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VALUE, MANAGEMENT, AND SUSTAINABLE USE OF BIODIVERSITY FROM SOFALA PROVINCE IN MOZAMBIQUE

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To my mother, Maria Isabel Charrua, and my daughter Aylla Charrua

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Abstract

Value, Management, and Sustainable Use of Biodiversity from Sofala Province In Mozambique

The general aim of this thesis is to present a multidisciplinary framework to provide Sofala Province (Mozambique) with technical and scientific data, focusing on management, sustainable use, and conservation of the local ecosystems. The first chapter provides an overview of Sofala and states the main focus of this PhD. Chapter 2 investigates the impacts of the Tropical Cyclone Idai using a Multi-temporal Landsat Satellite Imagery Analysis. Chapter 3 evaluates the vulnerability of coastal mangrove ecosystems, to identify priority areas for management interventions. Chapter 4 provides nutritional value of the most commercialised dry legume groups (*Phaseolus vulgaris* and *Vigna* spp.) in local markets. Chapter 5 explores the role of cultural heritage on natural resources conservation. Finally, Chapter 6 contains the conclusions drawn from the findings and recommendations for further studies in Mozambique.

Keywords: Climate Change, (Agro)Biodiversity, Cultural Heritage, Sofala

Original contributions

Journal papers included in the thesis

1. **Charrua, A.,** Havik, P. J., Bandeira, S., Catarino, L., Ribeiro-Barros, A., Cabral, P., Moldão, M., Romeiras, M. M. (2021). Food Security and Nutrition in Mozambique: Comparative Study with Bean Species Commercialised in Informal Markets, *Sustainability* 2021, *13*(16), 8839; https://doi.org/10.3390/su13168839.
2. **Charrua, A.**, Padmanaban, R., Cabral, P., Bandeira, S., Romeiras, M.M. (2021) Impacts of the Tropical Cyclone Idai in Mozambique: A Multi-Temporal Landsat Satellite Imagery Analysis, *Remote Sens.*, *13*(2), 201; doi: https://doi.org/10.3390/rs13020201.
3. **Charrua, A.**, Bandeira, S., Catarino, S., Cabral, P., Romeiras, M. M. (2020). Assessment of the vulnerability of coastal mangrove ecosystems in Mozambique, *Ocean Coastal Manag*., 189: 105145;

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Journal papers related to the thesis but not included in the thesis

1. Catarino, S., Brilhante, M., Essoh, A., **Charrua, A**.,… Romeiras, M. (2021). Exploring physicochemical and cytogenomic diversity of African cowpea and common bean, *Scientific Reports*, 11:12838; https://doi.org/10.1038/s41598-021-91929-2.

Published conference abstracts

1. Catarino S., **Charrua, A.**, Varela, D., Bandeira, S., Romeiras, M. (2019). Developing species distribution models to support the sustainable use of African forests: case-studies with Mozambique and Angolan trees. In: Book of Abstracts of the 15th European Ecological Federation (EEF) Congress and 18th National SPECO Meeting: Ecology across borders, Embedding Ecology in Sustainable Development Goals, 29 de Julho a 2 de Agosto, 2019. Lisboa, pp. 132.

2. **Charrua, A.**, Cabral, P., Bandeira, S., Catarino, S., Romeiras, M. (2018). Biodiversity and Development Symposium (Maputo, Mozambique) presented an oral communication titled "*Using species distribution models as a tool to*

conserve mangrove habitats of Mozambique", published in the Book of Abstracts of the 10th Scientific Conference of Eduardo Mondlane University (UEM). In Unidade Editorial da Revista Científica da UEM. Book of Abstracts, X Scientific Conference, Maputo 26-28 September 2018., p. 391. Link: http://www.cecoma.uem.mz/conferencias/index.php/ic/cc2018/index.

3. **Charrua, A.**, Catarino, S., Bandeira, S., Romeiras, M. (2018). Avicennia marina: *Uses and distribution of an emblematic mangrove species from Mozambique*, published in the book of abstract *Avicennia marina*: Uses and distribution of an emblematic mangrove species from Mozambique. In: Catarino L, Pedro M, Romeiras MM. Book of abstract, International Conference of Biodiversity, Luanda, 22-23 May, 2018. UAN Botanic Center, Luanda, p. 71-72. Link: http://www.cecoma.uem.mz/conferencias/index.php/ic/cc2018/index.

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Acronyms

AUC – Area under the curve

CA – Cluster analysis

BZ – Buffer Zone

CBC – Community-Based Conservation

CCAs – Community Conservation Areas

CH – Cultural Heritage

DEM – Digital Elevation Model

DN – Digital number

ECABREN – East and Southern African Bean Research Network

EI – Exposure Index

ES – Ecosystem Services

ESA CCI – European Space Agency, Climate Change Initiative

ETM+ – Enhanced Thematic Mapper Plus

FGDs – Focus Groups Discussions

FRELIMO – Liberation Front of Mozambique

FUNAB – National Fund of Environment

GDP – Gross Domestic Product

GEE – Google Earth Engine

GNP – Gorongosa National Park

GPA – General Peace Agreements

HDI – Human Development Index

ICH – Intangible Cultural Heritage

IFC – International Finance Corporation

INAM – Instituto Nacional de Metereologia

INE – Instituto Nacional de Estatística

INGC – Instituto Nacional de Gestão de Calamidades

ISA – Instituto Superior de Agronomia

ISRIC – International Soil Reference and Information Centre

LLHM – Local Linear Histogram Matching method

LULC – Land Use and Land Cover

LULCC – Land Use and Land Cover Change

MaxEnt – Maximum Entropy

MEA – Millennium Ecosystem Assessment

MINAC – Ministry of Agriculture

MITA – Ministry of Earth and Environment

NA – Not available values

NbS – Nature Based Solutions

NDVI – Normalized Difference Vegetation Index

NDVIpost – NDVI after cyclone

NDVIpre – NDVI before cyclone

NGOs – Non-governmental organization

NIR – Near-Infrared

ORNL DAAC – Oak Ridge National Data Archive

PCA – Principal Component Analysis

PIF – Pseudo-invariant features

RED – Red Reflectance

RENAMO – National Resistance of Mozambique

RF- Random Forest

ROC - Receiver operating characteristic

SDGs – Sustainable Development Goals

SDMs – Species Distribution Models

Sp – Spatial Data

SW – Summer Season

TCH – Tangible Cultural Heritage

TOA – Top-of-atmosphere

VIF - Variance Inflation Factor

WIO – Western Indian Ocean

WW – Winter Season

ΔNDVI – The difference in NDVI (Vegetation Damage)

3S – Spiritual and Sacred Sites

Chapter I

General Introduction

1. General introduction

1.1. Sofala: General Characterization

1.1.1. Geographic location

The Province of Sofala is in the Center-East of Mozambique, along the border of the Indian Ocean. The total area of the province is 68018 Km^2, about 8.5% of the total country area. The limits of the province are, to the North the provinces of Zambezia and Tete, through the Zambeze river; the South is bordered by the province of Inhambane, through the Save river; to the East, it separates from the Indian Ocean and to the West, it borders the Province of Manica (Fig. 1.1). This province is divided into 13 districts and has, since 2013, 5 municipalities: Beira (capital of Sofala Province), Dondo, Gorongosa, Marromeu, and Nhamatanda. Beira (with over half a million inhabitants) is located at centre-east of Mozambique at the mouth of Pungue river, it is the second largest city in country after Maputo city (country´s capital) and is among the most important port city in the Southern African Development Community (SADC, comprising 16 Member States) as it connects an extensive hinterland (including neighboring landlocked countries) with the Indian Ocean.

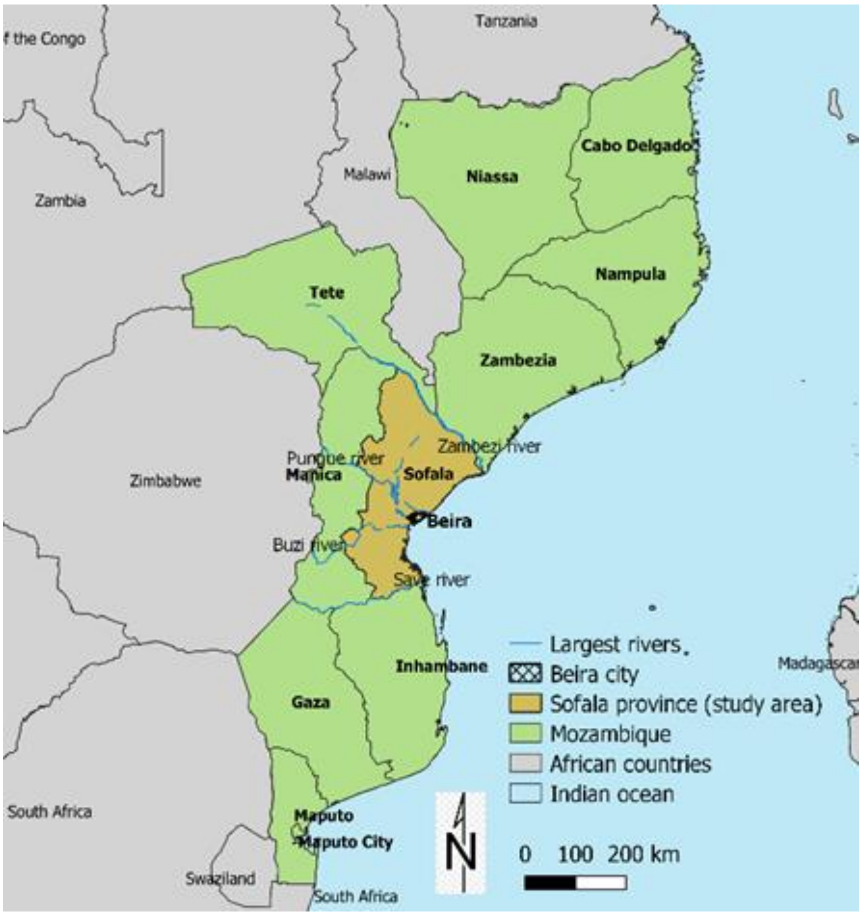

Figure 1.1. Geographical location of Sofala Province.

1.1.2. Historical background and socioeconomic characteristics

The second half of the 20th century was so painful to Mozambique because of two major armed conflicts, first in its fight for independence from Portuguese colonial rule (1964-1975), and then was a civil war (1977 to 1992). The civil war was fought between FRELIMO (the Liberation Front of Mozambique, the party in power since independence) and RENAMO (National Resistance of Mozambique, the strongest opposition party in Mozambique). These two are still to day the main political parties in Mozambique. The guerrilla actions were mainly conducted from Sofala province, where RENAMO had established its main headquarters in Gorongosa mountains (within Gorongosa National Park – GNP). The Sofala Province (Gorongosa mountain) is the spiritual home of RENAMO. It was the place where RENAMO´s late leader (Afonso Dhlakama) launched civil war in 1977 and where in 2013 (21 years since general peace agreements – GPA had been signed) he announced the withdrawal from the GPA to give place to a smaller scale armed conflict (centered in Sofala again) which ended with a peace treaty in 2019. Moreover, the province of Sofala has a particular historical importance in Mozambique. Before Portugal colonial rule set up his administration in Mozambique (until 1752), firstly stablished a base in Sofala (1505) as it was ruling the country from Goa, India.

Brutal warfares and massive destruction of critical infraestrutures (e.g. hospitals, rail lines, roads, and schools) and private goods (e.g. transport) left Sofala province highly impoverished. Sofala is amongst the most affected provinces by political conflicts in Mozambique with loss of lives, disrupted economic activities, service delivery, and environmental degradation as well. According to the Human Development Index (HDI), the country still remains in the lowest category being ranked 189th out of 189 in 2017 (Embassy of Sweden in Maputo, 2019).

According to the CENSUS 2017, Mozambique has 28,9 million people, and Nampula (5758920) and Maputo City (1120867) are the most and the least populated, respectively. Therefore, it has been reported a population number of 2259248 (roughly 8% of the national population) residents in Sofala province (INE, 2019). Most of these people are living in poverty and heavily rely on the nature for their livelihoods and incomes.

The latest armed conflicts centered in Sofala (2013-2019), the COVID–19 pandemic, and the insurgency in the gas-rich Cabo-Delgado northern province launched by a jihadist group affiliated with the Islamic State (ISIS) caused a significant decrease of country´s average gross domestic product (GDP) growth rate from around 7% in 2015 to roughly 2% in 2021 (FocusEconomics, 2022). Therefore, the contribution of Sofala Province to national GDP is estimated in around 10% (BRILHO, 2019). The economy is dominated by subsistence agriculture which absorb around 70% of the people (Embassy of Sweden in Maputo, 2019), a few of the cash crops include cashews, sugar cane, sesame seeds and cotton. Fishing is the second most important economic activity in Sofala. This has been practiced in rivers, lagoons, and sea. Around 60% of the population lives on the coast and practices artisanal fishing, whereas the semi-industrial and industrial fishery is mainly carried out offshore. The Sofala costal region is within so called Sofala Bank which stretches 950 km from the waters off Sofala and Zambezia province and halfway up northern province of Nampula. It is an extremely rich area in fishing resources and is an international shallow-water shrimp fisheries reference (IFAD, 2011). A study (Sousa et al., 2015) indicated that in 2014 a total of 2220 tons of fish were caught from artisanal fisheries on the Sofala bank, which corresponds to about 40% of the total catch achieved by the fishery. Livestock production is other important socioeconomic activity that insure local people employment, income and food security. A recent study has estimated that Mozambique has around 2209 dairy cows and 80% of those cows are in Sofala and Manica Provinces (Balakrishnan et al., 2021).

1.1.3. Description of biophysical characteristics

1.1.3.1. Freshwater resources

Sofala count on four major and international rivers drain into to the Indian Ocean along Mozambique’s 2,700 km coastline (the third longest in Africa). In the north, Zambeze River forms the border with Zambezia province. It is the largest and the most important river in Mozambique, feeds into Lake Cahora Bassa and the dam, and has around 2574 Km of total length shared with Angola, Botswana, Namibia, and Zimbabwe. In the south, Save River (644 Km) forms a border with Inhambane Province. Pungue (400 Km) and Buzi (374 Km) rivers cross the center of Sofala from west to east to drain in the sea through estuarine systems and deltas in Beira city where one of the country`s major harbours is located. The Pungue River, on which the city of Beira depends for its water supply, forms the southern boundary of Gorongosa National Park (GNP), creating a natural barrier. All these main rivers have their tributaries scattered throughout the Sofala province.

1.1.3.2. Climate

The Province of Sofala is characterized by a tropical climate with two distinct seasons: one rainy, from October to April, and another dry, from April to October (Barbosa et al., 2001). The annual average precipitation is around 1400 mm/year (Uamusse et al., 2017) and the heavy rain historically occur from December to March (Chemane et al., 1998), but nowadays, due to the climate change impacts it is less predictable. It has been reported that cyclone season in Mozambique including Sofala which is the most cyclone active area, generally spans from November to April (Consultec, 2007; Mavume et al., 2009). This province is dominated by lowlands and exibits mean annual temperatures of 25 °C in the coastal lowlands and 20°C in the interior highlands (Wils & Lutz, 2002) while temperature increases northward and inland.

1.1.3.3. Ecological regions

Mozambique possesses 14 ecological regions included in five main biomes as follow: (i) arid and semi-arid forest; (ii) tropical and subtropical rangelands, savannas, shrublands, and woodlands, (iii) flooded grasslands and savannas; (iv) mountain grasslands and shrublands; and (v) mangroves (Burgess et al., 2004; Ministério da Terra Ambiente e Desenvolvimento Rural, 2015; Odorico et al., 2022; Oslon, 2020; USAID, 2008). According to the Convention on Biological Diversity (2021), the sites with high importance in term of biodiversity in Mozambique includes the Gorongosa Mountains (within Gorongosa National Park in Sofala Province), the Great Inselberg Archipelago of Quirimbas (Cabo Delgado Province), and the Chimanimani Massif (Manica Province). Therefore, the three biodiversity hotspots are the East African Mangroves covering Sofala coastal region, the Maputaland-Pondoland-Albany, and the Eastern Afromontane (USAID, 2008). In addition, the Zambezian Coastal Flooded Savannah is an eco-region unique to Mozambique, most of it located in Sofala Province at the basins of the main aforementioned rivers (Zambezi, Pungue, Buzi, and Save).

According to Burgess et al. (2004) and Olson et al. (2001), six ecoregions are recorded in Sofala province (Fig.1.2): Eastern African Mangroves, Eastern Zimbabwe Montane Forest-Grassland Mosaic (at Gorongosa Mountain – GNP), Southern Miombo Woodlands, Southern Zanzibar-Inhambane Coastal Forest Mosaic, Zambezian Coastal Flooded Savana, and Zambezian and Mopane Woodlands.

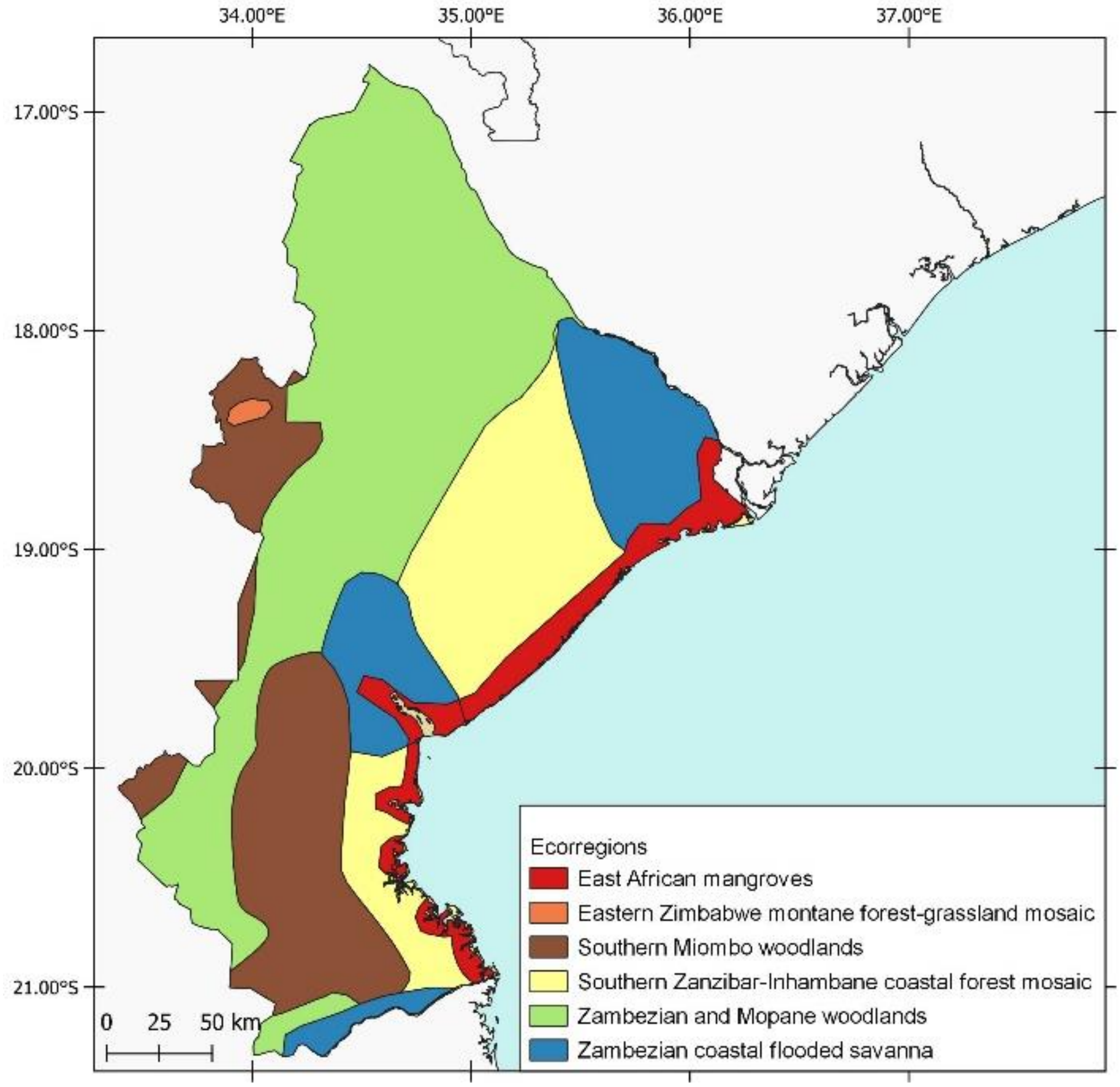

Figure 1.2. Ecoregions of Sofala province (Mozambique), according to Burgess et al. (2004) and Olson et al. (2001).

Therefore, the East African Mangroves, and Zambezian Coastal Flooded Savana have been reported to be ecological regions of global importance (USAID, 2008). The East African Mangroves is a marine ecoregion covering the whole Sofala costal area and is characterized by extensive mangrove swamps and coastal wetlands. Within Eastern African Region, Mozambique contains the largest Mangrove area covering a total of 305400 ha (Fatoyinbo & Simard, 2013) stretching almost the entire coast of the country of which roughly 50% lies in Central Mozambique including the provinces of Sofala and Zambezia (Charrua et al., 2020).

1.1.3.4. Species diversity

Mozambique is characterized by areas with high biodiversity which comprise over 6,264 plant species (Hyde et al., 2021) and 4,271 fauna species of terrestrial wildlife (CBD, 2021; The World Bank, 2014). The Province of Sofala encompasses a high richness of plant species and vast forest areas with several native and exotic species with differentiated strata (high, medium, and low), favoring the growth of certain animal species that adapt to each stratum. The present dissertation identified 1901 taxa occurring in Sofala, including 1684 species and 217 subspecies. Most of the taxa (1897) are angiosperms, but gymnosperms are also present with two native taxa and 2 introduced taxa. Among the 1901 taxa found, 46 are endemic to Mozambique, 1738 are native non-endemic, and 117 are introduced taxa.

Of the 1901 plant taxa occurring in Sofala, 185 were not reported in another province of Mozambique, 16 of them are endemics and 15 are introduced taxa. Zambezia is the province with the highest number of taxa shared with Sofala (1074), Manica has 984 taxa and Maputo 887. Niassa has the lowest number of shared taxa (525). Gaza and Inhambane also has a low number of taxa (587), although Inhambane is bordered to the northeast by Sofala (Fig.1.3).

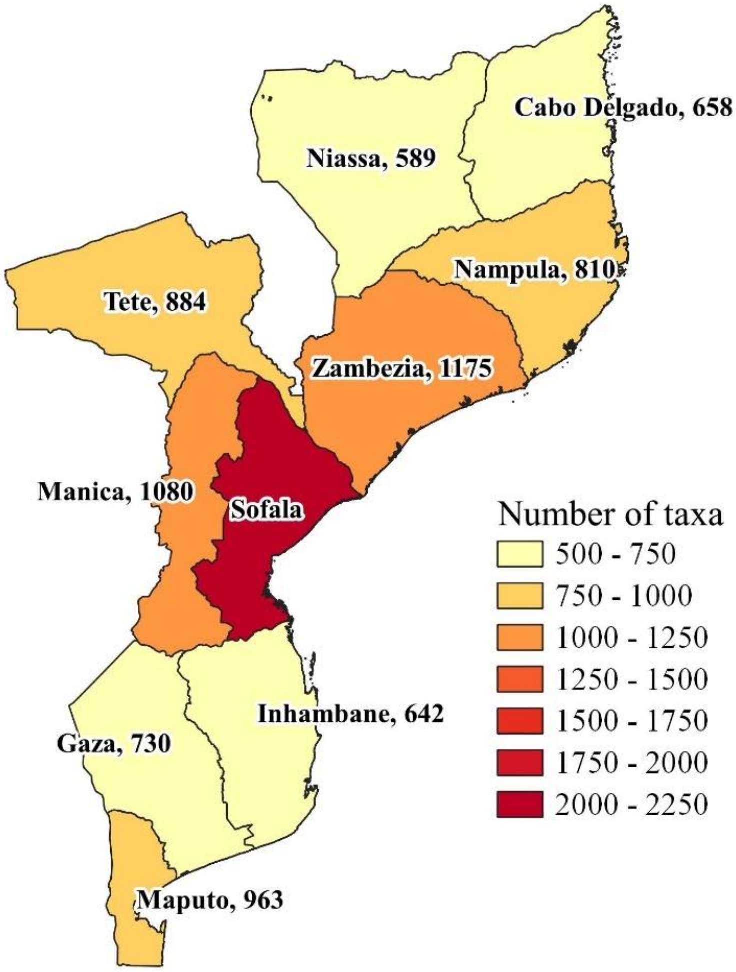

Figure 1.3. Number of shared taxa between the province of Sofala and the other provinces.

The diversity of families and genera is very high in Sofala. We found 158 different families and Fabaceae is the most diverse with 241 taxa, followed by Poaceae with 174 taxa and Rubiaceae with 106 taxa (Fig. 1.4A). Euphorbiaceae and Rubiaceae are the families with the highest number of endemic taxa (5 endemics each), while Fabaceae has the highest number of introduced (15 taxa). A total of 863 genera were found, *Hibiscus* has 25 taxa, *Crotalaria* has 24 taxa, and *Eragrostis* has 20 taxa (Fig.1.4B). *Euphorbia* is the genus with the highest number of introduced taxa (5 taxa).

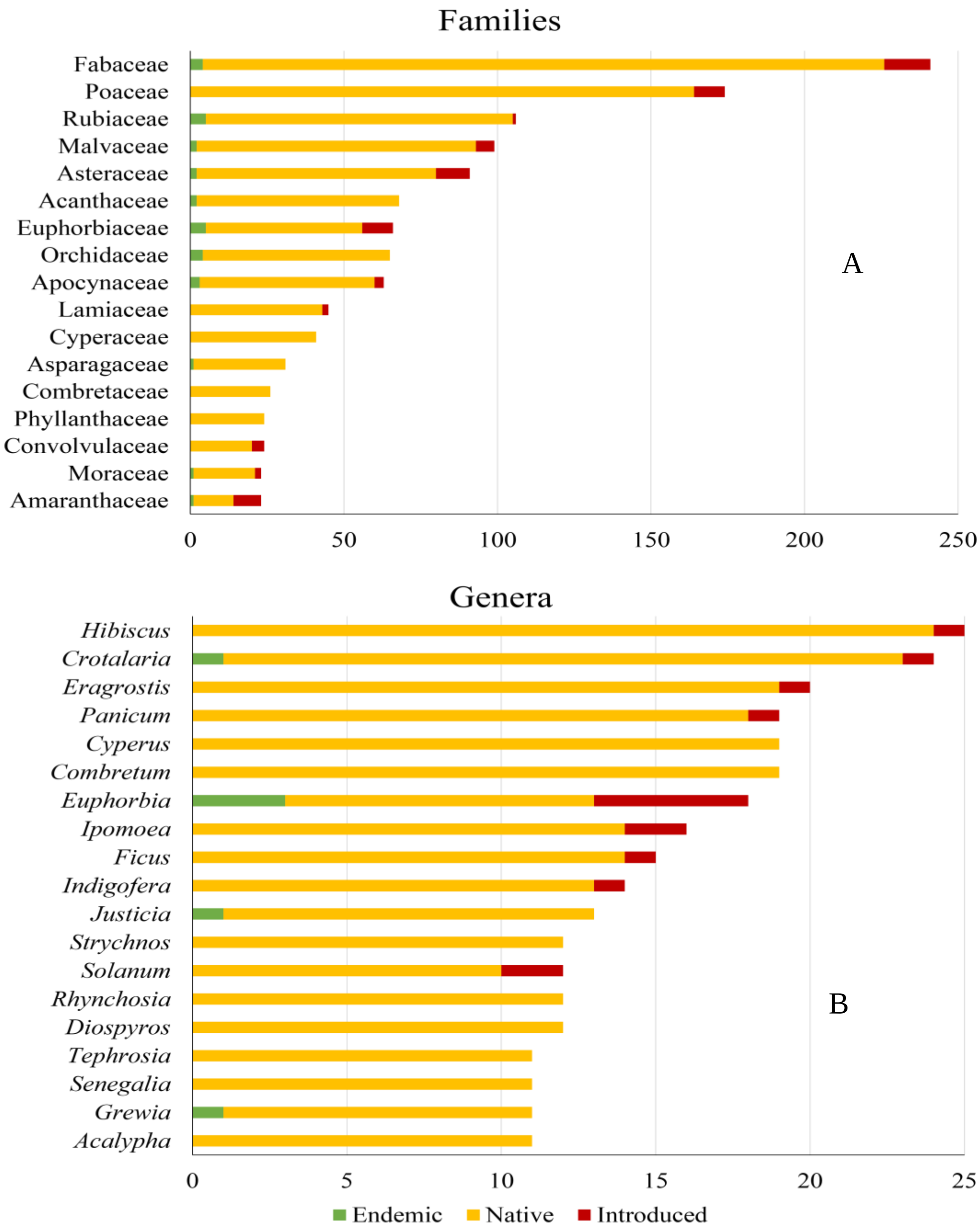

Figure 1.4. Number of endemics, native non-endemics, and introduced taxa occurring in Sofala province by (A) family (only families with more than 20 taxa are presented) and (B) genus (only genera with more than 10 taxa are presented).

Most of the studied taxa in Sofala are herbaceous plants (55%), 31% are shrubs or subshrubs, 12% are trees and 2% are vines (Fig. 1.5). Among the endemic taxa, we found 26 herbs, 16 shrubs and four trees.

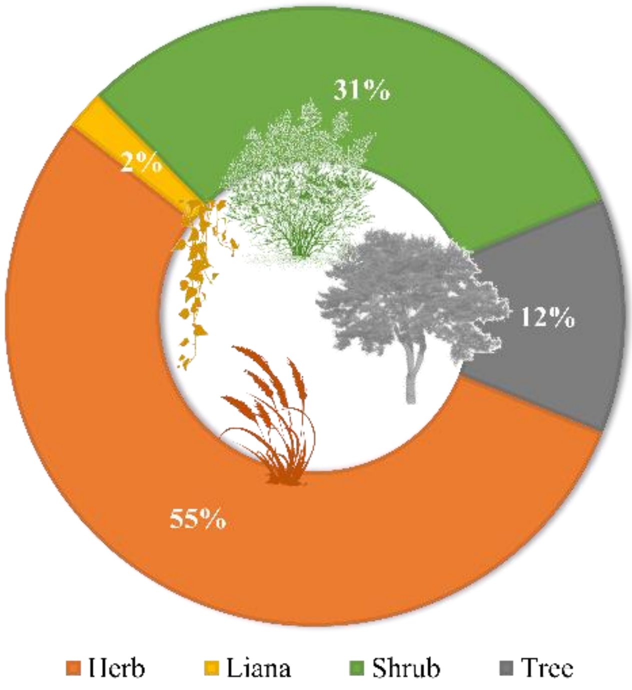

Figure 1.5. Life forms (growth habits) of the taxa occurring in Sofala.

1.2. Leguminosae family

Fabaceae, Leguminosae, or commonly known as the legume, pea, or bean family, are the third-largest plant family of flowering plants (angiosperms) with almost 770 genera and 19,500 species (with a staggering amount of diversity therein) after Orchidaceae and Asteraceae (Nadon & Jackson, 2020). Legumes are geographically distributed in a broader range of habitats throughout every continent, except Antarctica, with representatives in nearly every biome from deserts to tropical forests (Harris, 2004). Legumes are important example of diversification and adaptation in plants in the world. They grow as trees, shrubs, and herbaceous plants and have shown to adapt well to a variety of ecological and climate conditions (Simpson, 2010). In tropical and subtropical regions, such as Mozambique, Fabaceae are mostly woody (e.g. Miombo and Mopane woodlands which cover more than 70% of the country) (USAID, 2008) whereas in temperate regions they are herbaceous. The economic value of woody and herbaceous legumes in Sofala is immense ranging from timber, fuelwood, production of resins, medicinal plants, food products, and so on.

Fabaceae family are divided in three subfamilies: Caesalpinioideae, Mimosoideae, and Papilionoideae also known as Faboideae (Tekdal, 2021). Papilionoideae is the largest and the most economically important subfamily. It is distinctive and the most popular subfamily by including members of ornamental plants and (domesticated) food products such as soybean (*Glycine max*), peanut (*Arachis hypogaea*), common bean (*Phaseolus vulgaris*), alfalfa (*Medicago sativa*), pea (*Pisum sativum*), licorice (*Glycyrrhiza glabra*), cowpea (*Vigna unguiculata*), chickpea (*Cicer aerietinum*), and many more (Nadon & Jackson, 2020).

Phaseoulus and *Vigna* species are the most common herbaceous legumes in Mozambique and particularly in Sofala. They are among the stable crops with high importance in terms of food security. *Phaseolus* and *Vigna* species are a major source of dietary protein for local populations, hence they are also called “poor man’s meat” (Hayat et al., 2014). Moreover, these dry legumes are an important source of vitamins A, B, C, phosphorus, iron, calcium, and potassium. As many rural areas of Sofala provinces face hunger and malnutrition, the investigation of the nutritional value of dry legumes in context of agricultural biodiversity is crucial (Tekdal, 2021). In addition to the rich nutritional value of bean family, it enriches the soil inorganic nitrogen by fixation of atmospheric nitrogen through the nodules in its roots.

1.3. Climate change

Climate change is a long-term change in the average weather patterns that have come to define Earth’s local, regional and global climates (NASA, 2022). It may refer to a particular location, region or the planet as a whole. Climate change may cause weather patterns to be less predictable. The current climate change evidence observed since the early 20th century is largely driven by human activity particularly fossil fuel burning. Climate change is a global problem but in Africa it is more challenging that in developed countries.

Mozambique is a highly vulnerable country in terms of climate change. Within the country, the impact of climate change varies depending on the specific region and province. Therefore, due to its exposed coastal location (low-lying land and high tidal range), its vulnerable infrastructure and population, Sofala is the most vulnerable province and the most threatened region within the country as well as in Africa (World Bank, 2020). Additionally, vulnerability of this province to the impact of climate changes is exacerbated by socioeconomic drivers, such as lack of a solid, formal and comprehensive spatial planning system; precarious housing and basic infrastructure; lack of waste and storm water drainage systems; and a high poverty rate.

Nowadays, the extreme climatic events occur cyclically and take place within very short time intervals. For instance, from 2019 to 2021, three cyclones (Idai, Chalane, and Eloise) have hit Sofala province causing extensive flooding and a massive loss of life, herd and agricultural crops, natural biodiversity, and significant infrastructure damage as well (Macamo, 2021). Idai and Eloise were the two most severe cyclones, being Idai the strongest and deadliest cyclone ever seen in Southern Hemisphere. Idai made landfall in March 2019 and severely affected the city of Beira. Idai (with more than 200 mm in 24 h and strong winds up to 220 km/h) affected more than 1,5 million people in Mozambique, resulting in more than 600 deaths while over 1600 persons were injured. Cyclone Idai's socioeconomic impact in Mozambique was considered the highest to date, with damages and losses estimated at US $3.2 billion (2019 estimate) (Post Cyclone Idai Cabinet for Reconstruction, 2019). While far weaker than Tropical Cyclone Idai and Eloisse (January 2021), Tropical Storm Chalane (December 2020) has impacted some regions within the province, such as Dondo, Beira City, and Buzi (OCHA, 2020).

Cyclones are a serious threat to natural coastal ecosystems such as mangroves and sand dunes in Sofala. However, severe Land Use and Land Cover (LULC) damage caused by this catastrophic event has not yet been fully quantified. For instance, it has been reported that 2371 ha of mangroves suffered massive mortality caused by Idai in Beira, Dondo and Buzi in Sofala province (Menomussanga, 2020). This may be well below the real figures considering that two subsequent cyclones (Eloisse and Chalane) occurred in a short time period and have probably affected mangrove recovery capacity.

Future projections of climate change in Mozambique, specifically in Sofala, indicate an increasing frequency and intensity of extreme events occurrences such as cyclones, flood, drought, among others (Macamo, 2021). Additionally, it is expected the rising ground water and sea levels in around 1 m by the year 2100 (accompanying global warming) and ongoing coastal erosion due to local human action such as removal of coastal natural vegetation in Sofala (e.g. mangroves and dune vegetation) (Chemane et al., 1998; World Bank, 2020). Coastal erosion and inundation as a consequence of climate change has been identified as a serious problem in Beira city (Chemane et al., 1998). There is no published and/or well-grounded research on future projections of climate change specifically for Sofala province. The few existing publications for the whole country suggest that average temperature will rise up to 4,6^{o} C between 2010-2090 (UNDP Disaster Reduction Unit, 2004), rainfall will decline by 5 to 10 percent, and potential evaporation will increase by 9 to 13 percent (USAID, 2008). A previous study has reported an increase in temperature by 0.6°C from 1960 to 2006 and a decrease in precipitation to 2.5 mm per decade (Uamusse et al., 2017). Nowadays, in Sofala and in the whole country rain seasons start later, and the dry periods take longer. However, when there is rain it is very intense falling over a short period of time causing urban and rural flooding. It is expected that climate change may impact biodiversity ecology and food security in Sofala. Hence, Local Governments and Conservation Areas managers must take into account the impact of climate change in their decision making and management plans.

1.4. Food Security

Food security can be broadly understood as a measure of food availability and ability to access to it. The United Nations´ Committee on World Food Security argued that food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life (IFRI, 2022). Therefore, to ensure food security in Sofala Province in Mozambique four dimensions must be fulfilled simultaneously as follows (FAO, 2008): (i) Physical AVAILABILITY of food in which addresses "supply side" determined by food production, stock levels and net trade, (ii) Economic and physical ACCESS to food (policy, expenditure, markets and prices in achieving food security objectives), (iii) Food UTILIZATION which is the way that our body intakes the most of various nutrients as a result of food preparation, diversity of the diet, intra-household distribution of food, and individual/collective good care and feeding practices, and (iv) STABILITY of the three mentioned dimensions over time. This last dimension may be affected by several factors, such as adverse weather conditions (e.g, cyclones and inundation that cyclically occur in Sofala contributing for food insecurity), political instability (it is still a great concern in Mozambique because of terrorist insurgency in northern Mozambique and existence of suspected resurge in Sofala of RENAMO Military Junta, armed dissident faction of this opposition party), and economic factors (unemployment, and rising food prices).

In Mozambique, food insecurity is higher in the provinces of Cabo Delgado (aggravated by terrorism), Nampula (the most populated province), and Sofala (mainly ascribed to climate hazards) (Carrilho et al., 2016; Macassa et al., 2018). Food insecurity, malnutrition and poverty are deeply interrelated phenomena. Poverty which has been aforementioned to be higher in Sofala is undoubtedly a cause of hunger (food deprivation) and all hunger people are food insecure. Malnutrition is an outcome of food insecurity resulting from deficiencies, excess or imbalances in consumption of micro-and-or macro-nutrients. Malnutrition due to food insecurity continues to be a great concern in Mozambique and it affects a large part of the population. It has been reported that 80% of people in Mozambique can not afford an adequate diet and 42,3% of children under 5 are stunted (WFP, 2022). The Cost of Hunger in Africa analysis for Mozambique has reported that around 800 million Euros are lost every year because of stunting (chronic malnutrition) (Austrian Development Agency, 2019).

To address food (in)security in Sofala is crucial to understand its driver to inform food policy. A variety of drivers can be mentioned as influencing food security such as household farm production as it produce food, agricultural input use, production conservation (example: use of improved granaries), access to commodity and credit market systems, improved agricultural technologies, and food purchases (income, food prices, and access to food markets) (Benfica et al., 2017; Mabiso et al., 2014; Mather, 2009). However, negative shocks such us human-animal conflict which is a major problem in many regions of Sofala, specifically in the Gorongosa National Park buffer zone where elephants and buffalo indiscriminately consume family´s agricultural production, extreme weather events (cyclical floods, droughts, and ciclones) (Charrua, Padmanaban, et al., 2021; Usman & Reason, 2004), poor conditions of access roads for the outflow of agricultural production, and lack of in-depth knowledge of the nutritional value of agricultural crops such as legumes (beans) can also be deemed (negative) drivers of food security (Catarino et al., 2021; Charrua et al., 2021; Mabiso et al., 2014). The research on the contribution of agrobiodiversity with a focus on the use dry legumes to tackle food security by providing proteins and micronutrient, specifically for poor people living in rural areas, has been neglected to date.

1.5. Benefits of biodiversity and uses

1.5.1. Main uses of biodiversity

The concept of biodiversity is defined as the variability among living organisms on earth, including the different plants, animals, micro-organisms, the genetic variability among the population and the ecosystem they form. When we are talking about biodiversity, three major levels are considered within an area, biome or planet: (i) genetic variation (variation of genes within species and populations), ecosystem variation (variety of habitats, biotic communities, and ecological processes), species variation (number of species). Biodiversity provides numerous benefits and ecosystem services for the local people, and it also contributes to the Sofala´s economy through the generation of revenue from eco-tourism, fishing, agriculture, and so on. Biodiversity is crucial life support system in several ways to people well-being such as food, fuel, climate regulation, fruit trees, industrial raw material, medicine, and so on. The studied taxa are used for a high range of purposes, about 21% (404) were reported as useful species in Sofala. However, we found 659 records of uses, meaning that many species have been reported for more than one type of use. Specifically, three taxa were reported for 6 types of uses, six taxa for five categories, nine taxa for four categories, 41 taxa for three categories and 107 for two categories. Medicinal, food, and handicraft are the three most important taxa use in Sofala, respectively (Table 1.1).

Table 1.1. The main uses of the taxa occurring in Sofala.

Uses	Endemic	Introduced	Native	Total General
Beliefs	0	1	50	51
Cosmetic	0	1	11	12
Food	0	18	139	157
Fuel	0	1	17	18
Handicraft	0	9	91	100
Livestock Fodder	0	5	27	32
Veterinary	0	0	9	9
Medicine	1	30	241	272
Ornament	0	0	8	8
Total	**1**	**65**	**593**	**659**

Medicinal is the most reported, with 272 taxa used in traditional medicine, including the endemic taxa *Chamaecrista paralias* (Brenan) Lock. In Sofala the health system is weak and not comprehensive, especially for people living in remote areas. Therefore, it has been reported that about 80% of the people use medicinal plants to ensure their primarily health care in Mozambique (CBD, 2021; Tchacondo et al., 2012). Food is the second most reported use, with 157 taxa, including 18 introduced species. Since the beginning of agriculture 12000 years ago more than 7000 (wild and domesticated) plants have been used for human consumption (Rawat & Agarwal, 2015). The food products we eat come from agricultural biodiversity being practiced worldwide and particularly in Sofala, Mozambique. Therefore, biodiversity forms the basis for diverse food systems. Mozambique grows a variety of agricultural plants important for national trade, including many leguminous plants. Of these, common bean (*Phaseolus vulgaris* L.) and *Vigna* species were introduced to Mozambique but have become products with broad usage important for food security. It has been reported the disappearance of many relevant traits of cultivated plants due to climate change, soil erosion, urban development, and technological advances in the last century (Length, 2011). Hence, the investigation of beans cultivars that are appropriated for consumer demands, resistant against diseases pests and stress conditions, and have rich nutritional content especially for more healthy nutrition is a top priority in agricultural biodiversity in Mozambique. Handicraft with 100 taxa is based on cultural heritage in Sofala. Biodiversity is an enormous valuable source of intangible cultural heritage, intercultural exchange, creativity and innovation. People use biodiversity to produce a large variety of useful and decorative objects culturally important and with commercial value, such as wooden statues, mats, palm straw folders, pots, spoons, among others.

1.5.2. Dry legumes utilitarian benefits

Biodiversity plays an important role in human nutrition through the food production and the access to nutritious crop variety is crucial to human health. Nutrition and biodiversity are linked in different levels such as: the ecosystem, providing food to people as an ecosystem service; the species in the ecosystem and the genetic diversity within species. The nutritional composition of foods is very variable even within the same species, affecting micronutrient availability in the diet. Healthy local diets, with adequate average levels of nutrients intake, necessitates maintenance of high biodiversity levels (WHO, 2015). In Mozambique and Sofala particularly, *Phaseolus vulgaris* and *Vigna* spp. are among the most commercialised dry legume groups and are major source of dietary protein for people living in rural and urban areas. In addition, some legumes like *Vigna* species grow in wild environments and with less or no plant care. These beans species have contributed a lot to ensure the food security in the country, but their nutritional properties have not yet been sufficiently studied and disseminated (Charrua et al., 2021). *Vigna* species such as *V. unguiculata* leaves are edible, and the immature pods and seeds can also be consumed as a vegetable.

1.5.3. Mangroves Ecosystem Services

The term “Ecosystem services” has been widely used with different meanings from one study to another. Therefore, there is still no consensus about what is meant by ecosystem services (Danley & Widmark, 2016; Saarikoski et al., 2015). Millennium Ecosystem Assessment (MEA) has broadly considered ES as the benefits that humans derive from ecosystems (MEA, 2005). Mangroves and other coastal ecosystems provide a number of valuable ecosystem goods and services that contribute directly and indirectly to Sofala`s people well-being. Most of the people live in the coastal area and rely on mangrove for their daily life. Research on the benefits provided from ecosystem services (ES) on society well-being has been increasing day to day in last decades (Pirard & Lapeyre, 2014). Mangroves in Sofala provide the following categories of ES as classified by MEA (2005): (i) Provisioning (e.g. fuel wood, charcoal production, thatching material, house building material, fish, crab, honey, timber and medicine), (ii) Regulating (e.g. climate regulation, erosion control, carbon sequestration, storm protection, and flood control), (iii) Supporting (e.g. diversity of habitats, nursery grounds for different species, nutrient cycling and soil formation – as in floodplains), and (iv) Cultural (e.g. cultural/religious activities, worship, educational research, reflection, cognitive development, tourism, and heritage sites).

1.6. Main pressures on and drivers of change to biodiversity

There is growing concern about the loss of biodiversity and related change in environment in Mozambique. Here, we present direct and indirect groups of the main factors contributing for habitat alteration and destruction in Mozambique and specifically in Sofala.

1.6.1. Direct drivers

During the civil war 1976-1992, a massive destruction of fauna and flora has been registered in Mozambique, particularly in Sofala which was the main center of war in the country. After the signing of the General Peace Agreement between Government of Mozambique and RENAMO (Mozambican Political-Military Party), efforts have been directed towards the biodiversity restoration, especially within conservation areas. The direct threats to flora in Sofala are urban sprawl; increased demographic growth; clearing forest for mining; over-exploitation of biological resources (e.g. timber and non-timber forest products, coastal and marine resources, and hunting); uncontrolled exploitation for firewood, charcoal and poles; climate changes (extreme weather events), food insecurity and subsistence agricultural practices (slash-and-burn agriculture), soil depletion and erosion specifically along the coastal line; whereas the main threats to fauna are poaching, uncontrolled fires, and habitat destruction (Rawat & Agarwal, 2015; USAID, 2008).

Over-exploitation results from the harvest of biological resources at a rate higher than that technical and scientific recommended for its sustainability. It is still a serious problem in Mozambique. Moreover, true exploitation rate of biological resources in Sofala is poorly known and documented, and corruption in the public service has its due weight for the unsustainable exploitation of biological resources.

From 1975 (Mozambique independence) to 2022, the country population increased from 10433 million to more than 30 million and is forecast to reach a plateau of more than 42 million in 2050 (Francisco, 2010; INE, 2019). As the human population is increasing, there exists insatiable demand for raw materials, housing (urban sprawl), food (slash-and-burn agriculture and food insecurity), poaching, habitat destruction, and so on which is bound to cause changes in biodiversity. It has been reported the population growth has more impact on biodiversity than any other single driver (Dumont, 2012). Food insecurity leads to poaching and intensify the slash-and-burn agricultural practice, which contribute to the loss of biodiversity in Sofala. Population growth associated with the lack of alternatives for survival in rural areas makes people resort to poaching to make up for the protein deficit in their diet. Therefore, the investigation and dissemination of other alternative sources of protein such as dry beans are urgent and necessary.

The most significant effects associated with clearing forest for medium- to large-scale mining is the loss of animal and plant species due to the extraction of sand and stones largely used for the construction of housing in Beira city (urban sprawl). Urban sprawl is one of the main causes of mangrove destruction in Mozambique, with more emphasis on the city of Maputo.

Since electricity and gas are expensive and inaccessible especially in rural areas, families depend on charcoal and firewood to cook their food. The extraction of these products is problematic because it is commercially practiced supplying large urban centers. The extraction of firewood, charcoal and pole has also been mentioned as one of the main causes of mangrove destruction in Mozambique and specifically in Sofala province (Barbosa et al., 2001; Sitoe et al., 2014).

Extreme climatic events particularly cyclones and floods have become the main direct driver of overall biodiversity loss in Sofala province causing severe environmental damage which is not yet fully estimated up to date (Cabral et al., 2017;

Charrua et al., 2021). Cyclone Idai was a remarkable example of LULC destruction in Sofala Province.

Soil depletion and erosion in Coastal Sofala is a relevant environmental threat to biodiversity. This phenomenon can occur in the forms of water erosion, wind erosion, physical compaction, salinization, and chemical degradation. As Sofala province is prone to extreme climatic events, the water erosion (heavy precipitation) and wind erosion are the most important biodiversity declining factor. Despite the risk of erosion, the extraction of sand beach and its bagging to protect the roof of houses against cyclones has been a measure adopted by the population residing in the city of Beira.

1.6.2. Indirect drivers

According to USAID (2008) some of main the indirect driving factor for biodiversity declines are poverty and population dynamics, institutional/policy failure, and lack of public awareness and consultation. More than half of the Mozambican population lies below the poverty line and struggles to obtain at least one meal a day. Hence, the surrounding natural biodiversity is the rural people main source of survival in Sofala. Within this province as all others within Mozambique there are institutions created for the management of biodiversity. However, institutional/policy failures exist when managers do not internalize biodiversity values in decision-making that affect the environment. On the other hand, the corruption within the public sector makes all efforts to conserve biodiversity to be useless. Although we have national legislations (e.g. decree nr 54/2015) to include public and community participation in environmental issues, public awareness and debate are still weak in Sofala particularly in rural areas. It may be ascribed to many factors such as low levels of education, complexity of laws and regulations which need a degree of sophistication to be understood, and cultural aspects (e.g. local habits and customs). These, in some cases, may contribute negatively to biodiversity conservation.

1.7. Conservation and management of biodiversity

Biodiversity conservation is a way of guaranteeing life on earth by maintaining the health and full functionality of natural ecosystems. This includes all activities aimed at the preservation, maintenance, sustainable use, recovery and enhancement of biodiversity. Sustainable development is another important component of biodiversity conservation. It refers to the use of components of biological diversity maintaining its potential to meet the needs of the current and future generations. Cultural heritage carries within it the concept of sustainable development, insofar as the heritage resources (e.g. geophysical, biological, cultural/historic, aesthetic and recreational) should be used in the present but without compromising future generations and guaranteeing local development.

1.7.1. Cultural heritage-based biodiversity community management

It is clear that in Africa, specifically in Mozambique no legal provisions related with conservation of natural resources can obtain desired results unless local communities are involved in planning, management and monitoring conservation programmes. The conservation of biodiversity in rural areas is mostly based on community cultural heritages which is defined as the legacy of physical artifacts (e.g. sacred places and animals, paintings, and sculptures) and intangible attributes of society (e.g. traditional ecological knowledge, myths, and social custom and spiritual believes) inherited from past, experienced in the present, and transmitted to future generations (Keitumetse, 2014; Pelegrini, 2008; Willis, 2014). Cultural heritages include the sites, things, and practices a society regards as old, important, and worthy of conservation (Brumann, 2015). It refers to all tangible and intangible heritages that have a diversity of values to a local community such as symbolic, utilitarian value, historic, spiritual, artistic, aesthetic, ethnological or anthropological, scientific and social significance (UNESCO, 2009). Physical artifacts include sacred forest, works of art, literature, sacred lakes, archaeological and historical artifacts, sacred trees, cemeteries, as well as buildings, monuments, and historic places, whilst intangible attributes include rites, rituals, social customs, spiritual beliefs, oral traditions, indigenous knowledge, and practices concerning the natural environment, religion, so on.

The principle of biodiversity conservation is centered on environmental sustainability as a consequence of the cultural value that a specific natural resource represents in a certain community - Environment as cultural heritage/heritage resource (Laplante et al., 2005). The term value is referred to those qualities regarded by individuals, groups, or the whole local community as important or desirable (Carter & Bramley, 2002). The value attributed to heritage resources can be intrinsic or extrinsic. Intrinsic value refers to those qualities that inherently exist in a heritage resource, often objectively assessed, and do not require any modification or use for the value be realized (e.g. magnitude, representativeness, and diversity), whereas extrinsic value depends on human perception, often subjectively assessed, and generally needs to modify or use a specific resource for realize its value (e.g. cultural use, and aesthetic). The management approach applied to a certain heritage resource is closely related to its perceived values and significance. The World Heritage Convention has recognized that the management of heritage resource should drive in its protection, conservation, and rehabilitation. Therefore, recent approaches regarding the sharing of responsibility in heritage resource management encourage conservation rather than preservation, that is, give access to local people use and enjoy the valuable and significant natural resources (that they own and value them) respecting their culture and sustainability. In Mozambique, the current legal framework encourages community-based natural resource management and 20% of the revenue from any development project goes to the local community. Moreover, the community management of heritage cultural resources is an encouragement particularly associated with UNESCO 1972 and 2003 international conventions (UNESCO, 1972, 2003). However, cultural and heritage resources have yet been neglected as dominant enablers in sustainable development initiatives (Keitumetse, 2014).

1.7.2. National and international initiatives and legislation

The Ministry of Earth and Environment (MITA) is the entity in charge of all environmental issues in Mozambique. The protection of the environment and the well-being of people is stipulated in the Constitution of the Republic of Mozambique. The country has produced a wide range of legislation focused on protection of natural resources, as follow: the Agrarian Policy, Land Policy, Forest and Wildlife Law, Environmental Policy, Environmental Law (Law nr 20/97), National Biodiversity and Action Plan (2003), Regulation on Forestry and Wild Life (2002), Regulation on Environmental Audit (2003), Regulation on Pesticides (2003), Regulation on Bio-Medical wastes (2003), Regulation on Environmental Impact Assessment (2004), National Policy on Traditional Medicine (2004), and so on.

Roughly 70% of the Mozambique total area is covered by forests and/or other woody plants, and almost 26% of the land area of the national territory represents conservation areas such as national parks (zones of total protection by national law), national reserves (zones of total protection for protecting rare, endemic and/or endangered species of flora and fauna, and fragile ecosystems), Forest Reserves (partial protection managed under an approved plan), Coutadas or State Hunting Concessions (enjoy partial protection but government may allocate this land to other uses), games farms, and community conservation areas ("zones of use, historical and/or cultural value") (Ministry for the Coordination of Environmental Affairs, 2014). The National Network of Conservation areas comprises 8 National Parks (Quirimbas National Park, Mágoè National Park, Gorongosa National Park, Chimanimani National Park, Zinave National Park, Bazaruto Archipelago National Park, Banhine National Park, Limpopo National Park), 11 National Reserves (Niassa National Reserve, Gilé National Reserve, the Environmental Protection Area of the First and Second Islands, Marromeu National Reserve, Pomene National Reserve, Lake Niassa, Malhazine, Ponta de Ouro and the Inhaca Biological Reserve, Maputo Special Reserve, the Cape São Sebastião Total Protection Zone), 4 clusters of State Hunting Concessions or Coutadas (4 & 5; 7, 9, & 13; 6 & 15; 10, 11, 12 & 14) numbering 11 in all, 11 Forest Reserves (Moribane, Mecuburi, Marronga, Zombe, Matibane, Baixo Pinua, Mapalue, Ribaue, Derre, Mucheve, and Licuati), and14 Gazetted Game Farms (Adolfo Bila, Africaca, Cabo Delgado Biodiversity, Eco Safari Mucapana, Imofauna, Mafuia Safaris, Mahimba Game Farm, Mbabala Safaris, Mozunaf Safaris, Negomano Safaris, Nguenha Project, Paul & Ubisse, Sabie Game Park, and Sapap (Biofund, 2022; Government of Mozambique, 2018; Ministry of Tourism, 2010).

Of these conservation areas, Gorongosa National Park (5370 Km^2 Mozambique's flagship park), Marromeu National Reserve (1500 Km^2 Ramsar Site - wetlands of international importance), one Gazetted Game Farms (Mozunaf Safaris – 100 Km^2), one Gazetted Forest Reserves (Mucheve - 91 Km^2), and 5 State Hunting Concessions" (Coutada 5 – 6868 Km^2, Coutada 10 – 2008 Km^2, Coutada 11 – 1928 Km^2, Coutada 12 – 2963 Km^2, Coutada 14 – 1353 Km^2) are located in Sofala Province (Fig. 1.6) (Ministry of Tourism, 2010).

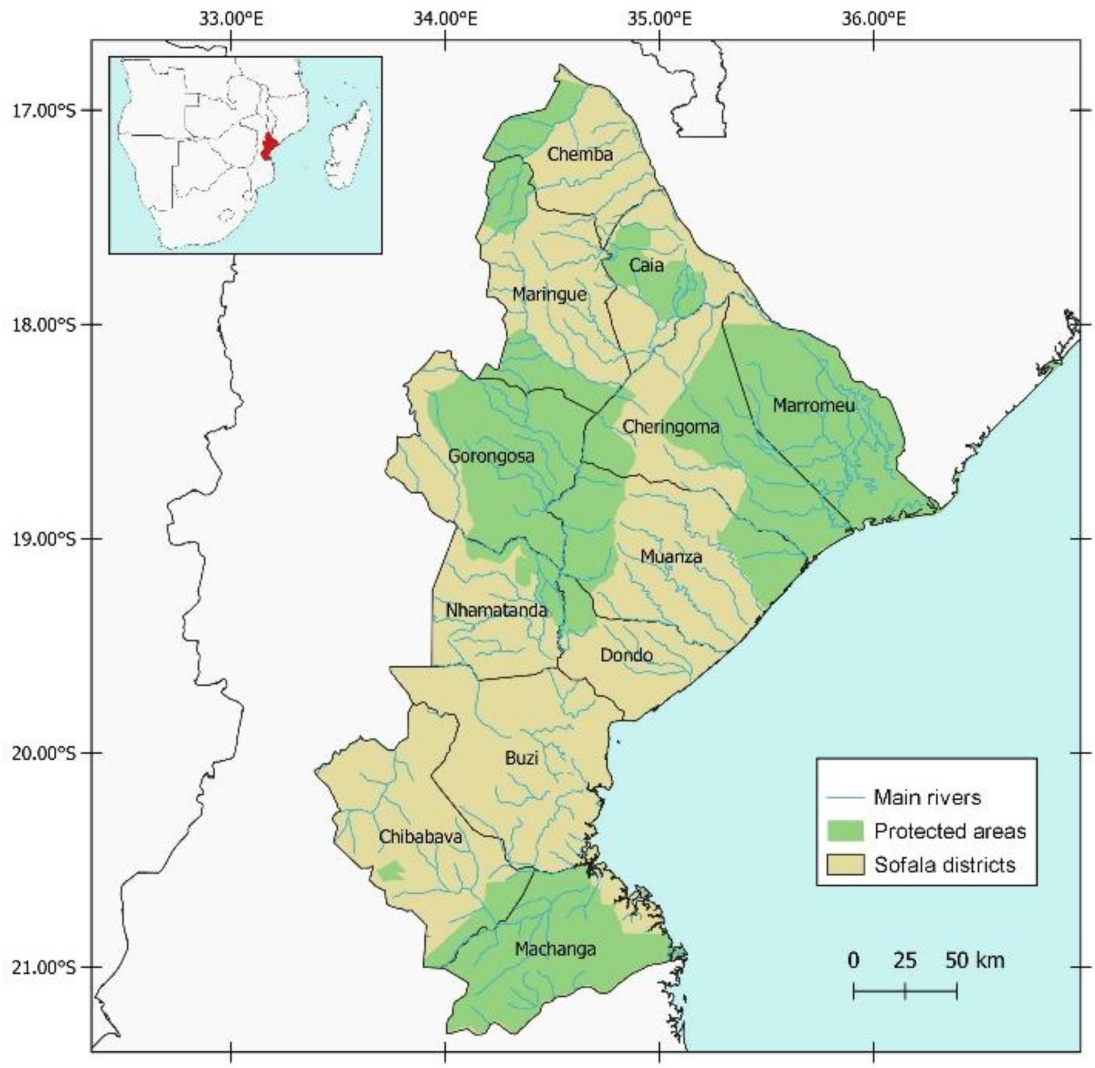

Figure 1.6. Map of Sofala province, including the districts' names and areas under protection.

In Mozambique the percentage of land dedicated to conservation is growing with the declaration of new parks, reserves, and community conservation areas (CCAs). This last one, are areas proposed and managed by the community according to their local traditions and norms, and customary practice (cultural heritage). There are many anonymous CCAs over the country but the most popular and officially recognized by Ministerial Decree are Tchuma Tchato (Tete province) and Chipanje Chetu (Niassa Province). Recently (2021), Gorongosa Project has established two clusters of CCAs within the buffer zones (BZ) of Gorongosa National Park (GNP) being first in north (Catemo, Nhabaua, Muanadimai, Chidanga, and Maciambosa all in Cheringoma district) and the second group in south (Bebedo, Nhampoca in Nhamatanda district and

Nhamacuenguere in Dondo) numbering 8 in all. Therefore, the south CCAs were subject of research in this dissertation.

The National Parks and Reserves within the country are governed by the Land Law (Law nr 19/97 de 1 de Outubro), Forest and Wildlife Law (Law nr 10/99) and the Conservation Law (Law nr 16/2004), and these areas are considered national assets in the public domain. The National Administration of Conservation Areas (Administração Nacional das Áreas de Conservação or ANAC) is a national-level directorate belonging to MITA and is responsible for the management of conservation areas in Mozambique.

The funding for biodiversity conservation, accessing technical training, and inter-institutional coordination have been a great challenge for the Government of Mozambique. Therefore, it has been supported by National Government through The National Fund of Environment (FUNAB) and foreign partners such as: The World Bank, European Commission, the French Development Agency and USAID, International Finance Committee, United Nations Development Programme, Danish International Development Agency, UNEP, International Conservation Union, WWF, Carr Foundation, U.K. Department for International Development, Food and Agriculture Organization, Millennium Challenge Corporation, and others.

The Mozambican government has signed several international treaties and agreements aimed to conserve local biodiversity. Some of these are: The Ramsar Convention on Wetlands of international importance, United Nations Convention on Biological Diversity, United Nations Basic Convention on Climatic Changes, African Convention on Conservation of Nature and Natural Resources, Convention on International Trade for Endangered species (CITES), Convention on Conservation of migratory species of wild animals, Kyoto Protocol, and International Union for the Conservation of Nature.

1.8. Motivation and aims

Over the past decades, following the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992, the conservation of biodiversity has come to be understood as an essential aspect of sustainable development worldwide (Najam & Cleveland, 2005). Nowadays, the conservation of biodiversity has been prioritized in Mozambique and included in many country development initiatives. The attention paid to the conservation of the local ecosystems is not only because of their ecological importance, but also because of the valuable ecosystem services they provide for people welfare and wellbeing (Benayas et al., 2009).

Mangrove forests provide a number of valuable ecosystem goods and services that contribute directly and indirectly to society well-being in Mozambique. However, either mangrove or terrestrial ecosystems are disappearing year after year in Sofala, a phenomenon that may be attributed to deficient management of natural ecosystems, lack of knowledge of its biodiversity value and its spatial distribution, unsustainable use of these natural resources, and extreme climatic events (cyclones and inundations). Furthermore, the Central Region of Mozambique (Sofala Province) bordering on the active cyclone area of the southwestern Indian Ocean has been cyclically affected by climate hazards specifically cyclones and floodings causing severe Land Use and Land Cover (LULC) damage not yet been fully assessed (Charrua et al., 2020; Charrua et al., 2021). In addition, the increasing demographic growth rates and urban expansion are threatening Sofala´s unique biodiversity and destroying several habitats of plants and animals.

It is worth mentioning that throughout Mozambique, the food condition of many inhabitants is weak, and the food security is still a concern in the country, namely in rural areas where poverty levels are very high food insecurity is also a major threat to biodiversity conservation, particularly in Sofala province where the civil war (1976-1992) occurred as well as the latest civil unrest (2013-2019). Moreover, the study of the agricultural biodiversity is important for people nutrition. *Phaseolus vulgaris* and *Vigna* spp. are important staple foods and a major source of dietary protein for local populations (Beebe et al., 2013), particularly for people living in rural areas who lack the financial capacity to include meat in their daily dietary options. In Mozambique, *Vigna* species such as *V. unguiculata* usually grow in smallholders' fields, home gardens, backyards and sometimes grow in the wild (Charrua et al., 2021).

Moreover, the leaves of this legume are edible, and the immature pods and seeds can also be consumed as a vegetable. Hence, specifically, the study of *Vigna* species not only contribute to promote food security and agricultural biodiversity, but also to disseminate their nutritional value which can be a deterrent to poaching in rural areas. People use their socio-cultural understanding of phenomena to interact with the environment. People are carriers of cultural heritage. Therefore, assessing value, management, and sustainable use of biodiversity in Africa and Mozambique in particular requires a holistic assessment of the ecosystem and both cultural heritages and western scientific knowledge should be included when they are available.

There is a concern with undervaluation, unsustainable use and weak management of natural products and services generated by local ecosystems in Sofala and on the driving forces behind the conversion of that ecological system into other types of land uses, particularly, in context of climate changes. As the literature about the coastal ecosystem in Sofala Province is still scarce, this study characterizes the current situation and produces useful information for sustainable use and management of mangroves. This study is the first to investigate the nutritional value of dry beans in the context of food security and conservation of agrobiodiversity in Sofala. In addition, it may help on raising the debate of the agricultural biodiversity and its role on people´s nutrition and conservation in Sofala and in Mozambique in general. Furthermore, it is also expected that this dissertation may help the Sofala government to promote sustainable use and management of natural resources based on the respect of the cultural heritages. Finally, this dissertation may contribute to call the attention to researchers, private sector, government and non-governmental organizations to include biodiversity conservation in public policy decision making.

The main objective of this thesis is to provide the Sofala Province in Mozambique with technical and scientific information about value, management and sustainable use of biodiversity, with focus on conservation of ecosystems. Specifically, we aimed to:

I. Analyze temporal changes in Land Use and Land Cover (LULC) across the Sofala Province using pre- and post-cyclone Idai Landsat satellite images with focus on understanding how the local biodiversity has been threatened by climate hazards.

II. Apply the Species Distribution Models to predict coastal mangrove habitats and their vulnerability to climate change with focus on getting priority areas for management interventions, using the Mangrove as a case-study.

III. Assess the nutritional properties of dry legumes (*Phaseolus vulgaris* and *Vigna* spp.) in the context of food security and agricultural biodiversity, using beans as a case-study

IV. Explore the role of cultural heritage on natural resources conservation with a focus on understanding the past (local traditional ways of conserving, valuing, and managing natural ecosystems) as an inspiration to propose sustainable natural resources management strategies for conservation purposes.

1.9. Outline of the thesis

Chapter I presents a general introduction, including Sofala biophysical and socioeconomic characterization, *Leguminosae* family, climate change, food security, benefits of biodiversity and uses, main pressures on and drivers of change to biodiversity, conservation and management of biodiversity, and motivation and aims.

Since the province of Sofala is vulnerable to the occurrence of extreme weather events with emphasis on the cyclones which have been a major threat to local biodiversity, in **Chapter II** we present a comprehensive assessment of the impacts of the Tropical Cyclone Idai in Mozambique using a Multi-temporal Landsat Satellite Imagery Analysis. Idai (category four, 2019) was the deadliest and most devastating tropical cyclone ever seen in the Southern Hemisphere. In this study we: (i) quantified and mapped the changes in LULC between 2012 and 2019; (ii) investigated the correlation between the distance to Idai's trajectory and the degree of vegetation damage, and (iii) determined the damage caused by Idai on different LULC.

Chapter III is focused on assessing the vulnerability of coastal mangrove ecosystems in Mozambique. Therefore, in order to understand which areas should be prioritized for management interventions on mangroves and costal dunes, we: (i) identified the most important environmental variables affecting the mangroves distribution patterns; (ii) predicted the spatial distribution pattern and suitable areas for their development; (iii) quantified *Avicennia marina* and *Rhizophora mucronata* Exposure Index (EI) to climate hazards and erosion; and (iv) provided new insights for the future management and conservation of coastal habitats, which are seriously threatened by a number of hazards, of both natural and anthropogenic origin.

Chapter IV presents a comprehensive assessment of nutritional value of the most commercialised dry legume groups in Mozambique **(***Phaseolus vulgaris* and *Vigna* spp.) which are important staple foods and a major source of dietary protein for local populations. This study contributes to the current debate on improving diets with locally produced nutritious legumes (agricultural biodiversity), promoting greater food security, agricultural biodiversity value and income generation among smallholder farmers.

Chapter V addresses the importance of cultural heritage (value) in the Buffer Zone of Gorongosa National Park (GNP), Sofala Province (Mozambique), with a focus on natural resources community management. Indigenous people use their socio-cultural understanding of phenomena to interact with the environment and manage their surrounding natural resource as well. Here, we: (i) identify local communities' cultural heritages and mapped them spatially; (ii) document the existing cultural heritages and their potential for the nature conservation and people well-being; and (iii) explore the native populations' expectations about the establishment of the Community Conservation Areas (CCA) and how it may affect their cultural heritages, way of life and welfare.

Chapter VI concludes the thesis, offering a summary of the main findings of the studies presented above, highlighting their main contributions for future biodiversity conservation planning and natural resources management policies. Supplementary data is included in the Appendix.

Despite the restrictions imposed by COVID 19, this dissertation was mainly based on field work in Sofala Province in very hard conditions, specifically during and immediately after the cyclone Idai hit that province. We expect this research work may contribute to understand the value, management, and sustainable use of biodiversity from Sofala Province in Mozambique in order to improve populations welfare The present thesis is organized into six chapters, including three articles published in peer-reviewed journals and one in preparation.

The four main chapters of this thesis (2 to 5) are well related as illustrated in Fig. 1.7. Since biodiversity is threatened because of the cyclical occurrence of extreme weather events in Sofala province, we started by analyzing the impacts of Cyclone Idai on Land Use and Land Cover Change (LULCC), in Chapter II. Our results revealed that wetland vegetation (mainly composed by mangrove forest) is one of the most devasted/threatened LULC by Idai within the province and it decreased by 57.4%. However, it was previously mentioned that Sofala coastal mangrove is an ecological region of global importance (see section 1.1.3.3, "Ecological regions") and most of the people living in coastal region heavily rely on mangroves for its daily life (for more detail see section 1.5.3, "Mangroves Ecosystem Services"). Hence, we have selected this natural ecosystem to analyze priority areas for management intervention (Chapter III). To diversify our study, we included the study of nutritional value of dry legumes (*Phaseolus vulgaris* and *Vigna* spp.) in context of agricultural biodiversity as it can contribute to conserve natural biodiversity (e.g. mangroves) by guaranteeing food and nutrition security for the local population (Chapter IV). In addition, the Leguminosae is the most abundant and the most important plant family in Sofala (see Fig. 1.4A, section 1.1.3.4) with innumerous uses, such as food, medicine, carbon sequestration, soil amelioration, among others (see section 1.5. "Benefits of biodiversity and uses"). The conservation, use and management of natural biodiversity (e.g. mangroves) and agrobiodiversity is closely related to indigenous knowledge of the local population (cultural heritages – Chapter V). Historically, the native community manages natural resources and agricultural crops in traditional way contributing to the fight against climate change and food insecurity. The cultural heritage is very little studied in African countries, specifically in Mozambique (Sofala).

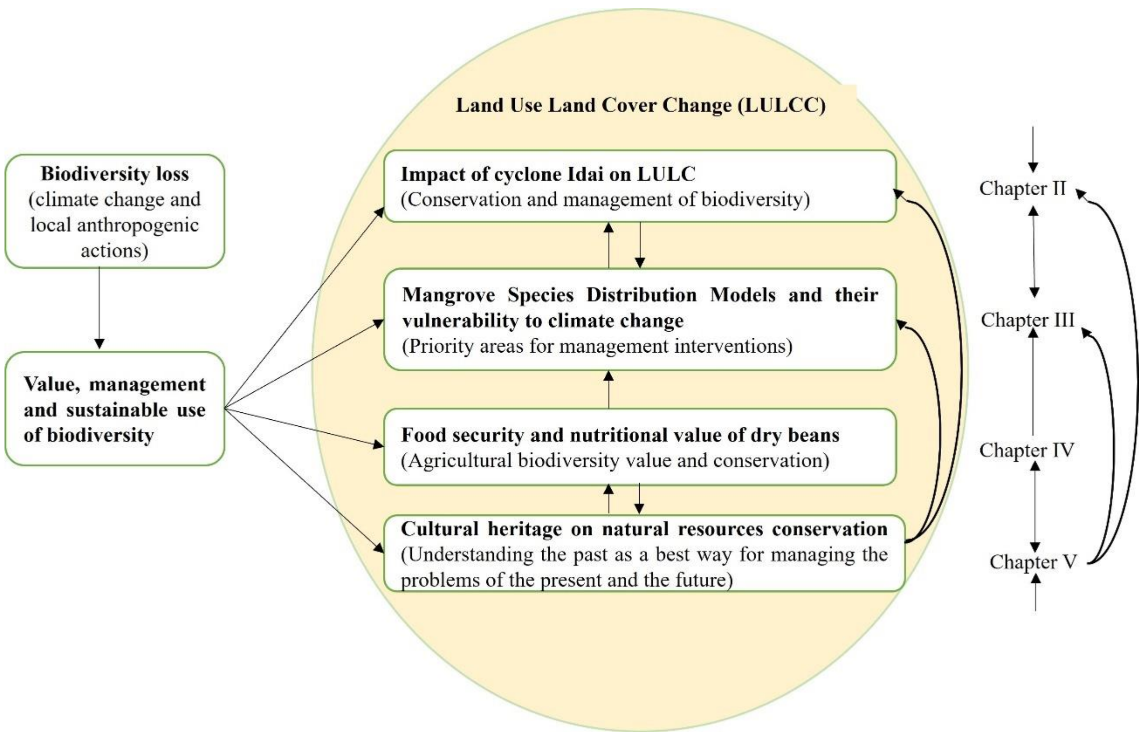

Figure 1.7. An infographic insight of the doctoral thesis approach and contents.

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Chapter II

Impacts of the Tropical Cyclone Idai in Mozambique: a Multi-temporal Landsat Satellite Imagery Analysis

remote sensing

MDPI

Article

Impacts of the Tropical Cyclone Idai in Mozambique: A Multi-Temporal Landsat Satellite Imagery Analysis

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Abstract: The Central Region of Mozambique (Sofala Province) bordering on the active cyclone area of the southwestern Indian Ocean has been particularly affected by climate hazards. The Cyclone Idai, which hit the region in March 2019 with strong winds causing extensive flooding and a massive loss of life, was the strongest recorded tropical cyclone in the Southern Hemisphere. The aim of this study was to use pre- and post-cyclone Idai Landsat satellite images to analyze temporal changes in Land Use and Land Cover (LULC) across the Sofala Province. Specifically, we aimed—(i) to quantify and map the changes in LULC between 2012 and 2019; (ii) to investigate the correlation between the distance to Idai's trajectory and the degree of vegetation damage, and (iii) to determine the damage caused by Idai on different LULC. We used Landsat 7 and 8 images (with 30 m resolution) taken during the month of April for the 8-year period. The April Average Normalized Difference Vegetation Index (NDVI) over the aforementioned period (2012–2018, pre-cyclone) was compared with the values of April 2019 (post-cyclone). The results showed a decreasing trend of the productivity (NDVI 0.5 to 0.8) and an abrupt decrease after the cyclone. The most devastated land use classes were dense vegetation (decreased by 59%), followed by wetland vegetation (−57%) and shrub land (−56%). The least damaged areas were barren land (−23%), barren vegetation (−27%), and grassland and dambos (−27%). The Northeastern, Central and Southern regions of Sofala were the most devastated areas. The Pearson Correlation Coefficient between the relative vegetation change activity after Idai (NDVI%) and the distance to Idai's trajectory was 0.95 (R-square 0.91), suggesting a strong positive linear correlation. Our study also indicated that the LULC type (vegetation physiognomy) might have influenced the degree of LULC damage. This study provides new insights for the management and conservation of natural habitats threatened by climate hazards and human factors and might accelerate ongoing recovery processes in the Sofala Province.

Keywords: Cyclone Idai; remote sensing; vegetation damage; land use and land cover; vegetation index

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1. Introduction

Tropical cyclones are among the most devastating natural disasters owing to their great potential for loss of human life, significant economic decline and severe environmental damage [1–3]. The Southwestern Indian Ocean is one of the main tropical cyclone areas

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Abstract

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Keywords: Cyclone Idai; remote sensing; vegetation damage; Land Use and Land Cover; vegetation index

2.1. Introduction

Tropical cyclones are amongst the most devastating natural disasters owing to their great potential for loss of human life, significant economic decline and severe environmental damage (Alam & Dominey-Howes, 2015; Lee et al., 2020; Tonkin et al., 1997). The Southwestern Indian Ocean is one of the main tropical cyclone areas in the world (Gray, 1968), and also the most cyclone active area in the Southern Hemisphere (Henderson-Sellers et al., 1998). Currently, the negative effects of climate change are an omnipresent reality in Mozambique, as this southern African country frequently experiences extreme weather and climate events such as drought, floods and cyclones (MICOA, 2005). The cyclone season in Mozambique generally spans the period of November to April. Every year, three to twelve cyclones form in the Mozambique Channel (Consultec, 2007; Mavume et al., 2009). The Central region of Mozambique, including the Sofala Province, is the area most prone to cyclones (6 cyclones in 16 years) and climate hazards. This region is characterized by a large tidal range (up to 7 m), and extensive low flatland (Asante et al., 2009; Cabral et al., 2017; Charrua et al., 2020). The most severe tropical cyclones striking Sofala and affecting the lives of millions of inhabitants were: Nadia in 1994, Bonita in 1996, Lisete in 1997, Eline in 2000, Japhete in 2003, and Idai in March 2019 (Post Cyclone Idai Cabinet for Reconstruction, 2019; UEM & FEWS, 2003). Idai (category four) was the most devastating and deadliest cyclone recorded in the Southern Hemisphere, in terms of the loss of human life, of facilities and of infrastructures (Kolstad, 2020; Salih et al., 2020). Idai primarily affected Sofala and impacted the surrounding provinces (Manica, Inhambane, Tete and Zambézia), while also wreaking havoc in Zimbabwe as well. It brought torrential rain (more than 200 mm in 24 hours) and strong winds (up to 220 km/h), causing severe widespread flooding (flood waters rose more than 10 m). Idai affected more than 1.5 million people in Mozambique, resulting in more than 600 deaths while over 1600 persons were injured. However, severe Land Use and Land Cover (LULC) damage has not yet been fully quantified. Cyclone Idai's socioeconomic impact in Mozambique was considered the highest to date, with damages and losses estimated at US $3.2 billion (2019 estimate) (Post Cyclone Idai Cabinet for Reconstruction, 2019).

Several studies using satellite images to assess the impact of cyclones on natural habitats have reported from different parts of the world, including the USA (Zhang et al., 2019), the Gulf of Mexico and Caribbean/Mesoamerican Region (Taillie et al., 2020), Australia (Paling et al., 2008), and India and Bangladesh (Bhowmik & Cabral, 2013). In Africa and Mozambique in particular, cyclone impact studies on LULC are comparatively rare.

The Sofala Province is an under-researched area. With the exception of two studies carried out on the Save River Delta (forming the border between South and Central Mozambique) which assessed the response of mangroves to cyclone Eline (2000) using SPOT images (Macamo et al., 2016), and the qualitative analysis of natural system management under recurrent catastrophic events (cyclones and floods) (Massuanganhe et al., 2015), no published reports have been detected. Our study is the first to document the impact of the category four Cyclone Idai on LULC.

Studying the impact of cyclones on LULC in the context of climate change is crucial to inform the design and implementation of natural vegetation management, identify threatened habitats, prevent and/or counter environmental threats, and enhance conservation efforts. Moreover, our study provides valuable information for evidence-based decision making and disaster management for a more effective recovery of both natural habitats and human infrastructures in the Sofala Province. It also gives relevant insights into the sensitivity and recovery of natural vegetation following a devastating cyclone. Since Idai damaged communication and transport networks, as well as other basic infrastructures, traditional field work to survey the large-scale destruction of vegetation is difficult, expensive and time-consuming when compared to remote sensing (Hoque et al., 2016; Hu & Smith, 2018; Zhang et al., 2013).

Vegetation indicators, including the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index, have been widely used to obtain useful information on vegetation destruction and sensitivity, particularly after a damage event (Ballanti et al., 2017; Li et al., 2018; Zhang et al., 2013). Landsat data images are easy to access, and have long been used to monitor land use and changes in vegetation cover (He et al., 2020; Hu et al., 2018; Schneibel et al., 2017). Therefore, the main purpose of this study was to use pre- and post- Idai Landsat imagery to analyze temporal changes in Sofala's LULC from 2012 to 2019. Specifically, we aimed: (i) to quantify and map LULC dynamics from 2012 to 2019; (ii) to investigate how the distance to Idai's trajectory related to vegetation damage, and (iii) to determine the degree of damage caused by the cyclone on different LULC classes. The findings of this study are meant to assist managers of natural resources to design and implement efficient strategies and practices in order to safeguard natural ecosystems and their services such as provisioning (e.g. food, and timber), regulating (e.g. climate regulation, and water purification), supporting (e.g. nutrient cycling, and soil formation), and cultural (recreation, and spiritual) (MEA, 2005).

2.2. Materials and Methods

2.2.1. Study area

Sofala is a coastal province in Central Mozambique, occupying a surface area of approximately 68,018 Km^2 (about 8.5% of the country). It borders on the Indian Ocean to the east, on the Zambezi River to the north, and the Save River to the south (Figure 2.1a). The Central part of Sofala is intersected by the Púnguè and the Buzi River, and the province is characterized by an inter-connected hydrological system of creeks, swamps, and lakes. All the region's main rivers discharge into the Indian Ocean, providing a suitable habitat for the growth and establishment of a great variety animal and plant species. According to the 2017 census, the total population of Sofala province was estimated at 2,259,248 inhabitants, most of them living in rural areas (INE, 2019) and largely dependent on unstable natural resources (threatened by climate hazards) for their subsistence. The main economic activities of the local population are slash and burn agriculture, fishing, raising cattle and commerce. The Province of Sofala is characterized by a tropical climate with rainy season (summer) running from November to March, and a dry season (winter) from April to October; southeasterly trade winds are predominant. The annual average temperature is 25 °C and average rainfall amounts to approximately 1,300 mm/year (Hoguane, 2007). According to Marzoli (Marzoli, 2007), LULC classes in Sofala are primarily composed of vast native forests (48.81%), wetlands (19%), agricultural lands (5.57%), urban areas (0.16%), barren areas (0.5%), with water and other vegetation formations (height < 5m) accounting for 25.96%. Sofala's coastline is characterized by the so-called swamp coast (Macamo et al., 2016) and it has one of the largest mangrove areas (932 km^2) in Mozambique, second only after to the Zambezia province (1,219 km^2) (Marzoli, 2007). Sofala is the province most prone to floods and cyclones (occurring in summer) which greatly affect LULC (Asante et al., 2009; Cabral et al., 2017).

2.2.2. The cyclone Idai

Cyclone Idai originated from a tropical depression that formed in the Mozambique Channel on 4 March 2019. On 9 March, the depression intensified, transforming it into the, as yet, moderate tropical storm Idai. The reigning conditions in the Mozambique Channel greatly favored the intensification of the winds to speeds of 175 km/h on 11 March. Idai then weakened and died down for a day, only to re-activate on 13 March. On the night of 14 to 15 March, Idai turned into a category four tropical cyclone making landfall near Beira, the main city in Central Sofala Mozambique's second largest city and a strategic maritime port which serves Mozambique interior as well as a vast southern African hinterland region (e.g. Zimbabwe, Botswana, Malawi, Zambia, and Democratic Republic of Congo) (Figure 2.1b). It brought strong winds (180-220 km/h) and torrential rain (more than 200 mm in 24 hours), flooding more than 3,000 km^2 of agricultural land. It displaced around 400,000 inhabitants, provoking over 600 deaths, while severely damaging LULC classes (Post Cyclone Idai Cabinet for Reconstruction, 2019). The winds receded as the cyclone moved inland, affecting provinces bordering on Sofala (Manica, Zambézia, Tete, and Inhambane) before moving to neighbouring Zimbabwe.

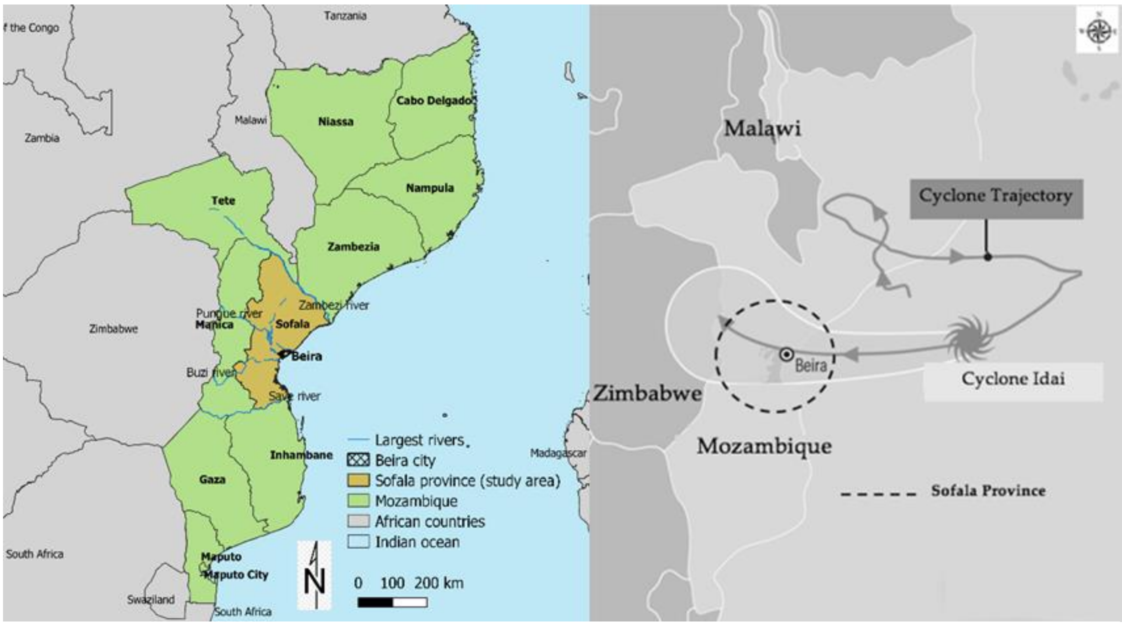


Figure 2.1. Location of the study area (1a, left) and trajectory of the Cyclone Idai (1b, right) (adapted from: Meteo France).

2.2.3. Data

We used Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) images from April of each year, from 2012 to 2015, and 2016 to 2019, respectively. Landsat 7 ETM+ and Landsat 8 OLI data both had a 30 m resolution and were downloaded from the United States Geological Survey (USGS) gateway (https://earthexplorer.usgs.gov/). Table 2.1 shows the list of satellite images used, acquisition date, and path row for the study area. The LULC and NDVI analyses can be influenced by seasonal differences (because of changes in atmospheric conditions and photosynthetic activities) (Jensen, 2005).

Table 2.1. Satellite imagery used in this study.

Date	Sensor	Path row
12 April 2012	Landsat 7 ETM+	166 / 73
19 April 2012	Landsat 7 ETM+	167 / 72,73,74,75
28 April 2012	Landsat 7 ETM+	168 / 72, 73, 74
13 April 2013	Landsat 7 ETM+	166 / 73
15 April 2013	Landsat 7 ETM+	167 / 72,73,74,75
22 April 2013	Landsat 7 ETM+	168 / 72, 73, 74
2 April 2014	Landsat 7 ETM+	166 / 73
16 April 2014	Landsat 7 ETM+	167 / 72,73,74,75
18 April 2014	Landsat 7 ETM+	168 / 72, 73, 74
12 April 2015	Landsat 7 ETM+	166 / 73
12 April 2015	Landsat 7 ETM+	167 / 72,73,74,75
19 April 2015	Landsat 7 ETM+	168 / 72, 73, 74
6 April 2016	Landsat 8 OLI	166 / 73
13 April 2016	Landsat 8 OLI	167 / 72,73,74,75
29 April 2016	Landsat 8 OLI	168 / 72, 73, 74
9 April 2017	Landsat 8 OLI	166 / 73
16 April 2017	Landsat 8 OLI	167 / 72,73,74,75
25 April 2017	Landsat 8 OLI	168 / 72, 73, 74
12 April 2018	Landsat 8 OLI	166 / 73
19 April 2018	Landsat 8 OLI	167 / 72,73,74,75
28 April 2018	Landsat 8 OLI	168 / 72, 73, 74
6 April 2019	Landsat 8 OLI	166 / 73
15April 2019	Landsat 8 OLI	167 / 72,73,74,75
22 April 2019	Landsat 8 OLI	168 / 72, 73, 74

2.2.4. Methods

This study was carried out in four main steps: (1) satellite data pre-processing, which included cloud detection, atmospheric correction, and geometric correction; (2) calculation of the vegetation indicators, including the Normalized Difference Vegetation Index (NDVI), the difference in NDVI (ΔNDVI), and the relative change in vegetation productivity after Idai (NDVI%); (3) producing the LULC map for April 2019; and (4) producing a distance bands map obtained using buffer analysis. These steps are detailed in Figure 2.2. The distance to the cyclone's trajectory was subjected to statistical analyses to evaluate its relationship with vegetation damage using a linear regression model with a single explanatory variable.

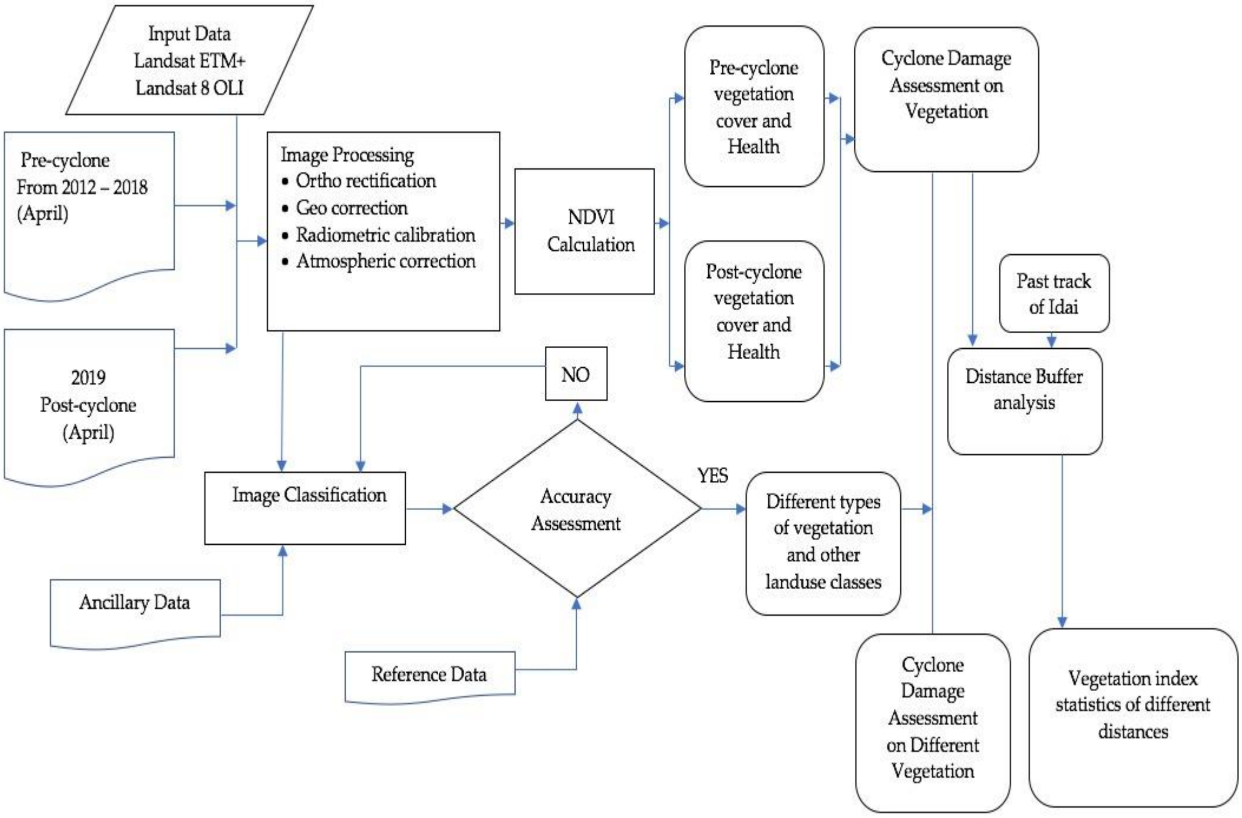


Figure 2.2. Workflow of LULC classification.

Initially, the Landsat 7 and 8 satellite data were geometrically corrected and ortho-rectified (Figure 2.2) using the Landsat packages ("georef" and "geoshift") in RStudio Software (Chen et al., 2011; Goslee, 2011; Padmanaban, 2017). All satellite images were georeferenced through the Universal Transverse Mercator (UTM) coordinate system. We were aware of the limitation of Landsat 7 ETM+ because of the Scan Line Corrector (SLC) failure (Hossain et al., 2015; USGS, 2003). To fill the gaps (Not available "NA" values) caused by that error, we applied the Landsat 7 Scan Line Corrector (SLC)-off Gap function, using the traditional Local Linear Histogram Matching method – LLHM (Chen et al., 2011; USGS, 2004). The ERDAS image processing software (version 8.7) was applied to perform Scan line error correction with the help of band-specific gap mask files, made with the Landsat 7 Level-1 data product. These mask files help to classify the location of every pixel affected by the original data gaps in the primary SLC-off scene (Padmanaban & Cabral, 2017). For this purpose, the DV values (0-255) were converted into top-of-atmosphere (TOA) radiance (at-satellite radiance values) using the parameters provided in metadata files (Chander et al., 2009;

Goslee, 2011; Gupta et al., 2018). We also applied absolute atmospheric compensation techniques (Dark Object and Modified Dark Object Subtraction Method) to identify and remove clouds, aerosols, and cirri (Padmanaban & Cabral, 2017; Pathak et al., 2016).

The pseudo-invariant features (PIF) function was used to examine the homogeneity of reflectance values of LULC in the images, and then corrected by using major axis regression. The Landsat 7&8 data were radiometrically and atmospherically corrected by using an atmospheric simulation model available in the Landsat and R package (RStoolBox) (Goslee, 2011; Leutner et al., 2020).

2.2.5. Land use and Land cover classification

The satellite images for 2019 were classified into nine LULC classes: dense vegetation, shrub land, grassland and dambos, agricultural land, wetland vegetation, barren vegetation, barren land, built-up areas, and water bodies (Table 2.2). This was performed by applying the Random Forest (RF) classifier. This technique has been recently used for mapping plant species and landscape due to its processing speed, improved accuracy, and reliable classification outputs (Li et al., 2019; Louarn et al., 2017). The processing chain for the RF classification algorithm optimized the proximities between data points (Padmanaban et al., 2017):

- Produces n-tree bootstrap model from the raster data;
- Runs an unpruned classification grown for all bootstrap models according to the Digital Number (DN) values.
- Produces N number of polygons in line with the DN raster values.
- Chooses the number of classifications of the LULC classes;
- Illustrates LULC classification.

For the LULC classification, we used “randomForest” packages (Liaw & Wiener, 2002) in the open-source RStudio software version 1.3.1073 (R Core Team, 2020). Furthermore, the packages Classes and Methods for Spatial Data (Sp) (Bivand et al., 2008), raster (Hijmans, 2020), and Raster Geospatial Data Abstraction Library (Rgdal) (Bivand et al., 2020) were used to process and visualize the spatial data.

Table 2.2. Land use and land cover types identified for the Sofala Province.

ID	Land use and Land cover types	Description
1	Dense Vegetation	Woodland and forest
2	Shrub land	Brush, scrubland, shrubs and bush
3	Grassland and dambos	Grasses, rush and sedge
4	Agricultural land	Pasture, crop cultivation area, hay and other fruit plants
5	Wetland vegetation	Coastal and marine ecosystems including swamps, saltmarshes, and mangroves
6	Barren vegetation	Stunted, sparse and limited vegetation form/structure
7	Barren land	Sand, rocks, dry salt flats (including salt pans), mines, gravel pits and quarries
8	Built-up areas	Settlements, roads, bridges, urban and other infrastructures
9	Waterbodies	River, open water, lakes, streams, estuaries and ponds

2.2.6. Accuracy assessment

The accuracy assessment is a widely applied technique to quantify how close the result of land cover classification is to the reference image. In this study, the accuracy was assessed by comparing the results of the obtained LULC map (classified image) with reference Google Earth images retrieved from the Google Earth Engine (GEE) (Assal et al., 2015) for the year 2019. From the classified LULC, seventy-five random point samples were produced for the study period. They were visually distinguished from GEE by comparison with the classified map. A confusion matrix was constructed to assess accuracy (Padmanaban et al., 2017). The quantitative accuracy assessment of the classified map was obtained by calculating the kappa coefficient (k) using ERDAS Imagine (version 8.7) (Walston et al., 2009). The model´s accuracy is classified according to k values as follows: poor ($k<0.2$), moderate ($0.4<k<0.6$) and near perfect ($k>0.8$) (see Jensen, 2005 and Louarn et al., 2017, for further detail).

2.2.7. Vegetation Indices

The Normalized Difference Vegetation Index (NDVI) is generally used to measure vegetation density and its health status (level of photosynthetic activity) and is less affected by topographic factors and illumination (Zhang et al., 2013). The NDVI is calculated as follows:

$$NDVI = \frac{(\mathrm{NIR}-\mathrm{RED})}{(\mathrm{NIR}+\mathrm{RED})}, \qquad (1)$$

where NIR and RED are the spectral reflectances corresponding to the fourth (0.77-0.90 μm) and third (0.63 – 0.69 μm) Landsat ETM+ bands, respectively (Zhang et al., 2013). For Landsat 8 OLI, NIR is the fifth band (0.85 – 0.88 μm) and RED is the fourth band (0.64-0.67 μm) (Hu & Smith, 2018). Normally, NDVI ranges between -1.0 and 1.0 with vegetation land covers ranging from 0.0 to 1.0. The difference in NDVI (hereafter referred to as ΔNDVI) can show the change in LULC, while a negative ΔNDVI represents the vegetation damage caused by Cyclone Idai. It is calculated by subtracting the NDVI image of one date (after) from that of another (before) using map algebra, which is a cell-by-cell process (Cakir et al., 2006; Zhang et al., 2013). In this study, the Average NDVI in April over the 7 year period (2012-2018) represents the situation before Cyclone Idai (hereafter referred as pre-cyclone) whereas the NDVI of April 2019 represents the post-cyclone situation (hereafter referred as post-cyclone). The ΔNDVI is calculated using the following equation:

$$\Delta NDVI = NDVIpost - NDVIpre, \quad (2)$$

where NDVIpre and NDVIpost are NDVI before and after cyclone, respectively. We also calculated the relative vegetation change activity after Idai (NDVI%) by using the equation below:

$$\text{NDVI\%} = \frac{\Delta NDVI}{NDVIpre} x100. \quad (3)$$

Please note that a higher NDVI% indicates lower damage. We used Sp (Bivand et al., 2008), raster (Hijmans, 2020), rts (Naimi, 2020), and Rgdal (Bivand et al., 2020) packages in R studio for calculation of NDVI and the changes in vegetation productivity.

2.2.8. Distance to the cyclone trajectory

A distance map based on the Cyclone Idai's track was produced with distance bands calculated using ArcGIS (ESRI, 2020); 10 multiple buffers at the specified distance of 25 km from the best track line were obtained (Hu & Smith, 2018).

2.2.9. Correlation Analysis

We used the Pearson Correlation Coefficient to assess the relationship between vegetation damage and the distance to the cyclone's trajectory. This relationship was measured by means of a least squares estimator from the linear regression model with a single influencing/explanatory variable (Hu & Smith, 2018; Zhang et al., 2013).

2.3. Results

2.3.1. Land use and Land cover

Figure 3 displays the nine LULC classes obtained for the Sofala Province. The kappa coefficient (>0.80) (Table 2.3) shows a high accuracy level, indicating a good agreement between the LULC map for April 2019 and ground-truth based on GEE images (Jensen, 2005; Louarn et al., 2017). Table 2.3 shows that the producer's accuracy (i.e. how often are real features on the ground correctly shown on the LULC map) and user's accuracy (i.e. how often the class on the LULC map will actually be present on the ground) presented different values for each class, with a much higher accuracy for barren vegetation (PA: 92.5; UA: 94.1) (Zhu & Woodcock, 2014).

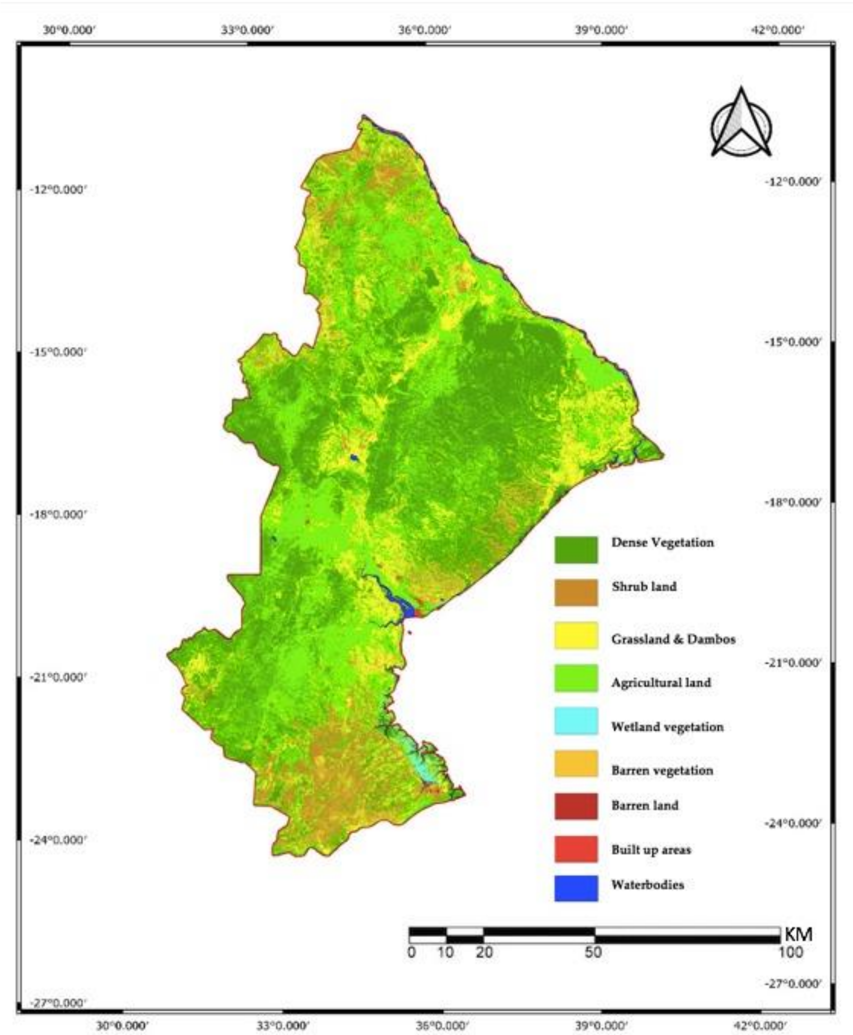


Figure 2.3. Land cover map of the Sofala Province in April 2019.

Table 2.3. The confusion matrix of the LULC map

LULC types	Producer accuracy	User accuracy
Dense vegetation	83.6	91.6
Shrub land	81.2	83.6
Grassland and dambos	89.9	92.7
Agriculture land	87.1	89.3
Wetland vegetation	88.3	92.4
Barren vegetation	92.5	94.1
Barren land	87.7	89.3
Built-up areas	80.6	84.2
Waterbodies	86.4	86.4

2.3.2. NDVI

Figure 2.4 illustrates the spatial distribution of pre-cyclone (left) and post-cyclone (right) NDVI. The comparison by optical remote sensing shows the loss of green leaves on the post-cyclone imagery, as indicated by the increase of no productivity and/or low productivity pixels (Hu & Smith, 2018; Zhang et al., 2013). Significant NDVI alterations were observed across the entire Province, with the largest LULC changes detected in the Northeast (NE), Central (C), and Southern (S) regions.

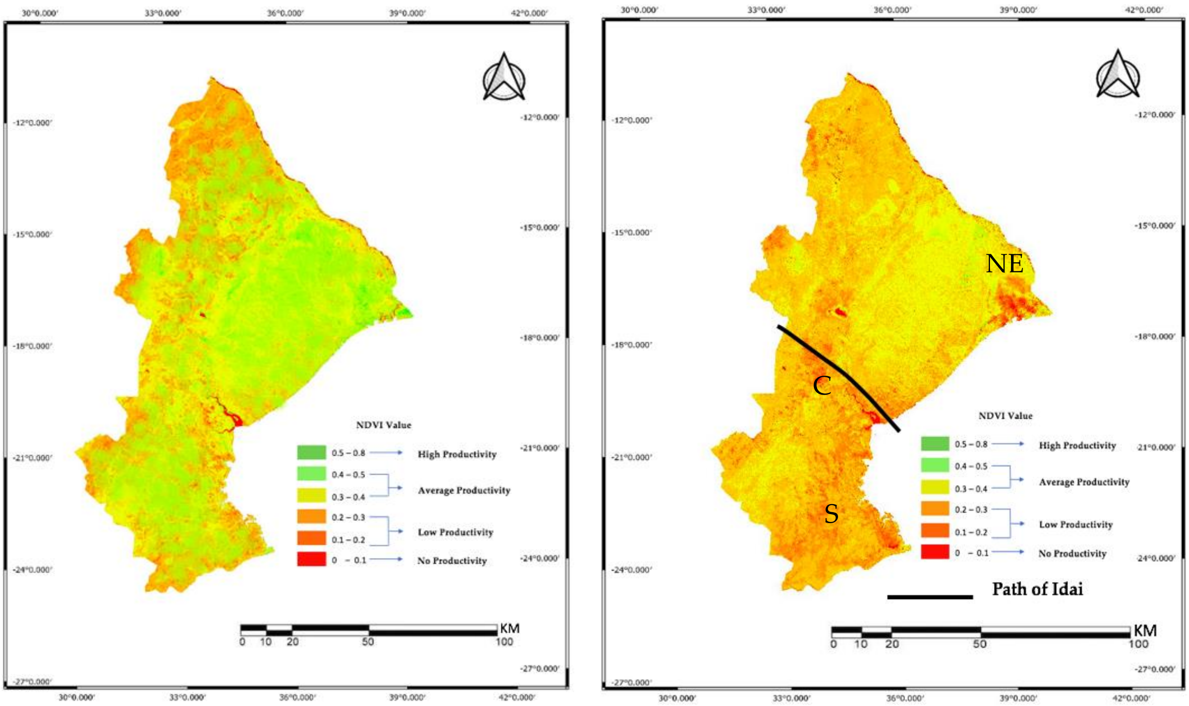


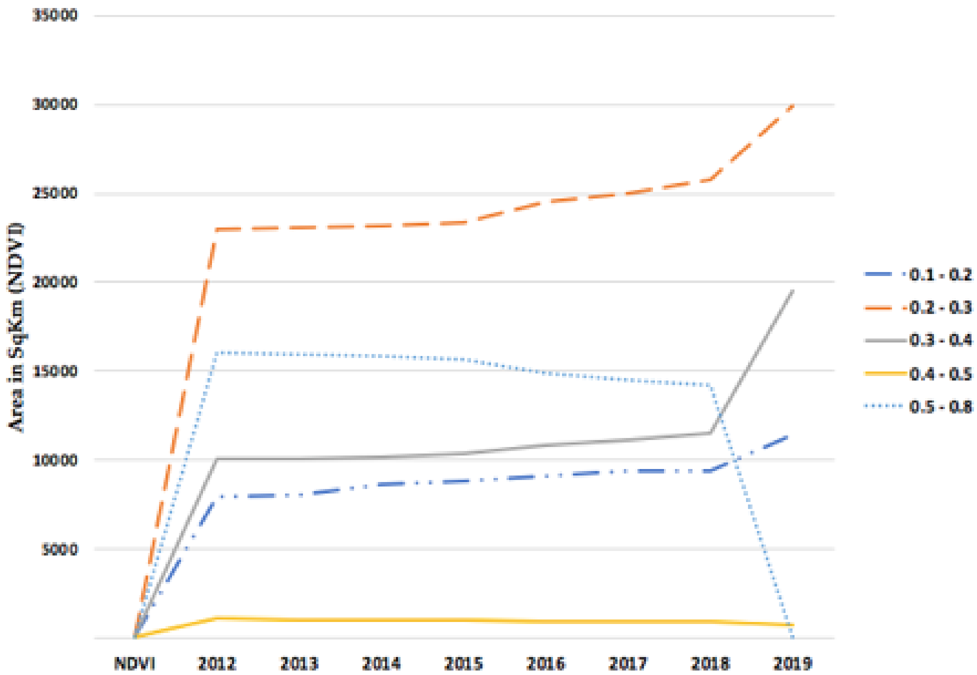
Figure 2.4. Spatial distribution of April NDVI averages in the Sofala Province. Pre-cyclone (left: Average NDVI over 7 years (2012-2018), and post-cyclone (right: 2019). NE - Northeastern, C - Central, and S - Southern regions of the Province.

Table 2.4 shows the land cover classes affected by the Cyclone Idai. All post-cyclone images were acquired within three or four weeks of Idai's passage through the Sofala Province, i.e. before the damaged vegetation had recovered. The ∆NDVI ranged from -0.07 to -0.46; the highest damage was found for dense vegetation (-58.9%), wetland vegetation (-57.4%), and shrub land (-55.5%); the least damage was observed in barren land (-22.5%), barren vegetation (-26.9%), and grassland and dambos (-27.1%).

Table 2.4. Land cover classes affected by the cyclone (Pre-cyclone: average April NDVI over 2012-2018; after-cyclone: April 2019).

Land Cover Types	Counts (Pixels)	Total area (SqKm)	Mean NDVI pre-cyclone	Mean NDVI post-cyclone	∆NDVI	NDVI%
Dense vegetation	45393777	40854.4	0.78	0.32	-0.46	-58.9
Shrub land	11070577	9963.52	0.63	0.28	-0.35	-55.5
Grassland and dambos	3980911	3582.82	0.59	0.43	-0.16	-27.1
Agriculture land	5705377	5134.84	0.66	0.45	-0.21	-31.8
Wetland vegetation	8104666	7294.20	0.54	0.23	-0.31	-57.4
Barren vegetation	23711	21.34	0.52	0.38	-0.14	-26.9
Barren land	399033	359.13	0.31	0.24	-0.07	-22.5
Built-up areas	42977	38.68	0.28	0.19	-0.09	-32.1

Figure 2.5 clearly shows an abrupt decrease of the area of highly productive vegetation classes (0.5-0.8) in April 2019, associated with a substantial growth of the low productivity vegetation area. Overall, almost all the highly productive vegetation experienced a severe decrease (over 99%) while the areas with low productivity vegetation increased by 22-80% as shown in the inset table of Figure 2.5.



Vegetation Productivity Classes	NDVI Values	Mean Pre-Cyclone	Post-Cyclone	Changes in Area Coverage	
				SqKm	%
Low Productivity	0.1 – 0.2	9059.24	11375.1	2315.86	25.56
	0.2 – 0.3	24379.22	29882.1	5502.88	22.57
Moderate Productivity	0.3 – 0.4	10811.26	19510.2	8698.94	80.46
	0.4 – 0.5	936.78	672.08	-264.7	-28.26
High Productivity	0.5 – 0.8	15016.54	72.20	-14944.34	-99.52

Figure 2.5. The time series of average of April NDVI from 2012 to 2019. Low Productivity: 0.1 – 0.2 and 0.2 – 0.3, Moderate Productivity: 0.3 – 0.4 and 0.4 – 0.5, and High Productivity: 0.5 -0.8. The inset table shows vegetation productivity changes (pre-cyclone vs. post-cyclone).

2.3.3. Influence of the distance to the cyclone trajectory

The distance to the Cyclone Idai trajectory map is shown in Figure 6 for Sofala Province. The NDVI% was calculated for each distance class (Table 2.5). NDVI% increased with the distance from the cyclone trajectory (Figure 2.7 and Table 2.5).

Table 2.5. Values of the vegetation indices changes at different distances from the cyclone trajectory.

Distance (km)	Counts (Pixels)	ΔNDVI	NDVI%
0-25	7,516,910	-0.38	-55.07
25-50	8,079,493	-0.32	-53.3
50-75	8,605,728	-0.36	-52.9
75-100	8,768,752	-0.25	-45.4
100-125	10,234,104	-0.19	-30.1
125-150	10,724,540	-0.13	-26.5
150-175	8,988,106	-0.15	-26.3
175-200	5,451,298	-0.13	-25.01
200-225	3,909,496	-0.11	-21.5
225-250	3,003,413	-0.12	-18.4

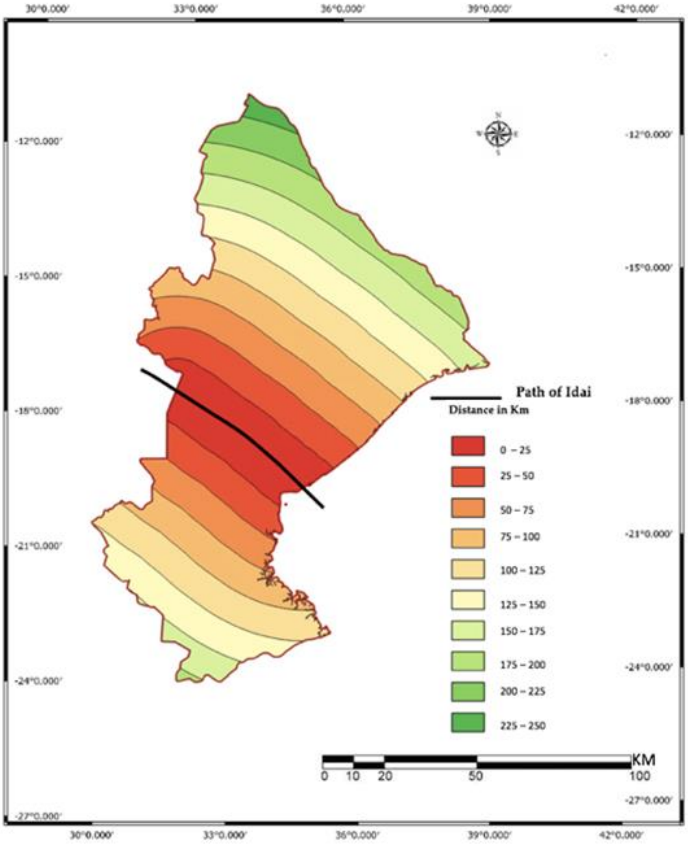
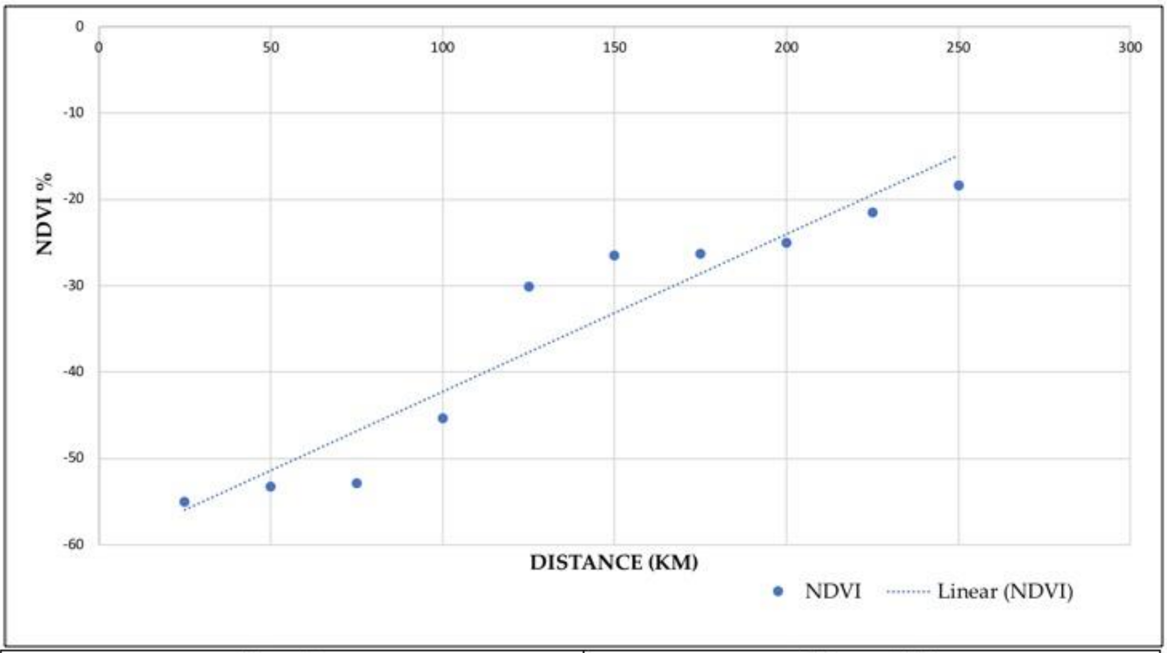


Figure 2.6. The Distance bands map (km) of Sofala Province.

At distances shorter than 75 km from the cyclone trajectory, land degradation was higher than 50% in NDVI. Even at distances over 200 km, NDVI was still above 20% (Figure 2.7 and Table 2.5).



Equation	Y = a + b*X
Plot	NDVI%
Weight	No Weighting
Mean	-35.48
Intercept	-60.54
Slope	0.18
Pearson's r	0.952483
R-Square, Coefficient of determination	0.9072244
Adjusted R Squared	0.8956274

Figure 2.7. Pearson's correlation between mean NDVI% and distance to the Idai's trajectory.

2.4. Discussion

2.4.1. The changes in NDVI

The vegetation productivity changes from 2012 to 2019 were quantified (Figure 2.5). In general, the areas with no productivity and/or low productivity tended to increase with time and an abrupt increase was observed in April 2019 (post-cyclone), whereas the high productivity pixels showed an opposite trend. The loss of vegetation productivity with time is a great concern globally and, most particularly, in low-income countries like Mozambique prone to climatic hazards. Mozambican forests and other natural ecosystems are under greater anthropogenic pressure (e.g. slash and burn agriculture, timber for building local infrastructures, firewood, and charcoal production, and urban expansion) while being adversely affected by natural factors (e.g. climate hazards, rising sea levels and frequent flooding) (Amone-Mabuto et al., 2017; Cabral et al., 2017; Silva et al., 2019). The category four tropical Cyclone Idai was the most devastating and deadliest ever recorded in the Southern Hemisphere. It brought strong winds and torrential rains, causing extensive flooding and leaving many communities in the Sofala Province submerged under 10 m of water (Devi, 2019). It also caused a loss of 99.5% of high productivity vegetation and an increment of up to 80.5% of the low and moderate productivity areas (Figure 2.5).

NDVI clearly changed over the whole Sofala Province after Idai's passage. The Northeastern, Central, and Southern regions (Figure 2.4) appear to be the most devastated areas. At "NE" a high concentration of the pixels of no productivity and/or low productivity region is clearly visible, where our results show the predominance of dense vegetation, agricultural area and water courses with regularly flooded wood and/or herbaceous species (Figures 2.3 and 2.4) (Li et al., 2021). Our findings are in line with Couto et al. (Couto et al., 2019) and Ramsar (Ramsar, 2015) who described this Northeastearn region as part of the Ramsar site of the Zambezi Delta and of the Marromeu Complex, which are designated Wetlands of International Importance (conservation hotspot). This region is characterized by a broad flat alluvial area with a rich mosaic of grassland and dambos, woodland, thicket, large water swamps, and an extensive area covered in mangrove. The devastation in Central Sofala Province is closely related to Idai's trajectory and the influence of the Púnguè and Buzi rivers and Urema Lake whose basins are locally considered as wetlands (Chabwela, 1991; Saket, 1994). In this region we found a mixed spatial distribution of the land cover, which mainly includes dense vegetation, agricultural land, and wetland along the coastline. The Southern region is characterized by abundant shrub land and a mixed vegetation distribution pattern including wetland vegetation, dense vegetation, and agriculture land which were all strongly affected by Cyclone Idai. To the south, the Save River, constituting the southern border of the Sofala Province, forms an estuary that is also considered wetland (Couto et al., 2019). Li et al. (2021) reported particularly significant levels of land degradation in the south-eastern region of the province, which could explain the more reduced agricultural land coverage we observed in this region.

2.4.2. Effects of Idai on different LULC

The changes in the different land-cover classes were calculated and compared with published literature. Dense vegetation (decreased by 58.9%), wetland vegetation (-57.4%) and shrub land (-55.5%) were among the most devastated vegetation classes, while barren land (-22.5%), barren vegetation (-26.9%) and grassland and dambos (-27.1%) were the least affected (Table 2.4). From a biological perspective, our results show that the intensity of damage to different vegetation classes is closely related to their physiognomy. Dense vegetation, wetland vegetation, and shrub land are more vulnerable to physical damage by a tropical cyclone than the barren areas and herbaceous or sparse vegetation because of the higher tree layer and greater tree canopy cover. Numerous studies reported that forest stands with older and bigger trees (height, diameter and canopy) are more prone to wind damage than open, short and sparse forest stands (Gardiner et al., 2008; Lanquaye-Opoku & Mitchell, 2005; Macisaac & Krygier, 2009). An intense tropical cyclone like Idai typically causes great defoliation, branch stripping, bole snapping and uprooting (Everham & Brokaw, 1996; Lin et al., 2020; Zimmerman et al., 1994). Other individual tree characteristics, such as less dense wood, poor health status, and growth in more exposed sites (e.g. coastal Sofala, as shown by Cabral et al., 2017 and Charrua et al., 2020) contribute to increase its vulnerability to cyclone related damage (Doyle et al., 1995; Everham & Brokaw, 1996). Other factors, such as the size of each LULC area need to be deeply investigated. Rossi et al. (2013) reported greater damage in larger forests, in Northern Nicaragua as a result of hurricane Felix (2007). Generally, the spatial distribution of severe post-Cyclone Idai damage in Sofala closely matched the spatial distribution of the most devastated LULC. The damage behavior shown in different LULC in our study is consistent with other findings (Doyle et al., 1995; Everham & Brokaw, 1996; Hu & Smith, 2018; Zhang et al., 2013).

2.4.3. The influence of distance on damage

Our results demonstrate a strong positive correlation between distance and damage. The greatest damage in NDVI was found at distances shorter than 75 km (NDVI% from -52.29 to -55.07, Table 2.5), in accordance with previous studies (Doyle et al., 2003; Hu & Smith, 2018; Zhang et al., 2019). The Pearson Correlation Coefficient between NDVI% and distance was 0.95 and R-square was 0.91, indicating a strong positive linear correlation (Figure 2.7). The spatial distribution of highly damaged regions across the Sofala Province (Figure 2.4) and the distance to Idai's trajectory suggest that the degree of damage does not entirely depend on the latter and that other factors may interfere, like the LULC type (vegetation physiognomy) (Foster & Boose, 1992; Rossi et al., 2013).

Although this was not a ground data based study because of the well-known difficulties of field research (e.g. time-consuming, limited availability of human and logistic resources), our results are realistic and they were satisfactorily verified with the local damage reports (Post Cyclone Idai Cabinet for Reconstruction, 2019). In fact, Landsat image analyses provided reliable results, and have been widely and successfully used to map LULC damages from cyclones (Chamberlain et al., 2020; Hu et al., 2018; Zhang et al., 2019; Zhang et al., 2013). This study can be employed as a future reference in related studies. Our approach clearly identified changes between pre- and post-cyclone LULC in Sofala; moreover, we found a strong correlation between the degree of damage and the distance from Idai's trajectory. Nevertheless, further studies are needed to quantify the local/regional changes that did not fit the linear model.

2.5. Conclusions

This study focuses on an analysis of the damage caused to the LULC by Cyclone Idai, which hit Sofala Province in Mozambique in March 2019. For that purpose, we used Landsat 7 and Landsat 8 images taken during the month of April over a 8-year period (2012-2019). All of the LULC classified areas showed a decrease of NDVI after the cyclone. The greatest damage was found in dense vegetation, wetland vegetation, and shrub land; barren land, barren vegetation, and grassland and dambos showed the lowest relative damage. The most heavily affected regions were the Northeast, Central and Southern Sofala. The distance to Idai's trajectory greatly influenced LULC damage levels: the greater the distance, the lower the damage. Besides the distance to Idai's trajectory, other factors such as LULC type (vegetation physiognomy) may have played an important role in terms of vegetation damage. The information here provided is relevant for LULC managers and all stakeholders to take appropriate measures for better planning and future management of the territory. In addition, our findings may help to speed up ongoing recovery processes that were activated in the wake of tropical Cyclone Idai.

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Chapter III

Assessment of the vulnerability of coastal mangrove ecosystems in Mozambique

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ABSTRACT

Mangrove forests are among the most productive ecosystems on Earth. However, there is still insufficient information available for strategic prediction of conservation and management intervention, particularly in the case of Mozambique. This country has the longest coastline and mangrove forests of Eastern Africa, but is prone to global climate hazards. Using recent field data and environmental parameters subjected to the Variance Inflation Factor (VIF) collinearity test (bioclimatic variables, slop, salinity, land cover, and elevation), we ran MaxEnt to model the distribution of mangrove forests based on occurrence data of the most emblematic and representative mangrove species in Mozambique (*Avicennia marina* and *Rhizophora mucronata*). Moreover, in order to understand which areas should be prioritized for management interventions on mangroves and costal dunes, an Exposure Index (EI) to climate hazards and erosion was compared with the potential distribution of these species. Our results showed that average wind speed of summer season, land surface elevation, Mean Diurnal Range, and saltwater exposure (salinity) were determinant on the distribution models of both species. The central coastal region of Mozambique (so-called swamp coast) presents the largest potentially suitable areas for mangroves species occurrence, having the highest levels of exposure. We also found that *A. marina* presents a higher EI than *R. mucronata*. The scarcity of studies concerning the central region of Mozambique; which was recently devastated by cyclone Idai (category four, 2019), which hit Mozambique and the neighbouring countries, reinforce the urgency for management intervention. The findings of this study should be used by managers and decision makers to promote best practices to safeguard lives and people's livelihoods and assets threatened by coastal climate hazards and anthropogenic impacts.

1. Introduction

Mangroves are highly productive carbon rich ecosystems as they receive nutrients from both sea and land, and local populations rely on them for fuelwood, construction material, medicine, food from mangrove fisheries, timber, and tannins (Aheto et al., 2016; Stephanie et al., 2018). They also play an important role in coastal protection against extreme tides, cyclones and storm water (Blankespoor et al., 2017). However, the global area of mangrove forests has declined by 30–50% over the past half century as a result of coastal development, aquaculture expansion and over-harvesting (Donato et al., 2011).

The Eastern African Region contains a remarkable diversity of coastal habitats, including sandy beaches, coastal dunes, coral reefs, estuaries, bays, seagrass meadows, and a huge mangrove-rich area (Hoguane, 2007). Within this region, Mozambique has one of the largest mangrove areas in Africa (with 3054 km^2), only second to that of Nigeria

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Assessment of the vulnerability of coastal mangrove ecosystems in Mozambique

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Abstract

Mangrove forests are among the most productive ecosystems on Earth. However, there is still insufficient information available for strategic prediction of conservation and management intervention, particularly in the case of Mozambique. This country has the longest coastline and mangrove forests of Eastern Africa, but is prone to global climate hazards. Using recent field data and environmental parameters subjected to the Variance Inflation Factor (VIF) collinearity test (bioclimatic variables, slop, salinity, land cover, and elevation), we ran MaxEnt to model the distribution of mangrove forests based on occurrence data of the most emblematic and representative mangrove species in Mozambique (*Avicennia marina* and *Rhizophora mucronata*). Moreover, in order to understand which areas should be prioritized for management interventions on mangroves and costal dunes, an Exposure Index (EI) to climate hazards and erosion was compared with the potential distribution of these species. Our results showed that average wind speed of summer season, land surface elevation, Mean Diurnal Range, and saltwater exposure (salinity) were determinant on the distribution models of both species. The central coastal region of Mozambique (so-called swamp coast) presents the largest potentially suitable areas for mangroves species occurrence, having the highest levels of exposure. We also found that *A. marina* presents a higher EI than *R. mucronata*. The scarcity of studies concerning the central region of Mozambique; which was recently devastated by cyclone Idai (category four, 2019), which hit Mozambique and the neighboring countries, reinforce the urgency for management intervention. The findings of this study should be used by managers and decision makers to promote best practices to safeguard lives and people’s livelihoods and assets threatened by coastal climate hazards and anthropogenic impacts.

Keywords: Eastern Africa; mangrove trees; MaxEnt; Coastal habitats; Exposure Index

3.1. Introduction

Mangroves are highly productive carbon rich ecosystems as they receive nutrients from both sea and land, and local populations rely on them for fuelwood, construction material, medicine, food from mangrove fisheries, timber, and tannins (Aheto et al., 2016; Romañach et al., 2018). They also play an important role in coastal protection against extreme tides, cyclones and storm water (Blankespoor et al., 2017). However, the global area of mangrove forests has declined by 30–50% over the past half century as a result of coastal development, aquaculture expansion and over-harvesting (Donato et al., 2011).The Eastern African Region contains a remarkable diversity of coastal habitats, including sandy beaches, coastal dunes, coral reefs, estuaries, bays, seagrass meadows, and a huge mangrove-rich area (Hoguane, 2007). Within this region, Mozambique has one of the largest mangrove areas in Africa (with 3054 km^2), only second to that of Nigeria (8573 km^2) (Fatoyinbo & Simard, 2013; Simard et al., 2019b).

Mangrove forests exhibit pronounced zonation, which has been attributed to the species responses to factors such as hydrology (e.g. river discharge/flow accumulation), bioclimatic (e.g. temperature and precipitation), land surface elevation (inundation vulnerability), and soil geochemistry (e.g. salinity) of these ecosystems (Blankespoor et al., 2017). In Mozambique, the most frequently dominant mangrove tree species are *Avicennia marina* (Forssk.) Vierh. and *Rhizophora mucronata* Lam., but there are other common trees such as *Ceriops tagal* (Perr.) C.B.Rob., *Bruguiera gymnorhiza* (L.) Lam., *Lumnitzera racemosa* Willd., *Xylocarpus granatum* J.Koenig, *Heritiera littoralis* Aiton, and *Sonneratia alba* Sm. (Bandeira & Paula, 2014; Sitoe et al., 2014).

Mozambique coastal regions are particularly affected by natural phenomena such as cyclones and floods (Macamo et al., 2016; Mavume et al., 2014). In March 2019, the central region of Mozambique (Sofala province and surrounding areas), characterized by the most representative mangrove forests, was hit by a devastating tropical cyclone, the category four "Idai" (Devi, 2019), and few days later the northern provinces of Nampula and Cabo Delgado were also hit, by cyclone "Kenneth". These cyclones brought torrential rains, floods and high wind speeds, resulting in massive destruction of coastal regions, with very negative impacts on vegetation. The vulnerability of the central region of Mozambique was previously highlighted by Cabral et al. (2017) who estimated that Sofala and Zambézia provinces have a high exposure to coastal climate hazards and erosion through the calculation of an Exposure Index (EI).

Exposure is defined by the United Nations International Strategy for Disaster Reduction (UNISDR, 2009) as "the situation of people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses", whereas vulnerability can be described as the susceptibility of elements exposed to damaging effects when impacted by a hazard event or disaster (Cardona et al., 2012). However, the word vulnerability is used, in a broad sense, including the element's exposure (UNISDR, 2009).

Although with several limitations due to inaccuracy of sources and biases, species distribution models (SDMs) are widely used to estimate the geographical distribution of species, being key modeling tools in ecology (Guisan & Thuiller, 2005) and conservation (Kaky & Gilbert, 2016; Root & Schneider, 2006). SDMs have been used to predict species spatial distributions in Africa under current and future climatic conditions (e.g. Zimbabwe: (Masocha et al., 2018) Burkina Faso: (Schumann et al., 2016) and Cape Floristic Region in South Africa: (Adu-acheampong et al., 2017)). Although, several studies using distribution models were published about Mozambique fauna (e.g. (Monadjem et al., 2010)) very few studies used models to predict flora distributions in this country, which lacks well sampled local inventories for some areas and taxa. Moreover, the availability and quality of existing data, such as those found in public repositories (e.g. https://www.gbif.org/) are still insufficient to adequately feed such models.

The present study has two main goals. First, to update the inventory concerning *A. marina* and *R. mucronata*, the most emblematic and representative mangrove species in Mozambique, based on recent field surveys. Second, through MaxEnt (Phillips et al., 2017) to model the potential distribution of *A. marina* and *R. mucronata* as a *proxy* (indicators) of mangroves occurrence area, and an Exposure Index (EI) to climate hazards and erosion was combined with the output of the species distribution models, to better understand which areas should be prioritized for management interventions. Specifically, our goals were: (i) to identify the most important environmental variables affecting the mangroves distribution patterns; (ii) to predict the spatial distribution pattern and suitable areas for their development; (iii) to quantify *A. marina* and *R. mucronata* exposure to climate hazards and erosion (EI); and (iv) to provide new insights for the future management and conservation of coastal habitats, which are seriously threatened by a number of hazards, of both natural and anthropogenic origin.

3.2. Materials and Methods

3.2.1. Study area

Mozambique is located in the south-eastern coast of Africa between latitudes 10^{o} 20'S to 26^{o} 50'S and has an area of 800,000 km^2, with 11 provinces. It shares land borders with six countries: Tanzania, Malawi, Zambia, Zimbabwe, South Africa, and Swaziland (now called Kingdom of Eswatini). To the east, the country is bordered by the Indian Ocean, and the main coastal cities include Maputo (the capital and the largest city), Maxixe (Inhambane province), Beira (Sofala province), Quelimane (Zambezia province), Angoche and Nacala (both in Nampula province), and Pemba (Cabo Delgado province) (Cabral et al., 2017) (Fig. 3.1). The country is characterized by a tropical climate, with a wet summer season from November to March, and a cooler dry winter season from April to October (Barbosa et al., 2001; Hoguane, 2007). Mozambique comprises 11 main international rivers (the Zambezi and Limpopo being the largest) and about 104 river basins (Cabral et al., 2017) that are vital to valuable ecosystems, including mangroves. The Mozambique coastline extends for about 2770 km and hosts a variety of biodiversity-rich ecosystems. According to Macamo et al. (2016) the coastline is divided into three regions with different geomorphological characteristics: (i) coral coast, located in northern Mozambique (from Angoche northwards) and mostly dominated by shallow reefs forming hermatypic corals but with mangrove forests confined to sheltered bays and river estuaries; (ii) swampy coast or "so-called swampy coast", stretching from Bazaruto archipelago (southern province of Inhambane) to Angoche in the northern province of Nampula, and dominated by mud rich in organic matter. The swamp coast includes the Sofala Bank (the largest fishing ground in Eastern Africa), with the highest number of rivers (ca. 24) discharging into the Indian Ocean, and encompasses almost continuous mangroves from the Zambezi River to near Beira and then southwards to the estuary of the Save River (Inhambane); and (iii) cooler sand dune coast in the south, between Ponta do Ouro to Bazaruto archipelago, characterized by predominant sandy beaches and taller sand dunes, with mangroves in sheltered bays and estuaries such as Maputo Bay.

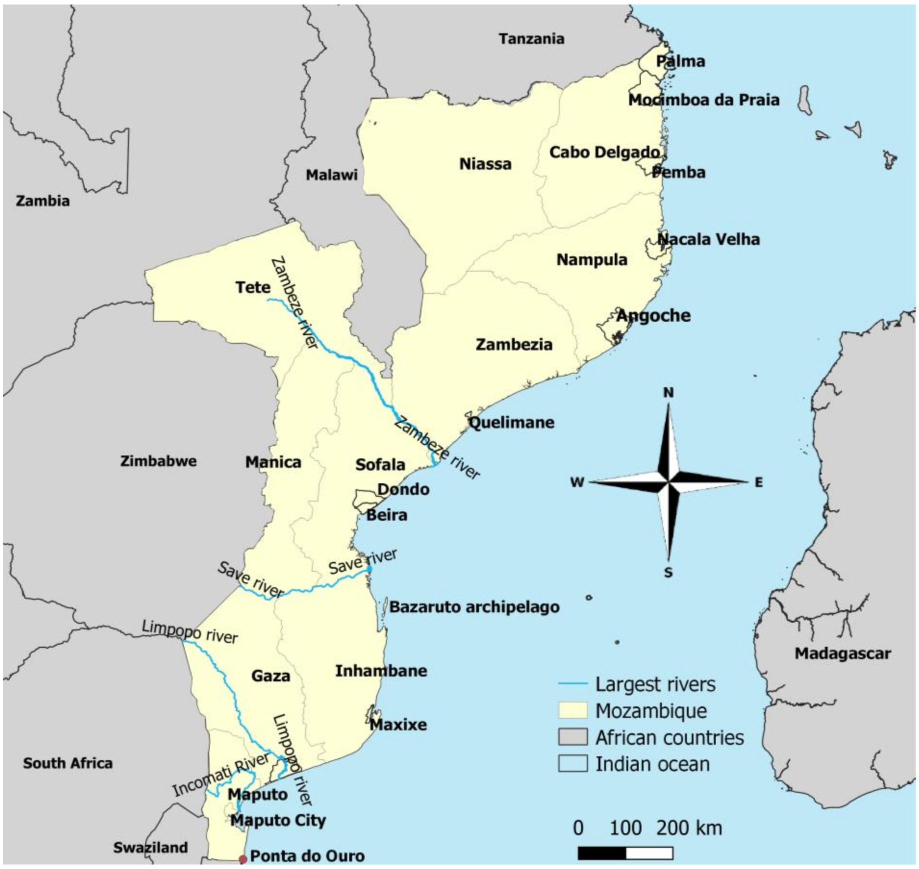

Figure 3.1. Map of Mozambique, showing the main rivers and coastal cities.

3.2.2. Species occurrence data

Our field data was collected in mangrove areas of the Sofala Province, from November 2018 to February 2019. This fieldwork was conducted in Nhangau, Casa Partida and Chiveve (Beira district) and in Mvisa and Fernando Óleo (Dondo district). We collected 58 occurrence records, including 24 of *A. marina* and 34 of *R. mucronata*. The geographical coordinates of the occurrence points were obtained using a high-sensitivity handheld Global Positioning System (GPS) receiver (GPS 72H, Garmin, Taiwan) with positional accuracy around 5 m. Field surveys led by the second author (S. Bandeira) in March 2016 in Nacala Velha (province of Nampula, north Mozambique) (29 occurrence records) and across all eight coastal provinces of the country (51 occurrence records) were also included in our database.

The field data was complemented with available information: (i) in GBIF (2018) (https://www.gbif.org/) (65 occurrence records); (ii) herbarium specimens housed by the Herbarium of the Instituto de Investigação Científica Tropical, University of Lisbon

(LISC) (11 records); and (iii) literature search (e.g. Barbosa et al., 2001; Massuanganhe et al., 2015; Sitoe et al., 2014; Trettin et al., 2016).

The occurrence records without geographical coordinates were georeferenced using Google Earth Pro, version 7.3.2.5491 (Serea, 2018). Duplicated records and records without data on the environmental layers were discarded to avoid inaccurate predictions, and a total of 65 and 54 presence records for *A. marina* and *R. mucronata*, respectively, were obtained and used for the distribution models. We previously ran two individual species distribution models (one for *A. marina* and another for *R. mucronata*) and no significant differences were found. So, the occurrence data of both species were pooled and thus used to produce a model to identify potential mangrove areas in Mozambique.

2.3. Environmental variables

The species distribution model is determined by biophysical and bioclimatic variables (Kaeslin et al., 2012). Hence, selected environmental variables were considered as the main predictors for this study. Initially we had 29 bioclimatic, hydrological, and geomorphological variables (Table 3.1), including 19 bioclimatic variables (summary statistics of precipitation and temperature: bio1 to bio19) (Record et al., 2013) and wind speed data downloaded from WordClim dataset for 1970-2000 with 30 seconds (~1 km^2) resolution (Fick & Hijmans, 2017). The wind speed is a crucial parameter influencing ocean circulation (tidal) as well as an important variable in a cyclone prone areas like Mozambique. As the wind speed varies seasonally (Chevane et al., 2016), we calculated average wind speed in the winter season (WW) and the average wind speed in the summer season (SW). According to Taillie et al. (2019), we used soil sodium concentration as a proxy for saltwater exposure (salinity), which is an important predictor of vegetation shifts. Soil sodium concentration was retrieved from the International Soil Reference and Information Centre (ISRIC) dataset with 250 m resolution (Hengl et al., 2015). A land cover map of year 2016 with a spatial resolution of 20 m was downloaded from the European Space Agency, Climate Change Initiative (ESA CCI) database (European Space Agency, 2019); land surface elevation and a digital elevation model (DEM), both with 90 m resolution, were downloaded from CGIAR-CSI Consortium for Spatial Information (CGIAR-CSI, 2018). Land surface elevation has been used as a proxy for inundation vulnerability (Taillie et al., 2019) and it is an important variable influencing mangroves exposure. River discharge was calculated based on catchment size and represented by flow accumulation derived from DEM (Jenson & Domingue, 1988; Record et al., 2013). The slope was calculated using the terrain analysis tool available in QGIS 3.4.4 with GRASS 7.4.4 (QGIS Team, 2019). The maps of mangrove aboveground biomass, maximum canopy height, and basal-area weighted height with 30 m resolution were downloaded from the Oak Ridge National Data Archive (ORNL DAAC) (Simard et al., 2019a). Using QGIS 3.4.4., all environmental variables were resampled to the same pixel size (30 seconds, ~1 km^2) and projected into the same Geographic Coordinate System (WGS 1984). To avoid model over-fitting (Graham, 2003), the collinearity test was conducted by applying the Variance Inflation Factor (VIF) in R v3.6.0 (´car` package) (Hijmans & Van Etten, 2012) and 18 variables were removed; only 11 variables remained for use as model predictors (Table 3.1). These 11 variables were converted into Raster ASCII grids (.asc) format, to run the model as required by Maxent.

Table 3.1. Environmental variables used in this study, percent contribution and permutation importance. Variables in bold were selected through the multi-collinearity test and then used for the model.

Code	**Environmental variables**	**Unit**	***Mangrove species*** % Contribution	Permutation importance	***Reason to be chosen***	***Reference***
BIO1	Annual Mean Temperature	◦C			Bioclimatic variables (precipitation and temperature) are commonly used to predict species distribution models including mangroves. Temperature has crucial effects on seedling establishment, survival and mangroves species distribution. Temperature varies significantly within mangrove forests as well as geographically across its distributional range. The effects of temperature (heat or cold tolerance in tropical and sub-regions) on early growth and physiology of mangrove species have been reported (Krauss et al., 2008). Moreover, higher temperature increases evaporation, resulting in higher salinity which in turn influences species distribution. The increasing of mean air and ocean temperatures favors the expansion of mangrove forests (E. Schumann et al., 1995).	(Kaky & Gilbert, 2016, 2017; Krauss et al., 2008; Record et al., 2013; E. Schumann et al., 1995)
BIO2	**Mean Diurnal Range (Mean of monthly (max temp - min temp))**	**◦C**	**13.1**	**44.1**		
BIO3	Isothermality (BIO2/BIO7) (* 100)					
BIO4	**Temperature Seasonality (standard deviation *100)**	**(coeff. of variation °C)**	**0.6**	**7.7**		
BIO5	**Max Temperature of Warmest Month**	**◦C**	**1.9**	**0.2**		
BIO6	Min Temperature of Coldest Month	◦C				
BIO7	Temperature Annual Range (BIO5-BIO6)	◦C				
BIO8	Mean Temperature of Wettest Quarter	◦C				
BIO9	Mean Temperature of Driest Quarter	◦C				
BIO10	Mean Temperature of Warmest Quarter	◦C				
BIO11	Mean Temperature of Coldest Quarter	◦C				
BIO12	Annual Precipitation	mm			Precipitation is an important driver of mangrove productivity, nutrient up-take, propagules movements, and species survival. Higher precipitation may imply increase	(Simard et al., 2019b; Snedaker, 1995; Tomlinson, 1998)
BIO13	Precipitation of Wettest Month	mm				
BIO14	**Precipitation of Driest Month**	**mm**	**0.7**	**5.3**		
BIO15	Precipitation	(coeff. of				

	Seasonality (Coefficient of Variation)	variation; %)			run-off, decreased salinity, moderate acid sulphide soils, and increased mangrove forest expansion, richness and productivity. Precipitation, temperature and cyclone frequency greatly explain the global trends in mangroves canopy height (Simard et al., 2019b). As salt secretion by some mangrove species is a means to cope with "salt root", so does rainfall help to wash the salt off the leaves and keep them healthier.	
BIO16	Precipitation of Wettest Quarter	mm				
BIO17	Precipitation of Driest Quarter	mm				
BIO18	**Precipitation of Warmest Quarter**	**mm**	**1.3**	**2.5**		
BIO19	**Precipitation of Coldest Quarter**	**mm**	**0.5**	**0.6**		
hmax	Mangrove canopy maximum height (height of the tallest tree)	m			Since biomass can be used as indicator of productivity of mangrove stands, and of healthy and unhealthy forest, aboveground mangrove biomass, canopy maximum height, and basal-area weighted height can predict habitat suitability for mangrove species.	(Komiyama et al., 2005; Numbere & Camilo, 2018)
agb	Aboveground mangrove biomass	Mg ha^{-1}				
hba	Mangrove basal area-weighted height (individual tree heights weighted in proportion to their basal area)	m				
LULC	**land use/land cover**	**10 types**	**0.6**	**0.9**	Land cover is widely used to predict species distribution models. It is a crucial environmental variable to assess biodiversity patterns	(Amatulli et al., 2018)
SLO	**Slope**	**Degree**	**1.4**	**3.2**	Elevation and slope affect hydrological processes by influencing flow direction and runoff velocity, erosion, inundation, soil moisture, local precipitation and temperature as well. Moreover, the survival of mangrove species depends on their ability to keep pace with the rise of sea level through the rates of slope and substratum elevation changes. Therefore, elevation can be used as a *proxy* of inundation vulnerability.	(Amatulli et al., 2018; Day et al., 2008; Kaky & Gilbert, 2016, 2017; McIvor et al., 2013; Simard et al., 2006)
Elev	**Land surface elevation**	**m**	**25.1**	**13.9**		
SW	**Average wind speed in summer**	**m s^{-1}**	**49.4**	**8.1**	Wind is an important driver of mangrove distribution patterns, especially in cyclone prone regions as Mozambique. Wind can influence water level fluctuations, propagules distribution, and mangrove plant structure. Furthermore, different wind intensities produce different effects on mangrove forest.	(Yang et al., 2014)
WW	Average wind speed in winter	m s^{-2}				
Na	**Saltwater exposure/salinity (Soil sodium concentration)**	**cmolc kg^{-1}**	**5.4**	**13.6**	Soil sodium has been used as proxy for saltwater exposure which is a crucial factor for establishment and early development of different types of mangroves, as well as for species migration. Salinity limits water uptake and photosynthetic rates of mangrove species.	(Krauss et al., 2008; Taillie et al., 2019)
FlowAcc	Flow accumulation	m^2			Flow Accumulation is used to represent river discharge, an important carrier of nutrients from high to lowlands, favoring mangrove establishment and development. River discharge plays an important role on salinity reduction of mangrove areas and it has been reported to influence mangrove distribution at relatively small scales.	(Record et al., 2013)

3.2.4. Maximum Entropy modeling (MaxEnt)

Maxent is a Java-based software package which uses known data (species presence/occurrence data together with predictor variables which can be continuous and/or categorical) to establish a model of habitat suitability with a maximum entropy(Elith et al., 2011; Phillips et al., 2006; Phillips & Dudík, 2008). We used a recent version of the Maximum Entropy model v3.4.1 (Phillips et al., 2017) to predict the distribution of *A. marina* and *R. mucronata*. For relatively few records and presence-only data, this software has been reported to perform better than other algorithms (Elith et al., 2006; Franklin & Miller, 2009). After exhaustive runs with different combinations of settings, the following options were used to obtain the best models: feature classes QPT, 10000 background points, cross-validation with 10 repetitions, 1000 maximum iterations, 10% training presence thresholding, logistic output format and Jackknife to measure variables importance (Kaky & Gilbert, 2017). We previously ran different training data percentages to select the "best model". The percentage of occurrence records used for the training model was 70, and the remaining 30% were used for model validation (Abolmaali et al., 2018).

According to Yi et al. (2016), four results are possible when we use Maxent for prediction results of SDMs: (1) the studied species exist where the model predicted to exist (true positive, TP), (2) the studied species does not exist where the model predicted to exist (false positive, FP), (3) the studied species exist where the model not predicted to exist (false negative, FN), and (4) the target species does not exist where the model not predicted to exist (true negative, TN). Therefore, both FN and FP are the most common errors found. To evaluate the accuracy of each model, we used AUC, which is the area under the Receiver Operating Characteristic (ROC) curve (Phillips & Dudík, 2008); it has been used as an excellent index of model's goodness-of-fit as is not affected by choice of threshold (Vanagas, 2004). AUC generally ranges from 0.5 to 1, and a higher AUC indicates a better model. According to (Araujo et al., 2005), the AUC can be categorized as: "excellent" (>0.9), "good" (0.80 < AUC < 0.90), "fair" (0.70 < AUC < 0.80), "poor" (0.60 < AUC < 0.70), and "fail" (0.50 < AUC < 0.60).

The importance of the environmental predictors was analyzed using three different approaches in MaxEnt: the percent contribution, the permutation importance and the Jacknife test (Phillips et al., 2006). The percent contribution of environmental variables is heuristically defined and depends on the path used by MaxEnt model to obtain the optimal solution. The permutation importance indicates the percentages of contribution of each variable, determined by permuting the values of the variable among the training points and measuring the resulting decrease in AUC. The Jacknife test excludes each variable in turn and creates a model with the remaining variables.

The application of Maxent theory for prediction results of species habitat suitability express that the most reasonable prediction for an area be considered suitable or not suitable for the species are both 0.5 (Yi et al., 2016). Therefore, the probability bands ranged from 0 to 0.9892 and was divided into four classes: “Low potential” (<0.3); “Moderate potential” (0.3-0.6); “Good potential (0.6-0.9); and “High potential” (>0.9) (Abolmaali et al., 2018).

3.2.5. The Exposure Index

The obtained species occurrence points and the map of Mozambique’s exposure to climate coastal hazards and erosion (Cabral et al., 2017) were overlaid. The term “exposure” and “vulnerability” are used in many different ways by various scholarly communities, and even within the same knowledge domain (Fussel, 2007). In this work, exposure is considered as biophysical (or natural) vulnerability (Cutter et al., 2003; Martins et al., 2012) which has been reported as one of the determinants of social (or socioeconomic) vulnerability (KLawn & Nicholls, 1999). The Exposure Index (EI) measures the relative exposure of the Mozambican coastline to climate coastal hazards and erosion and was estimated using the Coastal Vulnerability model in InVEST (for more details about this model, see (Tallis et al., 2015)). InVEST is an open-source tool developed by the Natural Capital Project, available at www.naturalcapitalproject.org, and it includes a set of different ecosystem service models. For Mozambique, the EI ranged from 1.39 to 4.26 and was categorized into five quantiles: “Very low” (< 2.54); “Low” (2.54–2.90); “Moderate” (2.90–3.22); “High” (3.22–3.53); and “Very high” (> 3.53). Further information about the EI calculations can be found in Cabral et al. (2017). We also calculated the average value of the EI for each species because coastal climate hazards and erosion are factors with a great potential to threaten mangrove along the coastline (Langa, 2007; Massuanganhe et al., 2015).

3.3. Results

3.3.1. Models accuracy and variables contribution

All the models showed a good performance in terms of AUC values, ranging from 0.891 to 0.994 (mangroves; mean: 0.975, standard deviation: 0.032). Among the eleven environmental predictors used for the model, average wind speed of summer season (SW), land surface elevation (Elev), Mean Diurnal Range (BIO2), and saltwater exposure (salinity, Na) were found to be the most important variables affecting mangrove species distribution model and the importance of each predictors in the model varies with Maxent evaluation ways (percent contribution, permutation importance, and Jacknife) (Phillips et al., 2006). The percentage of contribution of these top four variables decreased in the order SW > Elev > BIO2 > Na and together they had more than 90 % of contribution while the permutation importance decreased as follow BIO2 > Elev > Na > SW (Table 3.1). These findings are in agreement with the Jackknife test results (SW > Elev > Na > BIO2), reinforcing that these are the environmental variables with higher gain when used in isolation (Fig. 3.2).

Figure 3.2. The Jackknife test to evaluate the relative importance of environmental variables for mangrove species in Mozambique coastal area. Variables: Bio02 - Mean Diurnal Range (Mean of monthly (max temp - min temp)); Bio04 - Temperature Seasonality (standard deviation *100); Bio05 - Max Temperature of Warmest Month; Bio14 - Precipitation of Driest Month; Bio18 - Precipitation of Warmest Quarter; Bio19 - Precipitation of Coldest Quarter; Elev – Land surface elevation; LULC – Land Use/ Land Cover; Saltwater exposure (salinity, Na); SLO – slope; and SW – average wind speed of summer (SW).

3.3.2. Mangrove species distribution in Mozambique

The predicted distribution of mangrove species in Mozambique is shown in Fig. 3.3. The maximum probability of occurrence for both species along the coastline was approximately equal to 1 (Table 3.2). According to the model (Fig. 3.3), the most suitable areas for mangroves species occurrence are in Maputo Bay (south) and swampy coast (central region) including the stretch from the northern bank of the Save River (near the border between Inhambane and Sofala provinces) up to Angoche, in Nampula province (further north). The areas of highly suitable habitat (>0.6) for mangrove species were about 890 km^2 in Sofala, 645 km^2 in Maputo, 412 km^2 in Inhambane, and 413 km^2 in Zambézia. The less suitable areas are in the provinces of Cabo Delgado and Gaza (Table 3.3).

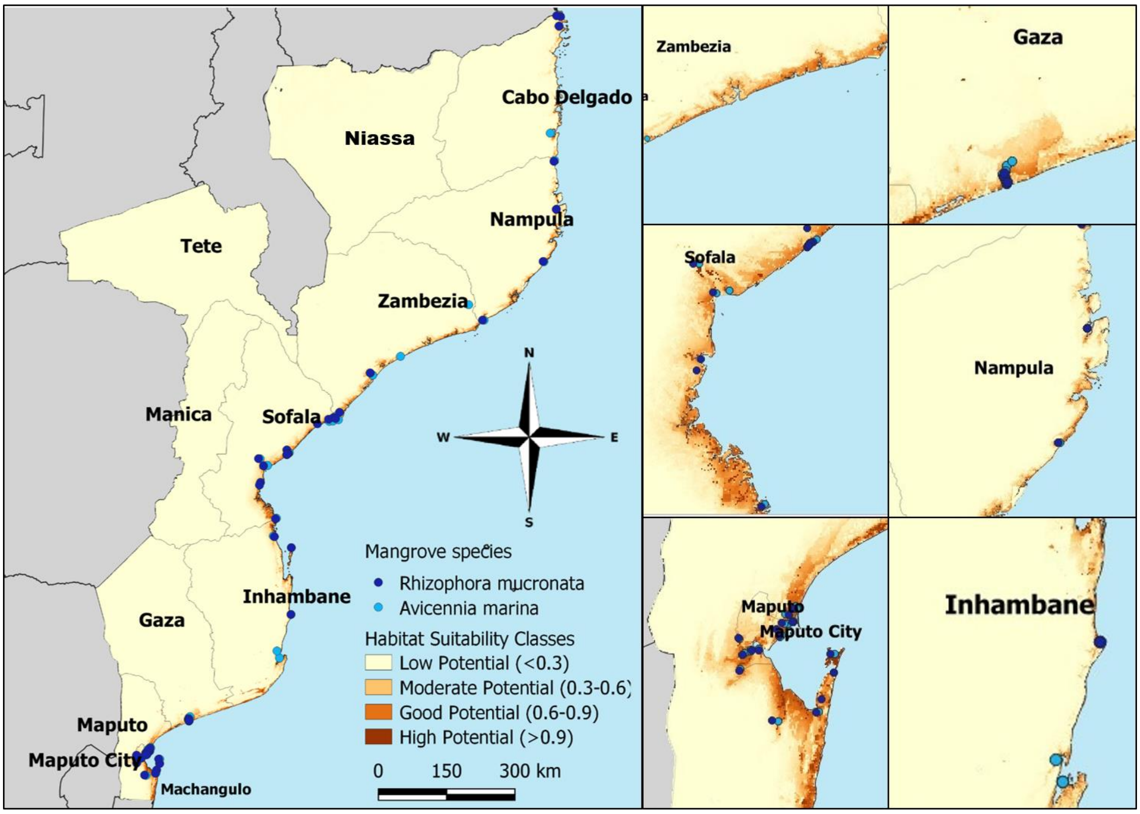

Figure 3.3. Predicted potential distribution of mangrove species (*A. marina* and *R. mucronata*) in the coastal area of Mozambique.

Table 3.2. Descriptive statistics of the probability of occurrence of *A. marina* and *R. mucronata* in Mozambique and of the erosion and climate change exposure index in the coastal area.

Provinces	Mangrove species				Exposure Index			
	Min	Max	Mean	STD	Min	Max	Mean	STD
Maputo City	0.05	1	0.54	0.37	2.08	3.66	2.65	0.45
Maputo Province	0	1	0.08	0.21	2.08	3.98	2.77	0.50
Sofala	0	1	0.04	0.15	1.94	4.26	2.96	0.42
Inhambane	0	0.98	0.03	0.11	1.94	3.43	2.83	0.34
Cabo Delgado	0	0.90	0.01	0.06	1.75	3.87	2.62	0.39
Nampula	0	0.91	0.01	0.08	1.49	3.8	2.46	0.50
Zambezia	0	1	0.02	0.11	2.00	4.26	3.20	0.50
Gaza	0	0.95	0.01	0.07	2.68	3.22	3.02	0.21
Manica	0	0.01	2E-04	6E-04				
Tete	0	0.01	3E-04	1E-03				
Niassa	0	0.01	4E-05	2E-04				

Where: Min – Minimum, Max – Maximum and STD – Standard deviation

Table 3.3. Estimation of suitable areas for *A. marina* and *R. mucronata* according to different ranges of probability of occurrence in the coastal provinces.

Provinces	Regions	Estimated Occur. Area of Mangrove Forest				Literature review of mangrove estimated areas (km^2)
		<0.3	0.3-0.6	0.6-0.9	>0.9	
Cabo Delgado (km^2)	North	75446	479	108	25	369*
Nampula (km^2)	North	75002	933	232	3	Not available
North region (km^2)		**150448**	**1412**	**340**	**28**	
Zambezia (km^2)	Central	98907	1447	408	5	Not available
Sofala (km^2)	Central	62872	1508	819	71	932**
Central region (km^2)		**161779**	**2955**	**1227**	**76**	
Inhambane (km^2)	South	65373	903	405	7	Not available
Gaza (km^2)	South	72629	570	162	18	Not available
Maputo (km^2)	South	20265	1009	628	17	Not available
South region (km^2)		**158267**	**2482**	**1195**	**42**	
Total (km^2)		**470494**	**6849**	**2762**	**146**	**3054*** **

*(Ferreira et al., 2009)

** (Marzoli, 2007)

*** (Fatoyinbo & Simard, 2013)

3.3.3. Exposure Index for *A. marina* and *R. mucronata*

The erosion and flooding EI of the coastal area of Mozambique ranges from 1.39 to 4.26 (Fig. 3.4). The exposure indices in Sofala and Zambézia were classified as "High" and "Very high", and had ranges of 1.94 – 4.26 and 2– 4.26, respectively (Fig. 3.4; Table 3.2). The high risk found in the central region is related to large estuaries and deltas forming low-lying lands (land surface elevation below 5 m) vulnerable to floods, some originated by tropical cyclones, and to the transnational and torrential nature of the big rivers associated with them. Moreover, it has been reported that Sofala Bank (so-called swamp coast) exhibits the largest tides in the Western Indian Ocean (WIO) (Da Silva et al., 2009; Hoguane, 2007). However, our models showed that the provinces of Sofala and Zambezia provide an important habitat for the studied mangrove species. The average EI for *A. marina* distribution was 2.94 (classified as Moderate) whereas EI was 2.75 for *R. mucronata* (classified as Low) (Table 3.4). It is worth mentioning that results shown in Fig. 3.4 revealed the need for effective management practices in order to protect the coastal areas with high EI, as well as throughout the whole country coastline.

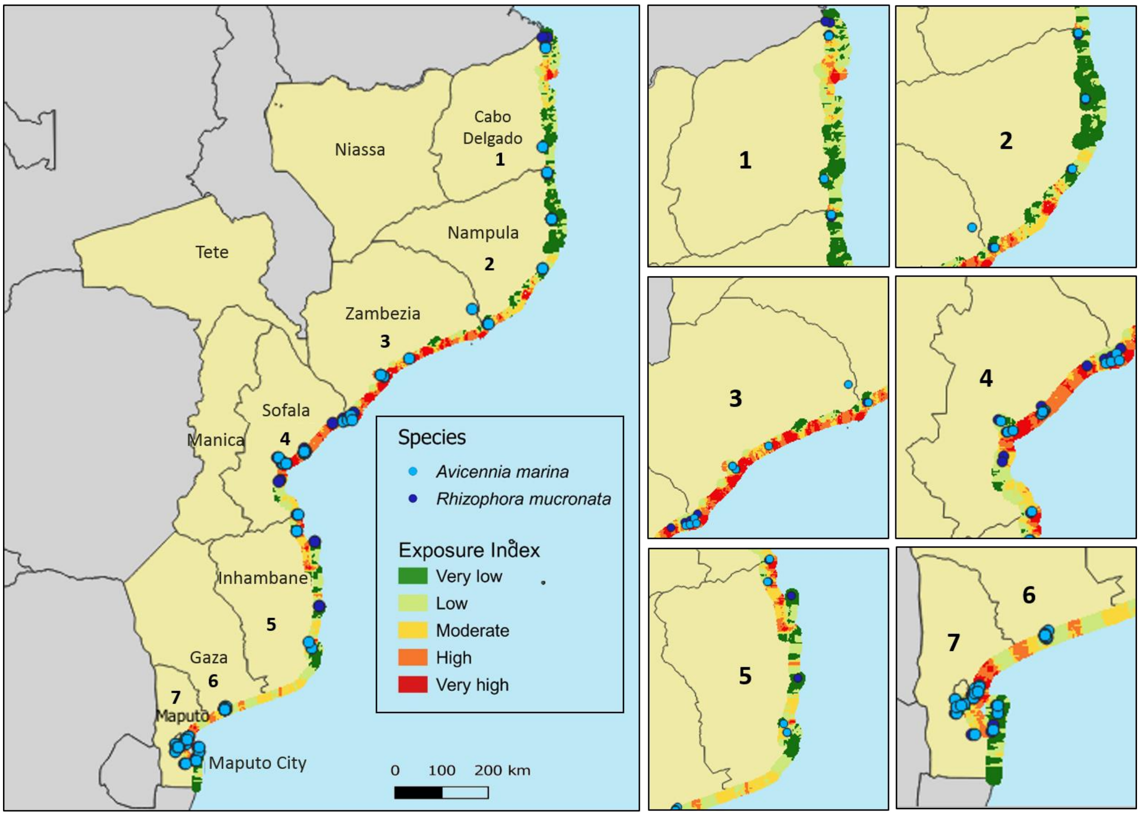

Figure 3.4. The sample points of *A. marina* and *R. mucronata* and the exposure index (EI) to coastal climate hazards and erosion of Mozambique (left). Details for each of the seven coastal Mozambique provinces are provided (right). Adapted from Cabral et al. (2017).

Table 3.4. Coastal erosion and inundation exposure index of *A. marina* and *R. mucronata*.

Species	Exposure Index			
	Min	Max	Mean	STD
A. marina	2	3.66	2.94	0.67
R. mucronata	2	3.46	2.75	0.53

3.4. Discussion

3.4.1. Suitable areas for the occurrence of mangrove species

Based on recent field surveys across all seven coastal provinces of the country, this work presents a comprehensive study of the most emblematic mangrove species in Mozambique, providing an important step towards the protection and management of this coastal ecosystem at both national and global level. The new potential areas of occurrence for *A. marina* and *R. mucronata* revealed by our models pointed out that Southeastern region (e.g. Machangulo Peninsula, Maputo province) as having a high potential for mangrove forests occurrence. Although, this region is currently dominated by sand dunes (Bandeira & Paula, 2014) and coastal lakes and lagoons (Da Costa & Ribeiro, 2017), other studies performed in the Amazon Coast of Brazil (see Costa et al., 2016) revealed a high rate of survival and growth of mangrove seedling survival on sandy soils. Excluding estuaries, coastal Mozambique has rather sandy sediments; the sand dunes dominating the long stretch of southern Mozambique, and also South Africa (Kwazulu/Natal) (Tinley, 1985) are potentially favourable for mangrove recolonization provided that a conducive condition exists, such as regular tidal flooding (Spier et al., 2016). For wise management, emerging mangrove areas such as those reported in our study for Maputo Bay are paramount for the protection of local communities and their assets, specially in these tropical cyclone-prone areas, given their high vulnerability to climate hazards (Devi, 2019; Macamo et al., 2016).

Although the Maputo Bay area was revealed as a new potential area of occurrence for *A. marina* and *R. mucronata*, the central coastal region of Mozambique - Sofala Province (so-called swamp coast) presents the largest potentially suitable areas for mangroves species occurrence (890 km^2) (see Fig. 3.3). It must be noted that all Mozambique Rivers drain into the Indian Ocean, and around 80% of this flow feeds the Sofala Bank, which is the largest fishing bank in Eastern Africa (Hoguane, 2007). *Avicennia marina* is the dominant plant species of the estuary of the Chiveve Creek (locally called “Chiveve River”), which is a mangrove natural river-creek system with about 3 km long, runs across Beira City (the capital of Sofala Province and the second largest city in the country after Maputo City), and has rather high regeneration rate (António, 2018). The high dominance of this species was also reported for other Mozambique coastal areas, such as Quelimane, in northern Zambezi delta (Bandeira & Paula, 2014; Macamo et al., 2015).

The mangrove habitat of the Zambezi River Delta (a part of Zambezi Province) has been mentioned as the second largest continuous one in Africa (305 km^2), extending for 150 km along the coastline and around 50 km inland (Barbosa et al., 2001). This agrees with our results, as the entire Zambezia province showed a predicted suitable mangrove area (suitability >0.6) of 413 km^2 (see Table 3.3). Inhambane also presented a considerable suitable mangrove area (412 km^2), probably related with the Save River estuary (Macamo et al., 2016). These results are in line with a previous study indicating areas of 932 km^2 for Sofala (Marzoli, 2007). Moreover, our model estimated a suitable area of 645 km^2 for the entire Maputo province (suitability >0.6), which matches the findings of previous works reporting a 175.96 km^2 mangrove area in Maputo Bay with an expected increasing trend (Bandeira & Paula, 2014; Bosire et al., 2016). On the other hand, an area of 369 km^2 of mangrove in the northern province of Cabo Delgado has been reported (Ferreira et al., 2009), while in our study we found a suitable area around 308 km^2 with a probability higher than 0.6. Fatoyinbo and Simard (2013) estimated a total area of 3054 km^2 for all mangrove species in Mozambique and our model estimated (prob.>0.6) a total of 2904 km^2 (north: 368 km^2, central region: 1303 km^2 and south: 1237 km^2). Therefore, the estimated mangroves area (see Table 3.3) strongly depended on the given range of suitability.

This study could not model individual species distribution occurrence in the context of climate change and its consequences which greatly affect mangrove species occurrence and dynamics (e.g. seawater level rise, extreme climate events, and species shifting as well). However, *A. marina* has been found to occupy both inner (at the seaward edge) and outer areas of mangroves (dwarf mangroves) (Bandeira & Paula, 2014; Neukermans & Koedam, 2014) and a similar pattern was observed in neighbouring South Africa (Rajkaram & Adams, 2015). In the regions of southern Mozambique, we expect *A. marina* to occupy more areas wherever mangrove colonization opportunities exist. Over 90% of mangrove trees by the Chiveve Creek (central Mozambique), and the Incomati estuary (southern Mozambique), correspond to *A. marina* (António, 2018; Macamo et al., 2015). Therefore, more attention should be given to *R. mucronata,* as few individuals occur or are expected to expand easily. *R. mucronata* is frequently found inland and on creek banks, which is probably related to its lower tolerance to salinity variation (Bandeira & Paula, 2014; Hoppe-Speer et al., 2011). We hypothesize that, in general, creeks near the coastline have a stable salinity

(Lutjeharms, 2006; Neukermans & Koedam, 2014) and are suitable for the continuous presence and colonization by *R. mucronata*.

3.4.2. Important environmental variables influencing mangroves distribution

The selection of adequate environmental variables is crucial for the construction of robust models (Elith & Leathwick, 2009). Our results revealed that the most important environmental variables responsible for mangroves distribution patterns were land surface elevation (elevation), average wind speed in the summer season, thermal amplitude (i.e. mean diurnal range) and salinity (saltwater exposure). The real influence of these factors on African mangroves' distribution patterns and their optimum range for each species is still largely unknown. Wind direction and velocity particularly influence the spatial diversity and dispersion of mangrove species, and are even responsible for mechanical damage (high speed winds) (Krauss & Osland, 2019). If we take this into account, *A. marina* seems less resistant to wind damage than *R. mucronata*, supporting previous findings of (Wadsworth & Englerth, 1956). Moreover, sand-carrying winds can change the original soil structure by gradually burying and reshaping the mangrove species composition (Blasco, 1984). The southern and central Mozambique areas are predominantly subject to southeast trade winds, whereas a monsoon regime with northeast winds during the summer and southwest winds during the winter affects the northern areas (Hoguane, 2007). During summer the average wind speed is weak but shelf waters are sensitive to tropical cyclones which generally move poleward through the Mozambique Channel (Van Heerden & Taljaard, 1998). Data from the National Institute of Meteorology of Mozambique show wind speeds ranging from 0.28 to 8.31 m/s during the wet season, and from 7 to 9 m/s, with gusts up to 27 m/s, in the dry season (INAM, 2019). Therefore, average summer wind speed (2.48 m/s) can be associated with rain and mild water levels rises, and with salinity drops due to fluvial discharges and runoff from upland areas (Lutjeharms, 2006). These factors, adding to the increase in rainfall and river flow from January to March in the South, and from January to May in the North of Mozambique (Asante et al., 2009), greatly contribute to geomorphic processes (Thom et al., 1975) and to mangrove distribution along the coastal line as predicted by MaxEnt.

Water and air temperatures and their amplitudes (daily, monthly and annually) are essential bioclimatic factors contributing to mangrove geographical distribution. According to Blasco (1984), mangrove species are extremely sensitive to cold, with the exception of some *Avicennia* species. A study of mangroves communities in Australasia reported mangrove disappearance when the average temperature in the coldest months reached ≤ 16 °C (Saenger et al., 1977) while other studies found a decline of mangrove species with a temperature below 19 °C (Alongi, 2002, 2008). The southernmost limit of mangroves in Eastern Africa is the Gqunube estuary (near the city of East-London, South Africa), having only *A. marina*; these are areas where mangrove management must be continuously reinforced. The southernmost limit of mangroves in Africa are limited by currents - warm Agulhas Current in east Africa (Rajkaram & Adams, 2015) and cold Benguela current in its southern limit in Angola here with *Avicennia germinans* (Beentje & Bandeira, 2007). Southern Mozambique tip and Maputo Bay are the southernmost limits of the mangrove species *Xylocarpus granatus, Lumnitzera racemosa* and *Rhizophora mucronate* (Beentje & Bandeira, 2007; Paula et al., 2014). Known primary causes of destruction of mangroves in Maputo Bay include deforestation and urban expansion (Macamo et al., 2015; Paula et al., 2014); this should be reduced. Whenever mangrove extraction is intense and difficult to halt, a system of rotating blocks might favour easy regrowth in previously deforested areas (Murdiyarso et al., 2015). The strategic Mangrove Management Plan of Action as, for example, those developed for Kenya (GoK, 2017) should be concluded with wider stakeholder engagement, and later implemented locally. The photosynthesis of some mangrove species sharply drops when air temperature reaches 35 °C (Moore et al., 1972) and the mangrove community is also extremely sensitive to thermal amplitude. It has been reported that the typical response of mangroves to drops in temperature and thermal amplitude is the reduction of species richness, as well as of species’ height and diameter (Lugo & Zucca, 1977). As we move northwards along the coastal area, the temperature tends to increase (INAM, 2019). In Maputo Bay, mangroves develop with a water surface temperature averaging 23 °C and a between-seasons thermal amplitude of 8 °C, suggesting that a small increase in temperature could promote the development of mangrove forests (Boer, 2002). While Maputo is sub-tropical, located some 450 km south of the Tropic of Capricorn, the swamp coast in central Mozambique is within the tropics, with temperatures between 27 and 30 ºC (maximum) and 18 and 21 ºC (minimum), where our model indicates the highest suitability for mangrove forests. In the coral coast (north), where the model predicts less suitable areas, the temperatures are much higher (average of monthly max > 30 ºC) (INAM, 2019).

In Mozambique, elevation decreases from inland to the sea. A study carried out in Mobbs Bay-Australia found *A. marina* and *R. mucronata* occurring at elevations ranging from 0.01 to 0.79 m (Youssef & Saenger, 1999). The coastal morphology of Mozambique is characterized by low areas (44% of the coastal region) (Kokusai, 2000) with favorable characteristics for mangrove stabilization and development. However, the Sofala Bank (swamp coast) is a flat coastal plain with many large rivers and an elevation rarely exceeding 5 m. This elevation range is also found in some specific sites of Maputo Bay, and in a few regions of the low-lying offshore islands in the northern province of Cabo Delgado (INGC, 2009). Accordingly, our model indicates a significant probability of mangrove occurrence in those regions.

The salinity increases from inland to the sea (Hoguane & Armando, 2015) and the salinity of shelf waters in Mozambique presents seasonal variations with the river outflow, with the lowest salinity value in summer (February) (Lutjeharms, 2006). Sofala Bank (swamp coast), where our model found the most suitable area for mangroves, is one of the most important ecological areas of Mozambique coastline (Hoguane, 2007) and presents the lowest salinity average ranging from 32 to 35 psu, and further drops (down to around 20 psu) during summer (rainy season) (Gammelsrød, 1992) due to freshwater discharge from numerous rivers draining into the Indian Ocean. This also contributes to the high productivity of the swamp coast, mainly through the input of terrigenous nutrients (Nehama et al., 2015). High definition mapping of mangroves of expanding urban mangroves (Ghosh et al., 2020) would be an added management tool to better forecast and plan intervention.

3.4.3. Coastal vulnerability of Mangroves

The Exposure Index (EI) was calculated for individual mangrove species to provide new insights on their exposure and help decision-makers to define priorities for management and conservation of mangrove ecosystems in Mozambique. The “Moderate” and “Low” EI found for *A. marina* (2.94) and *R. mucronata* (2.75) may be explained by the fact that they easily occupy tidal areas that may be also prone to land-based erosion, namely the seaward edge in the case of *A. marina* and the creeks in the case of *R. mucronata*.

The overall EI calculated for Mozambique also shows the severity of the impact of climate events and erosion (see Cabral et al., 2017). The sites with a high EI (Fig. 3.4), a high potential distribution of mangrove (Fig. 3.3) and, simultaneously, are important population centers where urbanization and mangrove cutting for building material and firewood tend to be more pronounced (Macamo et al., 2016) were considered priority for mangrove management actions. Examples of such sites are Palma and Mocímboa da Praia (both in Cabo Delgado province), Angoche (Nampula), Quelimane (Zambezia), Beira (Sofala), Maxixe (Inhambane) and Maputo, where issues of erosion, sedimentation, deforestation, as well as mangrove encroachment due to infrastructure development, have already been identified. Nonetheless, inundation by sea level rising has also been found to cause retreat (negative rates of change) and advance (positive rates of change) of sea edge mangroves in Cameroon Estuary between 1975 and 2007 (Ellison & Zouh, 2012). Moreover, floods and cyclones may have contrasting results. It was already mentioned that central Mozambique (including Sofala and Zambézia) presents lower elevation, higher tides and is more exposed to tropical cyclones, with 6 cyclones in 16 years (INGC, 2009). Globally, tropical cyclones were responsible for about 45% of global mangrove mortality over the past six decades (Sippo et al., 2018). The intensity of the damage to people and environment, caused by a tropical cyclone, depends on its category. For instance, the central region of Mozambique was recently hit by the strongest tropical cyclone ever recorded in the Southern Hemisphere (“Idai”, category four, 14th March 2019) which brought high-speed winds, torrential rains and floods (Devi, 2019). It caused human deaths and severe mangrove damage (due to wind speed and to mangrove drowning by still water for several days) yet to be quantified. Recommendation is to use mangrove forests as smart solutions, a forefront protection line for community houses and other infrastructures. Frontal mangroves should be spared at any cost as they guarantee an important degree of protection of people and their assets in a country that is highly vulnerable to climate hazards.

3.4.4. New insights for management of coastal regions of Mozambique

The potential areas of mangroves occurrence in Mozambique revealed in our study (e.g. Maputo Bay, Sofala and Zambézia provinces) highlight the need to reinforce appropriate best practices issued from international and national bodies (e.g. Owuor et al., 2019). For instance emanated by Sustainable Development Goals (SDGs), including Nature Based Solutions (NbS) (Islam & Shamsuddoha, 2018); regional seas programmes such as UNEP-Nairobi Convention from Western Indian Ocean (WIO) (Barwell et al., 2018; Bosire et al., 2015; Owuor et al., 2019); and national Mozambican initiatives and related instruments to safeguard mangroves goods and services (Bandeira & Paula, 2014). Recently, Mozambique hosted the first conference focused on the country and the western region of the Indian Ocean (see http://growingblueconference.gov.mz/index.php/en/). During this conference it was recognized the need to increase the scientific knowledge on critical habitats like mangroves, and to target investment resources, both in training and building technical and institutional capacity, which will enable the development of a sustainable Blue Economy.

The NbS are highlighted in international agreements such as the Sendai Framework for Disaster Risk Reduction 2015–2030, as promising strategies to reduce disaster risk, adapt to climatic change, and strengthen community resilience (Arce-Mojica et al., 2019). NbS is rather smart, rather cheap green solution and can be recommended for similar circumstance for such as control of storm water and extreme tides in regions that presents both the largest potentially suitable areas for mangroves species occurrence, and have the highest levels of EI, as it was revealed for the central coastal region of Mozambique. However, the high population density found along this coastal area, is another factor in mangrove forest degradation, as the population (urban poor and rural communities) still depend on the mangrove for their economic activities. For instance, several mangrove potential areas do not have sufficient electricity, so the local people still depend on fuelwood, and particularly, *Rhizophora* and *Avicennia* are being threatened due to overexploitation (Macamo et al., 2016). Unless electric power can be utilized in these areas, the protection of mangrove forests will be seriously destroyed in the near future. Thus, relevant gaps should be identified in order to promote the sustainable use of these species and contribute to mangrove conservation. A successfully use and management of mangrove in Mozambique, specifically in high EI areas, require carefully thought and rules application, thereby contributing to achieve the benefits such as community development, stakeholders commitment, biodiversity conservation, and social equity (Feka, 2015; Van Lavieren et al., 2012).

3.5. Final Remarks

This study used the Maximum Entropy method (MaxEnt) to predict the potential distribution of *A. marina* and *R. mucronata*, as a proxy to identify potential mangrove areas in Mozambique. Our results showed the probability of their occurrence or their suitable areas, determined species EI to coastal climate hazards and erosion, and quantified the importance of the environmental variables contributing to species occurrence. They also revealed that average wind speed of the summer season, Mean Diurnal Range, elevation, and salinity (saltwater exposure) played a determinant role on the *A. marina* and *R. mucronata* distribution model. The most suitable areas for these two emblematic mangrove species are Maputo Bay, already with most of its perimeter covered with mangrove forests, and the stretch from the northern bank of the Save River up to Angoche, in Nampula province.

In Mozambique, mangroves can be wisely managed and protected based on directories of global platforms such as SDG 14, regional seas programs under UNEP-Nairobi Convention from Western Indian Ocean (Barwell et al., 2018; Bosire et al., 2015), main national governance instruments (e.g. Regulation on the Prevention of Pollution and the Protection of the Marine and Coastal Environment – Decree 45/2006 of 30th November) and associated international conventions (e.g. Ramsar - Resolution nr. 45/03, 5th November 2003). Sustainable management of mangrove forests is still a great concern across the country, particularly in areas with high EI. Highlights for mangrove management are the preservation of mangrove ecology integrity, sustainable harvesting and promotion of mangrove restoration; integration of local stakeholders and communities in overall design of management initiatives; investment of municipalities and corporates on climate adaptation of habitats and people; and community empowerment, among other initiatives.

The comparison of the three defined coastal regions indicated the so-called swamp coast (in central Mozambique) as the most important one for extensive mangrove occurrence. Moreover, the average inundation and erosion exposure indices of *A. marina* and *R. mucronata* were “Moderate” and “Low”, respectively. Nowadays, the effects of climate change are a great global concern to African countries including Mozambique which has a vulnerable coastline, demanding urgent and more effective management and conservation measures for mangroves.

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Chapter IV

Food Security and Nutrition in Mozambique: Comparative Study with Bean Species Commercialised in Informal Markets

sustainability

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Article

Food Security and Nutrition in Mozambique: Comparative Study with Bean Species Commercialised in Informal Markets

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Abstract: In Mozambique (South-eastern Africa), *Phaseolus vulgaris* and *Vigna* spp. are important staple foods and a major source of dietary protein for local populations, particularly for people living in rural areas who lack the financial capacity to include meat in their daily dietary options. This study focuses on the potential for improving diets with locally produced nutritious legumes whilst increasing food security and income generation among smallholder farmers. Using bean species and varieties commercialised as dry legumes in the country, it sets out to characterize and compare the chemical properties of *Phaseolus vulgaris* and *Vigna* spp. among the most commercialised dry legume groups in Mozambique. The principal component analysis showed a clear separation between *Phaseolus* and *Vigna* species in terms of proximate composition, whereas protein content was quite uniform in both groups. It concludes that the introduction of improved cultivars of *Phaseolus vulgaris* and *Vigna* species maize–legume intercropping benefits yield, diets and increases household income with limited and low-cost inputs while enhancing the resilience of smallholder farmers in vulnerable production systems affected by recurrent drought and the supply of legumes to urban informal markets.

Keywords: East Africa; pulses; *Vigna*; *Phaseolus*; Leguminosae; malnutrition; chemical composition

1. Introduction

Legumes (e.g., *Phaseolus vulgaris*, *Vigna* spp., *Vicia faba*, *Lens culinaris*, *Cajanus cajan*, and *Glycine max*) have attracted great attention as a primary source of nutrients for millions of people throughout the world [1]. As the issue of nutrients (e.g., proteins) became part of the global nutrition debate since the 1940s, research into deficiencies focused on vulnerable populations in low-income countries have gained greater momentum over the last two decades. Reducing (multiple) nutrient deficiencies in children, the incidence of related conditions, and infant mortality rates, currently forms an integral part of the development agenda under the aegis of international agencies, partnerships and NGOs [2]. Promoting

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Food Security and Nutrition in Mozambique: Comparative Study with Bean Species Commercialised in Informal Markets

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Abstract

In Mozambique (South-eastern Africa), *Phaseolus vulgaris* and *Vigna* spp. are important staple foods and a major source of dietary protein for local populations, particularly for people living in rural areas who lack the financial capacity to include meat in their daily dietary options. This study focuses on the potential for improving diets with locally produced nutritious legumes whilst increasing food security and income generation among smallholder farmers. Using bean species and varieties commercialised as dry legumes in the country, it sets out to characterize and compare the chemical properties of *Phaseolus vulgaris* and *Vigna* spp. among the most commercialised dry legume groups in Mozambique. The principal component analysis showed a clear separation between *Phaseolus* and *Vigna* species in terms of proximate composition, whereas protein content was quite uniform in both groups. It concludes that the introduction of improved cultivars of *Phaseolus vulgaris* and *Vigna* species maize–legume intercropping benefits yield, diets and increases household income with limited and low-cost inputs while enhancing the resilience of smallholder farmers in vulnerable production systems affected by recurrent drought and the supply of legumes to urban informal markets.

Keywords: East Africa; pulses; *Vigna*; *Phaseolus*; Leguminosae; malnutrition; chemical composition

4.1. Introduction

Legumes (e.g., *Phaseolus vulgaris*, *Vigna* spp., *Vicia faba*, *Lens culinaris*, *Cajanus cajan*, and *Glycine max*) have attracted great attention as a primary source of nutrients for millions of people throughout the world (Ali et al., 2013). As the issue of nutrients (e.g., proteins) became part of the global nutrition debate since the 1940s, research into deficiencies focused on vulnerable populations in low-income countries have gained greater momentum over the last two decades. Reducing (multiple) nutrient deficiencies in children, the incidence of related conditions, and infant mortality rates, currently forms an integral part of the development agenda under the aegis of international agencies, partnerships and NGOs (Semba, 2012). Promoting a (greater) diversity of diets and reinforcing multiple nutrient intakes by diversifying domestic food production and the supply of affordable marketable crops such as legumes constitute prime drivers of Sustainable Development Goals (SDGs) 1, 2 and 3 (Mensi & Udenigwe, 2021).

Of all beans of the Leguminosae family, the *Vigna* and *Phaseolus* are the best-known genera, and several species are among the most used beans in Africa, playing an important role in smallholder farmers' income generation and food security in many countries (e.g., Latin America and the Caribbean) (Diana et al., 2018; Takeoka et al., 1997). *Vigna subterranea* and *V. unguiculata* are native to the African region, whereas *Phaseolus vulgaris* and *Vigna radiata* originate from Latin and Central America, and India, respectively. Currently, they are extensively cultivated all over the world (Balogun et al., 2018; Gonçalves et al., 2016; Graham & Ranalli, 1997; Singh et al., 2017). These beans have a high nutrient value, are crucial for nutritional and food security, and reduce mal- and sub-nutrition levels in developing countries, above all in sub-Saharan Africa (Hayat et al., 2014; Lin et al., 2008) but also in densely populated countries such as India (Acharya, 2007).

The consumption of dry legumes, including *Vigna* spp. (e.g., *V. radiata* or mung bean), *V. subterranean* (bambara-nut), *V. unguiculata* (cowpea) and several cultivars of *Phaseolus vulgaris* (common bean), contributes to the treatment of and has a protective effect against some degenerative chronic diseases, such as diabetes, cancer, obesity, neoplasms, and cardiovascular diseases (Englyst & Hudson, 1996; Jenkins et al., 2002; Xu et al., 2007). *Phaseolus vulgaris* and *Vigna* spp. are important and affordable sources of vitamins, carbohydrates, minerals, energy, proteins, dietary fibres and essential amino acids for people living in developing and developed countries (Lin et al., 2008; Morrow, 1991; Nielsen, 1991; Tharanathan, 2003). In Latin America and Africa (including Mozambique, see Figure 4.1), *Phaseolus vulgaris* and *Vigna* spp. are important staple foods and a major source of dietary protein for local populations (Beebe et al., 2013), particularly for people living in rural areas who lack the financial capacity to include meat in their daily dietary options. Therefore, dry beans are also called “poor man’s meat” as legume grains are rich in protein (ranging from 17% to 30%) (Costa et al., 2006; Genovese & Lajolo, 2001; Hayat et al., 2014; Tharanathan, R. N. Mahadevamma, 2003). Belonging to the Fabaceae family, the majority of *Phaseolus* and *Vigna* species can fix atmospheric nitrogen through symbiosis with nitrogen fixing bacteria (Dakora et al., 2008). Thus, the beans are a valuable crop species for crop consociation or crop rotation and have useful components for agroforestry systems (Atangana et al., 2014).

Several *Phaseolus* and *Vigna* species comprise different varieties and/or cultivars, with distinct crop needs and organoleptic properties. For instance, *Vigna* species are drought-tolerant crops, resistant to pests and diseases, and thrive under harsh environmental conditions (Duodu & Apea-Bah, 2017; Pitrat, 2012). In Mozambique, *Vigna* species such as *V. unguiculata* usually grow in smallholders’ fields, home gardens, backyards and sometimes grow in the wild. Moreover, the leaves of this legume are edible, and the immature pods and seeds can also be consumed as a vegetable. The nutritional value of dry beans has been the subject of studies in several parts of the world, including the US, UK, Sultanate of Oman, China, India, Brazil, and Poland (Ali et al., 2013; Costa et al., 2006; Mazur et al., 1998; Mohan & Janardhanan, 1993; Piecyk et al., 2012; Shi et al., 2016). In Africa, the importance of pulse crops (i.e., edible seeds of plants from the Leguminosae family), including the common bean, for food and nutritional security has been recognised, as well as yield, marketing, and consumption patterns, and the key role of smallholder farming in this respect (Katungi et al., 2009; Larochelle et al., 2015; Snapp et al., 2018, 2019). Regional research networks have been set up in Africa, including the East and Southern African Bean Research Network (ECABREN), to promote new technologies for seed breeding, multiplication, and delivery. Nevertheless, published research on the nutritional value of highly nutritious crops such as dry beans in Eastern and Southern African regions remains rare, and the few available studies mostly focus on South Africa (Adebiyi et al., 2019; Harris et al., 2018).

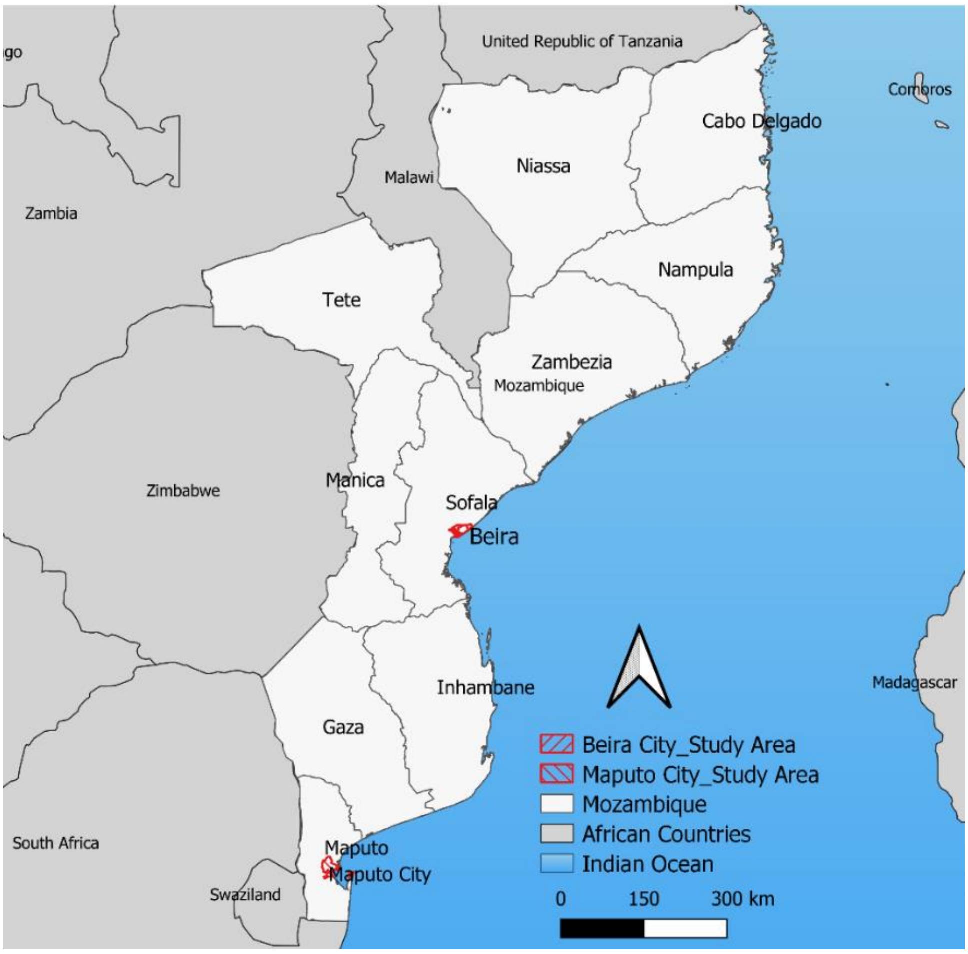

Figure 4.1. Geographic location of study area.

Over the last two decades, Mozambique has been the focus of projects centring on the distribution of improved seed varieties of the common bean, as well as the cowpea, groundnut, pigeon pea, and soybean, to enhance food security among smallholder producers and on improving value chains (Government of Republic of Mozambique, 2010; Walker et al., 2015). In addition, the country has adopted a national multisectoral strategy to reduce food insecurity and chronic malnutrition affecting more than 40% of children aged 0–5 years. This strategy advocates the need for improving families' access to and use of highly nutritious crops and foodstuffs (Government of Republic of Mozambique, 2010). Although some studies were undertaken on the common bean in Mozambique (Burridge et al., 2016, 2019), very few studies on the laboratory characterization of the nutritional value of dry beans or their commercialisation have been published except for a summary account on the *Vigna unguiculata's* response to water stress and proline accumulation (Chiulele & Agenbag, 2004).

As far as we are aware, this is the first study addressing the nutritional value of *Phaseolus vulgaris* and *Vigna* spp. commercialised in Mozambican (in)formal markets (see Figure 4.2) with a focus on food security, dietary improvement, and poverty alleviation. The nutritional value of dry beans depends on a variety of factors, including genetic characteristics, regional variability, agroclimatic conditions, and postharvest processing (Ali et al., 2013; Gonçalves et al., 2016). Most of the *Vigna* spp. are legume varieties indigenous to sub-Saharan Africa, including Mozambique. Despite their importance as a traditional food source, these legumes are relatively underutilised and under-researched compared with the better-known common beans (Duodu & Apea-Bah, 2017). Hence, *Vigna* spp. are considered neglected food crops (National Research Council, 2006) and were recently listed as a strategic crop in Mozambique.

This study aims to contribute to the current debate on improving diets with locally produced nutritious legumes and promoting greater food security and income generation among smallholder farmers. Using bean species and varieties of most commercialised dry legumes in Mozambique, we extracted quantitative data on the nutritional composition of *Phaseolus vulgaris* and *Vigna* spp. sold in two informal markets in Maputo and Beira cities (see Figure 4.2). This study also provides insights into their production, consumption, and sale based on a review of the literature and observation in loco. Specifically, we aimed to characterise and compare the chemical properties of *Vigna* spp. and *Phaseolus vulgaris* cultivars, which are among the most commercialised dry legume groups in Mozambique.

Figure 4.2. Informal markets in Mozambique. **(A)** Maquinino informal market in Beira city, and **(B)** Zimpeto informal market in Maputo city.

4.2. Materials and Methods

4.2.1. Study Area

Mozambique comprises a surface area of about 800,000 km^2 which is divided into 11 provinces. Maputo (southern Mozambique) is the capital of the country (1.08 million inhabitants), and Beira, in Sofala province (central Mozambique), is the second largest city (552.825 inhabitants, Figure 4.1). According to the 2017 census (INE, 2019), Mozambique's population totalled 26.99 million inhabitants (66.65% rural population), with the Maputo and Sofala regions accounting for 2.05 and 2.22 million, respectively. Smallholder farmers produce 95% of Mozambique's agricultural output and account for almost all the beans produced, mainly cultivated by women.

Given that the markets of Maputo city and Beira are the most important in the country (Figure 4.2), we selected the principal markets in Beira (Maquinino informal market: Figure 4.2A) and Maputo city (Zimpeto informal market: Figure 4.2B) for the purpose of this study. Maputo and Sofala markets are located in coastal regions where beans are mostly cultivated on rainfed soils. The study areas are subjected to cyclical flooding during the rainy/monsoon season (from October to March), recurrent in the Beira region and its hinterland (Charrua et al., 2020). Beans are generally grown on poor soils, often intercropped with cereals (such as maize and sorghum), cassava, or other bean species; different varieties are planted in small quantities with relatively low yields. Harvest losses are incurred owing to pests, drought, floods, and soil degradation (Wortmann et al., 1998). Together with *Phaseolus lunatus* (butter beans), *Cajanus cajan* (pigeon peas), *Vigna* spp. (cowpeas), *Cicer arietinum* (chickpeas), *Vicia faba* (faba beans), and *Glycine max* (soybeans), *Phaseolus vulgaris* (common beans and black beans) are a source of cheap proteins, oils, complex carbohydrates, and vitamins for vulnerable rural communities and fast-growing urban populations in the selected study areas.

4.2.2. Samples and Prices

A total of eight grains' samples of dried beans (*Vigna* spp. and *Phaseolus vulgaris*) including *Vigna subterranea var. subterranea* (Bambara groundnut, MP1Vs), *Phaseolus vulgaris* (common beans, MP2Pv), *Vigna unguiculata var. tenuis* (cowpea, MP4Vu), *Phaseolus vulgaris* (black beans, MP5Pv), *Vigna radiata var. radiata* (mungbean, MP6Vr), *Phaseolus vulgaris* (common beans, SO7Pv), *Vigna unguiculata var. unguiculata* (cowpea, SO12Vu), and *Phaseolus vulgaris* ("catarino beans or haricot catarino”, SO13Pv) were purchased in the Maquinino informal market in Beira, Sofala province (Figure 4.2A) and Zimpeto informal market in Maputo (Figure 4.2B). The selection of these eight bean samples was based on their local importance, place of purchase, and difference in seed quality attributes (e.g., colour, size, and shape of seeds). The initial letters “MP” and “SO” were used as acronyms for the samples of beans acquired in Maputo and Sofala (Beira) provinces, respectively. The samples were previously chosen to select grains of beans free from defects and remove external material as well.

The price of each bean variety was recorded in local markets in new metical (MZN, Mozambican currency) and then converted into US dollars according to Millennium *Banco Internacional de Moçambique* (BIM–International Bank of Mozambique) exchange rates. The exchange rate on 23 March 2021 was: USD 1 equivalent to 71 MZN (https://www.millenniumbim.co.mz/pt/particulares (accessed on 23 March 2021)).

4.2.3. Chemical Analysis of Proximate Composition

Samples were analysed concerning moisture, ashes, proteins, lipids, fatty acids (saturated, monosaturated, and polyunsaturated), carbohydrates, dietary fibre, and energy; mostly according to the Association of Official Analytical Chemists (AOAC) and ASTM procedures. Chemical analyses were performed at the SGS Laboratory (an international and certified laboratory with global standards, https://www.sgs.com/en/certification (accessed on 23 March 2021)), which works in partnership with the Instituto Superior de Agronomia (ISA) in Lisbon, Portugal. The moisture and ash contents were determined using a TGA701 Thermogravimetric Analyzer (LECO, EUA; Michigan) according to the ASTM D5142 standard (ASTM D5142-09, 2009). Lipids were determined by the extraction of hexane using a Soxhlet apparatus (FOSS, soxtec 2050; Höganäs, Sweden). A Fat Extraction System (FOSS, Hillerød, Denmark) was operated according to the AOAC standards method 945.16 (AOAC, 2007). Fatty acids were determined by gas chromatography coupled to a flame ionization detector (GC-FID) with an Agilent 7820A Gas Chromatograph system (Agilent Technology, Santa Clara CA, USA) running GC Chemstation software (version E.02.02). The instrument was equipped with a 30 m × 250 μm × 0.25 μm column (Agilent Technology, USA), and experimental GC/FID setup that comprehended the following conditions of analysis: injector temperature (250 °C), split ratio (1:80), oven temperature (220 °C), detector temperature (270 °C), injection volume (1μL), and a flow rate of carrier gas (hydrogen) (0.7 mL/min) (Servent et al., 2018). Protein content was measured by the Dumas combustion method (analyser LECO FP-528 LC, USA) using Windows-based software FP-528 with a default protein factor of 6.25 and AOAC Method 992.23. Energy was determined according to the ASTM D5865 standard (ASTM-D5865, 2019). Dietary fibre was performed through VELP system using a digester dietary fibre analyser (VELP Scientifica, Italy) in accordance with AOAC Method 991.43 (and equivalent AACC Method 32-07.01) (AOAC, 2012). Total sugars were determined by using the Portuguese standard 1420 and the Luff–Schoorl technique (NP-1420, 1987). Total carbohydrates were determined by the Phenol-Sulfuric Acid Method and AOAC Method 44.1.30 (Nielsen, 2017; Scherz & Bonn, 1998). Salt content was obtained by calculation using Volhard Titration of Chloride in Plant Material (AOAC Method 915.01) (Ward & Carpenter, 2010) adapted from AOAC International (AOAC, 2007).

4.2.4. Statistical Analysis

All dry bean data were presented as mean values. The statistical analysis was performed using the RStudio program version 1.4.1106 (The R consortium, Boston, MA, USA) (RStudio Team, 2021). Since our data did not follow a normal distribution and the variance was not homogeneous, we performed a non-parametric Kruskal–Wallis test (univariate analysis) for all variables at the 95% confidence level. Principal component analysis (PCA) was performed based on the correlation matrix. The Kaiser criterion (eigenvalues higher than 1) was applied to explain the samples of beans projections on a two-dimensional graph (PC1 and PC2) (Kaiser, 1960). All variables were auto-scaled prior to multivariate analysis (mean = 0, and standard deviation = 1). Cluster analysis (heatmap function) was performed to group the samples using the Ward hierarchical agglomerative method and Euclidean distance (Fan & Beta, 2017). All chemical properties of samples of beans were measured in triplicate.

4.3. Results

All species are annual crops well adapted to the climate and soil conditions of Mozambique. *Phaseolus vulgaris* is native to Tropical America, but currently, several cultivars are cropped globally, whereas the three *Vigna* species are native to tropical Africa. Prices for dry beans in the local markets at the time of acquisition were found to range from 1.11 USD/kg (SO13 Pv) to 2.7 USD/kg (MP6 Vr), showing vast differences between both types of beans and the Maputo and Beira markets (Table 4.1).

Table 4.1. Characteristics of the bean samples analysed, from the Maputo and Beira markets, Mozambique.

Species	Market (Accession)	Common Names	Price ($/kg)	Cropping And Ecology
Phaseolus vulgaris L.	Maputo (MP2 Pv)	common beans feijão manteiga	1.51	Annual twining herbs, erect. Species native to tropical America, currently and extensively cultivated all over the world. It grows well in warm temperatures and prefers a warm sunny position and well-drained soil. The roots can produce a symbiotic interaction with nitrogen-fixing bacteria.
Phaseolus vulgaris L.	Beira (SO7 Pv)	common beans feijão manteiga	1.39	
Phaseolus vulgaris L.	Maputo (MP5 Pv)	black beans, feijão-preto	2.19	
Phaseolus vulgaris L.	Beira (SO13 Pv)	feijão catarino	1.11	
Vigna radiata (L.) Wilczek	Maputo (MP6 Vr)	mungbean feijão soroco	2.7	Annual herbs, erect, twining, or creeping. This species is the main source of bean sprouts. It is widely cultivated in tropical and subtropical regions. It prefers a sunny environment, well-drained soils rich in organic matter and warm temperatures. The plant root enriches the soil with nitrogen due to symbiosis with nitrogen-fixing bacteria.
Vigna subterranea (L.) Verdc.	Maputo (MP1 Vs)	bambara groundnut feijão jogo, feijão ticochane	**2.04**	Annual herb with creeping stems. Native to Tropical Africa, the species is remarkably drought-resistant and is an important crop in semi-arid regions. It prefers sandy soils, warm temperatures and can produce a symbiotic interaction with nitrogen-fixing bacteria.
Vigna unguiculata (L.) Walp.	Maputo (MP4 Vu)	Cowpea, feijão nhemba-	1.69	Annual or perennial herb, erect, trailing, or twining, native to Tropical Africa with several subspecies. It prefers a warm

		nhachengua		climate, full sunlight, and tolerates a wide variety of soils so long as they are well-drained.
Vigna unguiculata (L.) Walp.	Beira (SO12 Vu)	Cowpea, feijão-nhemba	1.48	This species usually engages in a symbiotic relationship with nitrogen-fixing bacteria.

4.3.1. Proximate Chemical Composition

Table 4.2 presents the mean values for moisture content (moist.), protein (prot.), fat, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), total carbohydrates (TCH), energy, dietary fibre, ash content, salt, and total soluble sugars (TS). The range of values obtained for samples of beans were: from 11.8% (MP6 Vr, MP1 Vs) to 15% (SO7 Pv) for moisture; from 17.8% (MP1 Vs) to 24.4% (MP5 Pv) for protein; from 0.3 g/100 g (SO7 Pv, SO13 Pv, MP2 Pv) to 0.8 g/100 g (SO12 Vu, MP6 Vr, MP1 Vs) for SFA; from 0.2 g/100 g (SO7 Pv, SO13 Pv, SO12 Vu, MP2 Pv) to 4.2 g/100 g (MP1 Vs) for MUFA; from 0.5 g/100 g (MP6 Vr) to 1.5 g/100 g (SO7 Pv, MP2 Pv) for PUFA, from 56% (MP5 Pv) to 61% (MP4 Vu, MP1 Vs) for TCH; from 322 Kj (MP4 Vu) to 1431 Kj (MP1 Vs) for energy; from 14.1% (MP6 Vr, MP4 Vu) to 21% (MP2 Pv) for dietary fibre; from 2.95 (SO12 Vu) to 3.55% (SO13 Pv) for ash content; from 0.22 g/100 g (SO7 Pv) to 0.48 g/100 g (MP2 Pv) for salt content; and from 5.2% (SO7 Pv) to 5.7% (SO12 Vu) for TS.

Table 4.2. Proximate analysis of dry beans.

Market/Accession	Moist. (%)	Prot. (%)	Fat (%)	SFA (g/100)	MUFA (g/100 g)	PUFA (g/100 g)	TCH (%)	Energy (Kj)	Fibre (%)	Ash (%)	Salt (g/100 g)	TS (%)
Maputo												
MP1 Vs	11.8 d	17.8 d	6.2 a	0.8 a	4.2 a	1.2 cd	61 a	1431 a	14.9 d	3.05 e	0.45 c	5.6 ab
MP2 Pv	14.0 abc	20.5 c	2.0 d	0.3 b	0.2 c	1.5 a	60 ab	1251 b	21.0 a	3.38 b	0.48 b	5.5 abc
MP4 Vu	13.8 bc	20.1 c	2.3 b	0.7 a	0.4 ab	1.2 cd	61 a	322 c	14.1 e	3.01 e	0.36 d	5.3 bc
MP5 Pv	14.5 a	24.4 a	2.1 c	0.4 b	0.3 bc	1.4 ab	56 c	1247 d	20.8 a	3.26 c	0.43 c	5.4 abc
MP6 Vr	11.8 d	23.8 a	1.7 e	0.8 a	0.3 bc	0.5 e	60 ab	1343 e	14.1 e	2.99 f	0.26 f	5.0 abc
Sofala												
SO12 Vu	13.2 cd	22.0 b	2.0 d	0.8 a	0.2 c	1.0 de	60 ab	1305 f	16.9 c	2.95 g	2.14 a	5.7 a
SO13 Pv	14.4 ab	21.1 b	1.8 e	0.3 b	0.2 c	1.3 bc	59 bc	1268 g	17.1 b	3.55 a	0.34 e	5.5 abc
SO7 Pv	15.0 a	20.1 c	2.0 d	0.3 b	0.2 c	1.5 a	60 ab	1284 h	15.3 d	3.17 d	0.22 g	5.2 c

Values followed by different letters in the same column are significantly different (Kruskal–Wallis test, followed by Kruskal–Wallis post hoc test at $p < 0.05$).

4.3.2. Principal Component Analysis (PCA)

PCA was applied to evaluate the data of proximate composition for eight bean samples. PCA analysis showed that the first two components accounted for 75.3% (PC1–48.7% and PC2–26.6%) of total variance for the proximate composition (Figure 4.3).

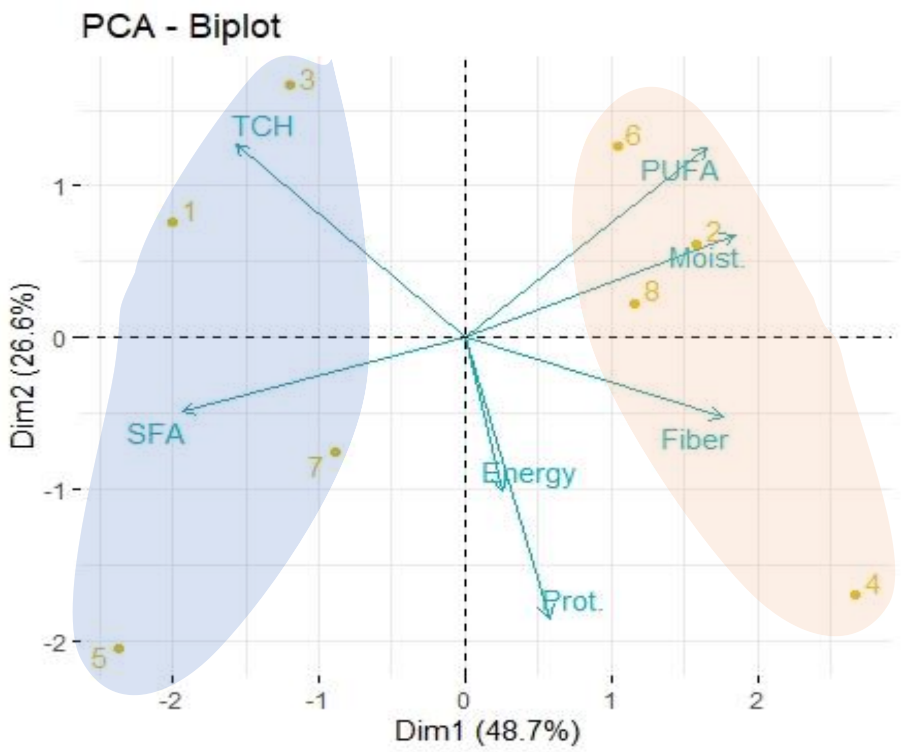

Figure 4.3. Biplot of the principal component analysis (PC1 and PC2) scores for eight samples of beans (proximate composition), namely: 1:MP1 Vs, 2:MP2 Pv, 3-MP4 Vu, 4:MP5 Pv, 5:MP6 Vr, 6:SO7 Pv, 7:SO12 Vu, 8:SO13 Pv.

4.3.3. Cluster Analysis (CA)

From the correlation matrix, heatmaps were constructed using the Ward hierarchical agglomerative method and Euclidean distance, where clusters of accessions are in the horizontal lines, whereas in the vertical lines are clusters of chemical characterisation data for seven proximate contents (Figure 4.4). The lowest values are displayed by dark violet boxes, while the highest values are represented by dark yellow boxes. The heatmap differentiates between two major groups of accessions, namely: *Vigna* species (Cluster 1) and *Phaseolus vulgaris* (Cluster 2). The proximate composition (Figure 4.4), moisture content, protein, total carbohydrates, saturated fatty acids, polyunsaturated fatty acids, energy, and dietary fibre were analysed in eight bean samples from Beira (Sofala) and Maputo in Mozambique. Cluster 1 is related to the samples of beans that presented relatively high values of total carbohydrates and saturated fatty acids, while Cluster 2 is defined by samples that contained relatively high values of fibre, polyunsaturated fatty acids, and moisture. For both groups (Clusters 1 and 2), intermediate values of energy were found in the samples.

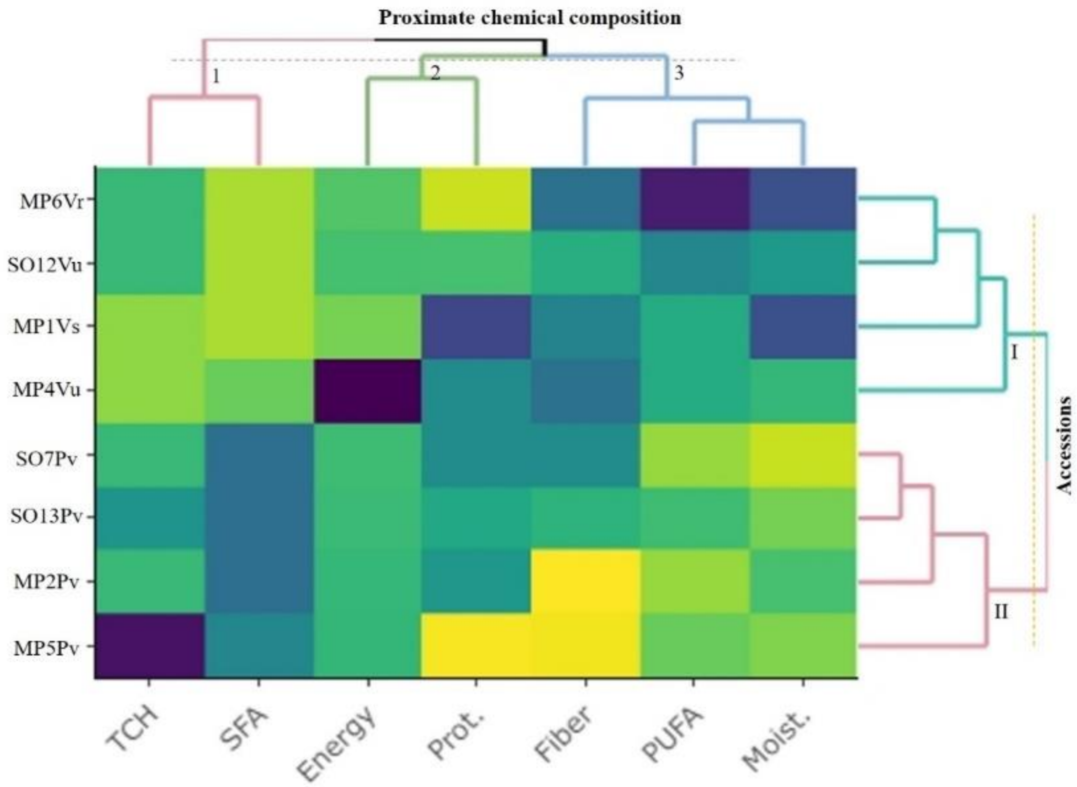

Figure 4.4. Heatmap of the eight accessions of dry beans (four *Phaseolus vulgaris* and four *Vigna* species) obtained from chemical characterisation data for seven proximate contents. Violet and yellow boxes indicate low values and high values, respectively.

4.4. Discussion

In Mozambique, beans are appreciated for their valuable nutritional properties, containing significant amounts of nutrients such as proteins, vitamins, and minerals (Baptista et al., 2017). Our study shows that *Phaseolus* and *Vigna* species can be distinguished from each other, namely in terms of proximate composition (see Figures 4.3 and 4.4). In line with our findings, a recent study conducted by Catarino et al. (Catarino et al., 2021), using cluster analysis, showed a clear difference between *Phaseolus* and *Vigna* species in terms of mineral composition. Nevertheless, the protein content is quite uniform among the studied *Phaseolus* and *Vigna* species, but the samples from these two species collected in Maputo markets (i.e., MP5 Pv and MP6 Vr) revealed the highest protein content. These beans also attain the highest prices per kilogram in the local markets of Maputo, the capital of Mozambique. In general, these products present a high content of TCH (>56%), with an appreciable content of fibre (>14%) and low content of soluble sugars (<5.7%). The lipid fraction is rich in MUFA and PUFA. The global analysis allows us to conclude that *Phaseolus* and *Vigna* species are considerably balanced foods that can contribute to decreasing food insecurity.

Phaseolus and *Vigna* species and pulses in general (i.e., dry beans, dry broad beans, dry peas, chickpeas, cow peas, pigeon peas, lentils, bambara beans, vetches, and lupins) also promote sustainable agriculture, providing ecological benefits by enriching the soil with their symbiotic interaction with nitrogen-fixing bacteria, and using less water than other crops (Barbeau et al., 2015). Consociated cultivation, combining *Vigna* species and other crops such as maize and sorghum, is a common practice that enriches the soil. These species have multiple applications at the household level, through the processing and cooking of seeds, pods, and leaves to prepare foodstuffs, popular local dishes as well as being commonly used in traditional medicine.

The size and composition of smallholder farms differ as do the types of agricultural systems, cultivation techniques, and marketing options (Makate et al., 2018). Despite efforts to quantify production and characterise agricultural systems via annual nationwide agricultural surveys, there is a lack of comprehensive data and understanding of smallholder bean production, consumption, and commercialisation patterns. Available survey data on smallholder farmers show that maize, cassava, and beans tend to rank among their principal crops and source of farmer households' agricultural revenue. One-fifth of smallholder farmers are under 30, whilst 23% of smallholder households are headed by women whose inputs are critical for both crop production and marketing. The great majority (71%) of cultivated smallholder plots are 2 ha in size or smaller. In Mozambique, the cultivated area dedicated to the production of bean species increased by approximately 50% between 2015 and 2019. In the provinces of Sofala and Maputo, the growth is above average (60%) while doubling in the Maputo region over the same period (INE, 2020).

Nevertheless, acute food insecurity among farmer households worsened during the same period, and markedly so in the Sofala region. Lately, the region has been affected by the impact of the strongest and most devastating tropical cyclone, Idai (category four, 2019), ever recorded in the Southern Hemisphere (Anderson & Learch, 2016; Charrua et al., 2021), and by politico-military instability in central Mozambique. Acute malnutrition levels in the Sofala region among children between 6 months and 5 years of age are among the highest in the country, significantly higher than in the Maputo region (Picolo et al., 2019). Hence, food security for already vulnerable groups practising subsistence agriculture appears to be under threat, not in the least because more than half of smallholder households live beneath the poverty line (Anderson & Learch, 2016). The low intake of nutrients associated with chronic malnutrition among children under five years old is regarded as a severe health and growth risk in the country (Picolo et al., 2019), prompting authorities to introduce a Multisectoral Plan for Chronic Malnutrition Reduction in 2010. Legumes, and beans and peas among them, are particularly suited to alleviate malnutrition. Evaluations of food security have revealed significant stress levels, owing to low productivity, irregular precipitation, limited knowledge of food stock management, and a lack of quality and improved seeds. Nevertheless, diet adequacy in the Sofala and Maputo regions appears to be higher than the national average (Government of Republic of Mozambique, 2010, 2017).

Phaseolus vulgaris and *Vigna* spp. are the most common legumes for sale in local markets, both in Beira and Maputo, and are the most consumed and incorporated in traditional dishes. The *Vigna* spp. are less care-demanding and cropped in rural homesteads, while *Phaseolus vulgaris* is typically found in urban vegetable gardens. However, the volume of production of *Vigna radiata* and *V. subterranea*, especially the latter, is considerably smaller than that of the common bean in Mozambique. The prices were recorded at the Maputo and Beira markets, where the beans are sold in small quantities. Most consumers can probably obtain beans at lower prices from other sources (e.g., wholesale markets) or crop them in vegetable gardens, subsistence or smallholder farming. The prices fluctuate according to the seasonal cycle, being the lowest just after the harvest period when the supply is greater, and highest during the dry season, especially in the dryer areas such as the south of Mozambique.

At the time of fieldwork, a greater diversity of beans was observed in Maputo's than in Beira's markets. *Vigna radiata* and *V. subterranea,* and black beans were mostly found in Maputo, yielding higher prices. While prices per kilogram were generally higher in Maputo, the most expensive beans in the capital (black beans, mung bean, and bambara groundnut) were much less common in Beira, reflecting differences in purchasing power and consumer preferences. Higher prices are quoted for *Vigna radiata* and *V. subterranea*. Overall, the marketed beans seem to be rather expensive for local consumers and many families' budgets.

Published studies on the marketing of crops in informal markets are rare, limited to a few project reports. The Ministry of Agriculture (MINAC) implemented a price information system for several agricultural commodities (SIMA), but most smallholder farmers have difficulty accessing the information, owing to their limited access to mobile phones and networks.

For smallholders, whilst most crops are produced for domestic consumption, smaller portions are sold for cash or bartered. Hence, legume markets constitute important outlets for generating household income for smallholders (Chagomoka et al., 2014). In this respect, beans rank among the crops with the largest share of harvests destined towards revenue generation, on par with maize (Anderson & Learch, 2016). Despite beans' importance as a key dietary component, and their broad acceptance, market prices appear to be rather high for the purses of many Mozambicans, affecting, above all, economically vulnerable populations such as those in the study areas. Hence, priority should be given to promoting better linkage between producers and end consumers by improving the performance of (informal) marketing circuits, limiting the role of intermediaries, and enhancing understanding of consumer preferences in urban markets. As a result, producers will be able to better adapt to production on demand and thus reap greater benefits for themselves and their dependents.

Very few studies have been conducted on value chains for legumes - and beans in particular - which include informal markets (Chagomoka et al., 2014; Homann & Tui, 2015). Most smallholders sell their produce directly to their local clients and to a lesser extent via intermediaries, such as wholesale or retail agents. In terms of crop marketing, the fact that beans are the most stocked crops following maize (Anderson & Learch, 2016), increasing farmers' stock capacity may augment income from the sale of beans in (in)formal markets (Homann & Tui, 2015). However, limited smallholder household access to land, labour, funding, and income act as constraints upon the production, investment, and quality levels, whilst seasonal factors contribute to considerable price fluctuations and varying returns.

4.5. Conclusions

The smallholder production of agricultural commodities in Mozambique, which accounts for more than 95% of national output, forms the basis of populations' food security. Nevertheless, despite its importance, smallholder production of legumes, and bean species in particular, and their contribution to local diets remains under-researched and under-supported; notwithstanding the fact that *Phaseolus* and *Vigna* bean species rank among the most complete and balanced food products in terms of nutrients in Mozambican diets, constitute key ingredients in local dishes requiring relatively limited and low-cost inputs and are in great demand in accessible, informal urban markets as this study demonstrates. The introduction of improved cultivars of *Phaseolus vulgaris* and *Vigna* species would render greater yields and increase revenue from smallholder plots whilst diversifying diets with the aid of key proteins, fibres, MUFA, and PUFA. Given the existence of significant levels of sub- and malnutrition in Mozambique, including the study areas set in vulnerable farming systems, increasing the availability of beans at affordable prices would undoubtedly benefit populations', health, diet, and food security.

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Chapter V

Assessing Local Populations´ Perceptions of the Importance of Cultural Heritage in the Gorongosa National Park (GNP), Sofala Province, Mozambique

This chapter is in preparation for publication

Assessing Local Populations´ Perceptions of the Importance of Cultural Heritage in the Gorongosa National Park (GNP), Sofala Province, Mozambique

Abstract

Global climate change and traditional societal dynamics over time threaten cultural heritage, especially in African countries. Existing Protected Area (PA) networks in Mozambique have some shortcomings in that they commonly neglect cultural heritage (CH) in environmental governance, and indigenous people living in or outside PAs often resent their formal management. Gorongosa Restoration Project is in the process of establishing Community Conservation Areas (CCAs) involving the communities of Bebedo, Nhampoca and Nhamacuenguere in the southern region of Gorongosa National Park (GNP) Buffer Zone (BZ) in Sofala Province, Mozambique. Here, we investigated the local people perception of the importance of CH to their wellbeing, CH potential for the nature conservation, current threats to CH, and the local populations' expectations about the establishment of CCA. The data of this qualitative research were collected through a fieldwork using Focus Groups Discussions (FGDs) and participatory mapping of Spiritual and Sacred Sites (3S). We found 35 lakes, 6 cemetery forests, 4 forests, and 2 trees associated with ancestral spirits or deities and are worshiped by local people. These 3S are historically governed through intangible cultural heritages (e.g. myths, taboos, beliefs, traditional rituals, among others) with little or no governmental involvement. Describing the CH, the FGDs participants frequently mentioned: (i) Spiritual beliefs, rituals, ceremonies, social customs and traditional rules, (ii) The role of nature in cultural heritages and traditional uses, (iii) Change in cultural heritage, and (iv) Maintenance of the cultural heritage. The People´s expectations about CCAs were grouped into single overarching theme. All the FGDs participants perceived the importance of CH to their wellbeing, and they are interested to maintain this legacy in order to guarantee the normal life within their communities and appease ancestors' spirits. The local people are aware of the numerous advantages and some disadvantages that the creation of CCAs can bring to the communities involved. However, the construction of the electric fence to dissuade elephants from entering residential areas within GNP-BZ and causing conflicts is their top priority. Our study highlights the importance of CH to natural resources conservation and people wellbeing and reinforces the need for a better understanding of the CH complexity. Furthermore, the incorporation of CH into conservation strategies/projects could enhance the effectiveness of conservation efforts and harness the support of local people.

Keywords: Cultural heritages, Gorongosa National Park, Spiritual and Sacred Sites, Community Conservation Areas, Perceptions.

5.1. Introduction

Over the last several decades, there have been a number of attempts to recognize the multiple dimensions of cultural heritage (CH) emphasizing narratives of safeguarding mankind's cultural and natural heritage, nature conservation, and people well-being as established, for example, by the 1972 UNESCO World Heritage Convention (Alberts & Hazen, 2010). CH has been defined as the legacy of physical artifacts and intangible attributes that people inherited from past generations, experience in the present, and transmit to future generations through the socialization processes (Willis, 2014). According to UNESCO (2020), CH encompass the following main categories: (i) Tangible cultural heritage which includes movable cultural heritage (e.g. paintings, and sculptures), immovable cultural heritage (e.g. monuments, and archaeological sites), and underwater cultural heritage (e.g. shipwrecks, underwater ruins and cites); (ii) Intangible cultural heritage (e.g. social customs, oral traditions and spiritual believes, stories, customs, local practices, indigenous knowledge and rituals); (iii) natural heritage (e.g. cultural landscape, and forest); and (iv) heritage in the event of armed conflict.

Protected Areas (PAs) in Africa hold a long history of human-nature interaction, which has shaped individual and collective identities, and, therefore, the natural environment. They are crucial to secure the existing biodiversity, mitigate climate change effects, and provide a number of other highly valuable ecosystem goods and services (provisioning, regulating and cultural) that contribute directly and indirectly to well-being (Petursson & Vedeld, 2017; Saura et al., 2017). Among the Ecosystem services (ES) there is so-called cultural ES and its subcategory of CH which greatly contributes to enhance all other ES. Yet, there is no consensus among the researchers about what CH refers to within the ES approach (Hølleland et al., 2017). Griffiths et al. (2020) point out that sacred places, such as cemeteries, preserve high biomass accumulation (carbon sequestration) compared to other land use types in the vicinity.

Given the profound relationship between nature and the traditional communities in Africa, the cultural values attributed to nature, influencing knowledge, social norms, beliefs and traditional practices (Pretty et al., 2009), have to be respected for the success of conservation efforts (Ormsby & Bhagwat, 2010). CH is of utmost importance for the rural African context (Mabulla, 2000). It represents a sense of pride and satisfaction for young and future generations, being strongly associated to the sense of belonging and attachment to the land, such as in the case of specific trees, animals, plants, as well as to the areas where the communities' ancestors are buried. Thus, there are different ways in which those communities, conservation managers, decision-makers and society in general can benefit from acknowledging native populations CH.

Although the cultural richness of African communities is acknowledged to play an important social role, namely, in motivating environmental friendly behaviours (Himes-Cornell et al., 2018), studies based on primary data are lacking. While use values, typically associated to recreational activities (tourism-related), have been the subject of research, to date, non-use values remain relatively neglected and poorly studied in Africa, in general, and in Mozambique, in particular. This may be ascribed to several reasons, such as their "intangible" nature, and therefore, invisibility, the lack of available data, as well as the challenges and complexity of collecting and integrating qualitative and quantitative data into decision making processes. These challenges also have consequences when selecting the appropriate method(s) to assess those values. This study aims to contribute to fill this gap.

The Gorongosa Natural Park (GNP), located in Sofala province, Mozambique, owing to its aesthetic beauty, pristine environment, biological diversity, and the provision of multiple services, which undoubtedly underpin human wellbeing, has attracted scientific attention captivated by the challenging coexistence of biodiversity conservation with human and economic development. In line with this principle, recently the GNP ("Gorongosa Restauration Project") has launched Community-based conservation (CBC) initiatives by establishing two clusters of Community Conservation Areas (CCAs) in the GNP buffer zones (BZ). The two proposed groups of CCAs include the communities of Bebedo, Nhampoca, and Nhamacuenguere in the south, and those of Catemo, Nhabaua, Muanadimai, Chidanga, and Maciambosa in the north (Figure 5.1). The establishment of CCAs along the BZ of GNP intends not only to preserve local unique biodiversity and promote sustainable use of natural resources to improve livelihoods of local communities, but also to reduce the rising human-wildlife conflicts (with emphasis on elephant attacks) by setting participatory zoning limiting the CCA by using electric fences.

Within a CCA the local community has authority to manage natural resources and to appropriate the benefits provided by a collaborative management framework with relevant stakeholders, such as GNP, government agencies, and non-governmental institutions. The conceptual foundation of CBC is that for the community to be actively involved in any sustainable natural resource management project they must receive a direct benefit from it (Mbaiwa, 2011). The establishment of a CCA can help to develop a sense of ownership over local natural resources management and governance. However, it also comes with numerous challenges related to populations' perceptions and expectations regarding the contribution of the project to secure the preservation of their cultural identity, traditional livelihood activities and lifestyles, among others. Thus, it is important to understand the perceptions of the populations living in the GNP buffer zones, regarding their existing CH, evolution, and what may represent present and future threats, especially when the implementation of CCAs may complement or conflict with the cultural values of local communities. It may also help to design policies and strategies to ensure coexistence between conservation objectives and the cultural values of the locals for sustainable development purposes. The assessment of the native people perceptions of the cultural values may also provide local and global public awareness of the importance of nature-based cultural value to human well-being while contributing to improve management practices for sustainable development.

To address the cultural heritage while implementing any community development project is a recommendation of the Convention Concerning the Protection of the World Cultural and Natural Heritage which has been implemented through the Performance Standard 8 of the International Finance Corporation (IFC) (International Finance Corporation (IFC), 2012). Therefore, this study explores the challenges of assessing native populations´ perceptions of cultural heritages for preservation purposes. In particular, the study was developed in the GNP, involving the communities living in the south buffer zone, respectively, where one the proposed CCAs is located (Bebedo, Nhampoca, and Nhamacuenguere). The goals of this research are to: (i) identify local communities' cultural heritages and map them spatially; (ii) document the existing cultural heritages and their potential for nature conservation and people well-being; and (iii) understand the local populations' expectations about the establishment of CCA and how it may affect their cultural heritages and way of life. Therefore, this study aims to contribute to better inform those involved in the design of the CCA for welfare enhancing.

5.2. Background

5.2.1. Study site

The Bebedo and Nhampoca (both in district of Nhamatanda) and Nhamacuenguere (district of Dondo) are all located within the Buffer Zone of the Gorongosa National Park in Sofala province, central Mozambique (Figure 1). GNP is located at the southern end of the Great Rift Valley and was proclaimed in 1960 (formerly it was a hunting reserve). It has 4067 km^2 that integrates the Gorongosa Mountain (an isolated 1863 m a.s.l. massif), one of the highest peaks in Mozambique, with biological and hydrological importance to GNP. Gorongosa Mountain contributes to generate orographic rainfall that feeds a variety of watercourses existing within the GNP including Urema Lake which has been reported to be crucial to sustain the GNP's wildlife through its rich grasslands (Pringle, 2017; Tinley, 1977). GNP is expanding its protection area by including Coutada 12 (private hunting reserve which has been upgraded) (Club of Mozambique, 2016) and the Coastal Marromeu National Reserve (wetland of international importance and conservation hotspot) on the right bank of the Zambezi River. The BZ (5333 km^2) has more than 200000 people living in different communities scattered within it (Stalmans et al., 2019). The interior of the GNP and its surroundings has a vast network of water resources (rivers, streams, swamps, and lakes) and fertile soils for agriculture which is the main economic activity of the local population followed by fishing. Pungue is an international river that crosses the GNP at its southern limit and receives the overflowing water from Urema lake which is the epicentre of the drainage of rivers and streams within GNP. The Pungue river is the main source of water in the southern region of GNP-BZ which includes CCA of Bebedo, Nhamacuenguere, and Nhampoca; and this river drains to the Indian Ocean through the city of Beira, capital of Sofala province (where it is the main source of drinking water). The climate in Central Mozambique and in the study area is sub-tropical with a wet season from November to April and dry season from May to October (Easter et al., 2019). Moreover, the average rain at the study area ranges from 800 to 900 mm (Stalmans & Beilfuss, 2008).

5.2.2. Flora and fauna

Historically, the GNP and its surroundings supported a wide variety of wildlife population such as wild dog (*Lycaon pictus*), leopard (*P. pardus*), lion (*Panthera leo*), jackal (*Canis adustus*), hyena (*Crocuta crocuta*), crocodile (*Crocodylus niloticus*), herds of buffalo (*Syncerus caffer*), elephant (*Loxodonta africana*), zebra (*Equus quagga*), waterbuck (*Kobus ellipsiprymnus*), hippo (*Hippopotamus amphibius*), impala (*Aepyceros melampus*) and so on. During the civil war (1977-1992) GNP´s megafauna was significantly affected and reduced by as much as 95% (Daskin et al., 2016). The civil war was centered in Sofala province and, particularly, at GNP which was a traditional stronghold of RENAMO (the largest opposition party in Mozambique which was fighting with Government Forces), with its military headquarters in Gorongosa mountain inside the Park's boundaries during several decades until the peace agreement reached in 1992 (Leão, 2007). Hunting for bush meet and poaching for ivory and skins sales were the main source of livelihood and income generation to sustain the RENAMO guerrilla.

According to Tinley (1977), the GNP and its buffer zone is characterized by four regions characterized by geological-geomorphological-climatic features, as follow: Gorongosa Mountain, Midlands, Rift Valley, and Cheringoma Plateau. The CCAs of Bebebo, Nhampoca and Nhamacuenguere is part of Rift Valey Region which comprises the central part of the GNP and its BZ. These regions define the landscape types found in and around this conservation area; and within a specific landscape it can be found heterogeneity in terms of plant communities. A total of fifteen landscapes were recognized within GNP and its BZ based on dominant vegetation type and hydrology. The landscape found at studied CCAs is designated Riftvalley Riverine and Floodplain characterized by a mix of mostly open plant communities which includes pure grassland, sparse palm veld, open *Acacia xanthophloea* and *Faidherbia albida* woodlands (Stalmans & Beilfuss, 2008).

5.2.3. GNP co-management agreement

In 2008 the Government of Mozambique signed a co-management agreement with the non-profit Gregory C. Carr American Foundation (so called Gorongosa Project) to restore GNP wildlife to its former glory, recover local ecosystems through a science-based management approach, and promote a sustainable development of the local communities (e.g. guarantee the allocation of 20% of GNP's revenues in favor of the local community, promote education and healthcare, recruit local employees, and provide agricultural and agroforestry assistances). Since recovery efforts began, the population of wild animals have been steadily increasing and spreading to different areas including the GNP-BZ where the local communities traditionally live and practice their subsistence activities (Pringle, 2017). Nowadays there are no people living inside the south CCAs, some have left due to the increasing attacks by elephants in recent years and some people, especially in Nhamacuenguere, left in 2013 due to the latest civil unrest (2013-2019) in Sofala province. However, those who live in the surrounding vicinities of the CCAs (approx. nr of households: Bebedo - 6534, Nhampoca - 5650, and Nhamacuenguere – 592, as of 2021, data received from the Community Relations Department at GNP) rely on the resources that exist within the CCAs for their survival, keeping their cultural habits. Through a participatory work in 2021, the local community was reallocated to establish CAAs, as follows: around 54 Km^2 in Nhamacuenguere, 12 Km^2 in Bebedo, and 53 Km^2 in Nhampoca. The establishment of CCAs is expected to implement an electrical fence limiting the CCAs and protecting the community.

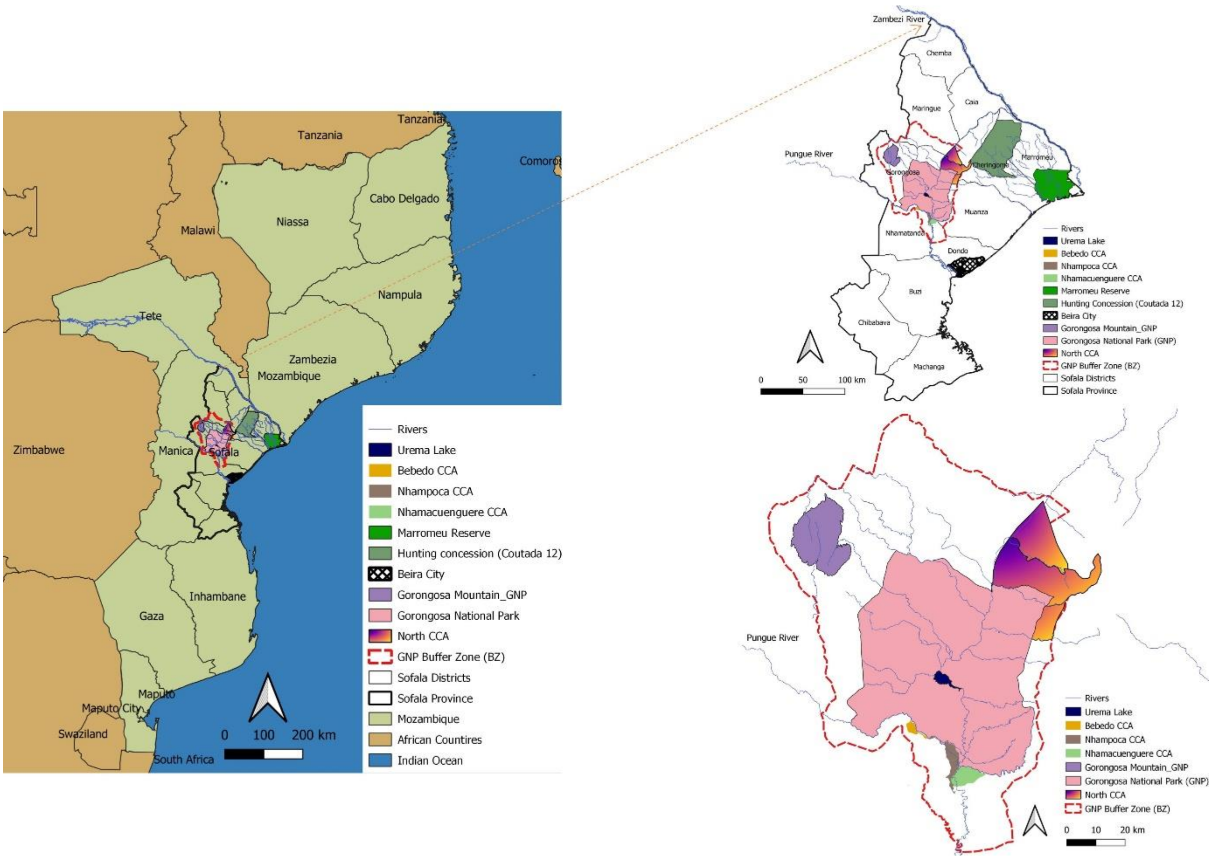

Figure 5.1. Location of study area.

5.3. Methods

The collected data were obtained from a fieldwork that was conducted in the southern region of GNP-BZ, between September and October 2021, including the communities of Bebedo, Nhampoca, and Nhamacuenguere, using a deliberative participatory approach (Focus Groups Discussions - FGDs) and participatory mapping of cultural heritage sites. The cultural heritage was grouped in two categories, namely: (1) tangible/natural (cultural and spiritual sites – 3S: trees, forests cemetery forests, and lakes/ponds), and (2) intangible (e.g. myths, stores, rituals, ceremonies, social habits and oral traditions, spiritual beliefs, indigenous knowledge, among others), based on the UNESCO (2020) classification.

5.3.1. Focus Group Discussion

To avoid the dominance of a given group in the discussion, thus losing its intended richness and heterogeneity, we grouped the participants with similar characteristics (e.g. age groups, gender, and/or income) that are associated with the core focus of the study (Trady, 2009). We conducted five cultural FGDs (composed by eight to fifteen participants each) in each community, involving a total of 166 respondents, using the principle of maximum diversity, as follows: (i) adults and elders (>50 years old: Mid&Elders´FGD); (ii) young people (18-40 year old: Y&Y`s FGD); (iii) men relying on natural resources for their livelihood (Men´s FGD); (iv) Women relying on natural resources for their livelihood (Female´s FGD); and (v) members of the local natural resources management committee(s) (NMRC´s FGD).The goal was to assess their cultural knowledge, views and concerns, signalling potential conflicts, and proposing alternatives. In a given community the number of the FG meetings could overlap (take place several times) in the same site but in different hours/days according to the community convenience and availability to attend the discussions. Hence, in Bebedo we had five FGDs corresponding to the same number of sites, in Nhampoca we had five FGDs that took place in four sites, and in Nhamacuenguere we had five FGDs that occurred in a unique site. However, since the meetings were held outdoors in open places, the number of attendees turned out to be more than expected as people passing joined the discussion. Thus, we did not expel anyone to avoid insulting the local communities or even causing embarrassment. The meeting was held in Portuguese and/or local tribal languages (“Xisena” or “Xindau” if the participants were not fluent in Portuguese). The interviews were preceded by reading an oral consent and, then, a request for permission for photos and recording of the conversation was asked for. Participants typically accepted to be recorded and photographed, so the facilitator verbally translated responses while the principal investigator took notes. This method is identified in the literature as an important contribution to build social capital in traditional communities given the shared dimension of cultural heritage, in line with the proposed CCAs to GNP (Mowat and Rhodes, 2020; Constant et al., 2020; Sandefur et al. 2020). With the support of the community traditional leaders, we agreed on the best time and place for the FGDs in the surrounding vicinities of the CCAs where people live. However, this meant that the principal investigator had to rely on the local traditional leaders to help convene meetings with the appropriate participants as he was not yet familiar with the communities under study and their dynamics. In order to overcome the bias that could be introduced into our data because of the participants selection process (particularly who is convened and selected to participate in FGD), the principal investigator invested a considerable amount of time with each traditional leader to discuss the research, the purpose of the FGDs, and the profile of the ideal participants. Moreover, in an effort to make the participants more willing to talk, the traditional leader attended only the adult and elderly FGD which belonged to his category. In addition, to avoid any bias in the answers, before the FGDs, it was emphasized that the interviewer is not a GNP employee not even a worker from the government, but an independent person with purely research-oriented objectives. The principal investigator presented his university researcher identification, to leave people more comfortable. The interview guidelines with open-ended questions were previously tested with two focus groups in the community of Bebedo and the necessary adjustments were introduced before its implementation (see the FGDs guide - Supplementary Data V.1.). The interview guide included completion of a brief sociodemographic survey to facilitate our FGDs. A poster containing images referring to tangible and intangible cultural heritage was prepared and distributed to focus groups participants to facilitate their perception (Supplementary Data V.2). The conversations were relaxed to let them take it easy and create an atmosphere of closeness and sympathy between the parties. The FGDs were conducted with all due respect for the privacy of the participants, and they could interrupt whenever necessary. The conversation took around two hours and at the end of each meeting, all the participants were served a snack to restore their energy and motivate them, given that some walked long distances to participate in the FGDs.

The FGDs addressed in broad the following: the understanding of what the cultural heritage consists of in the study areas; list of existing cultural sites within the CCAs and sacred wild animals and their associated intangible cultural heritage (e.g. stories, oral traditions, myths, ceremonies, spiritual believes, social customs and traditional rules); the role that intangible cultural heritage plays in the conservation of natural resources and people well-being; cultural/traditional uses of tangible goods from nature; how the community perceives the positive and/or negative effects of the cultural sites; and the local people expectations regarding the establishment of CCAs.

5.3.2. Mapping

After the FGDs, we were able to gather a significant amount of information and a list of the spiritual and sacred sites (3S) within a specific community. The geographical coordinates of the presence of 3S were obtained using a high-sensitivity handheld Global Positioning System (GPS) receiver (GPS 72H, Garmin, Taiwan). Due to the poor accessibility in the park, the long distances to walk in the forest, and the danger due to movement of wild animals (mainly elephants and buffalos), it was not possible to visit all the 47 cultural sites listed during the FGDs. Therefore, with the support of the local leadership, a participatory selection of some less dangerous and more accessible sites was carried out for mapping. The movement of the mapping team from one point to the other was done by motorcycle and by foot, covering long distances in the bush. The mapping was participatory, with the support of the local traditional/spiritual leaders, namely the local chief/kinglet ("régulo"), vice-chief ("Saphanda"), and the neighbourhood representative ("Mfumo") who explained the significance of each cultural site visited; local guides with proven knowledge of the study area; and two GNP inspectors equipped with firearms and rockets to chase away wild animals, if necessary. Thus, the field team was composed by six to eight members.

5.4. Data analysis

Audio-recording from 15 FGDs were transcribed and analysed thematically using a deductive approach driven by the research question(s) and the analyst researcher following the six-phased method described by Braun and Clarke (2006). The codes were generated from the data extracts, organized in a meaningful way in order to identify the patterns (themes) that better represent the qualitative data. The themes were identified with a semantic approach within the explicit/surface meanings of the data, meaning that the analyst focuses exclusively on what the participant said and nothing beyond that (Braun & Clarke, 2006; Frith & Gleeson, 2004). The thematic analysis was a flexible process involving moving back and forward, and read and re-read the information from the FGDs in order to confirm initial ideas for codes and themes. It was performed manually using Microsoft Excel. Some extracts of data remained uncoded, some were coded once, and some were coded many times. The different codes listed were analysed and similar codes were grouped to form potential overarching themes. Then, a set of candidate themes were crosschecked, reviewed and refined to generate the final themes (see Supplementary Data V.3 for themes and codes).

5.5. Results

5.5.1. Respondent characteristics

The total participants in FDGs were 166 including 103 male (62%) and 63 female (38%). The gender disparity was expected even though around 52% of the Mozambican population is female, according to the latest National Population and Housing Census (INE, 2019). The reasons behind this disparity may be the fact that under cultural norms a man is the head of household (the chief decision maker) who is supposed to meet the daily needs of his wife (wives) and children, whereas women are considered the most apt to care for children and other family members. It has been reported that in African countries women spend around 3.4 more time in unpaid domestic and care work than men (International Labour Organization, 2018) and in rural areas the situation is more critical. Most of the participants in our total sample had never studied (33%) or had only up to elementary education (32%) ranging from grade 1 to grade 5. Out of 63 women who have participated in FGDs, 56% had never studied. As expected, young people (Y&Y FGDs) have the higher level of education and 50% had basic secondary level ranging from grade 8 to grade 10. All of the participants on FGDs rely directly on agriculture for their livelihood, whereas fishing, trade, among others are secondary economic activities. Christianity is the most prevalent religion where 58% of respondents attend protestant churches and 4% are Catholic. There is a considerable number of respondents who have pagan beliefs (36%) and a Muslim minority (2%). Most of the participants in FGDs (94%) are not native and have been living in the studied community for more than 10 years. The search for fertile land for agriculture (90%) was the main reason behind the population's immigration. The existence of several lakes inside the CCA and land with natural fertilization by green manure (dead organic matter) and wild animal excrement is a very attractive for agricultural practice. Despite the human-elephant conflict, the interior of the CCA is an important reference on beans (*Phaseolus* and *Vigna* species) production that supplies several markets in the province as well as on the commercial production of sesame.

5.5.2. Survey of the local communities' cultural heritages

According to the FGDs, the existing Cultural Sites (CS) in all three Community Conservation Areas (CCAs) in the south region GNP BZ include 35 sacred lakes (Nhampoca – 24, Bebedo – 5, and Nhamacuenguere – 6); 4 sacred forests (all in Nhampoca); 6 cemetery forests (Bebedo – 4, and Nhamacuenguere – 2); and 2 sacred trees (one in Nhampoca and another in Bebedo) (Figure 5.1, Table 5.1). Of those, we mapped 29 (Fig. 5.2, Table 5.1, Supplementary Data V.4) out of 47 cultural sites existing within the CCAs being 15 in Nhampoca (2 sacred forests, 1 sacred tree, and 12 sacred lakes and ponds); 10 in Bebedo (4 cemetery forests, 1 sacred tree, and 5 lakes and ponds); and 4 lakes in Nhamacuenguere. The list of the 18 that remained unmapped 3S is presented in Supplementary Data V.5. The sacred lakes and ponds are the most predominant 3S.

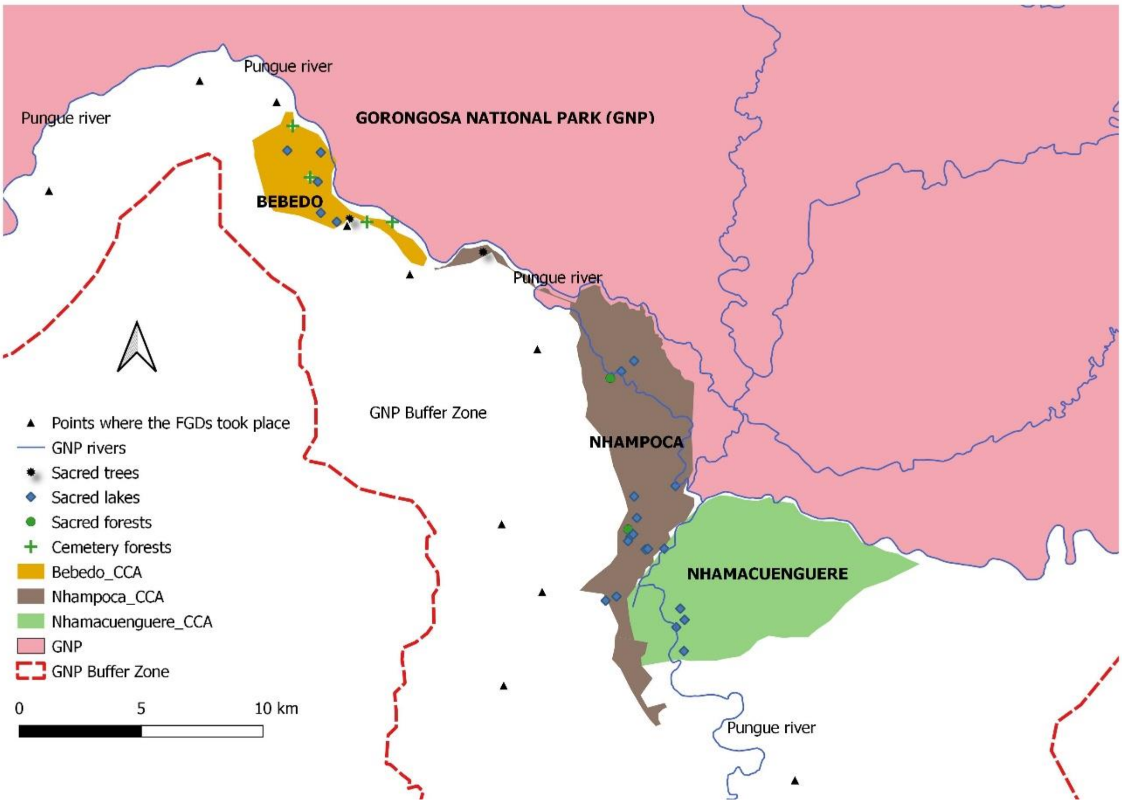

Figure 5.2. Mapping of cultural sites within the CCA of Bebedo, Nhampoca and Nhamacuenguere in the Buffer Zone of Gorongosa National Park.

The local people live in the surrounding vicinities of the CCAs but their main source of livelihood is inside the CCA where they practice lake/river side agriculture, fishing, collection of medicinal plants and raw materials for traditional housing construction, extraction of palm wine (traditional drink used in rituals), among others (Table 5.1). In addition, the native people are historically linked with their land as some cultural important/sacred/spirits sites (e.g. cemeteries) are inside de CCAs. In the past there were some families living inside the CCAs but they left the area due to the resurgence of the human-animal conflict and a recent smaller scale armed conflict (2013-2019) centered in GNP where RENAMO had some bases spread throughout the conservation area and its surrounding areas. The natural resources are historically governed by Intangible cultural heritage - ICH (e.g. oral traditions and rules, stories, and myths) that came from past generations, is kept by present generations, and passed through new generations.

Apart from the aforementioned CS, thirteen wild animals including woodpecker bird, hippopotamus, gazelle, rat locally called FUSSI, chameleon, double-headed serpent, lion, pangolin, an elephant locally called "Chuva", owl, a giant rat, a bird locally called by Mbalame, and hyena have been mentioned as spirits and sacred animals (Table 5.2). The community considers these animals as messengers of: death in the community, curse, an imminent occurrence of (intense) rain or flooding, droughts, (un)happiness, and anger and revolt of ancestors because of disobedience of the local traditions. The characteristics of each animal (physical size, rarity, habitat, habits and customs, among others) is generally related to the type of message it brings to the community. For example, the African lion is a large and powerful cat with a distinctive loudest roar that can be heard 8 km away and it has been historically considered as a symbol of courage and strength (National Geographic, 2022). Hence, the lion appearance in the community or when it roars unexpectedly in GNP is considered as a punishment and repression because of disobedience or gradual abandonment of traditions (ICH) left by the ancestors.

Table 5.1. List of 3S reported and visited within CCA within GNP-BZ.

Nr	Cultural sites	Area	Characteristics	Perceived benefits from 3S	Perceived drawbacks of 3S	Intangible cultural heritage associated: Oral traditions and local management rules	Who does the traditional ceremony?
1	Regulo´s lake	NP	It is a permanent lake surrounded predominantly by low herbaceous vegetation.	Fish, and lakeside agriculture	None	The ceremony is organized for being successful in fishing and protected from attack of wild animals existing in the water. The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season). A part of the fish (first fish to be caught) must go to the traditional chief locally called Régulo.	Kinglet or his family
2	Nhassambo/ Zuanane lake	NP	Nhassambo/Zuanane is a permanent lake surrounded predominantly by tall and dense grass and some trees and shrubs scattered around. Inside the lagoon, water lily can be noticed. Nhassambo was historically known for a wide variety of fish and the highlight goes to *Oreochromis mossambicus* (locally known as Pende fish).	Fish, lakeside agriculture, building material for housing	E+B	The ceremony is undertaken for the success in fishing and for protection from attack by wild animals existing in the water. The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season). A part of the fish (first fish to be caught) must go to the Zuanane´s family.	Nhassambo´s family
3	Tcharaze lake	NP	Tcharaze is a permanent lake near the Pungue River and it is surrounded predominantly by a dense herbaceous vegetation.	Fish and lakeside agriculture	E+B	The ceremony is undertaken for the success in fishing and protection from attack by wild animals existing in the water (e.g., snake, crocodile, and hippopotamus). The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season).	Tcharaze (Xaroso)´s family

4	Bhobho pond	NP	Bhobho is a temporary natural water retention site with shallow and still water and it has water in the rainy season and is dry in the dry season. Bhobho is in the middle of a dense forest with a predominance of trees and tall grass.	None	None	It is believed that there is an invisible individual (locally called NDJUNDJU) living in this lake, under the water. The stories relate a total ban on fishing, bathing and farming. In case of disobedience, there is immediately torrential rain accompanied by strong winds and there may even be death of people on the spot. It is considered a dangerous lake, nothing should be explored, and whoever carries an evil spirit can disappear just by approaching the site.	
5	Txissandja mwawa pond	NP	Txissandjamwawa is a temporary body of freshwater with shallow and still water and it has water in the rainy season and is dry in the dry season.In the dry season its bed is completely covered by tall and dense grass. On the edges of the lake there is a variety of trees scattered in the form of a curtain.	Fish, lakeside agriculture, and building material for housing (e.g., stakes and grass for roofing houses)	None	The ceremony is undertaken for the success in fishing and protection from attack by wild animals existing in the water. The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season).	Traditional leaders
6	Nhauthuiro lake	NP	Nhauthuiro is a permanent lake surrounded predominantly by low herbaceous vegetation and some trees including palm trees scattered around. There are many termite mounds along the periphery.		None		
7	Maziara lake	NP	Lake is a permanent surrounded mostly by shrubs and low grass. There are palm trees along the periphery.	Fish and palm wine extraction from nearby palm trees	E		
8	Smaller Nhamathede lake	NP	Smaller Nhamathede is a permanent lake surrounded mostly by tall grass and there are some trees along the periphery. In the rainy season, it works as an outlet for the Bigger Nhamathede lake.	Fish and building material for housing (e.g., stakes)	E+B		
9	Bigger Nhamathede lake	NP	Bigger Nhamathede is a permanent lake surrounded by herbaceous, shrubby and arboreal vegetation with an emphasis on palm trees.				

10	Xindongue lake	NP	Xindongue is a permanent lake surrounded predominantly by low herbaceous vegetation and some trees including palm trees scattered around. In the place there is a lot of presence of birds and wild edible undergrowth.	Fish	E+B		
11	Xitunde lake	NP	Xitunde is a permanent lake surrounded predominantly by tall grass and forest around. In the waters there is water lilies that have been widely used to feed the local people, especially in times of drought and famine.	Fish, lakeside agriculture, building material for housing (e.g., stakes)	E+B		
12	Rufupa lake	NP	Rufupa is a permanent river where half is inside the CCA and the other half is outside. It is surrounded by low grass and has a high bird diversity.				
13	Mvunguti tree (*Kigelia africana*) in Matarandvú bush	NP	Kigelia africana ("Mvunguti) is a tree traditionally used for traditional rites since ancient times. This tree is in a bush with a predominance of a shrub locally called Matarandvú which means hippopotamus shrub. According to native people, the hippopotamus is very fond of being in this bush.	Apart from the people's satisfaction/believe associated with the request for rain, *Kigelia africana* is a medicinal plant traditionally for male sexual health	None	The traditional ceremony is undertaken to ask for rain and also for success and protection in fishing in a nearby pond called Nhabupho (outside the ACC).	Traditional leaders
14	Nhamathede forest	NP	Forest with predominance of palm trees. The people of the community (men) culturally produce palm wine (traditional drink used for traditional ceremonies, consumption and business in the community).	Building material for housing (e.g. stakes) and palm wine which is locally known as "sura".	E	The ceremony is annually undertaken for success in palm wine production and protection from attack by wild animals existing in the forest.	Traditional leaders
15	Nhambira forest	NP	The forest that occupies a vast area in the community. Nhambira forest presents a mixture of high and medium tree strata with diversified species, with palm trees being the most predominant. It is rich in wild animals and small herbivores (gazelles).	Obtaining construction material for traditional housing, palm wine extraction, medicinal plants, and firewood. In the past, hunting and wood extraction were carried out.	E+B	The ceremony is undertaken for the success and safety in the activities of salt extraction, logging and hunting. The ceremony protects against attack by wild animals in the forest (e.g. lion, elephant and buffalo). It is also believed that, given the large extension of the forest area, the ceremony prevents the person from getting lost inside the forest. However, for the collection of material for survival in people's daily lives (eg firewood) there is no need for a ceremony.	Traditional leaders

16	Smaller Nhahamba lake (SNL)	BB	Smaller Nhahamba is a permanent lake, surrounded predominantly by low herbaceous vegetation.	Fish	None	The ceremony is undertaken for the success in fishing, request from rain and protection from attack by wild animals existing in the water (e.g., snake, crocodile, and hippopotamus). The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season).	
17	Nhamanguena lake	BB	Nhamanguena is a permanent lake surrounded predominantly by low herbaceous vegetation.				
18	Tximuxambo lake	BB	It is a permanent lake located inside a dense forest. In the surroundings there are several trees among them the palm trees. Inside the lake, the existence of water lilies stands out.				
19	Guiriro cemitery	BB	The Guiriro cemetery is located inside a forest with a predominance of several trees, including palm trees. On the day of the visit, there were traces of fire passing through the cemetery and the author and motivation were unknown, but it could also be accidental given that forest fires are common in the dry season.	It is a cool and shady place for the dead. In addition, forests have a positive influence on rainfall.	None	The ceremony is performed as a ritual to inform and/or ask the ancestors for permission to bury someone. As a rule, the cemetery is an untouchable place from which no resources should be removed (e.g., firewood, housing construction material, among others).	
20	Caterpillar cemitery	BB	Cemetery in a forest with a predominance of medium height grass and scattered trees. The graves are inside the forest and almost invisible.	It is a cool and shady place for the dead. In addition, forests have a positive influence on rainfall.	None		
21	Mathumusse cemitery	BB	Cemetery in a forest with a predominance of trees. The graves are inside the forest and almost invisible.	It is a cool and shady place for the dead. In addition, forests have a positive influence on rainfall.	Elephant and buffalo hideout	The ceremony is performed as a ritual to inform and/or ask the ancestors for permission to bury someone. As a rule, the cemetery is an untouchable place from which no resources should be removed (e.g., firewood, housing construction material among others). During funeral ceremonies no one should cry in this cemetery under penalty of being attacked by a swarm of bees.	Traditional leaders
22	Sexto Bairro Cemetery	BB	Forest with predominance of palm trees and cement graves inside.	It's a cool, shady place for the dead. You can enjoy the singing of birds and watching some wild animals. This location is also an important site for bee pollination.	Elephant hideout		

23	Macalangana pond	BB	Macalangana is medium-sized natural water retention site (pond). It is a body of freshwater with shallow and still water. Macalangana is covered in dense grass and surrounding trees in the dry season while in rainy season it is totally covered in water.	Fish	None	The ceremony is done for success in fishing, request from rain and protection from attack by wild animals existing in the water (e.g., snake). The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season).	
24	Mussapassua pond	BB	Mussapassua is a small natural water retention site. It is small body of freshwater with shallow and still water and it has water in the rainy season and is dry in the dry season. Mussapassua has muddy soil, surrounded by tall grass and some scattered trees.				
25	Mfula tree (*Sclerocarya birrea*)	BB	A large dioecious and deciduos tree growing wild in a bush along the street in Caterpillar (Bebedo). The tree is surrounded by herbaceous vegetation and some shrubs.	Shadow	None	The ceremony is done to scare away wild animals in the area (elephant, lion and leopards) and request for rain	
26	Dhambaladju lake	NC	It is a permanent large-sized lake surrounded by tall grass and scattered trees, especially palm trees. In the rainy season, this area is completely flooded and the height of the water reaches the palm trees.	Fish, lakeside agriculture, building material for housing (stakes and reeds), and edible fruit of water lily (*Nymphaea sp.*)	None	The ceremony is done for success in fishing, request from rain and protection from attack by wild animals existing in the water. The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season).	Traditional leaders
27	Nsolo Wa Mbidzi lake	NC					
28	Gunga lake	NC					
29	Nsica small lake	NC	It is a permanent small-sized lake near *Nsolo Wambize* lake. It is surrounded by grass and scattered shrubs. In the rainy season, this area is completely flooded.				

Where: NC – Nhamacuenguere, BB – Bebedo, NP – Nhampoca, E – Elephant, and B – Buffalo.

Table 5.2. List of cultural animals reported in CCAs within GNP-BZ.

Nr	Cultural animal	FGDs	Characteristics/Oral tradition/Stories/Miths
1	Woodpecker bird (locally known as Nhangogogo) - *Dendrocopos sp.*	NC: Mid&Elders´ FGDs	"*Nhangogogo is a bird that its chirping sounds like a laugh or whistle. Laughter means something good will happen in the community while whistling means some curse*".
2	Gazelle (*Gazella thomsonii*)	NC: Y&Y´s FGDs	*"Gazelles are thin antilopes that usually live bush. Therefore, when the gazelle voluntarily appears in someone's house, then it is a sign of the death of a member of that family"*.
3	Hipoppotamus (*Hippopotamus amphibius*)	BB: Female´s FGDs	"*The hippo is a large herbivorous and semiaquatic mammal that likes to live in shallow bodies of water (rivers and lakes). When a hippo cries-like grunt it is an announcement of floods. This animal leaves the water and walks towards dry land up to the limit where the flood waters will reach and then returns to the water*".
4	Rat locally called FUSSI (*Rattus sp.)*	BB: Female´s FGDs	*"Fussi is a rat that lives underground and comes out to the community to take our agricultural production to his hole. It culturally brings a message of curse and/or death when this rat stops on two legs and starts with laugh-like squeak"*.
5	Chameleon (*Chamaeleo sp.*)	BB: Famale´s FGDs	"*Chameleons are reptiles that live in a variety of habitats that range from rainforest to desert. When you come across this animal crossing your path, then someone in the family will die*".
6	Double-headed serpent (*Amphisbaena alba*)	NP: NRMC´s FGDs	"*The appearance of a two-headed snake in someone's house means that a member of that family will die*".
		NP: Man´s FGDs	*"When someone crosses paths with the two-headed snake locally called Dhinga, something bad happens in the family"*.
7	Lion (*Panthera leo*)	NC: Mid&Elders	"*The appearance of a lion in the community announces that the spirits of the ancestors are angry because of certain acts of disobedience to the traditions of the community"*
		BB: Mid&Elders FGDs	"*When the lion roars strangely in the GNP or its appearance in the community is synonymous with curse and punishment to the community for disrespecting the cultural heritage."*
8	Pangolin (*Manis spp.*)	NP: NRMC´s FGDs	Pangolins is a mammal species of the family Manidae, uniquely covered in tough and overlapping scales. "*The Pangolin is a rare animal, and the community believes that this is one that falls from the sky. Therefore, its appearance is an announcement of a lot of rain (flood) or a lot of droughts in the community"*.
9	An elephant locally called "Chuva" (*Loxodonta africana*)	BB: famale´s FGDs	"*The elephant attacks were not as common in the past as they have been in recent years. The explanation is associated with the inhibition of access to sacred sites existing within GNP such as cemeteries of traditional leaders. When a traditional chief called Chuva died, he was buried in the GNP buffer zone (outside the usual cemetery). This brought the fury of the elephants who immediately went to destroy the traditional leader's grave and began to take revenge by invading the local community. We believe that the most vengeful elephant is the reincarnation of the Chuva traditional leader, and this elephant was called Chuva because when it arrives at people's homes it eats corn from the barn and strangely, it also eats chickens, drinks palm wine, among other atypical foods*".
10	Owl (*Athene noctua*)	NP: NRMC´s FGDs	"*There is a type of owl that when it arrives in a certain place and starts to chirp strangely, it announces the imminence of a lot of rain*".

		NC: Man´s FGDs	"*Owls are enigmatic birds, by turns mysterious. Owls live a mainly nocturnal lifestyle. However, when the owl arrives at someone's house in broad daylight and starts to chirp, it is understood as an announcement of the death of a member of that family"*.
11	Giant rat (*Rattus norvegicus*)	BB: Famale´s FGDs	*"The giant rat usually lives in bush. Therefore, when you have a sick child at home and you cross paths with a giant rat, it is an indication that that child is going to die"*
12	Bird locally called by Mbalame (*Scopus umbretta*)	BB: Male´s FGD	"*Mbalame is a rare bird but when it appears in the community it is an imminent rain announcement*".
13	Hyena (*Crocuta crocuta*)	NC: Famale´s FGDs	"*The cry of hyenas from the GNP is an announcement of unhappiness in the community or even death of someone*".

Where: NC – Nhamacuenguere, BB – Bebedo, NP – Nhampoca, E – Elephant, and B – Buffalo.

5.5.3. Important aspects of cultural heritages

Four major themes have emerged from the focus groups' discussions thematic analysis of people´s perceptions of the importance of cultural heritage, ranked by frequency of what they have mentioned.

5.5.3.1. Theme 1: Spiritual believes, rituals and ceremonies, and social customs and traditional rules

This theme that was mentioned more often is part of intangible cultural heritage encompassing the spiritual believes, rituals, ceremonies, traditions, and social customs (Fig. 5.3). Therefore, the spiritual approaches have been mentioned in all FGDs and the local people perform rituals and ceremonies for several reasons in their daily live aimed to appease the ancestors' spirits. The participants of FGDs believe that the ancestors spirits live in some local sites considered spiritual and sacred, such as lakes/ponds, cemetery forest, forest, and trees. Hence, these sites must be respected, and nothing should be done without performing due traditional rituals and ceremonies as if not they risk being sanctioned by the spirits of the ancestors. There are myths, stories and beliefs associated with some wild animals and the fact that their appearance to the community brings a (strong) message, for instance, the appearance of lion in the community or when it roars in a strange manner is a signal that the ancestors' spirits are unpleased because of disobedience to the local traditions and customs (Nhamacuenguere: Mid&Elder´s FGDs).

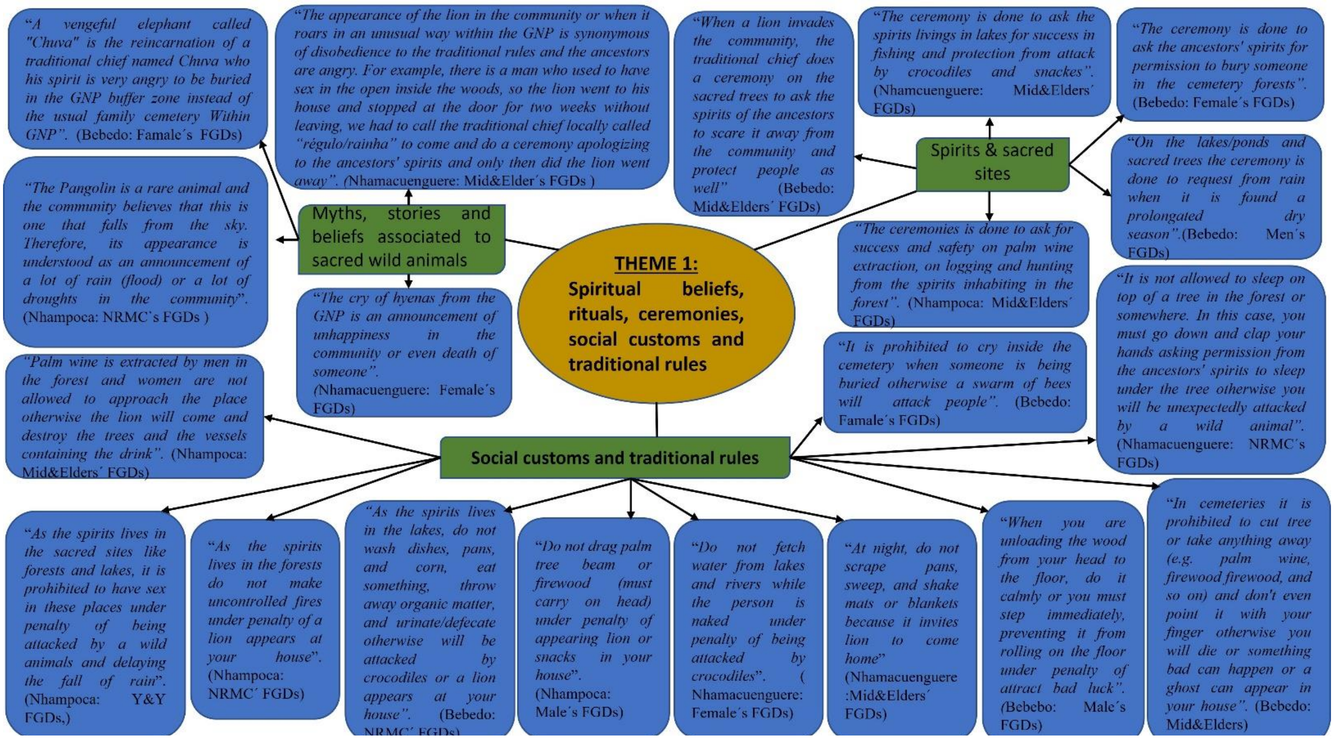

Figure 5.3. Representation of the four themes (in yellow) including the most frequently mentioned codes (in green) and associated quotation from FGDs (in blue).

5.5.3.2. Theme 2: The role of nature in cultural heritages and traditional uses

The role of nature in cultural heritages and its traditional uses was the second most frequently mentioned theme (Fig. 5.3). The spiritual and sacred sites are elements of Nature, and the local people rely on natural resources for their survival and maintenance of their local cultural heritage. Therefore, the natural resources have been traditionally used as medicinal plants, spiritual and sacred sites, plant derivates for ceremonies and rituals, and accessing/harvesting natural resources. The participants of all FGDs reported an historical use of medicinal plants to treat illness (e.g., headaches, flu, stomach ache, heal wounds), male and female sexual health, new-born baby care, among others. In all three communities, palm wine locally called “sura” is considered a spiritual drink. It has been used by traditional chiefs to perform ceremonies and rituals within the community (linked with theme 1). The local people rely on the banks of Pungue River and lakes to practice agriculture on fertile land, collect edible wild plants, raw materials for the construction of traditional houses and traditional arts and crafts (e.g. mats, hats and baskets), among others. Nature provided spirits and sacred sites that should be respected and managed under local traditional norms to appease the ancestors’ spirits (linked with theme 1).

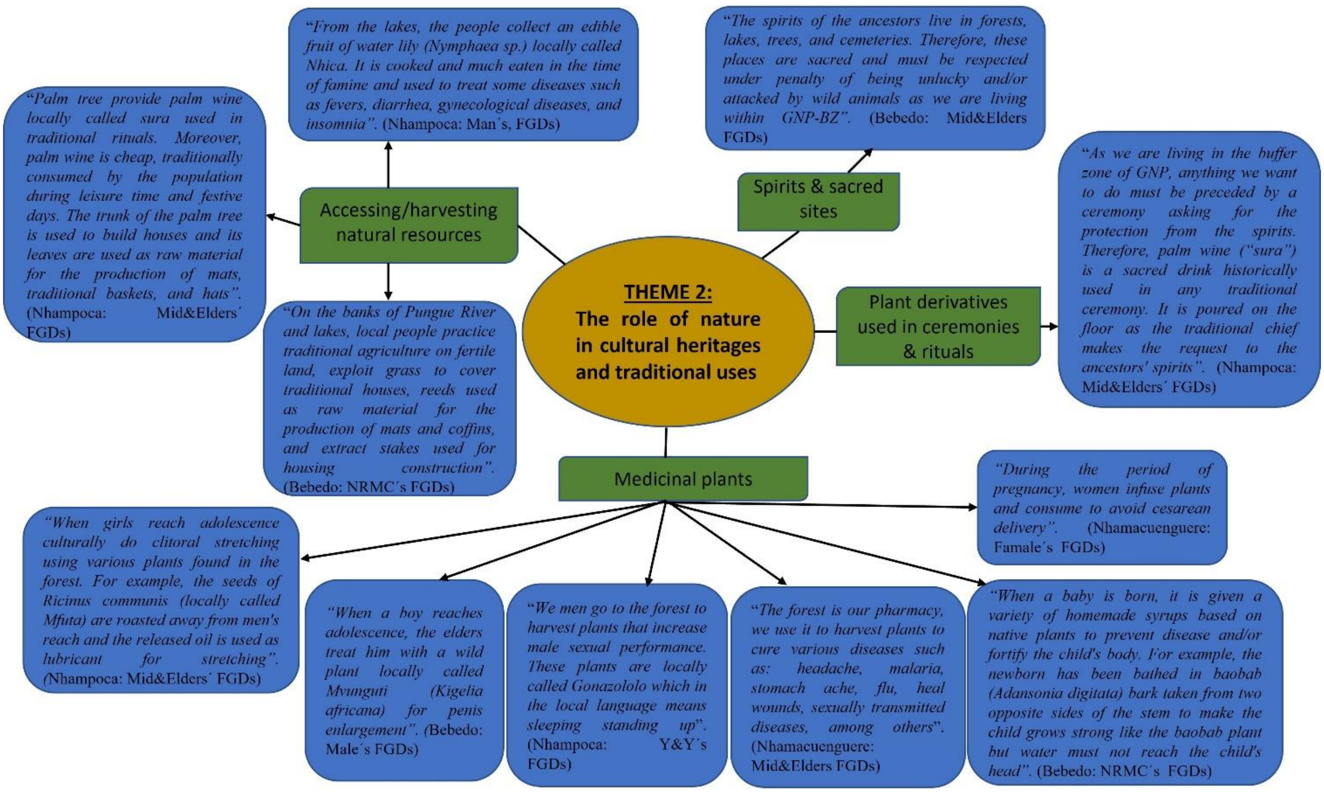

Fig. 5.3. (*continued*)

5.5.3.3. Theme 3: Changes in cultural heritages

This theme describes the change in cultural heritages which was the next mostly frequently mentioned (Fig. 5.3). The FGDs in the three communities (Bebedo, Nhampoca, and Nhamacuenguere) were consensual that the cultural heritage has changed for the worse and there is a significant loss of cultural values and traditions left by the ancestors. It is mainly attributed to ignorance, naivety, unbelief, and contempt (based on frequency of mention); but other reasons recurrently mentioned were: religion; western culture, modernity and education; civil unrest (2013-2019) and raising conflict human-wildlife; and climate change and poverty. Decreasing beliefs of local traditions, ignorance, naivety, and contempt were the main reasons behind the loss of cultural heritage. Respondents said that it is mostly because many people have never suffered as consequence of their actions, and some people feel that the tradition has lost strength since in the past, immediately after the performance of the traditional ceremony, rain fell as a sign of success of that ritual, but nowadays it doesn't happen anymore. Additionally, new generations are no longer interested in the traditions left by their ancestors. The existing protestant churches are contributing to cultural heritage and traditions to become less important as they do not accept that their believers follow local traditions and worship any other “god” (e.g. ancestors spirits, sacred and spiritual sites) than the Lord. Climate change and rising poverty have also influenced cultural heritage as some sacred threes have been toppled by extreme climatic events (e.g., cyclones) which also caused losses of people´s properties and agricultural crops. Some families who lived in the GNP buffer zone (within the south community conservation areas) abandoned important sites of the local culture (e.g. cemeteries, spiritual and sacred lakes) due to increasing elephant attacks and the latest small scale armed conflict centered in Sofala/GNP (2013-2019) (particularly in Nhamacuenguere). This clearly contributed to the impoverishment of the local culture. Moreover, western culture, modernity, and education have due influence on the disappearance of culture and traditions as the new generations are more informed and globalized.

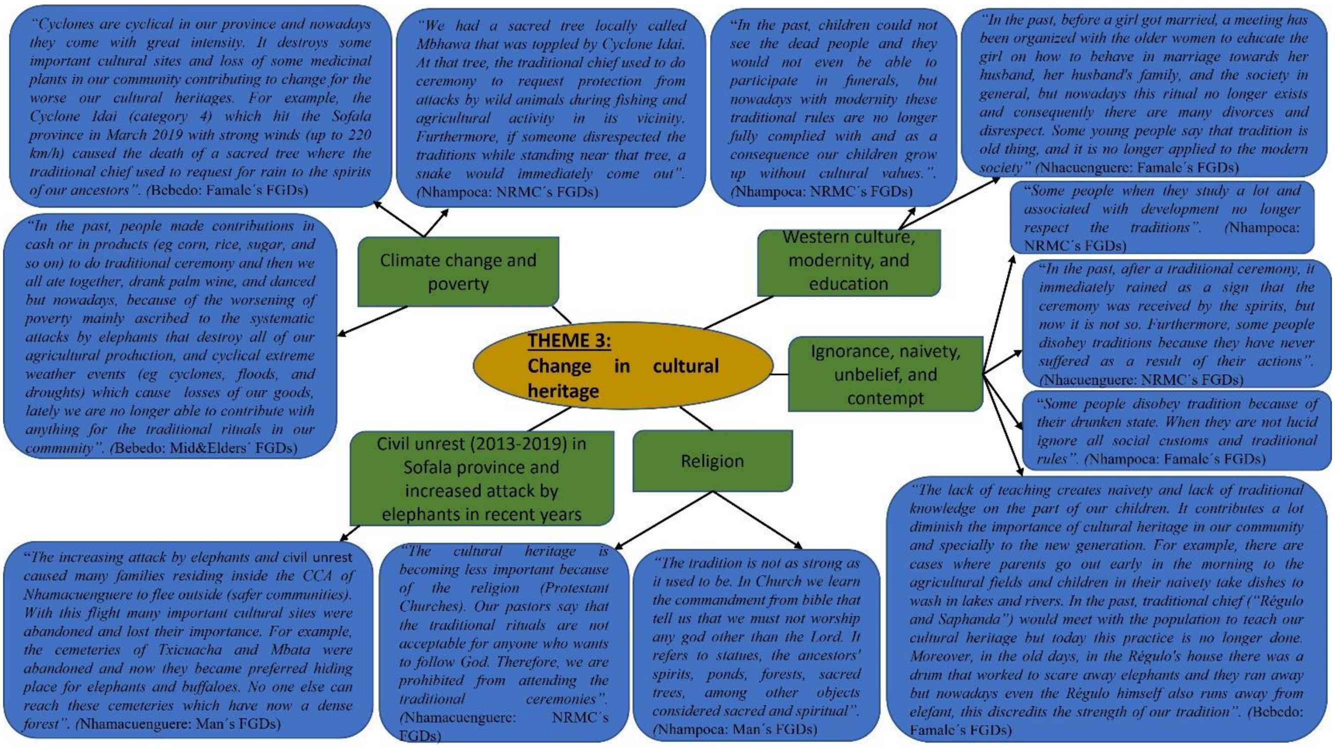

Fig. 5.3. (*continued*)

5.5.3.4. Theme 4: The maintenance of cultural heritage

The maintenance of the cultural heritage was the fourth most frequently mentioned theme (Fig. 5.3). All the FGD participants unanimously mentioned the need for an unconditional maintenance of the cultural heritage. The reasons for the maintenance of the cultural heritage include: (1) people´s well-being, prevention/protection against wildlife and curse; (2) Legacy; (3) Dealing with the impacts of climate change; and (4)

Nature conservation. The most important reason to maintain the cultural heritage is people´s well-being, prevention/protection against wildlife and curse; followed by legacy, and then dealing with the impact of climate change. Therefore, all these three reasons are clearly related to the ancestor´s spirits and traditions (theme 1). According to the FGD participants, the maintenance of cultural heritage means to appease ancestors' spirits and it will guarantee people´s well-being, prevention/protection against wildlife and curse. The respondents defended that the cultural heritage is a legacy left from past, must be experienced in the present, and must be transmitted to future generations in order to perpetuate the traditions and appease ancestors' spirits as well. The FGD participants associate the climate change impacts (e.g. prolongated rains and/or droughts) to the punishment from ancestors´ spirits because of disobedience of the local traditions. Therefore, the cultural heritage has been used to overcome the negative impacts of climate change. Some people have supported the maintenance of the cultural heritage to conserve natural resources as the local tradition prohibits and penalizes practices that are harmful to the environment, such as the use of fine meshed nets in fishing (e.g. mosquito net) and uncontrolled fires.

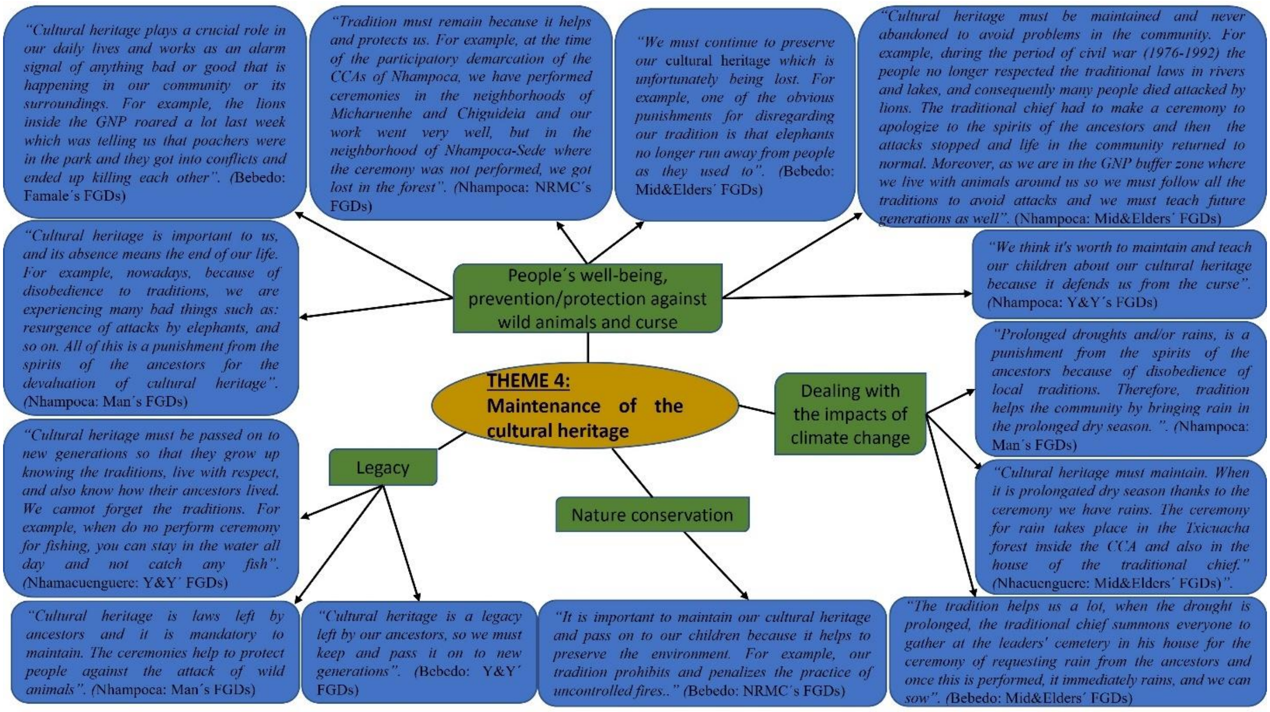

Fig. 5.3. (*continued*)

5.5.3.5. The role of cultural heritage in nature conservation and people wellbeing

Fig. 5.4 shows the influence of tangible and intangible cultural heritage to the positive and negative externalities. In this study, the tangible cultural heritage (TCH) refers to the spirits and sacred sites which include lakes/ponds, cemetery forests, sacred forest, and trees. According to the local tradition, no resources should be removed from the cemetery (e.g., firewood, palm wine, among others). However, the sacred and spiritual lakes/ponds and forests are used the most for the local people livelihoods (provisional ecosystem services) but under the local traditional rules. The Intangible cultural heritage (ICH) includes social customs and rules; and ritual, ceremonies and spiritual believes. Social customs and rules are mainly community stated norms to avoid misfortunes, whereas ritual and ceremonies are performed to ask for permission, protection/safety against wildlife, luck and success, and requests (e.g., ask for rain, and ask the spirits to scare away the lion in the community). Before burying someone in the cemetery, a ceremony must be performed to inform the ancestors and/or ask for their permission. To fish in the lake or to extract wood or palm wine in the forest a ceremony must be performed to ask for protection/safety against wildlife existing in these ecosystems. Moreover, the ceremony is also to ask for luck and success during extractive activities such as fishing, palm wine extraction, logging (formerly often done in the Chichuacha and Nhambita forests in Nhamacuenguere and Nhampoca communities, respectively), among others. The TCH provides goods and services to the local people, whereas ICH guarantees sustainable use of natural resources from TCH and avoid the tragedy of commons as well. Disrespecting the local traditions has negative consequences for the environment (e.g. reduction of ecosystem services and/or ecosystem disservices) and the social well-being (e.g., increased wildlife attack as frequently mentioned in FGDs). The local communities understand that to respect ICH is a natural way to reduce human-wildlife rising conflicts. On the one hand, conservation of TCH contributes to increase ecosystem services (provision, cultural, regulating, and supporting), but on the other hand the wildlife which attack the local people mostly look for shelter in TCH.

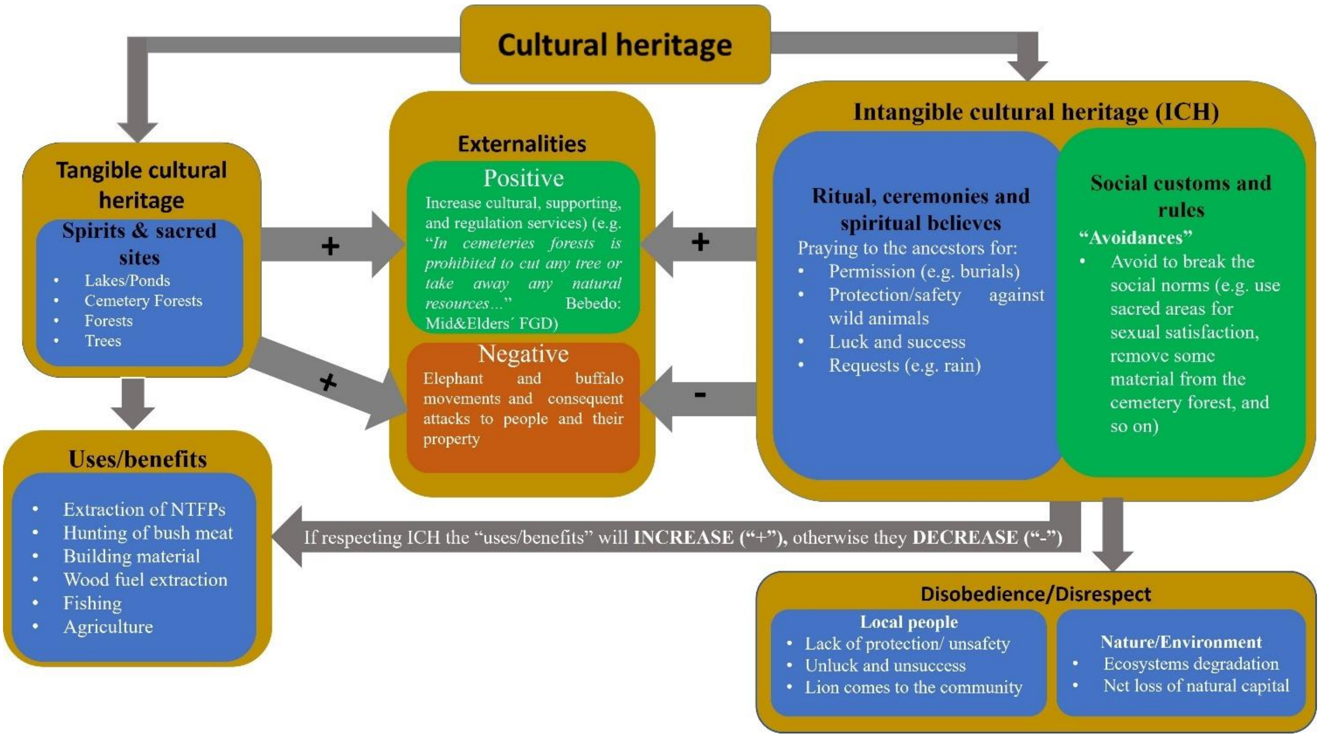

Figure 5.4. Influence of tangible and intangible cultural heritage to the positives and negatives externalities and people well-being.

5.5.4. The native populations' expectations about the establishment of CCA

The local people expectations about the establishment of CCA was found to be an over-arching theme (Fig. 5.5). It encompasses feelings, concerns, and expectations, such as conditional positive perceptions, conditional negative perceptions, unconditional positive perceptions, and negative perceptions. During the FGDs the respondents in all three communities studied brought up more conditional positive perceptions. When focus groups were asked about the expectation on the establishment of CCA the first that came to mind was to erect an electric fence to separate the elephants from the humans and eliminate conflicts human-elephants which is a top priority for the local communities. Therefore, all other benefits, such as increasing the crop production, community safety and protection against fear, food security, among others will happen if an electric fence is put up. The conditional negative perceptions are the reverse side of conditional positive perceptions as the respondents mentioned that if the electric fence will not be installed, then everything else about the establishment of CCA will be negative as, on the one hand, they will have limited access to natural resources and some sacred and spiritual sites existing inside the CCA, and on the other hand the elephants will keep going to the field crops and people´s houses, destroying barns and eating all the agricultural production. There are some people, specifically the young generation, and members of the natural resources management committee that unconditionally support the establishment of CCA as it can bring job opportunities, tourism promotion, local development, and contribute to increase conservation of fauna and flora. Very few respondents have mentioned negative perceptions about the establishment of CCA.

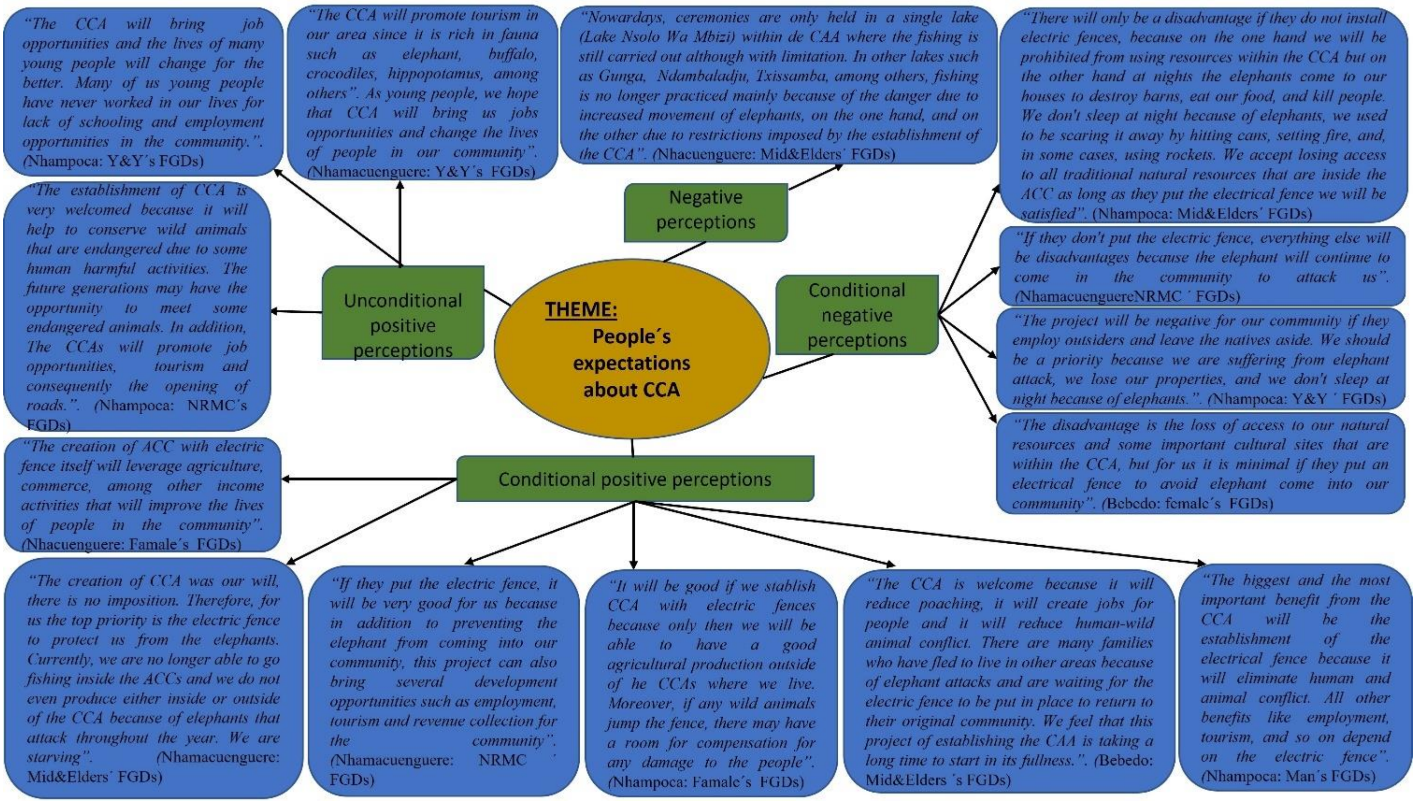

Figure 5.5. Representation of a single theme (in yellow) including the most frequently mentioned codes (in green) and associated quotation from FGDs (in blue).

5.6. Discussion

5.6.1. Perceived importance/value of cultural heritage to people's wellbeing

Our results indicate that the importance of cultural heritage was rated high in all three communities studied regardless of the education level, age, gender of FGDs participants, and community geographic location. A study by Bowra & Mashford-Pringle (2021) found that indigenous people are connected with their cultural heritage (e.g. 3S, land, traditions, myths, taboos, languages, among others) and this greatly increases people's well-being and their satisfaction. Of all of the 3S mentioned, the sacred lakes appeared to be the most valued by local people as they are well known, exist in all three communities, people practice agriculture on the banks of lakes/rivers (main economic activity), fishing, and local people collect reeds for the production of coffins, materials for handicrafts (e.g. mats) and housing construction on the banks of lakes/rivers. The National Population and Housing Census reported that around 51% of the Mozambican population lives in grass-covered housing and 67% of the national population practices agriculture, fishing, forestry and mining (INE, 2019). The FGDs participants are aware of the high potential of the 3S and the CCA in general to attract tourists as they recognized the richness of their area in terms of fauna and flora. Since the local people rely on tangible and intangible cultural heritages to meet their basic needs like food, shelter, and protection against wild animals and adversity from climate change, they unconditionally support its maintenance. Similar results were found by Griffiths et al. (2020) in a study on nature-based cultural values. The local people place great value on cultural heritage because they understand that the end of it means the end of life in the community, mainly because people share the same habitat with wildlife. In addition, cultural heritage is seen as a legacy that must be perpetuated from generation to generation so that the local people can be protected by ancestors' spirits from all harm and live in harmony and mutual respect within the community. An old study (Chittham, 1979) defended that the lives of human beings are guided by a supernatural force that provides them with happiness and the fulfillment of their desires. Similarly, Thammawat (1978) stated that the belief is born as a result of the limitation and incapacity that people face in solving their day-to-day problems.

We found that behind any existing taboo (ICH) in the community, there is a social rational to guarantee respect and well-being within the community, which should be deeply investigated. For instance, all FG participants in Nhampoca stated that it is strictly forbidden for women to approach the palm wine extraction site in the forest under the penalty of the appearance of a lion that will destroy the palm trees, spill all harvested palm wine all over the ground, and causes damage to people. This measure implicitly aimed at preventing sexual harassment or other undesirable behaviour practiced by men under the influence of alcohol. Another tradition with an important social role is the prohibition of sexual intercourse in the forest or in lakes/rivers under penalty of being attacked by a wild animal. In our view, this traditional norm aims to discourage extramarital relationships and prevent people from putting their lives in danger since these places (forest and lakes) are habitats for wildlife. Our findings are an initial step to claim and revitalize indigenous cultural heritages mainly in the context of the ongoing process of creating community conservation areas within GNP buffer zone.

The ignorance, naivety, unbelief, and contempt were found to be the main reasons behind the loss of cultural heritage. As expected, we found that younger respondents are more educated (50% had basic secondary level ranging from grade 8 to grade 10. However, this has not influenced their responses with respect to the importance of cultural heritage in their community and daily lifes. In most of the African countries, it has been reported that young people tend to disrespect 3S and no longer obey the local traditions and norms (Bhagwat & Rutte, 2006; Ekblom et al., 2019). The proliferation of protestant churches in recent times has significantly contributed to reduce the importance of the local traditions insofar as the believers are prohibited to worship the spirits of the ancestors and the 3S. We found that 58% of respondents attend protestant churches and it is in agreement with the percentage of existing Christians across the country (60%) (INE, 2019). It was expected that the negative impact of climate change and poverty could negatively influence the local traditions because the cyclones destroyed some sacred trees and worsened people's poverty, and they are no longer able to contribute with products for the performance of certain traditional rituals as was done in the past. To reverse this scenario and ensure the maintenance of tradition, traditional chiefs have identified alternative trees for performing traditional ceremonies. As in many other African parties (Holmes et al., 2018; Pretty et al., 2009), the FGDs participants have reported that western culture, modernity, and education are factors that contribute to diminish traditional belief among the local people.

In summary, regardless communities’ geographical location and sociodemographic differences, all focus group respondents have a positive perception of the importance of cultural heritage in ensuring the well-being of the population. Moreover, we have found that even believers in Protestant churches are close to their cultural heritage insofar as they grew up learning about its importance. The results have implications for GNP conservationists and managers, and policy makers, in particular those associated with cultural heritages.

5.6.2. The role of cultural heritage in conservation of natural environment

We found that sacred lakes, sacred forests, cemetery forests, and sacred trees are the existing spirits and sacred sites (3S) in all three CCAs within the south GNP buffer zone. The sacred lakes are the most predominant 3S. The history of these 3S is still vague as it passed from generation to generation via oral transmission. Since the local communities believe that the ancestor spirits live in the 3S, these cultural sites must be respected and managed under local social customs and traditional rules, cultural myths, and spiritual beliefs (Intangible Cultural Heritages - ICH). The 3S are conserved through ICH in different parts of the world (Basnet & Dendup, 2021). For instance, in India there are stretches of some important lakes and rivers considered sacred groves, and fishing is strictly prohibited (Anthwal et al., 2010). The human-nature relationships are not uniform in different parts of the world, as they are shaped by worldviews, environmental ethics, values, and day-to-day interactions. Despite the importance of indigenous ICH, it has been neglected in natural resources governance, in part because of its intangible nature and therefore difficult to evaluate (Yletyinen et al., 2022). To the best of our knowledge, we are the first to document how the ICH contributes to environmental conservation around Gorongosa National Park (Mozambique) which is an important biodiversity conservation area in Africa.

Sacred forests only exist in Nhampoca. We visited two (Nhamathede and Nhambira forests) out of four forests which have been mentioned during the FGDs. These spiritual and sacred forests are governed by traditional norms (ICH). Nhambira is a large extension of the forest which had once been used for logging and hunting. These extractive activities have stopped because of CCA initiative and the resurgence of human-animal conflict. Whenever wood was extracted and hunting intook place in Nhambira forest, a traditional ceremony should be undertaken to prevent either being attacked by wild animals living in the forest (e.g. lion, elephant, buffalo, among others) or getting lost inside it. However, to collect the material for peoples daily lives (e.g. firewood, collection of medicinal plants, among others) no ceremonies were required. The same traditional rule is applied in sacred lakes/pods where the ceremony is held annually for group fishing (extractive fishing using a net) to prevent being attacked by wildlife existing in water (mainly crocodiles), while individual fishing for subsistence (with a hook) does not require any ceremony. This suggests that the ancestors' spirits which are regarded glorious are very demanding with respect to extractive activities because they can negatively impact the environment and cause the "tragedy of the commons". The ancestors' spirits are considered the entity that protect and govern life and natural resources within the community. Traditional ceremonies and rituals are performed by local traditional leaders implying that all extractive activities must occur with their consent. Therefore, it prevents unbridled natural resources exploitation, and promotes equity and fairness for future generations (bequest value). Disrespecting local traditions means being willing to pay very high costs that should be quantified. We found that the local people valuate and/or govern the 3S according to the symbolic needs that people believe they satisfy which is in line with a previous study (Ormsby, 2012). For instance, Nhambira forest had once been used for logging and hunting whereas Nhamathede forest where palm trees are dominant is a main provider of traditional alcoholic beverages locally called "sura" (a whitish or colorless and sugary sap). The existence of palm sparse community around the CCAs has been reported by Stalmans and Beilfuss (2008). "Sura" is a spiritual alcoholic drink culturally extracted by men (tapped from the palm stem before it begins to flower) and is used in all traditional ceremonies/rituals (local traditional chief usually pours it on the ground while requesting positive actions from the ancestors' spirits), daily consumption, and business within the community. The extracted sap is usually left in a recipient to ferment for a few hours or even some days to brew (Obahiagbon, 2009). Locally, palm trees were traditionally used in crafts (e.g. mats, hats, and baskets) and construction. Moreover, it has been reported the use of palm trees as medicine (Adedeji & Aiyeloja, 2016), in particular, for ritual purposes to treat baby's in West Africa (Towns et al., 2014), and the use of "sura" in the traditional ritual of libation in southern Mozambique (Martins & Shackleton, 2021). The CCAs' landscape is characterized by the Riftvalley Riverine and Floodplain (Tinley, 1977). Therefore, it suffers frequent flooding during the rainy season. So, the exploitation of "sura" only takes place in the dry season, when it is possible to have access to the palm trees forest. As the tall grass is dry, it is less dangerous and has good visibility in the forest. A concentrated palm tree sap which is considered a high quality "sura" can be then obtained. The palm tree wine exploitation in Nhamathede forest is preceded by an annual traditional ceremony that sets the beginning, under penalty of being attacked by wildlife. Several reasons are behind the protection of spiritual and sacred forests in different parts of the world, such as spiritual and religious practices, burial grounds, their watershed value, among others (Ormsby, 2012). Despite the cultural value of sacred and spiritual sites (sacred forests, sacred lakes, sacred threes, and cemetery forests) and their contribution to biodiversity conservation (based on ICH), they are often sidelined in the main dialogue on natural resource governance in Mozambique. Therefore, there is an urgent need to make profound reforms in policies for the conservation of natural resources in order to integrate the cultural preservation in the management plans.

In the cemeteries, the ceremony is performed as a ritual to inform and/or ask the ancestors for permission to bury someone. According to the traditional norms, collecting any kind of resource (e.g., firewood, housing construction material, among others) in the cemetery is strictly prohibited under penalty of being attacked by wildlife or being visited by ghosts. Since communities co-inhabit with wild animals, the punishment for disobedience to traditional commandments is mostly the attack by the wildlife, which can even be fatal, and everyone fears. Cemetery forests contribute significantly to biodiversity conservation. Therefore, a more comprehensive analysis of the cemetery forests in the country and especially within the GNP and its surroundings is needed. Cemetery forest is considered untouchable because the community believes that the dead need shade. Besides, forests have a positive influence on rainfall, they are a shelter for birds and other animals, and an important site for bee pollination. It should be noted that bees/hives are of great value for scaring away elephants, a technique widely used in Bebebo CCA with support of GNP. Since the dead want peace and no disturbances in the cemetery's ecosystem, in some cemeteries, such as Mathumusse and Caterpillar both in Bebedo CCA, during funeral ceremonies no one should cry under penalty of being attacked by a swarm of bees. From these traditional practices, we can deduce that the local communities give a high importance to bequest and existence values of the natural resources and also to the safeguarding of different ecosystem services (e.g. regulating and support). A previous study carried out in Canada (Quinton et al., 2019) found that local people value highly cemetery forest than forest in other environment, particularly because of shade provision, improved personal wellbeing, and a sense of place.

The local community understands that long droughts or rains (floodings) are punishments of the spirits of the ancestors for disobedience of traditional norms. This is in line with previous studies (Phongsapit, 1990; Phromkaew, 2001) which reported that in the past when people faced any problem (e.g. natural disaster) and could not withstand it, they believed that it had been caused by gods or ancestors spirits who had power over humans. Traditional leaders in CCA beg to sacred trees and some sacred lakes to ask for rain. The request for rain is also made in cemetery forest where the former traditional chiefs were buried, as it is the case of the Cemetery at Sapanda's (vice-traditional chief) house in Bebedo (out of CCA). Sacred trees are preserved under traditional norms and the place is well respected within the studied communities. Sacred trees are keystone ecological entities and provide important cultural services to the local people. However, little is known about sacred trees in Mozambique and many of them may be endangered. In addition to asking for rain, the traditional leaders resort to sacred trees for many other reasons, such as asking for protection against wild animals and scaring them away in case of invasion of the communities. In Southern Thailand there is a (tall and large) sacred tree locally called Chao Bao Noi (the Little Bridegroom) which exists for over 100 years and the indigenous people believe that it is dwelled in by gods. At this tree, rituals are performed to ask for help regarding any concern that distresses the community, such as robbery, disease, natural disaster, among others, and when their wishes are fulfilled, they return to the Chao Bao Noi and perform the ritual of thanksgiving for the favors provided (Sung, 2018). Hindus are very respectful nature and consider it as something divine and/or a manifestation of God's presence. They use natural elements such as plants, animals, and fire in their ceremonies/rituals and worship (Anthwal et al., 2010). Only 2 sacred trees (one in Nhampoca and another in Bebedo) were found within studied CCAs and their protection depend on the local social and customary law, family regulations, myths and taboos. However, surveys of sacred trees in other areas should be undertaken and an effective management tool is urgently needed.

We found a variety of ICH including old beliefs, myths and taboos, social and traditional norms, among others, that have been used to sustainable manage human-nature interactions within CCAs. It prohibits certain practices of natural resources exploitation; prohibits exploitation of natural resources at certain time periods, level, and life stage; and it prohibits exploitation of certain species and/or in certain habitats. From different parts of the world, such as Central Himalaya (Negi, 2010) and Southern Madagascar (Tengö et al., 2007), the use of ICH as an informal institution to regulate the use of natural resources with focus on sustainable development has been reported to contribute more positively to regulate the use of natural resources with focus on sustainable development than official rules/state laws. This is in line with what we have found in the Southern CCAs, despite the various challenges. Therefore, the inclusion and/or promotion of the ICH in the management plans of the CCAs is crucial for the success of this initiative.

We also found that there is “science” underlying the ICH (“environmental taboos”), despite the community not being aware of it. This finding is in line with a similar study carried out in Indian Thar Desert (Yadav & Yadav, 2016). For instance, all FGDs were unanimous in stating that to wash dishes, pans, and corn, eat something, throw away organic matter, and urinate/defecate in lakes or river is strictly prohibited under penalty of being attacked by crocodiles. Therefore, crocodile is a major threat to people in lakes/rivers and it can be attracted to a certain water site due to availability of solid organic matter. Moreover, degradation of organic matter in water bodies occurs with the help of bacteria which consumes dissolved oxygen, and might significantly reduce the quantity available to support life in water (Ramachandra et al., 2015). In addition, the organic pollution can make water unsuitable for human consumption, cooking, among others. Also, water is a scarce resource during long dry seasons when some lakes dry up. Another example of taboos is related to dragging palm trees’ beam or firewood, and sudden discharge of firewood from the head to the ground. These actions are strictly prohibited under penalty of being attacked by wildlife. These taboos represent initiatives to prevent erosion within the CCA. Cabral et al. (2017) found that Sofala Province presents a high risk of erosion and flooding (climate hazard). The strong collision of firewood with the soil can cause the release of sand particles or even create a hole. This can weaken the soil, making it more susceptible to water erosion. Furthermore, the dragging of any heavy material over the ground can cause small openings in the ground that can develop into ravines because of heavy rains or flooding which are a cyclical phenomenon in this region. Therefore, whatever taboo or traditional norm existing in the community has an implicit rational that needs to be deeply investigated.

5.6.3. The native populations’ expectations about the establishment of CCA

In Mozambique the percentage of land dedicated to conservation is growing with the declaration of new parks, reserves, and community conservation areas (CCAs). This latter case is about areas proposed and managed by the community according to their local traditions and norms, and customary practice (cultural heritage). There are many anonymous CCAs over the country but the most popular and officially recognized by the Ministerial Decree are Tchuma Tchato (Tete province) and Chipanje Chetu (Niassa Province). Recently (2021), Gorongosa Project has established two clusters of CCAs within the buffer zones (BZ) of Gorongosa National Park (GNP) where the first is located in the north (Catemo, Nhabaua, Muanadimai, Chidanga, and Maciambosa all in Cheringoma district) and the second group in the south (Bebedo, Nhampoca in Nhamatanda district and Nhamacuenguere in Dondo) totalling 8 areas. Yet, due to financial constraints, only southern CCAs were the subject of our research.

The conflict human-elephant is a serious conservation issue in Bebedo, Nhampoca and Nhamacuenguere communities. Although the establishment of southern CCAs will limit access to natural resources which are crucial for people's survival and will imply the loss of access to sacred and spiritual sites existing within CCA, most of the FGDs participants are favourable to the creation of CCAs with the main condition of putting up an electric fence limiting the CCAs to reduce/eliminate the human-elephant conflict that has been critical and even deadly. The participants with conditional positive perceptions considered that all other upcoming benefits will be due to the construction of an electric fence. The same thought is held by those ("conditional negative perceptions") who have argued that everything will be negative if GNP does not erect an electric fence because nowadays it is no longer possible to produce agricultural crops either inside or outside the CCA (where people live) due to elephant crop raiding. Besides, the establishment of the CCA will be an additional limitation to people daily life. In Bebedo and Nhampoca the human-elephant conflict has occurred mostly in the dry season, whereas in Nhamacuenguere it happens throughout the year. This is because the Pungue River is a natural barrier that limits the GNP and the CCAs of Bebedo and Nhampoca. During the rainy season, the flow of the Pungue River has been very high, which makes it impossible for the elephants to cross to Bebedo and Nhampoca, but the same is not true for Nhamacuenguere due to its geographical location (Fig. 5.1). In these communities, crop raiding by elephants is a major problem that needs to be tackled urgently. In Bebedo and Nhampoca people are at least able to produce some agricultural crops and harvest them during the rainy season before the elephants start to enter the communities. However, in Nhamacuenguere the situation is more critical and there is a risk of food insecurity. In the rainy season, when the areas are flooded, and the soil tends to be muddy, human-elephant conflicts reduce significantly. A study found that elephants can move up to around 6 km/day in dry landscapes and decline up to roughly 3 km/day in the wettest ones (Loarie et al., 2009). In line with Phongsapit (1990) and Phromkaew (2001), the local community understands that the intensification of the human-elephant conflict in recent years is a punishment from the ancestors' spirits because of disobedience to the local traditional laws and norms. For instance, the community of Bebedo understands that the lack of access to sacred cemeteries that existed within GNP may be the main reason for the revolt of the spirits of old traditional leaders and these are incarnated in elephants. In fact, they believe that the most vengeful elephant is a traditional chief ("régulo") called "Chuva" who was buried in a common cemetery within the GNP buffer zone in Bebebo instead of in the traditional leaders' cemeteries inside the GNP. Hence, "Chuva" is locally considered a spiritual and sacred elephant. The idea of reincarnation of traditional chiefs in the form of elephants is also supported by the fact that when elephants arrive at people's houses, they damage properties including barns and eat corn, but strangely they also eat food that a common elephant (herbivore) was not supposed to eat, such as chickens, drinks "sura", among others. In addition, when people shout calling "Chuva", this elephant stops and looks at who is calling. Elephants have been locally considered thinking beings. Similarly, some studies (Locke, 2014; Poole & Moss, 2008) have reported that elephants are social beings with similarities to humans and like us, they have brains with a high encephalization quotient, have feeling, can learn, retain and transmit social information, and grieve the loss of any member. To minimize agricultural losses caused by elephants, the GNP is promoting the construction of cement silos in people´s houses to replace traditional ones made from a mixture of stakes, grass and reeds. During the Mozambique´s post-colonial civil war (1977–1992) which was centered at GNP, park´s megafauna declined by 90% (Daskin et al., 2016). Since 2008, under the Gorongosa Restoration Project, wildlife population has been steadily growing (Pringle, 2017). This may explain the resurgence of human-elephant conflicts in recent years in the communities under study. The trend of elephants' movement towards communities' areas (GNP buffer zone) can be explained by several factors including historical, ecological and also the success of conservation policies in force in Mozambique and specifically at GNP measured by the increased elephant population. It has been reported that 265 people were killed between July 2006 to September 2008 by wildlife in

Mozambique and about 1,116 ha of agricultural crops were destroyed in 2008 mainly by elephants (86%), and hundreds of wild animals have been killed each year (Ministério da Agricultura, 2009). This data is old, needs to be updated with specific data from GNP. Future studies should address the costs of elephant destruction and risks to the local cultural heritages in the GNP buffer zone in order to optimize management practices. Another research opportunity should be the evaluation of the monetary gains (benefits) from the establishment of an electric fence limiting CCAs. De Boer et al. (2007) found that the costs of elephant poaching, and elephant crop raid were greater than the cost of establishing an electric fence in the Maputo Elephant Reserve, Mozambique. Human-animal conflict is a general problem in conservation areas in Mozambique because communities and wildlife co-exist and share the same habitat and national conservation areas are not fenced. Also, the wildlife population is increasing in response to national conservation efforts. As everyone is concerned with the establishment of CCAs to improve nature conservation and the sociocultural well-being of people in a place of conflicting interests, neglected expertise, and ethical controversy; therefore, interdisciplinary research on human-elephant relations under the rubric of ethnoelephantology including social, philosophical, anthropological, ethnographical, and ecological complexity dimensions should be carried out.

Unconditional acceptance was found mainly by young people (Y&Y FGDs) and members of the local natural resource management committee focus groups (NRMC FGDs). Since employment opportunities are scarce, young people see the establishment of CCAs as an opportunity for employment and a change in their lives. The lack of employment opportunities and low schooling have been reasons for early marriage and school dropout, especially for girls. Therefore, as expected, we found that the level of illiteracy is very high in girls compared to boys which is in line with the latest National Population Census that reported an illiteracy rate of 27% for men and 49% for women (INE, 2019). It was expected that NRMC members would support the initiative to establish CCAs because their main mission is to promote the conservation and sustainable use of natural resources within their communities. One of the concerns mentioned in all communities is that when the CCA project starts operating, the local work force must be prioritized.

In general, we found that the local community is committed to the conservation of biodiversity and uses traditional practices. For example, although elephants cause massive damages, local people use non-harmful traditional methods for deterring elephants, such as hitting cans and loud noise, the use of fire, and focusing the elephant with flashlights, but sometimes these methods fail. The movement of elephants through the community begins at sunset and they only come out in the morning, which forces people to stay overnight to scare the animals away and even children have mastered the techniques to scare elephants away. Therefore, it has been revealed that elephants are more active at night when temperatures are low than within-day (Loarie et al., 2009). The local people motivation for conservation, in part, is associated with the fact that the Gorongosa Restoration Project supports the development of communities residing in the buffer zone in various aspects, such as agriculture (distribution of improved seed), beekeeping, providing health services, employ native people, education, among others. In addition, elephants have obtained conservation status in Mozambique.

The construction of electric fences to exclude elephants from community areas has been reported to be the best technical solution to the human-elephant conflicts (Thouless & Sakwa, 1995). Conservationists and wildlife managers have built electric fences in different parts of the world (Evans & Adams, 2016) including in the Maputo Elephant Reserve, Mozambique (de Boer et al., 2007). However, it is also necessary to consider that the placement of an electric fence may bring other challenges to the GNP conservationists and wildlife managers, such as increased pressure on natural resources because elephants to “bunch-up” at a certain site (Loarie et al., 2009), high costs of fencing and maintenance, and not all elephant fences can work effectively against elephants (Thouless & Sakwa, 1995). Hence, a large-scale elephant fencing project needs to be technically and scientifically very well planned (e.g. design, voltage, elephants ecology including their incentives to cross the fence, among other factors).

During the fieldwork, we felt that there is a need for constant and more detailed clarification on the model designed for the operationalization of the CCAs, that is, the management, alternatives to limiting the access to the use of the natural resources existing within the CCAs, sustainability of this initiative, cultural aspects, among others. The Ministry of Earth and Environment (MITA) is the entity in charge of all environmental and conservation issues in Mozambique. The protection of the environment and the well-being of people is stipulated in the Constitution of the Republic of Mozambique. The country has produced a wide range of legislation focused on protection of natural resources, as follow: the Land Law (Law nr 19/97 de 1 de

Outubro), Forest and Wildlife Law (Law nr 10/99, de 07 de Julho), the Conservation Law (Law nr 16/2004, de 16 de Junho), National Biodiversity and Action Plan (2003), among others. In the international arena, Mozambique is a signatory to several treaties and conventions, such as United Nations Convention on Biological Diversity, United Nations Basic Convention on Climatic Changes, African Convention on Conservation of nature and natural resources, Kyoto Protocol, International Union for the Conservation of nature, and so on.

5.7. Conclusion

Gorongosa Restoration Project has launched an initiative to create Community Conservation Areas (CCAs) encompassing the communities of Bebedo and Nhampoca (both in Nhamatanda District), and Nhamacuenguere (Dondo District) in the southern region of Gorongosa National Park (GNP) Buffer Zone (BZ) in Sofala Province, Mozambique, with focus on biodiversity conservation, decrease of human-wildlife conflict, and promote sustainable community development. Studies on the contribution of cultural heritage for nature conservation have been neglected in Conservation Areas in Mozambique mostly due to their intangible nature. However, in this specific case we believe that this study is crucial for the success of the CCA initiative. Our findings revealed that 35 lakes, 6 cemetery forests, 4 forests, and 2 trees are considered sacred and sacred sites (3S) in the studied areas, as the local people believes that 3S are dwelled in by ancestor spirits. The natural resources are historically governed by intangible cultural heritage (ICH) including indigenous ways of living, myths, taboos, stories, social norms, spiritual beliefs, rituals, traditional ceremonies, among others, and any disobedience to local traditions will mean that the offender has a high risk of being attacked by wildlife and it can be fatal. Therefore, the cost of disobeying local traditions and social norms should be estimated. The revitalization and prioritization of (intangible) cultural heritages have the potential to be a powerful tool to improve conservation efforts in CCAs and in the GNP in general and reinforce participatory management of natural resources with greater community involvement and commitment in the future. Regardless the variations of communities' geographic location and socio-demographic levels, we found that all FGDs participants are fully aware of the importance of cultural heritage in people wellbeing, and they are willing to maintain this legacy and pass on to future generations in order to perpetuate the local traditions and appease ancestors' spirits. However, the local people feel that the importance of cultural heritage tends to decline as people no longer respect traditional norms (ignorance, naivety, unbelief, and contempt), proliferation of protestant churches, people tend to be more educated, these communities tend to become more modernized, and negative impacts of climate changes and human-wildlife conflicts. Nowadays, these factors are a great challenge to maintain cultural heritage. Therefore, the protection of cultural heritage should be emphasized through the intervention of GNP managers/conservationists and government by including cultural heritage in decision making and sharing its role within the local communities as well as incorporate (intangible) cultural heritages into modern-day natural resources conservation strategies. Although the establishment of CCA will limit access to natural resources and 3S, all FGDs participants supported the initiative conditional that an electric fence should be erected to prevent elephants from entering the community areas. Therefore, a cost-benefit analysis of the electric fence construction should be carried out based on elephant population size, benefits derived from CCAs (tourism), costs of acquiring and maintaining the electric fence, crop raid costs, and cost of destroyed property.

Supplementary Data – Chapter V

Supplementary Data V.1. The interview guidelines with open-ended questions

Supplementary Data V.2. A poster containing images referring to tangible and intangible cultural heritage

Supplementary Data V.3. Themes and codes emerging from the thematic analysis

Supplementary Data V.4. Illustration of the 3S visited during fieldwork in the GNP-ZT

Supplementary Data V.5. List of 3S mentioned during FGDs but were not visited/mapped

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Chapter VI

Final remarks

6.1. Concluding remarks and prospects

In this concluding section, the key finding of this dissertation entitled "*Value, Management, and Sustainable Use of Biodiversity from Sofala Province in Mozambique*" have been summarized and broadly discussed. It also has broadly reviewed the limitations of this study and proposed opportunities for future research, as presented in the main dissertation chapters (2 to 5):

6.1.1. The impacts of the Tropical Cyclone Idai on Land Use and Land Cover (LULC)

Climate change that we are facing worldwide is increasing the occurrence of the natural catastrophes such as tropical cyclones in the low-lying coastal zones (Knutson et al., 2019; Peduzzi et al., 2012) such as Sofala Province in Mozambique. Hence, a systematic analysis of vulnerability and environmental degradation caused by tropical cyclones is required. We used pre- (2012–2018) and post (2019)-cyclone Idai Landsat satellite images taken during the month of April to analyze temporal changes in Land Use and Land Cover (LULC) across the Sofala Province (Chapter 2). This is the first study revealing the impact of the most devastating and deadliest Cyclone Idai (category four, winds: ~220 km/h, precipitation: >220mm) on different LULC in Sofala. Idai (March 2019) caused the greatest damage in the wood vegetation such as: dense vegetation (decreased by 58.9%), wetland vegetation (−55,5%), and shrub land (−55,5%), whereas barren land (−22,5%), barren vegetation (−26,9%), and grassland and dambos (−27,1%) were relative less affected. The greater damage in wood plants may be ascribed to the higher tree layer and greater tree canopy cover that make them more prone to wind damage than open, short and sparse forest stands (Gardiner et al., 2008; Lanquaye-Opoku & Mitchell, 2005; Macisaac & Krygier, 2009). Therefore, these findings highlight the need for further (field) research and a deep investigation of other factors that influenced the wood plants damage, such as the size of each LULC area, and wood vegetation health status. It is known that around 70% of Mozambique total area is covered by forests and/or other woody plants (USAID, 2008) and Sofala is one of the richest province in terms of plant species and forest with differentiated strata (high, medium, and low). Most of the local people, specifically those living in rural area, below the poverty line, rely on those most devasted plants for their livelihood. The value of wood plants for the local people in Sofala is immense ranging from timber, fuelwood, medicinal plants, food, among others. Future projections of climate change in

Mozambique, specifically in Sofala (most cyclone prone area) indicated an increase in frequency and intensity of cyclones and floods (Macamo, 2021). In addition, it is expected the rising ground water and sea levels in around 1 m by the year 2100 (Chemane et al., 1998; World Bank, 2020). Climate change is a serious threaten to natural (coastal and terrestrial) ecosystems implying the need for the most effective management approaches to protect biodiversity and ensure people's survival.

6.1.2. Vulnerability of coastal mangrove ecosystems

In chapter 3, we used MaxEnt software (Phillips et al., 2017) to model the potential distribution of *A. marina* and *R. mucronata* as a proxy (indicators) of mangroves occurrence area, and through a combination with an Exposure Index (EI) to climate hazards and erosion (Cabral et al., 2017). We found that Zambézia and Sofala provinces are the top priority areas for mangroves management intervention within the country as they presented “High” (1.94–4.26) and “Very high” (2–4.26) EI to climate coastal hazards and erosion, respectively. However, our model revealed that Sofala has the highest suitable habitat for mangroves occurrence (probability of occurrence >0.6, estimated area ~ 890 km^2). The high mangroves risk showed in Sofala and Zambézia is related to their low-lying lands (land surface elevation below 5 m) with many large rivers draining into the Indian Ocean (e.g. Zambezi, Pungue, Buzi, and Save), higher tides and it is more exposed to tropical cyclones, with 6 cyclones in 16 years (Asante et al., 2009). Sustainable management of mangrove forests is still a great concern in Sofala Province. Mangrove forest is paramount for the protection of local communities and their assets against cyclones (Devi, 2019; Macamo et al., 2016) as it is the first wood plants type to be impacted as cyclones move landward with regressive wind flow speed. Hence, future studies should explore the spatio-temporal simulation of the impact of cyclones on environment and society in Sofala under two different scenarios: 1 – With mangroves, and 2 - Without mangroves. It could help to increase local society's awareness about the crucial ecosystem services provided by mangroves and the urgent need for a wise management of mangroves based on directories of global platforms and national legislation.

6.1.3. Nutritional value of the most commercialised dry legume groups

Maintaining the balance between food insecurity and biodiversity conservation is still a major challenge in Sofala. This province is highly affected by food insecurity due to several factors, such as cyclical occurrence of climate events (cyclones and flooding), historical focus of political-military instability, and acute poverty particularly in rural areas where most of the people live beneath the poverty line (Anderson & Learch, 2016) and depend on the nature for their livelihood. Food insecurity is a major threat to biodiversity conservation. Leguminosae is the largest plant family in Sofala, composed by many wild and domesticated (cultivated/semi-cultivated) edible plants (some are endemics) but their nutritional value is still mostly unknown. Due to the scarcity or inexistence of qualified laboratories in Mozambique and the high costs associated with laboratory analysis of locally produced and consumed legumes, studies on this matter are rare and limited to a few project reports. Our study (Chapter 4) was the first comparing nutritional value of eight grains´ sample of dried beans (*Vigna* spp. and *Phaseolus vulgaris*) produced in local conditions (climate and soil) and commercialized in two main markets in Mozambique, namely Sofala and Maputo with focus on increasing food security and agrobiodiversity conservation. Chemical analyses of beans samples were performed at the SGS Laboratory in partnership with the Instituto Superior de Agronomia (ISA) - Portugal. The principal component analysis showed a clear separation between *Phaseolus* and *Vigna* species in terms of proximate composition, whereas protein content was quite uniform in both groups. It is in line with a similar study on mineral analysis of *Phaseolus* and *Vigna* species (Catarino et al., 2021). The production of dry beans is an environmentally friendly practice (enriches the soil inorganic nitrogen and carbon sequestration), and it is particularly suited to alleviate malnutrition. We found that Leguminosae family is the most diverse with 241 taxa within Sofala province. Therefore, future studies should be performed to survey edible Leguminosae taxa and access their nutritional value. It could undoubtedly benefit local populations', health, diet, and food security as well as contributes on (agro)biodiversity conservation efforts.

6.1.4. Importance of cultural heritage (value) on natural resources community management

After a long biodiversity devasting period caused by civil war (1977-1992) centered in Gorongosa National Park (GNP) in Sofala, in 2008 started the Gorongosa Restoration Project (GRP) aimed to restore GNP wildlife and plant biodiversity to its former glory and promote sustainable development of the local communities. In 2021, GRP has launched Community-based conservation (CBC) initiatives by establishing two clusters of Community Conservation Areas (CCAs) in the GNP buffer zones -BZ (South: Bebedo, Nhampoca, and Nhamacuenguere; and North: Catemo, Nhabaua, Muanadimai, Chidanga, and Maciambosa) with focus on biodiversity conservation, promotion of sustainable development, and reduction of the rising human-wildlife conflicts (with emphasis on elephant attacks) by setting participatory zoning limiting the CCA by using electric fences. Due to time and budget constraints, we have concentrated our research only at south CCA and we have assessed the native populations´ perceptions of cultural heritages (CH) for preservation purposes (Chapter 5). The study of cultural heritage is rare in Mozambique and to the best of our knowledge we are the first to perform a deep survey of tangible (e.g. spirits and sacred places/ecosystems) and intangible (e.g. myths, stores, and rituals) CH and map them spatially, and understand the native populations' expectations about the establishment of CCA and how it may affect their cultural heritages and way of life.

The collected data was obtained from a fieldwork that was conducted in the southern region of GNP-BZ using Focus Groups Discussions (FGDs) and participatory mapping of cultural heritage sites. Our results showed the existence of importance spirits and sacred sites (3S) in all three CCAs within the south GNP buffer zone including sacred lakes, sacred forests, cemetery forests, and sacred trees. The sacred lakes are the most predominant 3S. The local communities believe that the ancestor spirits live in the 3S, hence these cultural sites must be respected and managed under local social customs and traditional rules, and spiritual beliefs (Intangible Cultural Heritages - ICH). Cemetery forests contribute a lot to biodiversity conservation as it has been reported that local people put higher value on cemetery forest than forest in other environment, particularly because of shade provision, improved personal wellbeing, and a sense of place (Quinton et al., 2019).

The local people live in the surrounding vicinities of the CCAs but their main source of livelihood is inside the CCA where they practice lake/river side agriculture, fishing, collection of medicinal plants and raw materials for traditional housing construction, extraction of palm wine (traditional drink used in rituals), among others. In addition, the native people are historically linked with their land as some cultural important/sacred/spirits sites (e.g. cemeteries) are inside de CCAs. The ICH basically consists of imposing social norms to avoid breaking the local rules/traditions (e.g. the cemetery is an untouchable place from which no resources such as firewood, housing construction material among others should be removed), and praying for ancestors for (i) permission (e.g. burials), (ii) protection and safety against wild animals (e.g. The ceremony is undertaken for the success in fishing and protection from attack by wild animals existing in the lakes), (iii) luck and success, and (iv) request (e.g. The traditional ceremony is undertaken at sacred threes and lakes to ask for rain). Disobedience of the ICH has high social (e.g. attack by wild animals) and environmental (e.g. reduction of ecosystem services, and delayed rain and prolonged drought) costs that should be quantified in future studies. The ICH is an important biodiversity conservation and management tool passed down from generation to generation which contributes a lot to avoid the "Tragedy of the Commons" (Maljkovi´c et al., 2022).

Although the establishment of CCAs will limit access to natural resources which are crucial for people's survival and will imply the loss of access to sacred and spiritual sites, in general, the local communities are favourable to the creation of CCAs within the south GNP-BZ with the main condition of establishment of an electric fence limiting the CCAs to reduce the human-wildlife conflict (with emphasis on the elephant) that has been critical and even deadly. It has been reported that 265 people were killed between July 2006 to September 2008 by wildlife in Mozambique and about 1,116 ha of agricultural crops was destroyed in 2008 mainly by elephant (86%), and hundreds of problem wild animals have been killed each year (Ministério da Agricultura, 2009). This data is old and needs to be updated. Future studies should address the costs of elephant destruction and risks to the local cultural heritages in the GNP buffer zone. Another research opportunity should be the evaluation of the monetary gains from the establishment of the electric fence limiting CCAs. Human-animal conflict is a general problem in conservation areas in Mozambique because communities and wildlife co-exist and share the same habitat and national conservation areas are not fenced, and wildlife population is increasing in response to national conservation efforts.

6.2. Contribution for biodiversity conservation and management

We believe that this dissertation brought out interesting findings that can serve as a scientific basis for future research and a wise biodiversity management decision-making in Sofala Province, Mozambique. This work has several contributions in the field of biodiversity conservation and management, as follow:

1. Using Landsat 7 and 8 images (with 30 m resolution) taken during the month of April for the 8-year period, we were the first researchers to show the spatial distribution of LULC damage caused by Cyclone Idai across the Sofala Province and quantified the losses on different LULC types. The wood vegetation (dense vegetation, wetland vegetation, and shrub land) was the most impacted by idai and we recommended to be considered as a top priority for management interventions specifically in Sofala and Zambezia Provinces where were found the highest mangroves risk to climate hazards and inundation within the country. It is worth to mention that wetland vegetation includes mangroves which is an important national biodiversity hotspot and lies within the Sofala bank (coastal line) (USAID, 2008).
2. In order to obtain a better precision, the model was run with coordinates for the whole country (Chapter 3), but the main focus was the province of Sofala (study area). Our model found new potential areas of mangroves occurrence in Mozambique such as Southeastern region (e.g. Machangulo Peninsula, Maputo province) although it is mainly dominated by sand dunes (Bandeira & Paula, 2014). There are studies revealing a high rate growth and survival of seedlings of mangroves (*Rhizophora*, *Avicennia*, and *Laguncularia* species) on sandy soils in the Amazon Coast of Brazil (Costa et al., 2016).
3. Despite the importance of indigenous cultural heritage, it has been neglected in natural resources governance and even in risk in Mozambique, in part because of its intangible nature and therefore difficult to evaluate (Yletyinen et al., 2022). However, we documented the value of tangible and intangible cultural heritage for conservation efforts and initiatives in GNP-BZ and contributed for a revival of local cultural traditions, myths, stories, rituals, among others. Furthermore, this thesis reinforced the need to integrate cultural heritage into legal frameworks for

biodiversity conservation within GNP and surrounding areas thus contributing to broader inclusivity, enhanced social cohesion, and participatory community action and engagement.

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Supplementary Data – Chapter V

Supplementary Data V.1. The interview guidelines with open-ended questions

Guião de discussão de grupos focais para a pesquisa de campo intitulada "Assessing Native Populations´ Perceptions of the Importance of Cultural Heritage in the Gorongosa National Park (GNP), Sofala Province, Mozambique "

Consentimento Oral

Este estudo é parte do meu trabalho de doutoramento na Universidade Nova de Lisboa, Portugal, sobre a herança e o património cultural existente na Zona Tampão (ZT) do Parque Nacional da Gorongosa (PNG) em Sofala (Moçambique). Este estudo poderá trazer informação útil para melhoria das políticas conservacionistas, promoção dos valores culturais e bem-estar social das comunidades locais. A informação recolhida será usada para o meu trabalho académico mas também para informar futuras políticas e medidas de gestão, não só no contexto do PNG mas também para a conservação do património cultural a nível nacional e internacional. Gostaríamos de, no futuro, ter mais oportunidades de cá voltarmos para puder partilhar os resultados do nosso estudo e não só.

Aceitam a nossa "entrevista": sim ( ) não ( )

1. Introdução

Moderador: Assim que todos já preenchemos o formulário individual e aceitaram ter uma conversa colectiva, então, já podemos iniciar.

O moderador apresenta-se, agradece a participação.

- O meu nome é Alberto Charrua, sou docente e pesquisador afecto no Departamento de Ciências da Terra e Ambiente (DCTA- FCT) da Universidade Licungo na Cidade da Beira, Sofala.

Introduz o tema: hoje estamos aqui para conversarmos sobre a Importância do Património e Herança Cultural na Zona Tampão do Parque Nacional da Gorongosa (PNG), Província de Sofala, Moçambique.

- Moderador: Herança cultural é tudo que está representado nesta imagem (mostrar panfleto) e muitas mais coisas que só vocês conhecem melhor.

A vossa cultura tem muita importância ao nível nacional e internacional. Como muitos de nós não a conhecemos parte dela ficará perdida/esquecida. Recolher informação sobre o vosso património cultural que é único e documentá-lo é uma forma de o dar a conhecer ao mundo, contribuindo para mostrar a importância que tem para o vosso modo de vida ancestral e como pode ser mantido apesar da evolução natural da sociedade e das respectivas expectativas que terão de melhoria das vossas (e dos vossos filhos) condições de vida e de redução da pobreza. O desenvolvimento deverá andar de par com a preservação da vossa identidade cultural. Tal permitirá atrair turistas nacionais e internacionais e o interesse geral da sociedade e do mundo na preservação do património cultural.

Este estudo tem como objectivo poder ajudar a direcionar as políticas de conservação, nomeadamente, com o objectivo de desenhar soluções que possam contribuir para a coexistência pacífica entre a conservação da natureza e o respeito das tradições das comunidades locais.

Ninguém tem uma opinião errada em relação a nossa cultura e valores, apenas podem existir diferentes ideias. Esta sessão tem como objetivo recolher o máximo de ideias e opiniões que possam ter acerca deste assunto pelo que encorajamos a que todos se expressem livremente. É muito importante que possam aproveitar esta oportunidade, uma vez que os resultados deste estudo poderão influenciar futuras políticas a implementar no parque

Se tiverem alguma dúvida/questão não hesitem em perguntar. Por favor, não hesitem em perguntar, caso não entenderem algo, como conceitos ou linguagens utilizadas.

- Moderador: Gostaria de fazer gravação em áudio e imagens, só para uso interno. Sempre garantindo confidencialidade das respostas. Como a conversa será muito rápida, estamos com receio de não conseguir anotar tudo e acabar perdendo informação relevante. Alguém se opõe à gravação?

Breve apresentação dos participantes

Moderador: Pede que os participantes se apresentem.

Exemplo:

- Bom dia/Boa tarde, o meu nome é xxx, sou natural de xxxxxx, tenho xxx filhos, trabalho em xxxx e gosto de fazer yyyy .

2. Introdução e levantamento da Herança/Património cultural (*cultural heritage*)

2.1. Conceito

Património/herança cultural são atributos físicos e intangíveis herdados das gerações passadas, experimentados pelas gerações presentes e que podem ou não ser transmitidos para as gerações futuras. Os atributos tangíveis incluem florestas sagradas, cemitérios tradicionais, artefactos históricos e arqueológicos, objecto de arte, locais históricos, esculturas, cerâmica, moedas, armaduras, pinturas, etc. Os intangíveis são os costumes, crenças, ritos, rituais, cerimónias, conhecimentos indígenas, costumes e tradições sociais, entre outros. O nosso foco é abordar todos estes atributos no contexto da proteção/conservação da natureza.

- Moderador: mostrar cartaz/foto dos atributos físicos e intangíveis. Pode fazer uma brincadeira muito rápida com os participantes pedindo-lhes para identificar/apontar/assinalar no cartaz.

2.2. Identificação e mapeamento dos sítios culturais (*cultural heritage sites*) na comunidade local

Antes de iniciarmos a nossa conversa, peço que vocês mencionem todas as heranças tangíveis e intangíveis existentes nesta comunidade. Não se esqueçam de indicar os locais comuns ou individuais (e.g. cemitérios, árvores sagradas etc.) espirituais e/ou culturalmente importantes nesta comunidade. Depois, num outro dia a combinar, irei pedir apoio de um/dois representante(s) da comunidade para que visitemos os locais mencionados para representarmos num mapa.

- Moderador: Primeiro deixe que os participantes do focus group mencionem, livremente, os sítios culturais e vai-se preenchendo o que não estiver na tabela. O preenchimento é em grupo, os participantes falam e o moderador vai preenchendo na tabela. Caso algum atributo previamente preparado não tenha sido mencionado pelos participantes, o moderador poderá, a posterior, mencionar só para ajudá-los recordar ou criar uma discussão de grupo sobre um certo atributo caso seja aplicável para a referida comunidade. A dinâmica dos participantes do grupo será determinante para o fluxo da conversa e o moderador deve ser flexível. Todas as tabelas subsequentes seguirão a mesma metodologia.

Nr	Sítios culturais (“cultural sites”) (Nota: Os atributos pré-selecionados são simples exemplos. Primeiro deixe que os participantes, livremente, façam menção no *focus group* e só depois poder-se-á recorrer aos exemplos preparados, caso se adeque ou haja necessidade)	Há quanto tempo o sítio/espécie é importante sob ponto de vista cultural	Área (Km^2) (Nota: Será conseguida com o uso da imagem satélite, durante a fase de processamento de dados (“Trabalho de gabinete”)	Coordenadas geográficas (Nota: A ser preenchido num outro dia marcado exclusivamente para visitar os locais mencionados durante o *focus group*)	
				Lat.	**Long.**
1	Floresta sagrada (indicar os nomes caso haja)				
2	Árvores/espécies sagradas individuais				
3	Cursos de água/recursos hídricos sagrados (rios, lagos, pântanos, riachos, poças)				
4	Montanhas/Rochas/Morro de muchém				
5	Animais sagrados				
6	Matas				
7	Santuários				
8	Cavernas				
9					

3. **Percepção da importância do património cultural (*cultural heritage*) no contexto da preservação ambiental**

3.1. Património cultural tangível e os atributos intangíveis a ele associados

O respeito, importância e conservação de um dado património cultural tangível está relacionado com os atributos intangíveis a ele associados como, por exemplo, costumes, crenças, rituais, mitos, cerimónias, conhecimentos indígenas, costumes e tradições sociais associados aos respetivos sítios culturais. Então, neste quadro interessa-nos fazer o levantamento e descrição dos atributos intangíveis associados a cada sítio cultural anteriormente mencionado no ponto 2.2.

Nr.	**Sítios culturais ("cultural sites")**	**Mitos e histórias relacionadas, crenças e tabus, memórias:** 1. Casamento tradicional/funeral 2. Local para realização de cultos religiosos 3. Cerimónias tradicionais (ex. Rituais de recém-nascidos, pedido de chuva, redução da seca, afugentamento de pragas e maldição espiritual) 4. Mitos e histórias (heróis de guerra, "Deuses", vala comum em tempo da guerra civil ou da independência) 5. Ritos de iniciação (educação masculina e feminina após a adolescência) 6. Circuncisão masculina 7. Outros (mencionar………..) (Nota: Os atributos pré-selecionados são simples exemplos. Primeiro deixe que os participantes, livremente, façam menção no *focus group* e só depois poder-se-á recorrer aos exemplos preparados, caso se adeque ou haja necessidade)
1	Floresta sagrada (indicar os nomes caso haja)	
2	Árvores/espécies sagradas individuais	
3	Cursos de água/recursos hídricos sagrados (rios, lagos, pântanos, riachos, poças)	
4	Montanhas/Rochas/Morro de muchém	

5	Animais sagrados	
6	Matas	
7	Santuários	
8	Cavernas	
9	Pinturas	

3.2. Património cultural tangível e o benefício tangível por este providenciado

Já tendo sido apresentados/listados os sítios culturais, pretendemos explorar a utilização de bens tangíveis da natureza para rituais, crenças, práticas mágico-religiosas entre outras. Sabe-se que a biodiversidade ("Nota: *Moderador deve explicar que biodiversidade é variabilidade entre os organismos vivos de todas as origens: terrestres, aquáticos, marinhos e os complexos ecológicos dos quais fazem parte*") é utilizada para vários fins no contexto da cultura (ex. espiritual, medicina tradicional, matéria-prima na produção de objectos e equipamentos tradicional) e muitos outros que vocês melhor conhecem.

- Moderador: Antes de avançar para o quadro deve pedir para que os participantes deiam alguns exemplos das diferentes formas cultural e tradicional do uso da biodiversidade. Isto pode deixá-los um pouco mais a vontade. A estratégia deve ser primeiro deixá-los falar/discutir livremente e sempre que necessário ou se justificar use os exemplos pré-elaborados só para recordá-los. Usar-se-á a mesma metodologia usada para preenchimento colectivo das tabelas anteriores.

Nr.	**Sítios culturais ("cultural sites")**	**Uso cultural/tradicional de bens tangíveis da natureza** 1. Plantas/ervas medicinais (ex. *Kigelia africana*) e/ou utilizadas em rituais religioso e mágico) 2. Acesso ao uso cultural da biodiversidade (ex. fabrico de instrumento musical, indumentária para rituais tradicional, cestos de palha, casa de palhotas, peneiras, etc) 3. Totem (ex. símbolos tradicionais: pássaros, plantas) 4. Uso de parte da vegetação/animal como cobertura ("roupa") de sítios ou pessoas com fins de proteção espiritual 5. Outros (mencionar………..)
1	Floresta sagrada	
2	Árvores/espécies sagradas individuais	
3	Cursos de água/recursos hídricos sagrados (rios, lagos, pântanos, riachos, poças)	
4	Montanhas/Rochas/Morro de muchém	

5	Animais sagrados	
6	Matas	
7	Santuários	
8	Cavernas	

3.3. Património cultural intangível e os impactos/contribuição para a natureza e os seres humanos

Depois de termos explorado o património cultural tangível, agora gostaríamos de entender de vocês em relação ao património cultural intangível e o seu impacto para a natureza e o sere humano

- Moderador: Use, sempre, a mesma metodologia aplicada no preenchimento colectivo das tabelas anteriores.

Nr.	Património intangível	Impactos/contribuição para a natureza e pessoas Exemplos: 1. Pedido da chuva para o crescimento de culturas agrícolas beneficiando também a flora e fauna 2. A crença de que a colheita de uma planta ou animal traz azar permite a abundancia da mesma e outros seres vivos a ela associada (o contrário também pode ser verdade) 3. … 4. ….
1	Mitos	
2	Tabus	
3	Ritos	

4	Ceremónias	
5		
6		

4. Atitude em relação ao património cultural e a percepção da sua mudança histórica e implicações para conservação da natureza

Atendendo que a cultura é dinâmica, a mudança histórica dos costumes e tradições sociais, crenças, ritos, rituais, cerimónias, conhecimentos indígenas entre outras, obviamente, afecta todo o esforço para a proteção da natureza. Assim sendo, estando esta comunidade na zona tampão do PNG, gostara de perceber a atitude do grupo em relação ao património cultural, como percepcionam a sua evolução histórica e a devida motivação.

- Moderador: Deixe que as questões sejam discutidas oralmente no grupo e depois preencha/anote as respostas.

4.1. Consideram importante preservar os atributos culturais (tangíveis e intangíveis) que identificámos anteriormente?

☐ Sim ☐ Não

Justifique ______________________________

____

4.2. Visitam com frequência os sítios sagrados ou tradicionalmente importantes?

☐ Sim ☐ Não

Porquê______________________________

____

____

4.3. Tem algum sítio, planta ou espécie, ritual, cerimónia, utilização medicinal que no passado **era** importante, mas que **já não é** importante para a vossa cultura e tradição? Porquê?

☐ Sim ☐ Não

Porquê______________________________

____

____

4.4. Tem algum sítio, planta ou espécie, ritual, cerimónia, utilização medicinal que no passado **não era** importante, mas que **já é** importante para a vossa cultura e tradição? Porquê?

☐ Sim ☐ Não

Porquê____

____

____

4.5. Acham que vale a pena continuar a ensinar os mitos, tabus, tradições pró-natureza para as novas gerações?

☐ Sim ☐ Não

Porquê____

4.6. A vossa religião encoraja a utilização de mitos, tabus, tradições para a proteção da natureza?

☐ Sim ☐ Não

Porquê____

4.7. Acham que os sítios sagrados seriam importantes para atrair turistas para a vossa comunidade?

☐ Sim ☐ Não

4.8. Existe algum sítio que vos dá medo de lá irem porque provoca azar?

☐ Sim ☐ Não

Se sim, quais?____

4.9. Acham que as cerimónias e outros eventos tradicionais ainda funcionam e ajudam no bem-estar social da comunidade?

☐ Sim ☐ Não

Se sim, de que forma

____

____

____

____

4.10. Quais foram as mudanças históricas mais salientes que ocorreram na vossa cultura nos últimos 20 anos e que tenham a ligação com a natureza ?

____

4.11. Caso afirmativo, diga as causas:

- Moderador: deve esperar que os participantes enumerem as causas e vai colocando um "check" na lista pré-elaborada caso sejam mencionadas e paralelamente vai listando as que não constam da lista abaixo. No final vai confrontar os participantes com as causas abaixo e que não foram arroladas.

i. Falta de meios alternativos de subsistência levando a destruição de locais sagrados para prática de agricultura itinerante, caça com recurso ao fogo, etc)
ii. Aumento populacional (aumentando a pressão sobre os recursos)
iii. Mudanças climáticas (eventos climáticos extremos como ciclones, seca, cheias) tem contribuído para destruição de sítios e espécies culturalmente importantes
iv. Desenvolvimento socioeconómico (estímulo ao comércio de plantas e/ou animais)
v. Modernização e aumento do nível académico
vi. Aumento de circulação de pessoas externas a comunidade
vii. Religião (algumas igrejas desvalorizam o respeito pelo antepassado, *cultural heritages* entre outros valores culturais)
viii. Conflitos

5. Expectativas (futuras) referentes ao estabelecimento das Áreas de Conservação Comunitária (ACC)

Neste tema interessa colher a vossa expectativa com o estabelecimento das ACC relativamente a utilização cultural dos recursos naturais e diferentes incentivos/projectos de desenvolvimento relacionados com a conservação da natureza. Acreditamos que muitos de vocês podem ter expectativas (favoráveis e desfavoráveis). Assim, precisamos colher o vosso parecer que nos pode ajudar a contribuir para a definição das políticas de implementação da ACC e melhorar a convivência entre as partes envolvidas.

5.1. Questão geral: Qual é o benefício e o malefício que acham que a ACC possa trazer na comunidade?

Benefício:____
____
____

Maléfício:____
____
____

- Moderador: Faça questão aberta (pergunta nr 5.2) para discutir as expectativas dos participantes em relação a utilização cultural da biodiversidade e o acesso aos locais de relevância tradicional. Se não abordarem todos os aspetos pode partir para a tabela.

5.2. Quais são as expectativas em relação a utilização cultural da biodiversidade e acesso aos locais de relevância tradicional?

____
____
____

Legenda:

i) Quantidade do recurso cultural: 1 -Aumento, 2- Mantém, 3 – Redução

ii) Disponibilidade do recurso/serviço cultural para população: 1. Proibição total, 2- Restrição parcial/condicionado 4 – Livre acesso

Ord.	***Património cultural***	**Quantidade**	**Disponibilidade do recurso/serviço cultural para população**
1	Plantas/ervas medicinais usadas para fins culturais		
2	Local para realização de cultos e cerimónias tradicionais		
3	Acesso ao uso da biodiversidade para o uso cultural (ex. usado para fabrico instrumentos musicais, roupas usadas em rituais tradicional, cestos de palha, casa de palhotas, peneiras, objectos de arte, etc)		
4	Totem (ex. símbolos tradicionais: pássaros, plantas)		
5	Uso de parte da vegetação/animal como cobertura ("roupa") de sítios ou pessoas com fins de proteção espiritual		
6	Acesso a locais tradicional de pesca		
7	Acesso a locais de avistamento de animais culturalmente considerados importantes		
8	Acesso a água		
9	Acesso a terra para cultivo agrícola tradicional		
10			
11			

5.2. Expetativas em relação aos projectos de desenvolvimento comunitário e sua influência na herança/património cultural

Com esta abordagem interessa-nos colher a vossa percepção/expectativas em relação aos potenciais impactos dos projectos de desenvolvimento comunitário a serem implementados (no futuro) no âmbito do estabelecimento das ACC. Importa referir que os projectos selecionados são "amigos do ambiente" ("*environment friendly projects"*) e, obviamente, contemplam todas as dimensões do desenvolvimento sustentável (ambiental, económica e socio-cultural).

- Moderador: Antes de tudo faz uma pergunta aberta no sentido de colher a sensibilidade dos participantes em relação aos potenciais projectos de desenvolvimento comunitário no contexto socio-cultural.

5.2.1. Acham que estes projectos são bons para a vossa cultura? Terá algum impacto na vossa cultura?

1. Ecoturismo de contemplação/fotográfico ou associado a restauração e artesanato

2. Agricultura (Horticultura)

3. Fomento da apicultura

4. Lodge comunitário (Nhamacuenguere)

5. Pomar de cajú (Bebedo e Nhampoca)

6. Aquacultura (Nhampoca)

Moderador: Se não estiver satisfeito com as respostas, siga para o quadro abaixo que contém alguns exemplos de impactos (só para ajudar a conduzir a conversa, se julgar necessário)

Potenciais projectos	**Ambiente receptor/ atributo do património cultural**	**Impacto/influência sobre o *Património cultural (“cultural heritages”)***
Ecoturismo de contemplação/fotográfico ou associado a restauração e artesanato	Árvores, espécies animais e vegetais e locais sagrados	Ex. Aumento do valor cultural dos locais e plantas sagradas
	Rituais, mitos e histórias, crenças e tabus e memórias	
Agricultura (Horticultura)	Árvores, espécies animais e vegetais e locais sagrados	Ex. Contribui para segurança alimentar e, consequente, redução da pressão sobre locais/espécies sagrados
		Ex. A prática de agricultura sustentável reduz o risco de perda/degradação de locais sagrados pela eliminação de práticas tradicionais como o uso do fogo
	Rituais, mitos e histórias, crenças e tabus e memórias	Ex. Aumento da produção devido fomento agrícola reduz a necessidade de rituais para o pedido da chuva e aumento da produção
Fomento da apicultura	Árvores, espécies animais e vegetais e locais sagrados	Ex. As abelhas podem dificultar a colecta de espécies com importância cultural e/ou acesso aos locais sagrados
	Rituais, mitos e histórias, crenças e tabus e memórias	Ex. O uso de colmeias/abelhas pode substituir as práticas tradicionais de batucadas/foguetes para afugentar certos animais (ex. elefantes)
Lodge comunitário (Nhamacuenguere)	Árvores, espécies animais e vegetais e locais sagrados	
	Rituais, mitos e histórias, crenças e tabus e memórias	
Pomar de cajú (Bebedo e Nhampoca)	Árvores, espécies animais e vegetais e locais sagrados	

	Rituais, mitos e histórias, crenças e tabus e memórias	
Aquacultura (Nhampoca)	Árvores, espécies animais e vegetais e locais sagrados	
	Rituais, mitos e histórias, crenças e tabus e memórias	

6. Conclusão da discussão

Na nossa conversa hoje iniciamos com conceitualização do património/herança cultural (tangível e intangível), o levantamento/identificação (oral) da existência dos mesmos nesta comunidade, sua importância no contexto da conservação da biodiversidade e, também, a importância desta (biodiversidade) para a cultura local. Atendendo que a cultura é dinâmica, mais a diante, conversamos sobre a atitude dos participantes do grupo focal em relação ao património/herança cultural e a percepção (dos participantes) sobre a mudança histórica da sua cultura e implicações na conservação da natureza. E, no final da nossa conversa, discutimos sobre as vossas expectativas (futura) em relação ao estabelecimento das ACC. Estas informações são muito importantes para mim. Com a equipa que me acompanha nesta pesquisa iremos sistematizar a informação e partilharemos com os diferentes *stakeholders*. A informação por vós fornecida, certamente, irá contribuir para o melhoramento das políticas de implementação das ACC, do bem-estar social e da convivência entre as partes envolvidas.

6.1 Há alguma dúvida sobre o que foi discutido esta manhã/tarde?

____

____

__

6.2 Têm algo a acrescentar? Há algum assunto que tenha ficado por discutir?

____

____

__

6.3 Têm alguma sugestão?

____

____

__

Moderador:

Agradecer pelo tempo e participação na discussão.

INFORMAÇÃO INDIVIDUAL DOS PARTICIPANTES

Nome da Comunidade_____________________ Data__________________

- Moderador: Gostaríamos de obter algumas informações individuais dos participantes dos grupos focais. Antes de iniciarmos a nossa conversa vamos, juntos, preencher um pequeno formulário individual de cada participante do grupo focal.

Todas as respostas dadas são confidenciais.

Informação individual dos participantes do *focus group*
7. Nome: ______________________________
8. Gênero: M___ F___ Outro___
9. Idade: ________________
10. Estado civil: □ Casado □ Solteiro □ Co-habitação □ Viúvo/a □ Divorciado/ Separado
11. Nasceu nesta comunidade: □ Sim □ Não 5.1. Se não, há quanto tem vive nesta comunidade?________________ 5.2. Se não for natural, onde vivia antes?____________________ 5.3. Se não for natural, porquê migrou para esta comunidade?_____________________
6. Nível de educação ___________________
7. Religião ______________________________
8. Principal actividade económica: ________________________

Supplementary Data V.2. A poster containing images referring to tangible and intangible cultural heritage

Avaliação das percepções sobre a herança cultural das populações locais no Parque Nacional da Gorongosa (GNP), província de Sofala, Moçambique

1. Introdução

Património/herança cultural são atributos físicos e intagiveis herdados das gerações passadas, experimentados pelas gerações presentes e que podem ou não ser transmitidos para as gerações futuras. Os atributos tangíveis incluem florestas sagradas, cemitérios tradicionais, artefactos históricos e arqueológicos, objecto de arte, locais históricos, esculturas, cerâmica, moedas, armaduras, pinturas, etc. Os intangíveis são os costumes, crenças, ritos, rituais, cerimónias, conhecimentos indígenas, costumes e tradições sociais, entre outros.

2. Atributos tangíveis

2. Atributos intangíveis

Supplementary Data V.3. Themes and codes emerging from the thematic analysis

Theme 1: Spiritual beliefs, rituals, ceremonies, social customs and traditional rules	Theme 2: The role of nature in Cultural heritages and traditional uses	Theme 3: Change in cultural heritage	Theme 4: Maintenance of cultural heritage
Myths, stories, and beliefs	Building material for housing	Frequency of occurrence of extreme weather events	Teaching younger generations
Ancestors' spirits	Traditional Palm wine ("Sura")	Religion´s influence	Legacy left by ancestors
Social customs and traditional rules	Edible wild plant and fruits	Loss of cultural values	Nature conservation
Wild animals' attacks are punishment	Traditional arts and crafts	Modernity	People´s well-being
Fishing, logging, and palm wine extraction traditions	Medicinal plants	Higher education level	Prevention/protection against wildlife and curse
First harvest tradition of fish	Production of traditional coffins	Abandonment of spiritual and sacred sites	Dealing with the impacts of climate change
Traditional leaders and burial grounds	Specific harvesting / planting times	Ignorance and naivety	Cultural heritage is crucial for people's survival
Sacred and spiritual sites	Penis and clitoris stretching	Unbelief and contempt	Manner and behaviour
Ceremonies for rainy, luck, success, and protection	Firewood collection	Poverty	Maintenance of marriages
Traditional alcohol (Palm wine, "Sura")		Latest civil unrest	Luck and blessing
Improved sexual performance		Increased elephants attack	Men and women´s role
Punishment/anger for the spirits of the ancestors		Western culture	Appease ancestors' spirits
Untouchable place from which no resources should be removed		Loss of access to sacred and spiritual sites	
Places where no one should cry or have sex		Loss of access to natural resources	
Messages announced by wild animals			
Burial traditions			
Traditional rules of behaviour at night			
Traditional prohibition on water pollution and soil erosion			

Prohibition of women approaching sura extraction sites
Reincarnation of ancestors in animal form
Extreme weather events are punishment

Single Overarching Theme: People´s expectations about CCA
There will only be positive effects if they erect an electric fence
CCA will be totally negative if they don't build an electric fence
Tourism promotion
Job opportunities for natives
Elimination of human-animal conflict
Improvement of family income and quality of life
Better conservation of flora and fauna
Improvement of agriculture
Improvement of the condition of the roads
Fear of natives not being a priority in terms of job opportunities
Reducing hunger in the community
It doesn't matter if community loses access to natural resources and sacred sites as long as they put the electric fence

Supplementary Data V.4. Illustration of the 3S visited during fieldwork in the GNP-ZT

BEBEDO

Caterpillar cemetery

Mathumusse cemetery

Guiriro cemetery

Sexto Bairro cemetery

Nhamanguena lake

Smaller Nhahamba lake

Tximuxambo lake

Mfula tree

Macalangana pond

Mussapassua pond

NHAMACUENGUERE

Dhambaladju lake

Nsolo Wa Mbidzi lake

Nsica lake

Gunga lake

NHAMPOCA

Regulo´s lake

Rufupa lake

Xindongue lake

Tcharaze lake

Xitunde lake

Nhauthuiro lake

Maziara lake

Smaller Nhamathede lake

Bigger Nhamathede lake

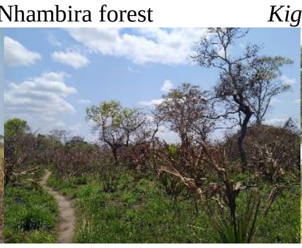
Nhassambo/Zuanane lake

Txissandjamwawa pond

Bhobho pond

Nhamathede forest

Nhambira forest



Kigelia africana (Matarandvú bush)

Supplementary Data V.5. List of 3S mentioned during FGDs but were not visited/mapped

Nr.	Cultural sites/thinks	Area	Perceived benefits from 3S	Perceived drawbacks of 3S	Intangible cultural heritage associated: Oral traditions and local management rules	Who does the traditional ceremony?
1	Nhamawero lake	NP	Fish	None	The ceremony is done for success in fishing and protection from attack by wild animals existing in the water. The ceremony is held annually for group fishing (manual fish catching) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season).	Nhamawero´s family
2	Nthunduhue lake	NP	Fish, lakeside agriculture, and building material for housing	E		Traditional leaders
5	Nhahuro lake	NP		E		
3	Nhampimbe lake	NP		E+B		
4	Mvunho lake	NP		E+B		
6	Sapaia lake	NP		E+B		
7	Tchicune lake	NP		E+B		
8	Txanguena lake	NP		E+B		
9	Nhamacone lake	NP		E+B		
10	Ndumbua lake	NP		E+B		
11	Tximbanda lake	NP		E+B		
12	Xahuihui forest	NP	Obtaining construction material for traditional housing, medicinal plants, and firewood.	E		
13	Tximbinda Txambondoro forest	NP	Housing construction material (stake)	E	The ceremony is done for protection against attack by wild animals.	
14	Kubhuyu forest	NP	Housing construction material (stake) and palm wine	E		
15	Lago Txissamba	NC	Fish, lakeside agriculture, building material for housing (stakes and reeds), and edible fruit of water lily (*Nymphaea sp.*)	E+B	The ceremony is done for success in fishing, request from rain and protection from attack by wild animals existing in the water (e.g., snake, crocodile, and hippopotamus). The ceremony is held annually for group fishing (using a net) while individual fishing (with a hook) does not require any ceremony. The ceremony is performed when the water starts to recede (mid-dry season).	
16	Lago Ndambaladju	NC	Fish, lakeside agriculture, building material for housing (stakes and reeds), and edible fruit of water lily (*Nymphaea sp.*)	E+B		
17	Cemitério de Txicuacha	NC	None	E+B	In the old days (when it was still used), The ceremony used to be performed as a ritual to inform and/or ask the ancestors for permission to bury someone. As a rule, the cemetery is an untouchable place from which no resources should be removed (e.g., firewood, housing construction material among others).	
18	Cemitério de Mbata	NC	None	E+B		

Where: NC – Nhamacuenguere, BB – Bebedo, NP – Nhampoca, E – Elephant, and B – Buffalo.