Relationships Between Fire and Protected Areas: A Mixed Methods Approach for Mozambique

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Abstract

This mixed methods research aims to examine the effects of some physical and human drivers on the occurrence of burned areas due to wildfires in the context of Mozambique, with particular consideration of protected areas. Mozambique provides a sub-/tropical developing country context with a rich recent history, where most of the population relies on functioning ecosystem services. The research aims to provide understanding of aspects of the wildfire system as a basis for informing strategies for fire and protected area management and further research. Exploratory data analyses and logistic regressions (on matched) physical and human variables derived from remotely sensed data, predict that nationally, protected area pixels are more likely to be burned. Secondly, this is also the case for the protected areas Niassa Special Reserve and Gorongosa National Park, whilst pixels within Limpopo National Park are less likely to be burned. Thirdly, by linking results from the quantitative analyses with qualitative results from data collected in Gorongosa National Park in 2012, the wildfire systems at the local context was examined through the relationships of the stakeholders, through issues such as land tenure, poverty and conflict. And lastly, any attempt to pick up on potential signals in the burned outcome due to general differences due to climatic, political, natural disaster events, in two time periods (2001-2006 and 2010-2015) have not been attributable to any differences.

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Abbreviations and Acronyms

AfDB	African Development Bank
ANAC	National Administration of Conservation Areas (*Administração Nacional das Áreas de Conservação*), Mozambique
B	Buffer Zone
CCA	Community Conservation Areas
CENACARTA	National Centre for Cartography and Remote Sensing (*Centro Nacional de Cartografia e Teledetecção*), Mozambique
CGIAR-CSI	Consortium of International Agricultural Research Centers – Consortium for Spatial Information
CI	Confidence interval
CIESIN	Center for International Earth Science Information Network
COP26	Conference of the Parties (2021 United Nations Climate Change Conference 31 Oct-12 Nov 2021)
DEM	Digital elevation model
DF	Degrees of freedom
DINAF	National Forestry Directorate (*Direcção Nacional de Florestas*), Mozambique
DS	Dry Season
DUAT	Use and benefit of land rights title (*direito de uso e aproveitamento da terra*)
EN	National road (*estrada nacional*)
ENSO	El Niño - Southern Oscillation
ESA	European Space Agency
ESA CCI	European Space Agency Climate Change Initiative
EU	European Union
FAO	Food and Agriculture Organization
FR	Forest Reserve
FRELIMO	*Frente de Libertação de Moçambique* (Liberation Front of Mozambique)
FS	Fire Season
GIS	Geographic information system
GNI	Gross national income
GNP	Gorongosa National Park
GoM	Government of Mozambique
GPA	General Peace Accord
GRP	Gorongosa Restoration Project
HDI	Human Development Index
HR	Hunting Reserve
HWC	Human-Wildlife Conflict
INAM	National Meteorological Institute (*Instituto Nacional de Meteorologia*), Mozambique
INGC	National Disaster Management Institute (*Instituto Nacional de Gestão de Calamidades*), Mozambique
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IQR	Interquartile range

ITCZ	Inter-Tropical Convergence Zone
ITOS	Information Technology Outreach Services
IUCN	International Union for Conservation of Nature
LC	Land cover
LNG	Liquefied natural gas
LNP	Limpopo National Park
MADER	Ministry of Agriculture and Rural Development (*Ministério da Agricultura e Desenvolvimento Rural),* Mozambique
MIMAIP	Ministry of Sea, Inland Waters and Fisheries (*Ministério do Mar, Águas Interiores e Pescas*), Mozambique
MIREME	Ministry of Mineral Resources and Energy (*Ministério dos Recursos Minerais e Energia*), Mozambique
MTA	Ministry of Land and Environment (*Ministério da Terra e Ambiente)*, Mozambique
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized difference vegetation index
NGO	Non-governmental organisation
NP	National Park
NR	National Reserve
NSR	Niassa Special Reserve
PA	Protected Area
PC	Principal component
PCA	Principal Component Analysis
PPP	Purchasing power parity
REDD+	'Reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries'
RENAMO	*Resistência Nacional Moçambicana* (Mozambican National Resistance)
RQ	Research question
S	Sanctuary
SADC	Southern African Development Community
SEDAC	Socioeconomic Data and Applications Centre
SIOD	Subtropical Indian Ocean Dipole
SOI	Southern Oscillation Index
SR	Special Reserve
SRTM	Shuttle Radar Topographic Mission
SST	Sea Surface Temperature
TFCA	Transfrontier Conservation Area
TRMM	Tropical Rainfall Measuring Mission
UN	United Nations
UNDP	United Nations Development Programme
UNEP-WCMC	United Nations Environment Programme – World Conservation Monitoring Centre
USAID	United States Agency for International Development
USGS	United States Geological Survey
VIF	Variance inflation factor

WASH	Water, Sanitation and Hygiene (UN Sustainable Development Goal 6)
WCS	Wildlife Conservation Society
WDPA	World Database on Protected Areas
WS	Wet Season

Declaration

I, the author, confirm that this Thesis is my own work. I am aware of the University's Guidance on the Use of Unfair Means (www.sheffield.ac.uk/ssid/unfair-means). This work has not been previously been presented for an award at this, or any other, university.

1. Introduction

1.1. The 'Problem'

Fire influences many aspects of the global environment, including ecosystem distribution, (e.g savannah-woodland ecosystems), maintaining biodiversity (e.g. Govender et al., 2006) as well as the carbon cycle, atmospheric chemistry and climate (Scholes, 1995; Shlisky et al., 2009; Aldersley et al., 2011). Fires can release great amounts of greenhouse gases from carbon stock in biota, affect local and regional air quality (Shlisky et al., 2009; Driscoll et al., 2010), and particulate matter propelled into the atmosphere (Figure 1-1) can cause cardiovascular and respiratory problems in humans, but also scatter and absorb solar radiation and interact with clouds (Liu et al., 2010; Herron-Thorpe et al., 2014).

Figure 1-1 Smoke plume from controlled fire (Pilanesberg National Park, South Africa, 12 May 2011)
Photo by author.

Wildfire events and fire regimes have complex environmental, social and economic effects and may continually change with regards to the stakeholders and ecosystems in question at different spatial and temporal levels (Gill, 2013). When fire regimes are altered spatially and temporally, resulting fires can have detrimental effects on ecosystems, such as changing community structures and species composition (e.g. Ribeiro et al., 2008), increasing the risk of species' extinction, creating pathways for invasive species (Driscoll et al., 2010) and have increasing impacts on climate change, by increasing emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and aerosols, which can increase albedo (IPCC, 2019). In turn, major factors affecting changes in global fire regimes, include climate change, agriculture, deforestation, rural and urban development, energy production, fire exclusion and suppression, invasive species, plantations and arson (Shlisky et al., 2009). Over 60% of the world's terrestrial habitats and over 70% of all fire-sensitive habitats (mostly evolved in absence of fire) have altered fire regimes (Shlisky et al., 2009).

Fires directly destroy human lives, livestock, property, infrastructure and fire-sensitive natural resources. On a landscape scale, wildfires can change hydrology, reduce water and soil quality, reduce soil fertility and increase soil erosion by wind and water (FAO, 2006). The global rural poor are most vulnerable to the effects of fires, their livelihoods depending on the integrity of functioning ecosystem services and often lacking the resources and governmental or other support to manage fires and their effects (FAO, 2006).

Lightning may ignite fires, but many ignitions are anthropogenic. In rural communities, especially in economically less developed countries, fire is an important tool used to clear land for agriculture (Figure 1-2), to burn agricultural residues, for the production of charcoal, to clear pathways, for hunting and sometimes as a means to voice discontent, e.g. arson of land from which communities have been displaced (Brockington et al., 2008; Shlisky et al., 2009).

Figure 1-2 Felled trees for agriculture (Mareja Community Reserve, Cabo Delgado, Mozambique, 17 Oct 2005)
Photo by author.

For protected areas fires are of particular issue. Although prescribed or planned controlled fires are used extensively as a management tool to influence vegetation structure, control grazing, maintain biodiversity and to reduce fuel load available to fires later in the dry season, to achieve conservation objectives (Govender et al., 2006; Archibald et al., 2010), additional unplanned fires may destroy species, push them out of protected areas and have detrimental effects on the ecology and ecosystems. Fires are a serious threat to protected areas, for example, in the Niassa Special Reserve in northern Mozambique, 61% of the Reserve was burned by fire in 2004 (SRN, 2005). Protected areas are implicitly defined as areas set up to protect sensitive/endemic species or ecosystems (Dudley, 2008) and tend to consist of large areas of homogenous vegetation types, or continuous vegetation, which may result in large burned areas if ignited (Archibald et al., 2009).

1.2. Wildfire Definition/Global Context

The term wildfire is used here to denote a fire started by human or natural causes, which spreads in 'natural' or rural areas, and may reach urban areas although does not usually start there. A controlled or prescribed fire for management purposes would become a wildfire if it 'escapes'. Other terms in usage are unplanned fire, landscape fire, bushfire and wildland fire (Gill, 2013).

Fires are part of the Earth's past and play a role in energy and geo-chemical cycles. Climate is a major determinant of fire regimes at global and local scales, and although rainfall has been a major driver of fires, human activities have dominated in influence since pre-Industrial times (IPCC, 2019). Southern Africa, in particular has seen an increase in burned area in the past 20 years, compared to global decreases, except in Australia (IPCC, 2019). This has however been accompanied in a shift from the type of land cover burned, where areas burned have decreased in grassland, savannah and other non-forest types and increased in forest land cover types (IPCC, 2019). Mozambique has witnessed some of the highest global fire densities (individual fires per unit surface), but individual fires are relatively small in size, except in areas such as in and around Gilé National Park (Artés et al., 2019). Much available fire research and coverage is available for more economically developed countries in the world, especially those experiencing large-scale individual fire events (such as megafires in the USA, Australia and in Europe), which also receive more of the global media coverage.

The IPCC projections for the coming century are that global mean surface temperature increases and changes to precipitation patterns, especially in the tropics/subtropics, such as southern Africa, will produce climatic conditions more conducive to frequent and extensive wildfires, including increased frequencies and intensity cyclones, compounded by water scarcity, land degradation, and reduced crop yields and food security (Archibald et al., 2009; Driscoll et al. 2010; IPCC, 2019). Mitigation strategies include improved land management (e.g. community-based resource management, eco-tourism, integrated and community-based fire management, etc.) and carbon sequestration (e.g.

afforestation, reforestation, carbon financing, other REDD+[1] mechanisms). However, accumulated carbon is then at risk of future fires (IPCC, 2019). Humans also affect fires by suppression, extinguishing fires, reducing spread and altering the available fuel (IPCC, 2019).

1.3. Aim and Scope

The overall aim of this research is to examine potential drivers of burned areas in the context of Mozambique, a sub-/tropical African country with a particular set of physical, climatic, political and socio-economic characteristics, at national and local level, with a particular view to the role of protected areas. A conceptual model of a wildfire system is perceived in this context, outlining physical and human drivers which affect this system.

In order to examine the effects of these drivers at a national level, this study uses available spatial datasets and derived variables, employing quantitative analyses to determine the effects of the drivers on burned outcome on a pixel level, with particular consideration of protected areas. Three protected area case study sites (Niassa Special Reserve, Gorongosa National Park and Limpopo National Park) are examined individually using the quantitative approach to compare burned outcome and drivers for each. The quantitative analyses are conducted for two distinct 6-year periods (2001-2006 and 2010-2015) to allow for possible temporal comparisons of burned outcome due to climatic, political, social, policy, etc., differences.

To link quantitative results to local contexts on the ground, this study uses an additional qualitative component to provide a different 'lens' and increased granular understanding in which to view the wildfire system, also serving as a mechanism for triangulation and validation. By combining quantitative and qualitative methods and results, it is hoped that the wildfire system in Mozambique, and more widely in similar global contexts, is better understood; that decision making, strategies and policies can be better informed and that the wildfire 'problem' is viewed more holistically, also at local contexts (for protected area management and the associated buffer zones). Hopefully, it will also provide inspiration for further research, especially for the future, given the climatic, political and socioeconomic challenges facing nations such as Mozambique.

[1] REDD+ refers to 'reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries' first negotiated under the UNFCCC (United Nations Framework Convention on Climate Change) in 2005. The objectives are to reduce greenhouse gas emissions in participating developing countries through forest management and expansion (FAO, 2020).

1.4. Thesis Overview

Following on from this introductory chapter, the theoretical framework underpinning the research is detailed in Chapter 2. It describes the conceptual framework of the wildfire system, defining and explaining the factors and drivers involved in wildfires in the context of Mozambique.

Chapter 3 provides the context of the research for Mozambique, specifically the physical and climatic characteristics, general vegetation ecoregions, the political and socio-economic features, land tenure and finally, protected areas and an overview for each of the case study protected areas (Niassa Special Reserve, Gorongosa National Park and Limpopo National Park). This chapter is rounded off with the research questions and the rationale for the two time periods used (2001-2006 and 2010-2015).

The methodological framework is outlined in Chapter 4 detailing the mixed methods approach used. This includes explanations of the quantitative methods used on a pixel-by-pixel basis (exploratory data analysis, multivariate matching as a pre-processing technique, and logistic regressions) and qualitative methods (inductive reasoning grounded theory-based data collection and analysis) for which fieldwork was done in Gorongosa National Park in 2012.

Chapter 5 provides information on the sourcing and qualities of the physical and human spatial datasets used as variables for the quantitative methods detailed in the previous chapter. Chapter 6 provides the results of the initial exploratory analysis of the variables with regards to burned versus unburned pixels. This is followed by the details of the multivariate matching performed which produced the datasets used in the logistic regression to examine the differences in burned pixels considering the relevance of whether they are within or outside of a protected area at national level and in the case study sites.

The qualitative data and analysis is presented in Chapter 7 which is based on data collected in Gorongosa National Park. And finally, Chapter 8 presents the discussion of the quantitative and qualitative results, attempting to provide understanding of the wildfire system at the national picture and placement into the local context, specifically in the case study protected areas. Emerging questions and further areas for research are also noted.

2. Theoretical framework

2.1. Introduction

The theoretical framework for this research is based on a perceived conceptual framework of the wildfire system, given the physical and human drivers and their underpinning factors. This chapter sets out to present the conceptual model, describing key components and concepts.

2.2. Conceptual model of the wildfire system and key concepts

The wildfire system is an open complex system, i.e. its behaviour is difficult to model due to dependencies, competitions, relationships, or other types of interactions between components of the system and its environment. '*[The] interaction among constituents of the system, and the interaction between the system and its environment, are of such a nature that the system as a whole cannot be fully understood simply by analysing its components. Moreover, these relationships are not fixed, but shift and change, often as a result of self-organisation' (p. X, Cilliers, 1998).*

Although the conceptual framework is probably generally relevant for wildfire situations, it must be borne in mind that this research is based on a simplified snapshot of a current wildfire system within spatial and temporal constraints. The conceptual model used here is divided into physical (climatic, topographic, ecological, etc.) and human (socio-economic, demographic, political, etc.) drivers of fires. The delimitation between these two groups and individual drivers/factors are not necessarily clear-cut, can vary in importance in different conditions and may have antagonistic influences (Archibald et al., 2009). The individual drivers can also act at several spatial and temporal scales. The following section refers to this model (Figure 2-1).

For an ignition to occur, heat, fuel and oxygen are required. In a wildfire setting, oxygen is available in the air, the fuel is usually living or dead vegetation (carbon-based organic material) and heat for ignition is provided either by lightning or anthropogenically (intentional or accidental). Human ignitions in the Mozambican context, may stem from livelihood activities, such as household fires, clearing land for agriculture, burning of agricultural residues, charcoal production, honey collection, clearing and opening paths; from ecological management (usually in protected areas and buffer zones around protected areas) which may include controlled (early season) burning and creation of fire breaks; from (often illegal) hunting practices (e.g. encouraging new vegetation growth to attract prey, moving prey in certain direction, creating barriers between hunters and law enforcement, etc.) and from arson (FAO, 2006; Fusari and Carpaneto, 2006; Hoffmann et al., 2009; Matimbe, 2015).

The amount and characteristics of available fuel (fuel load, fuel continuity and flammability) as well as favourable fire weather such as hot, dry winds, longer stretches of dry weather after rain, etc., (Archibald et al., 2009; 2010)[2] and suppression efforts, will determine the fire characteristics and behaviour, such as intensity, rate of spread and extent.[3] Seasonality is determined by the relative timing of the ignition within the interannual seasonal rainfall and temperature patterns (Cochrane, 2009). The characteristics, frequency and seasonality of fires determine fire regime.

Rainfall can have antagonistic effects and acts on different temporal and spatial scales. As rainfall increases fuel production increases, but so too does fuel moisture which decreases the propensity of the fuel to burn. Similarly, where rainfall is high, dry seasons may be shorter and perennial rivers may act as barriers to fire spread (Archibald et al., 2009). Fuel for wildfires, such as grass and litter, can accumulate rapidly given enough rainfall, even after fires, and may be ready to burn after a few weeks of dry weather. Aldersley et al. (2011) determined the main drivers of fire occurrence and extent at a global scale to be high temperature, intermediate rainfall and long dry periods. Archibald (2009, 2010) concluded that climate drivers are the main determinants of burned area in southern Africa and rainfall is thought to be the limiting factor of fires and the determinant of inter-annual variability (Govender et al., 2006; Archibald, 2010).

Additionally, teleconnections affecting rainfall patterns have been observed and more frequent and extreme climatic dipole events (El Niño / Southern Oscillation and Indian Ocean Dipole) are predicted with climate change. Relationships between fire in southern Africa and the El Niño / Southern Oscillation have been observed, where above average rainfall was associated with an increase in fire (Archibald et al., 2010).

Topography affects ecology and therefore fuel characteristics, e.g. proximity to water, altitude, etc., but may also provide physical barriers to fires spreading, e.g. ridges, cliffs, rivers and lakes. However, increasing slope is the most important topographical feature in increasing fire rate and spread (Planas and Pastor, 2013; Shekede and al., 2019). Slope can also be a surrogate for agricultural potential, a human influence (Negret et al. 2020). In Eswatini (formerly Swaziland), land cover, elevation and climate (mean annual rainfall and mean annual temperature) were found to be strong predictors of wildfire occurrence (Dlamini, 2010).

The characteristics of fuel, i.e. the amount, type, composition, hetero-/homogeneity, flammability, etc., depends on ecology (edaphic, hydrological and topographic factors), or more simplistically land cover, and the response of the vegetation/habitat/ecology to climatic conditions in (preceding)

[2] Fire weather in this context is used to describe a group of favourable weather conditions affecting fire (solar radiation, air temperature, relative humidity, atmospheric stability, etc.), and wind which is the most important (Planas and Pastor, 2013).

[3] Cochrane (2009) provides a detailed overview of fire behaviour.

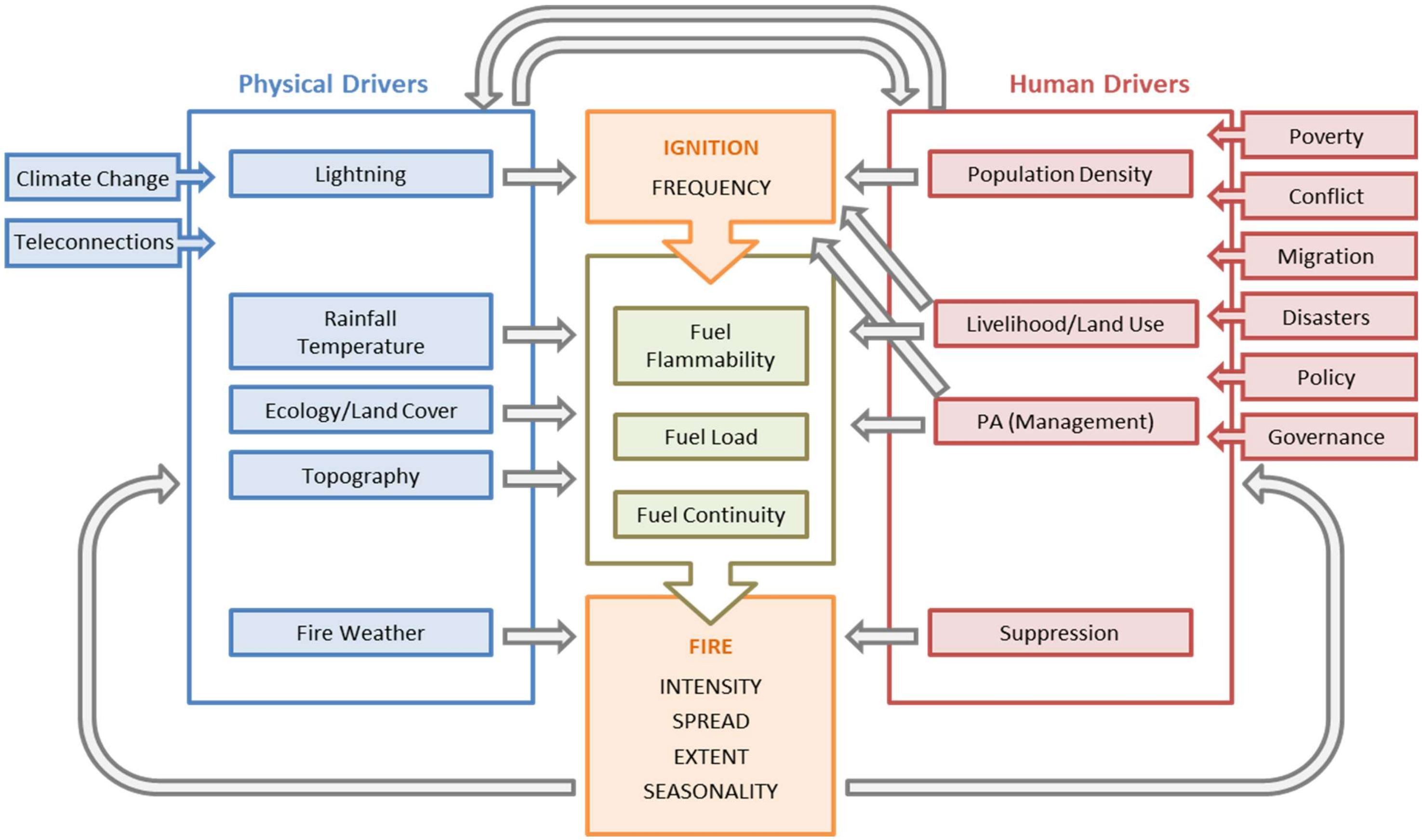


Figure 2-1 Conceptual model of physical and human drivers of wildfires in Mozambique. Components are referred to in section 2.2.

seasons, grazing pressure by domestic livestock and wildlife, and the presence of human population which may be altering the biomass and its characteristics directly by harvesting (e.g. grass for thatching, wood for fuel or construction, timber) and indirectly, and also management of animal species e.g. megaherbivore populations such as elephants. According to Archibald et al. (2009) in forests where tree cover exceeds 40%, the maximum possible burned area declines. This is probably due to a reduction in understory grass and other vegetation as tree density increases. *Miombo* forests are prevalent in northern and central Mozambique, which receive between 650 mm and 1,400 mm of rainfall per year and may be deciduous in drier areas but are evergreen in wetter areas (Nhantumbo et al., 2001). Zolho (2005) found the regeneration of miombo tree species to be greater in less frequently burned plots than in plots burned more often in Nhambita, Gorongosa. Biomass in Niassa National Reserve (Niassa Special Reserve) has found to be inversely related to frequency and intensity of wildfires (Ribeiro et al., 2008). Similarly, Gandiwa and Kativu (2009) found individual trees in *Mopane* habitats in Gonarezhou, Zimbabwe had more biomass in areas where fire frequency is lower.

Much research has been done on the effect of fire on savannah ecosystems/habitat structure and composition, which is more typical in the drier southern parts of Mozambique, especially in South Africa and within protected areas (e.g. Van Wilgen et al., 2010) and including in the Limpopo National Park, Mozambique (Ribeiro et al., 2017). Grazing, by wildlife or livestock, can modify vegetation structure which affects fuel characteristics. High densities of elephants, in protected areas and in human dominated landscapes where elephant movement is restricted, lead to over-browsing of woodlands, which increases the recruitment of grasses and smaller woody plants. This may increase fire frequency and intensity and favour a savannah dominant vegetation phase (Ribeiro et al., 2008). Invasive species, such as grasses or shrubs can increase fire intensity, to the detriment of woody species (Driscoll et al., 2010). For example, in the communal Mareja reserve in the buffer zone of Quirimbas National Park in northern Mozambique, a persistent invasive *Lantana* sp. shrub creates dense impenetrable thickets in disturbed areas crowding out endemic species and increasing fuel load for fire (personal observation, 2005).

A higher human population density will mean increased potential sources and number of fires (Archibald et al., 2009; 2010), although it should intuitively also increase the potential for active and passive fire suppression. Increased fragmentation of land for agriculture and other economic activities will decrease fuel continuity, although large scale monoculture agriculture (e.g. forestry, sugar plantations) may increase it, along with fuel homogeneity. In landscapes which are fragmented by human use through agriculture, livestock grazing, roads and intentional suppression mechanisms (e.g. fire breaks), fires do not spread easily and tend to be of smaller size as opposed to fires in protected areas where continuous vegetation allows fires to spread extensively, which results of this study indicate. Palumbo et al. (2011) found similar fire densities within protected areas in southern Africa and in their respective buffer zones area but higher fire intensities inside, especially in 'shrubland' and 'grassland' land covers.

Both Paritisis et al. (2013) and Stahl (2020) found that distances to roads and settlements were also strong predictors of fire occurrence. However, this also depended on different land use practices and past and present socioeconomic contexts. Ribeiro et al. (2008) report an increased incidence of fires in Mecula district where most settlements are located within the Niassa National Reserve (Niassa Special Reserve) in northern Mozambique. Shekede et al. (2019) observed that distance from settlements, dry matter productivity, mean annual temperature and slope significantly predicted spatial variations in wildfire clusters in Zimbabwe. Local natural resource management and livelihoods have also been shown to affect fire prevalence in the Okavango Wildlife Management Area, Botswana, e.g. tourism (low in areas strictly for photographic tourism vs. high in areas for hunting/walking safaris) and high prevalence in areas for thatching grass collection and fishing (Tacheba et al., 2009). Tacheba et al. (2009) also found that other factors such as ethnicity and literacy seem to play a part in determining these fire regimes. There is also a strong link between GDP and the characteristics of wildfires at a regional scale, where GDP is a good proxy for ecosystem fragmentation by humans which in turn affects the characteristics of fires (Aldersley et al., 2011).

Additionally, the human drivers in the Mozambican context are underpinned by the following interlinked factors:

- Migration/internal movement and (in)voluntary displacement of people

  Movement of people due to economic pressures, conflict, natural disasters, resettlement due to large-scale infrastructure projects such as roads and railways, creation of protected areas, etc.

- Quality of governance and land tenure

  In Mozambique, weak institutional capacity, particularly at sub-national level, regulation of (illegal) exploitation of flora and fauna, land tenure rights and possible resulting 'tragedy of the commons' where if a person or community does not own the land (in the Mozambican case it owned by the State), the people and community may not feel a sense of responsibility to care for it and simultaneously bear the burden of controlling fires and responsibility for a fire regime, with limited direct benefits and incentives (Dennis et al., 2005; Sitoe et al., 2012). Also, traditional authority in Mozambique is weak (Muala, 2015).[4]

- National development priorities and associated policies and programmes

This includes the development of coal/gas extraction and mining sector (and any shifts in these post-COP26), dependence on aid, commodity agriculture and reliance on export markets, and the necessity for more inclusive smaller-scale, more sustainable measures for food security, REDD+ mechanisms, etc. (Sitoe et al., 2012).

- Technological factors

The majority of agricultural activity is low-technology and low productivity. A low wood fuel efficiency prevails and high urban demand for fire wood.

Furthermore, wildfires will feed back on the drivers, directly altering the water, energy, nutrient, etc., fluxes between the soil, biomass and atmosphere. For example, the ecology and ecosystem services and therefore livelihoods and human population density, may exacerbate conflicts and migration. Fire patterns and regimes most likely alter in response to changes in population, land use and climate (Archibald et al., 2009; Driscoll et al. 2010). According to Archibald et al. (2010), predictions as to how climate change will affect fires in Africa need the inclusion of human variables in the analyses of fire size, fire frequency, climate and vegetation across the region.

[4] For example, according to Muala (2015) Gorongosa's traditional leaders (*nyakwawas*) were denied political activities from 1976, and replaced by political actors (*secretários*). They were only reinstated in 1994 when they struggled to reaffirm their leadership in communities which had been governed by others since 1976.

3. Mozambique: Context

3.1. Introduction

This chapter aims to provide an overview of the placement of the conceptual wildfire model in the Mozambican context, providing background on the physical and climatic, and ecological characteristics of the country, relevant political and socio-economic context, including issues regarding land tenure, and a general description of protected areas in Mozambique and specifically of the three protected area case study sites.

The research questions, ensuing from the conceptual framework and the Mozambican context, addressed in this thesis are provided and a rationale for the selection of time periods (2001-2006 and 2010-2015).

3.2. Physical Characteristics and Climate

Mozambique is located on the eastern coast of southern Africa roughly between 10°S and 26°S and 30°E and 40°E, the Tropic of Capricorn passing through Mozambique's Gaza and Inhambane provinces (Figure 3-1). Mozambique borders Tanzania, Malawi and Zambia in the north, Zimbabwe and South Africa in the west and South Africa and Eswatini (formerly Swaziland) in the south. Mozambique's eastern boundary (more than 2,500 km) lies along the Indian Ocean (Mozambique Channel) (MICOA, 2014).

The current climate of Mozambique is tropical to sub-tropical, moderated by mountainous topography in the west and north-west. There are generally two seasons: a colder, dry season from about May to September and a hot, wet season from October to April. Average temperatures are higher along the coast (20-27°C), whilst the inland and higher altitude northern regions experience cooler average temperatures of 15-22°C. The central region has average temperatures of 24-27°C and the southern region 20-26°C (INGC, 2009).

Annual rainfall varies spatially, generally, following a decreasing trend southward and inland. Coastal areas receive 800-1,200 mm annually while higher altitudes further inland in the north and centre receive around 1,000 mm annually. The southern parts of the country are generally drier, with an average rainfall of around 600 mm annually in the inland south and central regions, and rainfall less than 800 mm for the rest of the southern area.

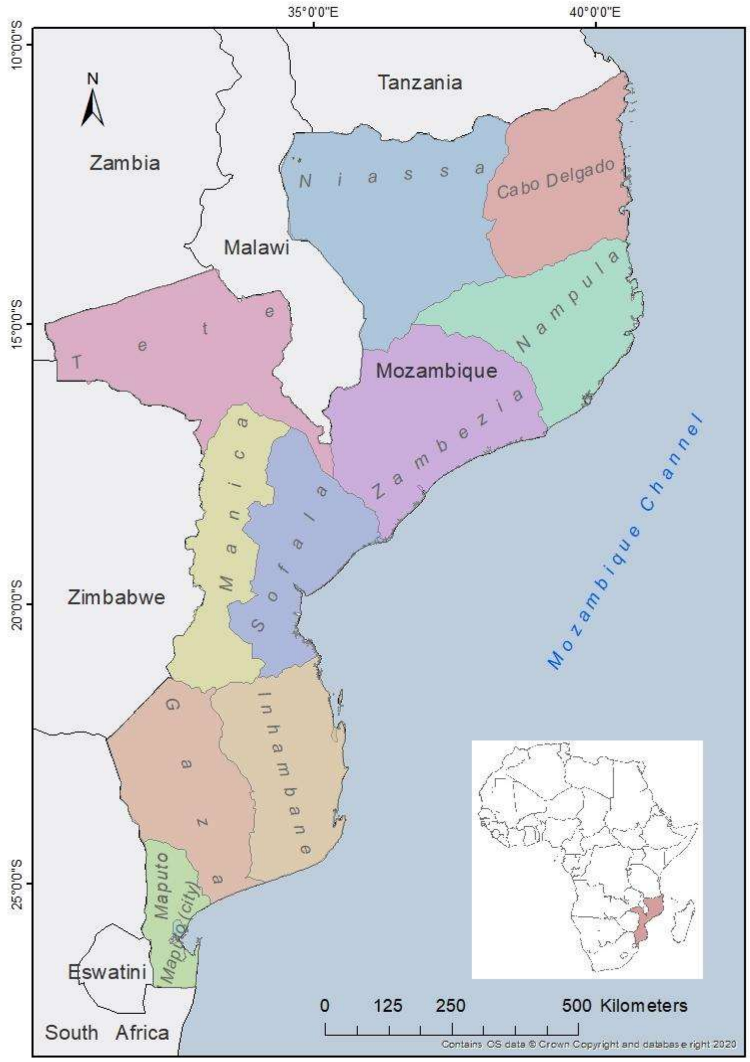


Figure 3-1 Mozambique location and provinces
Data: CENACARTA (2000c); Africa GeoPortal (2018).

The Inter-Tropical Convergence Zone (ITCZ) moves over Mozambique between October and April, bringing precipitation by deep convection and increased insolation. Water vapour in the warm, moist air at the surface cools and condenses, releasing enough latent heat to make air parcels buoyant. The water is returned to the surface by precipitation. Most rainfall in Mozambique is associated with the ITCZ, leading to about 45% of annual rainfall (Giannini et al., 2008; INGC, 2009).

Orography and large water bodies, such as Lake Malawi/Niassa also introduce significant modifications to the large-scale flow over the region (King'uyu et al., 2000). By changing humidity and temperature at the surface, or, temperature of higher levels of the atmosphere the system can be altered. Heat is efficiently distributed horizontally throughout the tropical atmosphere, therefore warming over the Indian Ocean can stabilize the atmospheric column over Africa, inhibiting precipitation by suppressing convection (Giannini et al., 2008).

Moisture supply into the region can also alter this system. Factors such as gradients in sea surface temperature (SST), or the temperature contrast between land and sea, induce changes in the pressure field, and thus in the large-scale flow field, to alter the low-level convergence of moisture into the region. Precipitation events relying on this type of moisture convergence may then be altered (Giannini et al., 2008).

Landfalling tropical cyclones are common in Mozambique (Table 3-1). The heavy rainfall associated with these types of events contributes a significant proportion of wet season rainfall over a period of a few days, as was the case with Cyclone Leon-Eline in 2000 exacerbating already devastating floods (Hoffman et al., 2009; INGC, 2009) and Cyclone Idai, followed six weeks later by Cyclone Kenneth in early 2019, leaving 1.85 million people in Mozambique in need of humanitarian assistance, and associated detrimental after-effects on healthcare and education (UNDP, 2019).

Table 3-1 Major landfalling tropical cyclones in Mozambique (2000-2021)

Date	Storm
January 2021	Eloise
April 2019	Kenneth
March 2019	Idai
February 2017	Dineo
March 2012	Irina
January 2012	Funso
January 2012	Dando
March 2009	Izilda
March 2008	Jokwe
February 2007	Favio
March 2003	Japhet
December 2002	Delfina
April 2000	Hudah
February 2000	Leon-Eline

In southern Africa pronounced dry and wet seasons are favourable to wildfires where rainfall is thought to be the limiting factor (Govender et al*.,* 2006; Archibald et al*.,* 2009; 2010). Interannual rainfall and temperatures in southern and eastern Africa vary considerably. The ITCZ and El Niño - Southern Oscillation (ENSO) are assumed to be the major determinants of spatial and temporal variability of climate in the region (e.g. King'uyu et al., 2000; Hulme et al., 2001; Anyamba et al., 2003; Giannini et al., 2008; Hoffman et al., 2009; INGC, 2009), although SST anomalies in the Indian Ocean, both by the Indian Ocean Dipole (IOD) and the Subtropical Indian Ocean Dipole (SIOD) provide combined and forced effects (Hoell et al., 2017).

ENSO generally describes the El Niño/La Niña phenomenon which involves the cyclic warming and cooling of the surface temperature of the eastern Pacific Ocean. The associated change in atmospheric pressure is known as the Southern Oscillation. The eastern Pacific is normally cooler than its equatorial location would suggest, cooled by the Humboldt Current. An El Niño phase relates to the formation of unusually warm waters in the eastern and central equatorial Pacific Ocean, and a negative Southern Oscillation Index[5] (SOI). Unusually cold water formation in the same region is known as La Niña and has a positive SOI (Anyamba et al., 2003, Hoffman et al., 2009, INGC, 2009).

The effect of ENSO on climate variability in southern and eastern Africa is both direct, via an atmospheric teleconnection, and indirect, via the response of the Atlantic and Indian basins to ENSO. The direct influence of ENSO is a stabilization mechanism (Giannini et al., 2008). During a negative SOI / El Niño phase the tropical troposphere warms in response to the warming of parts of the Pacific Ocean, stabilizing the atmospheric column over southern Africa which initially has a negative effect on precipitation over southern Africa, usually in the months of November to February. Above average precipitation is experienced in eastern equatorial Africa, in the short rainy season in October to November. The decreased rain over southern Africa is associated with the cloud band of the ITCZ moving offshore, and with it the highest rainfall (Hulme et al., 2001, Giannini et al., 2008, Hoffman et al., 2009, INGC, 2009).

During a positive SOI / La Niña event the dipole pattern over southern and eastern Africa is reversed: rainfall is enhanced over southern Africa and drought conditions prevail in eastern equatorial Africa (Giannini et al., 2008, Hoffman et al., 2009). Increased SST in parts of the Indian Ocean caused by ENSO-induced surface winds can reverse the initial atmospheric stabilization and lead to destabilization of the tropical troposphere from the bottom up. This effect together with an increased transport in moisture associated with enhanced evaporation over the warmer than average Indian Ocean, can lead to increased rainfall for eastern equatorial Africa (Giannini et al., 2008).

IOD events, with positive events bringing increased summer rainfall to Mozambique, especially in the north of the country (Reason, 2001). Positive SIOD events cause increased summer rains over large parts of south-eastern Africa by bringing enhanced convergence of moisture. Higher temperature over the Southwestern Indian Ocean warm pole results in increased evaporation, and this moist air is advected to Mozambique and eastern South Africa, which is strengthened by the low pressure anomaly generated over this warm pole (Reason, 2002). Opposing ENSO and SIOD phases have strong southern Africa climate impacts during the wet season, where ENSO events are stronger (Hoell, 2017).

[5] The Southern Oscillation Index (SOI) is the difference between normal sea level pressure at Tahiti and Darwin, Australia.

3.3. Vegetation

Following the biome and ecoregion classification by WWF (Olson, 2001), in general terms, the coastal areas of Mozambique lie within a forest belt running along the coast, the Southern Zanzibar-Inhambane Coastal Forest Mosaic, extending southwards as the Maputaland Coastal Forest Mosaic (Olson et al., 2001) (Figure 3-2). The coastal forest belt supports mosaics of dry forest, savannah woodland, grassland, wetland habitats and mangroves (Olson et al., 2001; MICOA, 2013). Pockets of East African and Southern Africa Mangroves ecoregions are dotted along the coastline.

Generally, the areas further inland north of the Zambezi River lie within the Eastern Miombo Woodlands ecoregion which extend westwards in along the Zambezi River, and south of the Zambezi River, as Southern Miombo Woodlands and Zambezian and Mopane woodland ecoregions (Figure 3-2) (Olson et al., 2001). The term *Miombo* is used to describe the forests and woodlands of southern Africa that are dominated by trees of the subfamily Caesalpinioideae, mainly of the genera *Brachystegia*, *Julbernardia*, *Pteleopsis* and *Isoberlinia.* Miombo structure seems to be determined by climate and fire, with fire being an important ecological factor (Olson et al., 2001). Ryan and Williams (2011) suggests a fire return rate in the Southern African Miombo of two to four years. *Mopane* refers to the dominant tree/shrub species *Colophospermum mopane* (Olson et al., 2001).

The Miombo, Zambezian and Mopane Woodlands, contain patches of habitats and transitions between them, such as forests, woodlands, thickets, grasslands and wetlands (Figure 3-3) (Olson et al., 2001). Rivers in the ecoregions are lined by deciduous riparian forests and large rivers (e.g. Zambezi) show Zambezian Coastal Flooded Savannah and Zambezian Flooded Grasslands ecoregions near their mouths (MICOA, 2009).

Eastern Zimbabwe Montane Forest-Grassland, and Southern Rift Montane Forest-Grassland Mosaics, exist at higher altitudes such as the borders with Zimbabwe, and Malawi, as well as on Gorongosa Mountain and other inselbergs in central and northern Mozambique (Figure 3-3). These include semi-evergreen high rainfall tree savannah, and often, relic moist evergreen forests reliant on atmospheric moisture rather than groundwater (Olson et al., 2001; MICOA, 2009), such as the relatively recent discovery of the relic montane forests, and species new to science on Mount Lico and Mount Mabu in Mozambique (The Guardian, 2018).

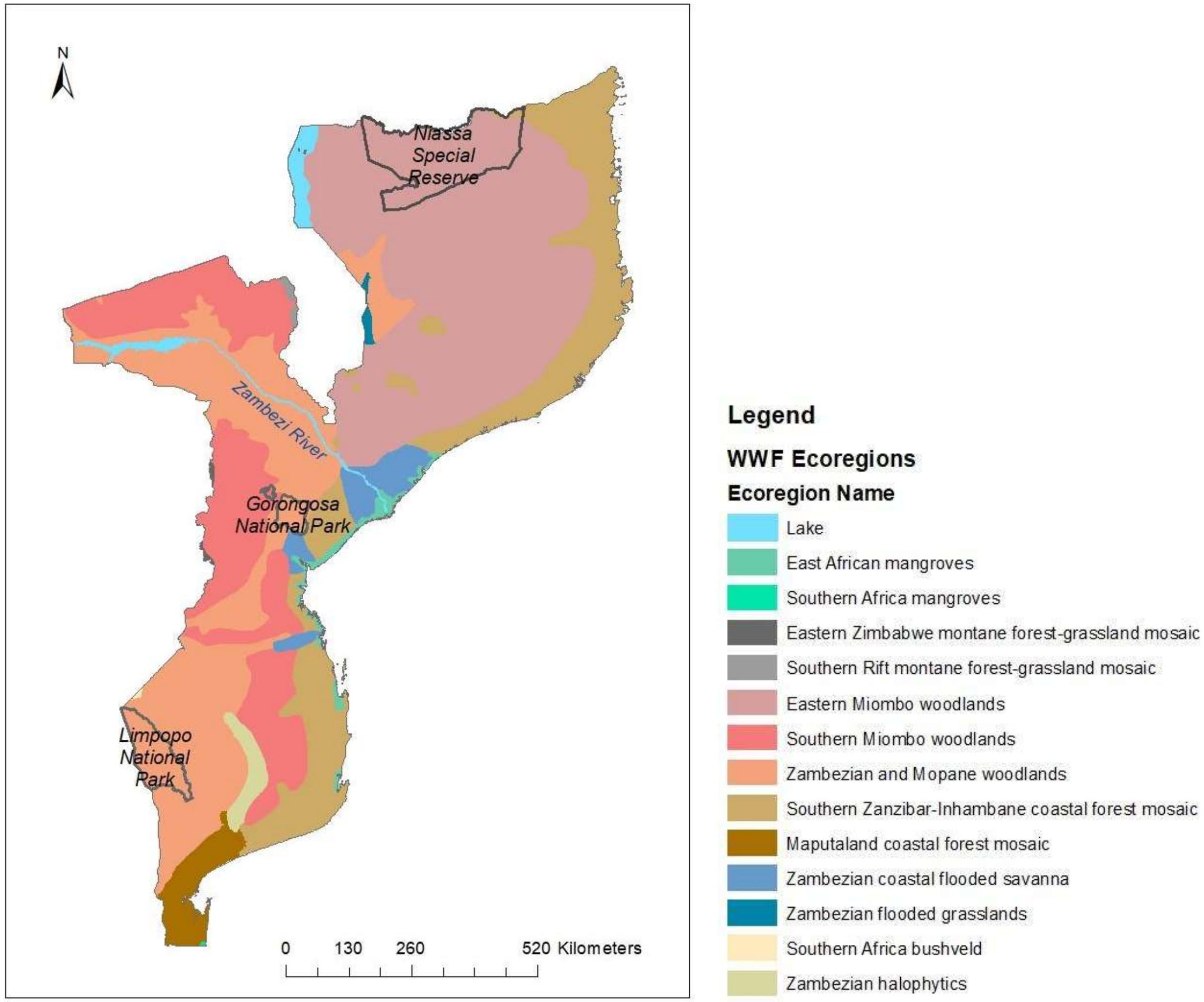


Figure 3-2 WWF Ecoregions of Mozambique and case study protected areas
Data: Olson et al. (2001).

Figure 3-3 Examples of Ecoregions
Left: Zambezian and Mopane Woodland in Gaza Province, Mozambique (near Limpopo National Park, April 2012). Right: Inselberg in Eastern Miombo Woodland, Cabo Delgado Province, Mozambique (Mareja, Pemba-Metuge, May 2006).
Photos by author.

3.4. Political and Socio-economic

Mozambique has a population of about 30 million people, projected to be more than 37 million in 2030 (INE, 2020), and has one of the lowest Human Development Indices[6] (HDI) globally (UNDP, 2019). The majority of the population is rural (about 60%) and relies on rain-fed agriculture, natural resources and ecosystem services for their livelihood (INE, 2020). Poverty remains widespread and about 50% of the population is in 'severe multidimensional poverty' as defined by the UNDP (2019), the main contributing factors being 'standard of living' (50.3%), 'education' (32.5%) and 'health' (17.2%). The nation has, however, abundant arable land, water, energy resources (hydroelectric, coal, globally significant natural gas reserves, etc.) and mineral resources (titanium, rubies, gold, etc.) (World Bank, 2020).

As well as a movement of people from rural to urban areas, Mozambicans have and continue to be displaced by natural disasters, such as Cyclones Idai and Kenneth (2019), major floods (e.g. in southern

[6] For Mozambique the Human Development Index, a comparative measure of life expectancy (60.2 years), education (mean years of schooling 3.5 years) and standards of living (gross national income (GNI) PPP $1,154 per capita) for countries worldwide, is very low (ranked 180 of 189) (UNDP, 2019).

Mozambique in 2000), droughts, and conflict (most recently the so-called jihadist insurgency in the Cabo Delgado province and the longer-standing conflict involving RENAMO in the centre of the country). Apart from foreign investment into mega-projects and the coal and gas industries, of which most Mozambicans do not benefit, a shift is needed towards a better environment to support a broader domestic and rural-focused private sector development (Dietsche and Esteves, 2018).

In its more recent history, Mozambique was a colony of Portugal (for details see Appendix 1 – Historical timeline). In 1975 Mozambique gained Independence from Portugal after a 10-year guerrilla campaign by the nationalist movement FRELIMO (*Frente de Libertação de Moçambique*). This was shortly followed by a Civil War between the Marxist-Leninist FRELIMO regime and RENAMO (*Resistência Nacional Moçambicana*), an anti-communist militia sponsored by white-minority rule governments in Rhodesia and South Africa. The Civil War lasted from 1977 to 1992, when the General Peace Accord (GPA) was signed in Rome, Italy, by FRELIMO and RENAMO. Apart from many casualties, millions of people were displaced or fled to neighbouring countries. FRELIMO has been in power since 1992, winning all general elections, although some have been disputed by RENAMO. RENAMO has also felt that aspects of the GPA have failed to be delivered, and in 2012 the RENAMO leader and a contingent of supporters ensconced themselves in the Vunduzi area (near Gorongosa National Park in the centre of the country) and re-engaged in 'war' with the government (FRELIMO). Consequently, after talks, a second and third peace agreement were signed, in August 2019, in conjunction with a decentralisation reform and the demobilisation and reintegration of RENAMO guerrillas.

Initially post-GPA, Mozambique experienced high economic growth due to successful economic reform, foreign investment projects, and the revival of the tourism, agriculture and transportation sectors. However, the high growth rate was disrupted due to the repercussions of the economic and fiscal fallout from the US$ 2.2 billion 'hidden debt'[7] for dubious fisheries and maritime security projects which came to light in 2016, and decreased foreign direct investment and aid (dos Santos, 2020; World Bank, 2020). Simultaneously, reduced global demand and prices for gas and coal slowed the investment into these two key industries.

Since 2017, so-called jihadist insurgents have attacked and killed civilians and occupied villages and towns in the northern province of Cabo Delgado. Clashes between the army/police (and foreign mercenaries) and the insurgents have displaced thousands of people, and several countries (Rwanda, USA, Portugal, etc.) have provided troops and training in aid of the Mozambican forces. The World

[7] For more details see, for example, Hanlon, J, 2017. Mozambique should not pay the hidden debt. English version of Portuguese article published in Savana, Maputo, 28 July 2017. https://www.open.ac.uk/technology/mozambique/sites/www.open.ac.uk.technology.mozambique/files/files/FMO-Should_not_pay_secret_debt-Hanlon.pdf

Bank (2020) warns that '*[t]he risk that violence can spread to other areas of the country should not be underestimated*' and the coincidence of the presence of the insurgents with the gas reserves and associated infrastructure for the liquefied natural gas (LNG) production projects is problematic. As of September 2021, all on-shore operations had been halted. The compounding effects of the current global COVID-19 pandemic on economic activity will also be detrimental and is yet to be seen (World Bank, 2020).

3.5. Land Tenure

In pre-colonial time land in Mozambique was regulated by traditional law and open access. This changed during the colonial period when land was appropriated by the colonial power, Portugal. Communities were settled into marginal land around privately-run concessions to provide a cheap source for labour (a system known as *chibalo*) (Newitt, 1995). Later, after Independence in 1975, during nationalisation, rural populations were settled and employed in state farms. Land policy was reformed in post-GPA in 1997 (Law 97/17) due to the inadequacy of existing land legislation and institutional frameworks. Driving the reform were the shift from a centrally-planned to a market-oriented economy, privatisation, increased urbanisation, democratisation, increased population densities, dwindling and deterioration of natural resources and increased poverty (Nhantumbo et al., 2001).

The Land Law 19/97 guarantees tenure rights to most Mozambicans to the land they occupy and use, and Article 13 states that the absence of a formal title shall not prejudice (traditional) land use and benefit rights. The Law stipulates the nature and conditions or rights and access for individuals, communities and corporations (Kaarhus and Martins, 2012). All land is, however, owned by the State, meaning that it cannot be sold, disposed of, mortgaged or commercialised (Law 19/97, Article 3) (GoM, 1997). Although the State is the owner of land and /resources, rural communities are allowed to use the land and resources, without causing degradation, and if no other instrument is in place which confers the right onto another (GoM, 1997). A formal certificate of land use can be issued to communities, where a 'community' is defined as a group of families or individuals living within the boundaries of a locality, who share resources and have a common interest in their management (Article 1). This means that DUAT (*direito de uso e aproveitamento da terra*) or 'use and benefit of land rights' titles are issued (Kaarhus and Martins, 2012; MCC, 2012). This requires the formation of a local representative entity to hold the rights on behalf of the community and the provision of the delimitation of the community (Nhantumbo et al., 2001).

The users of community areas define the rules of access, use and management of resources and are expected to monitor compliance. This entails participation of users in decision-making concerning their rules, taboos, and other beliefs known to have contributed to rational utilization of resources, such as the taboo of the use of fire in sacred forests (Virtanen, 2002; Nhantumbo et al., 2001). Practices which undermine the principles of conservation, such as setting fire to clear land, should be avoided (GoM, 1997). DUATs cannot be issued for land in nationally protected zones (in this case for conservation, nature preservation, defence and national security) although national protection can be revoked (Articles 7 and 9 of Land Law 19/97), as, for example, stipulated in the Mining Law (14/2002) which states that mining operations have priority over other land uses when economic and social benefits related to these operations are higher (UNDP, *undated*). Additionally, in the wildfire context, the Ministry for the Coordination of Environmental Affairs' national fire management plan assumes that '*[f]ires have always been set by rural communities in a controlled manner using knowledge passed down through generations. In recent times […] we see the country on fire due to uncontrolled fires, devastating natural resources that are the basis of the national economy*' and '*[t]he assumption for the success of the actions advocated […] is based on the predominant role played by communities and by local authorities* (MICOA, 2008).[8]

Institutionally, the Ministry of Land and Environment (MTA) and its delegations at provincial and district level, is currently the government's key agent for land management and issuance of titles. A separate mining cadastre is held by the Ministry of Mineral Resources and Energy (MIREME).

Land has increasingly become a global commodity and investment in land, forestry, cash crop agriculture, and mineral resource extraction, has increased (Kaarhus and Martins, 2012; DfID, 2013). For example, rising food prices during the 2007/2008 global economic downturn, increased interest in agriculture in Mozambique (Kaarhus and Martins, 2012) and the climate change agenda increased the demand for 'biofuels' and REDD+-related activities, such as forestry projects which are also used as pension and hedge funds (Kaarhus and Martins, 2012; DfID, 2013), as well as a turning away from fossil fuels post-COP26. In this context it is important to consider the issue of 'land grabbing' and potential marginalisation of 'traditional' and community land users, (Fairbairn, 2012; DfID, 2013), as well as the weakness of land tenure security which may be illustrated by cases of multiple claims on land and slow and cumbersome conflict resolution (DfID, 2013). The disenfranchisement of local people, in development and resource extraction (rubies and natural gas) by multinationals and government, have played an important role in sowing the seeds for the current, so-called Islamist insurgency in Cabo Delgado (dos Santos, 2020).

[8] Translation from Portuguese by author

3.6. Protected Areas

A Protected Area (PA) in this context is used to mean '*a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*' (Dudley, 2008). As such, protected areas are constructs delineating an area which can have a variety of conservation, social, cultural and management objectives (Brockington et al., 2008; Dudley, 2008). The IUCN has developed categories in an attempt to standardize the primary objectives of protected areas ranging from Category Ia (*Strict Nature Reserve*) where human influence is very restricted, to VI (*Protected Area with Sustainable Use of Natural Resources*) where human activities are explicitly included in the definition of the protected area (Stolton et al., 2013).[9]

Historically the model for protected areas, particularly in Africa, was 'fences-and-fines' where, upon the delineation of the protected area for economic, scientific and/or tourism values, the areas were necessarily separated from people, and people who originally lived in the area were moved out (Cochrane, 2009; Matusse, 2019). More recently, many initiatives are linking conservation efforts with socio-economic development with the rationale that centres of biodiversity conservation are mostly in the poorest parts of the world, where development needs are the greatest (Brockington et al., 2008; Dudley, 2008).

Protected areas provide natural resources to rural communities, which are harvested legally or illegally, by hunting, extracting timber and non-timber forest products, as well as providing ecosystem services. They may also offer opportunities for alternative livelihoods such as carbon credit schemes, tourism, employment within the protected area, etc. The recognition of communities as an entity involved in the management of natural resources may also provide legal access to resources, land and increased devolution of power (Nhantumbo et al., 2001). Support, through inclusion of local communities, or opposition, by (perceived) exclusion, may enhance or hinder the management and conservation objectives of protected areas, respectively (Brockington et al., 2008). The varying degrees of involvement and their relationships between people and protected areas, ranging from exclusion of people to their involvement in management, may in turn have consequences for wildfire activity.

Protected areas aim to achieve management objectives, usually conservation of ecosystems, species or cultural landscapes. The conservation success of protected areas is often measured in the

[9] The IUCN Categories are: Ia - Strict Nature Reserve, Ib - Wilderness Area, II - National Park, III - Natural Monument or Feature, IV - Habitat/Species Management Area, V - Protected Landscape/ Seascape, and VI - Protected Area with Sustainable Use of Natural Resources.

intactness of habitats/forests, and deforestation around protected areas is a common observation (Naughton-Treves et al., 2005). In the past, for example in southern Africa, fire was commonly excluded from the protected areas, however, more recently, emphasis has been put on using controlled or prescribed fires to achieve conservation objectives. To conserve all species in a given area, mosaic burning has been encouraged (Driscoll et al., 2010), for example, in the Kruger National Park in South Africa, fire management objectives are laid out in the Park's management plan: '*fires should vary widely over space and time at as many scales as possible, the belief being that this will lead to a range of fire types, intensities and effects over space and time and that this will most likely best maintain biodiversity*' (SanParks, 2008). To achieve this, rangers are given monthly burn targets based on rainfall of the preceding two growing seasons (SanParks, 2008). However, reliable knowledge about a broad range of species and their responses to fire is necessary for effective fire management. This is not usually the case as the effects of different components are poorly understood (Govender et al., 2006; Driscoll et al., 2010).

3.6.1. Protected Areas in Mozambique

Mozambique has about 25% (185,700 km²) of its terrestrial area under some form of protection (MICOA, 2014; ANAC, 2015), including two Ramsar[10] Wetland sites of International Importance (Zambezi Delta and, Lake Niassa and its Costal Zone) (for details see Appendix 4 – Protected Areas of Mozambique (from WDPA, selected variables, excluding Ramsar Sites)). The number of protected areas using national designations are: National Parks (9), National Reserves (4), Special Reserves (2), Community Conservation Areas (3), Forest Reserves (14), Hunting Reserves (20), Ecological Park (1), Environmental Protection Area (1), Environmental Conservation Area (1), Sanctuary (1) and Buffer Zones (3) (Figure 3-4) (ANAC, 2003; Biofund, 2020; WDPA 2020).

[10] International Convention on Wetlands of International Importance signed in Ramsar, Iran, in 1971.

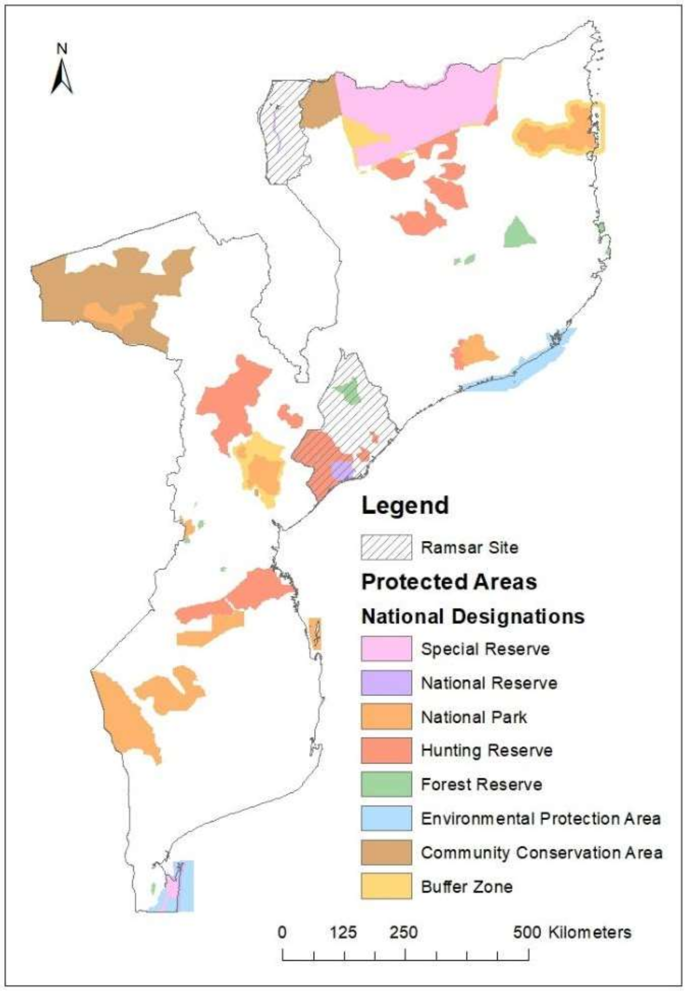


Figure 3-4 Current protected areas in Mozambique (national designations and internationally designated Ramsar sites)
Data: UNEP-WCMC and IUCN (2020).

Most protected areas in Mozambique are currently under the remit of the National Administration of Conservation Areas (ANAC) under the jurisdiction of the Ministry of Land and Environment (MTA) which defines the terms and conditions, with other sectors and private stakeholders, for management, and it licenses, controls and supervises the exploration of subterranean resources of the protected areas. Forest Reserves, are under jurisdiction of the National Forestry Directorate (DINAF) and one protected area (Lago Niassa National Reserve) due to its location in Lake Niassa and its shore, is under the jurisdiction of the Ministry of Sea, Inland Waters and Fisheries (MIMAIP). Strategic objectives include institutional development, biodiversity conservation, economic and financial sustainability, and community development. Legally, 20% of the revenues of a protected area need to be shared out between the communities within the buffer zone to be used for development purposes which do not conflict with conservation objectives (Forests and Wildlife Law 1999).

Many Mozambican protected areas were originally established as hunting concessions during colonial times and there was no requirement at that time for compensation of displaced people as they were not protected by law. The land policy reform in 1997 did not affect state-protected areas defined during the colonial period, irrespective of whether local communities were forcibly removed earlier (Nhantumbo et al., 2001). People living within protected areas cannot acquire the right to use the land (DUAT), are not provided with basic services, and are restricted in their activities (ANAC, 2003; GoM, 2003). According to the Government of Mozambique, resettlement of people can only occur through 'a consultation process' and by 'appropriate measures' (GoM, 2003).

According to ANAC (2003; 2015), the majority of people currently living within or in surrounding areas of protected areas were displaced people (and returnees) from the civil war or had some other reason for settling (e.g. access to land, natural resources, safety, etc.), although some communities were included within protected area limits, as was the case in Quirimbas National Park (ANAC, 2015).

3.6.2. Niassa Special Reserve

Gazetted in 1954, the Niassa Special Reserve (NSR) (previously also known as Niassa National Reserve) (IUCN category VI) lies in the north of Mozambique in Niassa Province, delineated by the Rovuma River along the border with Tanzania in the north and the Lugenda River in the east. It covers an area of more than 42,000 km² mostly made up of vast expanses of Miombo woodlands, savannahs, riverine forests, wetlands, enormous granite inselbergs with unique afromontane habitats and biodiversity, as well a rich human cultural history of the Yao and Ngoni cultures and languages, cave art thousands of years old and sacred sites. It has been managed by a public-private partnership between the Wildlife Conservation Society (WCS), other partners, and the Government since 2012 (WCS, 2020).

Since 2007, the NSR, together with the Selous Game Reserve, in Tanzania, and a corridor joining the two areas, form the Niassa-Selous Transfrontier Conservation Area (TFCA) (SADC, 2020). This TFCA was home to the second largest elephant (*Loxodonta africana*) population in the world (over 70,000 in the early 2000s) but due to unmanageable levels of poaching commencing around 2008 the population has declined to about 20,000 in 2016 (WCS, 2020). However, this area does provide a huge range for elephants (120,000 km²) if the numbers can recover. It also is home to about half the world's African wild dog (*Lycaon pictus*) population (WCS, 2020).

The management of NSR, between ANAC, local governments, WCS and other partners, aims '*to reconcile biodiversity conservation and human development needs across the broader landscape*', within '*diverse and cohesive blocks in cooperation with residents*' (WCS, 2020). The two main threats to the NSR outlined by WCS (2020) are the illegal extraction of high-value resource for commercial gain i.e. ivory poaching and hardwood timber logging. The main drivers for these are external markets, mainly in east Asia, which are enabled by poor local governance, weak and corrupt law enforcement, and strengthening criminal networks (WCS, 2020). Other illegally extracted resources include (commercial) bushmeat poaching, collection of carnivore (particularly lion (*Panthera leo*)) and vulture body parts and bones (killing the animals by poisoning and endangering the lives of other animals and humans), and artisanal mining, which has led to land degradation, pollution of rivers, associated bushmeat poaching, and a negative social impact on local communities (WCS, 2020).

Additional pressures include changes in land use for agriculture, peri-urban expansion, collection of fuelwood and wood for construction, the extraction of other resources for subsistence (fishing, non-timber forest products, etc.), Human-Wildlife Conflict (HWC) and consequent negative attitudes towards wildlife and NSR, and human-wildlife-livestock disease (rabies, sleeping sickness, etc.) (WCS, 2020). This is in addition to an increasing human population, a lack of economic opportunity for people, and continued dependence on natural resources, in an area characterised by poor governance and corruption (WCS, 2020).

3.6.3. Gorongosa National Park

Gorongosa National Park (GNP) (IUCN category II), lies roughly in the centre of Mozambique in Sofala Province, and is made up of two discrete areas: the low-lying area around Lake Urema (3,719 km²) proclaimed a protected area in 1960, and the top of Gorongosa Mountain (Serra da Gorongosa, proclaimed in 2010) (above the 700 m contour line) (367 km²) (GoM, 2016). As colonisers took ownership of the land in 1935 the precursor of the current National Park was declared a hunting reserve by the Mozambique Company,[11] and as such, was managed for recreational hunting purposes. The reserve was transferred to the colonial government when the Mozambique Company's charter ended in 1941 and initial steps were taken to ban hunting and to promote the reserve for tourism. In 1960, the reserve was declared a National Park and, by then, had become a popular international tourist destination. Much of the investments in the GNP and its tourism infrastructure came from revenue generated from hunting taxes and licences in other parts of the country. In 1960, the Park boasted 200 lions (*Panthera leo*), 2,200 elephants (*Loxodonta africana*), 14,000 buffaloes (*Syncerus caffer*) and 3,500 hippos (*Hippopotamus amphibius*) (Parque Nacional da Gorongosa, 2012).

During the War of Independence, from 1964 to 1975, GNP suffered little damage although illegal hunting occurred. By 1981, the Civil War was underway and the Chitengo camp (the main administration and tourism centre in the Park) was attacked by RENAMO. With an increase in violence

[11] The Mozambique Company was a private company which held land concessions including the current Mozambican provinces of Sofala and Manica, for the exploitation of resources and manpower (mainly through the forced labour *chibalo* system) between 1891 and 1940 (Newitt, 1995).

GNP was closed and abandoned in 1983 and became a scene of intense fighting. Infrastructure was destroyed and much wildlife was killed for food and for ivory, to buy arms and supplies. RENAMO controlled much of Gorongosa district and people sought refuge within the Park. By the time the General Peace Accord was signed in 1992, large mammal populations were reduced by 90% or more (Parque Nacional da Gorongosa, 2012). In 1994 a rehabilitation plan was developed by the African Development Bank (AfDB), with assistance from the IUCN and EU, employing and training staff and reopening roads.

The Gorongosa National Park (GNP) is currently being managed by a public-private partnership between the Gorongosa Restoration Project (GRP) and ANAC for a period of 20 years (since 2008) (Parque Nacional da Gorongosa, 2012). The mission of GNP is twofold: '*to guarantee the restoration and protection of biodiversity and natural processes of the GNP and in its Buffer Zone to a functioning ecosystem with great biodiversity, to contribute to the wellbeing of people in the Buffer Zone and beyond*' (GoM, 2016, p. 538).[12] Apart from investing heavily in conservation, efforts as part of the project include the development of tourism, infrastructure, international awareness and aiding in the development of the communities in the Park's Buffer Zone (Parque Nacional da Gorongosa, 2012). The respective communities receive a share of 20% of GNP's revenues to allocate as determined by community committees. The GRP also invests in providing alternative livelihoods and provides training in less harmful farming methods amongst other things, such as crop rotation and planting of legumes, no burning, no tilling, mulching, permaculture and integrated pest management, in specific projects, for example, shade coffee cultivation, providing livelihoods and reforestation, and also in education projects, such as the Girls Club encouraging girls to attend school for longer, delaying pregnancy and ending child marriage (Parque Nacional do Gorongosa, 2011).

3.6.4. Limpopo National Park

Limpopo National Park (LNP) (IUCN category II), originally designated a hunting reserve in colonial times, was only proclaimed a national park in 2001. It lies in the southwestern Gaza Province, bounded by the Elephantes and Limpopo Rivers and the border with South Africa, with an area of about 10,000 km². The area is relatively remote, drought-prone, and dominated by grassland, Mopane and forested savannahs.

As early as 1938, the formation of a transfrontier conservation area was discussed (DNAC, 2003). The Peace Parks Foundation has supported the development of this TFCA since 1998. Limpopo National Park (LNP), together with adjacent Kruger National Park in South Africa and Gonarezhou National Park in Zimbabwe (joined by the Sengwe Corridor), with the addition of other protected areas in the area

[12] Translation from Portuguese by author.

(including Banhine National Park and Zinave National Park in Mozambique) they form the Great Limpopo TFCA established in 2002, measuring almost 100,000 km² (Peace Parks Foundation, 2020).

The aim is to manage the TFCA across the international borders by a joint management committee integrating and harmonising policies, strategies and operations (Peace Park Foundation, 2020). The TCFA's objectives are to ensure ecological connectivity on a landscape and hydrological level, reintroduction of wildlife, reducing rhino and elephant poaching, developing tourism and providing benefits to communities living in the surrounding areas, through livelihood diversification, education, etc. (Peace Parks Foundation, 2020).

A resettlement programme is in place to move eight villages (1,500 households) from inside the LNP to development nodes outside (DNAC, 2003; Peace Parks Foundation, 2020). According to the Peace Parks Foundation (2020) three villages (488 households) have already been relocated and with resettlement, people obtain new housing and titles to land, access to education, health services and energy, access to a share of 20% of park revenues, and potential employment opportunities by the Park. People living in the area are mainly Tsonga, with traditional and familial ties to communities across the borders in South Africa and Zimbabwe. Social, economic and political situations in the three countries have, and cause, trans-border movement of people (DNAC, 2003).

The management and development plan for LNP (most recently available for 2003), outlines that in the absence of adequate resources '*natural wildfires should continue as they are an ancient and inherent part of the system*' and recommends a '*revaluation after five years of whether controlled burns* [as a fire management tool] *are necessary'*[13] (DNAC, 2003: 46). It further stipulates that incidences of fires in the LNP should be monitored and data collected to be compared to fire data from Kruger National Park, to inform future management decisions and finally, that awareness should be raised within communities of harmful practices and alternatives, if necessary (DNAC, 2003).

3.7. Research Questions

By placing the conceptual model (Figure 2-1) into the context of Mozambique provided in the previous sections, the questions examined in this study are:

RQ1: What physical and human variables predict a pixel to be burned on a national scale in Mozambique during given time periods?

To address the first research question the whole national extent has been rasterised and the burned data and other suitable spatial physical and human variables for the time periods examined (2001-

[13] Translated from Portuguese by author.

2006 and 2010-2015) are aligned to provide values for all variables on a per pixel basis. The variables used as proxies for the components of the conceptual model are spatial data products and/or remote sensing derived, and suitability was based on the spatial and temporal, extent and resolution, preferably at little to no cost. The variables were then examined individually to identify any observable shifts between un-/burned pixels, including any effects protected area status and other PA subtypes may have. This exploratory analysis provides some initial results which lead on to the next research question.

RQ2: Are there differences between the variables that predict burned outcome between protected areas and non-protected areas, specifically in the three case study sites?

To address the second research question, the variables examined for RQ1, are used to match pixels from extant protected areas (for each time period) with pixels with similar characteristics outside of protected areas, at a national level and at the level of the case study sites (Niassa Special Reserve (NSR), Gorongosa National Park (GNP) and Limpopo National Park (LNP) in the north, centre and south of the country respectively). The matching increases the similarity between the protected area (treatment) pixels and the non-protected area pixels (control) to increase the power of further analysis. Logistic regressions were subsequently applied to examine the effect of protected area status on the odds that a pixel is burned.

RQ3: How does the qualitative data collected at local level (Gorongosa National Park) con-/diverge with results from the quantitative data analyses?

The results from the quantitative data analyses in addressing RQ1 and RQ2, are then compared aiming to link the bigger picture obtained from the quantitative analyses, to a local context using a different 'lens', i.e. to the perception of people on the ground in one case study site (Gorongosa National Park and its Buffer Zone). Most qualitative data for this research was collected during fieldwork (10-24 October 2012) by interviews. The main themes and results from both the quantitative and qualitative analyses are compared to examine convergent and divergent ideas.

RQ4: Do the time periods with different climatic, political, natural disaster events, etc., characteristics show differences in the burned areas, at national/local level?

The final research question tries to deal with more general predictions between burned pixel outcome, and, changes and shifts (policies, politics, livelihood practices, natural disasters, teleconnection patterns, human population increase, migration and displacement of people (due to conflict, natural disasters, etc.) seen in the two time periods. Patterns may indicate areas for further research and some suggestions for future scenarios.

3.8. Time Periods

The two time periods 2001-2006 and 2010-2015 were chosen because INAM data was already available for 2001-2006. Additionally, after considering potential data sources, burned area product from MODIS Terra and Aqua, and other datasets were available for after 2000. Fieldwork was conducted in 2012 which placed it in the middle of the second time period (see Appendix 1 – Historical timeline).

4. Methodological Framework

4.1. Introduction

This chapter provides an overview of a mixed methods approach, followed by the approaches and methods employed for the quantitative and qualitative data and analyses. The following chapter will present the quantitative datasets used.

4.2. Mixed Methods Approach

Despite the wildfire system being complex (Figure 2-1), this research broadly deals with physical and human drivers and their relationship with fire within spatial and temporal constraints. Therefore, a framework using mixed and complementary quantitative and qualitative approaches was deemed to be most useful to gain a more granular understanding of factors at play at different spatial and temporal resolutions, and using different 'lenses' (Roos et al., 2014). This allows for increased validation by methodological triangulation as each method may produce different and unique outcomes. This combined approach, at different resolutions and sets of comparisons, using different types of evidence, is also deemed suitable to prioritise internal validity and increased 'authenticity of context' (Turner et al., 2015).

Multi-disciplinary, interdisciplinary, hybrid or mixed methods approaches for 'linking fire and people', can be powerful. Research such as Tacheba et al. (2009), Eriksen et al. (2011) and Dennis et al. (2015) illustrate the importance for integrating remote sensing technology with social science approaches to link research 'to the ground' for relevance and context and '*nuanced understanding of the local dynamics of large-scale phenomena*' (Tacheba et al. 2009), and to be able to translate and make research and results usable, for example, to develop strategies for fire management and policy. This approach leads to a shift from research driven by theory to problem-driven research.

Wildfires in the Mozambican context are therefore envisaged to be described by answering the research questions in a methodological framework (Figure 4-1). The quantitative approaches use rasterised geographic information data resulting in associated variable values per pixel. Specifically the burned pixels are examined to identify relationships between the burned signal and the variables, via descriptive and exploratory data analysis. Results from these analyses aim to address RQ1 (What physical and human variables predict a pixel to be burned on a national scale in Mozambique during given time periods?).

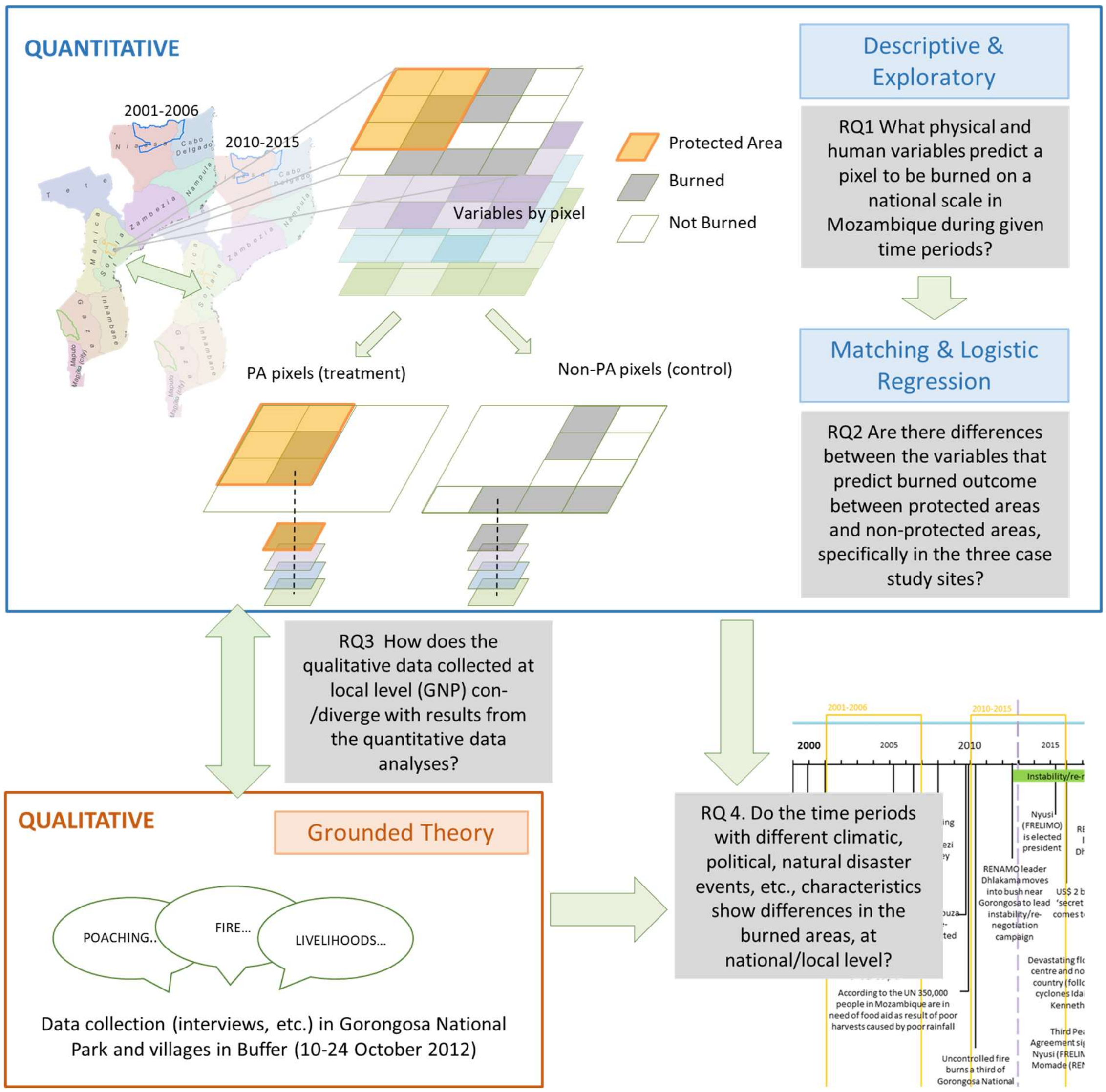


Figure 4-1 Methodological framework used in this study

In order to understand the role of protected areas in the likelihood of a pixel being burned (RQ2), the pixels and their corresponding values are matched to identify pixels with similar characteristics (matched) within and outside of protected areas. Theoretically this should allow for causal inference, by logistic regression, on the protection status of a pixel and the likelihood of it being burned. The results from the quantitative analyses are compared and contrasted to the themes arising from qualitative data collection and analysis conducted in one of the case study protected areas (Gorongosa National Park) to address RQ3.

Finally, the characterisation of the two time periods by examining differences in the quantitative data and other anecdotal evidence is presented and taken into consideration to indicate possible similarities and differences in examined or unknown variations in burned pixels, to answer RQ4.

4.3. Quantitative approaches

4.3.1. Variable Selection

Using the conceptual framework (Figure 2-1) variables for the physical and human drivers are used (Figure 4-2). A burned area product, providing burned status on a pixel level, is used as the 'fire' data. The physical driver datasets used are *rainfall*, *temperature*, *elevation*, *slope* and *land cover*. *Land cover* is also considered as part of the human drivers for the class of *Cropland*. The other human drivers data proxies are *population density*, *distance to settlement*, *distance to road* and the subset of *protected areas*. The examination of the separate time periods (2001-2006 and 2010-2015) are used to indicate other potential underpinning factors influencing the drivers.

The datasets were chosen on the criteria of accessibility (no charge, where possible), availability for the given time periods and processability with useable spatial and temporal resolutions and formats.

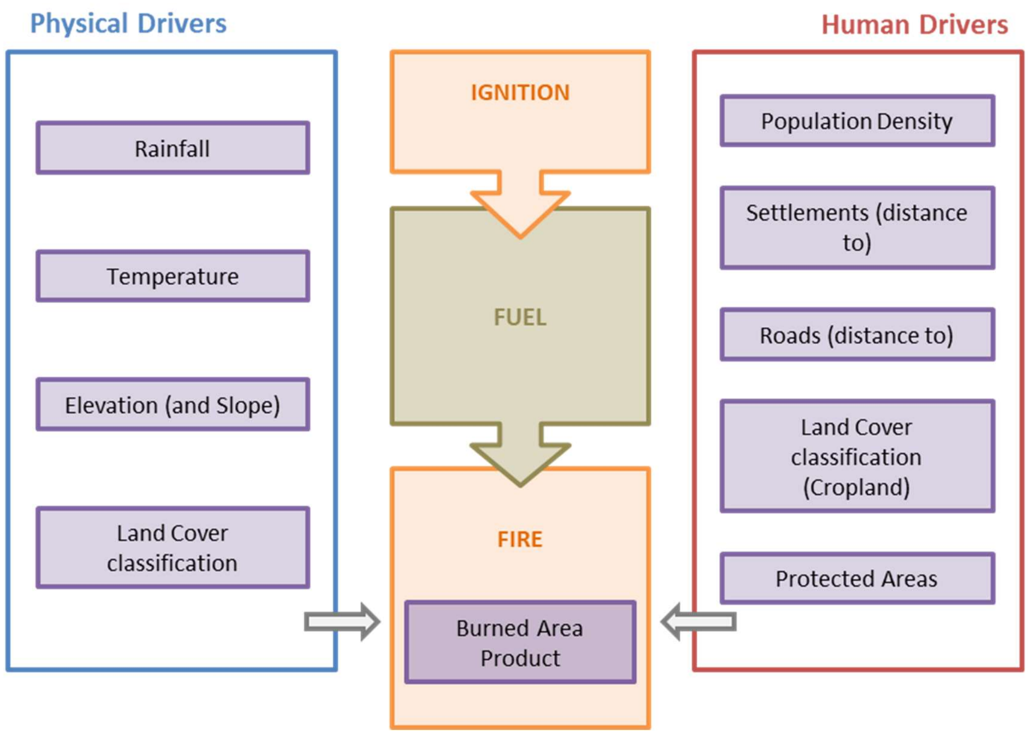


Figure 4-2 Datasets (and derivatives) used as elements of conceptual framework

The raw datasets were processed (reprojected, resampled, summarised, reclassified, distances/slope extracted, as necessary) to align with each other as rasters (grids), for the same spatial (national) extent, for each of the two time periods. This provided each unique pixel at the national extent, with values (at the centre of the pixel) for all variables. Any subsequent quantitative analyses were then performed on a pixel-by-pixel basis.

4.3.2. Descriptive Statistics and Exploratory Data Analyses

Descriptive and exploratory data analysis approaches are used to visualise the variables for each time period, to gain understanding of the data and to inform, develop and refine further analyses (Tukey, 1977; Hartwig and Dearling, 2011). Bivariate relationships of the variables were plotted (against un-/burned status), for each time period (2001-2006 and 2010-2015) to indicate any observable shifts in the variable characteristics in predicting un-/burned outcome.

For each time period, principal component analysis (PCA) for protected area and for burned pixels, were performed to indicate the strength of the variables providing the variation in the data. The variables examined in the initial exploratory data analyses were then used for matching pixels to generate similar groups of 'treatment' and 'control' groups, within and outside of PAs, respectively, which were then compared using logistic regression, in order to provide information on the role of protected area status on burned outcome.

4.3.3. Matching as Pre-processing

In order to examine the role of protected area status in the likelihood of a pixel being burned (RQ2, Figure 4-1), multivariate matching is used in this study as a pre-processing technique to improve inferences that are more robust and less sensitive to modelling assumptions (Greifer, 2020d), by creating sets of binary 'treatment' and 'control' pixels *ex-post*, in this case 'treatment' denotes within a PA, and 'control' is non-protected (outside a buffer of 10 km from PAs), while controlling on pre-treatment variables which are prognostic of the outcome (Rosenbaum and Rubin, 1983; Greifer, 2020d). Matching has been used as a pre-processing method in examining the effectiveness of protected areas within conservation biology (e.g. Andam, et al., 2008; Negret et al., 2020; Schleicher, 2020). The goal of matching is to achieve for the distributions of covariates in the two groups to be approximately equal to each other (covariate balance) as they would be in a successful randomized experiment. This allows for increased robustness and decreased selection bias (Greifer, 2020d , Shadish et al., 2002).

The first step for matching, is the classification of pixels which have undergone treatment (within protected areas established before the respective time periods) and control pixel (outside of other extant PAs) and their associated values for the variables presented in Chapter 5. The selection of potential covariates on which the matching is done is based on the conceptual framework, available datasets and the initial exploratory data analysis of these. The potential control pixels are subset from the Mozambican national extent to satisfy the condition to be outside a 10 km buffer from (all types of) nationally designated protected areas (i.e. including Buffer Zones, but excluding Ramsar sites established prior to the time period). The additional 10 km buffer is to control for any spillover effect the protected areas may show in nearer pixels and which tapers off with distance, and although 10 km is arbitrary, is commonly used in studies (e.g. Fuller et al., 2019, Schleicher et al., 2020). The final selection of covariates should be those that cause variation in the outcome (un-/burned) and selection into treatment group (protected area or not), i.e. the confounding variables (VanderWeele, 2019) and obviously, these measurements should be free of errors and missing values (Randolph et al., 2014; Greifer, 2020d; Schleicher et al., 2020).

This is followed by the actual matching, the appropriateness and method of which is determined by applications of matching methods, given the best quality of fit (Greifer, 2020a, c, d; Schleicher et al., 2020). Exact and coarsened matching are the most powerful methods as they aim to balance the entire joint distribution of covariates. However, exact matching was not possible in this study as continuous variables are present and coarsened matching resulted in fewer pairs of variables than nearest neighbour (method = nearest). Nearest neighbour propensity-score matching was used in this study, which collapses the matching covariates into a single variable which predicts the probability of the pixel being in the treatment or the control group by means of a logistic regression, with a caliper (0.25, i.e. paired pixels to be within 0.25 standard deviations of the propensity scores) to impose a tolerance level to avoid bad matches if the closest neighbour is far away (Rosenbaum and Rubin, 1985; Negret et al., 2020; Schleicher et al., 2020).

The matching is then assessed by the covariate balance using the difference in standardized means between the treatment and control groups before and after matching, with the difference ideally being < 0.1 (but < 0.25. being acceptable) and visual assessment of love plots and propensity score histograms (Schleicher et al., 2020). The matched groups are then used for further statistical testing.

4.3.4. Logistic Regression

Where matched data is obtained by greedy types of matching (e.g. nearest neighbour, with or without caliper), traditional univariate or multivariate statistics can be used to compare groups on the outcome, and simpler matching designs (1-to-1, without replacement, and no weighting) lend themselves to simpler analyses (Ho et al., 2011; Bai and Clark, 2019). There is a debate on whether the comparison should between-subject or within-subjects if groups are substantially well-matched, where if the cases are matched on the propensity score based on several characteristics they would be more similar than they would be if randomly assigned to groups (Austin, 2007; Bai and Clark, 2019). Within-subjects analyses have the advantage of showing smaller error variances and having more statistical power. However, in the context of this research, where propensity scores are computed from a limited number of variables and may not include all covariates that influence selection bias, the matched groups are assumed to be independent observations, i.e. the propensity scores may be similar, and the actual covariates may not necessarily be the same (Bai and Clark, 2019). Logistic regressions comparing groups on a single binary outcome variable, were used to estimate the effect on a pixel on burned outcome, with the PA status (0/1) as one of the explanatory variables. The burn outcome variable (un-/burned) for each time period was attached to the matched datasets. The propensity score was only used for matching and was not included in the logistic regressions (Luo et al., 2010).

4.4. Qualitative Data Collection and Analysis Approach

4.4.1. Qualitative Fire Research

Qualitative research into the drivers of wildfires is limited and is often focussed on mitigation, management strategies and dealing with the challenges and effects of fires (e.g. Devisscher et al., 2016; Otero and Nielsen, 2017; Kroepsch et al., 2018; da Silva et al., 2019). Matimbe (2015) investigated the consequences of wildfires (land degradation, soil erosion and resulting flooding and deforestation) and the mitigation of effects (reforestation, raising awareness and education, etc.) in Mapinhane District, Mozambique, and Davies et al. (2010) in miombo habitats in Malawi. Qualitative research has also been used in evaluating the (mis-)match between local fire use practices and national policies in Zambian savannahs (Eriksen, 2007).

4.4.2. Inductive Reasoning in Grounded Theory Data Collection and Analysis

Most qualitative data for this study was collected during fieldwork (10-24 October 2012) in or near Gorongosa National Park, which temporally places data collection more or less in the middle of the second time period examined in this study (2010-2015). GNP was the preferred choice for qualitative data collection, as it did not form part of a Transfrontier Conservation Area (TFCA), unlike NSR and LNP.

The data was collected and analysed by inductive reasoning in a grounded theory-based methodological approach (Glaser and Strauss, 1967; Sapiains et al., 2020). This means analysis and development of theories are interrelated and occur during and after data collection, 'grounded' in actual data (Corbin and Strauss, 1990; Strauss and Corbin, 1994).

Some initial informal conversations and interviews were done with park staff (Park Administrator, members of the Scientific Services and Community Relations Teams, and potential interviewees with villagers (in the Buffer Zone)) were initially selected opportunistically through members of the community working in the Park and the hotel in Chitengo and consequently through snowballing. Two group discussions were held in two separate villages in the buffer zone which were piggy-backed on the GNP's Community Relations Team's visits to the villages. Given the time and financial constraints of the fieldwork (self-funded) and previous knowledge, this worked well with the assumption that sampling for grounded theory of '*specific groups of individuals, units of time, and so on, but in terms of concepts, their properties, dimensions, and variations'* (Corbin and Strauss, 1990). The interviews were unstructured and open-ended, aimed to collect perceptions of '(wild)fire', the role of fire in the interviewers' day-to-day life (in agriculture and other livelihoods), incidents of (specific) fires, relationships of fire with other factors (drought, social factors), cultural significance, etc. General areas for questioning were determined previously and consequently through feedback from the interviewees and guided by the responses given and the interviewees' knowledge and comfort (details of interviewees are provided in Appendix 5 – List of informants during fieldwork).

Given the constraints of the fieldwork, the number of participants, was not established prior to arrival at GNP. Group discussions were held with members of the Vinho community (close to the GNP's main camp in the buffer zone) (4 women, 6 men), members of agricultural associations in Vinho (3 women, 5 men) and members of another community, Nhanguo in the buffer zone of the Park (5 men). Individual informal interviews were conducted with 5 community members, and with 3 GNP staff.

My association with the GNP staff may have influenced the responses given by people living in the buffer zone of the Park in interviews. I stayed in Chitengo, the main camp of GNP, in the independently-run tourism facilities, collecting data with permission granted through the GNP administration and access and transport to communities was facilitated by GNP staff. Several factors may have affected interviewers' responses, especially by villagers: the presence of GNP staff (to facilitate access or translation), the reliance of Chitengo camp / hotel on agricultural produce and labour from nearby communities (particularly from Vinho village), the relationship of the communities in the buffer zone of GNP and GNP itself in terms of benefits (share of 'the 20%', training, logistical support, etc.), and no clear delineation of 'park' and 'government'. The second village visited, Nhanguo, relies to a very limited extent on employment by GNP and tourism facilities and is located in a charcoal producing area (D. Muala, personal communication, 15/10/2012). Additional interviewer effects could be the fact that I am an 'outsider' and a foreigner, and my ethnicity and gender. The interviews were either conducted in Portuguese (the official language of Mozambique) and although I am fluent, I am not a native speaker, or interpreted from XiSena by available persons (GNP staff or other members of community). Although most interviews were conducted in Portuguese it is a second language for most Mozambicans. Group discussions were recorded, transcribed and translated from Portuguese by the author, and notes were taken by the author during one-to-one interviews. All interviewees were explained the nature of the study and its relevance and all data collected are treated confidentially and the identification of participants will not be made available, unless participants have consented to be identified.

For the analysis, by manually comparing similarities and differences between concepts in the interviewees' responses, concepts were labelled and used as building blocks to form higher and more abstract categories, and relationships between them (Corbin and Strauss, 1990; Sapiains et al., 2020). Reiterations of comparisons of the theory-in-progress were made to reduce bias, increase precision and consistency (Corbin and Strauss, 1990). Abstraction of the concepts into categories make a grounded theory generalizable and more applicable although the theory specifies the condition, the observation of particular phenomena, and may be modified for other situations, and when sampling is increased systematically and widespread (Corbin and Strauss, 1990).

Around the time of the fieldwork, it just happened that the leader of RENAMO (the guerrilla movement during the Civil War, now-opposition party) and a contingent, had ensconced themselves somewhere near Vunduzi, just east of Mt Gorongosa, near RENAMO's former base Casa Banana (for details of location see Figure 7-2 Gorongosa National Park, Buffer Zone, surrounding area and locations of data collection). Due to the local history, support for the opposition was still strong in this area and the media reported that RENAMO was drumming up support and filling its ranks with armed members, to 'remind' the FRELIMO-government that RENAMO's demands included in the GPA of 1992 should not be continued to be ignored, and support for the opposition within the population should not be discredited. The situation escalated into a low-level 'war' including attacks on civilians and transport routes, and confrontations with government forces, which continued into 2020. Due to this political instability, and later Covid-19, any follow-up fieldwork/visits were rendered unfeasible within the context of this research.

5. Quantitative Data

5.1. Introduction

Once possible data proxies for the components of the conceptual model were identified as detailed in Figure 4-2, the usefulness of datasets was determined by the spatial and temporal, availability and resolution (Appendix 2 – Temporal availability of potential data). The datasets used in this study and their provenance are listed in Table 5-1.

5.2. Data Availability and Quality

All spatial datasets were compiled, processed (reprojected, resampled, summarised, reclassified, distances/slope extracted, as necessary) in ArcMap (version 10.7.1) (ESRI, 2019), in WGS84/UTM 37S projection for the national extent of Mozambique, based on national administrative boundaries of the shapefile provided by CENACARTA (2020c). The burned area datasets were used as the base datasets for pixel size (500m) and to snap all other datasets to. Rasters were transformed to point data for all variables (centre of pixel) and values for the points (pixels) were joined by Spatial Join (Analysis toolbox), to obtain variable values for each individual pixel, for the national extent (n = 2,681,608).

5.3. Administrative Boundaries

Shapefiles for administrative boundaries for Mozambique boundaries (national > province > district) were obtained from CENACARTA for the national terrestrial extent (including the Mozambican portion of Lake Niassa). According to details supplied with the data, administrative boundaries are from existing data held by CENACARTA. The shapefiles were provided in geographic (latitude/longitude) coordinate system, Tete (Clarke 1866 ellipsoid) datum.

5.4. Burned Area Product

The National Aeronautics and Space Administration (NASA) (Terra and Aqua combined) Moderate Resolution Imaging Spectroradiometer (MODIS) Burned Area product (MCD64A1) was used in this study. The algorithm detects changes in reflectance coupled with active fire observations, to produce a 500 m gridded layer identifying burn dates for each pixel and quality information.

The MCD64A1 tiles covering the area of Mozambique (h21v10, h20v11, h20v10, h21v11, per month) were downloaded for the periods 01 January 2001 to 31 December 2006, and 01 January 2010 to 31 December 2015. Pixels were reclassified into burned (1) and unburned (0) classes for each calendar month.

Table 5-1 Datasets used

Variable	Dataset Name	Temporal Resolution	Spatial Resolution	Source	Access
Administrative boundaries	*Limites administrativos*	single (2000)	vector (digitized at scale 1:250,000)	*Centro Nacional de Cartografia e Teledetecção* (CENACARTA)	In situ (Maputo, Mozambique)
Burned Area Product	Burned Area Monthly L3 Global 500m MCD64A1 (Collection 6)	1 month	500 m	NASA MODIS	https://reverb.echo.nasa.gov/reverb
Rainfall	TRMM (TMPA/3B43) Rainfall Estimate L3 1 month 0.25 degree x 0.25 degree v7	1 month	0.25°	NASA TRMM	https://gpm.nasa.gov
Temperature	*Dados Diários/Mensais: Capitais Provinciais*	1 day (2001-06) 1 month (2010-15)	point data for national weather stations (Mozambique)	*Instituto Nacional de Meteorologia* (INAM)	In situ (Maputo, Mozambique)
Elevation	SRTM 90m Digital Elevation Database v4.1	single	90 m	CGIAR-CSI	http://srtm.csi.cgiar.org
Population Density	Gridded Population of the World UN-Adjusted Population Density v4	1 year / 5 yearly (2000/05/10/15/20)	1 km	CIESIN	https://sedac.ciesin.columbia.edu/
Settlements	*Cidades e Vilas*	single (2000)	vector (digitized at scale 1:250,000)	*Centro Nacional de Cartografia e Teledetecção* (CENACARTA)	In situ (Maputo, Mozambique)
Roads	Global Roads Open Access Data Set v1 (gROADSv1)	single	vector	CIESIN and ITOS	https://sedac.ciesin.columbia.edu/
Land Cover Classification	Land Cover Maps - v2.0.7	1 year	300 m	ESA CCI	ftp://geo10.elie.ucl.ac.be/v207/
Protected Areas	World Database on Protected Areas (WDPA)	single cumulative, ongoing	vector (varying methods of digitization, accuracies, etc.)	UNEP-WCMC and IUCN	https://www.protectedplanet.net

The burned area product was chosen as being the most suitable 'fire data' for this study (Archibald et al., 2009; 2010) as compared to other products relating to fires (active fires, radiative fire power, etc.) as it summarises the extent of a fire event over time as a burn scar rather than providing instantaneous information about occurrence or energy release of the fire. Burn scars in a sub-/tropical context usually show regrowth of vegetation by the next 'dry season' after the 'wet season' and therefore allowing repeated burning of pixels over a period of years. Although burn scars can disappear very quickly where rainfall, and dry weather follow soon after the fire event. The MODIS product also implicitly works on the assumption that the burned area is derived from heat, i.e. fire. It has to be borne in mind that the extent of burning at the sub-pixel level is not available, and a pixel will be flagged as burned regardless of the size of the area burned or the number of ignitions. Temporal resolution for the Terra and Aqua image the Earth's surface every 1-2 days (NASA, 2019).

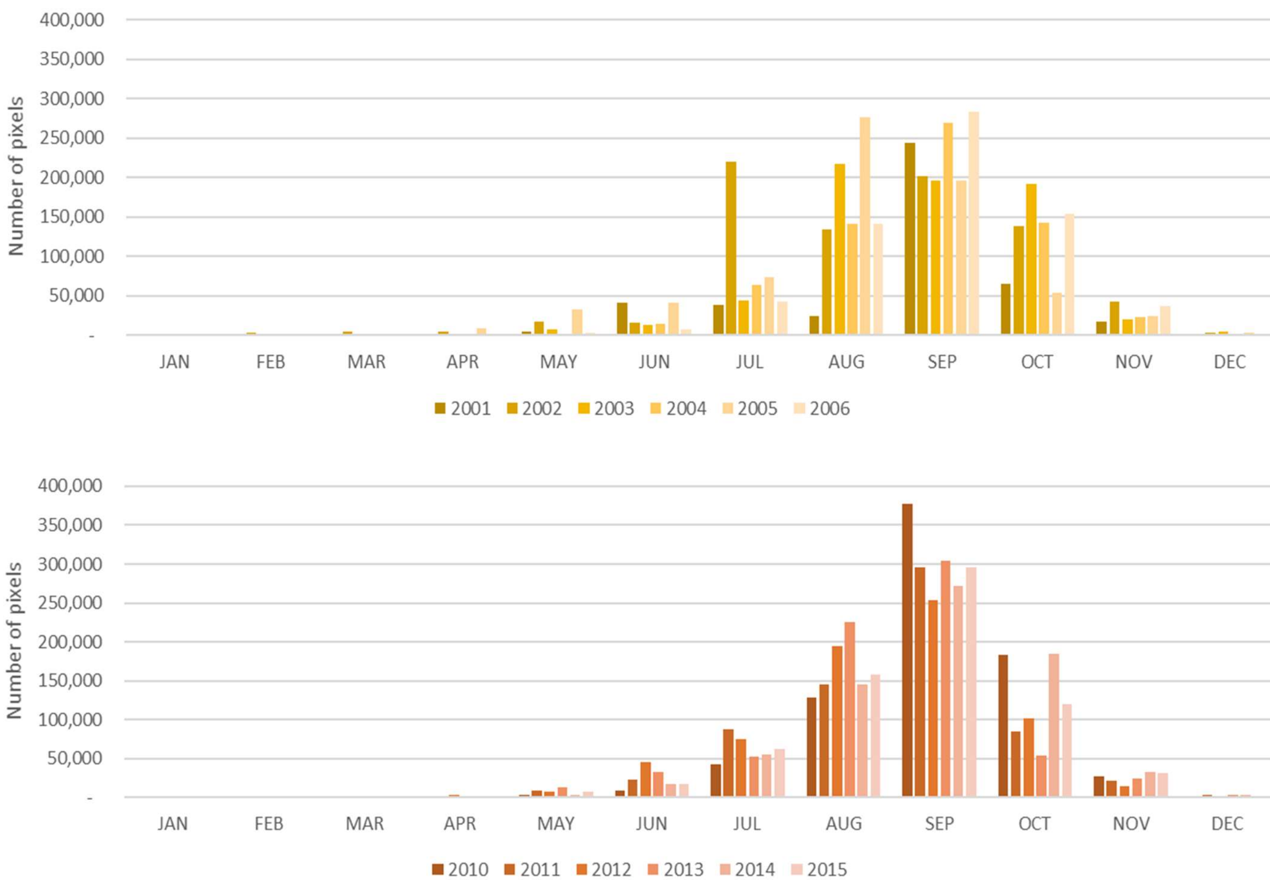


Figure 5-1 Burned pixel counts per month for the time periods 2001-2006 and 2010-2015 (n = 2,681,608 pixels)

Most fires in Mozambique occur between May and November (MJJASON), with September, generally, showing the peak of burned pixels (Figure 5-1 Burned pixel counts per month for the time periods 2001-2006 and 2010-2015 (n = 2,681,608 pixels)Figure 5-1). This period is taken to be the Fire Season (FS) when >97% of burned pixels occur during each year in the given time periods (2001-2006 and

2010-2015). This coincides with the drier and cooler months of the year. For further analyses the data were transformed to provide whether a pixel was burned, or not, during the FS in a given year, and for each time period. Burned pixels outside the FS are not considered.

Initially, the MCD45A1 (Collection 5.1) data was considered, which was superseded by the MCD64A1 (Collection 6) which was subsequently used in these analyses. This was deemed favourable as for Collection 6, surface reflectance and active fire input data is used to generate the product (vs. Collection 5), omission error has been reduced and it shows significant improvement in detection of small burns, especially in forests and cropland (Roy et al., 2008; Giglio et al., 2016). There was a reported outage from 16 June to 2 July 2001 which affects the product quality during that time (Giglio et al., 2013). Additionally, persistently cloudy areas may be systematically underestimated and '*the temporal uncertainty in persistently cloudy regions can be many times larger than the underlying temporal resolution of the data set itself*' (Giglio et al. 2013). No measures to address these issues have been taken for this study.

5.5. Rainfall

For rainfall, NASA's Tropical Rainfall Measuring Mission (TRMM) monthly rainfall data were used (TMPA/3B43 Rainfall Estimate L3 1 month 0.25°x 0.25° v7). The data are created from merged microwave-infrared precipitation rates in mm/hr and root-mean-square precipitation-error estimates (TRMM, 2011).

The total monthly rainfall for each calendar month (mm per month), during the two time periods were calculated from the rainfall rate supplied by TRMM product (mm per hr). The data were also transformed into total rainfall per Wet Season (WS) (preceding a Fire Season) where a WS is generally from November to April (NDJFMA) (although the characteristics of which vary spatially across the national extent given the longer double-peaked wet season in northern areas due to the ITCZ overpassing twice per WS). To provide the total rainfall for the first WS in each time period, November and December for 2000 and 2009, respectively, were also included. A second rainfall dataset, total rainfall per Dry Season (DS) (MJJASO), was also calculated.

Table 5-2 Selected weather stations for Mozambique

Station	Latitude	Longitude	Elevation (m)
Mocimboa	-11.36	40.36	27
Pemba	-12.98	40.53	50
Montepuez	-13.13	39.03	535
Lichinga	-13.30	35.23	1,365
Cuamba	-14.82	36.53	607
Lumbo	-15.03	40.67	10
Nampula	-15.10	39.28	441
Tete	-16.18	33.58	150
Quelimane	-17.90	36.90	6
Chimoio	-19.12	33.47	732
Beira (Aeroporto)	-19.80	34.90	16
Vilanculos	-22.02	35.31	14
Inhambane	-23.87	35.38	15
Chokwe	-24.50	33.00	33
Maputo (Aeroporto)	-25.92	32.57	44

Data: CENACARTA (2000a)

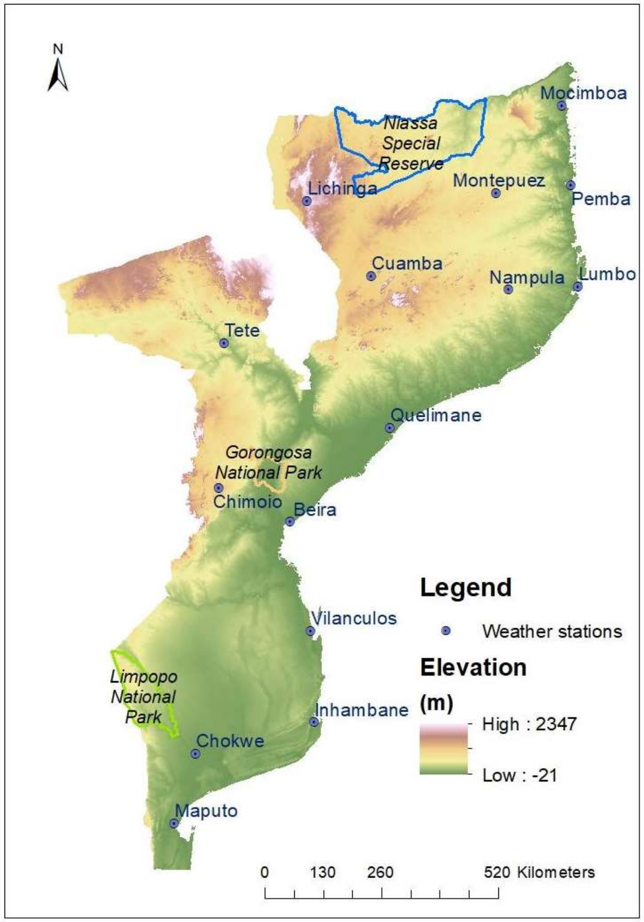


Figure 5-2 Selected weather stations and elevation (metres) for Mozambique
Data: INAM (2001-2006a); CENACARTA (2000a); Jarvis et al. (2008); UNEP-WCMC and IUCN (2020).

Initially rainfall (and temperature) data were acquired for the time periods from the Mozambican National Meteorological Institute (*Instituto Nacional de Meteorologia* – INAM) for the time periods 1 January 2001 to 31 December 2006, and 1 January 2010 to 31 December 2015. The data for the period 2001-2006 were available as daily total rainfall (in mm, over 24 hours from 0900 to 0900). Missing daily precipitation values were disregarded, and all daily precipitation values used to obtain total monthly precipitation, in mm. For the second time period (2010-2015), data were only available as total monthly rainfall (in mm, 0900 to 0900, daily readings processed by INAM, missing values provided as blanks). Fifteen stations were selected as they had the most complete records for the two time periods and are reasonably well spread across Mozambique (Table 5-2 and Figure 5-2).

The monthly totals were then interpolated in ArcGIS for the national extent. However, as some records were quite patchy or missing, no indication of missing values/error was given for 2010-2015 and the type of readings available (daily vs. monthly) were different for the two time periods, the INAM weather station total monthly rainfall readings were used to compare to TRMM data (point values for total monthly rainfall derived from the TRMM rainfall rates) for each available INAM weather station value. Although the visual similarities between the TRMM and INAM values are good (Figure 5-3), given the issues with the INAM data, the TRMM data being more consistently generated and needing less processing, were therefore used. The scatterplots (Figure 5-4), show a better correlation for the data for 2001-2006, which being available as daily values aggregated to monthly values, probably have less inherent processing errors than the data for 2010-2015, which had many missing values. No adjustment of the TRMM data was made based on the comparison to the available INAM data.

As cumulative monthly rainfall is used, any effects stemming from the high-resolution TRMM rainfall rates being based on indirect and possibly infrequent satellite measurements, should be less pronounced (Huffman and Pendergrass, 2017). According to Huffman and Pendergrass (2017) the TRMM algorithm '*likely underestimates precipitation in (a) regions of intense, small-scale convection and (b) at higher latitudes*'.

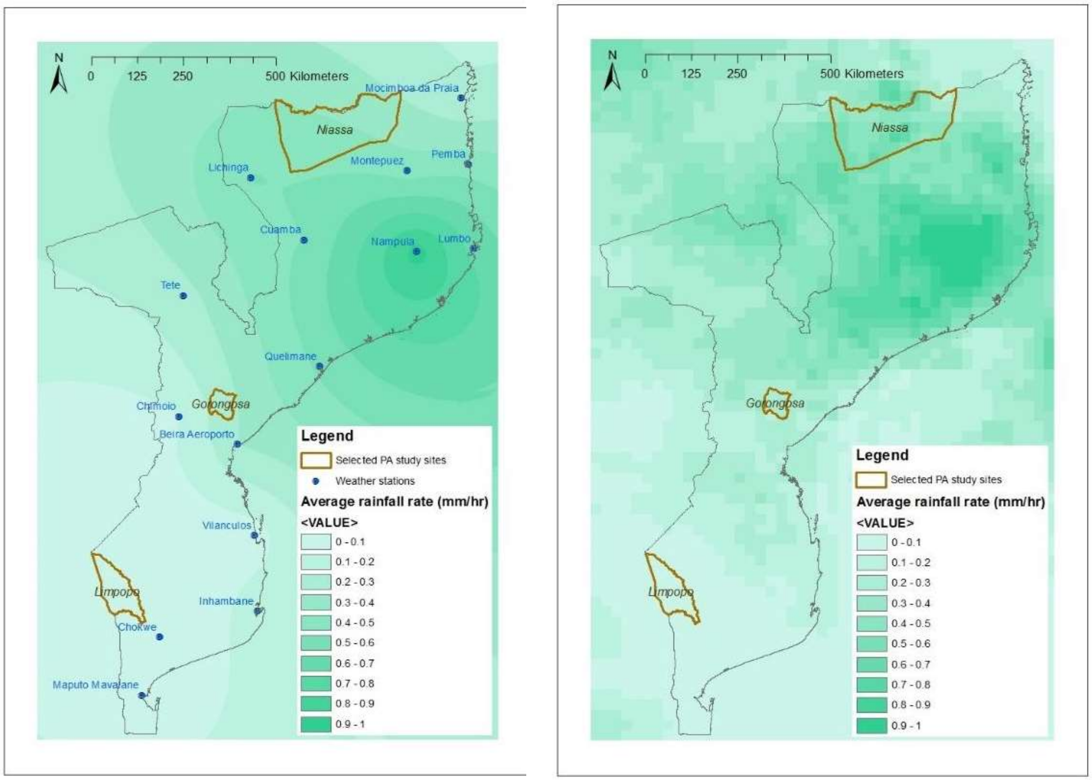


Figure 5-3 January 2003 rainfall estimates (showing high rainfall rate near Nampula due to Severe Tropical Storm Delfina making landfall on 31 December 2002)
Left: INAM interpolation of monthly average rainfall rate (mm/hr) and weather stations used for interpolation. Right: TRMM monthly average rainfall rate (mm/hr).
Data: CENACARTA (2000a); INAM ((20001-2006b); TRMM (2011); UNEP-WCMC and IUCN (2020).

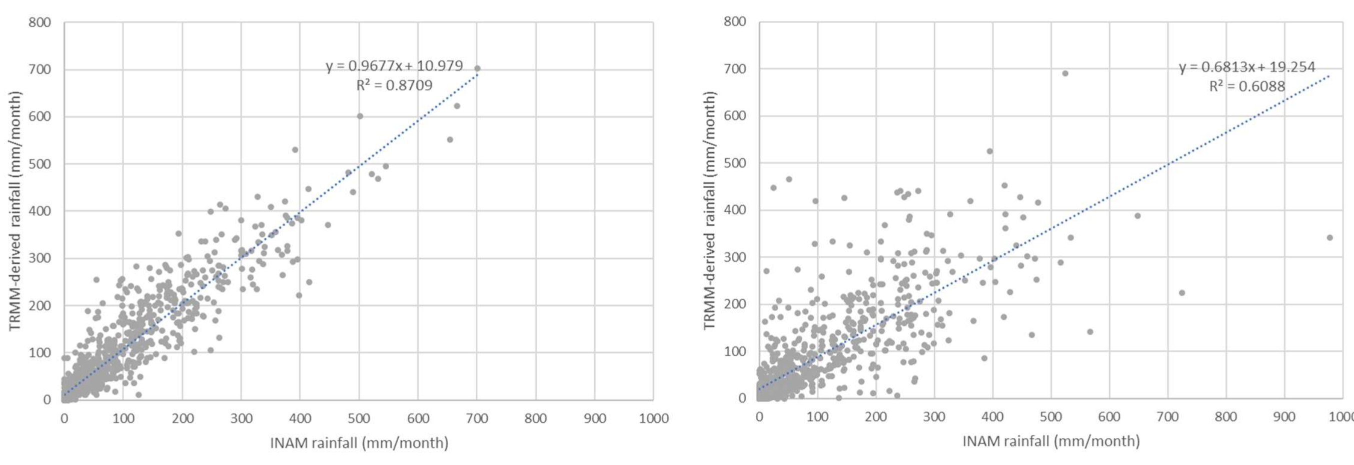


Figure 5-4 Scatterplots of TRMM and INAM total monthly rainfall (mm/month) at selected locations of INAM weather stations
Left: For 2001-2006. Right: for 2010-2015.
Data: derived from CENACARTA (2000a); INAM 2001-2006b; 2010-2015b ; TRMM (2011).

5.6. Temperature

Temperature data collected at national weather stations (Table 5-2) were acquired for the two time periods from INAM. Daily maximum and minimum temperatures in °C were available for the 2001-2006 time period and daily mean temperature was calculated. Where daily values were missing, gaps were filled by averaging previous and following day means. The INAM dataset for the period 2010-2015, mean temperature was already provided by INAM as monthly values, without details as to how the dailies/errors/missing values where processed/treated.

Interpolation of monthly temperature was done by Kriging in ArcGIS (3D Analyst extension), with default settings, to produce monthly rasters using mean daily temperatures (from max and min) for 2001-2006 and monthly means for 2010-2015. The temperature datasets were processed to provide the mean of monthly mean temperature per Fire Season (FS) for each time period.

The most complete weather station records are for the capital city, Maputo, and the second largest city, Beira, where weather stations are located at the respective airports. The data records for other stations are patchy in terms of recorded temperatures and possibly quality, and the weather stations with more complete records show a skewed spatial distribution where coastal areas / urban centres and lower altitudes are favoured (Figure 5-2). This would most certainly affect the interpolated values of temperatures, leading to unreliable estimates for pixels further inland and/or at higher altitude.

Additionally, the format of the data for the two time periods was not the same: the earlier time period (2001-2006) data were daily and later period (2010-2015) were monthly values, thus there will be differences in the way missing daily values have been treated and the potential filling of gaps in temperature for 2010-2015. Another caveat of the temperature data is simply that to create spatial dataset for use in this study the data were interpolated. Inferred relationships between the temperature data with other variables may simply be relationships with the method of interpolation.

5.7. Elevation and Slope

The digital elevation model (DEM) (Figure 5-2) used for the analyses is the Consortium of International Agricultural Research Centers – Consortium for Spatial Information (CGIAR-CSI) SRTM 90 m Digital Elevation Database v4.1. The data originate from the USGS/NASA Shuttle Radar Topographic Mission (SRTM) and have been hole-filled by using ancillary data sources where available (Reuter et al. 2007).

To calculate slope, the ArcGIS Slope tool in the Spatial Analyst toolbox was used (output value in degree rise [0-90°], method = planar, Z-factor = 1) (Figure 5-5).

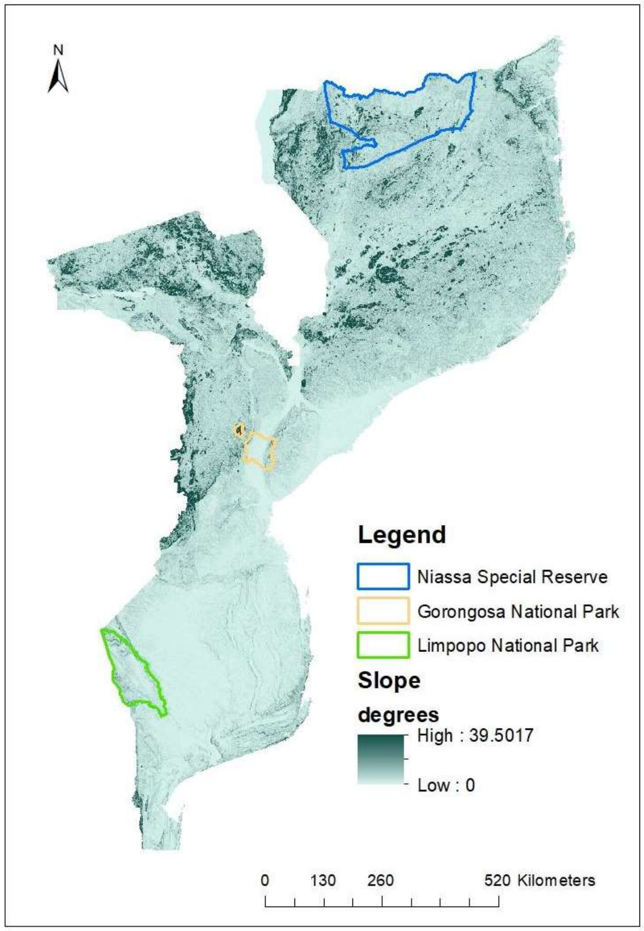


Figure 5-5 Slope (in degrees)
Data: derived from Jarvis et al. (2008).

5.8. Population Density

The NASA Socioeconomic Data and Applications Centre (SEDAC) UN-adjusted population density (GPW UN-Adjusted Population Density v4) datasets have been used, held by the Center for International Earth Science Information Network (CIESIN) at Columbia University, providing human population density per district (persons per km^2) (Figure 5-6). The datasets closest to the beginning of each time period were used for analyses, as differences between the earliest (2000) and the latest (2015) values are relatively low for most of the national extent (Figure 5-7), i.e. the 2000 dataset was used for the 2001-2006 time period and the 2010 dataset for 2010-2015.

The population density dataset has a limited resolution as units are at third administrative level (national > province > district) i.e. single value for large areas without regard for high density areas (settlements) within, although larger urban areas are subdivided into relatively small urban districts better accounting for population density in cities and towns (although these are less relevant for this research).

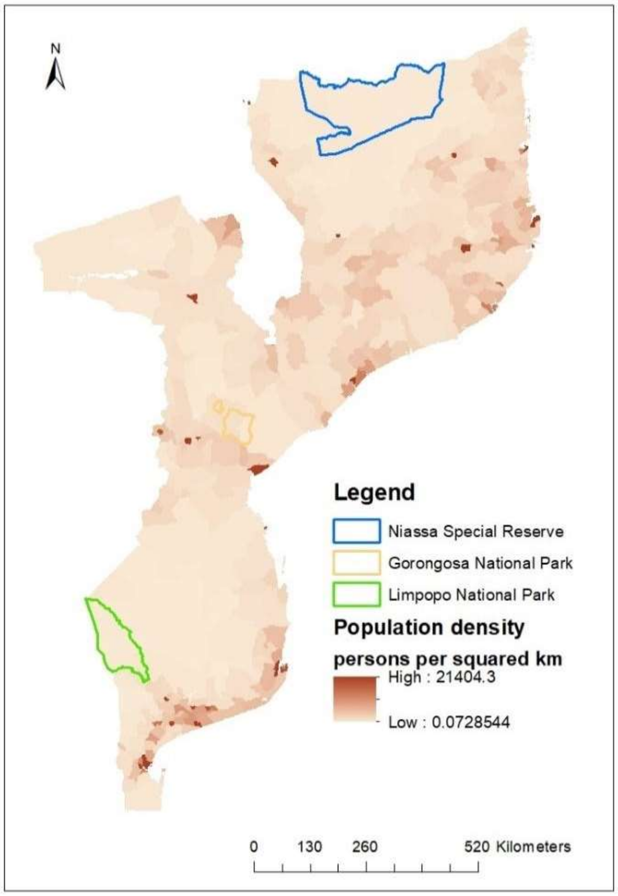


Figure 5-6 Population density (per district, persons/km²) for 2000
Data: CIESIN (2013)

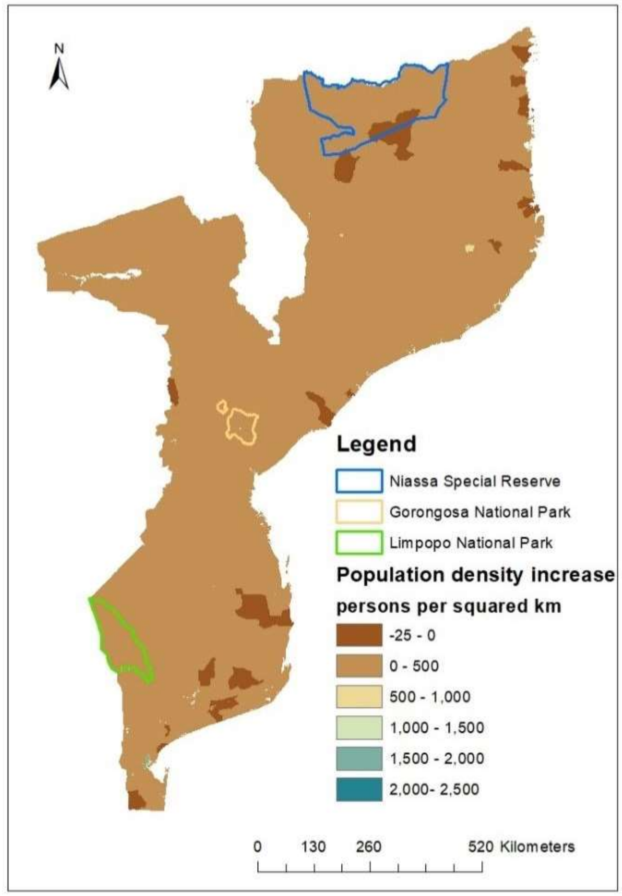


Figure 5-7 Increase in population density (per district, persons/km²) between 2000 and 2010
Data: derived from CIESIN (2013).

5.9. Distance to Settlement

Point shapefiles for 'cities and towns/villages'[14] were obtained from the Mozambican National Centre for Cartography and Remote Sensing (*Centro Nacional de Cartografia e Teledetecção* – CENACARTA) based on data held by CENACARTA. The shapefiles were provided in geographic (latitude/ longitude) coordinate system, Tete (Clarke 1866 ellipsoid) datum. From the point shapefiles, a raster of distance to nearest settlement (in m, and converted to km) was made using the Euclidean Distance tool (planar distance method) in the Spatial Analyst toolbox (Figure 5-8).

[14] '*Cidades e Vilas*' (translation from Portuguese by author) (CENACARTA, 2000a).

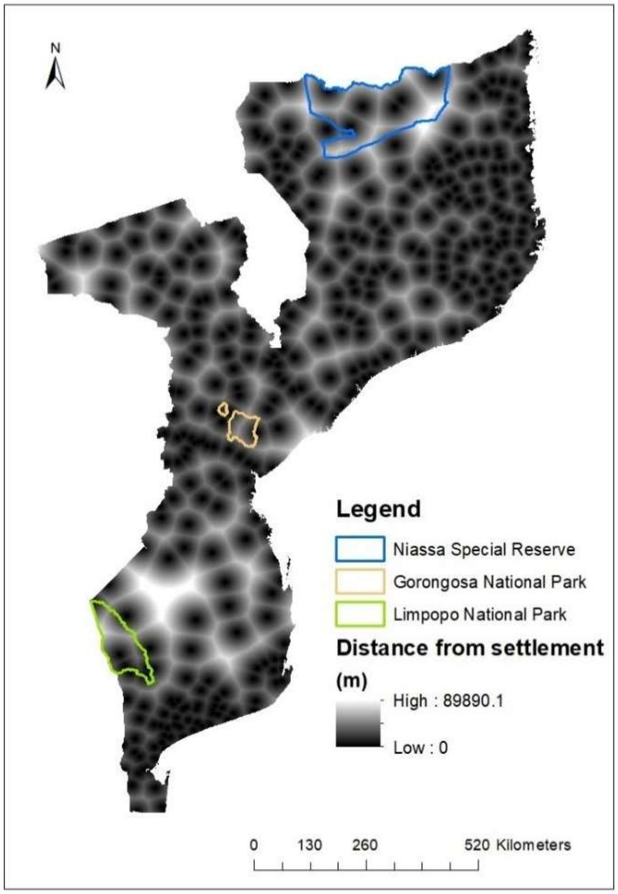


Figure 5-8 Euclidean distance from nearest settlement (in metres)
Data: derived from CENACARTA (2000a)

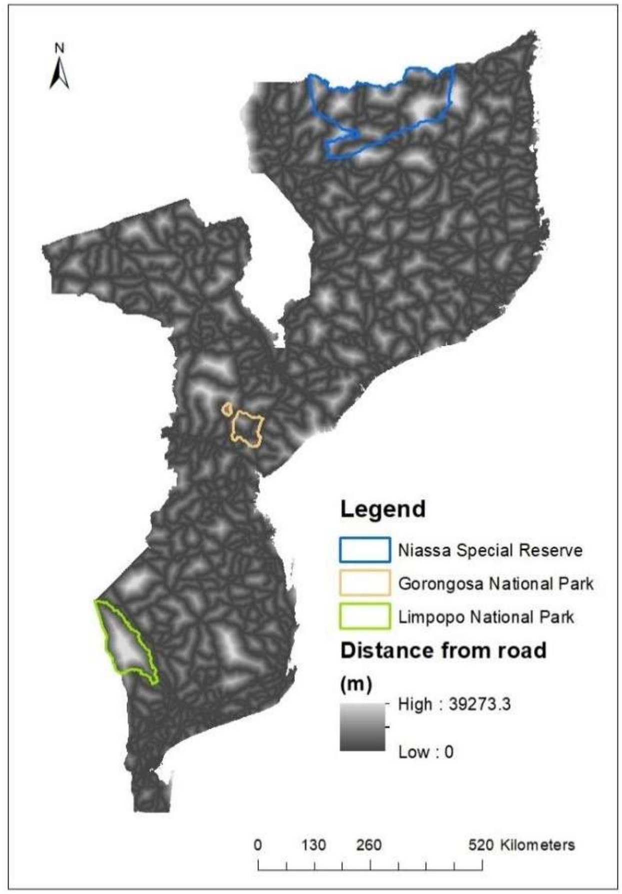


Figure 5-9 Euclidean distance from nearest road (in metres)
Data: derived from CIESEN and ITOS (2013)

There is no information available as to how these datasets have been produced, what criteria have been used to determine as to what defines a 'city' or 'town/village' in this context (although by visual examination settlement IDs are hierarchical and include provincial capitals and next biggest/important towns), the method of digitisation, base data, etc. The dataset is from 2000 and no later versions are available.

Also, the effect of Euclidean distance to a settlement is taken to be uniform, without taking into account a weighting by, for example, population size of a settlement, as no population data was supplied with the dataset. In terms of relevance to fires, a higher population relying on agriculture, use of natural resources, etc., may have an increased frequency of ignitions, change of fuel characteristics, but also fire suppression and fragmentation of fuel.

5.10. Distance to Road

The NASA SEDAC Global Roads Open Access Data Set, v1 (gROADSv1), provided by the Center for International Earth Science Information Network (CIESIN) at Columbia University, and Information Technology Outreach Services (ITOS) at the University of Georgia, was used to generate rasters giving the Euclidean distance (planar distance method) to roads, converted to km (from metres) (Figure 5-9). The effect of Euclidean distance to road is taken to be uniform, not as a weighted measure which would, for example, take road hierarchy or busy-ness into account.

Initially, the dataset 'primary and secondary roads and rail'[15] from the Mozambican National Centre for Cartography and Remote Sensing (*Centro Nacional de Cartografia e Teledetecção* – CENACARTA) was considered, which is based on visible roads / railway lines on Landsat TM (30 m) images and data held by CENACARTA, released in 2000. However, new roads and railway lines have been built since then and existing roads and railways have also been upgraded and therefore usage of these and others may have changed. Therefore, the gROADS dataset was chosen over the CENACARTA dataset as it possibly combines more recently available datasets and a method for 'ground truthing' in Google Earth (CIESIN, 2013).

5.11. Land Cover Classification

The 300 m European Space Agency Climate Change Initiative Land Cover (ESA CCI-LC) classifications (ESA CCI Land Cover Maps - v2.0.7) were used in this study.

Three land cover products were initially considered: the ESA CCI-LC, ESA GlobCover land cover products (ESA Globcover 2005 Project (2005) and ESA GlobCover 2009 Project (2010)) and MODIS Land Cover Type (MCD12Q1) Collection 5 - IGBP classification (Friedl et al., 2010). In order to compare the different classifications, the respective classifications for 2005 were reclassified into more general classes, i.e. *Cropland* (any classes which use 'crops' or similar in their description, aiming to identify agricultural areas), *Forest* (any classes that use 'tree cover' or 'forest' in their description), *Mosaic/Shrub/Grassland* (descriptions including 'shrub-', 'grass-' or 'savannah'), *Sparse* (any class description referring to 'sparse' vegetation), *Flooded* (any labels indicating temporary or permanently waterlogged/flooded ground) and *Urban/Bare/Water* (all in one class as they should be irrelevant to this study in terms of fires). *Cropland*, *Forest* and *Mosaic/Shrubland/Grassland* are the most relevant classes with respect to fires.

[15] *Estradas principais, ligando capitais provinciais, estradas secundárias, ligando sedes distritais e linhas férreas* (author's translation from Portuguese: 'primary roads linking provincial capitals, secondary roads linking main towns of districts, and railways' and referred to as 'primary and secondary roads / rail') (CENACARTA, 2000b).

There is some overlap of the classification codes between the ESA CCI and GlobCover datasets which facilitated the process (see Appendix 3 - Reclassification of Land Cover products). Figure 5-10 shows relatively good similarities between the reclassified ESA CCI (2005) and GlobCover 2005, with the reclassified MODIS (MCD12Q1) classes being too coarse to be informative in the context of this research. Ultimately, the ESA CCI-LC product was chosen over the other two classifications as it, once reclassified, had a wider range of classes (unlike the MODIS (IGBP) classification), and had consistent treatment of the input data for the land cover classification and was available as a yearly product for the time periods of study (unlike GlobCover which uses different input methodologies and was only available for 2005/6 and 2009).

ESA CCI possibly overestimates *Flooded* pixels particularly around the Zambezi Delta (Figure 5-10) and it is a relatively new product so less validation has been done than for the other two classification, but no adjustments have been made.

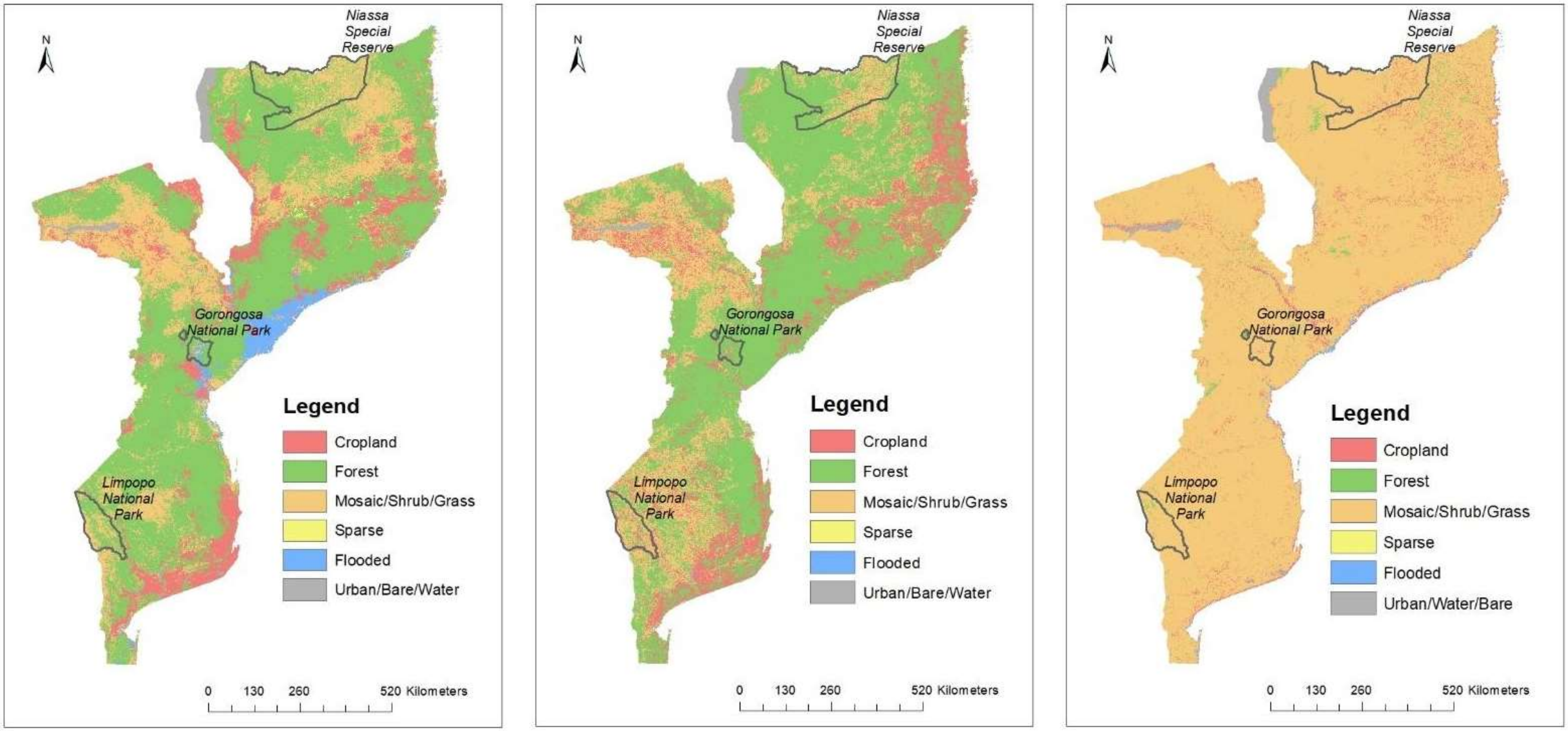


Figure 5-10 Comparison of reclassified land cover products (for 2005) and location of case study protected areas
Left: ESA CCI-LC. Centre: GlobCover 2005. Right: MODIS (IGBP). The reclassifications give relatively good visual overlap for ESA CCI-LC and GlobCover2005.
Data: derived from ESA Globcover 2005 Project led by MEDIAS-France/POSTEL (2005); Friedl et al. (2010); ESA (2017).

5.12. Protected Areas

Shapefiles for, and details regarding, protected areas in Mozambique were accessed via the United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC) and International Union for Conservation of Nature (IUCN) World Database on Protected Areas (WDPA) (for a subset of the WDPA data see Appendix 4 – Protected Areas of Mozambique (from WDPA, selected variables, excluding Ramsar Sites)). The two Ramsar sites, Zambezi Delta, and Lake Niassa and its Coastal Zone, have not been included in the analyses as they are internationally designated.

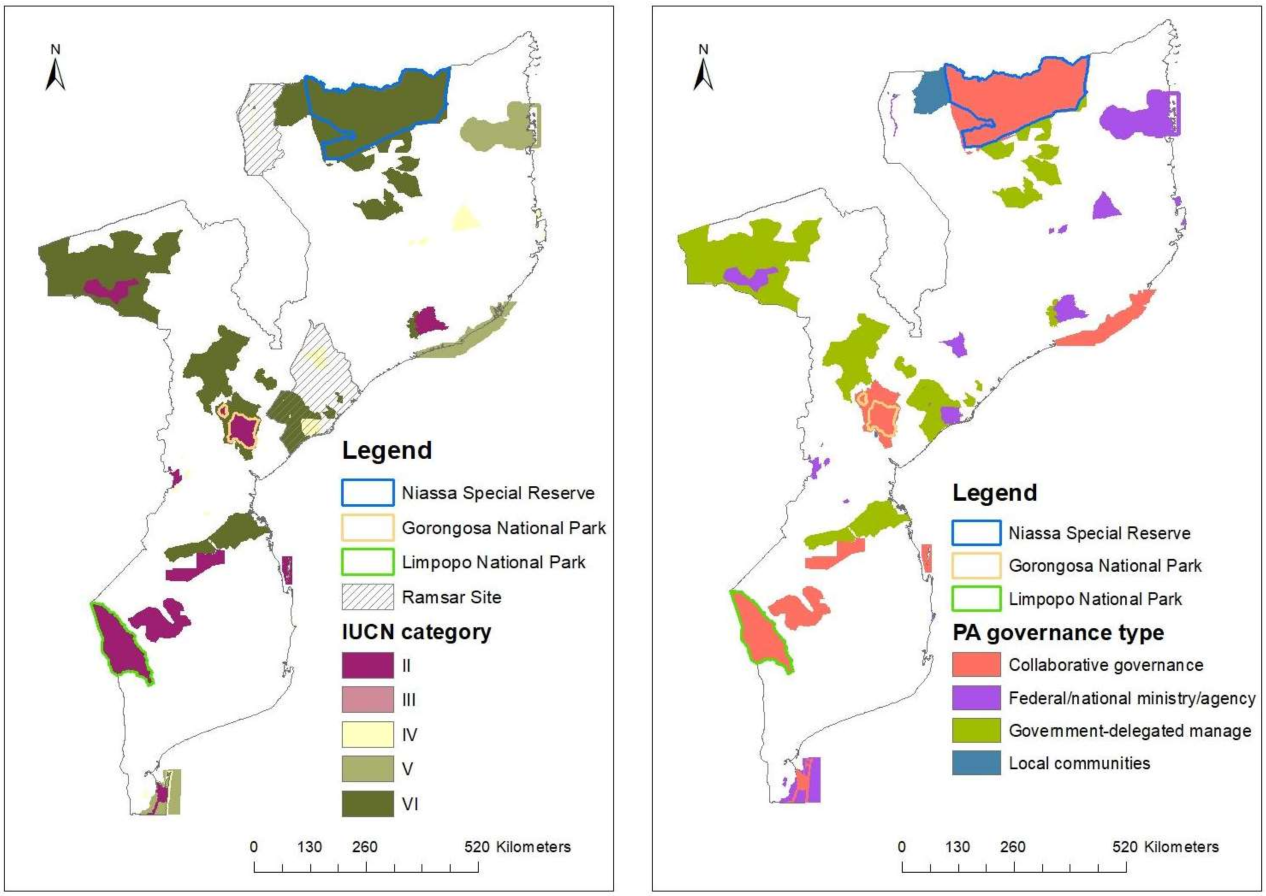


Figure 5-11 Protected areas in Mozambique
Left: IUCN Categories of protected areas, and internationally designated Ramsar sites. Right: Nationally designated protected areas by type of governance.
Data: UNEP-WCMC and IUCN (2020).

Apart from *Name*, the variables available within the WDPA considered potentially useful for this study were *National Designation* (Figure 3-4), *IUCN Category* and *Governance Type* (Figure 5-11), *Management Plan* and *Status Year*. These were deemed most useful in providing an indication of national objectives, of management priorities, age of the protected area, etc. For all available protected areas in Mozambique (last updated in November 2020) polygon shapefiles were available and according to the database have been 'verified by the State' (*Verification* variable in WDPA).

Name and *National Designation* were combined to create a unique character string for each protected area, for example, to differentiate between Niassa Special Reserve and Niassa Buffer. *National Designation*, *IUCN Category* and *Governance Type* exist for all Mozambican protected area shapefiles, whereas *Status Year* and *Management Plan* do not. The availability of a management plan within the WDPA is dependent on input into the database, and does not necessarily provide an indication of the implementation thereof, and the low numbers of protected areas for which management plans were available for (19 of 60), led to the exclusion of this variable for this study. *Status Year*, which indicates when a protected area was proclaimed, exists in the WDPA for 34 of 60 PAs.

Table 5-3 Protected Areas of Mozambique by National Designation and IUCN Category

		IUCN Category					
		II	III	IV	V	VI	
		National Park	Natural Monument or Feature	Habitat/ Species Management Area	Protected Landscape/ Seascape	Protected area with sustainable use of natural resources	Total
National Designation	Buffer Zone	-	-	-	1	2	3
	Sanctuary	-	-	1	-	-	1
	Community Conservation Area	-	-	-	-	3	3
	Environmental Conservation Area	-	-	-	1	-	1
	Environmental Protection Area	-	-	-	1	-	1
	Forest Reserve	-	1	13	-	-	14
	Hunting Reserve	-	-	-	-	20	20
	Ecological Park	-	-	1	-	-	1
	National Park	9	-	-	1	-	10
	National Reserve	-	-	4	-	-	4
	Special Reserve	1	-	-	-	1	2
	Total	10	1	19	4	26	60

Data: UNEP-WCMC and IUCN (2020)

National Designation was used, partly for unique identification of protected areas, as well as providing some form of reflection of national objectives. *IUCN Category* is also used as the categories' aim to systematically define, record, and classify the aims and objectives of protected areas, and are recognised globally (Stolton et al., 2013). However, it is important to note that the national designations do not neatly align with IUCN categories, even for similarly named/categorised protected areas, for example, *National Park* as a national designation is not necessarily equivalent to the IUCN *Category II National Park* (Table 5-3).

The caveats regarding these data to be noted are that the WDPA is not necessarily a complete repository of (designated) protected areas, as protected areas may not yet have been digitised, new areas may not have been submitted or are being quality checked (UNEP-WCMC and IUCN, 2020). Polygon and point shapefiles of protected areas are dependent on submission by countries and boundaries and vary in terms of digitization method, accuracy and resolution.

For all three protected area case studies, and their buffer zones, polygon shapefiles exist with indications of IUCN category, status year and availability of management plan (Table 5-4). Gorongosa National Park (GNP) is made up two distinct areas (see 3.6.3 Gorongosa National Park), and the WDPA provides the status year for both as 1960, although officially, Serra da Gorongosa (Gorongosa Mountain) was proclaimed in 2010 (GoM, 2016).

Table 5-4 Case Study Protected Areas and respective Buffer Zones

Case Studies PAs	Name	National Designation	IUCN Category	Status Year	Management Plan
NSR	Niassa	Special Reserve	VI	1954	Y
NSR buffer	Niassa	Buffer Zone	VI	1954	
GNP	Gorongosa	National Park	II	1960	Y
GNP	Serra da Gorongosa	National Park	II	1960*	Y
GNP buffer	Gorongosa	Buffer Zone	VI	2010	
LNP	Limpopo	National Park	II	2001	Y

**WDPA gives this as 1960 – officially, GoM (2016) gives this as 2010.*

Data: UNEP-WCMC and IUCN, 2020

6. Quantitative Analyses and Results

6.1. Introduction

Following on from the presentation of the quantitative datasets in the previous chapter, this chapter provides details of the initial exploratory data analyses of the derived variables in relation to un-/burned pixel outcome at the national extent (Figure 6-1). This initial examination provides indications of the effects of the variables, including the PA status of a pixel, on burned outcome which goes towards addressing RQ1 (What physical and human variables predict a pixel to be burned on a national scale in Mozambique during given time periods?). This is followed by details of the matching of pixels within and outside of PAs, using the other variables to provide similar treatment (PA) and control (non-PA) groups, and subsequently, post-matching, to determine the effect of PA status on the burned outcome of a pixel by using logistic regressions (Figure 6-1). This final component of the quantitative methods goes towards addressing RQ2 (Are there differences between the variables that predict burned outcome between protected areas and non-protected areas, specifically in the three case study sites?). The results, together with qualitative results, are discussed in Chapter 8.

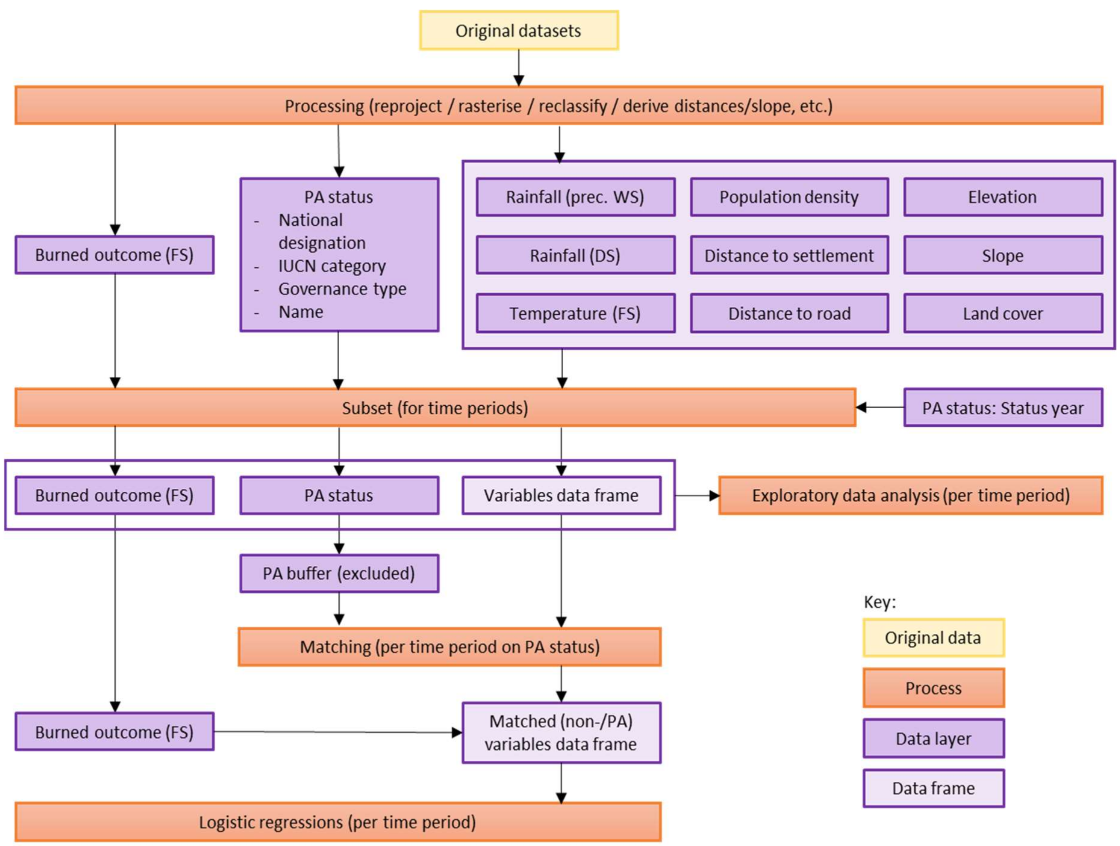


Figure 6-1 Workflow for quantitative data

The variables visualised against un-/burned outcome during FS for each time period are the physical and human variables as stand-ins for the physical and human drivers in the conceptual model (Figure 2-1) to provide an indication of shifts in each variable's effect on un-/burned outcome of a pixel: the continuous physical variables include climatic (*rainfall in preceding WS*, *rainfall in DS*, *mean temperature in DS*), and topographic variables (*elevation* and *slope* (although slope can be indicator of agricultural potential, a human variable)) (Figure 6-1). The continuous human variables include *population density*, *distance to settlement* and *distance to road*. For the discrete variables, *land cover* provides a combination of physical and human categories, and finally *PA status* (with subtypes *national designation*, *IUCN category*, *governance type* and *name*) gives a subset of national pixels with particular management objectives (Figure 6-1). Burned outcome is binary, and PA status is initially examined at the subtype level, but for subsequent analyses is used as a binary measure, respective of the extant PAs for each time period. The raw data / spatial datasets presented in Chapter 5, from which the variables are derived, are referred to throughout the initial examinations of the variables.

For the following analyses, the outcome (un-/burned), treatment/control (non-PA/PA) and all associated values for the other variables used are on a pixel-by-pixel basis from rasters created in a GIS for the national extent of Mozambique. Data were imported into R as text and variables merged on the pixel ID. Analyses were done in R (version 4.0.2) (R Core Team, 2020) using RStudio (RStudio Team, 2020). For visualisations the packages ggplot (Wickham et al., 2020), vcd (Meyer et al., 2006) and factoextra (for PCA) were used, as well as Microsoft Excel. The R MatchIt package was used for matching (Ho et al., 2011) and any other R packages used for specific tasks are provided in the text.

6.2. Exploratory Data Analysis of Variables

For the continuous variables, data are visualised by un-/burned outcome, using boxplots, where the 'box' makes up the interquartile range (IQR), showing the median as a line in the box. The whiskers extending to either side of the box indicate data lying within 1.5 times the IQR, with individual points beyond this, indicating outliers. The boxplots allow for simple visual comparisons between the un-/burned classes and provide a summary of the structure of the data (McGill, 1978). The discrete variables (*land cover* and *PA status* (including subtypes)) are visualised using proportions.

6.2.1. Burned Outcome

Of the pixels which the national extent of Mozambique was divided into, between 23.6% (in the 2002 FS) and 28.6% of pixels (in the 2010 FS) showed as burned (at least once) during each Fire Season (MJJASON) in the two time periods (2001-2006 and 2010-2015) (Figure 6-2).

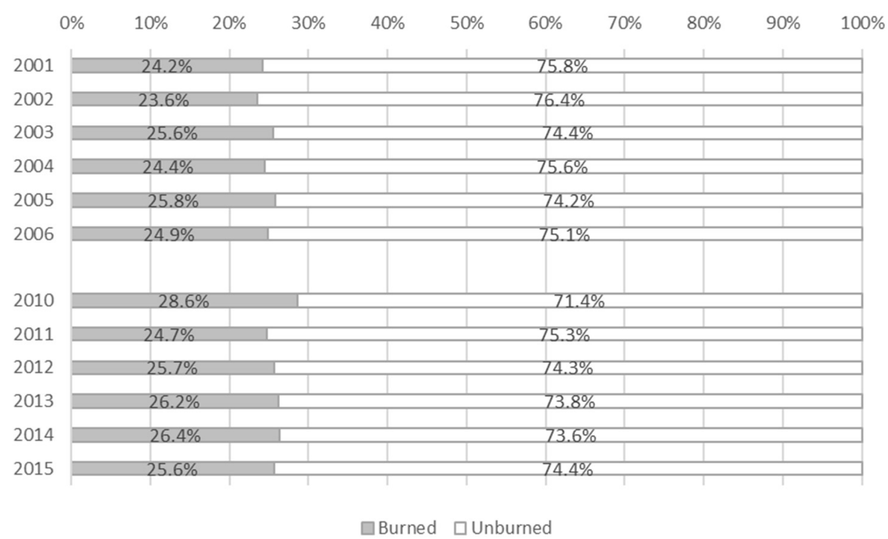


Figure 6-2 Proportions of pixels un-/burned per FS (2001-2006 and 2010-2015)

6.2.2. Rainfall in Preceding WS

Mean total rainfall per Wet Season (NDJFMA) (preceding each FS) was higher for the period 2010-2015 (Figure 6-3). The boxplots showing the mean total rainfall (per WS preceding a FS) for each time period for un-/burned pixels, indicate higher rainfall for pixels which were burned (just over 1,000 and just under 1,000 mm/WS) compared to unburned pixels, respectively.

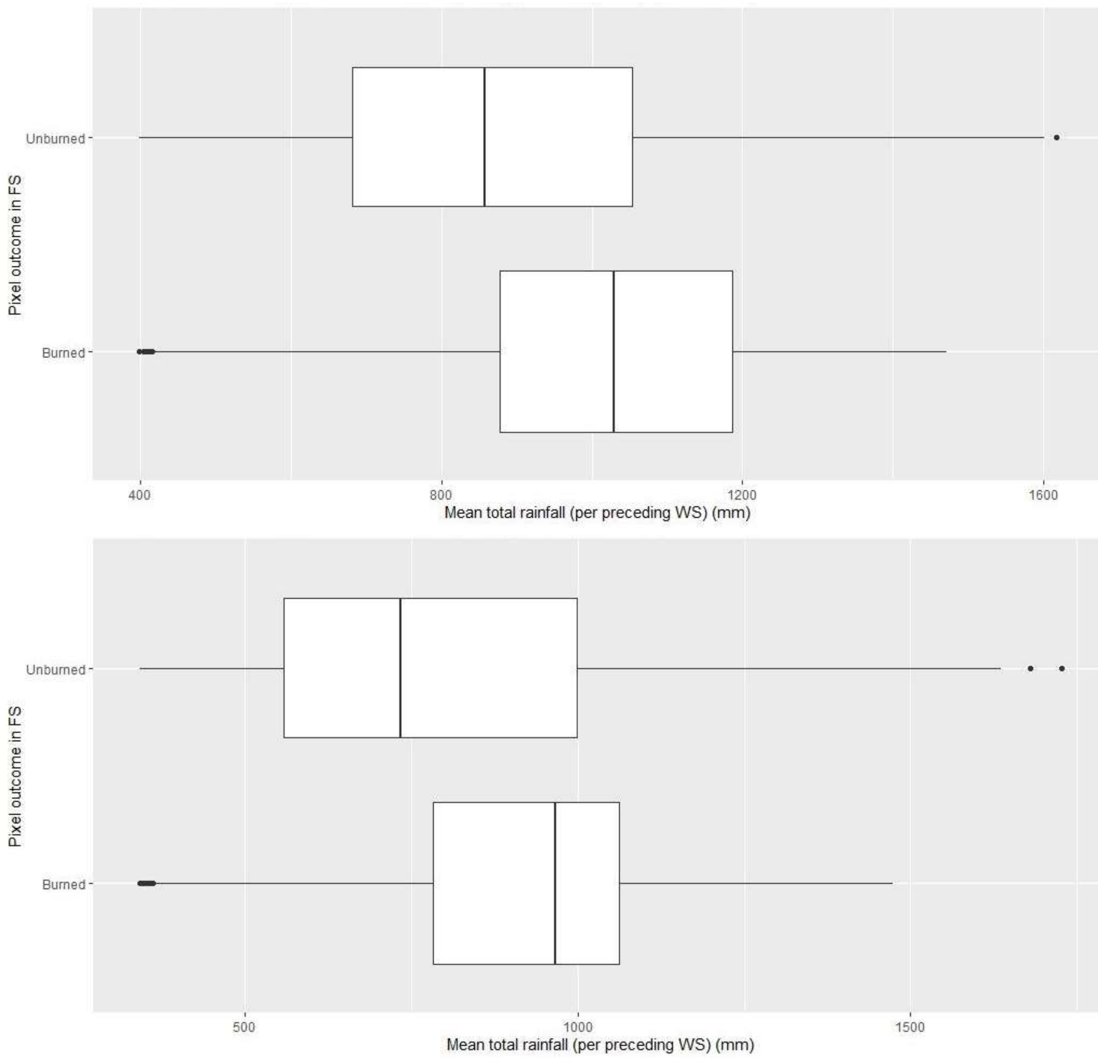


Figure 6-3 Boxplots of un-/burned pixel outcome (in FS) by rainfall in preceding WS (mm) (n = 2,645,464)
Top: for 2001-2006. Bottom: for 2010-2015.

6.2.3. Rainfall in DS

The boxplots for mean rainfall per DS indicate that burned pixels receive less rainfall than unburned pixels, for the two time periods (Figure 6-4). The extreme outliers in the 2010-2015 time period, for rainfall > 1,000 mm/DS, are due to consistently high rainfall estimates in the TRMM data during the DS months in that time period. The pixels exhibiting these high rainfall estimates, are located on the shore of Lake Niassa, and have not been excluded for the subsequent matching, as their extreme values would make them very likely too different to be matched with pixels in a treatment group anyhow.

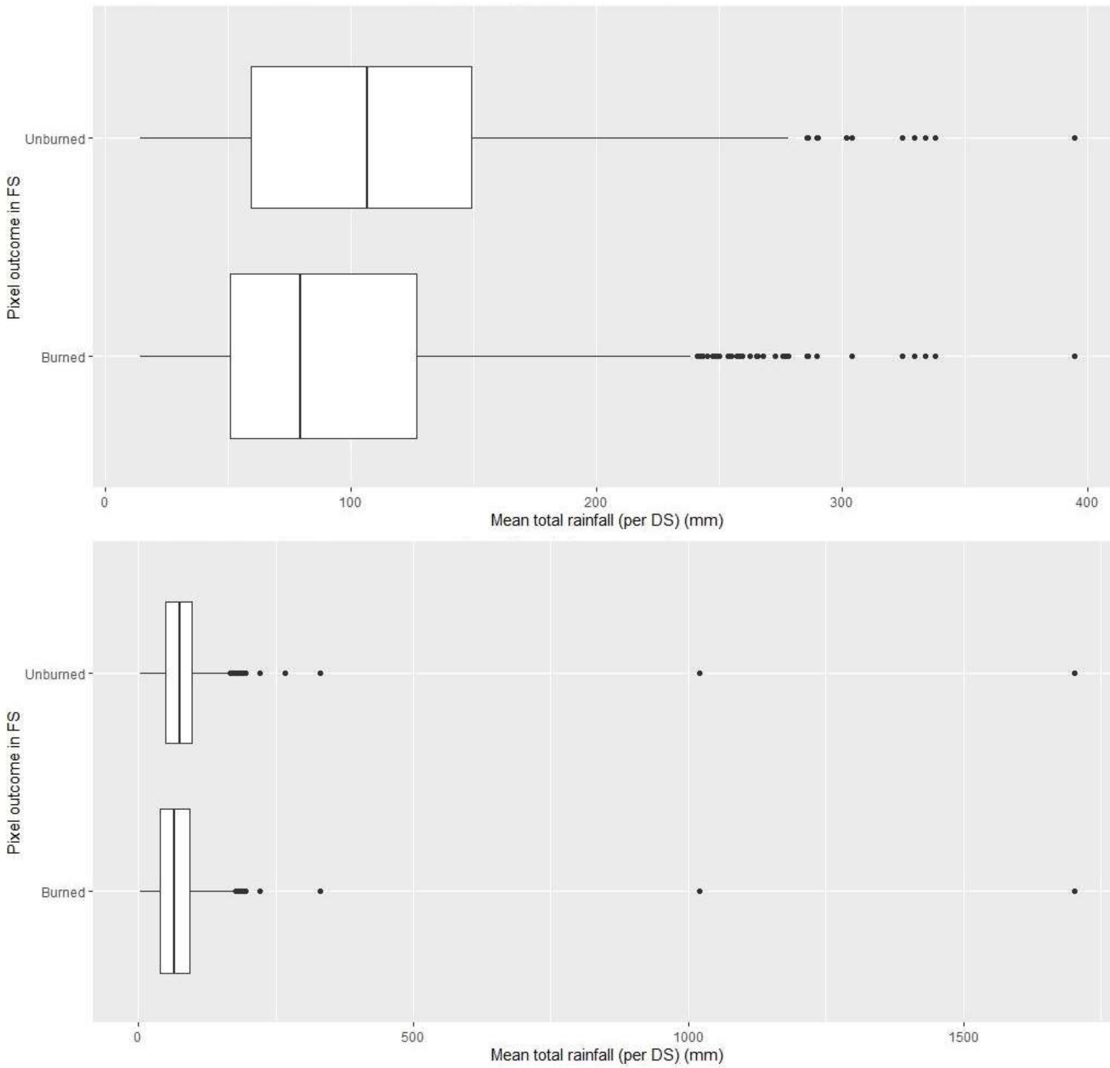
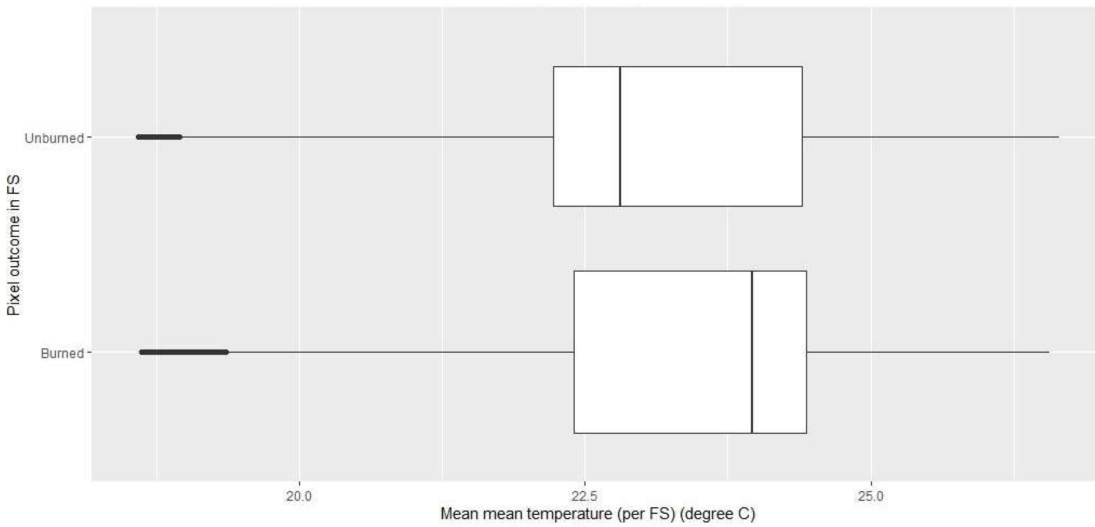


Figure 6-4 Boxplots of un-/burned pixel outcome (in FS) by rainfall in DS (mm) (n = 2,645,464)
Top: for 2001-2006. Bottom: for 2010-2015. The extreme outliers for 2010-2015 (>1,000 mm/WS) are pixels located on the shores of Lake Niassa for which very high rainfall estimates are provided by the TRMM data in that time period.

6.2.4. Temperature in FS

For the period 2010-2015, the data show lower median FS mean temperature than for 2001-2006 (Figure 6-5). The data for 2010-2015, also show narrower inter-quartile ranges and more outliers. For both periods, however, burned pixels show (slightly) higher median FS temperature.



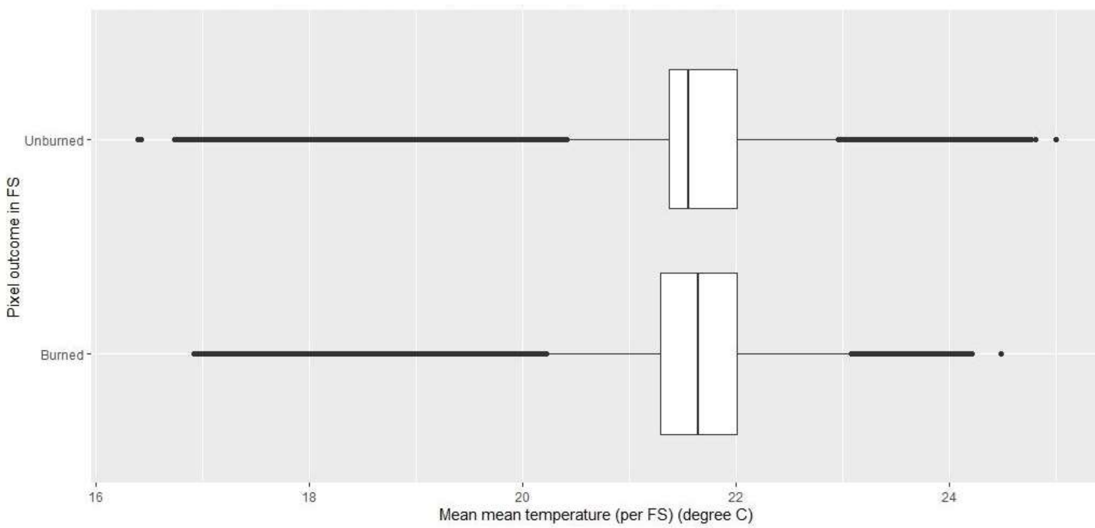


Figure 6-5 Boxplots of un-/burned pixel outcome (in FS) by mean temperature in FS (°C) (n = 2,645,464)
Top: for 2001-2006. Bottom: for 2010-2015.

6.2.5. Elevation

Much of Mozambique is relatively low-lying, in coastal areas and some floodplains, with higher altitudes towards the northern and western parts of the country (Figure 5-2). Larger urban centres tend to lie along the coast (e.g. the capital Maputo in the south; Beira the second city in the centre and other port towns further north (Quelimane and Pemba).

The boxplots for the two time periods (2001-2006 and 2010-2015) are similar, where burned pixels indicate higher altitudes than for unburned pixels (Figure 6-6).

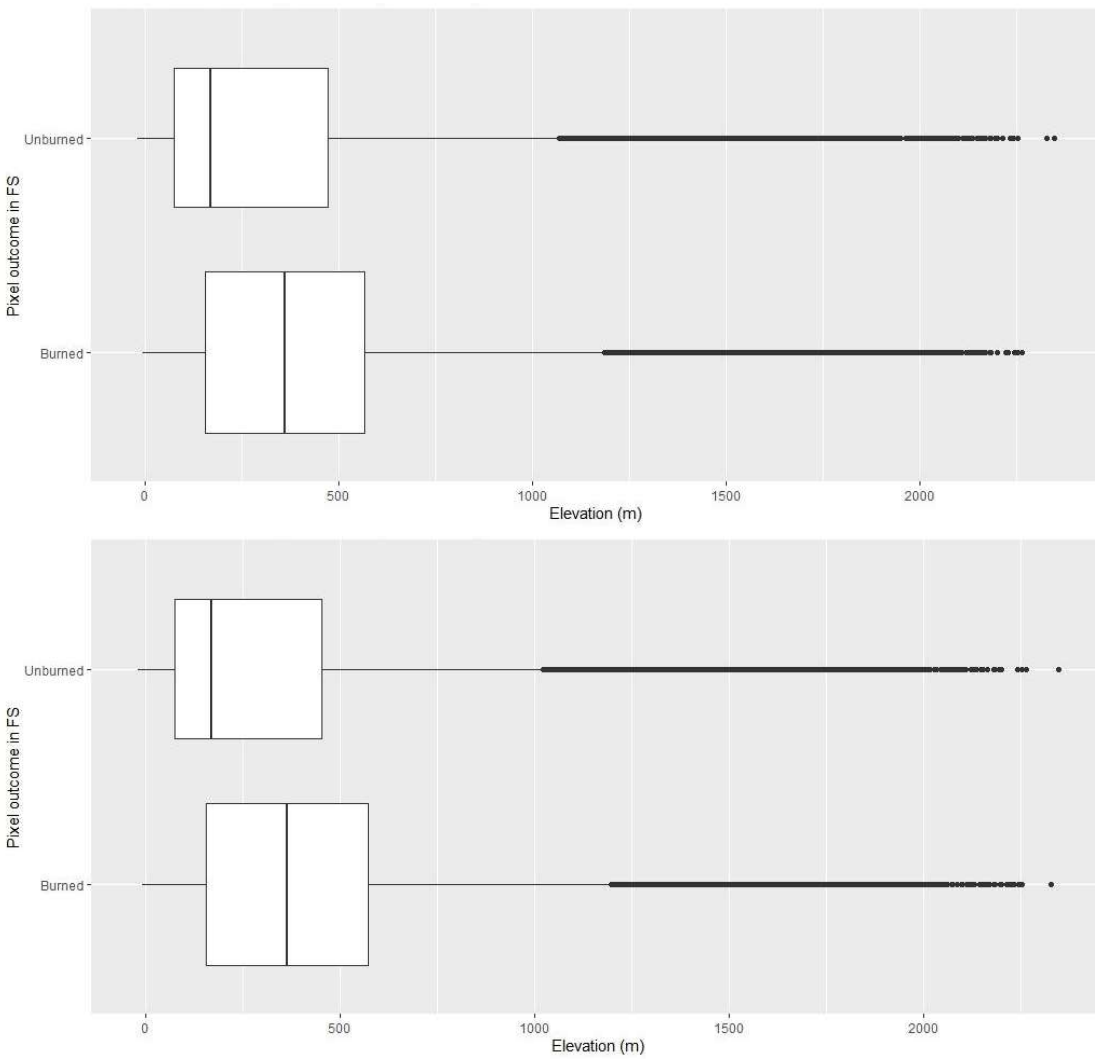


Figure 6-6 Boxplots of un-/burned pixel outcome (in FS) by elevation (m) (n = 2,645,464) Top: for 2001-2006. Bottom: for 2010-2015.

6.2.6. Slope

Most pixels within the national extent of Mozambique show low slope which includes much of the southern and central parts of the country, which are coastal areas, floodplains and the southern tip of the Rift Valley (Figure 5-5). Slope values are higher in the northern parts and the western parts of the country where elevation is also higher, including inselbergs. As such, the boxplots for slope are left skewed, with small IQR at low slopes, and many outliers at higher slope (Figure 6-7). The boxplots for the two time periods showing un-/burned pixels by slope are similar, and indicate slightly higher slopes for burned pixels.

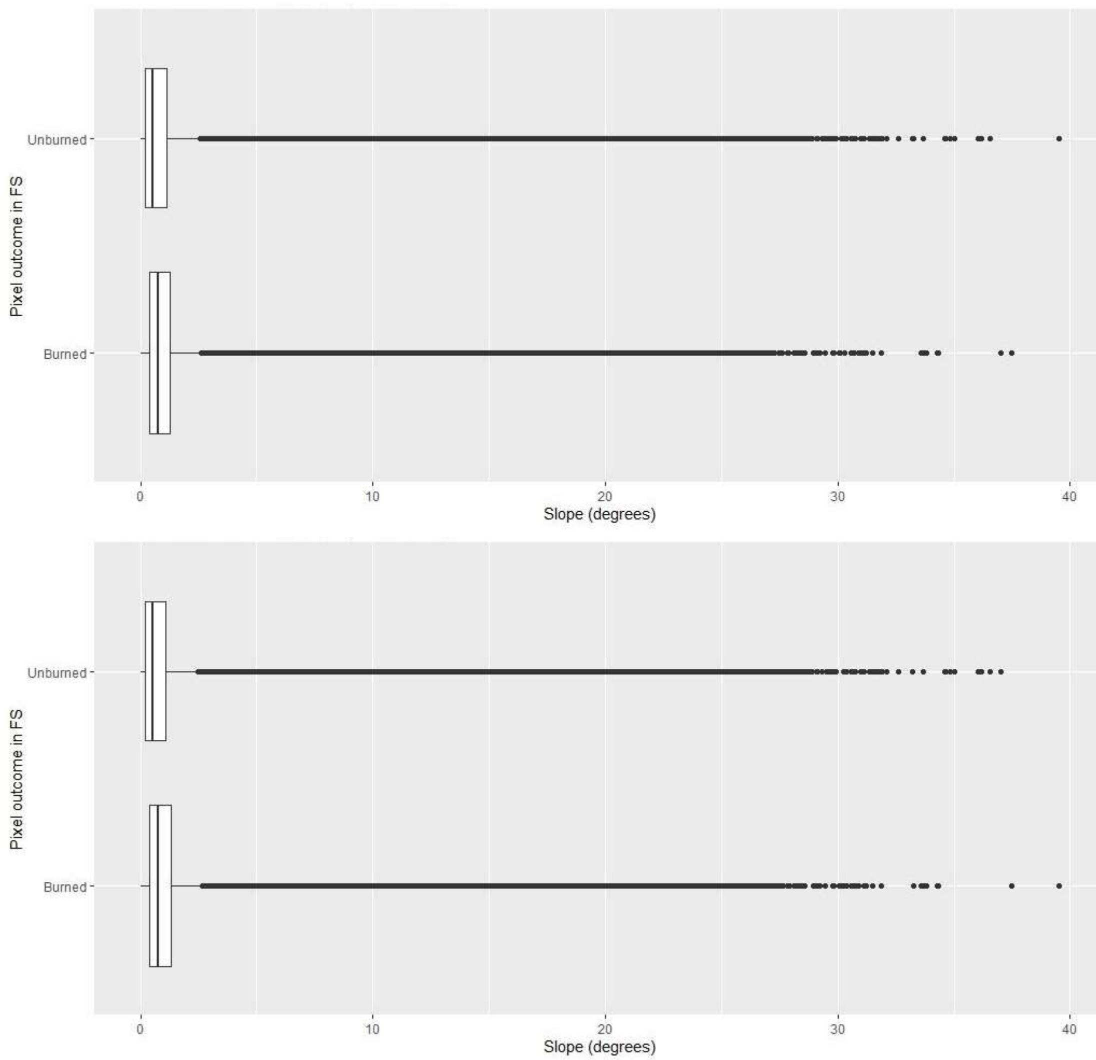


Figure 6-7 Boxplots of un-/burned pixel outcome(in FS) by slope (°) (n = 2,645,464)
Top: for 2001-2006. Bottom: for 2010-2015.

6.2.7. Population Density

Zero values in 36,144 cases of the processed population density datasets were replaced with NA values, and are therefore not included in the analyses, as population density per district is assumed not to be zero in any case where a district administration is in place. Zero values are assumed to be missing values rather than trues zero and are put down to differences in the original spatial data extents. As the population densities for the national extent are very left-skewed (vast majority of pixels are low density, while very few urban pixels have extremely high densities along the coast in the extreme south of the country, some along the Beira Corridor in the centre (from the coast westwards to Zimbabwe) and some along the coast and further inland in the northern parts) (Figure 5-6), the variable is transformed to be the natural log of the original values.

There is a general estimated increase in population density for most districts, between 2000 and 2010 (Figure 5-7), which are the years used for analyses. Although some rural districts are shown to have a slight reduction in population density and some urban centres have experienced high increases (e.g. the cities of Maputo and Nampula).

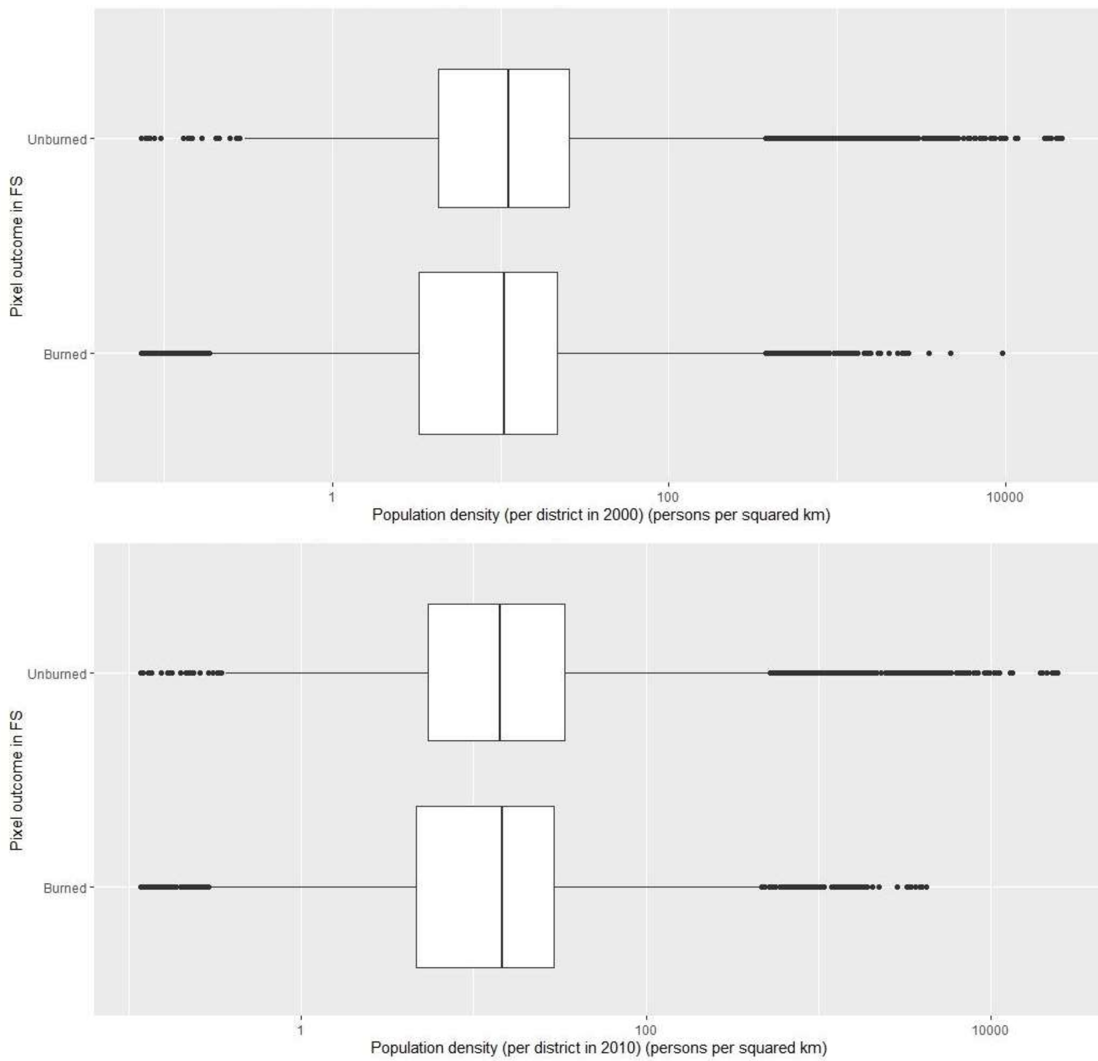


Figure 6-8 Boxplots of un-/burned pixel outcome (in FS) by population density per district (natural log of persons/km2) (n = 2,645,464)
Top: for 2001-2006. Bottom: for 2010-2015.

During the two time periods, population density, at least at a district level, seems to have a marginal effect on whether a pixel is burned or unburned, as medians are very similar and the IQR show much overlap (Figure 6-8). This may be because the vast majority of pixels of the national extent are relatively low density and within a small range, except the urban centres, which are small in size and represent relatively few pixels, and should not necessarily show as burned.

6.2.8. Distance to Settlement

In the distance to settlement dataset, in terms of spatial distribution, distances are lower where settlement density is higher such as in the extreme south of the country, along the coastal areas in the north of the country, and along transport corridors, such as the Beira Corridor running from the coast westwards to Zimbabwe (Figure 5-8). The highest distances are found in the extreme north of the country (near and around the Niassa Special Reserve) and in the inland southwest of the country (near Limpopo National Park). These more remote areas intuitively show overlap with protected areas.

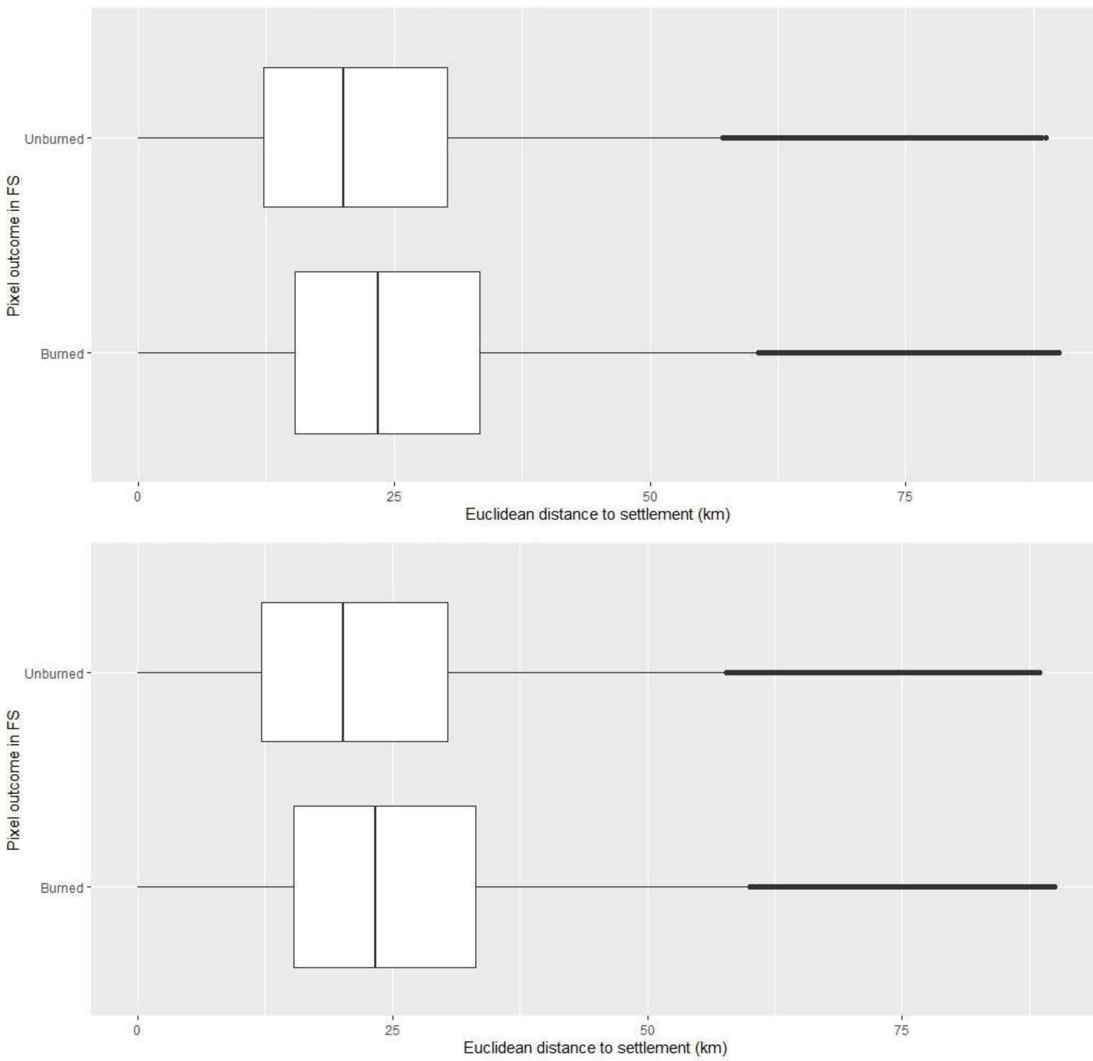


Figure 6-9 Boxplots of un-/burned pixel outcome (in FS) by distance to nearest settlement (km) (n = 2,645,464)
Top: for 2001-2006. Bottom: for 2010-2015.

The boxplots showing burned/unburned pixels by distance to the nearest settlement (km) (Figure 6-9) show similar features for the two time periods. Burned pixels are slightly further away from settlements than unburned pixels. This could mean that very near to settlements, fires are less frequent as there is a lack of fuel (or ignitions), that fire suppression effort is higher, and that areas where fire is employed as a tool for agriculture and for other purposes, are slightly further away from settlements. Although there is a difference between the distances of un-/burned pixels, this difference is relatively small.

6.2.9. Distance to Road

The distance to road for most pixels in Mozambique are relatively small. Distance to road shows similarities with distance to settlement, where settlement density is high, road density is as well. This is particularly true for the extreme south of the country, where the capital Maputo is located, and road infrastructure has been more heavily developed (Figure 5-9).

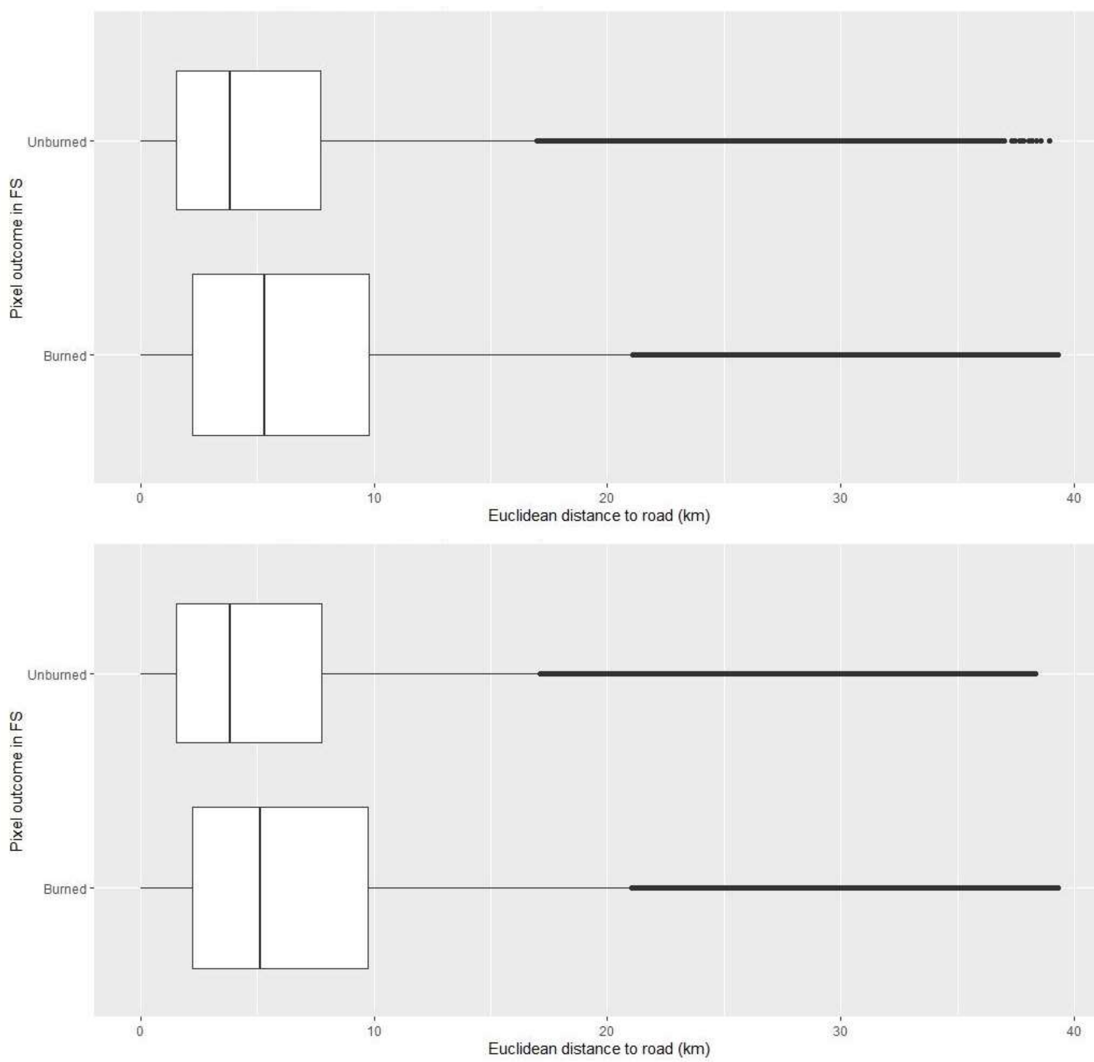


Figure 6-10 Boxplots of un-/burned pixel outcome (in FS) by distance to nearest road (km) (n = 2,645,464)
Top: for 2001-2006. Bottom: for 2010-2015.

The un-/burned pixels by Euclidean distance to the nearest road (km) for the two time periods are similar (Figure 6-10). Burned pixels tend to be slightly further away from roads.

6.2.10. Land Cover Classification

Most pixels for Mozambique are in the *Cropland*, *Forest* and *Mosaic/Shrub/Grassland* classes, together making up just over 95.5% for both the 2003 and 2012 reclassifications, the largest class being *Forest* at just over 57% for both periods, followed in size by *Mosaic/Shrub/Grassland* and *Cropland* (Table 6-1).

Table 6-1 Proportions of pixels assigned to land cover classes (2003 and 2012) (n = 2,645,464)

	Year	
	2003	**2012**
1 Cropland	14.63%	14.70%
2 Forest	57.15%	57.25%
3 Mosaic/Shrub/Grassland	23.75%	23.55%
4 Sparse	0.05%	0.05%
5 Flooded	2.90%	2.92%
6 Urban/Water/Bare	1.52%	1.53%

Of these three largest land cover classes *Mosaic/Shrub/Grassland* shows the highest proportion of pixels burned in this class (59.97% and 61.67%) followed by *Forest* (52.65% and 52.59%) and *Cropland* (39.86% and 37.74%) in each time period respectively (Figure 6-11). This is expected to some extent, where increased forest cover reduces the area burned (Archibald et al., 2009), and mosaic, shrub- and grassland providing continuous fuel beds, at favourable fuel conditions for burning. Interestingly the proportion of pixels classified as *Cropland* that are burned in the two periods are lower than both *Forest* and *Mosaic/Shrub/Grassland*, and all other land cover classes, except *Urban/Water/Bare*. This may indicate a lack of the use of fire in agricultural activity or at least only during a relatively short time of the DS for preparing field for sowing just before the WS, or high rates of active or passive suppression. It could also be that because of the size of a pixel (500 m) numerous ignitions at sub-pixel level resulting in small burn scars in a given month, will only provide the single pixel showing as burned for that month.

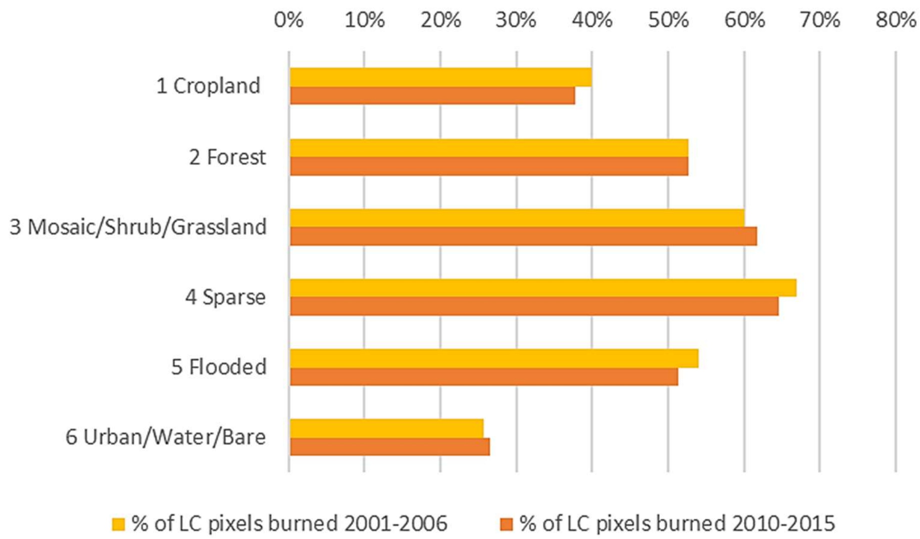


Figure 6-11 Proportions of burned pixels by land cover class (2001-2006 and 2010-2015) (n = 2,645,464)

The proportion of burned pixels within the land cover class *Flooded* are 54.04% and 51.27% in the two time periods, respectively. This may be the result of many of the pixels being located at the mouth and floodplains of the Zambezi River. This area is temporarily flooded during the year and agriculture is the main livelihood on the alluvial soils in the Zambezi Delta. There are also some protected areas managed for hunting, such as Marromeu NR (Beilfuss et al., 2000). As these pixels are possibly overestimated by the ESA CCI Land Cover Classification, and are a relatively low proportion of the overall number of national pixels, they are not explicitly dealt with in the subsequent analyses.

The highest proportion of pixels burned is in the *Sparse* class but will not be examined in detail as the class is the smallest contributor of land cover classes at the national extent. Burned pixel proportions within *Urban/Water/Bare* are the lowest, and are also excluded as they should be irrelevant with regards to wildfires.

6.2.11. Protected Areas

6.2.11.1. Status year

Extant protected areas were determined by WDPA *Status Year* to indicate PAs established before each time period (i.e. pre-2001 and pre-2010) (Table 6-2). However, this does not necessarily indicate active management of PAs, or, the quality or effectiveness thereof, for example GNP was managed for different purposes in its history, using different methods, management was not uniformly applied for the whole extent, as well as it being abandoned during times of conflict.

Also, for 26 Mozambican PAs in the WDPA no status year is provided (258,338 pixels / 39.17% of pixels within PAs by 2020) (Figure 6-12). Of these PAs which includes two Community Conservation Areas, 11 Forest Reserves, 12 Hunting Reserves and one National Park, only one has a management plan which may indicate a lack of implementation of management for the rest.

Table 6-2 Protected areas in Mozambique by Status Year (provided in the WDPA)

		PA	IUCN category	Governance type	Status Year (WDPA)	Pixel count (terrestrial)
Pre-2010 Status Year	Pre-2001 Status Year	Mecuburi FR	IV	Nat ministry	1950	7,981
		Niassa B	VI	Coll gov	1954	15,008
		Niassa SR	VI	Coll gov	1954	124,213
		Baixo Pinda FR	IV	Nat ministry	1957	636
		Derre FR	IV	Nat ministry	1957	5,268
		Gilé NP	II	Nat ministry	1960	9,619
		Gorongosa NP	II	Coll gov	1960	12,577
		Serra da Gorongosa NP	II	Coll gov	1960	1,248
		Marromeu NR	IV	Nat ministry	1960	5,280
		Maputo SR	II	Coll gov	1960	3,666
		Pomene NR	IV	Nat ministry	1964	179
		Bazaruto NP	II	Coll gov	1971	4
		Banhine NP	II	Coll gov	1973	25,521
		Zinave NP	II	Coll gov	1973	14,289
		Chipanje Chetu CCA	VI	Loc comm	1998	21,559
		Cabo de São Sebastião S	IV	Non-prof orgs	2000	0
		Limpopo NP	II	Coll gov	2001	38,805
		Quirimbas B	V	Nat ministry	2002	14,630
		Chimanimani NP	II	Nat ministry	2003	2,281
		Nicage HR	VI	Gov-del mang	2008	2,040
		Ponta do Ouro NR	IV	Coll gov	2009	27

Coll gov = Collaborative governance
Gov-del mang = Government-delegated management
Loc comm = Local communities
Non-prof orgs = Non-profit organisations
Nat ministry = Federal or national ministry or agency

There may also be input or submission errors in the WDPA, as for example for Serra da Gorongosa component, the status year provided is 1960 (UNEP-WCMC and IUCN, 2020), although officially it is 2010 (GoM, 2016).

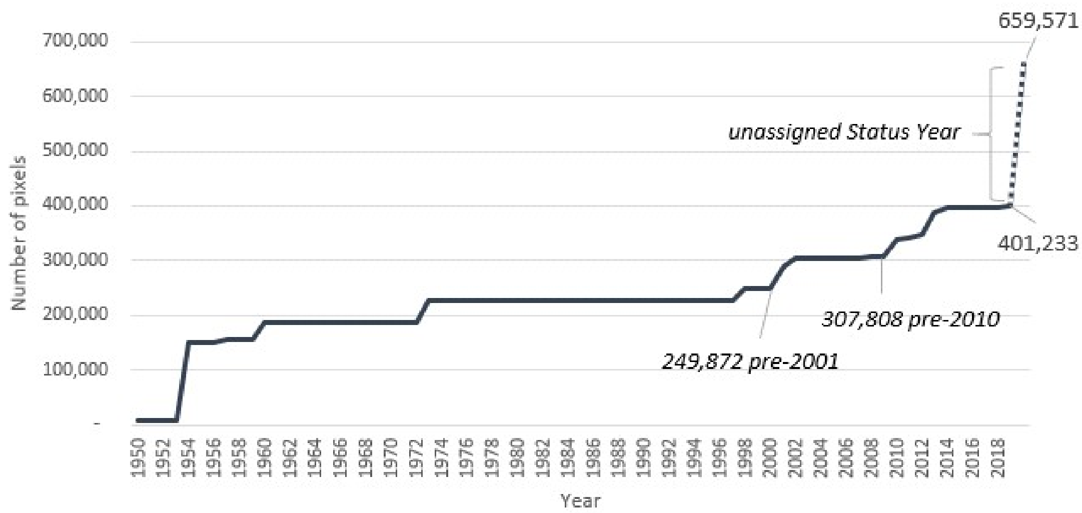


Figure 6-12 Cumulative number of pixels in protected areas in Mozambique (by Status Year provided in WDPA)
The influx in 2020, represented by the dashed line, is artificial and represents PA pixels with missing status year.

Using the status year to determine the extant PAs for the two time periods (and dismissing any PA pixels without status year), the proportions of PA pixels for the national extent are 9% and 12% for 2001-2006 and 2010-2015, respectively.

6.2.11.2. National Designation

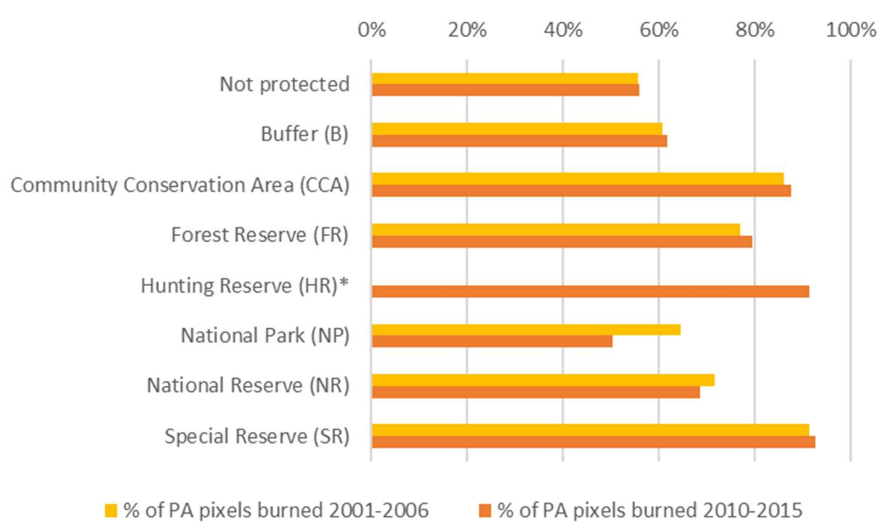


Figure 6-13 Proportions of burned pixels by PA national designation (for extant PAs 2001-2006 and 2010-2015) (n = 2,645,464)
**No Hunting Reserves existed pre-2001*

For pixels in non-protected areas the proportions burned in each time period are 55.59% and 56.00%, respectively. Of the pixels within extant PAs, the proportions of pixels burned during either time period are all higher than for non-protected pixels, with the single exception of *National Park (NP)* for 2010-2015 at 50% of pixels burned (Figure 6-13). This initial outcome goes some way towards addressing RQ 1 (What physical and human variables predict a pixel to be burned on a national scale in Mozambique during given time periods?), sets the scene for RQ2 (Are there differences between the variables that predict burned outcome between protected areas and non-protected areas, specifically in the three case study sites?), and is discussed in Chapter 8..

The designation *Special Reserve (SR)* shows particularly high proportions of burned pixels (91.37% and 92.61%, for the time periods respectively). This designation contains two PAs within it (Maputo SR (3,666 pixels) and Niassa SR (124,213 pixels)) and is the largest contributor of extant PA pixels for each time period (41.95% and 51.95% of extant PA pixels) (Table 6-2). The designation *Hunting Reserve (HR)*, composed of a single PA (Nicage HR) shows a similar proportion of burned pixels (for 2010-2015) at 91.47%. The designation *Community Conservation Area (CCA)* also show very high proportions of burned pixels (86.04% and 87.60%).

Interestingly, the designation *National Park (NP)*, which increased substantially in pixel numbers between the two time periods (Table 6-2), showed a reduced proportion of burned pixels in the second time period (Figure 6-13).

6.2.11.3. IUCN Category

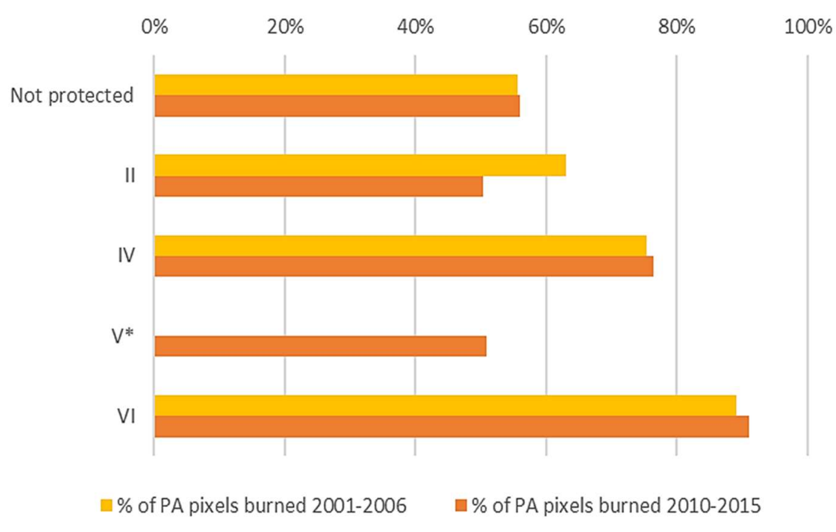


Figure 6-14 Proportions of burned pixels by PA IUCN category (for extant PAs 2001-2006 and 2010-2015) (n = 2,645,464)
**No IUCN category V PAs existed pre-2001*

Considering the IUCN category of a PA on the proportions of pixels burned within each category, the strictest category (II - National Park), shows the lowest proportions (62.94% and 50.37%), where the less strict categories, IV - Habitat/ Species Management Area shows 75.35% and 76.39%, and VI -

Protected area with sustainable use of natural resources shows highest proportions (89.06% and 91.02%), for the respective time periods. IUCN category V, in this case only contains one PA (Quirimbas Buffer) (Table 6-2), and shows the lowest burned proportion (50.78%).

6.2.11.4. Governance Type

Looking at the type of governance of a PA on the proportions of burned pixels, Local Community governance, exhibits the highest proportion (91.47% in 2010-2015), although this type only contains one PA (Chipanje Chetu CCA). Otherwise, it is mixed picture overall (Figure 6-15).

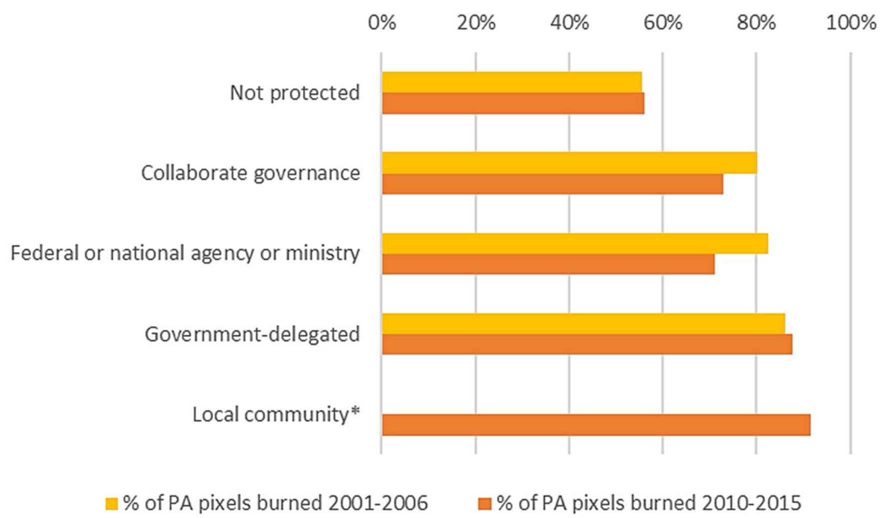


Figure 6-15 Proportions of burned pixels by PA governance type (for extant PAs 2001-2006 and 2010-2015) (n = 2,645,464)
**No PAs governed by Local Communities existed pre-2001*

6.2.11.5. PA Name

Looking at the individual PAs extant for each time period, the proportion of pixels within each that are burned vary between 0% and 98.36%. The two PAs with no pixels burned (Bazaruto NP and Ponta do Ouro NR) are mainly maritime PAs with only small terrestrial components (4 and 27 pixels respectively) (Table 6-2).

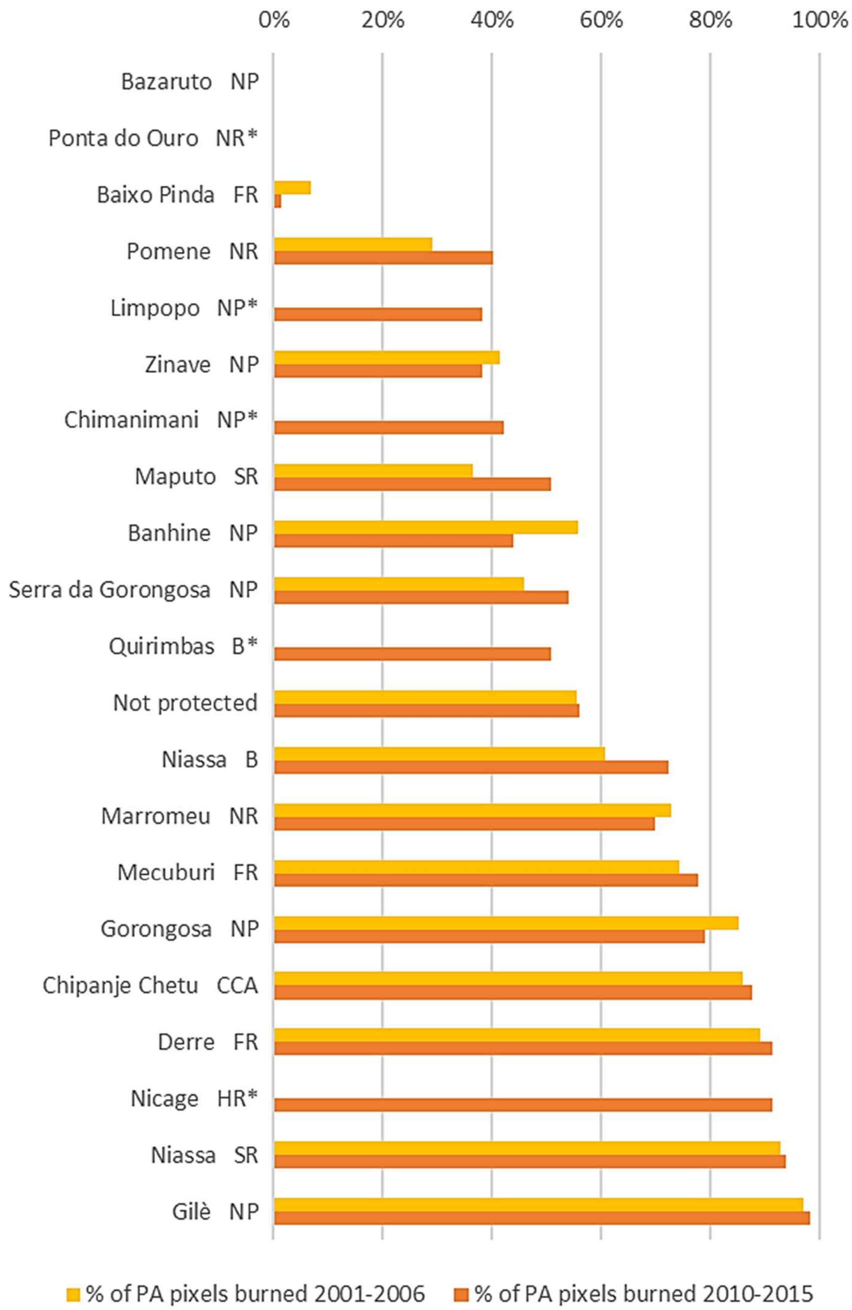


Figure 6-16 Proportions of burned pixels by PA name (for extant PAs 2001-2006 and 2010-2015) (n = 2,645,464)
Serra da Gorongosa NP (the Gorongosa Mountain component to GNP) is included here.
**PA did not exist pre-2001 (according to WDPA)*

In relation to the case study PAs, Limpopo NP shows 38.15% (of 38,805) pixels burned in the time period 2010-2015, which is less than for non-protected pixels. Serra da Gorongosa NP (Gorongosa Mountain component of GNP) has 45.91% and 54.17% (of 1,248 pixels) whilst the lower-lying component (Gorongosa NP) experienced 85.28% and 79.07% (of 12,577) pixels burned in the respective time periods. Niassa Special Reserve, the largest individual PA, had the second highest proportion of burned pixels for all PAs (92.99% and 93.85% of 124,213 pixels within the PA).

Of the PAs, with the lower proportions burned, Limpopo NP, Zinave NP, Maputo SR, Banhine NP, all lie within the drier southern parts of the country, which also seems to contribute to the lower burned proportions by national designations (Figure 6-16).

6.3. Matching as Pre-processing

Using the variables (except burned outcome and PA status) examined in the previous section as covariates with the addition of latitude and longitude, matching was performed on the binary PA status for each time period to create two similar groups – a pixel within a PA is used as 'treatment', and pixels outside of PAs (and outside of a buffer of 10 km around each PA) are used as potential recruits into the 'control' group. The burned outcome of a pixel is not included for the matching, as this is the outcome examined using the logistic regressions once the groups are matched.

6.3.1. Variables/Covariates for Matching

All variables (covariates) affecting selection to either the treatment (non-PA/PA for each time period) or the outcome (un-/burned), should be considered for matching (Schleicher et al., 2020). The final selection of covariates should be those that cause variation in the outcome and selection into the treatment group, i.e. the confounding variables, and if all are controlled for, the subsequent analysis should not suffer from hidden bias (VanderWeele, 2019; Schleicher, 2020).

Visualisations of principal component analysis (PCA) were used for all available variables to inform the selection of covariates for matching, by comparing patterns of visualisations of standardized variables in treatment (PA) (Figure 6-17) and outcome (burned) (Figure 6-18) (Schleicher et al., 2020) (for details see Appendix 7 – PCA summaries).

For the PA pixels in 2001-2006, the variables (vectors) with the greatest weight in the first two principal components (PCs) (which account for 56.6% of the variation in the data) are *elevation*, *latitude*, *longitude* and *temperature in FS*. For the PA pixels for 2010-2015 the first two PCs contribute 55.9% of the variation in the data, with the greatest vectors being *latitude*, *rainfall in preceding WS* and *longitude*, followed by *elevation*, *temperature in FS* and *rainfall in DS*. However, there seem to be few similarities in the variables in terms of negative/ positive direction.

For the burned pixels (2001-2006 and 2010-2015) the first two PCs account for 48.9% and 46.2% of the variation in the data, respectively. There also seem to be few similarities in the variables in terms of negative/ positive direction for the two time periods. For 2001-2006 the variables with the greatest effects are: *latitude, population density, longitude, rainfall in DS* and *elevation.* For 2010-2015, the greatest factors are *latitude, rainfall in preceding WS, elevation, longitude* and *population density*. Slope and distance to road have the smallest effect in both time periods.

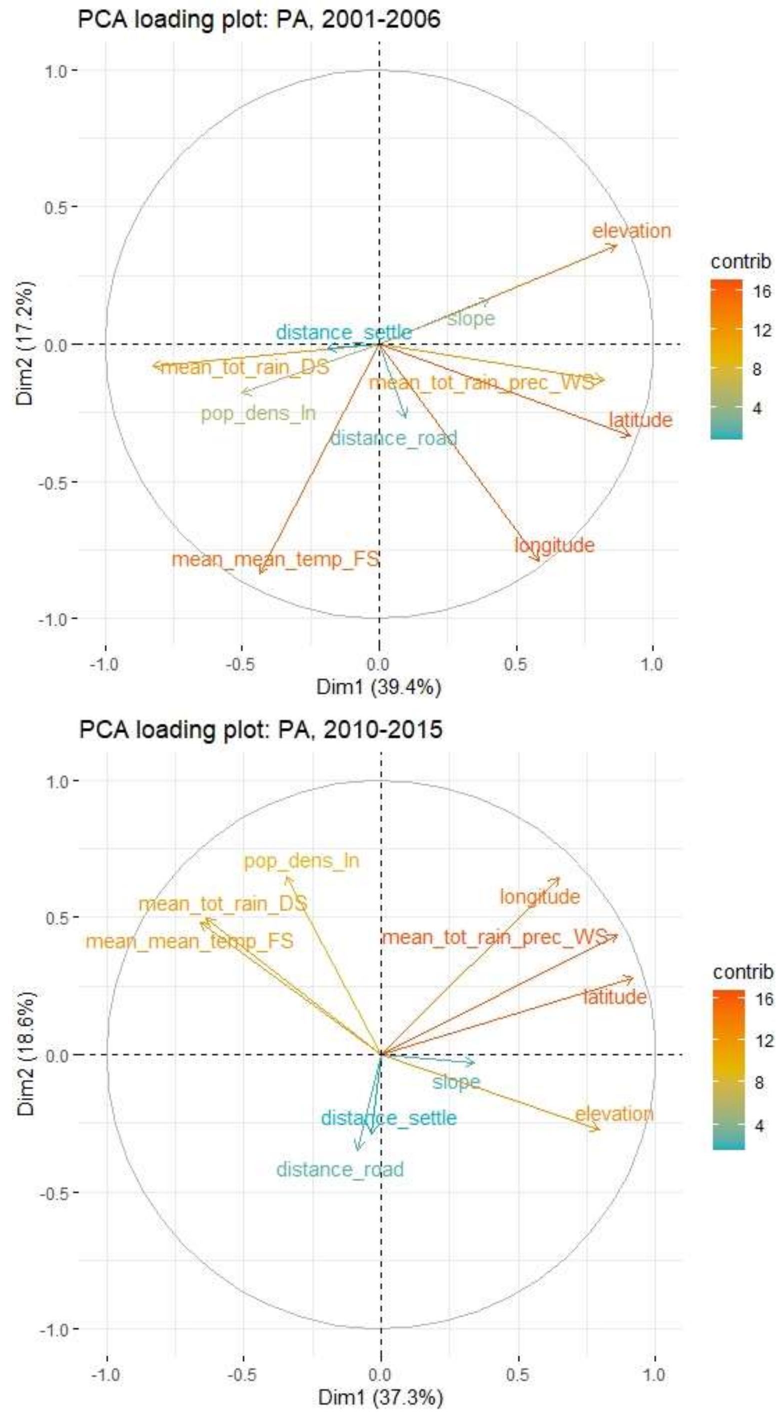
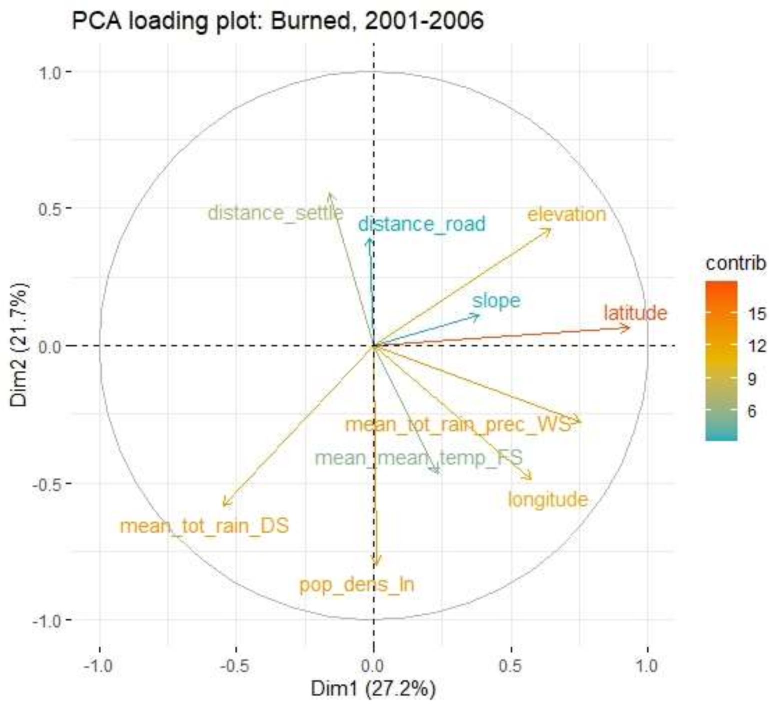


Figure 6-17 PCA loading plots for extant PA pixels
Top: 2001-2006; Bottom: 2010-2015.



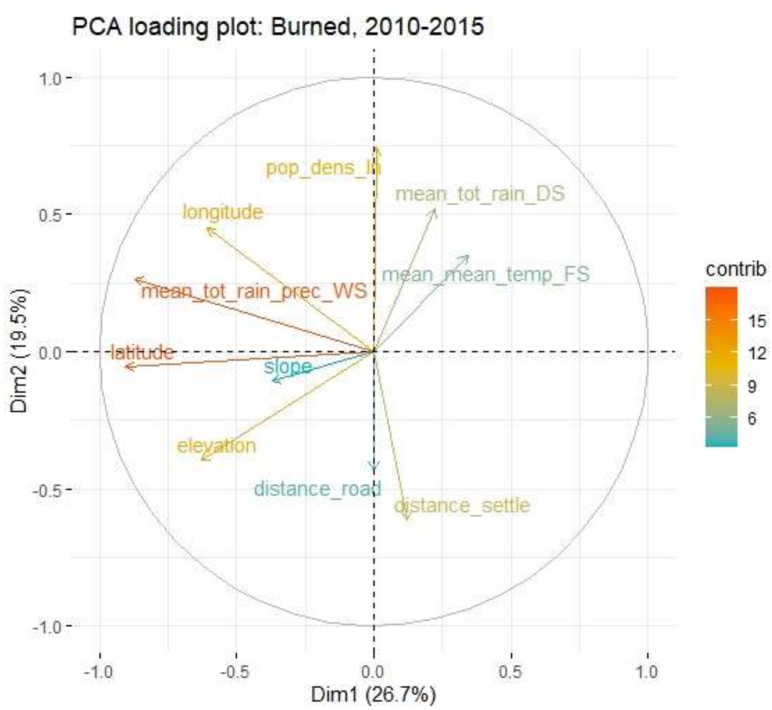


Figure 6-18 PCA loading plots for burned pixels
Top: 2001-2006; Bottom: 2010-2015.

6.3.2. Matching on PA Status – National Extent

Nearest neighbour propensity score matching with caliper (= 0.25) (Rosenbaum and Rubin, 1985) on all available treatment and potential control pixels (1-to-1) was performed for each time period (Table 6-3. The number of potential control pixels are more than 3-4 times larger than the number of treatment pixels, as recommended to ensure overlap of the matched pixels in the common support region (Olmos and Govindasamy, 2015). A caliper was employed to limit the distance between matched pixels which are too distant, resulting in treatment pixels which remained unmatched (99,771 for 2001-2006 and 74,971 for 2010-2015).

Table 6-3 Assignment of pixels for matching for all extant PAs for 2001-2006 and 2010-2015

Matching	**Pixel assignment for matching**	**Pixel condition**	**Available pixel count**	**Matched pixel count**
2001-2006	Treatment	Nationally designated PAs (status year pre-2001)	247,048	147,277
	Excluded	*Within 10 km buffer of extant PA*	*113,724*	
	Potential controls	Not treatment or excluded	2,284,692	147,277
2010-2015	Treatment	Nationally designated PAs (status year pre-2010)	304,831	229,860
	Excluded	*Within 10 km buffer of extant PA*	*161,027*	
	Potential controls	Not treatment or excluded	2,179,606	229,860
		National terrestrial extent	2,645,464	

For both time periods, matching improved almost all absolute standardized mean differences to below the tighter 0.1 threshold, except for *elevation* and *rainfall preceding WS* for 2001-2006 which are just above the threshold, but well within the < 0.25 acceptable threshold (Table 6-4 and Love Plots in Figure 6-19 and Figure 6-20). Histograms of the propensity scores before and after matching show much better similarity post-matching (Figure 6-19 and Figure 6-20).

Table 6-4 Standardized mean differences (pre- and post-matching for 2001-2006 and 2010-2015)

	Standardized mean difference					
	2001-2006			2010-2015		
	Unmatched	**Matched**	**% balance improvement**	**Unmatched**	**Matched**	**% balance improvement**
Propensity score	1.451	0.052	96.4	1.195	0.046	96.2
Rainfall preceding WS	0.345	-0.111	67.7	0.043	-0.053	-23.2
Rainfall DS	-0.848	0.052	93.8	-0.680	-0.084	87.7
Temperature FS	-0.851	0.006	99.3	-0.692	0.035	95.0
Elevation	0.103	-0.119	-16.0	0.022	-0.015	30.6
Slope	-0.100	-0.045	54.8	-0.069	-0.020	71.0
Distance to road	0.415	0.023	94.5	0.483	0.022	95.4
Distance to settlement	0.813	-0.017	97.9	0.697	-0.015	97.9
Population density (ln)	-1.352	0.017	98.7	-1.399	-0.031	97.8
LC: 1 Cropland	-1.089	-0.079	92.8	-0.949	-0.047	95.1
LC: 2 Forest	0.062	-0.015	76.0	0.051	-0.041	19.4
LC: 3 Mosaic/Shrub/Grassland	0.234	0.018	92.2	0.254	0.061	76.1
LC: 4 Sparse	-0.020	-0.007	66.3	0.049	0.014	72.1
LC: 5 Flooded	0.042	0.051	-20.4	0.000	-0.014	-7489.0
LC: 6 Water/Urban/Bare	-0.026	0.000	98.6	-0.029	0.000	99.9
Latitude	0.629	-0.058	90.8	0.339	-0.005	98.5
Longitude	0.407	-0.031	92.3	0.155	-0.060	61.6

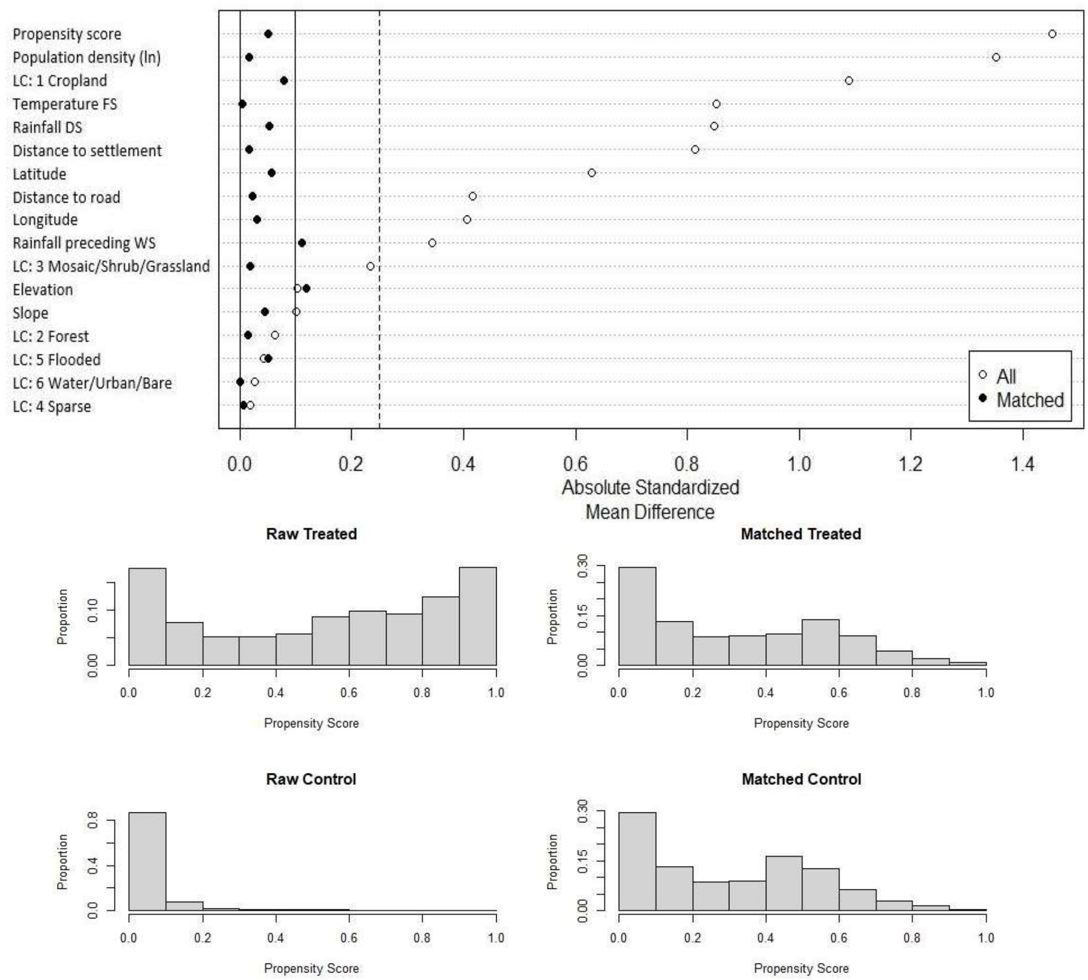


Figure 6-19 Pre- and post-matching data comparison for 2001-2006
Top: Love plot (all matched standardized means are below dotted line (0.25) threshold); Bottom: Histogram of propensity scores showing greater similarity for the matched data.

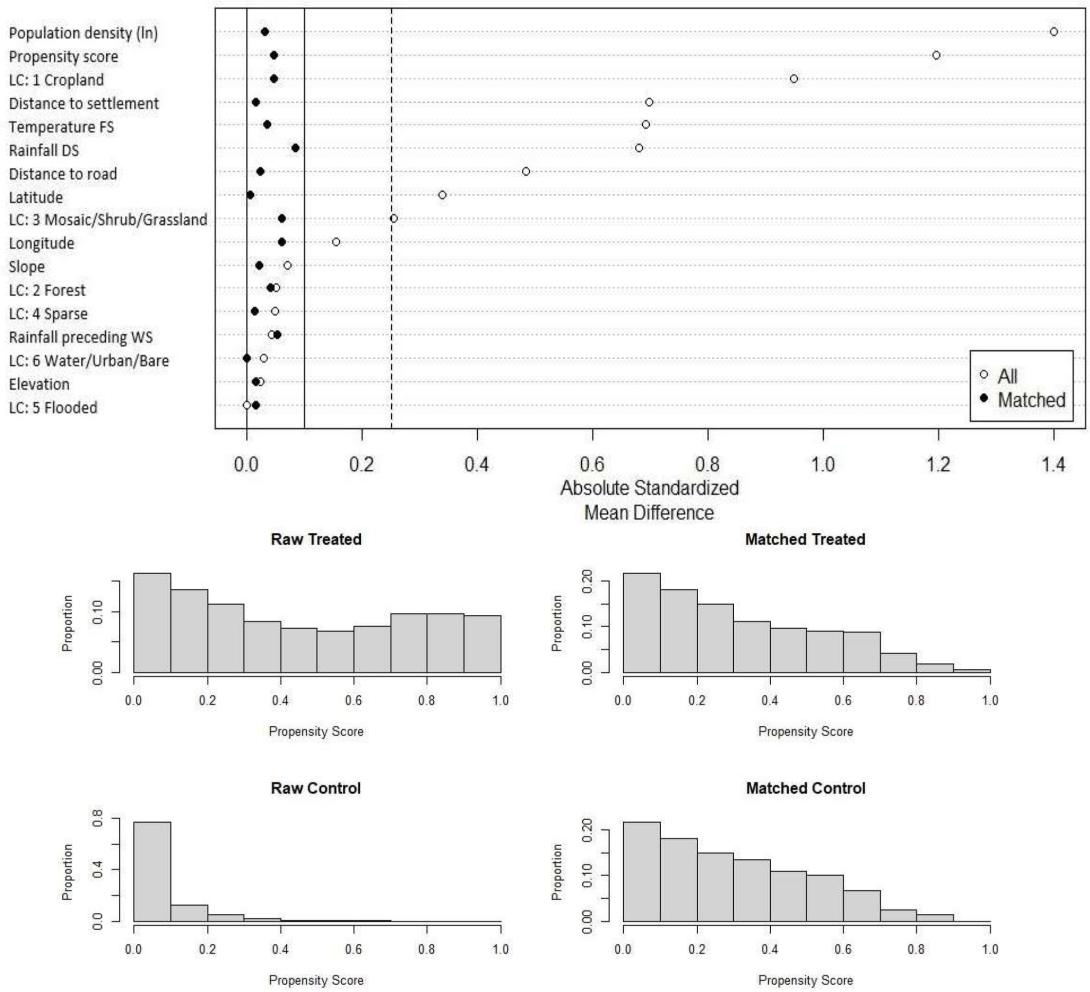


Figure 6-20 Pre- and post-matching data comparison for 2010-2015
Top: Love plot (all matched standardized means are below solid line (0.1) threshold); Bottom: Histogram of propensity scores showing greater similarity for the matched data.

6.3.3. Matching - Case Study PAs

The treatment pixels are the pixels within each case study protected area (Table 6-5): Niassa Special Reserve, Gorongosa National Park (GNP including Serra da Gorongosa/Mountain), and Limpopo National Park.

Table 6-5 Assignment of pixels for matching (PA case studies)

			2001-2006		2010-2015	
Case study	**Pixel assignment**	**Pixel condition**	**Pixel Count**	**Matched pixels**	**Pixel Count**	**Matched pixels**
NSR	Treatment	Niassa Special Reserve	124,213	28,057	124,213	12,472
	Excluded	*Within 10 km buffer of extant PA*	*236,559*		*341,645*	
	Potential controls	Not treatment or excluded	2,284,692	28,057	2,179,606	12,472
GNP*	Treatment	Gorongosa National Park*	12,577	12,571	12,577	12,025
	Excluded	*Within 10 km buffer of extant PA*	*348,195*		*453,281*	
	Potential controls	Not treatment or excluded	2,284,692	12,571	2,179,606	12,025
LNP	Treatment	Limpopo National Park	-	-	38,805	4,042
	Excluded	*Within 10 km buffer of extant PA*	-		*427,053*	
	Potential controls	Not treatment or excluded	-	-	2,179,606	4,042
		National terrestrial extent	2,645,464		2,645,464	

**Excluding Serra da Gorongosa NP component of GNP*

Nearest neighbour propensity score matching with caliper (= 0.25) (Rosenbaum and Rubin, 1985) on all available treatment and potential control pixels (1-to-1) was attempted for each PA per time period (except for LNP for 2001-2006, according to the WDPA, it was not proclaimed pre-2001). The caliper was employed to limit the distance between matched pixels which are too distant, resulting in treatment pixels which remained unmatched.

For all three case study PAs and respective time periods, matching improved all absolute standardized mean differences to below the 0.25 threshold (Table 6-6 and Love Plots in Figure 6-21, Figure 6-22 and Figure 6-23). Histograms of the propensity scores before and after matching show much better similarity (Figure 6-21, Figure 6-22 and Figure 6-23).

Table 6-6 Standardized mean differences (pre- and post-matching for case study site PAs (Niassa Special Reserve (NSR), Gorongosa National Park (GNP) and Limpopo National Park (LNP)) for 2001-2006 and 2010-2015

	Standardized mean difference														
	NSR						**GNP***						**LNP**		
	2001-2006			**2010-2015**			**2001-2006**			**2010-2015**			**2010-2015**		
	Unmatched	**Matched**	**% balance improv.**	**Unmatched**	**Matched**	**% balance improv.**	**Unmatched**	**Matched**	**% balance improv.**	**Unmatched**	**Matched**	**% balance improv.**	**Unmatched**	**Matched**	**% balance improv.**
Propensity score	3.599	0.145	96.0	5.793	0.231	96.0	0.815	0.001	99.9	0.736	0.005	99.4	4.794	0.082	98.3
Rainfall preceding WS	1.225	-0.049	96.0	2.332	0.064	97.2	-	-	-	-	-	-	-13.317	-0.027	99.8
Rainfall DS	-5.264	-0.107	98.0	-3.840	-0.090	97.7	1.618	0.112	93.1	2.129	-0.179	91.6	-1.756	-0.014	99.2
Temperature FS	-0.902	0.050	94.5	-1.377	-0.102	92.6	-2.359	0.097	95.9	-0.894	-0.070	92.1	-5.691	0.030	99.5
Elevation	0.572	-0.085	85.2	0.548	0.051	90.6	-4.677	-0.010	99.8	-4.740	0.008	99.8	-1.144	0.051	95.6
Slope	-0.008	-0.038	-409.9	-0.006	0.002	75.1	-0.900	0.012	98.7	-0.896	0.045	95.0	-0.884	-0.036	95.9
Distance to road	0.524	0.052	90.1	0.544	-0.035	93.5	0.002	0.005	-151.9	0.033	-0.037	-10.0	0.926	0.045	95.2
Distance to settlement	0.866	0.069	92.0	0.867	0.028	96.7	0.663	-0.089	86.6	0.664	0.117	82.3	0.381	-0.026	93.2
Population density (ln)	-2.168	-0.095	95.6	-2.295	-0.101	95.6	-0.436	0.000	99.9	-0.302	-0.047	84.4	-2.937	-0.109	96.3
LC: 1 Cropland	-3.806	0.007	99.8	-4.474	0.032	99.3	-0.542	-0.026	95.3	-0.602	-0.069	88.5	-0.646	-0.001	99.8
LC: 2 Forest	-0.080	-0.035	56.7	-0.045	0.011	74.8	0.157	0.007	95.7	0.176	0.145	17.6	-0.074	-0.038	48.7
LC: 3 Mosaic/Shrub/Grassland	0.454	0.034	92.5	0.434	-0.005	98.9	-0.549	-0.039	92.9	-0.528	-0.019	96.5	0.392	0.043	89.1
LC: 4 Sparse	-0.018	-0.002	87.7	0.003	0.010	-196.3	-0.023	0.000	100.0	-0.014	0.000	100.0	-0.014	0.000	100.0
LC: 5 Flooded	-0.703	-0.004	99.4	-0.719	-0.013	98.2	0.446	0.028	93.7	0.434	-0.138	68.1	-0.702	0.007	99.1
LC: 6 Water/Urban/Bare	0.012	0.001	88.7	0.011	-0.033	-207.8	0.057	0.009	84.7	0.053	0.038	29.0	-0.009	-0.017	-83.5
Latitude	13.058	0.016	99.9	12.957	0.045	99.7	-	-	-	-	-	-	-14.343	-0.062	99.6
Longitude	2.287	0.057	97.5	2.286	-0.148	93.5	-6.261	0.196	96.9	-	-	-	-11.949	-0.029	99.8

**Excluding Serra da Gorongosa NP component of GNP*

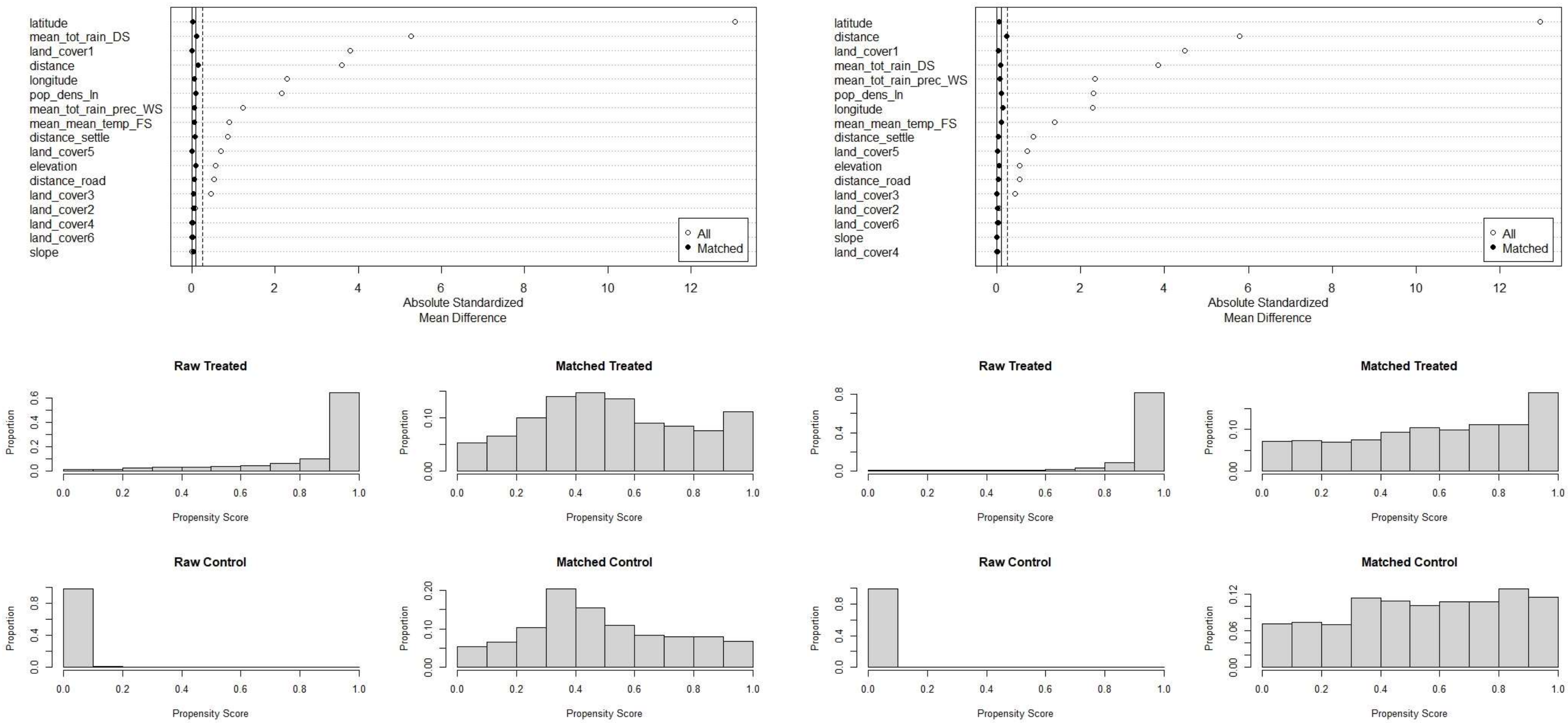


Figure 6-21 Pre- and post-matching data comparison for NSR

Top: Love plots (all matched standardized means are below dotted line (0.25) threshold); Left: for 2001-2006; Right for 2010-2015. Bottom: Histograms of propensity scores showing greater similarity for the matched data; Left: for 2001-2006; Right for 2010-2015.

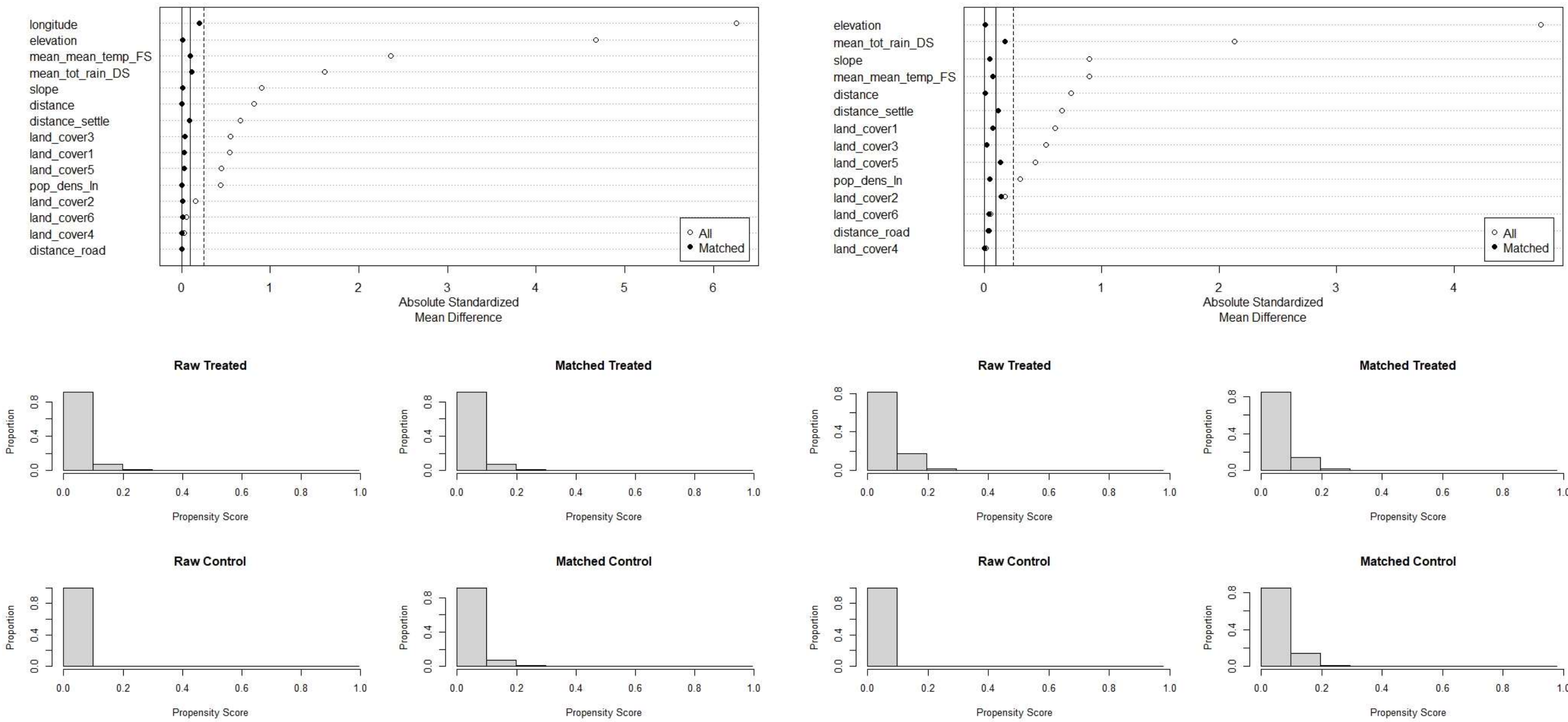


Figure 6-22 Pre- and post-matching data comparison for GNP (excluding Serra da Gorongosa/ Gorongosa Mountain)
Top: Love plots (all matched standardized means are below dotted line (0.25) threshold); Left: for 2001-2006; Right for 2010-2015. Bottom: Histograms of propensity scores showing greater similarity for the matched data; Left: for 2001-2006; Right for 2010-2015.

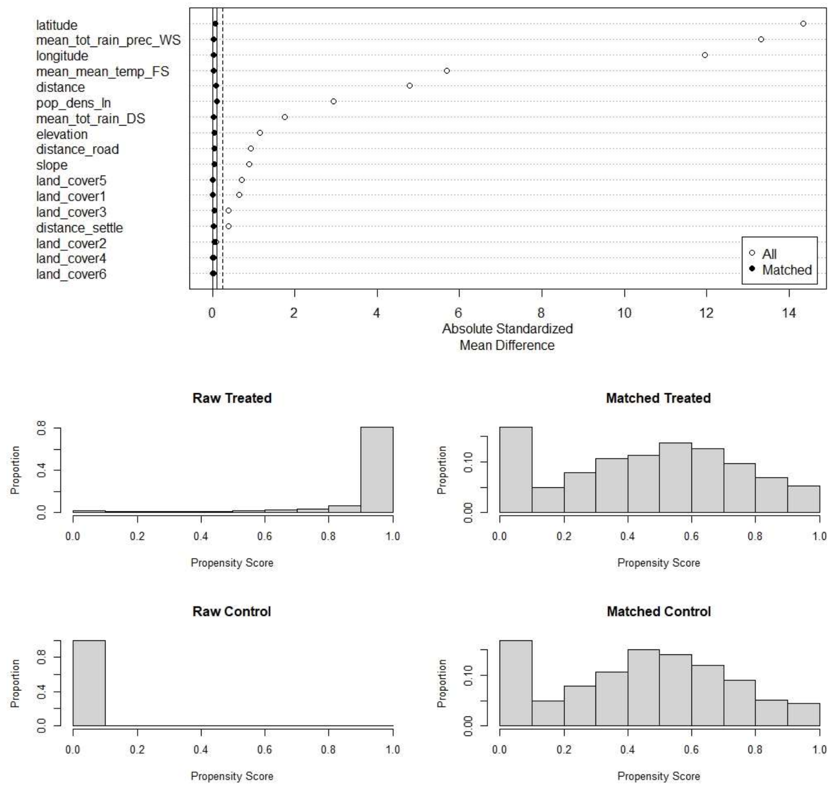


Figure 6-23 Pre- and post-matching data comparison for LNP (only for 2010-2015)
Top: Love plot (all matched standardized means are below solid line (0.1) threshold). Bottom: Histogram of propensity scores showing greater similarity for the matched data.

6.4. Logistic Regressions

6.4.1. Extant PAs – National Extent

Using the matched datasets (on non-/protected status) for both time periods, 2001-2006 and 2010-2015, the Pearson's χ^2 tests indicate a statistically significant difference for the un-/burned pixels within PAs and outside of PAs (df = 1 and α = 0.05) (Table 6-7).

Table 6-7 Pearson's χ^2 test results (extant PAs, 2001-2006 and 2010-2015)

2001-2006		
	Burned	Unburned
Non-PA	93,389	54,535
PA	107,507	40,417
χ^2 = 3091.3, df = 1, $p < 2.2 \times 10^{-16}$		

2010-2015		
	Burned	Unburned
Non-PA	138,912	91,013
PA	154,795	75,130
χ^2 = 2377.3, df = 1, $p < 2.2 \times 10^{-16}$		

Logistic regressions for the datasets for each time period, including the PA status as an explanatory variable, with un-/burned outcome as the outcome were then performed (Table 6-8 and Table 6-9). Variables with high variance inflation factors (VIF > 5) indicating high multicollinearity were assessed (using R car package) and excluded. The variable *elevation* was excluded for the time period 2001-2006. For the time period 2010-2015 no variables are excluded due to multicollinearity, but *elevation* has a relatively high VIF of 3.53.

Given the significant χ^2 values for the Likelihood Ratio tests (Table 6-8 and Table 6-9) both models give a significant improvement in the prediction of un-/burned pixels over the baseline intercept-only model only. The pseudo R^2 values (McFadden, Cox and Snell, Nagelkerke, calculated using R package: rcompanion (Mangiafico, 2021)) (Table 6-8 and Table 6-9) indicate that some variation is explained by the models, and although suggestive on their own, should serve to compare competing models for the same data, rather than using R^2 values like in linear regression models, as values for pseudo R^2 are relatively low. Using confusion matrices (using R package: caret (Kuhn et al., 2020)), the prediction versus the actual un-/burned outcome of a pixel were examined with the models for the respective time periods predicting the outcome with 71.85% (95% CI: 0.7168, 0.7201) and 71.49% (95% CI: 0.7136, 0.7162) accuracy (Table 6-8 and Table 6-9).

Table 6-8 Outputs for logistic regressions and associated tests for extant PAs, 2001-2006

	2001-2006							
	Estimate	**Stand. Error**	**z value**	**p-value**	**Sig.**	**Confidence Interval**		
Coefficients						**2.5%**	**97.5%**	**VIF**
Intercept	-8.5274	0.0827	-103.12	<2e-16	***	-8.6895	-8.3654	
PA: 1	0.5234	0.0086	60.88	<2e-16	***	0.5066	0.5403	1.02
Rainfall preceding WS	0.0025	0.0000	123.98	<2e-16	***	0.0024	0.0025	1.75
Rainfall DS	-0.0051	0.0001	-39.88	<2e-16	***	-0.0053	-0.0048	1.63
Temperature FS	0.2793	0.0033	84.07	<2e-16	***	0.2728	0.2858	1.22
Elevation								
Slope	-0.0676	0.0025	-27.34	<2e-16	***	-0.0725	-0.0628	1.19
Distance to road	-0.0018	0.0007	-2.43	0.0153	*	-0.0032	-0.0003	1.09
Distance to settlement	0.0207	0.0003	68.72	<2e-16	***	0.0201	0.0213	1.41
Population density (ln)	-0.1514	0.0044	-34.29	<2e-16	***	-0.1600	-0.1427	1.65
LC: 2 Forest	0.2907	0.0225	12.90	<2e-16	***	0.2465	0.3348	1.38
LC: 3 Mosaic/Shrub/Grassland	0.8609	0.0243	35.44	<2e-16	***	0.8133	0.9085	.
LC: 4 Sparse	0.3416	0.2462	1.39	0.1654		-0.1411	0.8242	.
LC: 5 Flooded	0.3387	0.0287	11.82	<2e-16	***	0.2825	0.3949	.
LC: 6 Urban/Water/Bare	-0.8321	0.0430	-19.37	<2e-16	***	-0.9164	-0.7479	.

*Significance: *** 0.001 , ** 0.01, * 0.05*

Null deviance:	371338 on 295847 degrees of freedom				
Residual deviance:	326911 on 295834 degrees of freedom				
Akaike's Information Criteria (AIC):	326939				
Number of Fisher Scoring iterations:	4				
Deviance Residuals:	Min	1Q	Median	3Q	Max
	2.5674	-1.0376	0.5899	0.8335	2.6108
Likelihood ratio test:	difference of log-likelihoods = -21992, X^2 = 43984, p-value = 0.0000				
Hosmer and Lemeshow test (binary model):	X^2 = 468.14, df = 8, p-value < 2.2e-16				
Pseudo R^2: McFadden	0.1184				
Cox and Snell (ML)	0.1381				
Nagelkerke (Cragg and Uhler)	0.1932				
Confusion matrix:	Accuracy: 0.7185, 95% CI: (0.7168, 0.7201)				

Table 6-9 Outputs for logistic regressions and associated tests for extant PAs, 2010-2015

	2010-2015							
	Estimate	**Stand. Error**	**z value**	**p-value**	**Sig.**	**Confidence Interval**		**VIF**
Coefficients						**2.5%**	**97.5%**	
Intercept	-3.6500	0.1409	-25.91	< 2e-16	***	-3.9263	-3.3741	
PA: 1	0.4164	0.0069	60.47	< 2e-16	***	0.4029	0.4299	1.02
Rainfall preceding WS	0.0037	0.0000	200.40	< 2e-16	***	0.0036	0.0037	1.98
Rainfall DS	-0.0019	0.0001	-14.33	< 2e-16	***	-0.0022	-0.0016	1.73
Temperature FS	0.0009	0.0064	0.14	0.8910		-0.0116	0.0134	1.62
Elevation	0.0002	0.0000	8.85	< 2e-16	***	0.0002	0.0003	3.54
Slope	-0.0718	0.0021	-35.00	< 2e-16	***	-0.0759	-0.0678	1.51
Distance to road	0.0217	0.0005	42.60	< 2e-16	***	0.0207	0.0227	1.10
Distance to settlement	0.0205	0.0002	88.93	< 2e-16	***	0.0201	0.0210	1.24
Population density (ln)	-0.1151	0.0037	-30.78	< 2e-16	***	-0.1225	-0.1078	1.71
LC: 2 Forest	0.3938	0.0183	21.52	< 2e-16	***	0.3579	0.4297	1.45
LC: 3 Mosaic/Shrub/Grassland	1.0170	0.0193	52.81	< 2e-16	***	0.9791	1.0546	.
LC: 4 Sparse	0.4371	0.0731	5.98	0.0000	***	0.2939	0.5802	.
LC: 5 Flooded	0.5541	0.0246	22.50	< 2e-16	***	0.5059	0.6024	.
LC: 6 Urban/Water/Bare	-0.8651	0.0374	-23.16	< 2e-16	***	-0.9383	-0.7919	.
*Significance: *** 0.001 , ** 0.01, * 0.05*								

Null deviance:		601632 on 459849 degrees of freedom				
Residual deviance:		511996 on 459835 degrees of freedom				
Akaike's Information Criteria (AIC):		512026				
Number of Fisher Scoring iterations:		4				
Deviance Residuals:		Min	1Q	Median	3Q	Max
		-2.6872	-0.9953	0.543	0.8573	2.4675
Likelihood ratio test:		difference of log-likelihoods = -44818, X^2 = 89636, p-value = 0.0000				
Hosmer and Lemeshow test (binary model):		X^2 = 741.87, df = 8, p-value < 2.2e-16				
Pseudo R^2:	McFadden	0.1490				
	Cox and Snell (ML)	0.1771				
	Nagelkerke (Cragg and Uhler)	0.2427				
Confusion matrix:		Accuracy: 0.7149, 95% CI: (0.7136, 0.7162)				

Most regression coefficients of the models for both time periods show statistical significance at α = 0.001, with the exception of the *distance to road* for 2001-2006 (which is statistically significant at α = 0.05, Wald *p*-value = 0.0153), whilst *LC: 4 Sparse* for 2001-2006 (Wald *p*-value = 0.1654) and *mean temperature FS* for 2010-2015 (Wald *p*-value = 0.891) are not statistically significant.

For easier interpretation, each regression coefficient (representing the change in the logit / natural log of the odds for each unit change in the variable) is given as the exponent of the coefficient to indicate a variable's effect on the odds ratio, whilst keeping all other predictor variables constant (Table 6-10). Therefore, moving a pixel from non-protected (PA: 0) (default in the regression) to within extant protected area (PA:1), the odds ratio of being burned increases by factors of 1.69 and 1.52 which means the odds increase by 68.77% and 51.64% for pixels within protected areas, for the time periods 2001-2006 and 2010-2015, respectively.

Table 6-10 Exponents of coefficients (for 2001-2006 and 2010-2015)

	Exponent of coefficient	
	2001-2006	**2010-2015**
PA: 1	1.68777	1.51646
Rainfall preceding WS	1.00247	1.00367
Rainfall DS	0.99493	0.99810
Temperature FS	1.32225	*(not stat. sig.)*
Elevation	*(excluded)*	1.00022
Slope	0.93461	0.93069
Distance to road	0.99822	1.02198
Distance to settlement	1.02090	1.02075
Population density (ln)	0.85952	0.89124
LC: 2 Forest	1.33734	1.48260
LC: 3 Mosaic/Shrub/Grassland	2.36532	2.76452
LC: 4 Sparse	*(not stat. sig.)*	1.54818
LC: 5 Flooded	1.40317	1.74043
LC: 6 Urban/Water/Bare	0.43512	0.42101

In the regressions, the variables with the strongest effects per unit, on the odds of being burned, are within the land cover classes, where the coefficients listed are all in comparison to *LC: 1 Cropland* (default in the regression). For both time periods, holding all other variables constant, *LC: 6 Urban/Water/Bare* decreases the odds (by 56.48% and 57.90%, for 2001-2006 and 2010-2015 respectively). Strong positive effects are shown by *LC: 5 Flooded* (40.31% and 74.04%) and *LC: 2 Forest*

(33.73% and 48.26%), although not as much as *LC: 3 Mosaic/Shrub/Grassland*, which has the overall strongest positive effect, (136.53% and 176.45%). *LC: 4 Sparse* shows an increase for 2010-2015 by 54.81%.

For the climatic variables, in 2001-2006 and 2010-2015, holding all other variables constant, increase by one mm in the *mean total rainfall preceding WS* increases the odds of a pixel being burned by 0.25% and 0.37% whereas an increase per mm in *mean total rainfall DS* reduces it by 0.51% and 0.19%, respectively. *Mean temperature FS* increases the odds by 32.22% (2001-2006) per °C increase.

Elevation for 2010-2015, shows an very slight increase in the odds of a pixel being burned with every metre increase, of 0.02%. In contrast, per degree increase in *slope*, decreases the odds, by 6.54% and 6.93%, for 2001-2006 and 2010-2015, respectively.

For both time periods, the effect of every km increase of *distance to settlement* is similar (2.09% and 2.07%, respectively), whilst *distance to road* slightly decreases for 2001-2006 (0.18%) and increases for 2010-2015 (2.20%). With every unit increase the natural log of *population density* decreases the odds of a pixel being burned, by 14.05% and 10.88%, for the two time periods.

6.4.2. Case Study PAs

Using the matched datasets (on non-/protected status) for each case study PA for the time periods available for each, the Pearson's χ^2 tests indicate a statistically significant difference for the un-/burned pixels within PAs and outside of PAs (df = 1 and $\alpha = 0.05$) (Table 6-11).

Table 6-11 Pearson's χ^2 test results (case study PAs, 2001-2006 and 2010-2015)

		2001-2006		2010-2015	
		Burned	Unburned	Burned	Unburned
NSR	Non-PA	19,921	8,136	9,599	2,873
	PA	24,407	3,650	10,977	1,495
		$\chi^2 = 2161.4$, df = 1, $p < 2.2 \times 10^{-16}$		$\chi^2 = 527.01$, df = 1, $p < 2.2 \times 10^{-16}$	
		Burned	Unburned	Burned	Unburned
GNP	Non-PA	5,530	7,041	4,823	7,202
	PA	10,721	1,850	9,476	2,549
		$\chi^2 = 4688.9$, df = 1, $p < 2.2 \times 10^{-16}$		$\chi^2 = 3734.4$, df = 1, $p < 2.2 \times 10^{-16}$	
				Burned	Unburned
LNP	Non-PA			1,060	2,982
	PA			662	3,380
				$\chi^2 = 1116.89$, df = 1, $p < 2.2 \times 10^{-16}$	

As for the logistic regression for all extant PAs above, for the matched PA case study datasets for each time period available, including the PA status as an explanatory variable, with un-/burned outcome as the outcome were then performed and variables with high variance inflation factors (VIF > 5) were excluded. Excluded variables or ones with remaining higher multicollinearity are climatic variables and *elevation* (for details see Appendix 8 – Logistic regression outcomes and associated tests (NSR, GNP and LNP)).

Given the significant χ^2 values for the Likelihood Ratio tests (Appendix 8 – Logistic regression outcomes and associated tests (NSR, GNP and LNP)) all models give a significant improvement in the prediction of un-/burned pixels over the baseline intercept-only models only and pseudo R^2 values, are generally higher for the case study logistic regressions, although should be used with caution. Confusion matrices, the prediction versus the actual un-/burned outcome of a pixel were examined with the models for each case study PA per time period predicting the outcome with between 72.89% and 83.34% accuracy.

Using the exponents of the coefficients from the logistic regressions for ease of interpretation (Table 6-12), moving a pixel from non-protected (PA: 0) (default in the regressions) to within a protected area (PA:1), whilst holding all other variables constant, the odds ratio of being burned increases for NSR by 140.53% and 84.61% (by factors of 2.41 and 1.85), for the two time periods respectively and for GNP (excluding Serra da Gorongosa component of GNP) by 496.28% and 263.61% (factors of 5.96 and 3.64). In the case of LNP, the odds are actually reduced by 58.18%, for 2010-2015, the only time period available.

Generally the climatic variables, show greater collinearity with other variables, as well as no clear-cut pattern, for the national and case study context. *Elevation*, generally shows a very limited effect in all case study sites on the odds of a pixel being burned, whereas slope reduces the odds to a greater or lesser extent. For the human variables *distance to road* and *distance to settlement*, effects on the odds tend to be small, positive or negative. *Population density*, although reducing the odds of a pixel being burned at the national extent, seems to play a role at the case study level, decreasing the odds for NSR, increasing them for GNP and not being statistically significant for LNP.

For all three case study PAs, considering the most relevant land cover classes, moving a pixel from *LC: 1 Cropland* (default in the regressions) to either *LC: 2 Forest* or *LC: 3 Mosaic/Shrub/Grassland* increases the odds of being burned, with the latter showing a higher factor per case study PA per time period.

Provided the overall increased odds of a PA being burned at the national level for extant PAs, and similar findings for at least NSR and GNP, the next chapter provides the details of the qualitative data and analysis to allow for an interpretation of these results in the context of GNP, which are discussed in Chapter 8.

Table 6-12 Exponents of coefficients (case study PAs 2001-2006 and 2010-2015)

	Exponent of coefficient				
	NSR		**GNP***		**LNP**
	2001-2006	**2010-2015**	**2001-2006**	**2010-2015**	**2010-2015**
PA: 1	2.4053	1.8461	5.9628	3.6361	0.4182
Rainfall preceding WS	1.0022	1.0039	1.0020	1.0032	*(excluded)*
Rainfall DS	1.0116	0.9795	0.9912	0.9984	1.0538
Temperature FS	*(excluded)*	0.6726	0.6525	1.3930	*(not sig.)*
Elevation	0.9985	0.9983	1.0015	1.0029	1.0103
Slope	0.9475	0.9741	0.8395	0.9138	0.5569
Distance to road	0.9782	0.9925	1.0234	0.9827	1.0903
Distance to settlement	1.0240	1.0316	1.0228	1.0138	1.0192
Population density (ln)	0.5144	0.5907	1.4360	1.1344	*(not sig.)*
LC: 2 Forest	1.4159	2.9252	1.1679	1.4996	1.9088
LC: 3 Mosaic/Shrub/Grassland	2.8222	6.0698	2.5276	2.6625	7.2609
LC: 4 Sparse	*(not sig.)*	*(not sig.)*	*(no samples)*	*(no samples)*	*(no samples)*
LC: 5 Flooded	0.4468	*(not sig.)*	1.5924	1.1906	*(not sig.)*
LC: 6 Urban/Water/Bare	0.3648	*(not sig.)*	0.5283	0.2947	*(not sig.)*

**Excluding Serra da Gorongosa component of GNP*

7. Qualitative Data and Analysis

7.1. Introduction

Following the qualitative analyses and results in the previous chapter, this chapter provides the qualitative data analysis by Grounded Theory during fieldwork in Gorongosa National Park (GNP) and in two villages in the Buffer Zone (for the methods and techniques used see 4.4.2 Inductive Reasoning in Grounded Theory Data Collection and Analysis). As outlined in the methodological framework (Figure 4-1), results from the qualitative component aim to help address RQ3 (How does the qualitative data collected at local level (Gorongosa National Park) con-/diverge with results from the quantitative data analyses?) at a local, case study site level, to 'provide another lens' with which to observe 'wildfires' and for a more granular understanding. This chapter is then followed by the discussion of the con- and divergence of results from the quantitative and qualitative results in Chapter 8.

7.2. Themes from Fieldwork in/near GNP and Analysis

The themes arising from the fieldwork are based on the interviews, group discussions and other evidence collected (photographs, literature, documents, maps, etc.). The emerging themes, and higher level concepts, were compared to the components outlined in the conceptual framework (Figure 2-1 Conceptual model of physical and human drivers of wildfires in Mozambique.). There seem to be distinct differences in fire regimes and sources of ignition within the GNP (around Lake Urema) and the Gorongosa Mountain (Serra da Gorongosa) of the protected areas and in the surrounding Buffer Zone. Ignitions and timing of ignitions are largely determined by livelihood activities and the GNP's fire management objectives, whereas, fuel characteristics are determined by habitat type and its distribution, and vegetation continuity as determined by the presence of physical barriers or fragmentation.

7.2.1. The 'Problem' and Definitions

Arriving at GNP and in the villages where I conducted interviews, when explaining the purpose of my visit, I was often told that I was in the right place as there are 'so many fires'. There was much evidence of fire occurring: smoke plumes, smouldering and burned vegetation (Figure 7-1), and accounts of specific large fire events. Although fires occur annually, 'fire' seemed to be something perceived as a 'problem' or something 'bad', however, there was a lack of explanation as to why, or what about fire, exactly the 'problem' is. There were a lot of fires and large areas burned, particularly in the protected area, but were these fires really a problem in themselves? And a problem for whom? Or, were the fires rather symptoms of 'other problems'?

Figure 7-1 Evidence of burned vegetation (October 2012)
Left: Burned grass near the access point to the Pungwe River (in Vinho). Right: A road having acted as a firebreak in GNP (near Chitengo) showing recently burned area on the right and unburned vegetation on the left.
Photos by author.

Definitions for the different kinds or aspects of 'fire' are also necessary, as fire is a useful tool in everyday life (to cook, for light, burning rubbish, clearing access/paths, etc.), while simultaneously, it can have detrimental effects depending on who perceives it and in what context. The term generally understood and used in Mozambique to denote larger uncontrolled fire events which tend to be seen to have negative effects, is *queimadas descontroladas* ['uncontrolled burns'], where the connotation is that fires are 'out of control'. Early season burns are called *queimadas frias* ['cold burns'] indicating lower intensity fires.

7.2.2. The PA – Gorongosa National Park (GNP)

7.2.2.1. The Gorongosa System

Tinley's (1977) excellent and comprehensive description of the Gorongosa System explains that Lake Urema at the southern end of the Rift Valley, is fed by rivers from the Gorongosa range to the west of the lake (Figure 7-2). Lake Urema and the surrounding floodplains can support large amounts of fauna, and the lake is a source of water throughout the dry season. The Urema River drains the lake to the southeast. The extant ecosystems (grasslands and forests) are known to have evolved in the presence of fire (Beilfuss et al., 2001; Envirotrade, 2008), although, according to Tinley (1977) the ecology is probably more determined by the inflow and outflow of water in the lake system.

There are two discrete areas to the GNP (Figure 7-2): the historical precursor of the Park including the low-lying, Rift Valley bottom around Lake Urema (15-80 m above sea level), with the Cheringoma Plateau along the east (at around 300 m), and the 'midlands' (up to 400 m) along the west. The second component is the area above 700 m of the 1,863 m-high Gorongosa Mountain (also referred to as Serra da Gorongosa NP in the WDPA) (GoM, 2016; UNEP-WCMC and IUCN, 2020). These two areas are surrounded by the Buffer Zone in which lie 16 communities. Generally speaking, the two discrete components of the GNP, and the Buffer Zone, all show different fire characteristics. However, fire characteristics are not homogenous for each and are not confined to each area, fires and people being able to pass from one in to the adjacent areas as well as from outside the Buffer Zone. Fires usually occur during the dry season, peaking around September/October (Figure 5-1).

The GNP has management objectives (enhancing ecology, conservation, tourism, social and economic development) where wildfires, when uncontrolled, can be detrimental to these objectives (PNG, 2010). As part of the management plan (2010-2012) the Park outlines re-stocking herbivores which were decimated during war, etc., in order to reduce grass biomass and stop encroachment of woody species, single species thickets and invasive species. Additionally, the management plan encourages the use of early season burns, to reduce dry season active fires (PNG, 2010). Challenges to the effective management of the GNP are, among others, poor ground access to much of the Park, settlements and agriculture within the protected area, a high level of poaching, and increasing human population pressure (PNG, 2010).

7.2.2.2. Gorongosa National Park (GNP)

Within the GNP, there were different priorities regarding fires, depending on the different departments in the Park Administration (Scientific Services, Community Relations, Conservation, Tourism, Communications, etc.) (for details see Appendix 6 – Organogram GNP). According to the members of the Scientific Services Team who are concerned with the management of the ecology of the Park, fires were not necessarily seen to be negatively affecting the overall ecology (see also Tinley, 1977) and suggestions for the annual burned area were between ¼ to ⅔ of the whole area of the Park.

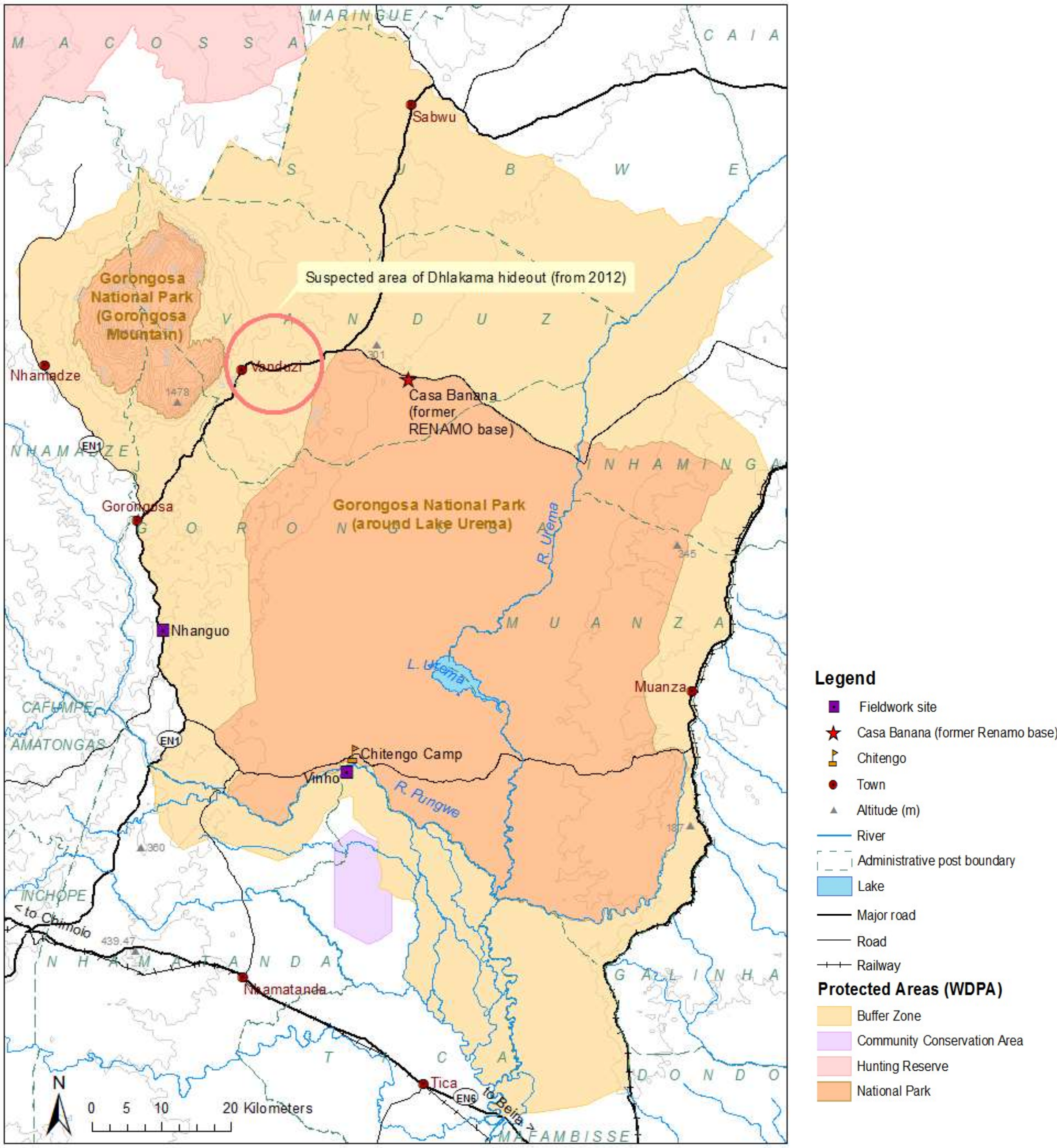


Figure 7-2 Gorongosa National Park, Buffer Zone, surrounding area and locations of data collection Data: CENACARTA (2000a; c); Jarvis et al. (2008); CIESIN and ITOS (2013); UNEP-WCMC and IUCN (2020).

Within the GNP, at least around Lake Urema, fire management is crucial to avoid devastating effects of fires later in the fire season which would be more destructive due to higher fuel load and increased flammability, although are only combated if they threaten infrastructure or human lives (GoM, 2016). This includes efforts to reduce fuel load with controlled early season burns, creating firebreaks around the Park, to act as barriers for fires moving in and out of the Park (Stahl, 2020) and around other sensitive infrastructure (GoM, 2016), as well as increased recruitment and training of law enforcement personnel and improved tactics of deployment and organisation to counter illegal activities within the Park, especially logging and poaching for which fires may be set.

By 2012, some early season burning was being done in GNP by the park administration as a protective measure, but mostly south-west of Lake Urema (Figure 7-2) where the most 'sensitive' areas are in terms of the infrastructure, tourism (Chitengo) and the Sanctuary (where translocated animals are kept). This was reflected in research from 2019 (Stahl, 2020) where areas close to roads, and Chitengo, experienced higher frequencies of fire due to early season burns. In this area, fire frequency was lower near rivers, probably due to lower fuel flammability (higher moisture) and more fragmented fuel beds (Stahl, 2020).

The general perception amongst GNP staff in 2012 was that apart from early season burns initiated by the Park Administration, most fires are started by poachers and that poaching occurs mostly during the dry season and seems to increase with drier years possibly as harvests are poorer. Apparently 2012 was a particularly bad year, as suggested by the rangers' extensive log of arrests of poachers and seizure of snares and traps, and other material associated with poaching, within the Park, and coincides with interviewees in the villages explaining that the previous 2-3 years had seen little rain and poor harvests, and possibly people need to access other sources of food. Illegal loggers, particularly along the northern borders of the GNP, were also implicated by the GNP staff in potentially igniting fires for accessing valuable, large trees for felling.

At the time of the fieldwork (2012) people were still living within the protected area. The population was estimated at around 5,000 families, especially in the north and north-east. One community of 72 families, Muaredzi, closest to the Park headquarters south of Lake Urema, was in the process of being resettled into an area east of the GNP in Muanza district (Figure 7-2). The Community Relations Team explained that the people living within the GNP live from fishing in Lake Urema and rivers, limited agriculture, but probably also poach within the Park. Ignitions by these communities for agriculture and for poaching, or any other purpose, cannot be ruled out. The communities have no right to receive part of the 20% of the GNP revenues, to use the land, or access to services and development (health, education, etc.). The Community Relations Team does visit the communities inside the Park, and reports that many people, although they have limited rights, and experience increased human-wildlife conflict (HWC), choose to stay on the grounds that their ancestors lived in these places before the Park was created and so have a perceived right to be there. For example, both Chitengo and Nhanguo are eponymic places names stemming from traditional chieftain lineages.

As Mateus Mutemba, GNP Administrator at the time of the fieldwork explained, the interactions between mega-herbivores and ecology/vegetation structure, and in turn fires, was an important aspect of the management of GNP, as herbivore numbers were dramatically reduced during the wars and animals were again being re-introduced and stocked-up (M. Mutemba, personal communication, 12/10/2012; PNG, 2010). Daskin et al. (2016) showed that herbaceous tree cover within the GNP (around Lake Urema) increased by 34% (362 km^2) between 1977 and 2012, mostly in the major habitat zones of the Park (including Miombo woodland, *Acacia-Combretum*-palm savannah, and floodplain grassland). Similarly, Herrero et al. (2017) showed increased tree cover, in at least the southwestern sector of GNP (around Lake Urema), being due to reduced browsing pressure by herbivores, rather than rainfall or fire trends (Daskin et al., 2016).

For the future, with the reintroduction of herbivores and other animals, and associated changes in vegetation and its distribution, and also effects on vegetation due to potential changes in weather patterns (e.g. slight reduction in annual rainfall over past decades has been observed (Herrero et al., 2017)), hydrological fluxes into and out of the Urema system (from Gorongosa Mountain range) altered by human pressures and possibly changes in the outflow in the Urema River, will be important aspects to consider in the management of fires within GNP. Human density in the area is highest around Gorongosa Mountain and along the EN1 and EN6 highways (Figure 7-2).

7.2.2.3. Gorongosa Mountain/Serra da Gorongosa

When I flew over the GNP on my way to Beira, I saw six smoke plumes rising from the top of Gorongosa Mountain (Figure 7-2) which I was later told, were set as acts of revenge or sabotage. I asked about the fires, and was not offered an explanation, however, I later learned by hearsay, that there was possibly an altercation between a Park ranger and a person felling a tree on the Mountain. The details were unclear, but the situation on the Mountain was particularly difficult for the GNP administration due to the lack of access and the unique microclimate and associated ecology of the Mountain, which is more fire-sensitive. During the Civil War the guerrilla movement, RENAMO established a base on the Mountain because it is difficult to access, to cache arms and as a refuge for guerrillas as well as people farming. One of RENAMO's main bases, Casa Banana (Figure 7-2) was nearby. At the time of fieldwork, Gorongosa Mountain (above 700 m) had only relatively recently (2010) been declared a protected area, based on the recommendation made by Tinley in 1977 to the importance to the lower-lying National Park, and there were obviously still people farming, harvesting natural resources and logging on the top. The extent of this was however difficult to establish as I did not visit the Mountain but I was told that agriculture is at least partly 'commercial' – people are hired to farm and the crops (e.g. potatoes) are sold elsewhere (D. Muala, personal communication, 15/10/2012; Schuetze, 2015). It was also mentioned that cannabis cultivation exists on the Mountain. Although cannabis is used traditionally to stave off hunger, thirst and tiredness by people working in the fields, it may also be destined for the urban market (D. Muala, personal communication, 15/10/2012). The people on the Mountain were perceived as 'lawless' by some members of GNP staff. In 2012, the Park seemed to have little resources and influence on the mountain and meetings had been taking place between the Park and communities on and near the mountain over some years. In the following years, given the presence of the RENAMO leader and his followers in the area and difficult relationships between the GNP and people on the Mountain, access by GNP staff to the Mountain had not necessarily improved (Stalmans and Victor, 2020).

Fires on Gorongosa Mountain, were likely ignited by people for clearing land and agricultural purposes, or as acts of revenge or sabotage, particularly to 'get back at' the Park and 'government', where the lines between 'park', 'government', the ruling party and other 'outsiders' are potentially blurred. Fires on the Mountain were assumed to be relatively small in size, given higher tree cover, and the relatively high humidity provided by the microclimate. It is worth remarking that fire activity on the Mountain has been noted in the 1970s by Tinley (1977) where '*the savannah and grassland slopes, and summit grassland are subject to annual grass fires*'.

In terms of achieving conservation objectives, the Mountain requires careful management for its unique ecology, as a source of water into the Urema system, and therefore the conservation success of the GNP, and its cultural and spiritual significance (Muala, 2015). Stalmans and Victor (2020) confirmed the loss, further fragmentation, an increasing number of ever-smaller forest patches and nibbling at forest edges, using high resolution satellite images (2010-2019) (and an KH-9/HEXAGON spy satellite image from 1977 for reference). The rate of loss in the recent years has stabilised at about 350 ha/year assumed to be caused by 'slash-and-burn' agriculture (Stalmans and Victor, 2020). In an attempt to stem the rate of loss of forest on the Mountain, a project by the GRP to grow shade coffee and plant native trees on parts of the Mountain was initiated in 2015, in the hope of allowing for sustainable income generation, reforestation with native trees, protection from fires and developing the most appropriate techniques for reforestation on Gorongosa Mountain, which seems to be yielding some success (Our Gorongosa, 2020; Stalmans and Victor, 2020).

7.2.3. Buffer Zone

7.2.3.1. Communities

Although labelled with a single label, the Buffer Zone is by no means homogenous, and neither are the 16 communities that lie within it. Communities are heterogeneous, varying in composition, ethnicity, culture, size, density, livelihood activities, practices, history, and the strength of traditional authority, between each other and within. Similarly, the term 'community' is somewhat problematic and is used here in the legal sense, as an assemblage of households living in a delimited area (Nhantumbo et al., 2001). Although, who is included in reality, in whose perception and for what purpose, also in terms of gender, ethnicity, culture, age, language, etc., is beyond the scope of this research. Also, it does not necessarily mean that members of a community behave in unison or agreement, or only within their delimited area. Or, in a fire context, that an extant fire regime is something that is chosen by the community, and that the community is or should be responsible for, although this is assumed, at least to some extent, in the 1997 Land Law.[16]

The 16 communities in the Gorongosa Buffer Zone number around 150,000 to 200,000 people (GoM, 2016). The integration of these communities into the Gorongosa Restoration Project provides incentives which include: access to the '20%' (share of Park revenues) and associated development (education, health, etc.), direct training and education (provided through the GRP), employment opportunities in Park or tourism sector, as well as opportunities for income diversification (for example, shade-grown coffee project). The Gorongosa Restoration Project has also garnered heightened international visibility (therefore should also provide scrutiny) of the communities involved. In a wider context, through a well-managed landscape, functioning ecosystem services and natural resources, including animals to poach, are also provided. On the other hand, increased Human-Wildlife Conflict (HWC) and (perceived) exclusion or unfairness can foster disenchantment and sabotage, also by communities outside the Buffer Zone (Brockington et al., 2008).

Data was collected from a limited number of members in two communities, Vinho and Nhanguo, which both lie in the southwestern part of the Buffer Zone, close to the GNP boundary. Although the data is informative, it is understood not to be conclusive and exhaustive for each community as a whole, nor to encapsulate all the 16 communities' experience in the Buffer Zone.

Vinho, is one village in the Buffer Zone I visited for fieldwork, across the Pungwe River from Chitengo (Figure 7-2). It has its particular history. Before Independence (pre-1975) people lived in Vinho had strong ties to Chitengo, in GNP, providing labour, but many inhabitants were not necessarily from the area. During the Civil War only very few people remained (the Park was also abandoned) and they only started coming back after Peace (1992) (GD2 Vinho; D. Muala, personal communication, 15/10/2012). Most of the families of the people I met in Vinho from the agricultural associations were from Maringue, a district north of the GNP (Figure 7-2). They had settled in Vinho in the proximity to

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[16] The Land Law 17 of 1997, Article 1 defines 'community' as '*a group of individuals and households within a delimited area, who aim to safeguard the communal interests by protecting residential areas, agricultural areas (cultivated or fallow), forests, sites of cultural importance, pastures, sources of water and areas of expansion'* (translation from Portuguese by author). Article 24 states that rural communities are to participate in: the management of natural resources, resolution of conflicts, in the process of gaining the DUAT (GoM, 1997).

the Pungwe River providing access to water for agriculture. One member of the agricultural association told me, '*I have a* machamba [field]*… by the river [Pungwe]… since '92. It was us who started'* (GD2 Vinho). There are some communities in the Buffer Zone which are more homogenous and whom have been in place for much longer, the villages not having been abandoned during the war (D. Muala, personal communication, 15/10/2012). It was however not possible to visit a village which had not been abandoned due to time and resource constraints.

The other village I visited, Nhanguo, is west of Chitengo and south of the Gorongosa Mountain (Figure 7-2). It is located between the Park boundary and the EN1 road. Similarly to the inhabitants of Vinho, members of the Nhanguo community told me that they moved there from Gorongosa Town after Peace in 1992, but many originally came from a village in Maringue district (Figure 7-2), although some are from Sena (further north at the banks of the Zambezi River) and Nhamatanda (south of the GNP and Buffer Zone along the EN6) (Figure 7-2). The groups in Vinho and Nhanguo explained that fires happen in the community but seem to be something that comes from outside the community, or are started by 'people unknown' [*desconhecidos*]. In Nhanguo I was also told that the fires often come from the direction of the Park into the community, as there is no river or other boundary between the two, unlike in Vinho. However, they are not sure who exactly ignites the fires in the Park. They also said that they know that the rangers in the Park use fires to 'open' *picadas* [paths, or roads, could also be used to describe a firebreak]. In response to whether people use fire to clear their *machambas* [fields], the interviewees said that even if people do not burn their *machamba*, it will be burned every year as the fires will pass through the area anyway.

In terms of loss of lives, houses and grain/food stores [*celeiros*], the effects of fires in the two villages seem to be very limited. The last major fire events mentioned included September 2007 (Interviewee 2) where 'many houses were destroyed and people died', September 2010 south of Vinho (in Madangua) (GD2 Vinho) and in 2008 in Nhanguo (GD Nhanguo). Apparently the 2010 fire near Vinho was started by a man hunting rats and '*one man lost his house with everything in it – he was left even without the shade of a tree because the mango tree also burned*' (Interviewee 3). The man who started the fire was imprisoned in Gorongosa Town for a year. The group in Nhanguo explained that the people who had incurred damages in 2008 got a '*plate and a blanket*' from the '*district*' (local government). They said that anyone who had lost their house would have to rebuild at their own cost. As one man put it, '*why should we help if they didn't take care?*', i.e. the person who lost their house should have cleared their yard to avoid the fire jumping to burn the house. I was also told that the man who set the fire in 2008 was taken by the community police and put into prison (GD Nhanguo).

For the people in both villages, 'uncontrolled fires' [*queimadas descontroladas*] were seen as something that comes from outside. Particularly in Nhanguo, the interviewees explained that by the time they would have needed to burn fields after harvest, the fires [from outside] would have already passed and they did not know who set them. The notion of fires being 'out of control' may play a role in this perception as the use of fire within the community would usually be controlled. Also, interviewees would have been unlikely to self-implicate their community for being responsible for uncontrolled fires, especially in the presence of GNP staff.

Arson, as an act of revenge does occur within the communities, for example, in response to '*someone stealing another's wife, stealing possessions, in land disputes, but also if someone is thought to be a* curandeiro *or* feitiçeiro' (D. Muala, personal communication, 15/10/2012).[17]

7.2.3.2. Agriculture

Fires are commonly used for agriculture, the main livelihood in Vinho and Nhanguo. It was not possible to quantify but the practice of clearing existing fields with fire, to prepare the plots for sowing before the rains, was used, although clearing fields without burning and leaving residues on the soil to reduce evaporation and ploughing residues into the soil, existed as well (D. Muala, personal communication, 15/10/2012; GD2 Vinho). Fire is used to 'open' [*abrir*] new fields in the 'bush' [*mato*] but it seemed that, at least in Vinho, areas available for new fields, are very far away from the river and the village. As Interviewee 2 put it '*I would have to start walking in the morning and would only get there [at 16:00]*'. Without an investment in a well or borehole crops would only be rain-fed and provide only one harvest a year, whereas by the river, two harvests or more were possible (Interviewee 3). The agricultural associations in Vinho have 38 members and there are eight water pumps, at least six of which are owned by individuals. Land for new fields is allocated by traditional authorities (*m'fumos, sapandas* and *régulos*)[18] who decide what land is available and are involved in the *imbeba* ceremony and rituals allowing the allocatee to use the land (Interviewee 2). Crops planted in Vinho include maize, cassava [*mandioca*], pumpkins, cabbages [*repolho*/*couve*], potato, chilli, okra, sorghum [*mapira*], beans, onion, garlic, tomato, peanut [*amendoim*], and lettuce (GD1 Vinho; GD2 Vinho; Interviewee 3).

Individuals were very knowledgeable as to when and how to use fire safely, such as, that residues are piled up in the middle of the field (D. Muala, personal communication, 15/10/2012), '*if* machambas

[17] *Curandeiro* is 'someone who cures' (traditional healer), while a *feitiçeiro* is 'someone who makes spells' (from Portuguese *feitiço*), but both have access to the spirit world (translation by author).

[18] Kinds and levels of 'traditional' leaders formed of structures of pre-colonial lineages, combined with structures co-opted by colonial/post-colonial governments. *Régulos* represent the highest level with conflict resolution and spiritual leadership roles. *M'fumos* administer smaller areas in a *régulado. Sapandas* are traditional officers (for more details see Convery (2006)).

are close together the [owners] will burn them together', '*in the morning there may be lots of mist and dew and the grass does not burn well*', '*at midday it is very hot and windy… and you shouldn't burn*', '*when [the temperature] is hot, the fire burns more*' and '*fire destroys the soil*' (Interviewee 3, GD2 Vinho).

There has been some work done in terms of raising awareness and training. Each community has access to an extension officer [*extensionista*], who is a government technician (currently from the Ministry of Agriculture and Rural Development (MADER)) responsible for a group of communities whose mandate it is to provide training and expertise in agricultural and other livelihood activities. Practices promoted include 'conservation agriculture' which involves, rather than burning crop residues, incorporating them into the soil or leaving them on the soil to increase nutrients and soil humidity, using chicken manure and compost to fertilise fields, promoting keeping of guinea fowl, growing bamboo, planting maize in rows for easier harvesting, keeping bees for pollination, planting trees for shade, fruits, and other products (e.g. edible nutritious leaves, fodder), agro-forestry systems and small-scale irrigation systems (Figure 7-3). In Vinho, in April 2012 with the help of the extension officer four tilapia fish ponds were created (Figure 7-3).

The members from both communities reported however, that their extension officer is frequently unable to visit due to problems with transport – '*she had a motorbike but it's in Beira and it's broken*' (GD Nhanguo) – and that the officer has many communities to visit.

In Nhanguo I was told that some members of the community have received training from the GNP in firefighting, but they said that it is difficult for them to do it as they do not have the equipment and access to water in their area is limited to the water pumps. A group of people from Vinho were also trained in another community, as an 'exchange of experience', in beekeeping and honey collection by the GNP. Another example of this cross-community exchange is that members of the Nhanguo community visited another community to learn about sanitation and hygienic practices, such as *latrinas melhoradas* ['improved latrines' – a pit with a cement cover as opposed to open, or no, latrines], personal hygiene, keeping cooking utensils on stands off the ground, etc. From the interviews and group discussions, I was however not clear about the exact roles and responsibilities, that the (local) government and the Park each have in the development context in terms of training and education, and even provision of development initiatives (health facilities, schools, access to WASH[19], etc.).especially when they are related to the use of 'the 20%' and how this is coordinated. This is partly due to the fact that interviewees commonly referred to the 'park' implementing projects, if they see

[19] UN Sustainable Development Goal 6: Water, Sanitation and Hygiene

GNP staff on the ground, or the extension officer as a 'government' representative, without necessarily knowing the links or cooperation between the two.

Figure 7-3 Evidence of agricultural practices and livelihood activities supported by government extension programmes and/or GRP/GNP
Top row: Left: Bamboo in the yard of a house in Vinho; Centre: Maize planted in rows for easier harvesting; Right: Beehive belonging to agricultural association in Vinho (training and hives provided by GRP/GNP). Bottom: Left: Nursery for fruit and shade trees for planting within community (Vinho); Right: Tilapia pond with fenced-off fish nursery in the background.
Photos by author (October 2012).

So to speak of 'uncontrolled fires' [*queimadas descontroladas*] stemming from ignitions for agricultural and other day-to-day activities, within the areas where the communities represented live, is probably not appropriate, apart from 'escaped' fires. The burned areas of the controlled fires are expected to be relatively small in size, and possibly relatively frequent (at least for part of the year when preparing fields for sowing) unless there is much coordination between villagers. Also the actual amount of available fuel would be very low in these situations. Some training provided in firefighting (by GNP/GRP) may, in combination with resources, increase the suppression of active fires.

Burned areas stemming from escaped fires or fires set in less populated areas of the Buffer Zone, are expected to be larger as there would potentially be less fragmentation of vegetation, although rivers, roads, and escarpments may act as barriers. So, within the Buffer Zone, intuitively, fuel availability and continuity should be relatively low in areas which are farmed, although these factors should increase with distance to human activity (settlements/roads). It is worth noting, however, that fuel availability, characteristics and load may be altered further away from populated areas, by human activities such as firewood collection, production of charcoal and logging, as well as variations in rainfall patterns, due to teleconnections and climate change, and finally, the fire regime itself.

In the use of fire for agricultural purposes, awareness and understanding of using fire safely as a tool for clearing land and residues, is very high. Punishments are in place for anyone who causes damage to property/lives, although possibly not for letting fires escape to surrounding areas which are not part of the community.

7.2.3.3. Poaching

People in the communities interviewed seemed to think that many fires in the villages and around the *machambas* are started locally by kids, teenagers or women catching small rodents. '*It's usually women… when they have no meat to put into their* caril *[stew]. … Boys hunt more with dogs. Maybe like 12 to 17 year-olds*' (Interviewee 5). The rats and mice are eaten or sold but only the 'rats and mice' from the 'bush' not the ones found in houses. The hunting is usually done before the rains when the animals assemble in areas where food and water is still available. To hunt the rodents an area is burned to be able to see the burrows better and to see where the rodents run. Burrows are smoked out, the animals chased, and killed with sticks, machetes, bows and arrows, etc. and sometimes with dogs. The 'rat hunters' are seen as being careless with fire, maybe because they are perceived to be inexperienced as they are young and/or female.

Hunting seemed to be part of the local livelihood. Interviewee 5, a former poacher, employed by GNP, explained that his father and brother were both hunters, and he learned what he knows from them. His father was hunting elephants with 'the Portuguese' for ivory in the Park already in the colonial times (pre-1975) while he, himself, was poaching until 2004, when he stopped as he gained employment in the GNP. Apparently quite a successful poacher, he explained that the demand for his work was so great that he supplied a hotel and two restaurants in Beira with bushmeat. When he was coming back from checking his traps in the bush, '*a car and cool boxes would already be waiting at [his] house to take the meat away*'. He said that he always had money and, following the death of his two brothers, he took in their children as well, increasing the number of children in his household to seventeen.

There are several reasons why poachers set fires and there are no fixed rules or practices (Interviewee 5). Fires are used to make animals flee into traps, fires encourage new grass shoots and so animals concentrate in an area where snares and traps are then placed, they are used to burn the undergrowth to have better access and sight, also to protect the poachers from danger '*hiding in the grass*', such as lions, snakes, and Park rangers, but are also used to create barriers between the rangers and the poachers, to create diversions, and, lastly, to '*get back at the park*'. Poachers also use fire to cook, they may smoke cigarettes, may have glass bottles with them which can all ignite fires, especially when the vegetation is dry.

The interviewees in Vinho and Nhanguo said that the poachers who go hunting in the Park for bushmeat are from '*other places*'. And that '*once in a while*' people, not necessarily residents, are arrested in the villages in possession of bushmeat (Interviewee 3). However, interviewees would probably not self-implicate their community in illegal activities, especially in the presence of GNP staff. Bushmeat includes gazelles, antelopes, hippopotamus, buffalo, warthog, birds and rodents. Elephant is consumed[20], but mainly hunted for ivory. Monkeys, crocodiles and other predators (lion, leopard, hyena, snakes, etc.) are not consumed, however body parts, bones and skins of these and other animals are in demand by traditional healers (Interviewee 5). The former poacher explained that many people hunt to eat the meat themselves, but also for 'commercial' gain from bushmeat, valuable skins and other parts, particularly ivory.

The techniques also vary (Figure 7-4) – some hunters hunt with automatic or home-made rifles, by stalking and shooting animals. The home-made rifles are muzzle-loading and the bullets are made from iron pellets cut from iron rods. The gunpowder is home-made including ashes of a certain plant and match heads. Other poachers leave traps and snares in the bush and check them about twice a week. The traps are kept in the same general area and the trappers know where other trappers have their traps in adjacent areas. Snares are used for all sizes of game from small gazelles to elephants,

[20] As was the case when an elephant which killed a park ranger and was subsequently culled by the Park authorities and the meat was handed over to the community in 2012 (GD2 Vinho).

Figure 7-4 Illegal hunting and poaching equipment seized by GNP rangers
Top row: Left: Homemade rifle; Right: Gin traps and snares. Bottom row: Left: Rodent traps; Right: GNP storeroom filled with confiscated materials.
Photos by author (October 2012).

varying in thickness (of the wire/cable), the suspended loop's diameter, the height of suspension and what the snare is anchored to – a shrub or trees. Gin traps are usually manufactured locally, for example, using leaf springs from car suspensions, and are used to catch larger animals up to the size of a buffalo. Rodent traps like large mousetraps, may be constructed from bicycle chain wheels and wire coils as springs.

The use of rifles is dictated by beliefs whereby a weapon, its owner, as well as a small wooden replica of the rifle placed in the house of the owner, all need to have a red cloth and white beads attached to it. These are placed on the weapon and replica in a ceremony, for '*the spirit to know*' that the weapon belongs to a certain person, to '*call the animals to the hunter*' and to keep harm at bay. A ceremony for the owners and their weapons has to be conducted annually to keep the owners safe. There are also *drogas* [literally 'drugs' but maybe better described as 'potions' or 'spells'] that can be used to make people '*bulletproof*', to make animals '*not realise that they are walking into a trap*', for the rangers '*not to be able to see the poachers*', etc., which, depending on the complexity, poachers can make themselves or need to be obtained from a *curandeiro* or *feitiçeiro* (Interviewee 5).

I was shown the GNP's storeroom where confiscated material from poachers, such as snares, nets with plastic bottle swimmers, home-made rifles, a bicycle, a crocodile skin, and other equipment used by illegal poachers, is kept. These are either found on patrol by rangers or confiscated from poachers. Semi-automatic firearms have also been confiscated by the Park authorities but these need to be handed over to the police. The semi-automatic weapons may still be remnants from the Civil War, as support for the opposition was, and is, strong in the area and many weapons were not handed in during demobilization, but are probably also available from more recent conflicts and through extant criminal networks, for example for ivory trading. Interviewee 5 explained that automatic rifles can also be acquired in larger towns and cities (for example, Gorongosa Town, Beira and Maputo) which are stolen by '*bandits*' from the police. He also said that poachers are sometimes '*helped*' by complicit Park rangers, in exchange for bribes.

Urban demand exists for bushmeat, such as in Beira, Chimoio and Gorongosa Town, and for animal parts. I was told '*you know, now people even come here to the restaurant [in Chitengo in GNP] and ask us if we have bushmeat. There isn't any one of my colleagues who hasn't been asked*' (Interviewee 5). However, demand for elephant ivory is in Asia (TRAFFIC, 2020). Transport of any product is facilitated by the fact that GNP and its Buffer Zone lie alongside and near major transport routes and nodes. The EN1 is the national north-south road, and the EN6, one of the main east-west axes, part of the Beira Corridor, connecting Beira and Zimbabwe (Figure 7-2). The port city of Beira is the capital of the Sofala Province and also the second largest city in Mozambique, and also has an international airport.

7.2.3.4. Timber and Fuel

The harvesting of timber and firewood do not necessarily directly relate to ignitions of fires, but the potential alteration in the fuel available, e.g. decrease in fuel load and fuel continuity, although bearing in mind that loggers have been implicated as potentially starting fires to the north of the GNP to clear the bush to be able to identify and access trees to fell. Charcoal production may be a source of ignitions of fire events, although the kilns are probably well-controlled to ensure that the wood actually is incompletely combusted into charcoal, as that would result in wasted effort and a consequent loss of revenue (D. Muala, personal communication, 15/10/2012).

Figure 7-5 Evidence of deforestation, logging and charcoal production
Top: Deforestation along EN1 near Nhanguo. Bottom: Left: Timber transported on EN6 towards Beira; Right: Sacks of charcoal for sale along EN1.
Photos by author (October 2012).

Nhanguo lies alongside the Mozambican main north-south road, the EN1. On the way there, along the road was much evidence of deforestation and cut down trees to possibly make way for fields, but possibly also for firewood and charcoal, which were sold by the roadside (Figure 7-5). The trees cut down for firewood or to make charcoal tend to be felled and left to dry until the wood is collected.

However, when land is cleared for agriculture the trees could be dried and used for firewood, but I was told '*we don't*' and they are usually burned (Interviewee 2). The members of the Vinho community confirmed that they use *lenha* [firewood] for fuel as it is cheaper to collect than to buy charcoal (GD2 Vinho); although charcoal is produced in the area, it is sold to other areas, such as Nhamatanda (south of GNP, along the EN6) where it is more easily transported to towns and cities where demand is greater (Figure 7-2).

On the EN6, on the way to the GNP and back to Beira, we passed a large number of lorries loaded with timber and charcoal (Figure 7-5). At the time of the fieldwork, a sack of charcoal cost 100 MZN (about £2.20) at the roadside, whilst in Beira the going price was 200 MZN (about £4.40), and in Maputo (the capital city) the asking price was up to 800 MZN (almost £18). Outside of Beira we also passed several huge timber yards, with timber most likely to be exported to Asia (Mackenzie, 2006).

7.3. Analysis

The collection of qualitative data in and around GNP provides a different approach by which to view the conceptual wildfire system (Figure 2-1). Specifically, relating the themes to the conceptual model, the fuel (load, continuity and flammability) in the different fire situations for the two GNP areas and the Buffer Zone, seem to be determined by rainfall (and temperature) patterns (seasonal and interannual), the land cover (vegetation/ecology/hydrology) and topography (rivers, lakes, slope, etc.). These may, however, be influenced by climate change, and changing patterns of teleconnections, especially with regards to the reliance on the functioning hydrology of the Urema System and the provision of water into the system from Gorongosa Mountain. The fuel characteristics (vegetation/ecology) are being affected by the type and strength of management (or lack thereof) for conservation objectives, such as herbivore stocking, monitoring, law enforcement, etc., of the GNP and the Gorongosa landscape, and fragmentation by human activities (agriculture, poaching, fuelwood collection, etc.), as well as by the fire management, through applying a fire regime of early season burning to reduce less severe fires later in the season, and fire suppression (Daskin et al., 2016).

The human drivers of fires increasing ignitions, are human density and human presence (along roads, and for livelihood activities), but also the ability for active and passive suppression. This is true for within and outside the protected area, although whether the ignitions cause large, uncontrolled/uncontrollable fire events varies across the different areas. Within populated areas in the Buffer Zone, fuel load is relatively low (agricultural residues, frequently burned vegetation, etc.) and it is fragmented by human activities (paths, roads, fields, yards, firebreaks, etc.). Also, the risk of being identified as the person responsible for setting a fire is high and punishments are in place. These dampers decrease further away from settled areas, and although ignitions may be less, burned areas from individual ignitions may be larger, as fuel load and continuity may be greater. This is seems to be true within the GNP (around Lake Urema) where apart from early season burning by the Park management, people who live within the GNP boundaries and people coming into the GNP (for poaching, or collecting other natural resources) use fire towards illegal activities or possibly as sabotage. On Gorongosa Mountain, it is assumed, the high tree density and high humidity, reduce fuel flammability and propensity to burn, and the associated burned area per ignition. However, the inaccessibility of Gorongosa Mountain at the time of fieldwork in 2012, made successful management by the GNP, extremely difficult and given its favourable farming conditions, cultural, spiritual and even political significance, may increase ignitions for livelihood activities, but also by possible acts of defiance against the 'park'/ the FRELIMO-government.

The different dimensions of relationships between the communities, the GNP/GRP, the government (at different levels), the ruling party, and outside stakeholders and actors, are crucial for any sustainable set of fire regimes in the study area (Figure 7-6), in addition to external factors influencing these relationships. In my opinion, for these relationships to be positive and conducive, an overall emphasis on sustainable development benefitting the communities, is paramount, increasing food security by reducing reliance on low-productivity, mostly rain-fed agriculture, through livelihood diversification and sustainable livelihoods, provision of services (education and health), political stability, strengthened institutional capacity, and aligned national policies. This means the integration of communities within the Buffer Zone, and if possible beyond, as empowered stakeholders in the management of the protected area, as is emphasised in the case of the GRP.

However, relationships and power relations between the different stakeholders and actors are complex in the GNP case study having social, economic and political dimensions. In this context, it may be important to consider the beginnings of the idea of Gorongosa Mountain as part of GNP before its integration (2006-2008) given the narrative of the Park (that it is essential for the existence of the Urema hydrological system, its unique afromontane habitats, that activities by people on the Mountain are detrimental, etc.) and a divergent narrative proposed by Schuetze (2015), that the residents of Gorongosa Mountain, through long-term tenure see themselves to have the legitimate basis to the land and its resources, which is central to their spiritual[21], political, economic and social life. The tenure of land on the Mountain has been contested at least since colonial times, and continued during the Civil War when RENAMO had a base on the Mountain and FRELIMO resettled residents to try subdue support for RENAMO (Muala, 2015; Schuetze, 2015). The Mountain was

[21] *Mhondoro*, and other spirits residing on the Mountain and in the surrounding area must be given due respect to prevent misfortune (Schuetze, 2015).

declared part of the GNP in 2010. The enduring claims to land, the '*fallacy of indigenous resource depletion*' (Muala, 2015), and the interest of including the Mountain in the GNP with the blessing of the government, can only but produce and maintain conflict between the stakeholders and actors if no compromise can be achieved, leading to outcomes counter to the desires of conservationists and/or the residents of the Mountain and/or the party in government/state and globally (Matusse, 2019).

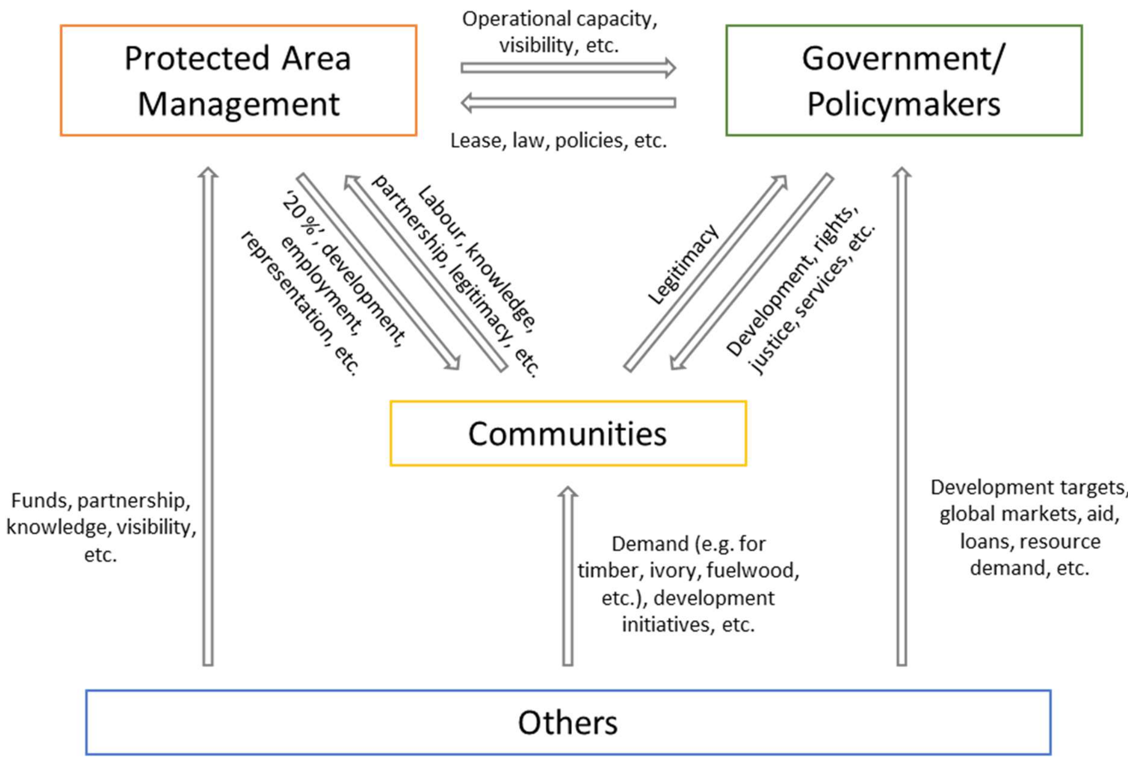


Figure 7-6 Stakeholders/actor relationships (in the GNP case study context)

And this is not only necessarily true for Gorongosa Mountain. Convery (2006) describes a '*complex web of linkages between the living and the dead, the production system, economy and the landscape, the political and the cultural*' in Nhambita, in the GNP Buffer Zone (Convery, 2006), while Muala (2015) describes this for the wider Gorongosa landscape. Although the fieldwork revealed some people in the two villages visited for fieldwork to be originally from other places further afield, many are not, or from within the wider landscape, and have direct links to the landscape, such as Interviewee 5, '*Dingue-Dingue, there were the [Park] ranger post is. There is red bamboo* [bambu vermelho] *there – it's from my great-grandparents*'. This raises the question of what makes up 'local communities', particularly with respect to those who have settled more recently, or who will in the future, and what rights they have? Communities also do not necessarily prescribe to conservation worldviews although this must be a basic assumption in the GRP, and as well as the benefits on offer, in 'buying-in' to the idea, the presence of the GNP may be a perceived threat to their land tenure, especially given possible lack of support for the party in power which seems to be inextricably linked to 'government' (Diallo, 2015). Being in a position of having less power, arson, is a very accessible tool to cause harm, and may explain the setting of fires seen on the Mountain during fieldwork. Also, good transport links (the north-south main artery EN1 and the EN6, connecting to Beira (port) on the coast and to Zimbabwe, enable the transport of, and access to markets for (legal and illegal) goods such as timber, ivory and bushmeat, as well as fuelwood or agricultural products grown on the Mountain, provide a livelihood option.

The high-profile Gorongosa Restoration Project taking up the collaborative management of the GNP in 2008, has definitely attracted international attention and partnerships ranging from research (links with national and international scientists and institutions), media visibility (e.g. National Geographic), funds from and initiatives by NGOs, private donors and government agencies (e.g. USAID, the Government of Ireland), with great success of showcasing Gorongosa National Park and GRP as an example of good practice of achieving long-term conservation and development objectives. This poses a question which is outside the scope of this research, but is nonetheless valid: Is the GRP therefore shaping national conservation policy, providing state functions and possibly placing the state's sovereignty into question (Diallo, 2015), in a situation where market-based approaches to conservation need to be examined in the context of '*global inequalities, extractivism, and neoliberalism*' (Matusse, 2019)?

The state clearly benefits from delegating conservation efforts, which it may otherwise not be able to afford. The collaboration with GRP for the FRELIMO government, may also be in the view to strengthening its influence in a traditional RENAMO stronghold, given the conflict with RENAMO in recent years and the Gorongosa Mountain, declared part of GNP in 2010 (Diallo, 2015). Additionally, in the wildfire context, the Ministry for the Coordination of Environmental Affairs' national fire management plan assumes that '*[f]ires have always been set by rural communities in a controlled manner using knowledge passed down through generations. In recent times […] we see the country on fire due to uncontrolled fires, devastating natural resources that are the basis of the national economy*' and '*[t]he assumption for the success of the actions advocated […] is based on the predominant role played by communities and by local authorities* (MICOA, 2008)[22] which squarely places the responsibility of the control of wildfires and fire regimes on communities and local authorities, as well as some political pressure on the GNP to reduce fires (GoM, 2016).

[22] Translation from Portuguese by author

Ultimately, given these power relations and the context, the communities whose '*lives, land and livelihoods*' (Schuetze, 2015) are at stake have to play a central role in the protected area and land management, by sustainable development and enhancement of ecosystem functions and services, alleviating poverty, protecting livelihoods and political stability (Naughton-Treves et al., 2005; Brockington et al., 2008). Not only are these key factors to provide sustainable fire management, and fire regimes, these are also imperative in allowing for adaptation and mitigation strategies for climate change (IPCC, 2019).

8. Discussion and Conclusions

The aim of this research to examine drivers of burned areas in the context of Mozambique, a sub-/tropical African country with a particular set of physical, climatic, political and socio-economic characteristics, at national and local level, with a particular view to the role of protected areas. By using the quantitative results obtained from the analyses based on the various spatial datasets (Chapter 6), and the qualitative results from the fieldwork conducted in GNP (Chapter 7), the following section provides a discussion and linkage of the results, tries to provide answers for the research questions (listed again below) and ultimately to satisfy the aim of this research. Emerging lines of questions and pointers to further research are also provided. As the occurrence of fires was investigated on a pixel basis, the discussion maintains this description.

The research questions are as follows:

RQ1: What physical and human variables predict a pixel to be burned on a national scale in Mozambique during given time periods?

RQ2: Are there differences between the variables that predict burned outcome between protected areas and non-protected areas, specifically in the three case study sites?

RQ3: How does the qualitative data collected at local level (Gorongosa National Park) con-/diverge with results from the quantitative data analyses?

RQ4: Do the time periods with different climatic, political, natural disaster events, etc., characteristics show differences in the burned areas, at national/local level?

Between 23.6% and 28.6% of the pixels for the whole of Mozambique showed as burned (at least once) during a Fire Season (MJJASON) in the two time periods examined (2001-2006 and 2010-2015). With regards to RQ1, which refers to the physical and human drivers for a pixel to be burned on a national scale in Mozambique, the initial exploratory data analysis helps to visualise shifts between burned and unburned pixels per variable. Regarding the climatic variables, burned pixels generally received more rainfall in the preceding WS, less concurrent DS rainfall, and FS temperature was slightly higher, which is also reflected in the results for the regressions at national level. Archibald (2009, 2010) initially concluded that climate drivers are the main determinants of burned areas in southern Africa. Both elevation and slope are positively correlated with burned pixels and increasing slope has also been identified by others as the most important geospatial metric that can increase fire rate and spread (Shekede and al., 2019; Planas and Pastor, 2013). For the national level regression, elevation shows an very slight increase in the odds of a pixel being burned with every metre increase, of 0.02%.

In contrast, per degree increase in slope, decreases the odds, by 6.54% and 6.93%, for 2001-2006 and 2010-2015, respectively.

As to the human variables in both the exploratory data and the regression of matched data at national level, population density is similar for un-/burned pixels in line with Archibald's (2016) findings where burned area declines for values above 10 people km^{-2}. For the regression at national level, with every unit increase, the natural log of population density decreases the odds of a pixel being burned, by 14.05% and 10.88%, for the two time periods respectively. Distance to either road or settlement are slightly higher for burned pixels at the national extent in the exploratory data analysis. For the regression results at national level, however, the effect of every km increase of distance to settlement increases (by 2.09% and 2.07%, respectively), whilst distance to road slightly decreases for 2001-2006 (by 0.18%) and increases for 2010-2015 (by 2.20%).

Looking in more detail at the exploratory data, of the three largest and most relevant land cover classes, for 2001-2006 and 2010-2015 respectively, *Mosaic/Shrub/Grassland* shows the highest proportion of pixels burned (59.97% and 61.67%) followed by *Forest* (52.65% and 52.59%) and *Cropland* (39.86% and 37.74%). This is reflected in the results for the national regressions, where strong positive effects are shown by a move from *Cropland* to *Forest* (33.73% and 48.26% increase in odds), although not as much as *Mosaic/Shrub/Grassland*, which has the overall strongest positive effect (by 136.53% and 176.45%).

Forest pixels are expected to show lower burned proportions compared to other land cover classes, as increased tree cover reduces the area burned (Archibald et al., 2009). However the actual proportions burned, while still lower, are worryingly high and close to the proportions observed in *Mosaic/Shrub/Grassland,* as well as being higher than in *Cropland*. This may indicate an ominous shift to more forest land cover types being burned (IPCC, 2019; Zubkova et al., 2019) and potentially to changes in land cover and continuity, hinted at by Interviewee 3 who explained that '*fires used to be slow moving*' and '*you could see them from far because it was all forest*' around the GNP. Further research could include analyses using remotely sensed (seasonal) vegetation indices, such as the normalized difference vegetation index (NDVI) providing information on green plants as well as using a greater and more fine resolution of land cover classes, and possibly temporal incidence of fires, and could make results more informative, as to what type of vegetation is being burned and possibly for what purpose (e.g. early season burning in protected areas).

Proportions of burned *Cropland* class pixels are lowest among these three general land cover classes, as fragmented landscapes and lower fuel supply reduce the overall area burned and because of the size of a pixel (500 m) numerous ignitions at sub-pixel level resulting in small burn scars in a given month would only result in a signal of a single pixel being burned for a given month (Archibald, 2016). However, it could also indicate a lack of the use of fire in agricultural activity and/or only during a relatively short time of the year, in preparation for sowing just before the WS, and/or high rates of active and/or passive suppression. Further research examining seasonal or monthly data for areas of known land use and comparison to seasonal calendars of livelihood activities could provide answers as to how and when fire is employed for agricultural/livelihood activities and at what scale.

At the national extent, for pixels in non-protected areas the overall proportions burned in each time period are 55.59% and 56.00%, respectively, and higher for almost all extant PAs. This is an important initial outcome, in that at a national level, PA pixels were significantly more likely to burn than areas outside of PAs. Further addressing RQ2, examining the differences in predicted burned outcome between PA and non-PA for the two time periods, specifically in the three case study sites, results from the logistic regressions for extant PAs indicate that moving a pixel from non-protected (PA: 0) to within a protected area (PA:1), the odds for burning increase by 68.77% and 51.64%, which echo conclusions drawn by Archibald (2016) and Alvarado et al. (2018). The increased odds of a pixel being burned are also observed at the local level by the logistic regressions for NSR (by 140.53% and 84.61%) and GNP (by 496.28% and 263.61%) during the respective time periods. For LNP this is, however, not the case and a pixel being within that PA actually reduces the odds of it being burned (by 58.18%, in 2010-2015).

In using these quantitative results summarised in the previous paragraphs, and relating them to the results obtained from the qualitative methods, addressing RQ3 (How does the qualitative data collected at local level (Gorongosa National Park) con-/diverge with results from the quantitative data analyses?) is attempted. Although the fieldwork specifically relates to GNP, the relevance of the results for NSR and LNP are discussed.

The two types of fire ignition occurring in GNP were (i) early season burning administered by the Park administration as a protective measure (not including the Serra da Gorongosa component of the GNP, at least by 2012) and (ii) fires set within the GNP, or outside but moving into the GNP, either escaped or purposefully set for (possibly illegal) livelihood purposes (agricultural, hunting and poaching, logging, etc.), or sabotage/arson. Higher frequencies of burning observed in the south western parts of the GNP (around Lake Urema) where most activity occurs (tourism, administration, etc.) were due to early season burning (Stahl, 2020). This specific combination of fire management and local practice may partly explain why GNP pixels are more likely to be burned than pixels outside. It is also possible that the perception by GNP staff , that the increased burning is due to fires started by poachers hunting occurring mostly during the (later) dry season, and seemingly increasing with drier years (compounded in sequence) as harvests are poorer and poaching activity is increased. Apparently 2012 was a particularly bad year for poaching (and associated wildfires), as suggested by the rangers' extensive log of arrests of poachers and seizure of snares and traps, and other material associated with poaching, within the Park, and coincides with interviewees in the villages explaining that the previous 2-3 years had seen little rain and poor harvests. This source of ignition in the context of climate change and changing weather patterns, frequency and severity of droughts and associated changes in vegetation, may become more problematic within the PA, as vegetation burns more readily, with the additional pressure of increased poaching, and potential ignitions, when crops fail due to droughts. Successful re-stocking of wildlife (herbivores), such as in the GNP, may also provide a greater incentive for poaching. These factors and their interplay together with counter shifts to increased poaching, by the creation of alternative livelihood streams for communities and law enforcement effort will be important in the future.

As fuel continuity is increased within the PA, via limitations to landscape fragmentation and alteration of fuel load/type through reduced human activities (i.e. agriculture, harvesting of resources, etc.) are burned by each fire event will be larger, as well as fires being more intense (Archibald, 2016). The converse seems to be true for the PA buffer zone where in settled areas, 'uncontrolled fires' [*queimadas descontroladas*] stemming from ignitions for agricultural and other day-to-day activities, are probably not appropriate, unless they escape to surrounding less fragmented (including protected) areas, and areas burned tend to be smaller in size.

On Gorongosa Mountain, however, the situation seems to be different, where, it is assumed that higher forest cover allied with high humidity reduces fuel flammability and propensity to burn. Here the burned area per ignition, is lower (45.91% and 54.17%) than for the lower-lying GNP component around Lake Urema (85.28% and 79.07%). In the latter area fires were probably not started for poaching, but rather for agricultural purposes and possibly to voice discontent, i.e. sabotage/arson.

For the case of the NSR, proportions of the Reserve burned are the second highest for the PAs examined in this study covering both time periods (92.99% and 93.85%), and pixels were more likely to be burned within NSR than outside. The effect on the odds of a pixel being burned within the PA is not as strong as in the case of GNP, but this may simply mean that all pixels are more likely to burn in this area regardless of protection status. Nhongo et al. (2019) identified increased biomass (NDVI) availability during the fire season as the major determinant for fires in the NSR, which is reflected in the logistic regression result that moving a pixel from *Cropland* to *Mosaic/Shrub/Grassland* greatly increases the odds of the pixel being burned, followed in magnitude by a move into *Forest*, which may explain the large proportions of the NSR burned, but as to the source of ignitions and towards what end, these aspects remain unclear. The major illegal activities recorded in the NSR are poaching, logging and mining and criminal networks exist for the illegal trade and export of these commodities (Mbanze et al., 2019; WCS, 2020). Based on the data collected in GNP, it is quite likely these activities may also be causes of ignitions.

Another difference between the NSR and the other two case study PAs, is that it is currently in IUCN category VI (national designation: Special Reserve) which denotes a *Protected Area with Sustainable Use of Natural Resources*, as opposed to both GNP and LNP, which reside in IUCN Category II *National Park* (and also in the national designation), which assumes communities from inside the PAs were/are to be relocated (GoM, 2016). A large number of people live within the NSR, estimated to have increased from 25,000 to 60,000 between 2003 and 2018 (Booth & Dunham, 2014; Mbanze et al., 2019). Nhongo et al. (2019) have shown that distance to settlements within the NSR, does not necessarily increase or decrease the probability of fire occurrence. However, results in this study show a slight increase in the odds of a pixel being burned, and as population density increases, the odds of a pixel being burned decrease relative to non-PA pixels. Whether the inclusion of communities within a PA increases the proportion of the PA burned in the case of Mozambique, would need further investigation at local level.

In the case of LNP, fires play less of a role, reflected in the proportion of pixels burned being relatively low when compared to other PAs in Mozambique (38.15% in 2010-2015) and lower than in non-PA pixels. Here, the predominant vegetation structure (savannah) is generally determined by geology (Ribeiro et al., 2019). This aligns with the logistic regression results which show that the strongest impact on the odds of a pixel being burned follows a move to *Mosaic/Shrub/Grassland*. Limited fire management has been recommended in coordination with the adjoining Kruger National Park, in South Africa, which may also keep the proportion of burned pixels low due to lack of early season burning, unlike in the case of GNP (DNAC, 2003; Ribeiro et al., 2019).

At a national level, the IUCN Category II (National Park) PA pixels are the only PA pixels which showed lower proportions of burned pixels than non-PA (in 2010-2015) (Figure 6-14). These data suggest that these PAs may be more intensely/better managed (e.g. via active fire management and law enforcement) as they are a priority for the national conservation strategy. It is also worth noting that quite a few of the National Parks (Zinave NP, Limpopo NP, Banhine NP) lie in the drier southern half of Mozambique, where fires possibly play less of a role.

Nationally, it is clear that pixels in PAs are more likely to be burned, but it is important to consider differences that exist in burning trends at local PA level. Further consideration of fire behaviour (i.e. seasonality, intensity, frequency, ignitions, spread, identification of single fires, etc.) would expand current understanding of fire regimes and the role of PAs, in a regional and local context and would go towards deepening knowledge. Key characteristics of a fire regime (i.e. seasonality, timing, intensity, etc.) also affect GHG and particulate emissions of fires (Archibald, 2016), as well as interactions with ecosystems and habitats, grazing and interactions with browsing pressures, particularly by elephants in NSR and LNP, and increased stocks of herbivores in GNP, and habitats within each PA. In addition, there are other considerations, such as maintenance of water quality and human safety (IPCC, 2019).

As noted in the results from GNP in the qualitative results (Chapter 6), extant fire regimes are partly taken to be symptomatic of the historic/current alignment of the objectives, relationships and interactions between the stakeholders/actors of the PAs (‘communities’, ‘the park’, ‘government’, and also external players and factors) including recognition/respect (of contributions and values), power/control (of whose priorities matter most) and trust/closeness. For all three PAs which were looked at these dynamics play out in issues around land tenure, human displacement, HWC and illegal activities (mainly poaching but also logging and mining), underpinned by poverty, weak governance, corruption, political instability and conflict, and climate change. Tacheba et al. (2009) also found that factors such as ethnicity and literacy seem to play a part in determining fire regimes, which could be an important consideration in the Mozambican context. Aldersley et al. (2011) have found GDP having a strong link to habitat fragmentation and therefore to the characteristics of regional fire regimes.

The government’s simple narrative of the ‘wildfire problem’ being the result of some kind of loss of generational knowledge (MICOA, 2008), and placing the responsibility of ‘controlled’ fire regimes on communities and local authorities (MICOA, 2008), is unhelpful, particularly where pixels in PAs, where communities have/had their rights and/or access restricted, are more likely to be burned than outside of PAs, where ‘communities’ are physically delineated and cultivated areas (*Cropland* pixels) burn proportionally less.

In all three case studies, communities have had their rights restricted by the presence of the PA. They have no right to receive part of the 20% of the PA revenues, to use the land, access to services and development (health, education, etc.), increased human-wildlife conflict, hunting ban, etc. People have a perceived right to stay, due to ancestral/customary rights, long-term tenure, in the context of a history of competing land tenure claims, of displacement of people and ‘re-configurations of communities’ due to colonisation, political instability, conflict and natural disasters. This does raise a tangential question as to what makes up a ‘community’ given the movement of people, and the rights to access land in the context of, for example, climate change and conflict in the future? Also, how is/will the creation and enlargement of TFCAs (in the cases LNP and GNP) affect communities included in these in terms of land tenure and rights?

In the case of the establishment of the LNP, the mainly pastoral communities, already with histories of relocation and economic migration, were to be resettled 'voluntarily' (Milgroom and Spierenburg, 2008). According to Milgroom and Spierenburg (2008) and Notelid and Ekblom (2021), donors, the government and the park (part of a TFCA) were using a narrative of resettlement as an 'attractive' option by effectively increasing Human-Wildlife Conflict (HWC) for communities in LNP, by relieving the high density elephant population from adjoining Kruger National Park which increased crop raiding, increasing numbers of lions killing cattle, and hippopotamus-human conflict at water points. Additionally, increased rhinoceros poaching has provided another 'reason' for the relocation of communities from the LNP and its TFCA (Massé, 2016). In a situation such as this, where resettlement is done with limited regard to: the socio-cultural cost (Strong, 2019), the socio-economic cost (e.g. the number of cattle herds can be larger and safer inside the LNP than in areas into which communities are resettled), and where livelihoods are interfered with (Milgroom and Spierenburg, 2008), increased vulnerability and decreased resilience of the communities is achieved (Lunstrum, 2016). The resulting perceptions of the 'park', 'government' and 'donors', and possibly conservation strategies, by the communities, may also not favourable. And although 'fires' may be less relevant for LNP, there are lessons to be learned for other (future) protected areas.

In NSR, large-scale illegal poaching for elephant ivory has increased since 2012 and has become 'unmanageable' for the NSR enforcement (WCS, 2020) given the massive size and difficult terrain of the NSR, limited manpower and resources, and the porous border with Tanzania for both elephants and poachers. Communities' passive encouragement of elephant poaching (by outsiders) may also play a role, for income and reduction of HWC. However, purely increasing enforcement efforts to stop poaching would also not be the solution, without addressing underlying factors such as poverty, lack of compensation for increased HWC, existing criminal networks for ivory, weak governance and widespread corruption (WCS, 2020). Also, if protected areas are successfully maintaining/increasing wildlife stocks available to poaching, this potentially increases ignitions associated with this activity. Higher densities of wildlife may also increase HWC, incentives for poaching, especially with existent criminal trade networks. These are questions which will need to be considered as PAs/TFCAs are established in order to increase protection of land, particularly if rights of communities are curtailed.

'Communities' also do not necessarily prescribe to conservation worldviews to which the 'parks' prescribe, as well as the benefits on offer in 'buying-in' to the idea. The presence of a PA may be a perceived threat to communities' land tenure, especially given possible lack of support for the party in power which seems to be inextricably linked to 'government' (Diallo, 2015). Nonetheless, the state clearly benefits from delegating conservation efforts, which it may otherwise not be able to afford and, by association, the party in power may also be gaining more control/influence in areas of the country where support for the party is weak (Diallo, 2015). This may be/have been an issue in and around GNP, especially on Gorongosa Mountain (Schuetze, 2015), where the opposition had bases during the civil war and the leader of RENAMO went into hiding in 2012 and re-engaged in a low-level 'war'. The division of 'park' and 'government' (i.e. the party in power) may not always be clear, and sabotage, for example arson or poaching within a protected area, may be a way to voice discontent.

The lack of support for the government/party in power may also be an issue in the more recent conflict in the north of the country, the so-called jihadist insurgency in Cabo Delgado. Cabo Delgado province has been neglected in terms of development (for more details see dos Santos, 2020) and although the insurgency seems to have been led by outsiders, some leaders and most recruits are Mozambicans who responded to the indoctrination provided stirring up resentment of the situation the people found themselves in, i.e. poverty, police violence, corruption, a self-serving government and politicians (e.g. 'hidden debt', marginalisation from LNG projects, etc.), with promises of provision of social justice and basic necessities (Feijó, 2021) whilst the actual government was initially untransparent and disorganised in its response. On the surface this situation may seem different to the RENAMO conflict, but they share some similarities in factors which enable them including poverty and reliance on natural resources, which may signal as problematic fire regimes.

With international military help, the situation in Cabo Delgado may be 'under control' at the time of writing, but the enabling factors are still present. People have been killed and displaced, infrastructure, towns, and villages destroyed, crops lost, etc., LNG activities abandoned or reduced (also in view of post-COP26 reduction of extraction of fossil fuels (?)). Tourism has also reduced due to the global Covid-19 pandemic. Could tapping into existing networks of (illegal) mining, logging and ivory trading as potential income streams for people (and the insurgents) be an option, all activities which have been linked to ignitions of fires especially in protected areas? Feijó's (2021) recommendations towards stability in the area include: socio-economic development by income generation through livelihood diversification, provision and quality of public services (health, education); the demonstration of the morality of the state and belief in justice and human rights, and finally, increased citizen participation in governance through peaceful means. These suggestions, again, echo some of the conclusions reached above for conducive interactions between stakeholders/actors in the PA case studies and therefore for predictable fire regimes.

In the case of GNP, the successful high-profile Gorongosa Restoration Project, aiming to achieve long-term conservation and development objectives, has taken up collaborative management with great influxes of effort, global attention and interest, scientific study, direct funding and associated projects. This poses a question which is outside the scope of this research, but is nonetheless valid: Is the GRP therefore shaping national conservation policy, providing state functions and possibly placing the state's sovereignty into question (Diallo, 2015) in a situation where market-based approaches to conservation need to be examined in the context of '*global inequalities, extractivism, and neoliberalism*' (Matusse, 2019)? Also, what about the other protected areas, landscapes or communities, within Mozambique which do not benefit from the same kind of resources being made available? Or which benefit from management with a different approach to conservation and development, how are these aligned nationally? Further understanding of how these relationships, and therefore fire regimes, have changed with the success of the GRP and the inclusion of Gorongosa Mountain in the protected area would be interesting in the case of GNP. Any follow-up data collection in the area was unfortunately stifled in the context of this research due to initially political instability and then Covid-19.

Ideally, wholesome relationships between the communities, PA management, government (at different levels), the party in power, external stakeholders, and their defined roles and responsibilities, are crucial for any sustainable set of fire regimes at a national scale and a PA level (Givá and Raitio, 2017). In my opinion, for these relationships and interactions to be positive and conducive they must foster mutual respect, empowerment and trust, maintaining the communities whose '*lives, land and livelihoods*' (Schuetze, 2015) are at the centre of the protected area and land management, with an overall emphasis on sustainable human development benefitting the communities involved, by reducing their reliance on low productivity, mostly rain-fed, agriculture through livelihood diversification and sustainable livelihoods reducing poverty, fair and transparent access to land, provision and quality of services, political stability, strengthened institutional capacity, and aligned national policies and legislation (Naughton-Treves et al., 2005; Brockington et al., 2008). These need to be rooted in good understanding of the national and local contexts and be able to offset the costs borne by the communities through the creation/existence of a PA (Booth & Dunham, 2014, Mbanze et al., 2019). Only in this way can conservation or any other objective, be an additional, albeit necessary, priority.

In summary, the challenge lies in achieving compromises in terms of needs, expectations, objectives, and responsibility, to be struck between the stakeholders/actors, with communities being at the centre of this, with a balance of narratives of conservation and development, and in the view that this must be adaptive, context-specific, in shifting local, national and global contexts (Massé, 2016; Givá and Raitio, 2017). This will be crucial in providing resilience and reducing vulnerability of communities, and adaptation and mitigation strategies, in the face of population increase, effects of climate change and increased extreme weather events, and allocation of land for other purposes (REDD+ projects, PAs, TCFAs, mineral extraction, post-COP26 alternatives to coal/gas, etc.) as well as ensuring the longevity and financing of PAs and their role in providing ecosystem services, and their regional and global roles (Gill et al., 2013; Lunstrum, 2016; IPCC, 2019; Mbanze et al., 2019).

Although it is not directly observable in this study, this research give some indication towards addressing RQ4, in the sense that ultimately fire regimes, in the context of Mozambique and consideration of protected areas, apart from being determined by the physical factors (climate, weather, ecosystems, habitats, geology, topography, etc.), changes within these systems are largely due to the needs, objectives and motivation of the stakeholders involved at different levels, local, regional and global. It is however difficult to attribute any such direct influence on burned outcomes of pixels. Shifts in the variables for un-/burned pixels are similar for the two time periods, similarly, the variables in the logistic regressions show much overlap at the national extent for the two time periods. At local level the influences of factors may show a signal, for example, in GNP (excluding Gorongosa Mountain) a reduction of proportion of pixels burned, although for what reason is undetermined. Serra da Gorongosa, which was not included for the logistic regressions, does show an increased proportion of pixels burned in 2010-2015, which may possibly have to do with the political situation, resentment due to RENAMO support and/or the Mountain being declared as part of GNP and/or simply increased activities on the Mountain, possibly due to poor rain and harvests in the preceding 2-3 years.

Further research into the roles of teleconnections, such as compounded effects of ENSO and SIOD events (Hoell, 2017) and associated weather patterns in the WS and DS/FS, as well as impacts of landfalling cyclones providing increased rainfall could help answer the last RQ at a subnational level. This may also be able to be done through an analysis protected areas of the narratives by the different stakeholders/actors with regards to fire for different PAs, as well as an increased ability to differentiate between controlled fires and unplanned fires in a PA management context, and information on the coincidence of fires and evidence of poaching (and illegal logging, mining, etc.) activities.

Data References

Africa GeoPortal, 2018. Africa Countries (Generalized). Esri-Africa. https://services8.arcgis.com/zNrTBuYXV2f35M0U/arcgis/rest/services/Africa_Countries/FeatureServer [Accessed 05 Dec 2019]

CENACARTA, 2000a. Cidades e Vilas de Moçambique (Pontos), base Topográfica Simplificada, digitalização à escala 1:250 000, Version 2000.

CENACARTA, 2000b. Estradas e Caminhos de Ferro de Moçambique (Linhas), base Topográfica Simplificada, digitalização à escala 1:250 000, Version 2000.

CENACARTA, 2000c. Limites administrativos de Moçambique (Polígonos), base Topográfica Simplificada, digitalização à escala 1:250 000, Version 2000.

CIESIN (Center for International Earth Science Information Network) - Columbia University, 2018. Gridded Population of the World, Version 4 (GPWv4): Population Density Adjusted to Match 2015 Revision UN WPP Country Totals, Revision 11. Palisades, NY: NASA SEDAC (Socioeconomic Data and Applications Center). https://doi.org/10.7927/H4F47M65. [Accessed 10 Jan 2020]

CIESIN (Center for International Earth Science Information Network) - Columbia University, and ITOS (Information Technology Outreach Services) - University of Georgia, 2013. Global Roads Open Access Data Set, Version 1 (gROADSv1). Palisades, NY: NASA SEDAC (Socioeconomic Data and Applications Center). https://doi.org/10.7927/H4VD6WCT. [Accessed 10 Jan 2020]

ESA, 2017. Land Cover CCI Product User Guide Version 2. Technical Report. maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf

ESA Globcover 2005 Project led by MEDIAS-France/POSTEL, 2005. Global Land Cover Product (2005-06). ESA and MEDIAS-France/POSTEL. http://due.esrin.esa.int/page_globcover.php

ESA GlobCover 2009 Project, 2010. GlobCover 2009 (Global Land Cover Map). ESA and Université Catholique de Louvain. http://due.esrin.esa.int/page_globcover.php

Friedl, MA, D Sulla-Menashe, B Tan, A Schneider, N Ramankutty, A Sibley and X Huang, 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *Remote Sensing of Environment*, 114: 168-182.

INAM (Instituto Nacional de Meteorologia), 2001-2006a. Temperature: Dailies (max/min) for Mocimboa, Pemba, Montepuez, Lichinga, Cuamba, Lumbo, Nampula, Tete, Quelimane, Chimoio, Beira

(Aeroporto), Vilanculos, Inhambane, Chokwe, Maputo (Aeroporto). Instituto Nacional de Meteorologia (INAM), Maputo.

INAM (Instituto Nacional de Meteorologia), 2001-2006b. Precipitation: Dailies (total) for Mocimboa, Pemba, Montepuez, Lichinga, Cuamba, Lumbo, Nampula, Tete, Quelimane, Chimoio, Beira (Aeroporto), Vilanculos, Inhambane, Chokwe, Maputo (Aeroporto). Instituto Nacional de Meteorologia (INAM), Maputo.

INAM (Instituto Nacional de Meteorologia), 2010-2015a. Temperature: Monthlies (mean) for Mocimboa, Pemba, Montepuez, Lichinga, Cuamba, Lumbo, Nampula, Tete, Quelimane, Chimoio, Beira (Aeroporto), Vilanculos, Inhambane, Chokwe, Maputo (Aeroporto). Instituto Nacional de Meteorologia (INAM), Maputo.

INAM (Instituto Nacional de Meteorologia), 2010-2015b. Precipitation: Monthlies (total) for Mocimboa, Pemba, Montepuez, Lichinga, Cuamba, Lumbo, Nampula, Tete, Quelimane, Chimoio, Beira (Aeroporto), Vilanculos, Inhambane, Chokwe, Maputo (Aeroporto). Instituto Nacional de Meteorologia (INAM), Maputo.

Jarvis, A., H.I. Reuter, A. Nelson, E. Guevara, 2008. Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database. http://srtm.csi.cgiar.org [Accessed 5 Apr 2019]

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., Kassem, K. R. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. *Bioscience* 51(11): 933-938.

TRMM (Tropical Rainfall Measuring Mission), 2011. TRMM (TMPA/3B43) Rainfall Estimate L3 1 month 0.25 degree x 0.25 degree V7. Greenbelt, MD: GES DISC (Goddard Earth Sciences Data and Information Services Center). [Accessed 30 Nov 2019]

UNEP-WCMC and IUCN, 2020. Protected Planet: The World Database on Protected Areas (WDPA) (November 2020). Cambridge, UK: UNEP-WCMC and IUCN. www.protectedplanet.net [Accessed 30 Nov 2020]

References

Aldersley, A, SJ Murray and SE Cornell, 2011. Global and regional analysis of climate and human drivers of wildfire. *Science of The Total Environment* 409(18), 3472-3481. DOI: 10.1016/j.scitotenv.2011.05.032

Alvarado, ST, TSF Silva, and S Archibald, 2018. Management impacts on fire occurrence: A comparison of fire regimes of African and South American tropical savannas in different protected areas. *Journal of Environmental Management*, 218: 79-87.

ANAC, 2015. *Plano Estratégico Administração Nacional das Áreas de Conservação 2015-2024*. Maputo: MITADER.

ANAC, 2020. Niassa-Selous. http://www.anac.gov.mz/en/parques-e-reservas/ [Accessed 30/9/2020]

ARCGIS, 2019. https://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-kriging-works.htm

Archibald, S, A Nickless, N Govender, RJ Scholes, and V Lehsten, 2010. Climate and the inter-annual variability of fire in southern Africa: a meta-analysis using long-term field data and satellite-derived burnt area data. *Global Ecology and Biogeography*, 19:794-809.

Archibald, S, DP Roy, BW van Wilgen, and RJ Scholes, 2009. What limits fire? An examination of burnt area in Southern Africa. *Global Change Biology*, 15: 613-630.

Artés T, D Oom, D de Rigo, T Houston Durrant, P Maianti, G Libertà and J San-Miguel-Ayanz, 2019. A global wildfire dataset for the analysis of fire regimes and fire behaviour. *Scientific Data,* 6(296). DOI: 10.1038/s41597-019-0312-2

Austin, 2007. Propensity-score matching in the cardiovascular surgery literature from 2004 to 2006: A systematic review and suggestions for improvement. *The Journal of Thoracic and Cardiovascular Surgery,* 134: 1128-1135. DOI:10.1016/j.jtcvs.2007.07.021

Bai, H, and MH Clark, 2019. Covariate Evaluation and Causal Effect Estimation. In: *Propensity Score Methods and Application*. Thousand Oaks: SAGE Publications, Inc, 65-88. DOI: 10.4135/9781071814253

Behera, S, and T Yamagata, 2001. Subtropical SST dipole events in the Southern Indian Ocean. *Geophysical Research Letters*, 28(2) DOI:10.1029/2000GL011451

Beilfuss, R, P Dutton and D Moore, 2001. Land Cover Change, Zambezi Delta. In: J Timberlake (ed.), *Zambezi Basin Wetlands Volume III*. Bulawayo: Biodiversity Foundation for Africa, and Harare: The

Zambezi Society: 31-106. http://www.biodiversityfoundation.org/documents/BFA%20No.8_Wetlands_v3_Land%20Use.pdf

Belcher, CM (ed.) 2013. *Fire Phenomena and the Earth System: An Interdisciplinary Guide to Fire Science*. Hoboken: John Wiley and Sons. ProQuest Ebook Central. [26 Feb 2020].

Biofund, 2020. Conservation Areas of Mozambique. http://www.biofund.org.mz/en/ [Accessed 30 Sept 2020]

Booth, VR, and KM Dunham, 2014. Elephant poaching in Niassa Reserve, Mozambique: population impact revealed by combined survey trends for live elephants and carcasses. *Oryx* 50(10): 94-103. DOI:10.1017/S0030605314000568

Brockington, D, R Duffy and J Igoe, 2008. Nature Unbound: Conservation, Capitalism and the Future of Protected Areas. London: Earthscan.

Chinamatira, L , S Mtetwa and G Nyamadzawo, 2016. Causes of wildland fires, associated socioeconomic impacts and challenges with policing, in Chakari resettlement area, Kadoma, Zimbabwe. *Fire Science Reviews,* 5(1). DOI: 10.1186/s40038-016-0010-5

CIESIN, 2013. Methods Used in the Development of the Global Roads Open Access Data Set (gROADS), version 1. Palisades, NY: NASA SEDAC:.

Chu, J-E,K-J Ha, J-Y Lee, B Wang, B-H Kim and CE Chung, 2014. Future change of the Indian Ocean basin-wide and dipole modes in the CMIP5. *Climate Dynamics,* 43: 535-551. DOI: 10.1007/s00382-013-2002-7

Cilliers, P (ed.) 1998. *Complexity and Postmodernism : Understanding Complex Systems*. Routledge. ProQuest Ebook Central. http://ebookcentral.proquest.com/lib/sheffield/detail.action?docID=165109 [Accessed 25 Feb 2020].

Cochrane, M, and KC Ryan, 2009. Fire and fire ecology: Concepts and principles. In: Cochrane, M, (ed.), *Tropical Fire Ecology: Climate Change, Land Use, and Ecosystem Dynamics*. Chichester: Springer/Praxis Publishing.

Convery, I, 2006. Lifescapes & Governance: The Régulo System in Central Mozambique. *Review of African Political Economy*, 109: 449-466.

Corbin, J, and A Strauss, 1990. Grounded Theory Research: Procedures, Canons, and Evaluative Criteria. *Qualitative Sociology*, 13(1).

Cracknell, AP, 1998. Synergy in remote sensing-what's in a pixel? *International Journal of Remote Sensing*, 19(11): 2025-2047. DOI: 10.1080/014311698214848

Da Silva, NTC, UF Paleo, and JAF Neto, 2019. Conflicting Discourses on Wildfire Risk and the Role of Local Media in the Amazonian and Temperate Forests. *International Journal of Disaster Risk Science*, 10: 529-543. DOI: 10.1007/s13753-019-00243-z

Daskin, JH, M Stalmans and RM Pringle, 2016. Ecological legacies of civil war: 35-year increase in savanna tree cover following wholesale large-mammal declines. *Journal of Ecology,* 104: 79-89. DOI: 10.1111/1365-2745.12483

Davies, GM, L Pollard and MD Mwenda, 2010. Perceptions of Land-Degradation, Forest Restoration and Fire Management: A Case Study from Malawi. *Land Degradation Development*, 21: 546-556. DOI: 10.1002/ldr.995

Dennis, RA, J Mayer, G Applegate, U Chokkalingam, CJ Pierce Colfer, I Kurniawan, H Lachowski, P Maus, R Pandu Permana, Y Ruchiat, F Stolle, Suyanto, and TP Tomich, 2005. Fire, People and Pixels: Linking Social Science and Remote Sensing to Understand Underlying Causes and Impacts of Fires in Indonesia. *Human Ecology*, 33(4): 465-504. DOI: 10.1007/s10745-005-5156-z

Devisscher, T, E Boyd, and Y Malhi. 2016. Anticipating future risk in social-ecological systems using fuzzy cognitive mapping: the case of wildfire in the Chiquitania, Bolivia. *Ecology and Society* 21(4): 18. DOI: 10.5751/ES-08599-210418

Diallo, RN, 2015. Conservation philanthropy in Gorongosa National Park, Mozambique. *Conservation and Society* 13(2): 119-128.

Dietsche, E, and AM Esteves, 2018. What are the prospects for Mozambique to diversify its economy on the back of 'local content'? WIDER Working Paper 2018/113. UNU-WIDER. https://www.wider.unu.edu/sites/default/files/Publications/Working-paper/PDF/wp2018-113.pdf [Accessed 29 Sept 2020]

Dlamini, WM, 2010. A Bayesian belief network analysis of factors influencing wildfire occurrence in Swaziland. *Environmental Modelling and Software,* 25: 199-208.

DNAC (Direcção Nacional de Àreas de Conservação), 2003. *Parque Nacional do Limpopo- Plano de Maneio e Desenvolvimento*. Maputo: MITUR.

Driscoll, DA, DB Lindenmayer, AF Bennett, M Bode, RA Bradstock, G J Cary, M F Clarke, N Dexter, R Fensham, G Friend, M Gill, S James, G Kay, DA Keith, C MacGregor, J Russell-Smith, D Salt, JEM Watson, RJ Williams, A York, 2010. Fire management for biodiversity conservation: Key research questions and our capacity to answer them. *Biological Conservation*, 143(9): 1928-1939. DOI:10.1016/j.biocon.2010.05.026

Dos Santos, FA, 2020. War in resource-rich northern Mozambique – Six scenarios. Bergen: Chr. Michelsen Institute (CMI Insight 2020:02).

Editoria Nacional de Moçambique, 2009. Atlas de Moçambique. Maputo, Mozambique: Publishers Limited:.

Ekblom, A, and L Gillson, 2010. Fire history and fire ecology of Northern Kruger (KNP) and Limpopo National Park (PNL), southern Africa. *The Holocene*, 20 (7): 1063-1077.

Eriksen, C, 2007. Why do they burn the 'bush'? Fire, rural livelihoods, and conservation in Zambia. *The Geographical Journal*, 173(3): 242-256.

Eriksen, C, N Gill and R Bradstock, 2011. Trial by Fire: natural hazards, mixed-methods and cultural research. *Australian Geographer*, 42(1): 19-40. DOI: 10.1080/00049182.2011.546317

ESRI, 2019. ArcMap (version 10.7.1). ESRI inc. https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview

FAO, 2006. Global Forest Resources Assessment 2005 – Report on fires in the Sub-Saharan Africa Region. Fire Management Working Paper 9, www.fao.org/forestry/site/fire-alerts/en [Accessed 16 Nov 2010]

FAO, 2020. REDD+ Reducing Emissions from Deforestation and Forest Degradation. http://www.fao.org/redd/overview/en/ [Accessed 21 Oct 2020]

Feijó, J, 2021. Caracterização e organização social dos machababos a partir dos discursos de mulheres raptadas. (Working Paper). Observatório do Meio Rural. www.omrmz.org

Freeborn, PH, MA Cochrane and MJ Wooster, 2014. A Decade Long, Multi-Scale Map Comparison of Fire Regime Parameters Derived from Three Publically Available Satellite-Based Fire Products: A Case Study in the Central African Republic. *Remote Sensing of Environment*, 6(5): 4061-4089.

Fuller, C, S Ondeia, BW Brook, JC Buettel, 2019. First, do no harm: A systematic review of deforestation spillovers from protected areas. *Global Ecology and Conservation*, 18. DOI: 10.1016/j.gecco.2019.e00591

Fusari, A, and GM Carpaneto, 2006. Subsistence hunting and conservation issues in the game reserve of Gile, Mozambique. *Biodiversity and Conservation*, 15: 2477-2495.

Gandiwa, E, and S Kativu, 2009. Influence of fire frequency on Colophospermum mopane and Combretum apiculatum woodland structure and composition in northern Gonarezhou National Park, Zimbabwe. *Koedoe*, 51(1): 36-48. DOI: 10.4102/koedoe.v51i1.685

Gill, AM, SL Stephens and GJ Cary, 2013. The worldwide ''wildfire'' problem. *Ecological Applications* 23(2): 438-454.

Givá, N, & K Raitio, 2017. 'Parks with People' in Mozambique: Community Dynamic Responses to Human–Elephant Conflict at Limpopo National Park. *Journal of Southern African Studies*, (43)6: 1199-1214. DOI: 10.1080/03057070.2017.1374810

Glaser, B, and A Strauss, 1967. *The Discovery of Grounded Theory*. Aldine Publishing Company: Hawthorne, NY.

Greifer, N, 2020a. Assessing Balance (R vignette("assessing-balance")), 15/12/2020. https://cran.r-project.org/web/packages/MatchIt/vignettes/assessing-balance.html [Accessed 12 Mar 2021]

Greifer, N, 2020b. Estimating Effects After Matching (R vignette("estimating-effects")), 15/12/2020. https://cran.r-project.org/web/packages/MatchIt/vignettes/estimating-effects.html [Accessed 12 Mar 2021]

Greifer, N, 2020c. Matching Methods (R vignette("matching-methods")), 15/12/2020. https://cran.r-project.org/web/packages/MatchIt/vignettes/matching-methods.html [Accessed 12 Mar 2021]

Greifer, N, 2020d. MatchIt: Getting Started (R vignette("MatchIt")), 15/12/2020. https://cran.r-project.org/web/packages/MatchIt/vignettes/MatchIt.html [Accessed 12 Mar 2021]

Govender, N, WSW Trollope, and BW van Wilgen, 2006. The effect of fire season, fire frequency, rainfall and management on fire intensity in savanna vegetation in South Africa. *Journal of Applied Ecology*, 43: 748-758.

GoM (Government of Mozambique), 1997. Boletim da República. I Série, Número 40, 3º Suplemento, Terça-feira, 7 de Outubro de 1997. República de Moçambique.

GoM (Government of Mozambique), 2016. Boletim da República. I Série, Número 88, Segunda-feira, 25 de Julho de 2016. República de Moçambique.

Gorongosa, 2020. Our Team. https://gorongosa.org/our-team/ [Accessed 01 Mar 2021]

Hartwig, F, and BE Dearling, 1979. *Exploratory Data Analysis*. London: SAGE. DOI: 10.4135/9781412984232

Herrero, HV, J Southworth, E Bunting and B Child, 2017. Using repeat photography to observe vegetation change over time in Gorongosa National Park. *African Studies Quarterly*, 17(2):65-82.

Herron-Thorpe, FL, GH Mount, LK Emmons, BK Lamb, DA Jaffe, NL Wigder, SH Chung, R Zhang, MD Woelfle, and JK Vaughan, 2014. Air quality simulations of wildfires in the Pacific Northwest evaluated with surface and satellite observations during the summers of 2007 and 2008. *Atmospheric Chemistry and Physics*, 14: 12533-12551.

Ho DE, K Imai, G King and EA Stuart, 2011. MatchIt: Nonparametric Preprocessing for Parametric Causal Inference. *Journal of Statistical Software*, 42(8): 1-28. https://www.jstatsoft.org/v42/i08/

Hoell, A, AE Gaughan, S Shukla and T Magadzire, 2017. The Hydrological Effects of Synchronous El Niño-Southern Oscillation and Subtropical Indian Ocean Dipole Events over Southern Africa. *Journal of Hydrometeorology*, 18: 2407-2424. DOI: 10.1175/JHM-D-16-0294.1

Hoffmann, AA, J-E Parry, C Cuambe, D Kwesha, and W Zhakata, 2009. Chapter 8 Climate Change and wildland fires in Mozambique. In: Cochrane, Mark (ed.). *Tropical Fire Ecology: Climate Change, Land Use, and Ecosystem Dynamics*. Chichester: Springer/Praxis Publishing, 227-259.

Huffman and Pendergrass, 2017

INE, 2020. Estatísticas. http://www.ine.gov.mz/estatisticas [Accessed 23 Sept 2020]

IPCC, 2019. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [PR Shukla, J Skea, E Calvo Buendia, V Masson-Delmotte, H-O Pörtner, DC Roberts, P Zhai, R Slade, S Connors, R van Diemen, M Ferrat, E Haughey, S Luz, S Neogi, M Pathak, J Petzold, J Portugal Pereira, P Vyas, E Huntley, K Kissick, M Belkacemi, J Malley, (eds.)]. In press. https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf [Accessed 06 Apr 2021]

Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT). http://srtm.csi.cgiar.org.

Justice, CO, L Giglio, L Boschetti, D Roy, I Csiszar, J Morisette, and Y Kaufman, 2006. MODIS Fire Products. MODIS Algorithm Technical Background Document: Fires.

Justice, CO, L Giglio, S Korontzi, J Owens, JT Morisette, D Roy, J Descloitres, S Alleaume, F Petitcolin, Y Kaufman. 2002. The MODIS fire products. *Remote Sensing of Environment*, 83: 244-262.

Kroepsch, A, EA Koebele, DA Crow, J Berggren, J Huda and LA Lawhon, 2018. Remembering the Past, Anticipating the Future: Community Learning and Adaptation Discourse in Media Commemorations of Catastrophic Wildfires in Colorado. *Environmental Communication* 12(1): 132-147. DOI:10.1080/17524032.2017.1371053

Kuhn, M, J Wing, S Weston, A Williams, C Keefer, A Engelhardt, T Cooper, Z Mayer, B Kenkel, R Core Team, M Benesty, 2020. Classification and Regression Training: Package ‘caret’, version 6.0-86. https://cran.r-project.org/web/packages/caret/caret.pdf [Accessed 02 Apr 2021]

Lehsten, V, P Harmand, I Palumbo, A Arneth, 2010. Modelling burned area in Africa. *Biogeosciences*, 7: 3199-3214. DOI:10.5194/bg-7-3199-2010

Liu, Y, J Stanturf and S Goodrick, 2010. Trends in global wildfire potential in a changing climate. Forest *Ecology Managament*, 259: 685-697. DOI: 10.1016/J.FORECO.2009.09.002

Lunstrum, E, 2016.Green grabs, land grabs and the spatiality of displacement: eviction from Mozambique’s Limpopo National Park. *Area*, 48(2): 142–152. DOI: 10.1111/area.12121

Luo, Z, JC Gardiner and CJ Bradley, 2010. Applying Propensity Score Methods in Medical Research: Pitfalls and Prospects. *Medical Care Research and Review* 67(5): 528-554. DOI:10.1177/1077558710361486

Mangiafico, S, 2021. Functions to Support Extension Education Program Evaluation: Package ‘rcompanion’, version 2.4.0. https://cran.r-project.org/web/packages/rcompanion/rcompanion.pdf [Accessed 02 Apr 2021]

Marshall, S, J Taylor, RJ Oglesby, JW Larson, and DJ Erickson, 1996. Climatic effects of biomass burning. *Environmental Software*, 11 (1-3): 53-58.

Massé, F, 2016. The political ecology of human-wildlife conflict: Producing wilderness, insecurity, and displacement in the Limpopo National Park. *Conservation and Society*, 14(12). DOI:10.4103/0972-4923.186331

Matimbe, DA, 2015. Participação comunitária na gestão de queimadas descontroladas no Posto Administrativo de Mapinhane - Distrito de Vilankulo. Licenciatura thesis. Departamento de Sociologia Rural, Eduardo Mondlane University.

Matusse, 2019. Laws, Parks, Reserves, and Local Peoples: A Brief Historical Analysis of Conservation Legislation in Mozambique. *Conservation and Society*, 17(1): 15-25. DOI:10.4103/cs.cs_17_40

Mbanze, AA, NS Ribeiro, C Vieira da Silva and J Lima Santos, 2019. An expert-based approach to assess the potential for local people engagement in nature conservation: The case study of the Niassa National Reserve in Mozambique. *Journal for Nature Conservation* 52. DOI: 10.1016/j.jnc.2019.125759

McGill, R, JW Tukey and WA Larsen, 1978. Variations of box plots. *The American Statistician,* 32: 12-16.

Meyer, D, A Zeilei and K Hornik, 2006. The Strucplot Framework: Visualizing Multi-way Contingency Tables with vcd. *Journal of Statistical Software* 17(i03). DOI: 10.18637/jss.v017.i03

MICOA, 2008. Plano de acção para a prevenção e controlo às queimadas descontroladas 2008-2018. Ministry for the Coordination of Environmental Affairs (MICOA): Maputo.

MICOA, 2009. Fourth National Report on Implementation of the Convention on Biological Diversity in Mozambique. Ministry for the Coordination of Environmental Affairs (MICOA): Maputo.

MICOA, 2014. Fifth National Report on the Implementation of Convention on Biological Diversity in Mozambique. Ministry for the Coordination of Environmental Affairs (MICOA): Maputo.

Milgroom, J, and M Spierenburg, 2008. Induced volition: Resettlement from the Limpopo National Park, Mozambique. *Journal of Contemporary African Studies*, 26(4): 435-448. DOI: 10.1080/02589000802482021

GoM, 2016. MITUR: Aprova o Plano de Maneio do Parque Nacional da Gorongosa para o período de 2016 a 2020. Boletim da República I (88) 25 July 2016. https://gorongosa.org/wp-content/uploads/2020/07/BR-Aprova%C3%A7%C3%A3o-Plano-de-Maneio-do-PNG-Jul-2016.pdf [Accessed 16 Nov 2020]

Muala DJ, 2015. Gorongosa: A History of an African Landscape, 1921-2014. MA History Dissertation, Utah State University. 4636. https://digitalcommons.usu.edu/etd/4636

NASA, 2019. TERRA The EOS flagship. https://terra.nasa.gov/about/terra-instruments/modis [Accessed 22 Dec 2019].

Naughton-Treves, L, MB Holland and K Brandon, 2005. The role of protected areas in conserving biodiversity and sustaining local livelihoods. *Annual Review of Environment and Resources*, 30: 219-252.

Negret, PN, M Di Marco, LJ Sonter, J Rhodes, HP Possingham and M Maron, 2020. Effects of spatial autocorrelation and sampling design on estimates of protected area effectiveness. *Conservation Biology*, 34(6): 1452-1462. DOI:10.1111/cobi.13522

Newitt, M, 1995. *A History of Mozambique*. Indiana University Press, Bloomington.

Nhantumbo, I, JB Dent, and G Kowero, 2001. Goal programming: application in the management of the miombo woodland in Mozambique. *European Journal of Operational Research*, 133: 310-322.

Nhongo, EJS, DC Fontana, LA Guasselli and C Bremm, 2019. Probabilistic modelling of wildfire occurrence based on logistic regression, Niassa Reserve, Mozambique. *Geomatics, Natural Hazards and Risk*, 10(1): 1772-1792. DOI: 10.1080/19475705.2019.1615559

Notelid, M, and A Ekblom, 2021. Household Vulnerability and Transformability in Limpopo National Park. *Sustainability*, 13: 2597. DOI: 10.3390/su13052597

Olmos, A, and P Govindasamy, 2015. Propensity Scores: a Practical Introduction Using R. *Journal of MultiDisciplinary Evaluation*, 11(25): 68-88.

Olson, DM, E Dinerstein, ED Wikramanayake, ND Burgess, GVN Powell, EC Underwood, JA D'Amico, I Itoua, HE Strand, JC Morrison, CJ Loucks, TF Allnutt, TH Ricketts, Y Kura, JF Lamoreux, WW Wettengel, P Hedao and KR Kassem, , 2001. Terrestrial ecoregions of the world: a new map of life on Earth. *Bioscience*, 51(11): 933-938.

Oteroa, I, and JØ Nielsen, 2017. Coexisting with wildfire? Achievements and challenges for a radical socialecological transformation in Catalonia (Spain). *Geoforum*, 85: 234-246.

Our Gorongosa, 2020. Our Story. https://ourgorongosa.com/ [Accessed 16 Nov 2020]

Palumbo, I, J-M Grégoire, D Simonetti and M Punga, 2011. Spatio-temporal distribution of fire activity in protected areas of Sub-Saharan Africa derived from MODIS data. *Procedia Environmental Sciences*, 7: 26-31.

Paritsis, J., A. Holz, T. T. Veblen, and T. Kitzberger. 2013. Habitat distribution modeling reveals vegetation flammability and land use as drivers of wildfire in SW Patagonia. *Ecosphere* 4(5): 53. DOI:10.1890/ ES12-00378.1

Peace Parks Foundation, 2020. Great Limpopo. https://www.peaceparks.org/tfcas/great-limpopo/# [Accessed 30 Sept 2020]

Piccolini, I, and O Arino, 2000. Towards a Global Burned Surface World Atlas. *EARTH Observation Quarterly*, 65.

Planas, E, and E Pastor, 2013. Wildfire Behaviour and Danger Ratings. In: Belcher, CM (ed.), *Fire Phenomena and the Earth System: An Interdisciplinary Guide to Fire Science*. John Wiley and Sons, Hoboken. Available from: ProQuest Ebook Central. [Accessed 26 February 2020].

PNG, 2010. Park Management Plan 2010-2012 (FINAL DRAFT). Parque Nacional the Gorongosa Moçambique. http://www.biofund.org.mz/wp-content/uploads/2015/03/GNP-Park-Mgmt-Plan-DRAFT-8-Feb-2010.pdf [Accessed 01/10/2020]

Randolph, JJ, K Falbe, AK Manuel, JL Balloun, 2014. A Step-by-Step Guide to Propensity Score Matching in R. *Practical Assessment, Research and Evaluation*, 19(18). DOI:0.7275/n3pv-tx27

Reason, CJC, 2001. Subtropical Indian Ocean Dipole SST dipole events and southern African rainfall. *Geophysical Research Letters*, 28(11): 2225-2227. DOI: 10.1002/joc.744

Reason, CJC, 2002. Sensitivity of the Southern African Cicrulation to Dipole Sea-Surface Temerature Patterns in the South Indian Ocean. *International Journal of Climatology*, 22: 377-393.

República Popular de Moçambique, 1986. *Atlas Geográfico, Vol. 1*. 2nd edition. República Popular de Moçambique: Maputo, Mozambique.

Reuter HI, A Nelson, A Jarvis, 2007, An evaluation of void filling interpolation methods for SRTM data, *International Journal of Geographic Information Science*, 21:9, 983-1008.

Ribeiro, N, G Ruecker, N Govender, V Macandza, A Pais, D Machava, A Chauque, and SN Lisboa, 2017. The influence of fire frequency on the structure and botanical composition of savanna ecosystems. *Ecology and Evolution*, 9: 8253-8264. DOI: 10.1002/ece3.5400

Ribeiro, N, H Shugart, and R Washington-Allen, 2008. The effects of fire and elephants on species composition and structure of the Niassa Reserve, northern Mozambique. *Forest Ecology and Management*, 255: 1626-1636.

Roos, CI, DMJS Bowman, JKBP Artaxo, WJ Bond, M Cochrane, CM D'Antonio, R DeFries, M Mack, FH Johnston, MA Krawchuk, CA Kull, MA Moritz, S Pyne, AC Scott and TW Swetnam, 2014. Pyrogeography, historical ecology, and the human dimensions of fire regimes. *Journal of Biogeography,* 41(4): 833-836.

Rosenbaum, PR, and DB Rubin, 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika*, 70 (1): 41-55. https://doi.org/10.1093/biomet/70.1.41

Rosenbaum, PR, and DB Rubin, 1985. Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician*, 39(1): 33-38.

Roy, DP, L Boschetti and AMS Smith, 2013. Satellite Remote Sensing of Fires. In: Belcher, CM (ed.) 2013. *Fire Phenomena and the Earth System : An Interdisciplinary Guide to Fire Science*. John Wiley and Sons, Hoboken. ProQuest Ebook Central. [Accessed 26 February 2020].

Roy, DP, PE Lewis, and CO Justice, 2002. Burned area mapping using multi-temporal moderate spatial resolution data—a bi-directional reflectance model-based expectation approach. *Remote Sensing of Environment,* 83: 263-286.

RStudio Team, 2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/

Ryan, CM, and M Williams, 2011. How does fire intensity and frequency affect miombo woodland tree populations and biomass? *Ecological Applications*, 21(1): 48-60.

SADC, 2020. Niassa-Selous Transfrontier Conservation Area. https://tfcaportal.org/node/441 [Accessed 27/09/2020]

Sapiains, R, AM Ugarte, P Aldunce, G Marchant, JA Romero, ME González and V Inostroza-Lazo 2020. Local Perceptions of Fires Risk and Policy Implications in the Hills of Valparaíso, Chile. *Sustainability*, 12(10): 4298. DOI: 10.3390/su12104298

Schleicher, J, J Eklund, MD Barnes, J Geldmann, JA Oldekop and JPG Jones, 2020. Statistical matching for conservation science. *Conservation Biology*, 34(3): 538-549. DOI: 10.1111/cobi.13448

Scholes RJ, 1995. Greenhouse gas emissions from vegetation fires in Southern Africa. Environmental Monitoring Assessment, 38(2-3):169-79. DOI: 10.1007/BF00546761.

Schuetze, 2015. Narrative Fortresses: Crisis Narratives and Conflict in the Conservation of Mount Gorongosa, Mozambique. Conservation and Society 13(2): 141-153.

Shadish WR, and MH Clark, 2004. Matching. In: MS Lewis-Beck, A Bryman and TF Liao (eds.) *The SAGE Encyclopedia of Social Science Research Methods*. DOI:10.4135/9781412950589.n531

Shekede, MD, I Gwitira, and C Mamvura, 2019. Spatial modelling of wildfire hotspots and their key drivers across districts of Zimbabwe, southern Africa. *Geocarto International*: 1-14.

Shlisky, AJ, A Alencar, MI Nolasco and L Curran, 2009. Overview: Global fire regime conditions, threats, and opportunities for fire management in the tropics. In: Cochrane, M, (ed.), *Tropical Fire Ecology: Climate Change, Land Use, and Ecosystem Dynamics*. Springer/Praxis Publishing, Chichester DOI:10.1007/978-3-540-77381-8_3

Sitoe, A, Salomão, A and Wertz-Kanounnikoff, S, 2012. O contexto de REDD+ em Moçambique: causas, actores e instituições. Occasional Paper 76. CIFOR: Bogor, Indonesia.

Stahl, MK, 2020. Pyric herbivory: Understanding fire-herbivore interactions in Gorongosa National Park. Department of Ecology and Evolutionary Biology, Senior Thesis, Princeton University.

Stalmans, M and M Victor, 2020. Forest cover on Gorongosa Mountain: Assessment of satellite imagery 2019. PowerPoint presentation. https://gorongosa.org/wp-content/uploads/2020/10/SerraGorongosa_2019ForestCover_15May2020.pdf [Accessed 12/11/2020]

Stolton, S, P Shadie and N Dudley, 2013. IUCN WCPA Best Practice Guidance on Recognising Protected Areas and Assigning Management Categories and Governance Types, Best Practice Protected Area Guidelines Series No. 21. IUCN: Gland, Switzerland.

Strauss, A, and J Corbin 1994. Grounded theory methodology: An overview. In: NK Denzin and YS Lincoln (Eds.), *Handbook of qualitative research*. Sage Publications, Thousand Oaks/London/New Dehli: 273-285.

Strong, M, 2019. People, place, and animals: using disemplacement to identify invisible losses of conservation near Limpopo National Park. *African Geographical Review*, 38(2): 95-108. DOI: 10.1080/19376812.2017.1303618

Tacheba, B, E Segosebe, C Vanderpost and R Sebego, 2009. Assessing the impacts of fire on the vegetation resources that are available to the local communities of the seasonal wetlands of the Okavango, Botswana, in the context of different land uses and policies. *African Journal of Ecology*, 47(1): 71-77.

The Guardian, 2018. Mozambique: the secret rainforest at the heart of an African volcano. Sun 17 Jun 2018. https://www.theguardian.com/world/2018/jun/17/mozambique-mount-lico-rainforest-new-species

Tukey, JW, 1977. *Exploratory data analysis*. London (etc): Addison-Wesley.

Turner, SF, LB Cardinal, and RM Burton, 2015. Research Design for Mixed Methods: A Triangulation-based Framework and Roadmap. *Organizational Research Methods*, 20(2): 243–267. https://doi.org/10.1177/1094428115610808

UNDP, *undated*. UNDP Project Document: Sustainable Financing of the Protected Area System in Mozambique. UNDP GEF PIMS 3938. https://www.thegef.org/project/sustainable-financing-protected-area-system-mozambique [Accessed 05/04/2021]

UNDP, 2019. Human Development Report 2019: Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. United Nations Development Programme, New York.

VanderWeele, TJ, 2019. Principles of Confounder Selection. *European Journal of Epidemiology*, 34(3): 211-219. DOI: 10.1007/s10654-019-00494-6

Van Wilgen, BW, GG Forsyth, H de Klerk, S Das, S Khuluse and P Schmitz, 2010. Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. *Journal of Applied Ecology*, 47(3): 631–638.

WCS, 2020. Niassa National Reserve. https://mozambique.wcs.org/Wild-Places/Niassa-National-Reserve-Test.aspx [Accessed 29/9/2020]

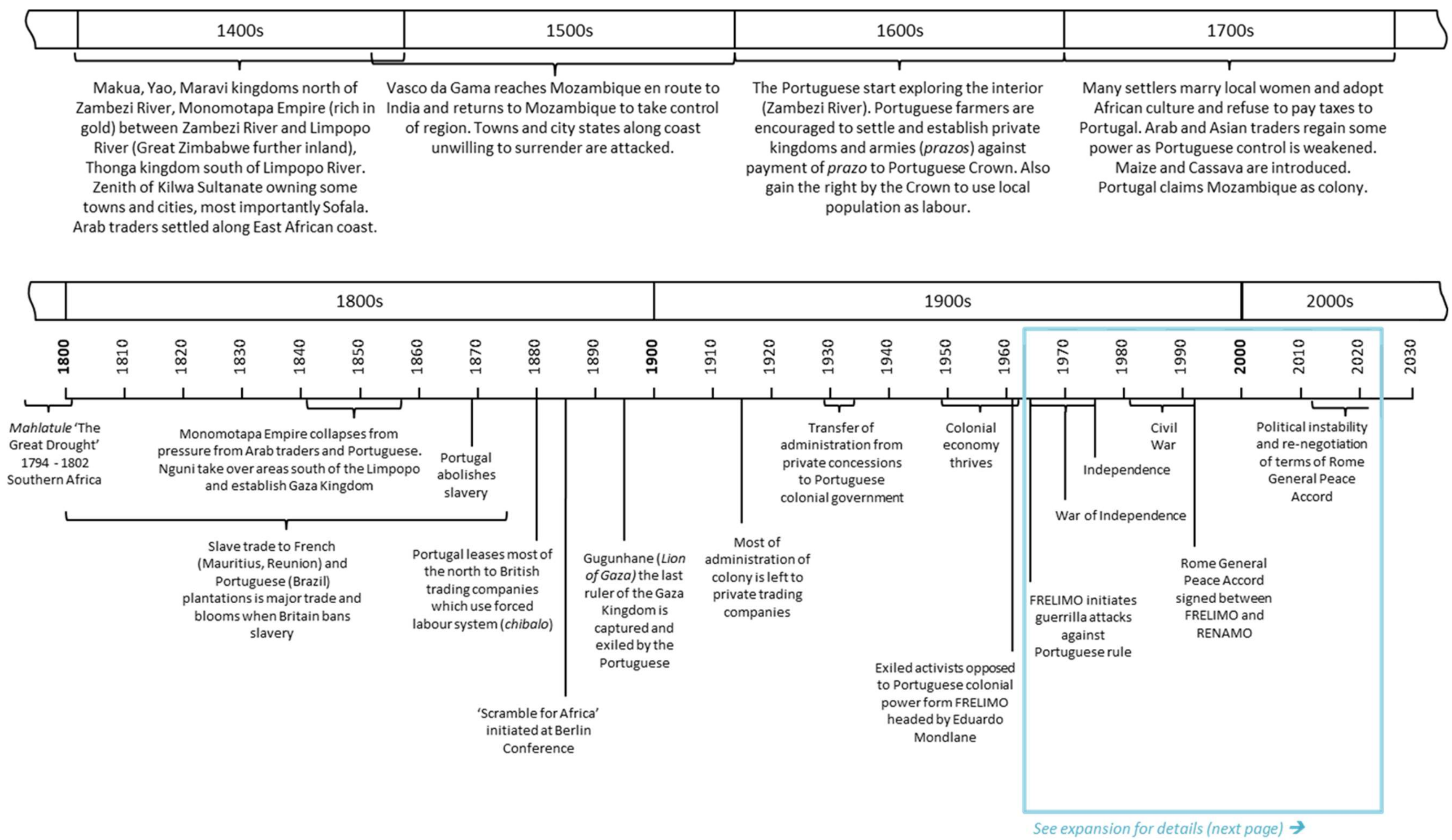
Wickham, H, W Chang, L Henry, TL Pedersen, K Takahashi, C Wilke, K Woo, H Yutani and D Dunnington. 2020. For R: Create Elegant Data Visualisations Using the Grammar of Graphics: Package 'ggplot2', 30 December 2020, Version 3.3.3.

Wooster, MJ, B Zhukov, and D Oertel, 2003. Fire radiative energy for quantitative study of biomass burning: derivation from the BIRD experimental satellite and comparison to MODIS fire products. *Remote Sensing the Environment*, 86: 83-107.

World Bank, 2020. The World Bank In Mozambique. Mozambique: Overview (updated 02 July 2020). https://www.worldbank.org/en/country/mozambique/overview#1 [Accessed 23/09/2020]

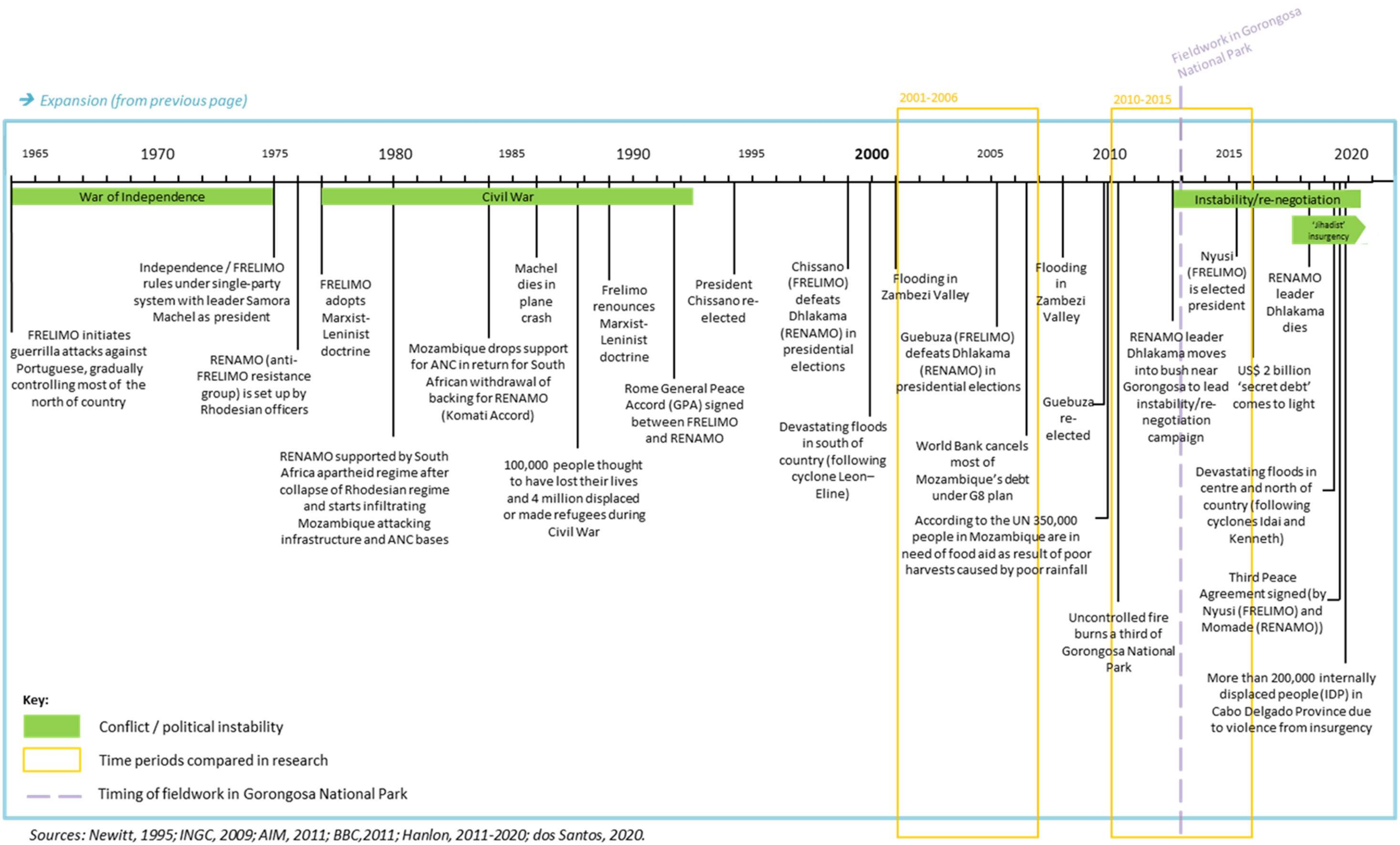
Zubkova, M, L Boschetti, JT Abatzoglou, and L Giglio, 2019. Changes in fire activity in Africa from 2002 to 2016 and their potential drivers. *Geophysical Research Letters*, 46(13): 7643-7653.

Appendix 1 – Historical timeline



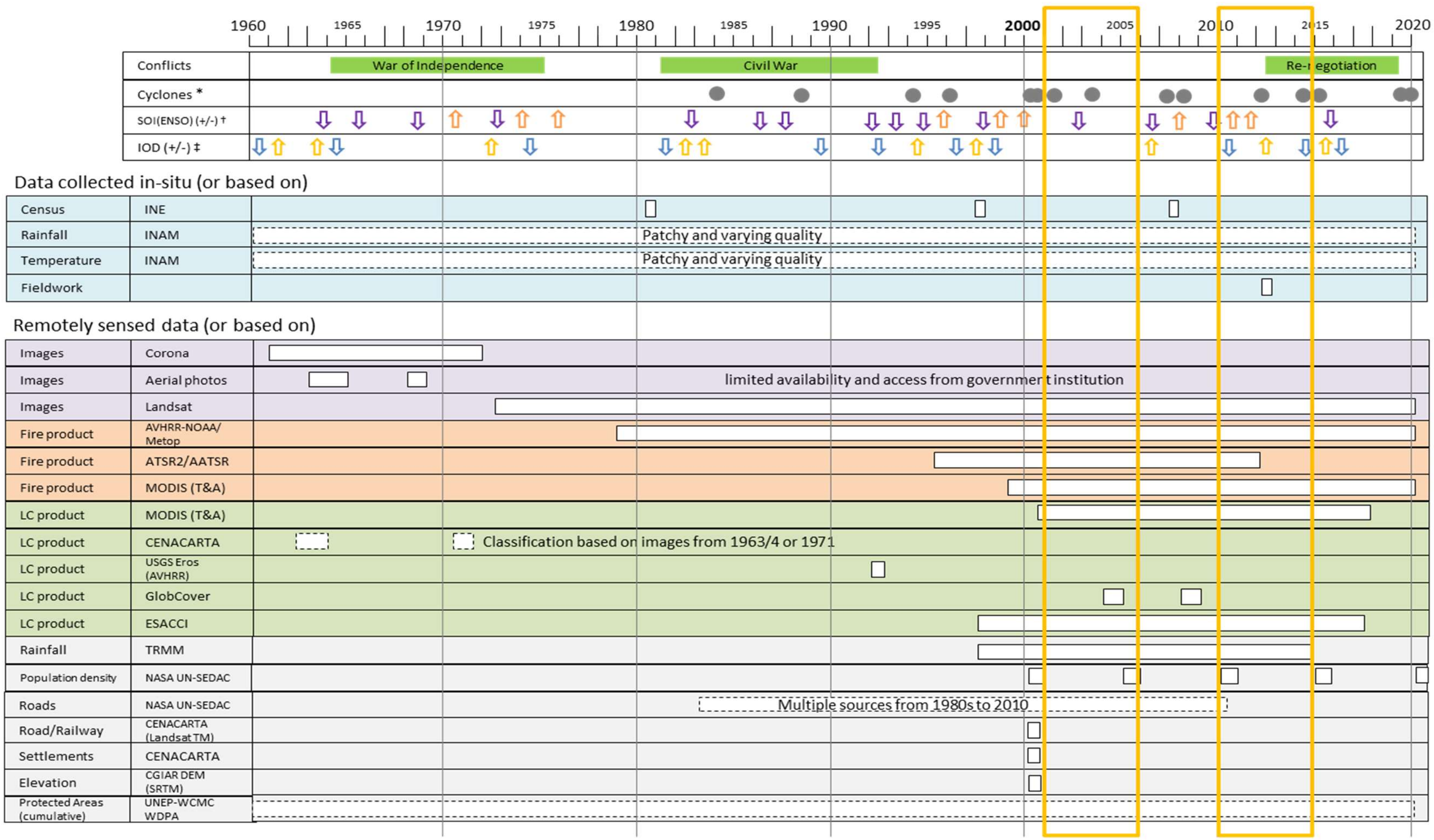
Sources: Newitt, 1995; INGC, 2009; AIM, 2011; BBC,2011; Hanlon, 2011-2020; dos Santos, 2020.

➔ Expansion (from previous page)



Sources: Newitt, 1995; INGC, 2009; AIM, 2011; BBC, 2011; Hanlon, 2011-2020; dos Santos, 2020.

Appendix 2 – Temporal availability of potential data



*Sources: Newitt, 1995; Jarvis & al., 2008; CENACARTA, 2011; GLCF, 2011; INE, 2011; CIESIN - Columbia University, 2013; Lehner & Grill, 2013; CIESIN - Columbia University, 2018; ATSR-WFA, 2019; Climate Explorer, 2019; NOAA, 2019; UNEP_WCMC, 2020. * Cyclone data for 1998-2018: http://www.meteo.fr/temps/domtom/La_Reunion/webcmrs9.0/anglais/index.html; †SOI/ONI (1952-2019) https://ggweather.com/enso/oni.htm. ‡Indian Ocean Dipole years (1960-2016) http://www.bom.gov.au/climate/iod/*

Appendix 3 - Reclassification of Land Cover products

Reclass value	Reclass description/label	ESACCI code	ESACCI description	MODIS code	MODIS label	GlobCover 2005 code	GlobCover 2005 classification
0	No Value	0	No Data	254	Unclassified		
				255	Fill Value		
1	Cropland	10	Cropland, rainfed	12	Croplands	14	Rainfed croplands
		11	Herbaceous cover	14	Cropland/Natural vegetation mosaic	20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
		12	Tree or shrub cover			30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
		20	Cropland, irrigated or post-flooding				
		30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (50%) / cropland (<50%)				
		40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)				
2	Forest	50	Tree cover, broadleaved, evergreen, closed to open (>15%)	1	Evergreen Needleleaf forest	40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
		60	Tree cover, broadleaved, deciduous, closed to open (>15%)	2	Evergreen Broadleaf forest	41	Closed (>40%) broadleaved evergreen and/or semi-deciduous forest (>5m)
		61	Tree cover, broadleaved, deciduous, closed (>40%)	3	Deciduous Needleleaf forest	50	Closed (>40%) broadleaved deciduous forest (>5m)
		62	Tree cover, broadleaved, deciduous, open (15-40%)	4	Deciduous Broadleaf forest	60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
		70	Tree cover, needleleaved, evergreen, closed to open (>15%)	5	Mixed forest	90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)
		71	Tree cover, needleleaved, evergreen, closed (>40%)			100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
		72	Tree cover, needleleaved, evergreen, open (15-40%)				
		80	Tree cover, needleleaved, deciduous, closed to open (>15%)				
		81	Tree cover, needleleaved, deciduous, closed (>40%)				
		82	Tree cover, needleleaved, deciduous, open (15-40%)				
		90	Tree cover, mixed leaf type (broadleaved and needleleaved)				
3	Mosaic/ Shrubland/ Grassland	100	Mosaic tree and shrub (>50%) / herbaceous cover (50%)	6	Closed shrublands	110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
		110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	7	Open shrublands	120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
		120	Shrubland	8	Woody savannas	130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)
		121	Evergreen shrubland	9	Savannas	134	Closed to open (>15%) broadleaved deciduous shrubland (<5m)
		122	Deciduous shrubland	10	Grasslands	140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
		130	Grassland			141	Closed (>40%) grassland
4	Sparse vegetation	140	Lichens and mosses	16	Barren or sparsely vegetated	150	Sparse (<15%) vegetation
		150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)			151	Sparse (<15%) grassland
		151	Sparse tree (<15%)				
		152	Sparse shrub (<15%)				
		153	Sparse herbaceous cover (<15%)				
5	Flooded vegetation	160	Tree cover, flooded, fresh or brakish water	11	Permanent wetlands	160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water
		170	Tree cover, flooded, saline water			170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water
		180	Shrub or herbaceous cover, flooded, fresh/saline/brakish water			180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water
6	Urban/ Water/Bare	190	Urban areas	0	Water	190	Artificial surfaces and associated areas (Urban areas >50%)
		200	Bare areas	13	Urban and built-up	200	Bare areas
		201	Consolidated bare areas	15	Snow and ice	201	Consolidated bare areas (hardpans, gravels, bare rock, stones, boulders)
		202	Unconsolidated bare areas			203	Salt hardpans
		210	Water bodies			210	Water bodies
		220	Permanent snow and ice				

Appendix 4 – Protected Areas of Mozambique (from WDPA, selected variables, excluding Ramsar Sites)

NAME	NATIONAL DESIGNATION	IUCN CATEGORY	GIS AREA	STATUS YEAR	GOVERN-MENT TYPE	MANAGING AUTHORITY	MANAGEMENT PLAN
Gorongosa	Buffer Zone	VI	9446	2010	Coll gov	ANAC	nr
Niassa	Buffer Zone	VI	4519	1954	Coll gov	ANAC	nr
Quirimbas	Buffer Zone	V	5718	2002	Nat ministry	ANAC	Y
Chipanje Chetu	Community Conservation Area	VI	6653	1998	Loc comm	ANAC	nr
Mitchéu	Community Conservation Area	VI	109		Loc comm	ANAC	nr
Tchuma tchato	Community Conservation Area	VI	34622		Gov-del mang	ANAC	nr
Malhazine	Ecological Park	IV	6	2012	Nat ministry	ANAC	Y
Maputo	Environmental Conservation Area	V	5732	2019	Nat ministry	ANAC	N
Primeiras and Segundas	Environmental Protection Area	V	8075	2012	Coll gov	ANAC	Y
Baixo Pinda	Forest Reserve	IV	199	1957	Nat ministry	DINAF	nr
Chirenzene	Forest Reserve	III	1		Loc comm	DINAF	nr
Derre	Forest Reserve	IV	1550	1957	Nat ministry	DINAF	nr
Inhamitanga	Forest Reserve	IV	17		Nat ministry	DINAF	nr
Licuati	Forest Reserve	IV	141		Nat ministry	DINAF	Y
Maronga	Forest Reserve	IV	150		Nat ministry	DINAF	nr
Matibane	Forest Reserve	IV	109		Nat ministry	DINAF	nr
Mecuburi	Forest Reserve	IV	2381	1950	Nat ministry	DINAF	nr
Moribane	Forest Reserve	IV	161		Nat ministry	DINAF	nr
Mucheve	Forest Reserve	IV	92		Nat ministry	DINAF	nr
Mupalué	Forest Reserve	IV	274		Nat ministry	DINAF	nr
Nhapacua	Forest Reserve	IV	26		Nat ministry	DINAF	nr

Régulo Zomba	Forest Reserve	IV	26		Nat ministry	DINAF	nr
Ribáuè	Forest Reserve	IV	129		Nat ministry	DINAF	nr
Luabo	Hunting Reserve	VI	554		Gov-del mang	ANAC	nr
Lureco	Hunting Reserve	VI	2296	2013	Gov-del mang	ANAC	nr
Marangira	Hunting Reserve	VI	2697	2014	Gov-del mang	ANAC	nr
Messalo	Hunting Reserve	VI	1323	2013	Gov-del mang	ANAC	nr
Micaune	Hunting Reserve	VI	247		Gov-del mang	ANAC	nr
Mulela	Hunting Reserve	VI	958	2013	Gov-del mang	ANAC	nr
Nacumua	Hunting Reserve	VI	2636	2010	Gov-del mang	ANAC	nr
Nicage	Hunting Reserve	VI	615	2008	Gov-del mang	ANAC	nr
Nipepe	Hunting Reserve	VI	1380	2010	Gov-del mang	ANAC	nr
Nº10	Hunting Reserve	VI	2598		Gov-del mang	ANAC	nr
Nº11	Hunting Reserve	VI	1821		Gov-del mang	ANAC	nr
Nº12	Hunting Reserve	VI	2717		Gov-del mang	ANAC	nr
Nº13	Hunting Reserve	VI	4708		Gov-del mang	ANAC	nr
Nº14	Hunting Reserve	VI	873		Gov-del mang	ANAC	nr
Nº15	Hunting Reserve	VI	1311		Gov-del mang	ANAC	nr
Nº4	Hunting Reserve	VI	3019		Gov-del mang	ANAC	nr
Nº5	Hunting Reserve	VI	6390		Gov-del mang	ANAC	nr
Nº7	Hunting Reserve	VI	4769		Gov-del mang	ANAC	nr
Nº9	Hunting Reserve	VI	3763		Gov-del mang	ANAC	nr
Nungo	Hunting Reserve	VI	3320	2013	Gov-del mang	ANAC	nr
Banhine	National Park	II	7256	1973	Coll gov	ANAC	Y
Bazaruto	National Park	II	1228	1971	Coll gov	ANAC	Y
Chimanimani	National Park	II	659	2003	Nat ministry	ANAC	Y
Gilé	National Park	II	2840	1960	Nat ministry	ANAC	Y
Gorongosa	National Park	II	3675	1960	Coll gov	ANAC	Y
Limpopo	National Park	II	11015	2001	Coll gov	ANAC	Y
Magoe	National Park	II	3560	2013	Nat ministry	ANAC	Y

Quirimbas	National Park	V	7788		Nat ministry	ANAC	nr
Serra da Gorongosa	National Park	II	367	1960	Coll gov	ANAC	Y
Zinave	National Park	II	4092	1973	Coll gov	ANAC	Y
Lago Niassa	National Reserve	IV	386	2011	Nat ministry	MIMAIP	Y
Marromeu	National Reserve	IV	1556	1960	Nat ministry	ANAC	Y
Pomene	National Reserve	IV	51	1964	Nat ministry	ANAC	Y
Ponta do Ouro	National Reserve	IV	698	2009	Coll gov	ANAC	Y
Cabo de São Sebastião	Sanctuary	IV	438	2000	Non-prof orgs	ANAC	Y
Maputo	Special Reserve	II	1040	1960	Coll gov	ANAC	Y
Niassa	Special Reserve	VI	3818 9	1954	Coll gov	ANAC	Y
Data: UNEP-WCMC and IUCN (2020)							

Key:

ANAC = National Administration of Conservation Areas

DINAF = National Forestry Directorate

MIMAIP = Ministry of Sea, Inland Waters and Fisheries

Coll gov = Collaborative governance

Gov-del mang = Government-delegated management

Loc comm = Local communities

Non-prof orgs = Non-profit organisations

Nat ministry = Federal or national ministry or agency

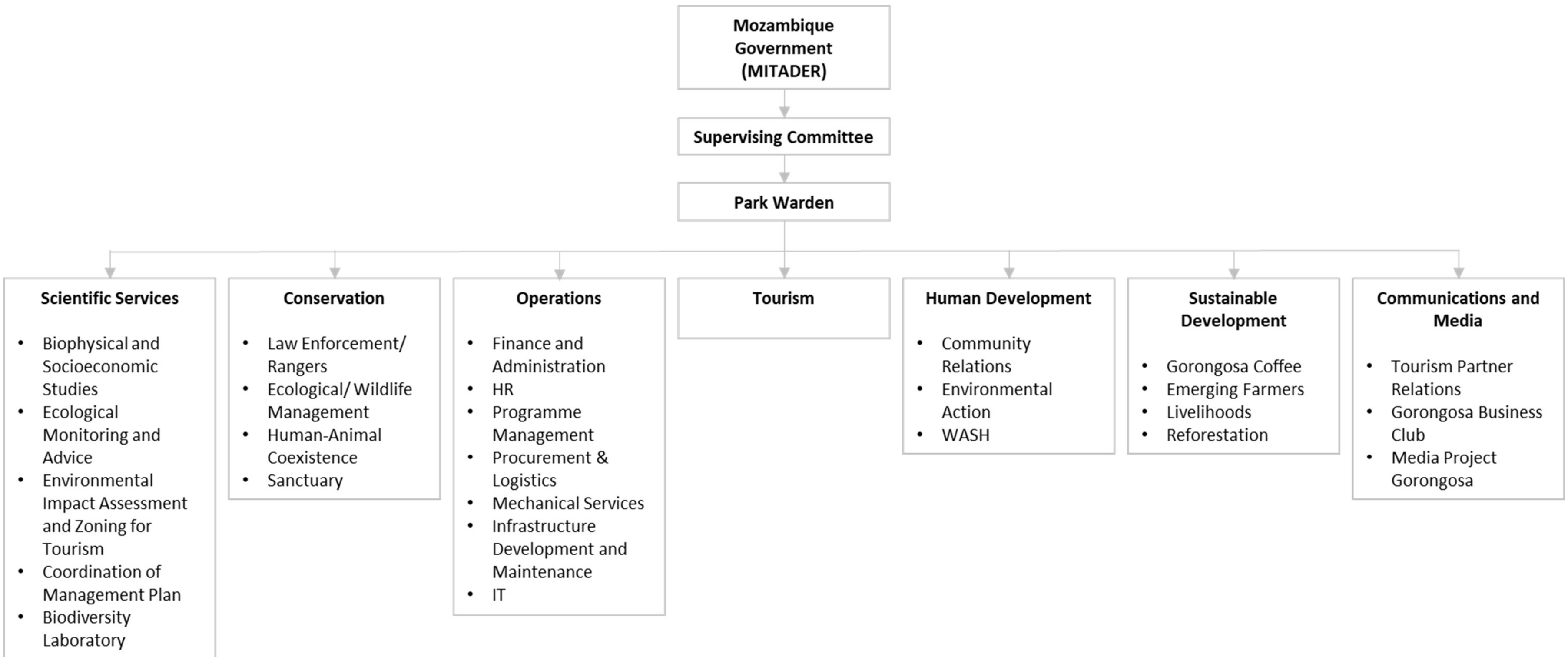
nr = not reported

Y = Yes

Appendix 5 – List of informants during fieldwork

Name/ Code	Position	Location	Date / type of data
Individuals (GNP staff)			
Mateus Mutemba	Park Administrator	Chitengo	12/10/2012, informal interview
Domingos Muala	Social Researcher	Chitengo	15/10/2012, informal interview
Marc Stalmans	Director of Scientific Services	Chitengo	Data, maps, etc.
Alan Short	Scientific Services Department	Chitengo	Data, maps, etc.
Tongai Castigo	Scientific Services Department	Chitengo	Data, maps, etc.
Piano Jantar	Manager of Human-Wildlife Coexistence and Ecosystem Integrity (now)	Chitengo	
Sandra Giroth	Community Relations	Chitengo	Translation, access to community
Herculano Ernesto	Community Relations	Chitengo	Translation access to community
Caisias Tembo	Operations Manager Community Education Centre	Community Education Centre, GNP	12/10/2012, informal interview
Vasco Galante	Communications Director	Chitengo	Access to media and literature on GNP
Group Discussions			
Group Discussion Vinho (GD1 Vinho)	Girassol Hotel staff from Vinho (4 women, 6 men)	Chitengo	14/10/2012, group discussion
Group Discussion Vinho (GD2 Vinho)	Representatives from agricultural associations in Vinho (3 women, 5 men)	Vinho	17/10/2012, group discussion
Group Discussion Nhanguo (GD Nhanguo)	Representatives from Nhanguo village (5 men)	Nhanguo	22/10/2012, group discussion
Individual members from communities			
Interviewee 1	Vinho villager (man employed at Hotel)	Chitengo	16/10/2012, informal interview
Interviewee 2	Vinho villager (man employed at Hotel)	Chitengo	17/10/2012, informal interview
Interviewee 3	Vinho villager (traditional authority, man, temporarily employed as labourer)	Chitengo	18/10/2012, informal interview
Interviewee 4	Muitchire villager (woman employed at Hotel)	Chitengo	18/10/2012, informal interview
Interviewee 5	Muitchire villager (man employed at Hotel and former poacher)	Chitengo	20/10/2012, informal interview

Appendix 6 – Organogram GNP



Adapted from: GoM (2016); Gorongosa (2020).

Appendix 7 – PCA summaries

```
Burned, 2001-2006
Ranked loading scores for PC2s:
         pop_dens_ln      mean_tot_rain_DS        distance_settle             longitude
         -0.54197052           -0.39643503             0.37720296           -0.33133678
     mean_mean_temp_FS             elevation          distance_road mean_tot_rain_prec_WS
         -0.31579859            0.28972713             0.26578515           -0.18767323
               slope              latitude
          0.07426576            0.04463337

Importance of components:
                          PC1    PC2    PC3    PC4     PC5     PC6     PC7     PC8     PC9    PC10
Standard deviation     1.6481 1.4729 1.1619 1.0045 0.98653 0.82000 0.74010 0.56900 0.39862 0.28170
Proportion of Variance 0.2716 0.2169 0.1350 0.1009 0.09732 0.06724 0.05477 0.03238 0.01589 0.00794
Cumulative Proportion  0.2716 0.4886 0.6236 0.7245 0.82178 0.88902 0.94380 0.97617 0.99206 1.00000


Burned, 2010-2015
Ranked loading scores for PC2s:
         pop_dens_ln       distance_settle       mean_tot_rain_DS             longitude
          0.53188902           -0.43816398             0.37224198            0.32409121
       distance_road             elevation      mean_mean_temp_FS mean_tot_rain_prec_WS
         -0.30891818           -0.28272830             0.25091780            0.18882969
               slope              latitude
         -0.07732465           -0.03931876

Importance of components:
                          PC1    PC2    PC3    PC4     PC5     PC6     PC7     PC8     PC9    PC10
Standard deviation     1.6348 1.3975 1.1821 1.0143 0.98305 0.81811 0.74008 0.68497 0.43055 0.33245
Proportion of Variance 0.2672 0.1953 0.1398 0.1029 0.09664 0.06693 0.05477 0.04692 0.01854 0.01105
Cumulative Proportion  0.2672 0.4625 0.6023 0.7052 0.80179 0.86872 0.92349 0.97041 0.98895 1.00000


PA, 2001-2006
Ranked loading scores for PC2s
     mean_mean_temp_FS             longitude              elevation              latitude
        -0.638558458          -0.601871109            0.274276482          -0.253637516
       distance_road           pop_dens_ln                  slope mean_tot_rain_prec_WS
        -0.206159879          -0.136874884            0.123570289          -0.100747112
      mean_tot_rain_DS       distance_settle
        -0.060723238          -0.009547147

Importance of components:
                          PC1    PC2    PC3    PC4     PC5     PC6     PC7     PC8     PC9    PC10
Standard deviation     1.9841 1.3102 1.1768 1.0010 0.86700 0.84538 0.55459 0.31582 0.23097 0.18200
Proportion of Variance 0.3936 0.1717 0.1385 0.1002 0.07517 0.07147 0.03076 0.00997 0.00533 0.00331
Cumulative Proportion  0.3936 0.5653 0.7038 0.8040 0.87916 0.95062 0.98138 0.99135 0.99669 1.00000


PA, 2010-2015
Ranked loading scores for PC2s
         pop_dens_ln             longitude       mean_tot_rain_DS     mean_mean_temp_FS
          0.47671452            0.47221714             0.36405480            0.35301909
mean_tot_rain_prec_WS         distance_road        distance_settle              latitude
          0.31927263           -0.25456580            -0.21004216            0.20384255
           elevation                 slope
         -0.19922735           -0.02227291

Importance of components:
                          PC1    PC2    PC3     PC4     PC5     PC6     PC7     PC8    PC9    PC10
Standard deviation     1.9301 1.3638 1.1667 0.98532 0.92829 0.80712 0.59945 0.38412 0.2025 0.14616
Proportion of Variance 0.3725 0.1860 0.1361 0.09709 0.08617 0.06514 0.03593 0.01475 0.0041 0.00214
Cumulative Proportion  0.3725 0.5585 0.6947 0.79176 0.87793 0.94307 0.97901 0.99376 0.9979 1.00000
```

Appendix 8 – Logistic regression outcomes and associated tests (NSR, GNP and LNP)

Outputs for logistic regressions and associated tests for NSR, 2001-2006

	2001-2006							
	Estimate	**Stand. Error**	**z value**	**p-value**	**Sig.**	**Confidence Interval 2.5%**	**97.5%**	**VIF**
Coefficients								
Intercept	-1.8530	0.2344	-7.91	0.000	***	-2.3128	-1.3940	
PA: 1	0.8777	0.0247	35.54	< 2e-16	***	0.8293	0.9261	1.08
Rainfall preceding WS	0.0022	0.0002	13.54	< 2e-16	***	0.0018	0.0025	3.70
Rainfall DS	0.0115	0.0012	9.45	< 2e-16	***	0.0091	0.0139	1.51
Temperature FS								
Elevation	-0.0015	0.0001	-15.71	< 2e-16	***	-0.0017	-0.0013	3.76
Slope	-0.0539	0.0052	-10.46	< 2e-16	***	-0.0640	-0.0438	1.33
Distance to road	-0.0221	0.0019	-11.61	< 2e-16	***	-0.0258	-0.0184	1.34
Distance to settlement	0.0238	0.0010	24.37	< 2e-16	***	0.0219	0.0257	1.39
Population density (ln)	-0.6648	0.0135	-49.23	< 2e-16	***	-0.6912	-0.6383	1.57
LC: 2 Forest	0.3477	0.1580	2.20	0.028	*	-1.4600	-0.1515	1.28
LC: 3 Mosaic/Shrub/Grassland	1.0380	0.1598	6.49	0.000	***	0.0380	0.6574	.
LC: 4 Sparse	-12.2400	56.6000	-0.22	0.829		0.7243	1.3507	.
LC: 5 Flooded	-0.8057	0.3338	-2.41	0.016	*	-123.169	98.6911	.
LC: 6 Urban/Water/Bare	-1.0080	0.1691	-5.96	0.000	***	-1.3399	-0.6770	.

*Significance: *** 0.001 , ** 0.01, * 0.05*

Null deviance:	57686 on 56113 degrees of freedom				
Residual deviance:	46877 on 56100 degrees of freedom				
Akaike's Information Criteria (AIC):	46905				
Number of Fisher Scoring iterations:	10				
Deviance Residuals:	Min	1Q	Median	3Q	Max
	-3.137	0.260	0.427	0.608	2.322
Likelihood ratio test:	difference of log-likelihoods = --5404.2, X^2 = 10808, p-value = 0.0000				
Hosmer and Lemeshow test (binary model):	X^2 = 738.85, df = 8, p-value < 2.2e-16				
Pseudo R^2: McFadden	0.1874				
Cox and Snell (ML)	0.1752				
Nagelkerke (Cragg and Uhler)	0.2728				
Confusion matrix:	Accuracy:0.8133, 95% CI: (0.81, 0.8165)				

Outputs for logistic regressions and associated tests for NSR, 2010-2015

	2010-2015							
	Estimate	**Stand. Error**	**z value**	**p-value**	**Sig.**	**Confidence Interval**		
Coefficients						**2.5%**	**97.5%**	**VIF**
Intercept	5.5421	1.1530	4.81	0.000	***	3.2824	7.8019	
PA: 1	0.6131	0.0391	15.69	< 2e-16	***	0.5365	0.6896	1.09
Rainfall preceding WS	0.0039	0.0003	11.71	< 2e-16	***	0.0032	0.0046	2.25
Rainfall DS	-0.0207	0.0016	-13.19	< 2e-16	***	-0.0238	-0.0176	1.53
Temperature FS	-0.3967	0.0483	-8.21	0.000	***	-0.4914	-0.3020	3.48
Elevation	-0.0017	0.0001	-12.04	< 2e-16	***	-0.0019	-0.0014	4.02
Slope	-0.0262	0.0080	-3.26	0.001	**	-0.0420	-0.0105	1.47
Distance to road	-0.0076	0.0025	-3.06	0.002	**	-0.0124	-0.0027	1.19
Distance to settlement	0.0311	0.0014	22.53	< 2e-16	***	0.0284	0.0338	1.20
Population density (ln)	-0.5265	0.0234	-22.51	< 2e-16	***	-0.5723	-0.4806	1.69
LC: 2 Forest	1.0734	0.1993	5.39	0.000	***	-0.5379	0.9107	1.46
LC: 3 Mosaic/Shrub/Grassland	1.8033	0.2002	9.01	< 2e-16	***	0.6828	1.4639	.
LC: 4 Sparse	-1.2716	0.7475	-1.70	0.089		1.4108	2.1958	.
LC: 5 Flooded	0.1864	0.3696	0.50	0.614		-2.7367	0.1935	.
LC: 6 Urban/Water/Bare	0.0167	0.2163	0.08	0.938		-0.4073	0.4407	.

*Significance: *** 0.001 , ** 0.01, * 0.05*

Null deviance:		23143 on 24943 degrees of freedom				
Residual deviance:		19238 on 24929 degrees of freedom				
Akaike's Information Criteria (AIC):		19268				
Number of Fisher Scoring iterations:		5				
Deviance Residuals:		Min	1Q	Median	3Q	Max
		-3.1978	0.2558	0.43	0.5674	2.2197
Likelihood ratio test:		difference of log-likelihoods = -1952.4, X^2 = 3904.9 p-value = 0.0000				
Hosmer and Lemeshow test (binary model):		X^2 = 86.953, df = 8, p-value < 1.887e-15				
Pseudo R^2:	McFadden	0.1687				
	Cox and Snell (ML)	0.1449				
	Nagelkerke (Cragg and Uhler)	0.2397				
Confusion matrix:		Accuracy: 0.8334, 95% CI: (0.8287, 0.838)				

Outputs for logistic regressions and associated tests for GNP (excluding Serra da Gorongosa / Gorongosa Mountain), 2001-2006

	2001-2006							
	Estimate	**Stand.**	**z value**	**p-**	**Sig.**	**Confidence Interval**		
Coefficients		**Error**		**value**		**2.5%**	**97.5%**	**VIF**
Intercept	7.357	0.650	11.311	< 2e-16	***	6.082	8.632	
PA: 1	1.786	0.043	41.875	< 2e-16	***	1.702	1.869	1.77
Rainfall preceding WS	0.002	0.000	16.572	< 2e-16	***	0.002	0.002	2.79
Rainfall DS	-0.009	0.001	-13.346	< 2e-16	***	-0.010	-0.008	1.73
Temperature FS	-0.427	0.028	-15.071	< 2e-16	***	-0.482	-0.371	2.28
Elevation	0.002	0.000	4.463	0.000	***	0.001	0.002	2.14
Slope	-0.175	0.018	-9.481	< 2e-16	***	-0.211	-0.139	1.40
Distance to road	0.023	0.003	7.736	0.000	***	0.017	0.029	1.05
Distance to settlement	0.023	0.001	20.063	< 2e-16	***	0.020	0.025	1.28
Population density (ln)	0.362	0.015	23.420	< 2e-16	***	0.332	0.392	1.71
LC: 2 Forest	0.155	0.075	2.083	0.037	*	0.308	0.622	1.59
LC: 3 Mosaic/Shrub/Grassland	0.927	0.092	10.083	< 2e-16	***	0.009	0.301	.
LC: 4 Sparse								
LC: 5 Flooded	0.465	0.080	5.813	0.000	***	0.747	1.108	.
LC: 6 Urban/Water/Bare	-0.638	0.121	-5.269	0.000	***	-0.875	-0.401	.

*Significance: *** 0.001 , ** 0.01, * 0.05*

Null deviance:	32668 on 25141 degrees of freedom				
Residual deviance:	25847 on 25128 degrees of freedom				
Akaike's Information Criteria (AIC):	25875				
Number of Fisher Scoring iterations:	4				
Deviance Residuals:	Min	1Q	Median	3Q	Max
	-2.835	-0.903	0.437	0.800	2.754
Likelihood ratio test:	difference of log-likelihoods = -3410.2, X^2 = 6820.4, p-value = 0.0000				
Hosmer and Lemeshow test (binary model):	X^2 = 266.62, df = 8, p-value < 2.2e-16				
Pseudo R^2: McFadden	0.2088				
Cox and Snell (ML)	0.2376				
Nagelkerke (Cragg and Uhler)	0.3267				
Confusion matrix:	Accuracy: 0.7398, 95% CI: (0.7343, 0.7452)				

Outputs for logistic regressions and associated tests for GNP (excluding Serra da Gorongosa / Gorongosa Mountain), 2010-2015

	2010-2015							
	Estimate	**Stand.**	**z value**	**p-value**	**Sig.**	**Confidence Interval**		
Coefficients		**Error**				**2.5%**	**97.5%**	**VIF**
Intercept	-10.670	1.045	-10.212	< 2e-16	***	-12.718	-8.622	
PA: 1	1.291	0.037	34.888	< 2e-16	***	1.218	1.363	1.52
Rainfall preceding WS	0.003	0.000	22.754	< 2e-16	***	0.003	0.003	1.94
Rainfall DS	-0.002	0.001	-1.974	0.048	*	-0.003	0.000	1.26
Temperature FS	0.332	0.048	6.846	0.000	***	0.237	0.426	1.86
Elevation	0.003	0.000	8.929	< 2e-16	***	0.002	0.004	3.02
Slope	-0.090	0.014	-6.426	0.000	***	-0.118	-0.063	1.67
Distance to road	-0.017	0.003	-5.837	0.000	***	-0.023	-0.012	1.06
Distance to settlement	0.014	0.001	10.593	< 2e-16	***	0.011	0.016	1.19
Population density (ln)	1.26E-01	1.78E-02	7.094	1.30E-12	***	0.091	0.161	1.61
LC: 2 Forest	4.05E-01	6.93E-02	5.849	4.95E-09	***	0.269	0.541	1.45
LC: 3 Mosaic/Shrub/Grassland	9.79E-01	8.53E-02	11.478	< 2e-16	***	0.812	1.147	.
LC: 4 Sparse								
LC: 5 Flooded	1.74E-01	7.50E-02	2.325	0.0201	*	0.027	0.321	.
LC: 6 Urban/Water/Bare	-1.22E+00	1.22E-01	-10.058	< 2e-16	***	-1.460	-0.984	.

*Significance: *** 0.001 , ** 0.01, * 0.05*

Null deviance:	32475 on 24049 degrees of freedom				
Residual deviance:	27004 on 24036 degrees of freedom				
Akaike's Information Criteria (AIC):	27032				
Number of Fisher Scoring iterations:	4				
Deviance Residuals:	Min	1Q	Median	3Q	Max
	-2.301	-0.8928	0.6146	0.7588	2.327
Likelihood ratio test:	difference of log-likelihoods = -2735.7, X^2 = 5471.3, p-value = 0.0000				
Hosmer and Lemeshow test (binary model):	X^2 = 305.61, df = 8, p-value < 2.2e-16				
Pseudo R^2: McFadden	0.1685				
Cox and Snell (ML)	0.2035				
Nagelkerke (Cragg and Uhler)	0.2747				
Confusion matrix:	Accuracy: 0.7289, 95% CI: (0.7232, 0.7345)				

Outputs for logistic regressions and associated tests for LNP, 2010-2015

	2010-2015							
	Estimate	**Stand. Error**	**z value**	**p-value**	**Sig.**	**Confidence Interval 2.5%**	**97.5%**	**VIF**
Coefficients								
Intercept	18.860	55.950	0.337	0.736		-90.808	128.520	
PA: 1	-0.872	0.069	-12.670	< 2e-16	***	-1.007	-0.737	1.18
Rainfall preceding WS								
Rainfall DS	0.052	0.003	17.151	< 2e-16	***	0.046	0.058	3.14
Temperature FS	-1.262	2.595	-0.486	0.627		-6.349	3.824	3.51
Elevation	0.010	0.001	20.392	< 2e-16	***	0.009	0.011	3.94
Slope	-0.585	0.071	-8.199	0.000	***	-0.725	-0.445	1.19
Distance to road	0.086	0.006	14.694	< 2e-16	***	0.075	0.098	1.24
Distance to settlement	0.019	0.003	5.542	0.000	***	0.012	0.026	1.43
Population density (ln)	0.058	0.040	1.462	0.144		-0.020	0.136	1.46
LC: 2 Forest	0.647	0.174	3.717	0.000	***	-393.215	378.884	1.35
LC: 3 Mosaic/Shrub/Grassland	1.983	0.174	11.429	< 2e-16	***	0.306	0.987	.
LC: 4 Sparse								
LC: 5 Flooded	-7.166	197.000	-0.036	0.971		1.643	2.322	.
LC: 6 Urban/Water/Bare	-0.364	0.797	-0.457	0.648		-1.925	1.197	.
*Significance: *** 0.001 , ** 0.01, * 0.05*								

Null deviance:	8373.8 on 8083 degrees of freedom					
Residual deviance:	6407.2 on 8071 degrees of freedom					
Akaike's Information Criteria (AIC):	6433.2					
Number of Fisher Scoring iterations:	10					
Deviance Residuals:		Min	1Q	Median	3Q	Max
		-2.330	-0.612	0.391	0.180	2.845
Likelihood ratio test:	difference of log-likelihoods = -983.27, X^2 = 1966.5, p-value = 0.0000					
Hosmer and Lemeshow test (binary model):	X^2 = 87.773, df = 8, p-value < 2.2e-16					
Pseudo R^2:	McFadden	0.2348				
	Cox and Snell (ML)	0.2159				
	Nagelkerke (Cragg and Uhler)	0.3347				
Confusion matrix:	Accuracy: 0.8289, 95% CI: (0.8205, 0.8371)					