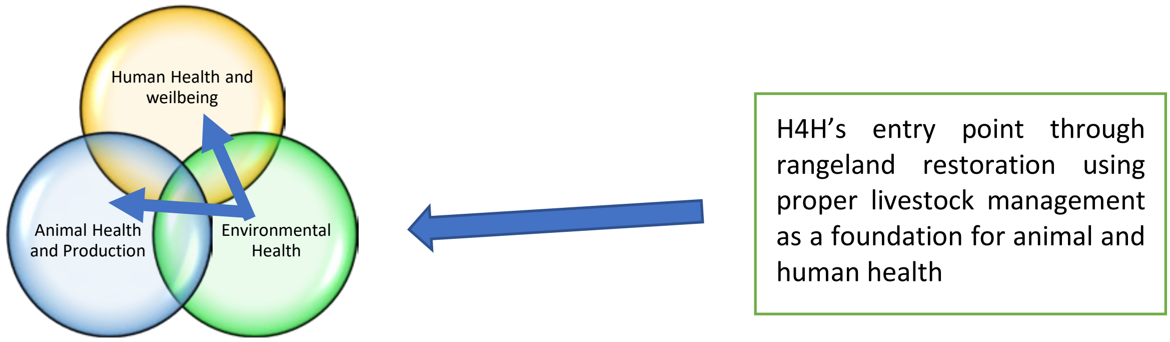


Figure 1: Model showing the interrelationship of human, animal and environmental health (One Health).

H4H promotes the Ecosystem-based Adaptation (EbA) approach to climate resilience via the execution of conservation agreements with vulnerable communities that agree to site-specific good practices defined by scientific and traditional knowledge. The desired ecosystem outcomes from the adoption of these good practices are increases quantity and quality of fodder, increased soil carbon sequestration, reduction of land surface temperature through improved basal cover and increased water filtration, all of which are known to build resilience to the impacts of climate change both for livestock farmers, but also the community more broadly. In most cases, much of the conservation agreement involves collective grazing or corralling that is implemented by professional herders called "Ecorangers". Restoration and wildlife protection elements of the agreement (Photo 1 below) are incentivised by livestock production and training support and sustained through access to markets for their livestock products (Figure 2).

a 

b 

c.

Photo 1: Examples of Herding for Health activities implemented in the Kruger Mnisi lands in South Africa (a: allowing a grazing camp to rest for a growing season with no cattle grazing, b: active erosion control with brush cutting and ponding to trap water and seeds on bare ground areas) and Massingir, Mozambique (c: use of mobile predator-proof bomas to replace current lethal predator management practices of poison and traps and to recycle nutrients into bare ground patches as part of rangeland restoration action).

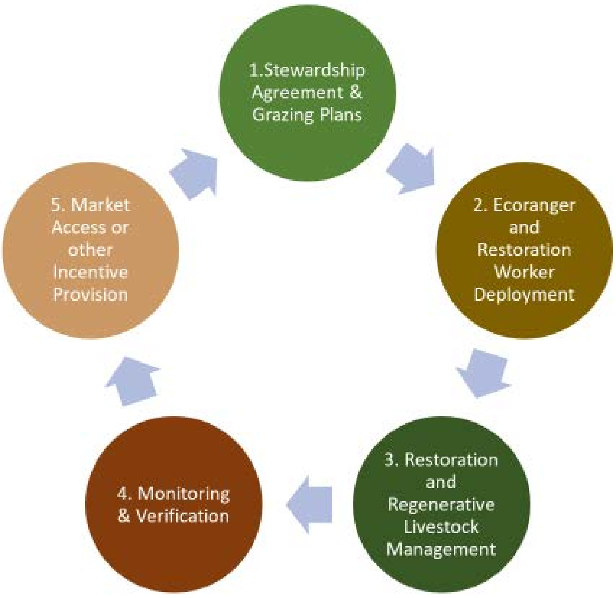


Figure 2: Overview of the Herding for Health Annual Implementation Model. An H4H initiative starts with an agreement on a spatially explicit grazing and vaccination plan (1) that is then implemented by Ecorangers and Restoration Workers (2). Specific indicators of ecosystem and livestock health (3) are then measured and once verified through a traceability system (4), premium or new market access options or fodder services are provided (5). It is important to note that the H4H system can only be implemented where there is full consensus by farmers, community leaders, broader community land-users and land-use oversight officials as partial implementation will not be able to reverse degradation. There may be intermediary phases planned to get to full compliance (see Leleifontein Commonage Case Study Overview in Appendix 4.2).

9. H4H Conservation Agreements and Grazing Planning

A conservation agreement (CA) is a negotiated exchange of benefits in return for changes in resource use, depending on verified performance. Behaviour change depends on incentives, and CAs are a powerful way to provide direct incentives. By using incentives, CAs also allow a fair distribution of burden and benefits of conservation among the stakeholders (community, implementing agent and donor). CAs are a simple approach because people have been making deals since the beginning of time: CAs make sense to communities, policy makers, and many funders hence their fundamental role and high degree of success in the H4H model.

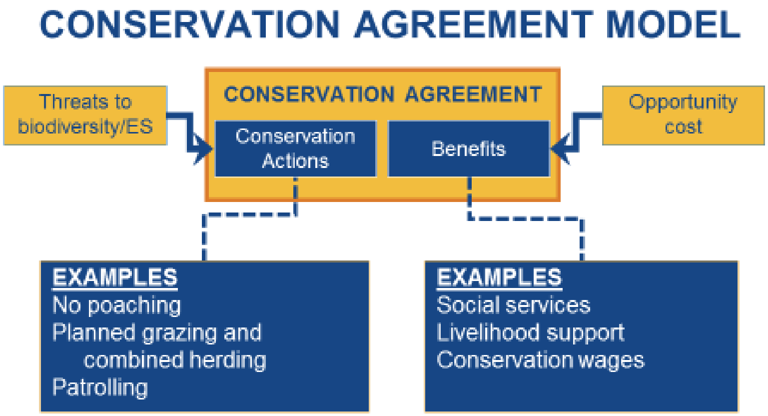


Figure 3. The conservation agreement model.

The model involves setting clear, measurable goals and targets that are 1) spatially explicit; 2) can be achieved using the resources available; and 3) have compliance sanctions clearly articulated and agreed as fair by all. Conservation agreements, Herding for Health and other community-based conservation efforts, have been deployed in more than 20 countries with more than 3,000 agreements around the world by Conservation International.[10] These agreements have made substantial contributions to global biodiversity goals, but also have been found to contribute to restoration efforts, strengthened leadership and governance, and strengthened territorial rights.

The process of establishing an H4H conservation agreement follows the cycle presented in Figure 4.[11] The process follows CI's Rights-based approach to:

- **Respect human rights,**
- **Promote human rights and wellbeing,**
- **Protect the vulnerable,**
- **Encourage good governance,**
- **Work in partnership,**
- **Ensure research ethics, and**
- **Free, prior and informed consent.**

Gender equity policies are respected and incorporated into conservation agreements, recognising that men and women use resources differently, have different access to information, and differ in decision-making authority. Key questions addressed in the negotiation process are: "Who uses resources?", "How is information shared?", and "Who makes decisions?". Fundamentally, the process embeds principles of Free, Prior and Informed Consent (detail provided in Appendix 4.2)

[10] https://www.conservation.org/about/conservation-stewards-program

and through annual re-negotiation (or updating), allows for full community participation and agreement on adaptation measures within the context of a changing climate (Appendix 4.3).

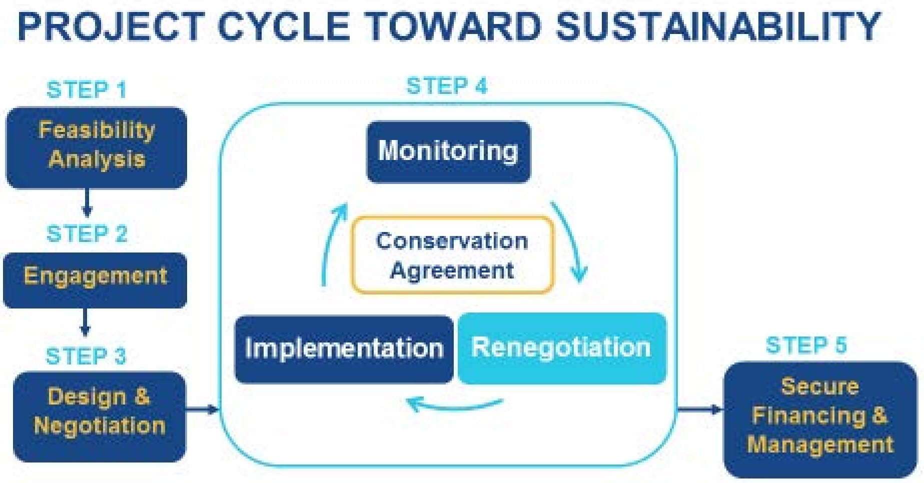


Figure 4. H4H Agreement Development Cycle.

The H4H project team are agreement facilitators, guiding and supporting the process and assisting with technical inputs, but it is important that the agreement the signatories are mandated authorities or legal entities and farmers. This is a key lesson learned over implementation of the approach by CI in South Africa and has led to the creation of three kinds of tools being developed by the partners in H4H (See Figure 5 and more in Section 6 of this Feasibility Assessment).

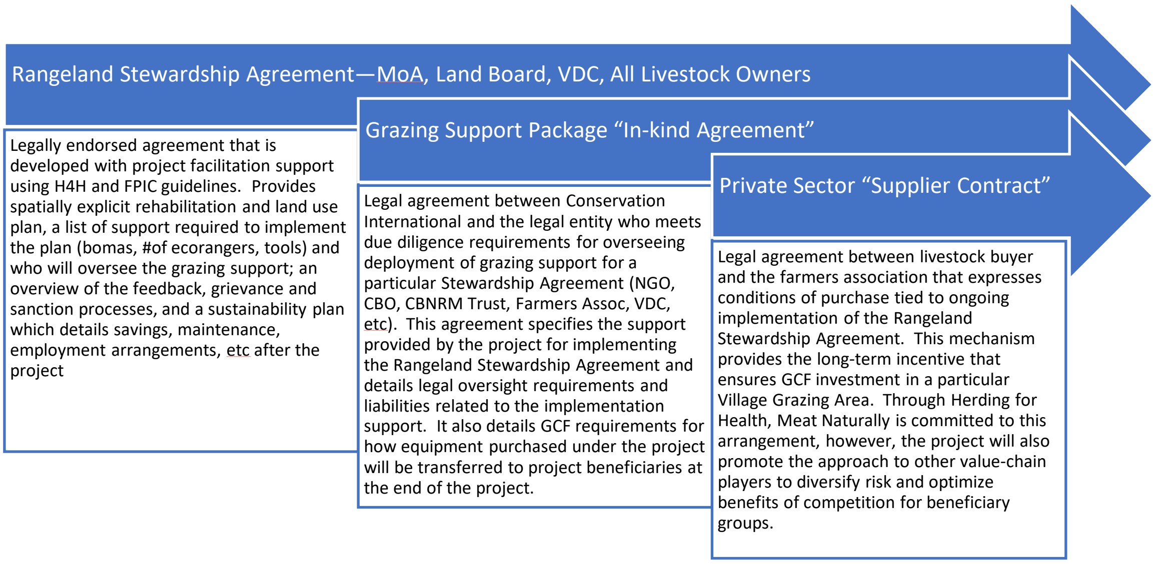


Figure 5. Contractual tools utilized within the H4H model during project implementation and for sustainability.

9.1 Ecoranger (Professional Herder) Training

In 2011, CI in South Africa first piloted the use of upskilling herders as part of conservation agreements for non-lethal and habitat restoration practices. Around the same time, the University of Pretoria started a Herding for Health study, led by Dr. Jacques van Rooyen, the current Director of CI's head of Herding for Health Programme in Africa (see Appendix 4.1). Both efforts practice and research, led to the conclusion that bringing skills and dignity to the tradition of herding was critical for regeneration and sustainability. The Ecoranger programme, (the job title Ecoranger was self-selected by herders in the programme who felt they wanted a new title to distinguish them from the role a child plays as a "herd-boy"), brings new technology like GIS and cybertrackers to enhance herders' ability to manage stock in an environmentally responsible manner. The programme has demonstrated an effective, wildlife-friendly method of protecting stock from predator loss while at the same time building capacity in these Ecorangers, who are paid by government job-creation programmes, to support rangeland restoration efforts. Additionally, due to their presence in the field every day, Ecoranger collected data related to predator activity, biodiversity, herd health and productivity, land-use condition, and climate change has proved vital to tracking trends that inform site-specific management decisions as well as long-term scientific studies.

The H4H Training Alliance is attracting the interest of government and farmers as a potential long-term initiative that can bring scientific and technological skills into stewardship and restoration of rangelands in a way that improves farm productivity—a programme where trained and accredited Ecorangers can become incentives (for communities) as well as support for conservation-based farming. While several institutions, particularly the Savory Institute and South African Herding Academy, have fantastic programmes for the upskilling of herders; the cost and literacy skills required for these in-house courses is more appropriate for Ecoranger Trainers. As a result, the Southern African Wildlife College (SAWC) worked with the H4H Training Alliance to develop an entry level Ecoranger course offered on-site, as well as a 1-month on-campus accredited course. Core skills for these courses within the accredited professional herder trainer course include:

- Life skills,
- Health and safety,
- Record-keeping and management,
- Environmental management,
- Planned grazing and rangeland restoration,
- Human-wildlife conflict management,
- Animal husbandry and low-stress animal handling,
- Primary animal health care (disease detection and mitigation),
- Basic ecology and climate change,
- Community governance and communication, and
- How to train others.

Where possible, H4H seeks to create partnerships with job creation programmes of national governments as a way of providing formalized, accredited training at scale. This model allows for an extensive deployment of formalised short courses on the first eight skills listed above supported by mentor farmers selected from each site that complement formal skills with practical, local expertise (Photo 2). This model is also in its early stages, but results are positive[12] and therefore integrated in the GCF Botswana project.

[12] Herding Academy Facebook page https://www.facebook.com/herdingacademy (see overview video on https://x.facebook.com/herdingacademy/videos/518202622309950/ and the change in perception for individuals who get to this level https://vimeo.com/299381878)


Photo 2: Ecorangers from Southern Africa at formal short course training and mentorship sessions with farmer/herder expert.

Exposure for the Ecorangers through national media is also a key incentive for keeping the trainees inspired and wanting to complete the programme and their certificate. It also raises the profile and job opportunities for these youth in the commercial farming sector. In South Africa, the Herding Academy students have been profiled on national television, national magazines, and used as models in a clothing advertisement for Jensen Clothing. For individuals who either do not make it through the Ecoranger programme or are not interested or able to undertake the nature of Ecoranger work, there will be other vocational training provided through the project enterprise development activities (Output 3.1). The specific trainings will be identified during the cluster-level business feasibility assessments. Partnerships with other initiatives offering training in those fields (such as meat processing, ecotourism, or crafts) will also be developed and leveraged to meet identified needs in alignment with the most viable options for a given area.

9.2 H4H Rangeland Restoration & Combined Herding

H4H is based on some fundamental principles of Holistic Planned Grazing, which was started in the 1960s by Allan Savory (https://www.ted.com/talks/allan_savory). Holistic Management (HM) involves the use of a practical decision-making process that effectively deal with complex systems from a holistic perspective. The term "holistic" is used because a fundamental principle of the system is that land cannot be viewed separately from the social, cultural and economic aspects of the community. Under the system, it is put forward that overgrazing is a function of time not animal numbers and occurs when animals return to grass plant before it has had time to regenerate. Time is viewed as the governing factor to the effect of trampling of soil; if animals are left in one place for too long or if they return to the same piece of land too soon then degradation is expected.[13] This has led proponents of HM to promote short-duration, high-intensity (SDHI) approaches to rotational grazing. Scientific debates on the SDHI approach are rife[14], and while H4H agrees that SDHI systems are not always appropriate, particularly in communal farming systems with fragile soils and ecosystems, it does promote the fundamental principles of managing for ecosystem rest and regeneration. Unlike other approaches, HM nor H4H do not advocate a fixed stocking rate for an area, but rather adopt an adaptive opportunistic strategy, where numbers will fluctuate widely in response to good or bad seasons i.e. strategic destocking and restocking. Under H4H annual conservation agreements (referred to in this GCF project as Rangeland Stewardship Agreements- details presented in 9) farmers agree to remove animals from the environment under harsh seasons and restock when conditions improve.

[13] J. BUTTERFIELD, S. BINGHAM, AND A. SAVOURY (2019). HOLISTIC MANAGEMENT HANDBOOK, THIRD EDITION : REGENERATING YOUR LAND AND GROWING YOUR PROFITS. ISLAND PRESS

[14] Heidi-Jayne Hawkins (2017) A global assessment of Holistic Planned Grazing™ compared with season-long, continuous grazing: meta-analysis findings, African Journal of Range & Forage Science, 34:2, pp 65-75.

All H4H recommended livestock management actions follow the guidelines compiled from premier regional scientists and practitioners in a Guidelines for Good Practice for Sustainable Rangeland Management in Sub-Saharan Africa[15] These practices are integrated into a spatially-explicit grazing plan based on the specific context of the village grazing area: size, natural characteristics, climate, type and number of livestock, availability of water, veterinary diseases present, nature of wildlife conflicts in the area; and other land-use needs in the area (village growth, ecotourism, and cropping).

In communal grazing lands, H4H rangeland stewardship actions include one or all of the recommended actions below in order to restore essential ecosystem processes (water cycle, carbon sequestration potential, and biological community dynamics—See Feasibility Study Section 3 for more details). The required actions include:

i. ***Creation of a collective herd/s in a village.*** The individual small herds owned by a single farmer or family that share a common grazing area are combined into one or a few large herds per village grazing area and are herded following the communally drafted and agreed grazing plan. The social aspect and advantage of combining small herds in a communal farming system into one or fewer larger, combined herds is that it encourages and enables combined decision making for managing the communally owned land where no individual can unilaterally make an impact as far as environmental management is concerned. Another major advantage of collective action is the increased ability to manage risk, and bear the cost of risk management.

ii. Manage livestock grazing for effective recovery period and rest.
   a. During the growing season of natural pastures, cattle should be moved to allow for shorter grazing periods with adequate rest for the grazed grass sward to recover adequately before being grazed again. In some systems (or when rainfall is high), the rest period can be for a few weeks, however, in most semi-arid savannas, the grass sward may need at least three to four months or a full season of rest to re-establish the root systems so as to remain productive at the onset of the next rainy season (Figure 6).
   b. During the non-growing/dry-seasons livestock numbers should be adjusted to available standing fodder. Trampling through excessive hoof action must be managed actively – especially in sandy soils which are common in most of Botswana. Supplementary fodder sources can assist significantly where available, such as grazing on post-harvest crop residues which also allow for the deposit of nutrients for the next planting season. The goal is that there will always be some vegetation cover on natural grazing lands to maintain ecosystem function and biodiversity.

[15] Liniger, HP. and Mekdaschi Studer, R. 2019. Sustainable rangeland management in Sub-Saharan Africa – Guidelines to good practice. TerrAfrica; World Bank, Washington D.C.; World Overview of Conservation Approaches and Technologies (WOCAT); World Bank Group (WBG), Washington DC, USA and Centre for Development and Environment (CDE), University of Bern, Switzerland. (downloadable at wwww.wocat.net)

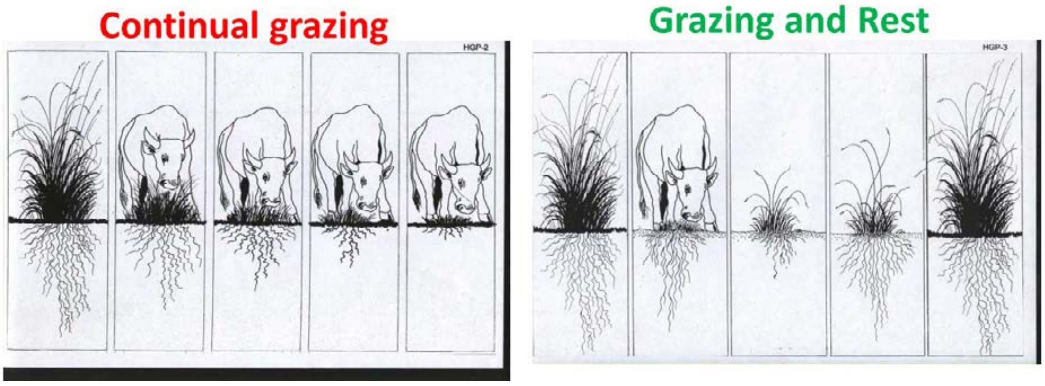


Figure 6. Example of what happens if a grazing area is continually grazed in 4/5 periods of a growing (i.e. rainy season) as opposed to when a resting period is introduced for 4/5 periods for a growing season. Root reserves are critical for plant regrowth and stabilising soils. Source: African Centre for Holistic Livestock Management.

iii. ***Address spread of invasive alien plants, manage bush encroachment and use of fire, and restore severe erosion*****:** In areas where invasive plant or bush encroachment is common, grasses lose their ecological territory to woody plants (shrubs/bush). People who use fire for bush control can cause further degradation or erosion and uncontrolled wildfires can exceed natural burning frequency thresholds leading to long-term degradation. Restoration teams (government or donor funded, or community volunteer efforts as part of the grazing plan) are often used to undertake the substantial habitat restoration work such as removing aliens, thinning bush encroached areas, controlling erosion points, and or ponding of sheet erosion. Restoration teams are also used to do initial clearing of strategic firebreaks that can facilitate implementation of a grazing plan (See Photo 3).

A

B C

Photo 3. Examples of restoration work A) Sheet erosion management: Mats of shaved bark are rolled out and pegged on bare ground with holes for bushes made around the mat. Brush cuts are placed on top of the mats to protect against grazing. B) "Ponding" or creating depressions to catch seeds and water is effective for re-creating patch-dynamic vegetation systems typical of arid zones; C) Erosion gully control: Low tech dams in erosion gullies captures soil that can then be stabilised through restoration mats.

iv. ***Manage livestock to maintain restored areas and regenerate bare soils.*** Where an area has been severely degraded, ecorangers move livestock to rest or utilise the habitat as required. Guided by rangeland ecology and traditional knowledge, mobile corrals are deployed to concentrate or remove animal impacts from a target area (See Photo 4).

Photo 4: Strategic corralling of livestock by Ecorangers using solar-powered electric corrals or predator-proof bomas (left photo) concentrates manure and breaks compacted soils to spark grass re-growth. The photo on the right shows an experimental plot on communal lands of South Africa corralling 200 animals each night for two weeks vs. an area which was left to normal livestock grazing pressure.

9.3 Monitoring and Verification

Monitoring is a key component of H4H for: 1) tracking impact of the selected grazing or restoration practices for stakeholders (farmers, community members, government, and donors); 2) contributing to traceability systems for veterinary disease control and market standards and certification schemes; and 3) monitoring participant compliance with conservation agreements and project protocols.

The monitoring of rangeland stewardship actions is very important. It forms the basis for sanctions against non-compliance by either party of the conservation agreement. The monitoring process involves:

- **Tracking verifiable and quantifiable results (number of animals in the herd, number of days an area was grazed, number of animals vaccinated, born, died, etc);**
- **Measuring conservation agreement compliance (were all animals in the village herd or outside of the designated rest areas at all times);**
- **Measuring ecosystem service impact (vegetation cover, biodiversity, soil carbon, water health indicators);**
- **Monitoring the socio-economic impact of the actions (improved well-being of herders, incidence of tapeworm/diarrhoea recorded at clinics; etc); and,**
- **Monitor human-wildlife conflict and risk factors associated with the presence of high-risk wildlife species, such as large carnivores and buffalo (carriers of various diseases that also affect livestock health, such as FMD).**

The above information is entered into a daily system by Ecorangers, verified by “implementing agents” (Farmers associations, NGOs, or government agencies), and consolidated automatically into an online system or portal. This can form a powerful decision-making tool from which market players or other interested parties can motivate further rewards for the farmers and communities where the conservation agreement is being successfully implemented. Trends detected in the monitoring information is used to inform re-negotiation of the next year’s conservation agreement (see Appendix 4.3). Remote sensing information on compliance with conservation agreements relative to fire and climate can provide important decision-making information as well, particularly for private sector players who can support the maintenance of the high-level verification well after project funding is over - see Figure 4 below and Section 5 of this Feasibility Assessment (sustainability approaches).

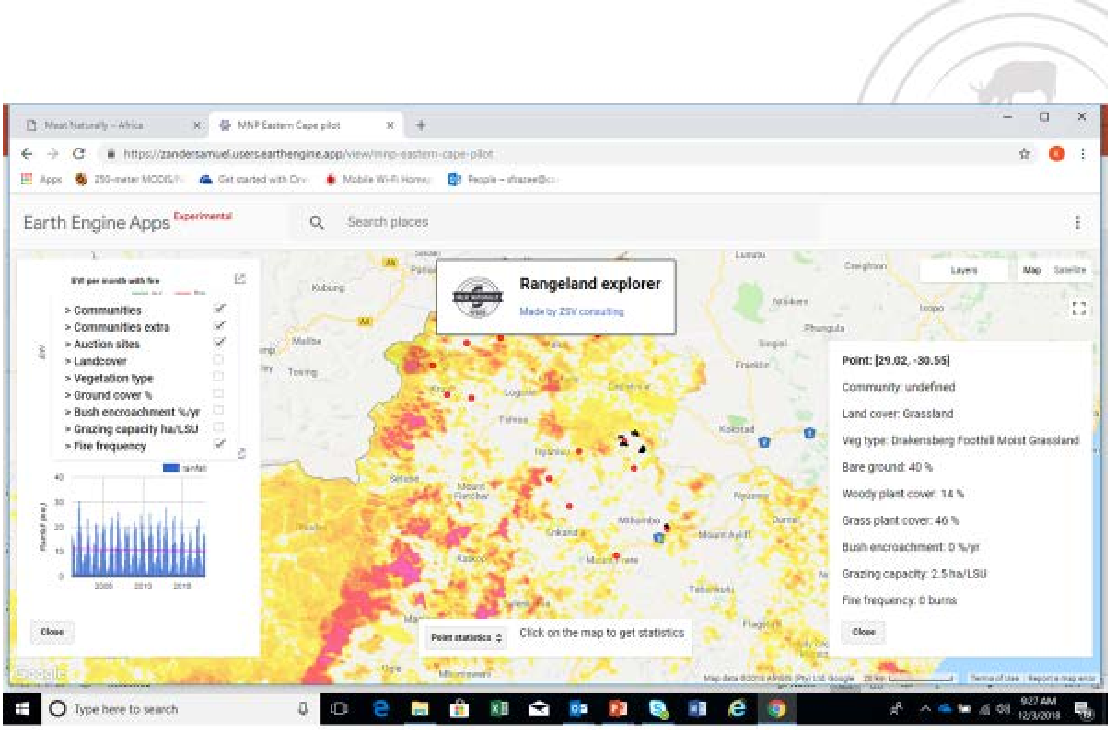


Figure 4. Meat Naturally has a customised monitoring tool, Rangeland Explorer, which overlays remote sensing data on fires, biomass, and precipitation to help assess/measure compliance with the conservation/grazing agreement. The base-layers of this tool are available to CI for use in the Rangeland Stewardship Information Portal for this Project.

9.4 Market access or other incentive rewards

If compliance is verified via data reports or online systems, H4H enterprise partners are encouraged to provide rewards. Currently, H4H implementing partners primarily work with Meat Naturally (www.meatnaturallyafrica.com) to provide market access and livestock production support incentives as rewards and Afrivet (www.afrivet.co.za) to provide animal health training and veterinary product support. The arrangement with these partners may or may not be exclusive, they generally allow for a site-specific reward package (such as varying commission rates or subsidized vaccination or fodder for better environmental impacts) with an implementing partner that can be embedded in a conservation agreement and agreed up front with farmers as an incentive for compliance. The impact of this reward-based project approach has been well-received and has now generated more than $2.4 million dollars for more than 2,000 impoverished communal farmers on 320,000 ha between 2016-2019. A performance evaluation report that focuses on the market access reward component of the H4H model is provided in Appendix 4.4 and examples of community agreements are provided in Appendix 4.5.

10. Requirements for successful implementation of H4H

Based on the H4H experiences in the region and conservation agreements globally, implementing village level Rangeland Stewardship Agreements are most successful when the following are in place:

- The existence of an enabling environment that mainly consists of strong collaboration within the communities, and among stakeholders; strong traditional leadership and governance structures; key policies in place to facilitate project implementation; government support across all levels; and basic infrastructure if needed (most of these can be facilitated if absent before project implementation as long as a project time frame allows for it);
- Definition of distinct boundaries for grazing planning and the enforcement of grazing rules. Use of historic boundaries known to elders and traditional leaders result in the highest success rate;
- Training of herders (Ecorangers) for effective grazing planning, livestock management, mitigating livestock-wildlife conflicts and resource-based monitoring;
- Reasonable salaries, prompt payment for Ecorangers and biometric capture of timesheets in remote areas is crucial to optimize effective delivery of the grazing plan. Encouraging study projects linked to implementation of the grazing plan can also help maintain task focus in what can be a lonely job;
- Basic market readiness training is crucial before any H4H sale, reasonable prices and prompt payment for livestock owners in H4H supported sales, and follow-up meetings immediately after a sale to clarify any questions or concern can avoid misunderstandings and loss of support for the conservation agreement;
- Ensuring availability of appropriate water infrastructure and natural fodder supplements is crucial for continued implementation of conservation agreements in time of climate stress and should be planned for at the beginning of every year;
- Enhancing market access, livestock marketing and value addition can expand income generating opportunities in the communities where H4H agreements are in place;
- Experiential learning, especially for the decision-making groups of the community. When farmers are exposed to other communities that are successfully implementing H4H they are more motivated and learn faster from other farmers than from extension or outreach activities;
- Exposure to Gender and Social Awareness training is critical prior to undertaking any final agreement negotiations to ensure the participation of women in project activities. Some examples of promoting the participation of women include: committee membership, training events, provision of services and goods, management of livestock planning and water

maintenance as well as targeting women as direct implementors with their own small-stock herd where appropriate.

11. Key References:

Heidi-Jayne Hawkins (2017) A global assessment of Holistic Planned Grazing™ compared with season-long, continuous grazing: meta-analysis findings, African Journal of Range & Forage Science, 34:2, 65-75, DOI: 10.2989/10220119.2017.1358213

Liniger, HP. and Mekdaschi Studer, R. 2019. Sustainable rangeland management in Sub-Saharan Africa – Guidelines to good practice. TerrAfrica; World Bank, Washington D.C.; World Overview of Conservation Approaches and Technologies (WOCAT); World Bank Group (WBG), Washington DC, USA and Centre for Development and Environment (CDE), University of Bern, Switzerland. (www.wocat.net)

Section 4 Appendices:

Appendix 4.1: Livestock Production and Animal Health Management Systems in Communal Farming Areas at the Wildlife-Livestock Interface in Southern Africa - Jacques Van Rooyen PhD – foundation for Herding for Health Model

Appendix 4.2: Conservation Stewardship Programme Synthesis Report-- Integrating the Free, Prior and Informed Consent Principle in the Implementation of Conservation Agreements

Appendix 4.3: Guidelines for Design and Implementation of Conservation Stewardship on Communal Lands

Appendix 4.4: SWFF Meat Naturally Performance Evaluation Report 2019

Appendix 4.5: H4H Conservation Agreements Example

Appendix 4.6 Lin Cassidy - Final Report on Feasibility of Conservation Agreements in Botswana

Appendix 4.7 Natural Resource Management Catalyser of Employment-South Africa

Appendix 4.8 OIE PVS Evaluation Follow-Up Mission Report of Botswana Veterinary Services

Appendix 4.9 Spreadsheet of beneficiary calculations

Appendix 4.10 Ecoranger and Team Leader Job Descriptions

Appendix 4.11 Botswana Regulatory Environment

Appendix 4.12 Rangeland Toolkit development

Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands

Annex 2 - Feasibility Study

Section 5: Market Assessment and Sustainability Plan

Prepared by Conservation International and C4 EcoSolutions through a Project Preparation Facility (PPF) Grant from the Green Climate Fund – September 2020

1. MARKET DEVELOPMENT STRATEGIES THAT SUSTAIN ADAPTIVE CAPACITY AND LOW EMISSIONS DEVELOPMENT IN PROJECT AREAS

Globally efforts to bring pastoralists into formal value chains has been seen to be a critical challenge and opportunity for sustainable development.[1] The Project theory of change is designed to facilitate the development of market demand and value-chains that both contribute to and benefit from climate responsive land and livestock management (Component 3). The approach aims to both unlock current red meat markets for communal farmers and build circular local economies that reinforce community participation and beneficiation. Importantly, the approach does not aim to subsidise poor quality production[2], but rather to shift communal livestock production to higher quality products that can contribute to lower-emissions national development. In the initial Phases (1&2) it is expected that the products generated from RSAs will be used to fulfill domestic and regional demand, by Phase 3 (Year 6) the operational traceability, regulation, and animal quality should be in place potential premium certification schemes such as Farm Assured Botswana, Wildlife-friendly Beef (under development) as well as meet EU trade standards.

Opportunities to influence the development of climate-smart value chains from meat, dairy, and other products from livestock provide (wool, leather, etc.) have been identified and successfully utilized by the Herding for Health Programme in South Africa (see Feasibility Assessment, Section 4). In Botswana, three recent studies conducted in 2017, 2018, and 2019 indicate that a similar approach is viable in two of the three project areas, namely Ngamiland and Bobirwa:

- ***Exploring Market Opportunities for Commodity-based Trade (CBT) of Beef from Ngamiland: Towards Harmonisation of Livestock and Wildlife Sectors (2017). Appendix 5.1***

- ***Meat Naturally Botswana Feasibility Report and Business Plan (2018). Appendix 5.2***

- ***Protecting Nature, Promoting Prosperity: A Report on the Feasibility of Using Business Value Chains to Support Herding for Health Initiatives in the Greater Mapungubwe Transfrontier Conservation Area (2019)[3]. Appendix 5.3***

In the Kgalagadi, the ongoing GEF-funded project has a specific activity aimed at developing similar value-chain opportunities that will be used to inform the role-out of Component 3 activities for this project in that area. Fortunately, the Kgalagadi is in a “green zone” with regards to the presence of FMD and is closer to the main Botswana Meat Commission trade centers and

[1] McGahey, D., Davies, J., Hagelberg, N., and Ouedraogo, R., 2014. Pastoralism and the Green Economy – a natural nexus? Nairobi: IUCN and UNEP

[2] Current reactive price incentives to incentivize de-stocking as has been implemented elsewhere or during drought conditions in Botswana perpetuates bad land management and creates price expectations by farmers that are not in line with market or ecological realities. (See Charles Pershings, 1997, “Stress, Shock and Sustainable Resource Use in semi-arid envrionments” in Economics of Ecological Resources, published by Edward Elgar Publishing Ltd. Cheltenham, UK.)

[3] The Greater Mapungubwe TFCA includes the Bobirwa sub-District of Botswana

therefore the Project expects to find greater range of market development opportunities for this region.

2. Current Market Forces: Beef Supply and Demand

2.1 Supply

Beef production and export has historically been a critical component of the Botswana agricultural economy. The nationwide herd size is in constant fluctuation, ranging from 2.5 -3.5 million head, consistently outnumbering the human population of 2.4 million[4]. Almost 57% of the nation's cattle is absorbed by the country's primary exporter, the Botswana Meat Commission. Currently, only 20% of the cattle received from producers in Botswana comply with EU requirements.[5] Low-quality cattle from communal lands will be offered less than 50%-80% the price of higher quality animals. This creates a vicious cycle whereby communal farmers have no incentive to offtake, and sales occur when money is needed for subsistence, school fees, or family events. Government drought and predation compensation also provide perverse incentives for apathy and poor management by farmers that lead to erratic offtake and empty abattoirs despite large animal numbers. Based on DVS records, the three Project regions have an average supply throughput of 70 carcasses per day in the Project Areas for domestic consumption or 25,550 carcasses per annum in 2020. This is slightly higher than the 5-7% offtake rate generally estimated as the offtake rate from communal lands and probably suggests some contribution from private and group ranches that will generally supply 12-18% of their herds into the market from commercially managed production systems. Accessing most export markets requires communal farmers to meet strict adherence to international trade standards for animal products. Total supply of exports from the Project Areas are unknown but currently, few, if any exports are coming from communal lands. Table 1 provides a SWOT summary of Botswana meat exports that should be considered in the development of the Project to inform the engagement strategy regarding expanding supply of sustainable beef from the Project areas..

[4] Dizyee, Baker, Rich "A quantitative value chain analysis of policy options for the beef sector in Botswana" (2017)

[5] https://www.farmersweekly.co.za/opinion/by-invitation/botswana-beef-exports-opportunities-for-sa-farmers/

Table 1: SWOT analysis of Botswana's Meat Market Status

Strengths	Weaknesses
▪ High proportion of free-range naturally produced beef. ▪ Stringent production standards, especially in processing. ▪ Meeting EU requirements. ▪ Botswana's positive image compared with many other African countries. ▪ Long cattle producing tradition. ▪ Extensive government support schemes.	▪ Ineffective and inefficient LITS system. ▪ High proportion of cattle in FMD-infected zone and prevalence of beef measles. ▪ Weak extension services. ▪ High cost structure. ▪ Lack of commercial and modern farming practices. ▪ Poor infrastructure. ▪ Inconsistent enforcement of standards. ▪ Lack of branding and absence of marketing capability. ▪ Support infrastructure for industry not meeting needs fully. ▪ Lack of competition in exports limits product innovation and market development. ▪ Poor awareness of regulatory compliance at primary production level.
Opportunities	**Threats**
▪ Preferential access to EU markets. ▪ Unexplored markets in region and internationally, with increasing imports in emerging markets. ▪ Import substitution to export higher value beef. ▪ Reduce input costs by producing feeds locally. ▪ Targeting higher value segments and commanding better price with branding and premium cuts.	▪ Reliance on a small number of markets targeted with a very narrow range of products. ▪ Reliance on one outsourced entity for entire country's exports. ▪ Disease outbreaks and droughts. ▪ Increasing competition in global markets. ▪ Reliance on imported inputs. ▪ Increasingly stringent and costly EU requirements

Source: ***Botswana CDE and ITC partnership project on value chains: Beef value chain findings, strategy and proposed interventions*** **report (2014)**

2.2 Demand

2.2.1 Export demand and competition

Botswana was the ninth largest beef exporter to the European Union in 2019, and one of the largest beef exporters in Africa. The EU agreement enables Botswana to export beef duty- and quota- free to the EU. Producers receive 60% for EU export than export prices to its largest regional importer, South Africa. All Botswana Meat Commission's (BMC) export abattoirs have halal slaughter certification which is used to access markets in Muslim-majority countries. The countries in **bold** have already developed MOUs with Botswana's Department of Veterinary Services (DVS) to import beef and beef products from Botswana with discussions underway with the others listed.

1. Middle Eastern countries: Egypt, **Kuwait**, Oman, Qatar, Saudi Arabia and the UAE;
2. Far Eastern countries/administrative region): Malaysia, **Vietnam**, China and Hong Kong;
3. African countries: Algeria, **Angola**, **Democratic Republic of Congo**, Ethiopia, Kenya, **Mozambique**, Tanzania, Uganda, Zambia and Zimbabwe.

Despite positive trade arrangements, Botswana has not been able to meet its quotas for any of the above arrangements over the last decade. Drought, disease outbreaks, and disruptions in BMC operations are most frequently quoted reasons for this economic failure.[6]

In the long-term, additional markets for Botswana in the EU are likely to open in order to meet demand for sustainably produced meat as areas with the potential to economically raise grassfed-meat at scale are limited. The *Botswana CDE and ITC partnership project on value chains: Beef value chain findings, strategy and proposed interventions* report (2014) highlights that high-quality grass fed beef can command twice the price of grain-fed varieties, particularly in European markets where Botswana exports are entrenched. Margins for value-add capture for producers are significant with Botswanan farmers earning between US$0.90 – $1.80 /kg for their cattle and European market consumer paying an average of US$ 23.60/kg for Botswana beef (Appendix 5.2). The National Grassfed Beef Strategy provides the MoA with a mandate to further develop grassfed meat export markets and certification for national grassfed products to generate greater returns for farmers and the Project will seek to capitalise on this effort in Phase 3.[7]

2.2.2 Domestic demand

Prior to COVID, surveys completed by Meat Naturally show that the tourism sector in the Project areas exceeded the locally available supply by more than 150 tons per annum. There is potential for growth demand—both domestic and foreign—of beef originating from the Project areas. Given the local demand for the tourism sector, there is also potential for sales to local higher-value markets that may be easier to reach and generate greater returns for farmers participating in the Project. The Project strategy is to meet this local demand in Phase 1 and Phase 2 to develop sufficient consistency in quality and quantity of offtake.

Based on this assessment, project beneficiaries will likely experience high demand for their offering and private-sector actors that are dedicated to sourcing and selling products from farmers in RSAs are likely to be supplier- rather than buyer-constrained.

3. Market access and beef value-chains in the Project Areas[8]

Market access for livestock in Botswana is highly regulated by the Livestock and Meat Act of 2008 and subsequent and associated amendments and regulations regarding trade and processing requirements (Annex 2, Section 4 Project Approach). Until 2017, the Botswana Meat Commission parastatal had a near monopoly on all formal trade. However, new private sector actors have been allowed to service both domestic and regional markets. The following provides an overview of new key players offering formal market access to farmers within the Project Areas.

3.1 Existing Private-Sector Actors

There are seven licensed export abattoirs that service domestic and export markets and two local authority abattoirs within the Project area that currently service only local consumption needs.

[6] Referenced in Appendices 5.1-5.4 and Parliamentary Special Select Inquiry into the Botswana Meat Commission and the Decline of the Botswana Beef Industry (2013)

[7] The strategy was adopted by Parliament in July 2020 and is now being led by the MoA with a focus on commercial farming in parallel to this Project.

[8] Small stock value-chain opportunities will be developed as part of the project Output 3.1.

Unfortunately, disease outbreaks, drought, and poor livestock condition and political influence over the Botswana Meat Commission impact the ability to consistently service the local and export demand from Ngamiland, Bobirwa, and Kgalagadi. Abattoirs in these areas are rarely operating at full capacity. Water and energy disruptions are exacerbated by regular—and increasingly frequent—supply disruption due to droughts and disease outbreaks resulting from climate change. Creating opportunities for stocking rates through efficient offtake facilitation by these facilities, particularly during times of drought or other climate stress will be critical for the Project's beneficiaries. In three communities in Ngamiland, 84% of farmers surveyed had lost animals to drought. New arrangements and response agreements between government, Project area abattoirs, and farmers will be pursued as part of the Component 3 project activities.

3.1.1. Botswana Meat Commission (BMC) Export Abattoirs: Botswana Meat Commission (BMC) was established to promote the development of the country's beef and related products globally. Within the Project Areas, it has two facilities in Maun (Ngamiland) and Francistown (near Bobirwa), in operation since 1983 and 1989, respectively. The Maun Abattoir was closed in 1996 due to shortage of cattle supply and re-opened in April 2010. Until 2014, it was slaughtering about 120 units per day coming from the quarantine facilities in Ngamiland. Privatization of the BMC abattoirs was recommended in a Parliamentary Inquiry Report in 2013, the political delays have stalled this process. However, there are indications that this will now move forward under Botswana's new administration. **Project sub-activity 3.2.2b aims to engage with this process and, where possible, create opportunities for communal farmers to provide inputs into these discussions, where their voices are often absent. The Project's support of these activities are crucial as the long-term nature of the project will allow more long-term engagement than parallel projects operating on shorter timeframes.**

3.1.2 Other export abattoirs: The table below provides a list of the abattoirs approved for export located in the Project areas. As described in Annex 2, Appendix 5.1, there is general acceptance that the number of abattoirs is sufficient as all are operating and under-capacity. Tati abattoirs, and Francistown, once dominated the regional export market to Angola. However, discussions with the Director of the Department of Veterinary Services (DVS) indicate that Angola has now shifted the bulk of their purchasing to producers from India, leaving Botswana exporters to sell their low quality products from "FMD red-zone areas" into the Democratic Republic of Congo. Batawana Beef and Ngamiland Beef regularly export to the Democratic Republic of Congo and shipments re generally in 1000 carcasses in halves and quarters sold into butcheries in that country.

Facility	**Location, Project Area**	**Status relevant to Project**
Ngamiland Abattoir	Maun, Ngamiland	Operational, exporting to DRC
Batawana Abattoir	Maun, Ngamiland	Operational, local market, tourism facilities and exporting to DRC
Tati Abattoir	Francistown, Outside but proximal to Bobirwa	Operational (status unknown)
Tshabong Meat	Tshabong, Kgalagadi	Export facility for small stock, under construction
Multi-species Abattoir Botswana Meat	Gaborone	N/A

Meat Naturally Botswana	Mobile	Herding for Health Partner, Owner and Operator of Mobile abattoir for use to incentivise improved rangeland management on communal rangelands

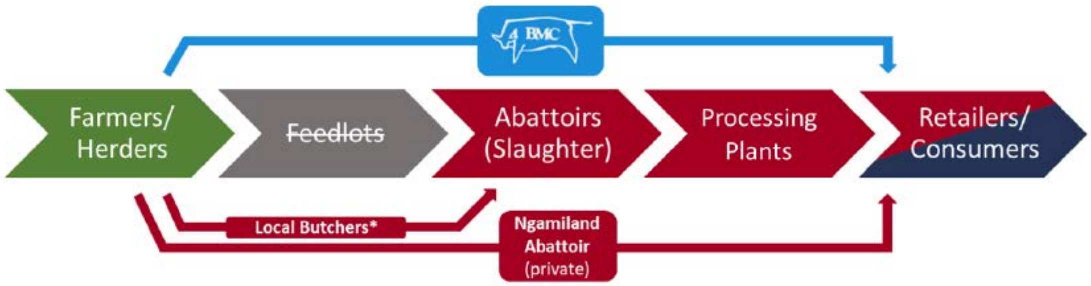
In addition, CI discussions with these abattoirs are already taking place, as part of the proposal development process. Representatives of Batawana Abattoir and Ngamiland Abattoir were involved in the stakeholder consultations for the Project. The Ngamiland Abattoir has agreed to host the Meat Naturally Botswana mobile abattoir trial for the authorization process, and both entities have expressed willingness to purchase carcasses from Meat Naturally for further onsale and/or export. The business model is viable for all parties and these relationships and the development of CBT protocols for the value-chain arrangements are being developed by Herding for Health Programme experts and will go to the AHEAD Programme for review and DVS for approval. No further funding is required from the GCF for this process, which is anticipated to be completed by the end of 2021. Lessons learned in the process should be shared in the GCF Project policy platforms described in Activity 1.5.1. as a way of expediting replication of the broader Project model and successful approaches that lead to demonstrable adaptation and mitigation benefits.

3.1.3 Local authority abattoirs: Finally, there are two low throughput abattoir facilities in the Project Areas at Bobonang and Kang that are run and operated by the local authorities. There is also a new NGO-supported community slaughter facility in Gumare in Ngamiland to help farmers and local butcheries with supply when the export abattoirs are processing exclusively for export. None of the local level abattoirs are commercially viable at the moment, but in combination with a mobile abattoir, they may be able to support local offtake for domestic consumption.

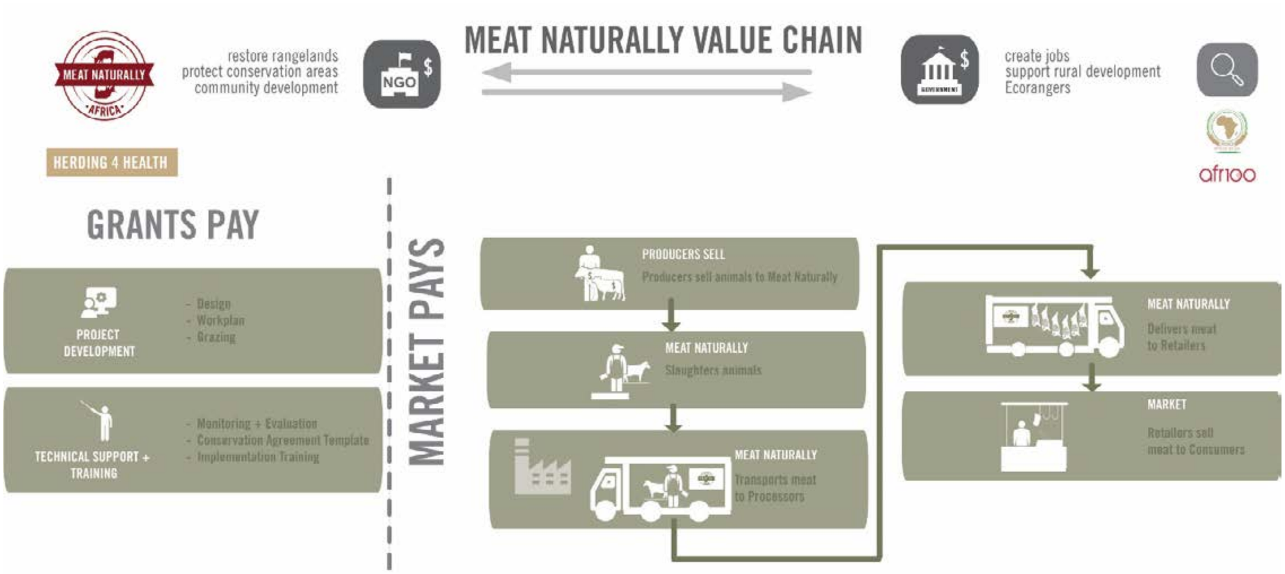
3.2 Red meat value-chains in the Project areas

Private sector players are the link between the livestock producers and consumers (domestic, regional, and international.) Depictions of potential value chains for livestock from the Project are found in Figure 1.

3.3 Value chain for livestock from the "green zone" including the Kgalagadi.



3.4 Value chain example in Ngamiland where both BMC and Ngamiland abattoirs purchase and sell low quality, canned meat for regional markets, primarily the Democratic Republic of Congo



c) Meat Naturally mobile abattoir value chain which could be deployed across all three project areas

d)

The Botswana beef value chain map (2010)

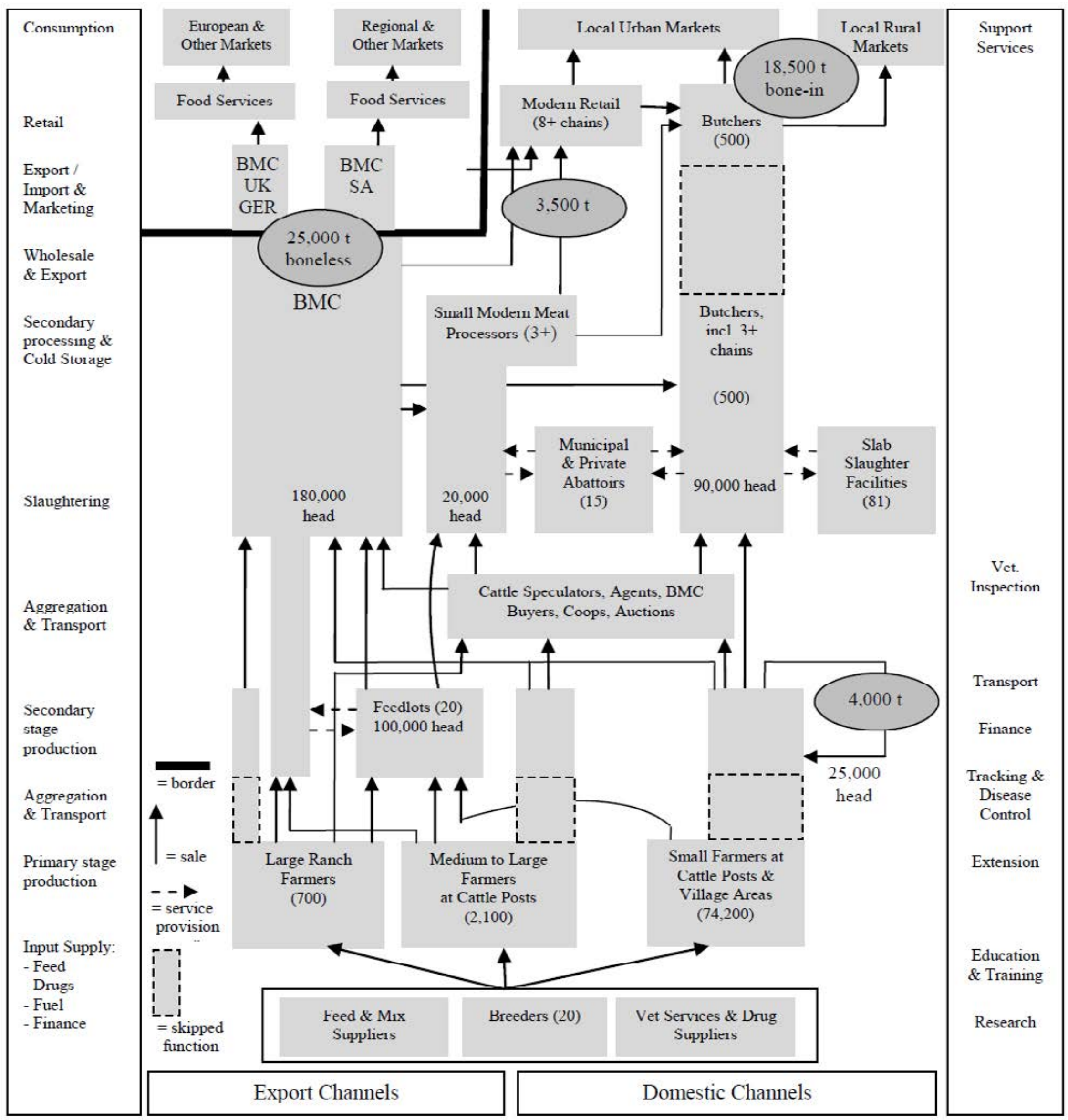


Figure 1: Depiction of red meat value chain in Botswana where a) a typical commercial value chain which utilizes a feedlot to add weight and fat before sale and transportation agents are used to facilitate movement of large numbers of animals in a single sale; b) depicts a typical communal lands value chain where direct sales to BMC do occur at infrequent and unpredictable times and although higher prices are paid, farmers are paid 6 -9 months after their sale (source: Appendix 5.2). A farmer may also choose to sell to a local butcher or new private abattoirs who pay less but have better payment terms (<3 months). Communal farmers also can sell on informal market for animals for traditional ceremonies, but in 2018 Botswana banned “under the tree slaughters” so this direct farmer to consumer option is no longer legal; c) depicts the Meat Naturally mobile abattoir value chain and links to other processing enterprises and retailers; d) details historic BMC value chain. Unfortunately, during the PPF process in 2019, BMC was not operational as privatization plans were being developed and its future is uncertain. Source: FAO Beef Value Chain Study; https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Agricultural%20Economic%20Fact%20Sheet_Pretoria_Botswana_6-9-2015.pdf

4 Viability and Benefits of Commodity-based trade from the Project Areas

The Project aims to unlock better prices from the BMC and private abattoirs, farmers and value chain players by building capacity for and implementing Commodity-based Trade guidelines (Appendix 5.4) for the management of Foot and Mouth Disease (FMD) [9]. By implementing the guidelines, meat from the Project target areas will achieve the new standards set by World Organization for Animal Health (OIE) through Article 8.8.22, Terrestrial Animal Health Code [TAHC] in 2016 in addition to national and regional meat safety regulations. Due to the focused effort on CBT in the Ngamiland region, farmers and officials already have a high degree of awareness and understanding of what is required. As such, the goal is to have this system in place by the project mid-term in Phase 2 in Ngamiland as a demonstration and learning site not only for the other Project Areas, but for other Botswana communal rangelands by the end of the Project. Figure 2 depicts key aspects of the new guidelines and how current and future practices through the Project Actions will enable a virtual cycle for enabling market access.

The Ngamiland Market Opportunity report (Appendix 5.1) provides India as a benchmark for how this Project Area can implement commodity-based trade to compete in FMD-equivalent markets. If the Project can help Botswana capitalise on advantages and overcome challenges relative to India Carabeef (Table 2), the report suggests that Botswana Meat Commission will be able to outcompete India for the following key FMD equivalent markets: Middle eastern countries (Egypt, Kuwait, Oman, Qatar, Saudi Arabia and the UAE); Far eastern countries (and an administrative region): Malaysia, Vietnam, China and Hong Kong; and African countries (Algeria, Angola, DRC, Ethiopia, Kenya, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe). This opens significant opportunities for existing and new private sector actors to play a role in creating markets that will incentivise farmers to participate in RSAs beyond the life of the Project. It is important to note that while CI agrees and promotes lower overall meat consumption to reduce global warming, projected demand for beef is rising in each of the above listed countries. This rising demand provides a market opportunity to enable sustainable production of meat from a habitat that is designed for extensive herbivory as opposed to one beef from Brazil's cleared forest habitats or with higher transport footprint.

Table 2: Benchmark analysis for Commodity-based Trade Market between India and Botswana.

CHARACTERISTIC	INDIA	BOTSWANA
Animal Type	Water buffalo (dairy animal)	Beef cattle
Offtake	In India, the majority of water buffalo marketed as carabeef are either excess male calves produced from the water buffalo milk herds, or older non-productive females. Average male slaughter age 4 years, females older. Current exportable product of 1.85 million tonnes in 2016.	In Botswana, the cattle are predominantly marketed from a communal herd structure. The animals are mostly full mouth oxen aged 5 years and over or cull cows of similar age. Last year, BMC Maun and Ngamiland Abattoirs slaughtered over 34,000 head with very little export.

[9] Foot and mouth disease (FMD) is a transboundary animal disease (TAD) that severely affect the production of livestock and disrupting regional and international trade in animals and animal products. It has no impact on human health and primarily impacts the milk of dairy cows. http://www.oie.int/en/animal-health-in-the-world/animal-diseases/Foot-and-mouth-disease/

Female production system	The average sized Indian herd is less than five animals, and these animals are the entire livelihood of the people that own them, being used for milk and draught power. Young males are fattened, where there are sufficient feed resources, for carabeef.	Many female cattle are a source of milk for the owners, so the calves are kept separated from the cows and remain in the villages or near the water points when the cattle go out to graze. This increases grazing pressure close to the calf kraals, as the cows come back to their calves, and are milked before being left with them for the night and taken out the following morning.
Male production system	The carabeef industry is integrally linked to the recycling of crop residues, with small herds being family managed so production is intensive.	Free-range grazing which changes seasonally from good nutrition during the rainy season to sub-maintenance during the dry season. Production is extensive with severe range degradation.
Owner responsibility for FMD control	Greater owner responsibility for FMD biosecurity. FMD is devastating to dairy animals, and can cause severe poverty due to a drop in milk production. The Indian state is unable to assist with financial support for farmers whose cattle/buffalo are affected by the disease, so owners appear to be very vigilant, and value chain operators (specifically at abattoir level) ensure cattle/buffalo from source herds are adequately vaccinated.	Little owner responsibility for FMD biosecurity as fences to separate buffalo from cattle are maintained by DVS, and cattle are biannually vaccinated for free, taking the onus off the owner. Presentation rates when vaccination falls within the rainy season are poor, and this affects market access. Vaccination can only be done by the Competent Authority (DVS).
Biosecurity	Biosecurity in India is easier to maintain as herds are stall fed and supervised most of the day, and intensively fed on crop residues.	In free-range extensive production systems, with large numbers of elephant to damage fences, and no active herding, biosecurity is very poor around cattle. Cattle access to Cape buffalo (the reservoir of SAT FMD viruses) around shared water points, especially in the dry season, can result in FMD outbreaks in kraals.
Government involvement in FMD control	FMD-endemic area, with types O, A and Asia 1 being present.	FMD-endemic area, with SAT serotypes being maintained by wildlife (no official OIE designation). Government of Botswana

Source: Ngamiland Market Opportunity Report (Bing et al, 2017, Appendix 5.1)

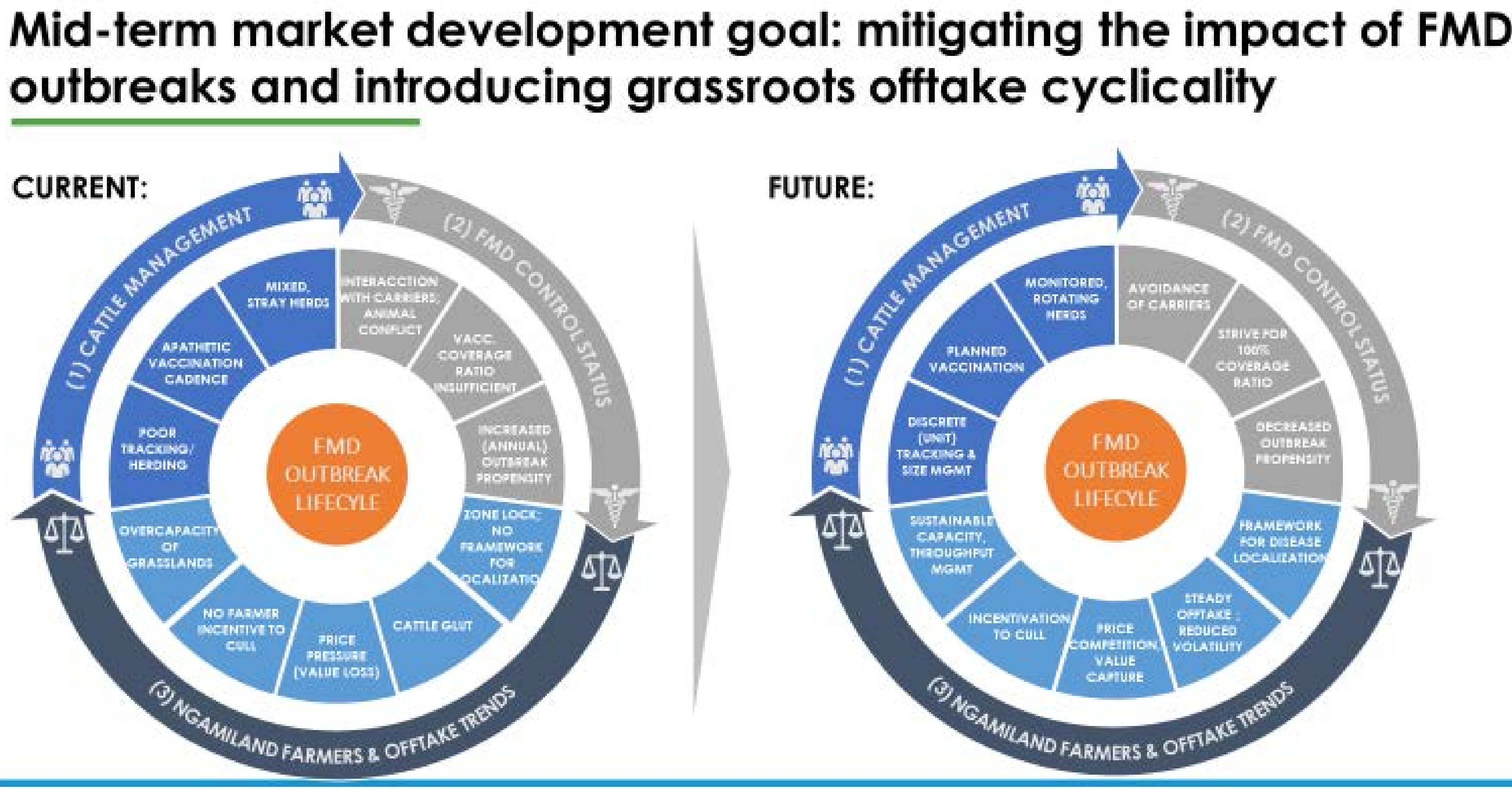


Figure 2: Mid-term market transformation goals of the Project for Ngamiland. The aim is to facilitate similar market condition trends in all Areas by the end of the end of the Project.

5 The Role of Meat Naturally in Unlocking Market Access

5.1 Meat Naturally Botswana Background and Current Status

Meat Naturally Pty is a social enterprise, constituted under South African legislation as a commercial business in 2016. However, 100% shareholding of the business is held by the Meat Naturally Shareholders Trust. The Trust beneficiaries are majority (60%) communal farmers who sell through it. The Trust currently represents over 2000 farmers in South Africa's communal lands, but all farmers who receive market access support are automatically included in the business shareholding via the Trust. The remaining 40% shareholding beneficiation is with Conservation South Africa[10]. This structure ensures the longevity of the conservation commitments supported by a sustainable business vehicle while helping local farmers gain shareholding in the formal private sector. Since 2016, Meat Naturally has helped communal farmers engaged in conservation agreements earn R42.8 million (roughly US$3.1 million) from livestock sales and supported regenerative grazing management on >320,000 ha of natural rangelands.

Meat Naturally Botswana is a legal entity and part of Meat Naturally Pty's strategy to develop a network of national, farmer owned, female-led Meat Naturally operations in Southern and Eastern Africa. Meat Naturally Botswana is in the process of establishing a co-op-like structure based on the South African model, creating ownership in addition to sales incentives for sustainable land use that will strengthen the value chain links to RSAs. Delays in finalization of this new structure due to COVID restrictions on meetings and border crossings have occurred, but the MN Botswana Directors hope to have this finalized by the second quarter of 2022. Meat Naturally and Meat Naturally Botswana will be governed by an Association commitment and not a franchise relationship as the intention of the social enterprise is to be a vehicle for development and create a profit-sharing mechanism for farmers, rather than profit for business owners. Meat Naturally Botswana's social enterprise registration and development was supported by grants and awards won by Meat Naturally for its innovation. Meat Naturally Botswana has completed business unit strategy development for all three of the Project areas and is the process of submitting an application to the DVS director via the local co-Director and other Botswana partners.

Surveys completed by Meat Naturally show that for markets in Ngamiland and Bobirwa, demand for dried meat products in 2020 outstrips supply by more than 1000 additional carcasses. Based on DVS records, the three Project regions have an average consumption of 70 carcasses per day or 25,550 carcasses per annum in 2019 and 2020. Based on its business plan, Meat Naturally Botswana will exclusively slaughter and process for the domestic and tourism market with mobile abattoirs and container-based processing facilities in Phase 1 while expanding to service local abattoirs and BMC in Phase 2 and Phase 3. Meat Naturally has an existing buyer for small stock in Upington in South Africa and will work with the Tshabong Abattoir to build on this relationship for export of Meat Naturally Botswana products, including small stock. As the quality of the rangelands and livestock improve and record-keeping systems are put in place, the business partners will start to explore direct exportation outside of Botswana.

[10] There is a pending change in the Trust deed to reduce Conservation South Africa's shareholding to 30% in 2021 as farmer understanding and ability to take over the Trust completely is the goal by 2026.

Given the high variability of the meat market, it is important for Meat Naturally Botswana to have a solid financial model, assurances, and investment track-record in the early stages. For this reason Meat Naturally is supporting Meat Naturally Botswana through its initial 3-5 years of operation with fundraising support and sharing of tools and SOPs. By the mid-term of the GCF Project, Meat Naturally Botswana is likely to be a completely locally-operated business and may be one of the CEDA-funded enterprises providing new job opportunities (Activity 3.1.2d) and income opportunities for farmers as part of the Project impact under Activity 3.1.1c.

5.2 Business model for Meat Naturally Botswana

As part of the broader Herding for Health Initiative, Meat Naturally has conducted feasibility assessments its farmer-owned social enterprise to operate in Ngamiland (Appendix 5.2) and Bobirwa (Appendix 5.3). In both regions, due to the regular outbreaks of FMD, the feasibility recommendations focused on the development and use of mobile abattoirs to service the regions. (Figure 3)

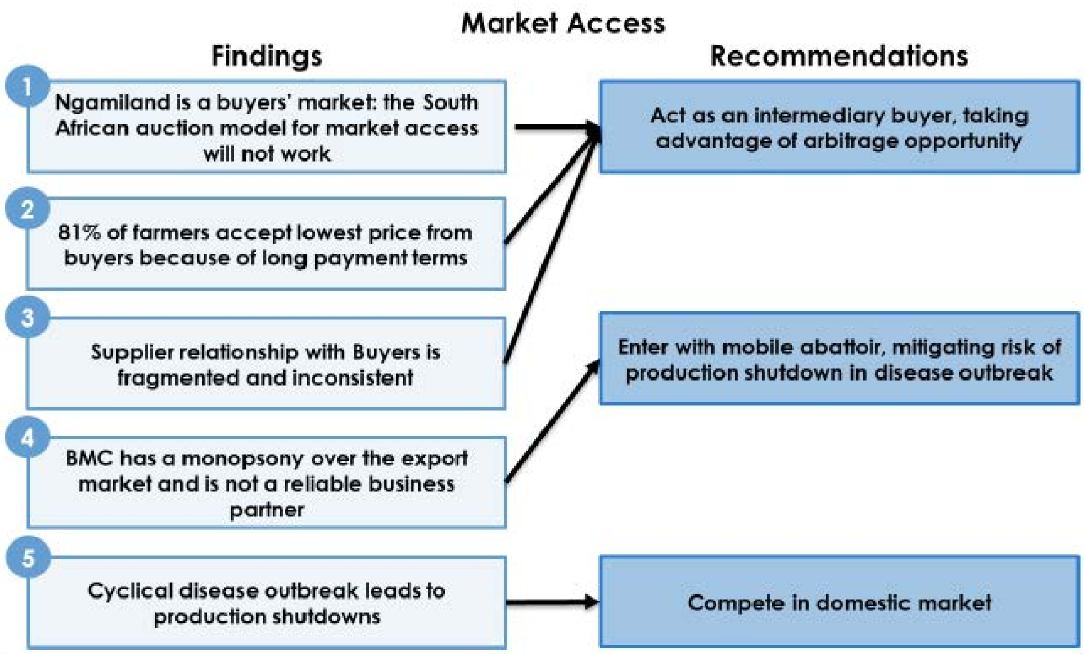


Figure 3. Key recommendations for Meat Naturally from its own Feasibility Assessment for Botswana operations indicate opportunities to become a service provider to existing abattoirs for export and/or to develop dried meat products for the domestic market, particularly tourism operations (Appendix 5.2)

In parallel to the project, Meat Naturally aims to build, test and deploy a new mobile abattoir and processing units prototype for the slaughter and processing of livestock in the Ngamiland region by 2021. This infrastructure would ensure that local farmers can supply the formal market and overcome zoning restrictions while complying with Hazard Analysis Critical Control Point (HACCP)[11] health and safety standards. Meat Naturally's business operations for a single unit become viable with slaughter of 1,500 animals per annum which equals 150 slaughter days. Due to its mobility, a single unit could service different clusters based on climate and livestock

11 HACCP https://globalfoodsafetyresource.com/haccp/

conditions and could even be moved across different project areas which adds resilience to the business model and rangeland stewardship approach of the broader GCF project. This is a critical initiative to incentivise and de-risk efforts to return to regenerative farming practices and achieve restoration and wildlife-friendly production at scale. It will also establish communal farmers as key suppliers to the formal market and foster inclusive economic growth. Figure 4 shows Meat Naturally's mobile abattoir business role within the Project and how the meat market sustains the ecological and social gains paid for by the GCF grant. As of January 2021, Meat Naturally's mobile abattoir is seeking registration license as a Moderate Throughput facility. Due to the fact that the current regulations apply only to a fixed facility, an exemption is being requested. The process outlined by the DVS is the granting of temporary authorization for a trial operation (which has been delayed by COVID) from which specific conditions for the license will be identified and included in the license to operate in partnership with the University of Botswana as a research effort aimed at helping the GoB develop regulations for this type of facility.

6 *Other Livestock Value Chain Development Opportunities*

The Project should capitalise on additional opportunities to identify and develop products that contribute to or make use of sustainable livestock production. Initiatives identified during the project consultations are found in Table 2.

Table 2: Summary of the range of ideas for potential spin off income generation opportunities catalysed by the project.

Meat Processing	A range of opportunities exist within the field of meat processing. * community-butcheries focused on servicing local tourism establishments (see Figure 3); * creating local community demand through availability of meat from an approved facility * the making of sausage and or dried meat products for wildlife rangers and tourism game drive snacks * Catering services focused on "Meat and beverage" pairing at lodges or for local events * Catering for traditional ceremonies
Wifi and Office Services	An idea that graduate monitors could be encouraged to sell airtime via the Project Internet Hubs that are placed in each VDC for Ecoranger reporting could be a mechanism for ensuring their maintenance and care beyond the life of the project.
Crafts from hides and skins	Production of skins or any leather/skin based product. Botswana has significant craft skills and markets that can be exploited to develop a market for such products.
Natural nutritional supplements	Bush fodder and making and selling of home-made nutritional licks for livestock is known traditional knowledge that the

	Project could catalyse a new market for (See Appendix 5.3 for bush-fodder business viability assessment for the Bobirwa region). Planting and selling of dry-season fodder as part of household food gardens could also augment income via the Project.
Agri-tourism	Botswana is seeking to diversify its tourism offering and day-trip or overnight packages to visit a working herd with Ecorangers or development of Volunteer tourism could expand income generation opportunities for project sites.
Collagen	Meat from FMD areas must be de-boned to move into a non-FMD area. It is not known if bone products that are cooked extensively could be made as all collagen-based products in Southern Africa are currently imported.
Other products from waste	Fertilizer, bone meal, and use of blood from abattoir as a growth medium for chicken feed were all raised in various discussions and can be explored during the project.

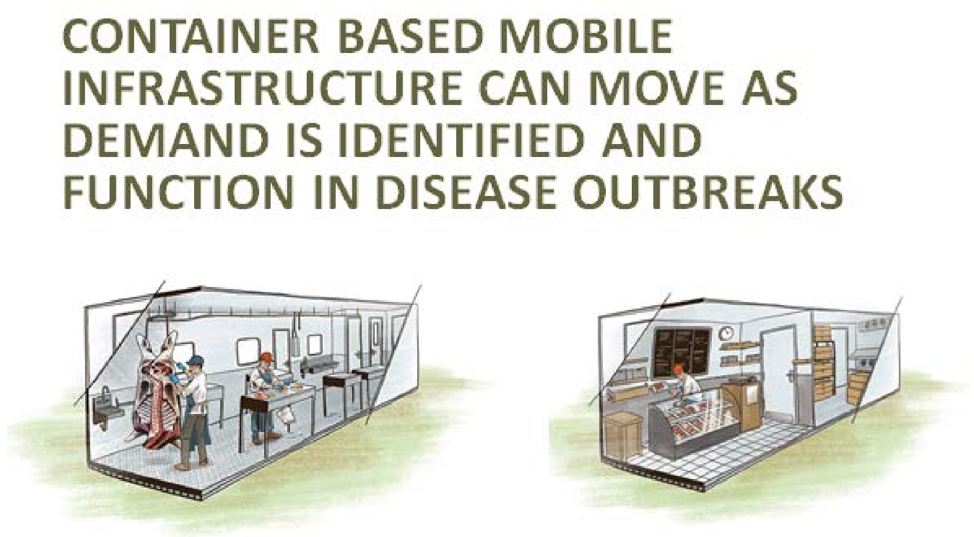


Figure 3: Example of other meat processing infrastructure that could be funded via CEDA or other sources in support of the Project goals and beneficiation.

7 Sustainability Plan

Individual household benefits from income generation opportunities from markets and red meat value chains are clearly viable and market conditions enable a range of new opportunities to be developed as part of the projects sustainability plan. As shown in the financial analysis (Feasibility Assessment Section 2), all the proposed EbA measures are financially attractive with a positive NPV value which will incentivize long-term implementation, especially if the GCF and government co-finance covers the short-term capital needs to overcome initial hurdles of human and operational resource provision to enable collective herd management. Returns across short, middle, and long term are higher for the Project relative to the current scenario and certainly much higher that BAU practices in the face of climate change. Realising this theory requires a sustainability plan that ensures all aspects of the project are sustained. The estimated Project area potential offtake from herd number of 320,000 animals for the sustainability analysis is 10%, or 32,000 animals per annum.

7.2 Sustaining Ecoranger Salaries at Village Level

Herding for Health experience has shown that, as with any community development project, the fact that markets generate greater benefits for those with larger herds (community elite), can lead to diminishing interest in collective investment for the common good after a project ceases. As such, the Project Farmer Facilitators must engage communities on issues of sustainability from the outset. In order to inform those discussions. A simple excel-based model was generated to evaluate how and when communities with different size village herds (500 – 10,000 cattle) might be able to sustain either a minimum number of five ecorangers or an optimum number of eight for a herd of 1000 animals at their project salary rates.[12] For the model, it is assumed that government will subsidize two sets of intakes (3 years each or six years in total) per village in order to get the Rangeland Stewardship system in place and having the restorative impact required for farmers to be able to reach sustainable production ecological capacity. During those six years, farmers should be asked to contribute to a herder savings fund to ensure a precedent for sustainability is established from the outset (see lessons learned document in Appendix 5.5)

Calculations were made for seven scenarios:

1. ***Farmers agree to contribute 5% of each sale into a Herders Fund. This can be collected as part of the normal farmer dues or, retained by the private sector partner and deposited in a bank account on behalf of the farmers' association in a system that is established during the Project.***
2. ***Farmers agree to contribute 10% of each sale into a Herder's Fund.***
3. ***Farmers agree to contribute 5% to the Herders Fund but substantially increase offtake rates to a more commercial rate of 20% (only likely to occur in largest village herds)***
4. ***Government agrees to continue subsidizing Ecoranger salaries by contributing 30% of their salaries into the Herders Fund***

[12] Although salary adjustments will be required, from Herding for Health experience, it is preferable to make additional payments through other contributions that either commit the herder to better management of the herd (i.e. calf or small stock ownership?) or make the job easier/more interesting (air time, new technology, etc…) Discussions on the raise package opportunity should occur in Year 2 and 3 and involve the Ecorangers as this builds motivation to complete their coursework and stay at the Village and not seek employment elsewhere after they complete their curriculum. Some rates of attrition and departures for commercial farm work are normal and career pathing should be presented at the full community level as well as within the group of Ecorangers in order to enable communication around what can become an emotive issue.

5. ***Government agrees to continue subsidizing Ecoranger salaries by contributing 50% of their salaries into the Herders Fund***
6. ***A combination of Farmers contributing 7%, an increase in offtake rates to a high 13%, and a 20% additional price per animal is realized through better condition animals or a price premium achieved or some Payment for Ecosystem Services (PES) payment***
7. ***A combination of Farmers contributing 8%, a moderate increase in offtake rates to 11%, and a 50% additional price per animal is realized through better condition animals or a price premium achieved or some Payment for Ecosystem Services (PES) payment***

Across the Herding for Health network, various forms of the above approaches are being used and lessons learned are still emerging. For example, H4H partners are also looking to establish one investment fund for all Ecorangers involved in the programme that can be used to bring in crowd funding from farmers, private sector tourism operators or PES financing. More and more institutions are designing methodologies at accessing carbon finance for rangeland and livestock management, but as there is no consensus yet on approaches that can accommodate the stochastic nature of Botswana's communal rangelands, it is not recommended that the Project count on this as the solution[13]. As such, the following conclusions indicate potential pathways to sustainability and can be used as guidance for building project sustainability plan in conjunction with the broader Herding for Health programme:

1. ***If farmers are willing to pay 10% of each of their livestock sale at a 5-10% offtake rate into a Herders fund, they will be able to pay the full salaries of a minimum number of Ecorangers. It will not, however, pay for all the Ecorangers initially supported by the project, but that is acceptable and more realistic as many move off for other jobs in the commercial sector and once the herd is "trained" number of herders can decrease. Additionally, Herding for Health is encouraging the use of a farmer "volunteer roster" that schedules farmer support time to assist Ecorangers. This can be negotiated as part of the Stewardship Agreement where for every percent less than an agreed off-take the community must commit to a set number of volunteers to make up for loss of income contribution to the Herders Fund. This approach also provides an incentive to increase off-take rates.***

2. ***If farmers can achieve a commercial offtake rate then they also will be able to continue funding a minimum number of Ecorangers whether you are a small or a large village herd(s). This is unlikely to be achieved across all communities for a variety of natural and cultural reasons however.***

3. ***If government continues to contribute to Ecoranger salaries they have to provide 50% in the case that neither price and offtake rates change. Farmer contributions of 5% per sale can be used to cover the other 50%.***

[13] Should this change during the Project, it is hoped this can be explored within the context of the activities in Component 3. See K Andeweg and A Reisinger (eds) 2018 Reducing greenhouse gas emissions from livestock: Best practice and emerging options. Global Research Alliance on Agricultural Greenhouse Gases for an assessment on current status of opportunities.

4. ***And a combination of seeking a price premium (or PES contribution to the price premium presented) with a level of increase allows large villages to fund optimum number of Ecorangers and extends sustainability to >10 years for a small village. The reality is that a small herd would probably grow to a larger herd, but conservation agreement will be in place to prevent that. Tourism enterprises Ngamiland and Bobirwa have already expressed a willingness to contribute to Ecoranger costs as they already pay herders to keep cattle out of the tourism areas and will be willing to contribute to this instead.***

Table 3: Calculation results on number of years until sustainable financing for Ecoranger wages is achieved.

Scenario	Assumptions			Number of Years With Sufficient Funding but No Breakeven Reached as Overall Costs Exceed Income (Unsustainable Scenarios) to maintain a minimum or optimum number of Ecorangers based on Herd Size				Number of Years to Sustainable Scenario Where No Additional Subsidy is Required for either a Minimum or Optimum Number of Ecorangers based on Herd Size			
	Average price per animal at 7+ Years	*% Offtake at 7+ Years*	*Farmer Contribution Per Sale*	*Minimum for Village Herd= 500*	*Optimum for Village Herd= 500*	*Minimum for Village Herd= 10,000*	*Optimum for Village Herd= 10,000*	*Minimum for Village Herd= 500*	*Optimum for Village Herd= 500*	*Minimum for Village Herd= 10,000*	*Optimum for Village Herd= 10,000*
5% Farmer Contribution to Herders Fund Only	7500	10%	5%	10	7	13	8				
10% Farmer Contribution to Herders Fund Only	7500	10%	10%		10		22	**6**		**6**	
Offtake Increase Only	7500	20%	5%		10		22	**6**		**6**	
Maintenance of a 30% Subsidy (gov't or PES)	7500	10%	5%	19	8	44	11				
Maintenance of a 50% Subsidy (gov't or PES)	7500	10%	5%		10		22	**6**		**6**	
Combination--High Offtake	7500	13%	10%		10			**6**		**6**	**6**
Combination--High Price	11250	11%	10%		14			**6**		**6**	**6**

7.3 Private-Sector as Exit Strategy for GCF-Funded Incentives

To ensure ongoing incentives for regenerative land and livestock management, the Project must embed stewardship linkages to long-term market incentives. Working with the private sector, CI and seconded Project staff should leverage supply chain opportunities to maintain and encourage organic continuation and replication of the restoration techniques. At the end of the Project implementation period, Rangeland Stewardship Agreements can convert into supplier contract agreements between farmers associations and private-sector buyers to continue their relationship and ensure sustainability of supply and demand in the value chain. (Meat Naturally Botswana has committed to this approach, and CI, with BMC, will solicit and encourage similar commitments from other private-sector actors.) Through supplier contract agreements, communities will continue to commit to restoration work and regenerative grazing practices (See Funding Proposal Figure 18b). CI should review 'exit-readiness' based on the Project Village Grazing Area Assessment Dashboard: ratings of 0 for no agreement; 1 for conservation agreement development complete but not yet signed or endorsed by Land Board; 2 for conservation agreement adopted, signed, and implementation in practice; 3 for conservation agreement adopted, signed, and implementation in practice and Land Board supporting enforcement; 4 for conservation agreement adopted and stakeholders progress report identifies the year as a "Project Success" according to the criteria established for climate vulnerability reduction in that landscape (Logframe MoV for A5). This standardized approach will allow for transparency and predictability in assessment of the communities. At stage 4, the project's FFT, enterprise development manager, and farmer association will start the transition to the VGA sustainability plan as agreed during the RSA negotiation (level 5). All 4 elements of the RSA as outlined in Table 14 in the FP will be handled in the transition process.

Rangeland Stewardship Agreement Components

Business interest in direct engagement with the Project is expected to grow as improvements in the quantity, quality, and consistency of livestock products increase through the Project phases. In the Foundation Phase (Year 1 and 2), existing 5% offtake rates across the 9 sites will likely continue, as CBT requirements will not yet be fully implemented/met. Current supply of carcasses for local consumption, culled from older, unproductive animals, is far below demand of 70 carcasses per day (25,550 per year) currently sold across the three target districts for local consumption. Even in the Foundation phase, while prices paid will be lower than for export, the absence of any convenient market access means that increased market access and amenable payment terms will be a sufficient incentive to catalyse farmer participation in the Project's RSAs, according to consultations with area farmers.14 The beef produced in the first year of implementation in each village area will likely only be acceptable for local consumption or dried or cooked product (biltong, snapstix, droewors, and pies) for the tourism sector. Meat Naturally's scale of operations is suitable for this market.

It is the cooperative-like business structure, and the further resilience generated by profit-share, that makes Meat Naturally the preferred sector partner for the Project. However, CI will not exclusively engage Meat Naturally, and will cultivate offtake arrangements with all private sector parties in the sector to ensure that incentives for RSAs are not fully dependent on Meat Naturally. In addition, by Phase 3, the capacity of Meat Naturally as a moderate-throughput abattoir operation will likely be exceeded. Improved conditions of quarantine facilities and management by Ecorangers of these facilities will enable larger quarantine operations for finishing and slaughter by BMC and others by Phase 3. As quality and record-keeping is established, larger abattoirs and BMC will be able to offer export prices to interested farmers involved in the Project. The Project should support farmers with the BMC registration process (https://bmc.bw/producers/) based on the records maintained by the Ecorangers, and the supply

14 See Annex 2, Appendix 5.6, pgs 17-18.

chain will be enabled as per standard BMC procedures and transport. Arrangements with the other abattoirs should be developed by the Enterprise Development Manager as supply and demand conditions warrant.

In Phases 1 and 2, CI should ensure that Meat Naturally Botswana and one other abattoir (BMC, Ngamiland, or Batawana) have completed purchasing arrangements with RSA-compliant farmers for income generation as per the diagram in Figure 18b. CI will ensure that the farmer commitments of the RSA are included in the purchase agreements between farmers and buyer, that farmer incentives for communal management are maintained, and that contributions to RSA-compliance activities are made from income generated by the farmers. To secure purchase agreements in Phase 1 and 2, CI should engage with Meat Naturally Botswana and local authority abattoirs and grow to export operators at Tshabong and Francistown (BMC & Tati) by Phase 3. Meat Naturally Botswana's business plan and financial model shows that as a moderate throughput facility within each landscape, it will break even in year 3 and achieve a low but positive Ebitida margin of 3.7% by year 5.[15] During the start-up phase, Meat Naturally Botswana will be supported by Meat Naturally Africa, but ultimately will be a financially viable structure representing communal farmers in the Project with additional Botswanan Directors and business arrangements that can take the business forward into Phase 3 and beyond the Project period.[16]

7.4 Sustaining Adaptive Capacity in Communal Rangelands of Botswana

Based on the assessment above, a blended model of government and markets (including farmers as key producers in the value-chain), is recommended to sustain adaptive capacity in Botswana's communal rangelands. (Figure 5.) The model envisages that government investment will be required to incentivize and enable communities to overcome governance, skill, and resource barriers for implementing climate smart land and livestock management. However, after an initial investment for six years, market returns and financing strategies will ensure that the new rangeland and livestock management system is sustained and continually improved. Based on the H4H model, CI has experienced that climate shocks and unpredictable financial flows from government can threaten and even lead to a breakdown of the system in some village. However, the number of villages and NGO supporters that manage to find new ways to sustain the system create new examples that are used by Herding for Health facilitators to reinforce and rebuild the weaker links. The project timeframe allows for enough of these normal hurdles to be reached and overcome. Ultimately, it is this collective and bottom-up nature of the project that will sustain the climate resilience desired by the Government of Botswana, Conservation International, and the GCF.

15 Annex 2, Appendix 5.2, Meat Naturally Botswana Business Plan.

[16] Meat Naturally Botswana directors are in discussion with BMC officials, but the political decision on the privatisation and operational arrangements of BMC need to be finalised before a clear supply arrangement can be finalised. Ministry of Agriculture has indicated it will table a proposal to Parliament on this before the end of 2021, COVID permitting.

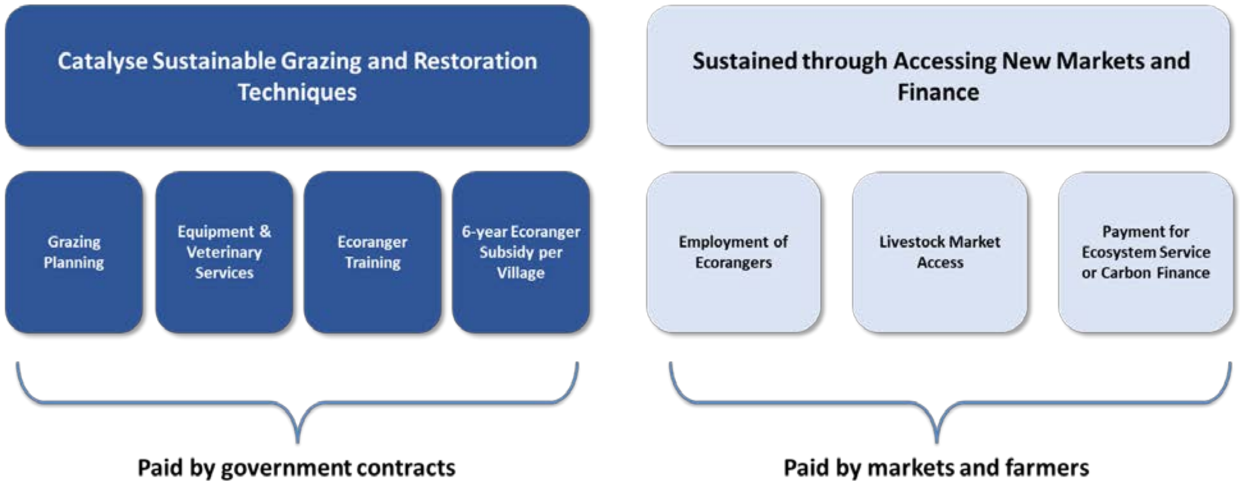


Figure 5. Distribution of investments required to maintain and grow the Herding for Health system in Botswana's communal rangelands. Tourism-based income source can perhaps be listed as an addition future measure sustaining access.

7.5 Other Exit Strategies that Sustain Project Impact and Enhance Replication Potential

Expanded awareness and capacity of individuals and institutions

The long-term sustainability of project interventions is further enhanced by the project's focus on individual and institutional capacity building with key stakeholders at all levels. Activities focused on institutional strengthening at the provincial and local level contribute significantly to the project's sustainability given Botswana's promotion of decentralisation and the increasing role and influence of local institutions over land use planning and management. The project is being implemented at an important transition time and establishing awareness and expertise through the Project will help mainstream climate-resilience into local policies ongoing decision-making. Ensuring there is ownership of all interventions will further enhance the ongoing implementation of such activities after project closure.

New techniques and tools for extension will continue to be available for use to improve access to knowledge on climate change and climate resilient land use. Consolidation of traditional knowledge on adaptation in pastoralism will further promote resilience in the livestock sector. Both the educational modules and approaches can be scaled up in a cost-effective way, and be used to reach diverse Village Development Areas, CBOs, and NGOs not only in the project area but elsewhere in Botswana.

Re-alignment of government job creation and training investment into Ipelegeng Rangeland Stewardship Programme

By aligning the project with key national climate policies, priorities, and commitments, including Botswana's NDC, National Development Plan and Vision 2016, the chances of its continuity after

GCF investment are very high. Improving job creation investments, natural resource management, building a climate-resilient livestock sector, adapting to and mitigating climate change, and enhancing livelihoods of local communities are explicit goals of Botswana's political leadership. As such, the Government of Botswana's commitment to continuation of the programme is likely to be sustained and ready for extension to other vulnerable communal lands in Botswana, particularly in the Chobe and Kweneng Districts.

Co-development and execution of a dynamic monitoring system in the Rangeland Stewardship Information Portal

The Project will ensure that both public and private sector institutions are involved in the development of the Rangeland Stewardship information portal to ensure that it meets the needs of both sectors. Again, as part of the design and refinement process, the project can engage parties in discussions on sustainable management after the project ends. Ideally, the funding already used by government agencies and private sector for traceability efforts can be extended to this joint effort that ultimately adds more value than siloed systems. Additionally, the development of associated user-friendly materials, including climate diary websites or picture books for each village, will help CBOs and extension agents to maintain knowledge and motivation to continue to utilise the system for informing climate-resilient land and livestock management. Once the system exists and demonstrates its value, there is no reason why it cannot be extended for national deployment.

Section 5 Appendices:

5.1: Exploring market opportunities for CBT of Beef from Ngamiland – 2017 Report

5.2: Meat Naturally Botswana Business Plan and Feasibility Assessment

5.3 Feasibility report – Business Value Chains to support H4H in Greater Mapungubwe TFCA - 2019

5.4 CBT FMD Guidance Report – AHEAD Project 3rd Edition

5.5 Herder's Fund Lessons Learned 2018 Report