

**IMPERIAL**



# **Fires Across Conservation Frontiers**

**Alternative management approaches for addressing wildfires in  
East and Southern African savanna-protected areas**

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# Fires Across Conservation Frontiers

## Alternative management approaches for addressing wildfires in East and Southern African savanna-protected areas

A PhD thesis by Abigail Rose Croker

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### Declaration of originality

I declare that this thesis “Fires Across Conservation Frontiers: Alternative management approaches for addressing wildfires in East and Southern African savanna-protected areas” is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

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## Abstract

Colonially inherited fire suppression policies and the expansion of exclusionary protected areas across East and Southern African savannas have engendered a wildfire paradox. Inside protected areas, efforts to eliminate fires from the landscape have paradoxically resulted in the accumulation of flammable biomass and higher intensity wildfires. Outside protected areas, rangelands are continuously reconfigured and reterritorialized, emerging as contentious biopolitical frontiers where livestock have replaced fire as the dominant fuel consumer. ‘Bottom-up’ fire management is increasingly recognised as an alternative fire management strategy to effectively and equitably address the wildfire paradox. Yet, there has been little investigation into the framing, nature, and extent of bottom-up approaches and the assumptions informing their implementation, exposing local governance structures to external appropriation and accelerating savanna degradation. This thesis interrogates current understandings of bottom-up fire management approaches across East and Southern African conservation landscapes to identify opportunities and challenges for their implementation, specifically their ability to mitigate wildfires, improve savanna health, and contribute towards resilient local livelihoods. To do this, a mixed-methodological bricolage approach was taken, consisting of two independent systematic reviews of the literature, fieldwork conducted in Kenya, and the development of a novel Belief Network model. The results show that wildfires are symptomatic of deep-rooted land and resource-based conflicts which have and continue to emerge from policy interventions supposedly designed to address inequalities. In this regard, bottom-up fire management approaches are externally constructed, governed, and reinforce ‘divide-and-rule’ policies pursued by colonial governments. Addressing these challenges requires a historical social-ecological perspective, and an interrogation of the strong (neo)colonial legacies that influence received knowledge and resource management. Shifting the focus from ‘community’ towards institutions can expose asymmetries that prevent resource benefits being acquired and equitably distributed at the community level, therefore highlighting opportunities for external institutions to support legitimate bottom-up fire management approaches with ‘win-win-win’ outcomes.

## List of Acronyms

|          |                                                              |
|----------|--------------------------------------------------------------|
| AET      | Amboseli Ecosystem Trust                                     |
| AGC      | Above-Ground Carbon                                          |
| AWF      | African Wildlife Foundation                                  |
| BBN      | Bayesian Belief Network                                      |
| BGB      | Below-Ground Biomass                                         |
| BGC      | Below-Ground Carbon                                          |
| BLF      | Big Life Foundation                                          |
| BN       | Belief Network                                               |
| CAMPFIRE | Communal Areas Management Programme for Indigenous Resources |
| CBFiM    | Community-Based Fire Management                              |
| CBNRM    | Community-Based Natural Resource Management                  |
| CDI      | Climate Delay and Inequality                                 |
| CDM      | Clean Development Mechanism                                  |
| CFA      | Community Forestry Association                               |
| CLA      | Community Land Act                                           |
| CPA      | Charcoal Producers Association                               |
| DSWT     | David Sheldrick Wildlife Trust                               |
| EDS      | Early-Dry Season                                             |
| FCMA     | Forest Conservation and Management Act                       |
| FFCD     | Fossil-Fuelled Climate Ambition                              |
| FPB      | Flexible Prescribed Burning                                  |
| FPIC     | Free, Prior, and Informed Consent                            |
| FSP      | Fire Suppression and Prevention                              |
| FHS      | Fuel Harvesting Scheme                                       |
| GCA      | Green Climate Ambition                                       |
| GCC      | Gulf Cooperation Council                                     |
| GELOSE   | Gestion Locale Sécurisée                                     |
| GHG      | Greenhouse Gas                                               |
| HGS      | Holistic Grazing Scheme                                      |
| IFM      | Integrated Fore Management                                   |
| IPLC     | Indigenous People and Local Community                        |
| IOD      | Indian Ocean Dipole                                          |
| ISFMI    | International Savanna Fire Management Initiative             |
| KA BP    | Thousand-Years Before Present                                |
| KFS      | Kenya Forest Service                                         |

|       |                                                 |
|-------|-------------------------------------------------|
| KWCA  | Kenya Wildlife Conservancies Association        |
| KWS   | Kenya Wildlife Service                          |
| LDS   | Late-Dry Season                                 |
| LSLI  | Large-Scale Land Investment                     |
| MAP   | Mean Annual Precipitation                       |
| MDN   | Median                                          |
| MRV   | Monitoring, Reporting, And Verification         |
| MWCT  | Maasai Wilderness Conservation Trust            |
| MYA   | Million Years Ago                               |
| NEMA  | National Environment Management Authority       |
| PES   | Payment for Ecosystem Services                  |
| PFM   | Participatory Forest Management                 |
| RRU   | Rapid Response Unit                             |
| SBEA  | Savanna Burning Emissions Abatement             |
| SOP   | Standard Operating Procedure                    |
| TAS   | Tropical Agroforestry Species                   |
| TCA   | Tsavo Conservation Area                         |
| TTWCA | Taita Taveta Wildlife Conservancies Association |
| VCS   | Verified Carbon Standard                        |
| WALFA | West Arnhem Land Fire Abatement                 |
| WCMA  | Wildlife Conservation and Management Act        |

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## Chapter 1. Introduction

Wildfires are ‘wicked problems’; highly complex, ill-defined and poorly understood, and influenced by subjective political pressures and economic decisions (Essen et al., 2023; Kreider et al., 2024). They are increasing in intensity across state governed savanna-protected areas in East and Southern Africa where colonially inherited policies of exclusion and fire suppression have paradoxically resulted in the accumulation of flammable biomass. Outside protected areas, livestock have replaced fire as the dominant fuel consumer, and the expansion of human settlements and intensification of pastoral-agricultural production systems have increased bare-ground cover and facilitated the invasion of fire-resistant woody species. Hence, the ‘wildfire paradox’ that characterises this region does not only synthesise vegetation and biogeophysical conditions inside protected areas (Tedim, Leone & McGee, 2019), but is simultaneously symptomatic of inequitable property-rights and changes in cultural heritage and land-use values. The wildfire paradox has replaced the historical intra-annual fire regime which facilitated the co-evolution of modern humans and biodiverse savanna ecosystems, consequently accelerating widespread savanna degradation and biodiversity loss (Williams et al., 2022; Kelly et al., 2023), and exacerbating livelihood vulnerabilities experienced by rural poor local communities. Despite these challenges, Clementsian views of vegetation succession are reinforced through forestation projects which present fires as creating ‘sub-climax grasslands’, while climax forest ecosystems are ‘destroyed and changed to savanna types of vegetation by burning’ (Pooley, 2021; Parr, te Beest & Stevens, 2024). These views have strengthened environmental degradation narratives, limiting opportunities for local participation in resource governance, and stalling political dialogue over how to best manage fire-prone savanna-protected areas.

Climate change, human population growth, socioeconomic transitions, and large-scale land reforms related to the expansion of exclusionary protected areas under the United Nation’s goal to protect 30% of terrestrial ecosystems by 2030, public-private land investments, and land sub-division and privatisation, continue to reconfigure fire regimes in space and time across Africa’s savanna rangelands (Lind, Okenwa & Scoones, 2020). These challenges are unfolding simultaneously with the emergence of a global jurisprudence on Indigenous land rights, and with the distribution and intensity

of fires increasingly symbolising historical injustices and inter-group conflict across conservation landscapes, there are growing pressures on governments and conservation agencies to redress ‘top-down’ fire suppression policies which have resulted in a highly conflictual wildfire-dominated fire regime (Kobziar et al., 2024).

In recent years, a growing body of literature has demonstrated the interrelated nature of biogeophysical, environmental, and sociocultural conditions in shaping fires, thus demanding that wildfires are considered coupled human-natural phenomena in management. While the biogeophysical aspects of fire regimes have been extensively studied, their social dynamics remain poorly understood and management recommendations are often based on little empirical evidence. For example, community-based fire management (CBFiM) has been proposed as an alternative ‘bottom-up’ fire management approach to ‘resolve all the human factors driving the wildfire paradox’, acknowledging both the regenerative and destructive role of fire in savanna ecosystems (Tedim, Leone & McGee, 2019). However, social dimensions of the wildfire paradox determining the opportunities and challenges for equitable participation in fire management across East and Southern African savanna-protected areas have not been explored. In few cases where conservation managers seek to engage traditional fire knowledges, it has been assumed that low-intensity early-dry season (EDS) burns are representative of traditional fire practices worldwide (Humphrey, Gillson & Ziervogel, 2021; Laris, 2021). This repetitively fails to treat wildfires as symptoms of broader ecological, social, economic, cultural, and historical problems (Xanthopoulos, Leone & Delogu, 2020).

### **1.1. Research problem**

CBFiM is increasingly heralded as an effective and equitable ‘bottom-up’ fire management approach to address the wildfire paradox, including local people in fuel reduction strategies where fire suppression policies have resulted in large flammable fuel loads. In an East and Southern African context where wildfires are concentrated in exclusionary state-governed protected areas, limited research has been carried out to assess these assumptions. Additionally, the very nature, framing, and extent of bottom-up fire management is uncertain or unknown. This has exposed ‘community-based’ approaches to external appropriation, particularly considering processes of coloniality in scientific knowledge production which have informed and sought to standardise local policy solutions worldwide.

Therefore, this thesis interrogates the current construction of ‘community-based’, bottom-up fire management in East and Southern Africa, contending that the imposition of external governance systems in local contexts and lack of property-rights in savanna-protected areas limit opportunities for the legitimate participation of local communities in fire management. Through an in-depth analysis of the micro- and macro-level political, legislative, social, economic, cultural, and environmental

dynamics that have historically, currently, and will likely interact in the future to inform local policy solutions and affect (un)intended outcomes, this thesis sets out to identify the opportunities and challenges for bottom-up fire management approaches to address East and Southern Africa's wildfire paradox. To this effect, this thesis seeks to redefine the wildfire paradox as a joint ecological-biocultural phenomenon across Sub-Saharan African conservation landscapes, offering a more comprehensive conceptualization of fire challenges to promote social-ecologically relevant research and solutions. This understanding of the wildfire paradox is also relevant in former colonial and settler colonialist states worldwide, where local communities reside in the peripheries of state and private land.

## 1.2.Aims and objectives

The overall aim of this thesis is to explore the opportunities and challenges for alternative 'bottom-up' fire management in East and Southern African savanna-protected areas to equitably and effectively address increasing wildfire challenges. This requires an analysis of the governance structures, historical-institutional dependencies, objectives, and social-ecological outcomes of implemented and proposed fire management approaches under future socioeconomic-climate change.

The results inform our understanding of the current and future potential drivers and impacts of the wildfire paradox that characterises African savanna-conservation landscapes, and whether and the extent to which alternative bottom-up fire management approaches can effectively mitigate wildfires, improve savanna health, and foster resilient local livelihoods.

### 1.2.1. Specific objectives and research questions

The first objective of this study is to gain a deeper understanding of the 'wildfire paradox' that characterises East and Southern African savanna-protected area landscapes, including its historical, existing, and emerging social-ecological drivers and potential impacts. Here, I question '*what are the overall trends and drivers shaping fire regimes across savanna conservation areas?*' Moreover, I explore the framing, nature, and extent of implemented and proposed alternative bottom-up fire management approaches to address increasing wildfire challenges, biodiversity loss, and livelihood vulnerabilities. Particular attention is paid to their governance structures to assess how rule-making organisations, property-rights, rules-in-use, and type of management regime interact with broader climate and environmental, socioeconomic, political, legislative, and cultural systems dynamics to affect opportunities and challenges for their implementation. In this regard, I also question '*how have recent carbon-based burning schemes influenced proposed bottom-up fire management strategies in East and Southern African savanna-protected areas? And what are the opportunities and challenges for prescribed EDS burning to achieve primary emissions reductions and carbon sequestration*

*objectives, as well as address equity and rights concerns, and deliver socioeconomic, cultural, and biodiversity co-benefits?’*

The second objective is to characterise scientific knowledge production on ‘community-based’ fire management and ‘traditional’ fire-use practices, specifically examining how (neo)colonial influences over, and geographical and representational inequalities within, produced knowledge have and continue to inform policy solutions in local savanna-protected area contexts. Drawing upon principles of decolonising methodologies, opportunities and challenges for developing bottom-up fire management approaches will be further explored through fieldwork in a local African conservation context. Utilising a mixed-method data triangulation approach to foreground experiential knowledge in the research inquiry, I question *‘what are the perceptions of diverse actors towards fire in the landscape – what are their land-use and fire-use values? And can bottom-up fire management approaches be developed for implementation in savanna-protected areas – if so, what might this look like in the local context?’* In this way, this study seeks to understand local perceptions of the wildfire paradox and bottom-up fire management approaches, identifying convergences and divergences between and within actor groups, and the systemic challenges affecting opportunities for collaborative solutions. This analysis can reveal key characteristics of, and enabling conditions (e.g., specific permission and intervention requirements) for, bottom-up approaches, and whether they can facilitate locally relevant social-ecological outcomes now and in the future.

The third objective is to develop a probabilistic model to evaluate the social-ecological network effects of exploratory and normative fire management approaches implemented in East African semi-arid and mesic savanna-protected areas to address the joint ecological-biocultural wildfire paradox defined in this study. This model (SAV BN) will integrate desk-based and participatory data gathered to achieve the first and second research objectives to build an inclusive Belief Network with locally relevant modelled outcomes. To better understand how fire management interventions might propagate throughout a savanna conservation area to affect wildfires and savanna health inside protected areas, and local livelihoods across the broader conservation landscape, I question *‘what are the systemic impacts of management interventions - are there specific climate, environmental, socioeconomic, and policy variables and pathways that significantly influence modelled outcomes?’* As such, SAV BN facilitates an analysis of system behaviours, emergent challenges, and potential outcomes, therefore providing a simple predictive tool to inform future fire management decisions in the local context.

### **1.3.Theoretical frameworks**

Three theoretical frameworks were iteratively drawn on and applied throughout this thesis to support a bricolage approach in exploring, understanding, and analysing emerging results in a complex,

dynamic research setting: (i) social-ecological systems thinking, (ii) historical institutionalism, and (iii) decolonising methodologies.

### **1.3.1. Social-ecological systems thinking**

African savannas are highly complex, stochastic social-ecological systems. Their fire regimes are inherently pyro-geographic, synthesising nuanced and dynamic interactions between climate and biological, environmental, and social and cultural conditions (Humphrey et al. 2021; Vigna et al., 2021). Historically, bioculturally diverse Indigenous peoples with strong connections to place continuously renegotiated with their environment, experientially acquiring knowledge as they adapted to local change (Lyver et al., 2019; Sharifian et al., 2022). However, protected areas have reconfigured governance systems over previously common-pool resources and public goods across Africa's rangelands (Ostrom, 2015), repudiating heterogeneous institutional and collective arrangements and asserting state and market dominance in the provisioning of public-private resources. Over time, this has affected the non-equilibrium processes that characterise African savannas, of which have served to maintain their structure and functioning between alternative stable states and, in-turn, their resiliency to episodic change (Staver, Archibald & Levin, 2011). For example, the isolation of people from their cultural-economic practices and processes for respecting the environment, and the introduction of fire bans preventing release-organisation-exploitation-conservation feedbacks in the savanna adaptive cycle, have accelerated synonymous processes of ecological and biocultural hysteresis (Gil-Romera, Turton & Sevilla-Callejo, 2011; Garmestani et al., 2023); fire suppression and exclusionary tenure arrangements have contributed to the breakdown of traditional land governance systems, resulting in biodiversity and knowledge loss and, in-turn, a decline in adaptive resilience. Current trends in environmental degradation are largely representative of multiple path-dependencies, and sustained interruptions can affect the system's future ability to self-reorganise, thus triggering a regime shift (Laris et al., 2016).

Social-ecological systems thinking rejects assumptions over the requirement for state-market governance over natural resources and acknowledges the diversity of local governance arrangements that can deliver long-term sustainable outcomes, explicitly addressing how 'top-down' and bottom-up institutions and rules interact to affect agency and opportunities for ecological and biocultural self-organisation, self-governance, and adaptive resilience. Considering that these processes are strongly influenced by historical and current changes in the provisioning of natural resources across African savannas, a comprehensive social-ecological systems (SES) framework was adapted from Ostrom, (2009), Epstein et al., 2013; McGinnis & Ostrom, (2014), Delgado-Serrano & Ramos, (2015), Marshall, (2015), and Vogt et al., (2015) to structure aspects of this research enquiry and theoretically ground discussions on the opportunities and challenges for bottom-up fire management in a historically 'top-down' governance landscape (Table 1).

**Table 1.** Adapted social-ecological systems framework. First tier variables: Social, Economic, and Political Settings (S); Related Ecosystems (ECO); Ecological Rules (ER); Governance System (GS); Actors (A); and Transformation Systems (TS). ER and TS were included in this framework to account for essential factors contributing to system outcomes and underpin conclusions (ER), and sustainability challenges which cannot be defined as exogenous to the focal SES (TS).

| 2 <sup>nd</sup> Tier SES Variables                         | 3 <sup>rd</sup> Tier SES Variables                                                                                                                                        |
|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b><i>Social, Economic, and Political Settings (S)</i></b> |                                                                                                                                                                           |
| S1 Economic Development                                    | Economic sectors; employment per sector; income per capita; income dispersion.                                                                                            |
| S2 Demographic Trends                                      | No. of inhabitants; population density; demographic structure; population growth rate; migration trends; settlement patterns.                                             |
| S3 Political Stability                                     | Democratic values; norm compliance; conflicts; drivers of political change.                                                                                               |
| S4 Government Resource Policies                            | Other governance systems; governmental regulatory framework for natural resources; environmental policies; compliance of environmental regulatory and policy frameworks.  |
| S5 Market Incentives                                       | Type of products; influence of global/local markets; access to markets; demand for natural resources; market incentives for conservation.                                 |
| S6 Media Organisation                                      | Presence of media; media deterrence capability; interest of media in social-ecological issues                                                                             |
| S7 Technology                                              |                                                                                                                                                                           |
| <b><i>Related Ecosystems (ECO)</i></b>                     |                                                                                                                                                                           |
| ECO1 Climate Patterns                                      |                                                                                                                                                                           |
| ECO2 Pollution Patterns                                    |                                                                                                                                                                           |
| ECO3 Flows In/Out Focal SES                                |                                                                                                                                                                           |
| <b><i>Ecological Rules (ER)</i></b>                        |                                                                                                                                                                           |
| ER1 Physical Rules                                         |                                                                                                                                                                           |
| ER2 Chemical Rules                                         |                                                                                                                                                                           |
| ER3 Biological Rules                                       |                                                                                                                                                                           |
| <b><i>Governance System (GS)</i></b>                       |                                                                                                                                                                           |
| GS1 Policy Area                                            |                                                                                                                                                                           |
| GS2 Geographic Scale                                       |                                                                                                                                                                           |
| GS3 Population                                             | General-purpose; task-specific                                                                                                                                            |
| GS4 Regime Type (macro-level organisation)                 | Democratic values; polycentric values                                                                                                                                     |
| GS5 Rule-making Organisations                              | Government organisations; Non-Governmental Organisations (not-for-profit); private sector organisations (for-profit); community-based organisations; hybrid organisations |
| GS6 Network Structure                                      | Social networks; community networks environmental networks; market networks                                                                                               |
| GS7 Property-rights Systems                                | Excludability; subtractability                                                                                                                                            |
| GS8 Rules-in-use                                           | Operational-choice; collective-choice; constitutional choice                                                                                                              |
| GS9 Monitoring and Sanctioning Rules                       | Monitoring processes; sanctioning processes                                                                                                                               |
| GS10 Community context                                     | Repertoire of norms and strategies; historical continuity                                                                                                                 |
| <b><i>Actors (A)</i></b>                                   |                                                                                                                                                                           |
| A1 Relevant Actors                                         | Number of actors and actor groups; direct users of natural resources; other actors                                                                                        |
| A2 Socioeconomic Attributes of Actors                      | Demographic attributes; economic attributes; social attributes                                                                                                            |
| A3 History of Use or Past Experiences                      |                                                                                                                                                                           |
| A4 Location                                                |                                                                                                                                                                           |
| A5 Leadership/Entrepreneurship                             | Leadership patterns; entrepreneurship patterns                                                                                                                            |
| A6 Norms (trust-reciprocity)/Social Capital                | Traditional forms of collaboration; social capital; attitude toward corruption; traditions and community values related to natural resource use                           |

|                                        |                                                                                                                                                                                                                                                           |
|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A7 Knowledge of SES/Mental Models      | Local knowledge on SES; knowledge of effect of over-harvesting, social attitudes toward natural resource management, and biological shocks on SES; mental models related to SES management (e.g., conservation, exploitation, human-nature relationships) |
| A8 Importance of Resource (dependence) |                                                                                                                                                                                                                                                           |
| A9 Technology Available/Used           |                                                                                                                                                                                                                                                           |
| <b><i>Transformation Systems</i></b>   |                                                                                                                                                                                                                                                           |
| T1 Transformation Systems              |                                                                                                                                                                                                                                                           |
| T2 Products                            |                                                                                                                                                                                                                                                           |

### 1.3.2. Historical institutionalism

This thesis takes a historical-institutionalist approach to understand how path-dependencies influence institutions and rules-in-use governing fire management, and how they interact to structure social, political, and economic behaviour and change. Historical institutionalism stands between rational choice and social institutionalism theory, understanding institutions as rules, social norms, and organisations that shape how individuals interact and see the world, and as choice domains that frame individual strategic behaviour (Thelen, 1999; Bucheli & Wadhwani, 2013; Fioretos, Falleti & Sheingate, 2016). Hence, institutions define and set the rules for actors, determining action situations and the options available to various actors to participate in decision-making processes and, in-turn, possible outcomes, including political preferences and governance strategies. Rules are not fixed, however, and actor behaviour is contingent on the individual, context, and how rules interact with these dynamics over space and time (Schmidt, 2008; Jackson, 2009). When these three variables interact to determine the action situation, there is no a-priori way of knowing the policy outcomes from a chain of independent events. Instead, the political action situation represents a temporal domain of interacting causal variables.

Existing SES studies have applied a historical-institutionalist lens to explore the politics of climate and sustainable development (Lockwood et al., 2017), international relations (Fioretos, 2011), human and ecological resilience to environmental change, political drivers of institutional design and diversity (Sjöstedt, 2015), institutional legacies of colonialism (Juan & Pierskalla, 2017; Opalo, 2022), and contested property-rights systems (Harriss, 2006). Persistence literature similarly applies causal inference to assess how persisting historical legacies influence current and emerging systems dynamics (Abad & Maurer, 2021).

Recognising how the wildfire paradox and processes of ecological and biocultural hysteresis are symptomatic of historical injustices in natural resource governance across African savannas, this thesis centralises the concept of path-dependency in its analysis of the opportunities and challenges for alternative fire management approaches. In this way, institutions and behaviours are recognised as the product of accumulative historical interdependencies between multiple causal variables (Berkes, 2017), of which need to be interrogated to understand the current political-economic environment.

### 1.3.3. Decolonising methodologies

To address the overall aim and second research objective of this thesis, principles of decolonising methodologies were applied throughout the research process. At its core, decolonising methodologies acknowledges that research is a political act, and the way in which researchers exercise and communicate knowledge is deeply embedded in global power dynamics (Smith, 2021). It seeks to pursue epistemological freedom and the equal and unassumed incorporation of ‘other’ knowledges into scientific research, thus transcending ontological assumptions and researcher subjectivities (Thambinathan & Kinsella, 2021). Decolonising methodologies are continuously evolving, challenging the ways in which research can reproduce colonial paradoxes in disciplinary power on decolonisation (Croker et al., 2024). Acknowledging its complexity and breadth, I led the Leverhulme Centre for Wildfires, Environment, and Society’s Decolonising Fire Science workshop series between 2022 and 2024 to explore opportunities for participatory research approaches that foreground relationality and experience in the construction of scientific understandings of fire-use communities and landscapes. This series centered questions of positionality, power, justice, legitimacy, and “otherness” to identify how patterns of power and privilege shape research inquiries in local contexts. In doing so, it revealed how discourse on bottom-up fire management approaches have mainly been constructed by Western researchers, or “outsiders”, in the local context in which they are researching. Hence, existing policy solutions are often underpinned by subjective interpretations of the published literature, of which often assimilate diverse knowledge systems and evolving practices into a singular epistemic tradition which can be easily extracted. This research sought to overcome some of these challenges by prioritising ethnical and non-extractive research relations with local people, thus aiming to produce locally relevant and meaningful results.

See Croker et al., (2022), Croker and Ford (2022), and Croker et al., (2024) for full workshop and case-study reports. These articles provide further detail over the principles of decolonisation applied throughout this thesis and highlight the relevant literature.

## 1.4. Thesis structure

This thesis consists of eight chapters to address the research aims and objectives:

**Chapter 1** has described the theoretical frameworks applied throughout this thesis to structure exploratory analyses and discussions, supporting a bricolage approach to holistically make sense of emerging results in a complex dynamic research setting (Lotteri et al., 2023; Kincheloe, 2011).

**Chapter 2** comprises a literature review to contextualise the research inquiry, results, and discussion. The review covers the following themes: (i) African context; (ii) co-evolution of modern humans, fire-use practices, and biodiverse grassy-savannas; (iii) evolution of the ‘wildfire paradox’; (iv) ‘wildfire paradox’: flaming conservation fronts; (v) community-based fire management (CBFiM); (vi) carbon

economy in environmental management; (vii) savanna burning emissions abatement (SBEA). Following this, Chapter 2 details two systematic reviews conducted independently on CBFiM and SBEA to ascertain a stronger understanding of current and proposed bottom-up fire management approaches in East and Southern African savanna-protected areas. This chapter discusses the biogeophysical, environmental, and sociocultural implications of the results on opportunities and challenges for future fire management, both in terms of drivers and impacts.

**Chapter 3** details the reasons for carrying out fieldwork across the Tsavo Conservation Area, Kenya, the methodologies applied to understand diverse perceptions of fire management, and how data was analysed and used to address the overall aim and objectives of this thesis, including a short description of the data's contribution to the development of a Belief Network model detailed in Chapter 6.

**Chapters 4 and 5** present and discuss the results and outcomes derived from thematic and semi-quantitative fieldwork data analysis, providing an in-depth discussion of the wildfire paradox in relation to broader multi-systemic processes (e.g., ecological, social, cultural, economic, political, legal) and its interconnected drivers, dynamics, and outcomes at the landscape-level.

**Chapter 5** is divided into 4 main sections to structure the discussion: (i) climate and biology, topographic environment, and fires; (ii) society, culture, and fires; (iii) wildfire attribution; (iv) fire policy and management. While this discussion draws on systemic challenges and policy and legislation specific to Kenya, similar challenges and policies are experienced across Sub-Saharan African and fire-prone savanna conservation landscapes more broadly, thus providing locally, regionally, and, in some cases, globally relevant findings.

**Chapter 6** details the development of a Belief Network (SAV BN) to achieve the third research objective of this thesis. First, by describing why the specific modelling approach was selected and its uniqueness, then by detailing the construction of joint socioeconomic-climate and fire management scenarios, the methodologies applied for developing the model network, parameterising scenarios, and carrying out a sensitivity analysis, and lastly by outlining future considerations.

**Chapter 7** presents the modelled outcomes and results. A comparative overview of fire management scenarios under socioeconomic-climate change is followed by a critical analysis of each scenario.

Lastly, **Chapter 8** directly addresses the overall aim and objectives of this thesis by summarising key findings and points of contention, discussing overall conclusions on the opportunities and challenges for alternative bottom-up fire management in East and Southern African savanna-protected areas. As such, this chapter highlights the importance of conceptually redefining the wildfire paradox in conservation environments to foster more social-ecologically relevant research and solutions, sharing policy recommendations and broader socioeconomic considerations for the development of equitable

fire management approaches under increasing socioeconomic-climate change. Lastly, gaps for future research and areas that could benefit from further development are identified.

## Chapter 2. Understanding bottom-up fire management in state-governed savanna-protected areas

This chapter draws on two peer-reviewed review articles developed by the author during this thesis to identify and describe the main opportunities and challenges for the implementation of alternative bottom-up fire management approaches in East and Southern African savanna-protected areas:

- (i) ‘Community-Based Fire Management in East and Southern African Savanna-Protected Areas: A Review of the Published Evidence’ (Croker et al. 2023a).

Reference: Croker, A. R., Woods, J. and Kountouris, Y. (2023) Community-based fire management in East and Southern African savanna-protected areas: A review of the published evidence. *Earth's Future*, 11, e2023EF003552. <https://doi.org/10.1029/2023EF003552>

**Information extracted from papers included in this analysis were recorded in a publicly available systematic map: <https://doi.org/10.6084/m9.figshare.21976316.v1> (Croker, 2023).**

- (ii) ‘Changing fire regimes in East and Southern Africa’s savanna-protected areas: opportunities and challenges for indigenous-led savanna burning emissions abatement schemes’ (Croker et al. 2023b).

Croker, A. R., Woods, J. and Kountouris, Y. (2023) Changing fire regimes in East and Southern Africa’s savanna-protected areas: opportunities and challenges for indigenous-led savanna burning emissions abatement schemes. *Fire Ecology*, 19(63). <https://doi.org/10.1186/s42408-023-00215-1>

All authors of the articles have agreed on their inclusion in this thesis.

### 2.1. African context

Unprecedented climatic changes, rapid human population growth, and (neo)colonial influences set East and Southern Africa apart from the rest of the world. These challenges interact to create a highly complex domain for the development of equitable, adaptive, and sustainable bottom-up fire management approaches to address wildfire challenges across savanna-protected areas.

Africa’s surface and mean annual temperatures exceed the global average, driving increased variability in annual wet and dry season conditions and lengthening the fire season across East and

Southern Africa by more than a month relative to the 1980s (Jolly et al., 2015; Covington & Pyne, 2020). The IPCC (2021) identified Southern Africa as the continent's 'hottest spot', warming at a rate four-times faster than the global average and experiencing a 220% increase in flash drought events (1961-2016) (Kruger & Sekele, 2013). East African countries are also experiencing an increase in extreme pluvial floods interspersed with prolonged agricultural ecological droughts<sup>1</sup>, resulting in severe savanna degradation (Funk et al., 2018; Kew et al., 2021). This increase in climate extremes and uncertainty over feedbacks between fire, rainfall, soil, vegetation, and herbivory complicate long-term fire predictions and raise questions over binary seasonal boundaries between the early- and late-dry season in prescribed fire regimes (Laris, 2021; Young et al., 2022).

Sub-Saharan Africa's population is projected to increase from 1.1 billion in 2020 to 3.8-5.7 billion in 2100 (UN DESA, 2019), thus experiencing the world's highest growth rate. In low-income countries, population growth is often compounded by high rates of migration, rapid urbanisation<sup>2</sup> and insecure settlement-governance arrangements (Güneralp et al., 2017), inter-group conflict and land disputes, food insecurity (FAO et al. 2021), and income inequality (Sulemana et al., 2019), exacerbating pressures on economic and infrastructure development (Peterson, 2017). In recent history, large-scale land-use change and tenure reforms have reorganised and privatised access to critical resources, intensifying the impact of population growth on subsistence-based economies, particularly (semi-) mobile pastoral communities. Where agro-pastoralists can benefit from the introduction of and increased access to (inter)national markets in rural areas, they are increasingly 'moving up' into commercial livestock production (e.g., ranching) and other high-return economic activities. The majority, however, do not have access to resources critical for pastoralism, thus depending on market access, are 'moving out' into high-return economic activities not directly linked to pastoralism, or are 'dropping out' into low-return, cash-based economic activities (often casual/temporary employment) (Lind et al., 2020; Kirui et al., 2022). Those 'moving up' and 'moving out' represent an emerging class of pastoral entrepreneurs and traders in Africa who place more value on non-livestock goods and services compared to their ancestors. While those 'dropping out' are increasingly engaging in perceivably 'low-risk high-return' illegal practices (see section 5.2) (Chege, 2015).

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<sup>1</sup>Agricultural and ecological droughts refer specifically to the impacts of rainfall deficits on joint agricultural-ecological systems, rather than on hydrological (i.e., water supply such as stream flow, lake levels, and ground water table) and socioeconomic (i.e., supply and demand of economic goods) systems. They consider how meteorological (i.e., rainfall deficit and consecutive dry days) and hydrological droughts impact the agricultural sector due to changing ecological conditions, such as the biophysical properties and moisture content of vegetation and soil, actual and potential rate of evapotranspiration, ground water and reservoir levels required for irrigation, and shifting seasonality. Therefore, are closely connected to socioeconomic droughts due to declines in agricultural commodities (Wilhite & Glantz, 1985).

<sup>2</sup>Sub-Saharan Africa is the fastest urbanizing region globally. Urban areas are currently inhabited by 472 million people. This figure is expected to double over the next 25 years. By 2050, more than 20% of the world's urban population will reside across this region (Saghir, 2018).

The prioritisation of resource extraction in colonial policy in Africa has established lasting power hierarchies between former colonisers and colonies in the global economy, reinforced by the international aid regime (e.g., green conditionalities on conservation-development projects) (Bailey & Bryant, 1997; Eriksen, 2007), and the re-territorialisation of communal rangelands increasingly viewed as development frontiers (Catley, Lind & Scoones, 2012). These challenges are pronounced in areas where weak governance, corruption, and lack of accountability have removed local monitoring and regulatory barriers, lowering the transaction costs of extractive activities (Koenig-Archibugi, 2004; Ford et al., 2020). The dependent position of resource-rich African states in the global economy has constrained their ability to utilise natural resource for generating national wealth (Besada, Lisk & Martin, 2015; Taylor, 2015). Rather, Western institutions and donors hold strong political influence over regional and local natural resource management projects, raising the possibility that the distribution of climate mitigation finance and the development of accredited carbon projects is influenced by colonial ties and contingent on the willingness of beneficiary countries to facilitate donor interests (Halimanjaya, 2015).

## **2.2. Co-evolution of modern humans, fire-use practices, and biodiverse grassy-savannas**

Humans have used fire as a livelihood and land management tool across Sub-Saharan Africa from as early as 1.5 Mya (Pooley, 2021), significantly influencing the evolution of tropical savanna ecosystems (Bond & Keeley, 2005). Elemental carbon studies show that fire incidences remained low until 400Ka BP when humans developed tools to ignite their own fires independent of wet season lightning events (Bowman et al., 2011; Archibald, Staver & Levin, 2012). Early fire-use altered the frequency and seasonality of fire incidences, while the more recent diversification of agropastoralism (~4,000 BP) across the continent transformed fuel connectivity and composition (Archibald, Staver & Levin, 2012; Western et al., 2021), creating a human-driven fire regime.

Savannas extend over 50% of the African continent, existing across highly arid (<100mm MAP) and mesic (~1000-1500mm MAP) environments, and exhibiting large spatiotemporal variability in their composition and functional diversity. Fires dynamically and non-linearly interact with multiple biogeophysical (e.g., nutritional gradients, rainfall, and herbivory) and sociocultural (e.g., economic activities and land-use values) variables to determine C<sub>4</sub> grass to C<sub>3</sub> woody species ratios and distributions (Archibald et al., 2005; Prior & Eriksen, 2013; Perreault, Bridge & McCarthy, 2015; Pyne, 2018).

Pyro-diverse fire regimes can minimise woody encroachment and support the regeneration of biodiverse C<sub>4</sub>-dominated grasslands able to maximise photosynthetic efficiency under increasing temperatures, thus contributing to biogeochemical cycling, long-term carbon sequestration, and sustained ecosystem productivity (Beerling & Osborne, 2006; Staver, Archibald & Levin, 2011). Arid and semi-arid savannas (<1000mm MAP) are often considered as ‘precipitation-limited’, where

vegetation growth is mostly constrained by rainfall. This is consistent with empirical evidence highlighting the linear (yet discontinuous) relationship between increasing rainfall on tree demographics, transitioning from (i) stable low tree cover, to (ii) bistable low-high tree cover, to (iii) stable high tree cover (Staver & Levin, 2012; Schertzer, Staver & Levin, 2015). Mesic savannas (>1000mm MAP) climatically overlap with forest ecosystems, therefore requiring frequent fire disturbances to prevent ecological succession to a closed-canopy state (Laris et al., 2016). As such, mesic savannas are often considered as ‘disturbance-driven’, where fire facilitates bistability in tree-cover under higher rainfall concentrations. However, fire spread has a threshold response to grass cover, with empirical evidence suggesting that fire occurrence declines at a threshold tree cover near 40%, implying a continuous grassy layer of approx. 60% (Abades, Gaxiola & Marquet, 2014).

Large herbivores have co-evolved with humans and savannas for millennia (Gowlett, 2016; Pennington, Lehmann & Rowland, 2018). Nine East and Southern African countries rank in the top 20 for the conservation of extant megafauna, with all countries across the region performing above the global average (excluding South Africa) (Ceballos & Ehrlich, 2006; Lindsey et al., 2017; Hocknull et al., 2020). Hence, herbivores exhibit a large influence over the structure and functioning of African savannas, interacting with fires on evolutionary and ecological timescales as critical disturbance events in the savanna adaptive cycle (Archibald & Hempson, 2016). Both fire and herbivores are controlled by and control vegetation dynamics across the precipitation gradient, competing as dominant fuel consumers. However, herbivore disturbances exhibit greater control over woody vegetation cover across arid-eutrophic savannas, particularly across the arid transition zone where savanna extent precedes fire occurrences (Crocker et al. 2023b), whereas fire disturbances have greater control across mesic-dystrophic savannas (Du Toit & Cumming, 1999; Staver, Archibald & Levin, 2011). Though commonly perceived as competitive (i.e., limiting fires can make consumable biomass available to herbivores, and vice-versa), herbivory-fire interactions are largely facilitative. While fires indiscriminately remove palatable and unpalatable herbaceous species, they facilitate the regeneration of nutrient-rich palatable grass species important for herbivore survival. Similarly, herbivores reduce ground fuel loads, while at the same time opening-up relatively closed-canopy woody structures, facilitating fire spread and the maintenance of open-canopy grass-dominated savannas (Bond & Wilgen, 2012; Venter, Hawkins & Cramer, 2017). Fire events are rapidly responding to anthropogenic climate change and novel environmental conditions, whereas herbivory, constrained by evolutionary and demographic processes, will take far longer to equilibrate, with rate of change often surpassing species’ ability to adaptively respond (Radchuk et al., 2019; Moore & Schindler, 2022). Over both ecological and evolutionary timescales, changes in the frequency, intensity, and distribution of disturbance events can disrupt the savanna adaptive cycle, driving a regime shift.

The determination of a ‘natural’ fire regime and its constituents have been widely contested in the literature (Ratnam et al., 2011), with some studies defining natural fire regimes as those which

preceded ‘the truly destructive forms of human fire’ (i.e., fires caused by lightning, geological processes and friction, or spontaneous combustions (Scott, 2000)) (Krebs et al., 2010). However, the co-evolution of modern humans and their fire-use practices with highly biodiverse savanna ecosystems makes it near impossible, possibly redundant, and increasingly problematic to decipher between human and natural aspects of the fire regime (Galvin & Reid, 2010; Laris & Jacobs, 2021). Situating fires within the region’s colonial context, this thesis defines ‘natural fire regimes’ as those resulting from diverse sociocultural and subsistence-based livelihood burns prior to 19<sup>th</sup>-century European colonisation, during and after which a singular ‘anthropogenic fire regime’ has dominated.

### 2.3. Evolution of the ‘wildfire paradox’

The discipline of fire ecology has evolved within early preservationist models of conservation which legally set aside land for royal and state hunting activities, displacing local people from their ancestral lands and introducing strict restrictions on livelihood practices (e.g., hunting, now deemed ‘poaching’ and resource harvesting) and fire-use (Pooley, 2021; Kobziar et al., 2024). For example, in 11<sup>th</sup> century England, Forest Law actively pursued afforestation to create woody hunting blocks across royal and manorial demesne, and across non-manor that were escheated as temporary royal demesne, including common land (Serovayskay, 2000; Robinson, 2020) Serovayskay, 2000; Robinson, 2020). This created greater divisions between political elites and the peasantry class, driving protests and collective uprisings symptomatic of the struggle against feudal institutions and their inherent exploitative nature. Fire increasingly became a symbol of agrarian resistance during this period, thus attributing burns to a ‘scrambled social order that was no longer able or willing to impose its image on the land’ (Pyne, 2012). This strengthened existing negative perceptions of fire perpetuated through imageries of hell and biblical accounts of fires ‘devouring’ forests<sup>3</sup>, which had significant socio-political influence at the time. Since the 11<sup>th</sup> century, the management of fire has become increasingly depoliticised through the institutionalisation of burning practices to standardise norms, beliefs, rules, policies, and legislation governing fire use.

Forestry sciences, formalised in the 15<sup>th</sup> century to protect and sustainably yield natural resources important for the shipping industry (mostly timber and oak), portrayed local fire-use as an ‘evil practice’ (Eriksen., 2007) and cause of ‘forest destruction’, transforming primary forest habitats into anthropogenic ‘species-poor’ secondary savannas (Bloesch., 1999). Political ecologists such as Lee (1984) determined that the concept of sustainable yields remained a central doctrine in forestry sciences and was ‘developed as an instrument for ordering social and economic conditions, as well as

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<sup>3</sup> For example, fire ‘may devour your cedars’ (Zechariah (11:1)); ‘I will kindle a fire in her forest, and it shall devour all that is round about her’ (Jeremiah (21:14)); ‘Fire has devoured the pastures of the wilderness, and flame has burned all the trees in the field’ (Joel (1:19)) (Pyne., 2012).

managing the production of wood from forests' (Lee, 1990). The establishment of forestry schools and institutions across Europe throughout the 18<sup>th</sup>-19<sup>th</sup> centuries, and later the USA and European colonies (Adams & Mulligan, 2002; Domínguez & Luoma, 2020), accelerated the expansion of exclusionary protected areas to grow and manage forests to meet the growing demands of the global capitalist economy, further rejecting the rights of local people to access ancestral lands and common resources. For example, in the wake of forest fires in the late 1800s and prominent discourses over their negative effects on timber supplies, the 1891 Forest Reserve Act was legislated in the USA to set aside reserves where the President retained complete authority, displacing local inhabitants and imposing strict punishments on fire-use practices and (now) illegal activities in the parks (e.g., access or resource extraction).

The seeds of this preservationist-based 'truth regime' were largely articulated through the 19<sup>th</sup>-20<sup>th</sup> century wilderness movement, romanticising notions of a nature devoid of humans. This created a Western-centric environmental discourse which 'define[d] various forms of agency, administer[ed] silences, and prescribe[d] various forms of intervention' (Brosius, 1999), thus leading to the establishment of the world's first formal wildlife-based national park system in the USA (Singh & van Houtum, 2002). Indigenous people were forcibly removed from their lands, and uniformed military personnel were employed and stationed in outposts to protect natural resources reserved for the state and for global elites able to pay for tourism and hunting privileges. Following the 1884 Berlin Conference and the demarcation of new African states, this 'fortress' model of conservation expanded across the continent to facilitate colonial extraction (e.g., planting and harvesting woody plantation species, game viewing and hunting), cutting across bioculturally diverse ecosystems and ethnic boundaries (Moura et al., 2019). Africa's physical environment provided a medium for colonial action, enabling colonial administrations to preserve their notions, meanings, and uses of nature (Shanguhya, 2018). Nelson (2003) suggests that the romanticisation of nature has created an Edenic narrative in conservation, aiming to 'protect the vestiges of the original natural order' prior to modern civilisation:

'Today, Africa is still being presented in such Edenic terms. However, the Eden myth with Africans present has been supplanted by images of an Edenic wilderness in which current Africans, as well as non-Africans (except tourists), must be excluded. [...] In Western eyes, the original innocence of nature is now found in places where modern Africans themselves are kept out because they have acquired the technical power to subject nature to human domination. Thus, the African Eden now survives only in protected places such as the national parks created in many African countries.'

Colonial ideologies and regimes were rationalized and routinised during the inter-war years (Young, 1994; Rash & Horan, 2020; Poncelet, 2020), driving the institutionalisation of militarized approaches

to conservation and natural resource management in Africa (Massé & Lunstrum, 2016; Duffy et al., 2019). Integrated fire management (IFM) frameworks emerged as a cross-sectoral fire suppression and prevention approach to limit fire in forested ecosystems and protect economically important resources. Centralised Incident-Command Systems, representative of the US Navy's military structure, tend to oversee IFM activities and allocate responsibilities when fire incidences arise (Tendim et al. 2020). Such top-down command systems limit opportunities for a paradigmatic shift away from 'War on Fire' towards 'Living with Fire' (Ekblom et al., 2019).

Historical efforts to eradicate fires have created lasting degradative narratives which have percolated into the discipline of fire ecology (Kobziar et al., 2024). Whereas other regions globally are beginning to recognise the sociocultural and ecological importance of fire and reconcile traditional fire paradigms with state-centric wildlife management plans (Rego et al., 2021), colonially inherited anti-fire wisdoms remain strong across independent East and Southern African states. This has contributed to the expansion of state-governed conservation areas and fire suppression operations in the absence of formal fire management (Bergius et al., 2020; Phelps et al., 2022).

## **2.4. 'Wildfire paradox': flaming conservation fronts**

The enforcement of strict bans on sociocultural burning practices, and reorganisation of people and livestock across time and space, have altered the distribution, density, and type of biomass synthesised by fires across East and Southern African savanna-conservation landscapes (Moura et al., 2019). Coupled with increasing anthropogenic climate change and fire-weather conditions, these processes have catalyzed a pyric transition across this region. Inside savanna-protected areas, a 'wildfire paradox' has replaced the historical fire regime, characterised by extreme wildfire events that exceed natural variability levels due to the exclusion of humans and livestock and, in-turn, the accumulation of flammable biomass (Tedim, Leone & McGee, 2019). Outside their boundaries, human settlement and sedentarisation patterns, trends in agricultural commercialisation (Bond & Keeley, 2005), and high livestock densities and stocking rates, have mostly eliminated fire from the landscape (Archibald, 2016; Probert et al., 2019). While livestock grazing is illegal in most protected areas across the region, encroachment along borders persists in the absence of effective exclusion mechanisms. This is likely to increase as pastoralists transition toward commercial cattle ranching, further reducing biomass available to fires and imposing forms of habitat compression on ecosystems within the protected areas (Lindsey et al., 2017; Yurco, 2017).

While declines in small-scale livelihood fires have reduced total burned area across African savannas (Andela et al., 2017), this ecoregion extends over 50-70% of the continent, accounts for >60% of global fire extent, and is responsible for approximately 71% of global savanna CO<sub>2</sub> emissions (UNU-IAS., 2015; Maraseni et al., 2016). These fires are concentrated in East and Southern African savanna-protected areas where >80% of annual large fire extent and emissions occur in the late-dry season

(LDS), driven by higher temperatures, lower relative humidity, high fuel loads, and high intensity fuel combustion conditions (Russell-Smith et al., 2021). As such, prolonged drought conditions interspersed with heavy rainfall events under future climate change poses a significant wildfire risk, particularly where chaotic and uncoordinated fire practices are pursued by local communities due to the breakdown of traditional land governance structures and ongoing antagonisms between local peoples and park authorities (Bloesch, 1999; Kull, 2002).

The juxtaposition of an absent versus wildfire-dominated fire regime that outstrips firefighting capacities has resulted in widespread bush encroachment (Gil-Romera, Turton & Sevilla-Callejo, 2011), savanna biodiversity loss, ecosystem degradation, socioeconomic vulnerabilities, and reduced vegetation and soil carbon sequestration potential (Pyne, 2018; Loehman, 2020; Osborne et al., 2018). Across fire-adapted savanna-dominated conservation areas, this juxtaposition is, of itself, a wildfire paradox, symptomatic of historical inequalities and the failures of colonial and post-independence resource management policies (Otero & Nielsen, 2017). While current conceptualisations of the wildfire paradox emphasise vegetational and geophysical factors driving extreme wildfire regimes, they often overlook the sociocultural factors, such as the role of exclusionary land tenure arrangements on the type, frequency, and distribution of fire ignitions.

## **2.5. Community-based fire management**

The 1971 Tall Timbers Fire Ecology Conference on ‘Fires in Africa’ highlighted the importance of both social and physical characteristics of savanna fire regimes (Trollope, 2011). In the 1990s, interdisciplinary research began documenting complex human-fire relationships in East and Southern Africa, acknowledging opportunities for CBFiM in local contexts (Pooley, 2021). CBFiM is defined as ‘a type of land and forest management in which a locally resident community has substantial involvement in deciding the objectives and practices involved in preventing, controlling, or utilising fires’ (Ganz, Fisher & Moore, 2003; FAO, 2011).

Extreme wildfire events are increasingly forcing governments to redress reactive fire measures and consider alternative anticipative approaches, acknowledging both the social and physical dimensions of the fire regime. In recent years, CBFiM has been proposed as an alternative bottom-up approach to address East and Southern Africa’s wildfire paradox, recognizing the dual role of fire as regenerative and destructive in savanna ecosystems, and the need to transcend formal organisations to include traditional governance structures in sustainable resource management (Tedim, Leone & McGee, 2019).

However, limited scrutiny of its defining features and divergent understandings of its objectives can compromise its effectiveness as an equitable fire management approach. The lack of a clear framework defining CBFiM gives rise to discursive understandings of the level and nature of

community participation required in decision-making and fire activities for projects to be considered community-based (Krah et al., 2020). Traditional fire practices have been applied in several types of wildfire management strategies worldwide (Smith et al., 2024), including state-mandated or voluntary projects that aim to revitalise cultural burning by local people (Petty et al., 2015; Neale et al., 2019), the establishment of community fire brigades to support local wildfire prevention operations (Dube, 2013), and payment for ecosystem services (PES) schemes for conducting prescribed burns to offset LDS fires and protect forests (McKemey et al., 2020), or to limit burning to reduce emissions and increase carbon sequestration (Khatun, Corbera & Ball, 2017). Hence, CBFiM currently describes projects where significant legal rights and authority over fire management are devolved to IPLCs, as well as projects enlisting select individuals as volunteers in centralized burning programs, where their roles and responsibilities are regulated by government officials (FAO, 2011).

Discursive understandings of CBFiM are further conflated by the concept of ‘community’ itself, often externally constructed and lacking specificity (Kumar, 2005). Terms including ‘participatory’, ‘community-inclusive’, ‘adaptive’, and ‘collaborative’ are often arbitrarily used by external agents when developing community-based projects (Profant, Cornwall & Eade, 2011; Sihlongonyane, 2009), contributing to poor CBFiM project design and implementation, and threatening opportunities for equitable and sustainable bottom-up fire governance (Mansuri & Rao, 2004).

## **2.6. Carbon economy in environmental management**

Since the inception of CBFiM in the 1990s, opportunities for bottom-up fire management in local contexts have been stymied by the concurrent rise of the international-intergovernmental climate agenda which has, inadvertently, reinforced anti-fire rhetoric in environmental management. The 1987 Montreal Protocol, 1992 UN Earth Summit and establishment of the UNFCCC, and 1997 Kyoto Protocol have formalised principles of ‘common but differentiated responsibilities’ for nation states to collectively ‘prevent dangerous human interference with the climate system’ by protecting the ozone layer and reducing GHG emissions. Hence, popular discourse reporting on ‘ferocious’ fires that ‘destroy the ozone layer’, reduce ‘critical carbon stocks’, and threaten national GHG objectives have contributed to the preservation and enhancement of centralised bans on burning (Smith et al., 2024).

The advent of the global carbon market under the Kyoto Protocol has driven an ideological shift in international and local resource governance. Management interventions are increasingly prioritised based on their carbon revenue potential, largely in relation to economic development, but also for reasons of political expediency potential (Douglass et al., 2011). For example, the Clean Development Mechanism (CDM) instituted by the Kyoto Protocol (UN, 1998: Article 12) is one of the largest sources of climate mitigation finance to developing countries, offering a flexible instrument for developed countries to achieve their national GHG reductions through cost-effective public-private offset projects (Fankhauser & Hepburn, 2010; Russell-Smith et al., 2015). Additionally, REDD+ can

increase private and voluntary investment in developing countries who receive results-based payments through forest preservation and associated emissions reductions.

The UNFCCC defines forests as lying within the following thresholds: (i) single minimum tree crown-cover value between 10-30%, (ii) single minimum land area value between 0.05-1ha, and (iii) single minimum tree height value between 2-5m, enabling host countries to determine sites eligible for carbon-based PES projects based on their own definition as long as it is within these limits. Considering the potential financial benefits accrued at the national level, projects instituted under the CDM, REDD+, IUCN Green Climate Fund, and World Resource Institute (amongst others) have proliferated across East and Southern Africa. Carbon accounting methodologies have mostly been informed by studies focusing on above-ground carbon (AGC), typically measuring high AGC densities in mesic and dry forests (or woodlands), and medium to low densities in agricultural encroachments and savannas. This has signalled negative land-cover change in tropical grassland regions, therefore promoting initiatives that aim to reduce human-induced land-use change, maximise carbon sequestration through above-ground woody biomass, and, in-turn, generate accountable carbon credits (Articles 2 and 3 of the Kyoto Protocol). These methodologies often do not consider or are practically constrained in measuring below-ground carbon (BGC) densities, despite evidence showing that BGC concentrations are higher than AGC in productive grass-dominated savannas (Pellikka et al., 2018). Under this definition of forest, ecosystems historically recognised as open-canopy savannas are increasingly understood as tropical forests, making them eligible for project implementation. Until recent history, this has reinforced Clementsian views on vegetation succession and fire suppression policies (Parr, te Beest & Stevens, 2024).

## **2.7. Savanna burning emissions abatement**

The wildfire paradox observed across East and Southern Africa's protected areas compromises local, national, and international biodiversity conservation and GHG emissions reductions targets (Russell-Smith et al., 2013; Osborne et al., 2018), particularly where LDS wildfires threaten carbon-based forestation projects. To mitigate these challenges, Kyoto-compliant savanna burning emissions abatement (SBEA) schemes are increasingly proposed as an alternative CBFiM approach in semi-arid and mesic African savanna-protected areas. SBEA schemes aim to reduce the frequency, intensity, and extent of savanna fires through a seasonal shift in burning from the LDS to the EDS, therefore offsetting associated GHG emissions (Corey et al., 2020)

SBEA schemes were first established across Northern Australia's sparsely populated eucalyptus-dominated savannas which extend over 1.9 million km<sup>2</sup> and experience high intensity LDS fires. Approximately 20% of these savannas are burned annually by LDS wildfires (Russell-Smith et al., 2013), contributing up to 50% of Australia's Northern Territory's annual total GHG emissions (Whitehead et al., 2008). Recognising these challenges, the Australian government incorporated

savanna burning as an emissions reduction activity in its National GHG Inventory, integrating Aboriginal fire management with Kyoto-compliant emissions reductions methodologies (Maraseni et al., 2016). In 1997, the West Arnhem Land Fire Abatement (WALFA) project was established over 28,000km<sup>2</sup> of fire-prone savannas (Russell-Smith et al., 2015). Since then, SBEA schemes have been formally accredited in the government's Emissions Reduction Fund, leading to over 70 SBEA projects being registered across Northern Australia, many with new Aboriginal-owned companies created to operate fire projects (Ansell & Evans, 2019; McKemey et al., 2020). Some projects have been implemented in conservation areas jointly managed by traditional landowners and government officials, such as Nitmiluk and Kakadu National Parks (Edwards et al., 2021).

Given the high contribution of Sub-Saharan African savannas to global CO<sub>2</sub> emissions, such 'Indigenous-led' SBEA projects operating under the CDM or other carbon-based mechanisms are presented as market opportunities in Africa, with 'real, measurable and long-term benefits related to the mitigation of climate change' through increased investment, the transfer of green technologies, and employment opportunities (UN, 1998; UNFCCC, 2011). In addition to achieving climate mitigation targets, they are promoted as 'win-win-win' solutions to simultaneously curb biodiversity loss (Tear et al. 2021) and build resilient communities through the diversification of landholders' incomes and improvement of local and national economic conditions (Russell-Smith et al., 2017; Moura et al., 2019). As such, they are framed as 'community-based' or 'decolonising experiments' in fire management (Neale et al., 2019), where the interest of pastoralists and indigenous landholders is a pre-requisite for project development (Lipsett-Moore, Wolff & Game, 2018). This implies that institutional legitimacy and the empowerment of local populations are critical components of SBEA schemes, supporting long-term sustainable resource management and avoiding uncontrolled fire use centred on individualistic short-term objectives (Bloesch., 1999).

Lipsett-Moore et al., (2018) identified 29 African states that could benefit from SBEA to reduce greenhouse emissions, 17 of which are Least Developed Countries and account for 37% of total savanna burning emissions. SBEA pilot sites have been identified across the Kavango-Zambezi Transfrontier Conservation Area, Luangwa Valley sub-region in Zambia, and Central Kalahari in Botswana (UNU-IAS., 2015). This is contingent on the enactment of Kyoto-compliant accounting methodologies and the establishment of a National Greenhouse Inventory, a National Emissions Registry, and a Designated National Authority to oversee SBEA activities (Russell-Smith et al., 2017).

## **2.8. Systematic review of alternative CBFiM approaches**

Two separate systematic reviews of the published literature were conducted to critically examine opportunities and challenges for the implementation of CBFiM in East and Southern African savanna-protected areas. The first review followed a systematic mapping methodology and applied a social-ecological systems framework to examine the framing, nature, and extent of CBFiM in the research

context, identifying (in)consistencies in the understanding and implementation of bottom-up approaches. This review revealed growing international interest in the development of “indigenous-led” or “community-based” savanna burning emissions abatement (SBEA) schemes, first implemented in Northern Australia, in East and Southern African savanna-protected areas. Hence, it was imperative to carry out an independent second review to critically analyse the influence of and interrogate the assumptions informing the transfer of Australian SBEA methodologies to the African context. A pyro-geographic framework was applied to assess how inter-regional variation and nuances in the human and physical environment might impact their implementation in African savannas.

### **2.8.1. Review methods**

Both reviews applied the Collaboration for Environmental Evidence's Version 5.0 review and synthesis protocol (CEE, 2022) and used a qualitative Population, Interest, Context (PICO) framework to structure the search strategy (e.g., development of search string syntax and inclusion-exclusion criteria). To maintain consistency across the two reviews, East and Southern Africa was defined as the region encompassing Angola, Botswana, Burundi, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Rwanda, Somalia, Somaliland, South Africa, Swaziland (or Eswatini), Tanzania, Uganda, Zambia, and Zimbabwe.

Initial scoping reviews of the literature were carried out to explore the current state of knowledge on CBFiM and SBEA in the research context. Test-lists consisting of 10 articles identified as relevant to the synthesis questions were established independently from the systematic searches and were used to develop and assess the performance of the search strategies (e.g., number of studies returned and retrieval performance of each search string syntax). Search terms were selected from test-list papers, grey literature (e.g., workshop reports and policy documents), and previous systematic reviews. Search string syntax were developed iteratively, applying Boolean operators (AND, OR) and wild cards (\*) to combine key words and phrases until all 10 test-list articles were retrieved. A high-sensitivity low-specificity approach was taken to capture the breadth of information and minimise potential cognitive and selection biases, such that a high number of articles were retrieved, but a low number of articles were identified as relevant to the synthesis questions during the screening process. The performance of the search strategies and retrieval saturation were recorded.

Final search strings were applied under the Topic Subject of Title, Abstract, and Keywords, and there were no limitations on publication date. Articles were retrieved in Scopus (both) and Web of Science (CBFiM) by application of pre-established inclusion and exclusion criterion based on the PICO framework used to structure the reviews. Retrieved articles were screened over a three-step process: title, abstract, full-paper, and final inclusion criteria was refined during the title and abstract screening stages. Articles were included in the final reviews if they met all the inclusion criteria, therefore only extracting information from relevant studies and reducing reviewer bias and inconsistencies in the

screening process. Only peer-reviewed articles published or translated in English were included to explore geographical and representational inequalities in scientific knowledge production on ‘community-based’ or ‘indigenous-led’ resource management, helping to understand the drivers of policy solutions and outcomes in local contexts worldwide.

The following sections detail each review’s specific methodologies and a discussion of their results. Further discussion is provided in Chapter 8 to help understand how these results affect opportunities and challenges for bottom-up fire management considering evidence elicited through fieldwork and predictive modelling approaches.

Figures and tables providing further information on specific review methodologies that are not presented in this thesis are included in the published review articles and their supporting information. This includes syntax development, search saturation and retrieval performance, and individual eligibility screening processes.

## **2.9. Community-Based Fire Management in East and Southern African savanna-protected areas**

The social-ecological systems framework described in Chapter 1 was applied to explore the synthesis question: does the framing, nature, and extent of CBFiM in East and Southern African savanna-protected areas differ conditionally on type of governance system? Multiple SES governance variables were assessed to: explore the role of IPLCs in CBFiM project design, including project establishment, sponsorship and funding, decision-making, and participation; identify (in)consistencies in the conceptualisation of CBFiM across existing and proposed projects; and characterize the opportunities and challenges for the practical application of CBFiM in protected areas (Gatiso et al., 2022).

### **2.9.1. CBFiM systematic mapping methods**

The PICO framework used to address the synthesis question and structure this review consisted of the following components: CBFiM in savanna-protected areas (population); governance system (interest); and East and Southern Africa (context). The following search was carried out in Scopus and Web of Science, and relevant articles were retrieved using an independent test-list<sup>4</sup> and through the application of a pre-established set of inclusion and exclusion criteria (Table 2):

TITLE-ABS-KEY (*‘community-based’ OR ‘community’ OR ‘traditional’ OR ‘indigenous’ OR ‘local’ OR ‘integrated’ OR ‘comanag\*’ OR ‘co-manag\*’ OR bottom-up OR ‘bottom up’ OR ‘coloni\*’ OR ‘pastoral\*’ OR ‘governance’ OR ‘institution\*’ OR ‘poli\*’ OR ‘management’*) AND (*‘fire\*’ OR ‘burn\*’*)

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<sup>4</sup>Bond and Archibald (2003); Eriksen (2007); Butz (2009); Dube (2013); Kamau and Medley (2014); Archibald (2016); Moura et al. (2019); Probert et al. (2019); Humphrey et al. (2021); Russell-Smith et al. (2021).

*OR 'wildfire\*') AND ('savanna\*' OR 'grass\*' OR 'wildland\*' OR 'grazing land\*') AND ('Africa\*' OR 'Angola' OR 'Botswana' OR 'Burundi' OR 'Ethiopia' OR 'Kenya' OR 'Lesotho' OR 'Madagascar' OR 'Malawi' OR 'Mozambique' OR 'Namibia' OR 'Rwanda' OR 'Somalia' OR 'Somaliland' OR 'South Africa' OR 'Swaziland' OR 'Eswatini' OR 'Tanzania' OR 'Uganda' OR 'Zambia' OR 'Zimbabwe')*

Information was extracted and coded from each of the articles included in the final analysis on (i) the studied savanna-protected area and its management structure, (ii) CBFiM project design, (iii) community context, (iv) fire policy and legislation, (v) wildfire events, (vi) land- and fire-use practices, and (vii) recorded impacts of (wild)fire in the landscape. Information extracted on the savanna protected-area, project design, community context was organised under broad second- and third-tier SES governance variables described in Chapter 1, Table 1, such as property-rights systems (excludability and subtractability), regime type (democratic and polycentric values), and community context (repertoire of norms and strategies; historical continuity), respectively. An informal grey literature review of references cited in papers included in the systematic map, conference proceedings, flagship reports, and articles available via online publication repositories (e.g., FAO, Fire Research Institute, ISFMI, SADC, United Nations) and existing fire databases (e.g., LIFE and DAFI), revealed critical aspects of CBFiM important in understanding project governance structures and outcomes in practical settings (Ganz, Fisher & Moore, 2003). Hence, these aspects were included as fourth- and fifth-tier variables in this analysis to elicit specific information on type of governance regimes, the nature and extent of community participation in implemented and proposed CBFiM projects, and whether communities' socio-cultural norms, fire strategies, and extant local institutions and rules are key attributes of project governance arrangements (Table 3).

To account for the role of colonial institutional legacies in resource governance, the following themes were also considered in the review's design and data extraction and analysis: (i) representation of countries, cultures, and IPLCs; (ii) (neo)colonial and post-independence influences on fire suppression policies and resource management (Njoh, 2000); (iii) state, market, and society relations; and (iv) anthropogenic pressures on fire use. To minimise bias and assumptions over authors' intentions, gaps were left in the database where information was missing or not explicitly communicated in relation to the extraction category.

**Table 2.** Inclusion and exclusion criteria applied to review the evidence on the nature, framing, and extent of CBFiM in East and Southern African savanna-protected areas based on PICO framework.

| PICO       |                          | Inclusion                                                                                                                                                                           | Exclusion                                                                            |
|------------|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| General    |                          | Peer-reviewed                                                                                                                                                                       |                                                                                      |
|            |                          | Published/translated in English                                                                                                                                                     |                                                                                      |
| Population | CBFiM                    | Local fire use as a practical livelihood and management tool                                                                                                                        | Focus: health and medicine, emissions, palaeontology, and spatial modelling.         |
|            |                          |                                                                                                                                                                                     | No mention of the social dimension of fire or active fire use by local peoples       |
|            | Savanna-protected areas  | Protected areas as defined by IUCN I-VI (may be locally recognised) and buffer areas                                                                                                | Operational firefighting guidelines                                                  |
|            |                          | Savanna ecosystem: savanna; woodland; grassland; veld; mopane savanna                                                                                                               | Outside protected areas (IUCN I-VI) and buffer areas (including communal rangelands) |
| Interest   | Governance System        | Formal and informal fire policy, institutions, governance, and management                                                                                                           | Non-savanna ecosystem: forest; desert; fynbos; Afromontane forest; Afroalpine        |
|            |                          |                                                                                                                                                                                     | No mention of local-level fire policy, institutions, governance, and management      |
| Context    | East and Southern Africa | Angola; Botswana; Burundi; Ethiopia; Kenya; Lesotho; Madagascar; Malawi; Mozambique; Namibia; Rwanda; Somalia; South Africa; Swaziland/Eswatini; Tanzania; Uganda; Zambia; Zimbabwe |                                                                                      |

**Table 3.** Tiered social-ecological governance systems variables adapted to extract information on the savanna-PA's property-rights system, CBFiM project design, and community context (Ganz, Fisher & Moore, 2003.; Ostrom, 2009; McGinnis & Ostrom, 2014; Delgado-Serrano & Ramos, 2015).

| Second- and third-tier variables                                        | Fourth-tier variables     | Fifth-tier variables                                                                    | Sixth-tier variables           | Description                                                                                       |
|-------------------------------------------------------------------------|---------------------------|-----------------------------------------------------------------------------------------|--------------------------------|---------------------------------------------------------------------------------------------------|
| Savanna-PA - Property-rights systems: excludability and subtractability |                           |                                                                                         |                                |                                                                                                   |
|                                                                         | Resource ownership        |                                                                                         |                                |                                                                                                   |
|                                                                         | Resource use              |                                                                                         |                                |                                                                                                   |
| Project Design - Regime type: democratic and polycentric values         |                           |                                                                                         |                                |                                                                                                   |
|                                                                         | Establishment             | Initiation                                                                              |                                |                                                                                                   |
|                                                                         |                           | Year of establishment                                                                   |                                |                                                                                                   |
|                                                                         | Sponsorship and donorship | Sponsorship organisations                                                               |                                |                                                                                                   |
|                                                                         | Decision-making           | Scale                                                                                   |                                |                                                                                                   |
|                                                                         |                           | Rule-making organisation(s)                                                             | International organisations    |                                                                                                   |
|                                                                         |                           |                                                                                         | Governmental organisations     |                                                                                                   |
|                                                                         |                           |                                                                                         | Non-governmental organisations | (non-profit)                                                                                      |
|                                                                         |                           |                                                                                         | Private sector organisations   | (for-profit)                                                                                      |
|                                                                         |                           |                                                                                         | Community-based organisations  |                                                                                                   |
|                                                                         |                           |                                                                                         | Hybrid organisations           |                                                                                                   |
|                                                                         |                           | Rules-in-use ( <i>level of community involvement in institutional layers of rules</i> ) | Operational                    | Local rules defining access to local natural resources                                            |
|                                                                         |                           |                                                                                         | Collective-choice              | Rules set by involved actors depending on local environmental, political, and economic conditions |
|                                                                         |                           |                                                                                         | Constitutional                 | Regional and governmental rules defining legal framework                                          |
|                                                                         |                           | Number of actors                                                                        |                                |                                                                                                   |
|                                                                         |                           | Level of community involvement                                                          |                                |                                                                                                   |
|                                                                         |                           | Nature of community involvement                                                         |                                |                                                                                                   |
|                                                                         | Participation             | Level of active participation                                                           |                                |                                                                                                   |
|                                                                         |                           | Willingness to actively participate                                                     |                                |                                                                                                   |
| Community Context                                                       |                           |                                                                                         |                                |                                                                                                   |
| Norms and strategies                                                    |                           | Project approach                                                                        |                                | Engagement with local cultural traditions and beliefs                                             |
|                                                                         |                           | Project support                                                                         |                                | Support of local cultural traditions and beliefs in management                                    |
| Historical continuity                                                   |                           | Local governance institutions                                                           |                                | Existing local governance institutions                                                            |

## 2.9.2. Framing, nature, and extent of CBFiM across exclusionary protected areas

The search retrieved 1,682 published papers and book chapters, of which 1,593 were excluded during title and abstract screening stages for omitting the social aspects of fire management. Sixty-nine papers were removed during full-text screening due to duplication or failure to meet the inclusion criteria. These papers and the reason for their exclusion are provided in [Crocker, Woods & Kountouris, \(2023a\)](#) Supporting Information. Twenty papers were included in the final systematic map (Crocker, 2023), highlighting the predominance of biogeophysical-oriented fire research and the disconnection between physical and social aspects of fire ecology (Sousa et al., 2022). This has sustained institutional silos targeting wildfire challenges, such as between international climate agencies, national governments, and local social processes governing fire use (Kuligowski, 2017; Shuman et al., 2022).

Sixteen papers referenced specific East and Southern African countries and four focused broadly on Sub-Saharan, East, and Southern Africa. No papers on CBFiM focused on South Africa, likely due to its long history of prescribed fire experiments in protected areas which have significantly influenced the development of EDS fire management across the region<sup>5</sup> (Wilgen, Biggs & Potgieter, 1998; Nieman, Wilgen & Leslie, 2021; Pooley, 2022). Seven studies were first authored by individuals from East and Southern Africa. In only three of these studies were the focus country, nationality of the first author, and institutional affiliation aligned: Botswana (Dube., 2013), Mozambique (Ribeiro et al., 2019), and South Africa (Trollope, 2011). Most studies were first authored by non-African nationals and first-affiliated with Western institutions classified as developed.

Nineteen papers were published after 2000, thirteen since 2010, and seven since 2015. This gradual increase in CBFiM research is consistent with the expansion of fire-related research across East Africa due to increasing wildfire challenges and ecological degradation (FAO., 2011; [Prior & Eriksen, 2013](#)), as well as the evolution of Indigenous rights discourses and key events promoting Indigenous representation, rights, and responsibilities in resource governance (Fig. 1).

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<sup>5</sup>Prescribed fire management experiments were first initiated in Kruger National Park in 1954 to test the effects of fire on vegetation, and later in Hluhluwe-iMfolozi Park in 1955, Kruger National Park in 1957, and Mkhuzi Game Reserve in 1960 as controlled EDS burns (van Wilgen et al., 1998; Nieman et al. 2021., Fig. 3). After the 1971 Tall Timbers Fire Ecology Conference, prescribed fire experiments that accounted for multiple fire regime components (e.g., type and intensity of fire, season, timing, and frequency of burning) expanded across Sub-Saharan Africa where existing controlled burning frameworks could be utilised (e.g., Marondera Grassland Research Station, Zimbabwe (Furley et al., 2008)). Despite growing recognition of the social dimensions of fire regimes since the 1990s, (Bowman et al., 2011; FAO, 2011; Prior and Eriksen., 2013), South Africa's experimental burns have had a much larger influence over the evolution of fire management across East and Southern Africa's savanna-protected areas than local ecological knowledges (Trollope., 2011). For example, using the same two online bibliographic sources, Nieman et al. (2021) review retrieved 55 papers on generalised fire management practices in African savanna-protected areas, of which more than 50% were sourced from South Africa. Comparatively, this review retrieved only 20 papers on CBFiM in the same context, including no papers sourced from South Africa.

The term ‘CBFiM’ was used inconsistently across the evidence base, referring to Community-Based Integrated Fire Management and Community-Based Forest Management, and was largely framed within cross-sectoral Integrated Fire Management (IFM) frameworks aiming to standardise fire suppression and prevention operations and enhance technical capacities through state-regulated Incident Command Systems (Dube, 2013; Tedim, Leone & McGee, 2019). This has given rise to misinterpreted understandings of CBFiM (e.g., between Humphrey et al., 2021 and Russell-Smith et al., 2017), mostly with regards to the level and nature of community involvement required in decision-making processes for projects to be considered ‘community-based’, resulting in large variability in project design and implementation (e.g., devolution of fire-use responsibilities versus centralisation of burning regulations) (Mansuri & Rao, 2004). Generally, the assumption that EDS burning is representative of traditional fire management systems worldwide continues to inform the adoption of CBFiM into government policy, limiting scope for decentralised fire management (Ekblom et al., 2019; Humphrey, Gillson & Ziervogel, 2021).

### **CBFiM Project Types**

Fifteen papers discussed 21 projects focusing explicitly on fire management or broader CBC and CBNRM frameworks, nine of which are already implemented, 12 are proposed. Five papers examined the broader social-ecological and institutional evolution of local fire-use and policies (Nangendo et al., 2002; Butz, 2009; Gil-Romera, Turton & Sevilla-Callejo, 2011; Trollope, 2011; Ekblom et al., 2019), including the relationship between biocultural heritage and the reterritorialization of communal rangelands, changes in state-market-society relations and pastoral socioeconomic organisations, distinctions between commercial and communal fire management systems, and scientific progress in savanna fire ecology.

### ***Implemented Projects***

Early conceptualisations of CBFiM prioritised customary rights and land tenure arrangements in project implementation. However, across state-governed protected areas where local fire-use and livelihood practices are incompatible with national laws, forestry departments have retained decision-making and property-rights (Reyes-García & Benyei, 2019). Three implemented projects highlighted the success of the 2007-2011 Eastern Caprivi IFM programme in involving community-based organisations in the development of fire prevention legislation, thus recommending it as a model for developing CBFiM across tropical savannas worldwide (Jurvelius., 2004; Humphrey et al., 2021). Yet, the decentralisation of decision-making rights through the implementation of a community-based IFM policy was limited to communal lands where customary rights over natural resources are already well established (Russell-Smith et al., 2017). In protected areas, the Ministry of Tourism reserves all decision-making rights. Similarly, Gestion Locale Sécurisée (GELOSE) laws introduced by the Malagasy government in 1996 to decentralise resource management through community-based

projects were incorporated into national forestry policy and environmental management plans in 1997, limiting local decision-making in CBFiM (Bloesch., 1999; Kull., 2002). These trends are further evidenced in Zimbabwe's Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) and the Namibian Communal Area Conservancies (Moura et al., 2019). While CBNRM frameworks can provide a platform for CBFiM policy development, asymmetries in local, national, and international resource politics introduce contentious hierarchies into rural governance systems (Petty et al., 2015), where ambition to protect commercial resources risks subverting local rights and responsibilities in community-based projects (Lind, Okenwa & Scoones, 2020; Donald, Young & Mach, 2022; Winkler et al., 2021). Instead, the transfer of practical fire management activities to local people living around protected areas can be viewed as conflict mitigation strategy, extending state influence over local fire-use (Pollini, 2010).

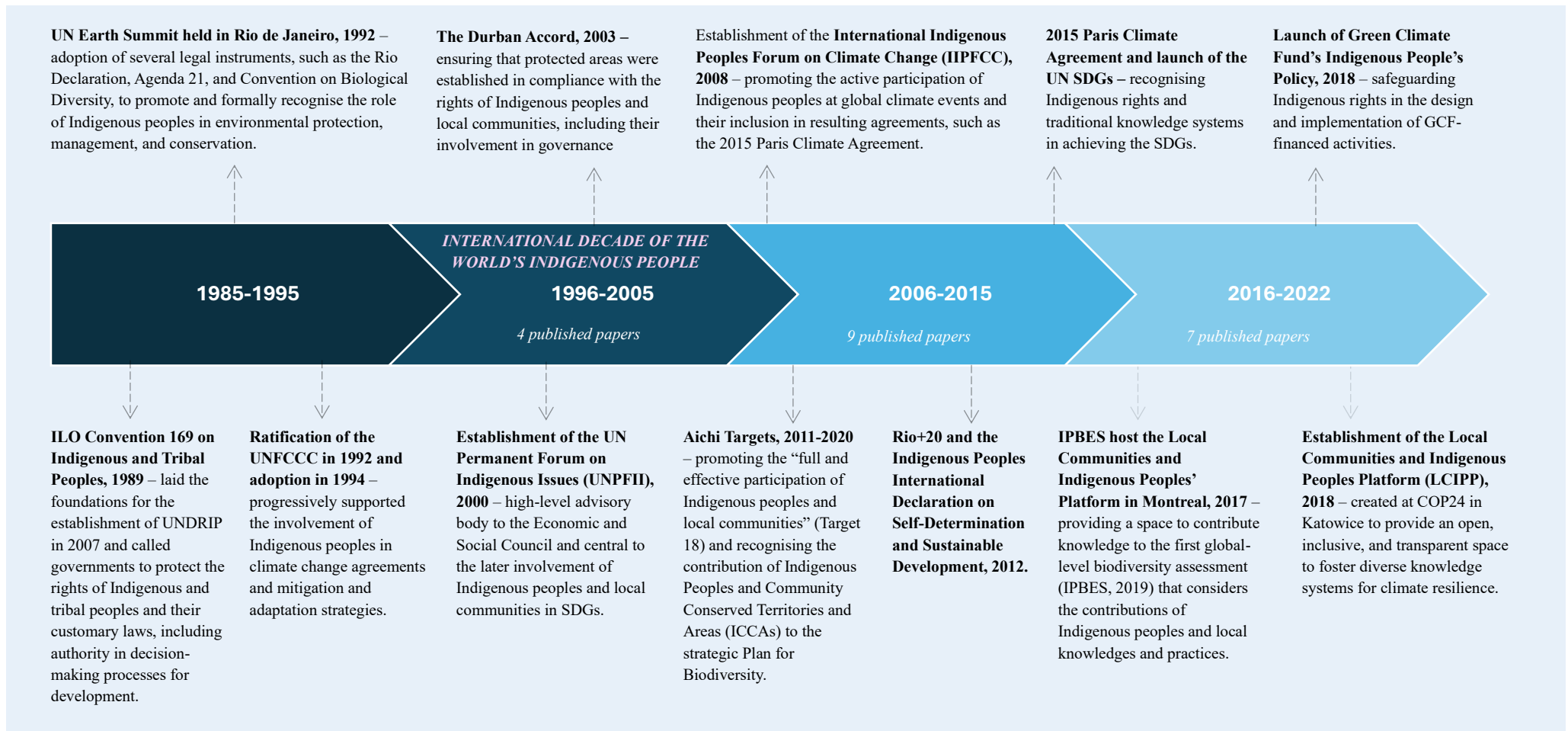


**Figure 1.** Influential events in promoting Indigenous representation and rights in environmental governance since 1989. All papers in the CBFiM systematic map have been published since 1999 (Croker, Woods & Kountouris., 2023a).

### ***Proposed Projects***

Proposed projects focused on the incorporation of traditional fire knowledge into existing scientific frameworks, advocating a temporal shift in fire seasonality from the LDS to the EDS to reintroduce perceived traditional fire regimes which have historically supported biodiversity (Shaffer, 2010; Humphrey, Gillson & Ziervogel, 2021). However, the active role of IPLCs in constructing this discourse is limited, and their involvement in project design and implementation is uncertain (Laris & Wardell, 2006). Rather, their involvement in carrying out burning activities aligned with top-down regulations reduces their participation to labour supply (Ganz et al., 2003).

Recent CBFiM proposals recommend the development of Kyoto-compliant SBEA schemes in African savanna-protected areas based on Northern Australia's WALFA project, spotlighting their success in delivering 'win-win-win' solutions across Aboriginal lands under freehold and joint Native Title arrangements (Russell-Smith et al., 2017; Moura et al., 2019; Russell-Smith et al., 2021). These studies recommend that CBFiM projects adopt similar methodologies across fire-prone savannas worldwide, mostly based on the perceived opportunities for national governments to achieve emissions reduction targets and generate carbon credits that can be traded in international carbon markets (UNU-IAS., 2015; Lipsett-Moore et al., 2018; Edwards et al., 2021). In East and Southern Africa, savanna-protected areas that are larger than 1,000km<sup>2</sup> and sustain low human population densities have been identified as suitable sites for community-based SBEA schemes (Lipsett-Moore et al., 2018). Though SBEA projects are framed as indigenous-led and community-based in the Australian and African contexts, respectively, top-down institutional regulations and accounting methodologies that prioritise emissions objectives over local empowerment, governance challenges, and highly excludable property-rights in the African context, restrict the legitimate involvement of IPLCs in fire management (Laris., 2021). Additionally, in alignment with broader proposals for CBFiM, the assumption that pastoral societies employ homogenous burning practices worldwide overlooks the socio-economically and culturally diverse reasons IPLCs use fire (Table A2), thus discounting the need for project developers to carry out nuanced inquiries in local contexts (Catley et al., 2013; UNU-IAS, 2015).

### **CBFiM Project Design**

CBFiM design largely depended on the project's geographical context and type of governance regime, such as whether CBFiM supported democratic and polycentric values in project establishment (e.g., objectives), financial structure and distribution of benefits, implied decision-making processes, and management activities (Table 3). All projects in the systematic map are initiated, funded, and managed by agencies external to the local community, typically in hybridised arrangements between governments, international NGOs, and private investors (Bloesch., 1999; Ribeiro et al., 2019). The

level of community involvement depended on the presence of these various actors and the degree to which central governments exercised authority (Kull., 2002; Shaffer., 2010).

All but three projects (Jurvelius., 2004; Eriksen., 2007; Kamau and Medley., 2014) are externally established and most rely exclusively on external funding from fixed-period grants or the government. This limits opportunities for the co-development of adaptive fire management and increases the risk of project failure in the medium-to-long term as funding is exhausted and political priorities change (Kull, 2002). Yet only four projects support internal funding structures together with external sponsorship to mitigate some of this risk (Dube., 2003; Jurvelius., 2004; Eriksen., 2007; Russell-Smith et al., 2017). While international conservation-development agencies can financially assist CBFiM and provide in-kind support (Bloesch., 1999; Smit and Pilifosova., 2001), this is often conditional on recipient governments pursuing specific policies to achieve fixed objectives (Bryant and Bailey., 1997; Eriksen., 2007). Additionally, NGO and corporate partners often oversee the establishment and management of protected areas, rearranging local governance systems within which CBFiM policies are developed and creating new ‘private indirect government’ structures that enable external agencies to retain authority over local fire users (Brockington, Duffy & Igoe, 2008; Scales, 2016). Instead, Dube (2003) and Russell-Smith et al. (2017) propose that CBFiM projects draw upon existing CBNRM arrangements to generate long-term financial benefits, such as by establishing locally-led fire management units that impose fire levies on land users or by developing SBEA schemes where groups of landholders can generate carbon revenue.

The development of rules and regulations governing CBFiM projects were mostly reserved to the state and hybridised state-private partnerships, thus reflecting the interests of more powerful socio-political coalitions. The participation of IPLCs in determining rules-in-use was mostly limited to the operational level, negotiating who, what, and how burning takes place, with little or no ability to challenge constitutional rules-in-use. Where state agencies collaborate with devolved institutions to promote participatory inter-cultural governance in CBFiM (Humphrey, Gillson & Ziervogel, 2021; Mistry et al., 2019), collaboration is often passive and consultation-based, reinforcing tokenistic forms of participation in project governance and providing more powerful actors the ability to judge the legitimacy of recommendations made by local communities and reinforcing (Arnstein, 1969).

Projects that implied some local involvement in determining collective-choice rules to achieve broader socioeconomic outcomes also acknowledged that local determination of rules-in-use are limited by the global political ecology of fire, informed by increasing experiences of extreme wildfire events (Eriksen, 2007; Humphrey et al. 2021; Jurvelius., 2004; Moura et al. 2019; Russell-Smith et al. 2017). Additionally, ongoing scepticism over Indigenous fire-use prevents IPLCs in determining operational, collective-choice, and institutional rules-in-use, and their inclusion in CBFiM projects is often aimed at limiting local fire-use and aligning behaviours with national conservation objectives (Mapaure, Campbell & Gambiza, 2009; Alvarado, Silva & Archibald, 2018).

## Community Context

The nature of bottom-up governance in CBFiM across diverse community contexts was evaluated based on the following characteristics: dependence on savanna resources; presence of traditional fire knowledges, beliefs, and institutions; market integration and available technologies; and policies and social rules regulating fire-use (Table 3). All studies acknowledged high local dependencies on savanna resources and the role of fire in achieving livelihood objectives (Table A2). However, these fire-use practices were mostly described in their historical context, rather than as components of CBFiM projects.

Some studies referenced local fire regulations where traditional leaders and governance institutions are present. For example, all studies in Madagascar mentioned *dina*; a set of social rules defined by elders to govern fire-use and conflict resolution procedures when fires escape their intended boundaries. Other studies referenced traditional institutions and authorities of social, political, ritual, and religious importance as retaining significant jurisdiction over local fire use, despite national bans on burning (Eriksen, 2007; Shaffer, 2010; Dube, 2013; Kamau & Medley, 2014; Gil-Romera, Turton & Sevilla-Callejo, 2011). However, rather than incorporating extant local governance systems into CBFiM projects, they have mostly been appropriated by external agencies in project management, changing their legitimacy and utilisation at the community level (Kull, 2002; Gil-Romera, Turton & Sevilla-Callejo, 2011). For example, *dina* was legally formalised in 1960 and incorporated into GELOSE law in 1996 and national forestry policy in 1997, thus community *dina* for GELOSE contracts now conforms with existing anti-fire legislation which makes no concessions for rural livelihoods (Bloesch, 1999; Kull, 2002). Only three projects (Jurvelius., 2004; Russell-Smith et al. 2017; Humphrey et al., 2021) and two proposed frameworks actively engage with local traditions and fire knowledges. Kamau and Medley (2014) and Moura et al. (2019) suggested that the emergence of subaltern politics across conservation landscapes and the increasing use of fire as a form of everyday agrarian resistance against extra-local authorities are symptomatic of colonial injustices. Hence, both studies advocate for asking IPLCs early in the planning stages to evaluate the potential contribution of their fire knowledge to management activities undertaken by other authorities. This can assist in legitimising local knowledges in formal institutions and empower communities in the co-development of inclusive and locally relevant policy (Donald, Young & Mach, 2022).

Twelve studies directly attributed changes in the dominant fire regime to colonial fire suppression policies sustained in independence by leaders educated in colonial institutions and by wildlife organisations aiming to eliminate fire to improve conservation outcomes (Kamau & Medley., 2014; Alvarado et al. 2018; Moura et al. 2019). Four studies did not explicitly reference colonialism, but attributed changes in the fire regime to suppression policies, the exclusion of humans and livestock from savanna-protected areas, and the breakdown of traditional land-use systems (Alvarado et al.,

2018; Butz., 2009; Russell-Smith et al., 2021; Shaffer., 2010). Five studies referenced legislation that indirectly supports the enforcement of state fire bans (Kull., 2002; Eriksen., 2007; Shaffer., 2010; Dube., 2013; Humphrey et al., 2021). Three studies did not mention colonialism nor fire suppression policies in their accounts of CBFiM, despite recognising the imperative to ‘to maintain (fire) disturbances’ (Nangendo et al., 2002) through the recovery of ‘*traditional practices*’ (Ribeiro et al., 2019) and ‘*inclusion of surrounding communities in the overall fire management programme*’ (Mapaure et al., 2009). Since colonial fire suppression policies were never formally legislated, the enforcement of fire regulations has been arbitrary and largely repudiated in rural areas, particularly where they do not align with communities’ social, cultural, and economic practices, or are enforced by state-appointed local leaders without community approval (Shaffer., 2010). Hence CBFiM projects established by external agencies across conservation areas can have greater local salience and authority over burning practices if they accept community fire-use as a legitimate land management tool (Kull., 2002).

However, opportunities for bottom-up CBFiM projects are limited where (neo)colonial interventions continue to drive the breakdown of traditional land governance systems historically organised around resource politics and ritual practices (Lyver et al., 2019). Such interventions include: large -scale land acquisitions, and government resettlement schemes which exclude rural communities from their ancestral lands (Thompson & Homewood., 2002; Gil-Romera et al., 2011; Lind et al., 2020), the rise of the Christian church as an independent political power (Okoye, 2021), government policies harnessing extant customary rules (Kull, 2002), the establishment of Incident-Command systems for firefighting and local anti-fire education programmes (Tedim, Leone & McGee, 2019), and efforts to actively disengage youth from local traditions (Ekblom et al. 2019).

In recent history, population growth, climate change, and government policies incentivizing permanent settlement, have accelerated processes of land sub-division and sedentarisation, forcing many local communities to modify their socioeconomic activities (Gil-Romera, Turton & Sevilla-Callejo, 2011; Korf, Hagmann & Emmenegger, 2015; Kaye-Zwiebel & King, 2014). Aided by the remittance industry and increasing access to mobile technologies, IPLCs are increasingly engaging in Africa’s growing informal cash economy to meet immediate survival needs (ILO, 2021).

Dependencies on market exchanges have resulted in the expansion of informal urban settlements concentrated around roadside villages, further creating greater dichotomies between modern market-based and traditional land management systems (Kaye-Zwiebel & King, 2014; Korf, Hagmann & Emmenegger, 2015). As IPLCs transition from (agro-)pastoral activities to cash-crop farming or tree-planting for charcoal production (Kull, 2002; Gil-Romera et al., 2011), the social, cultural, spiritual, political, and economic significance of fire-use continues to weaken (Mwangi, 2007; Butz, 2009; Kamau & Medley, 2014).

### 2.9.3. The truth is in the nuance

The legacy of European colonisation on property-rights, fire-use, and wildfire is recognised in the literature (Moura et al., 2019). However, there is limited discussion on the role of different colonial regimes and their transplantation in colonised states over the reorganisation of local communities, power dynamics, traditional knowledge systems and, in turn, the opportunities and challenges for locally legitimate bottom-up fire management across East and Southern Africa. ‘Divide and rule’ policies pursued under both indirect and direct colonial regimes in Africa were used to control local populations and prevent insurgencies. Yet, the approaches adopted to achieve this varied across colonial governments depending on their historical common or civil law traditions, administrative styles, and wider political-economic goals (Young, 1994; Njoh, 2000). Consistent with the broader literature, the transplantation of common and civil law under British indirect ‘unranked’ and French direct ‘ranked’ colonial regimes, respectively, have resulted in observed differences in social and economic outcomes and post-independence politics, affecting opportunities for local governance over natural resources.

British indirect rule relied on a system of ‘Native Administration’ and territorial exclusion whereby traditional authorities were empowered, forced, or invented by the colonial government to manage day-to-day affairs in rural localities where centralised administrative control was limited and costly (Crowder, 1964; Christopher, 1988). One of the main aims of this approach was to maximise cooperation with native communities while promoting ‘competitive ethnicity’ where, in the absence of prescribed cultural divisions of labour, ethnic competition for socioeconomic advantages would foster ethnic divisions and prevent mobilisation against the colonial state. Traditional authorities evolved into a new cadre of intermediaries (Rodgers, 2021), often motivated by political-economic imperatives rather than the interests of their community (Okoye, 2021; Rash & Horan, 2020).

Today, given the inherited role of local chiefs in public office, and increased bargaining power of local political and economic elites and their access to government and social resources, bottom-up fire management approaches that engage these individuals on behalf of entire communities need to consider the limitations this imposes on the opportunities for community-based governance (Mansuri & Rao, 2004), particularly with respect to representation, procedural justice, and the distribution of project benefits. Uncoordinated fire use for individual management preferences has increased across East and Southern Africa, while community cooperation has declined (Dube, 2013; Humphrey, Gillson & Ziervogel, 2021). Therefore, burning practices currently exercised by local elites might reflect individualistic ambition rather than the wider communities’ general sentiment or management objectives (Thompson & Homewood, 2002; Eriksen, 2007).

The direct approach to governance pursued by the French and Portuguese colonial governments relied on assimilationist policies and military interventions to vertically stratify ethnic groups into a singular

social system controlled by the central administration (Njoh, 2000). This system had strong Cartesian and Jacobin impulses which repudiated empiricism in knowledge accumulation and promoted the Bonapartist rationalisation of the state; in other words, direct rule presumed public consent over the absolute authority of the centralised state and refuted local knowledges developed through experience. Cultural divisions of labour and new social classes were introduced along ethno-linguistic lines (Young, 1994), resulting in a socio-politically and economically distinct elite trained in European culture who directly replaced local chiefs and traditional authorities, and a peasant majority consisting mainly of labourers. The reservation of power to elites in independence and appropriation of local social rules and community regulations have enabled strong colonial anti-fire wisdoms to persist in resource management (Kull, 2004).

The breakdown of traditional land management systems and loss of fire knowledge in countries historically under indirect colonial administration has also been directly attributed to the presence of Christian missionaries spreading Western cultural norms in rural localities (Eriksen, 2007; Gil-Romera, Turton & Sevilla-Callejo, 2011). New types of intra-group conflict and inter-personal distrust emerged between traditional religious leaders and community members who separated themselves from their pre-colonial beliefs and societies (Okoye, 2021), often due to instilled fears of bewitchment or punishment for practicing witchcraft (Gershman, 2016). Termed the ‘new missionaries’ of the twenty-first century, NGOs have a significant influence over local ‘community-based’ conservation-development projects, largely aiming to empower, educate, and change local behaviour to align land-use values and objectives. Studies show that the expansion of NGOs rarely strengthens or empowers IPLCs in community-based projects due to the conditionalities imposed on them by donors who overlook or do not understand local governance systems and societal organisations (Banks, Hulme & Edwards, 2015).

Independent African states exposed to French colonial rule and civil law are typically believed to exhibit heavier central regulations, reduced local political freedom, less secure property rights, and greater corruption in administrative affairs than ex-British colonies which have inherited a common law system (Glaeser & Shleifer, 2002). Therefore, countries previously exposed to British colonial rule are often perceived as being less susceptible to authoritarianism at the local-level and better able to pursue community justice, thus present greater opportunities for the decentralisation of management rights to local communities in fire management (Burset, 2023). However, research explicitly exploring these beliefs in the fire management context are absent.

## **2.10. ‘Indigenous-led’ savanna burning emissions abatement schemes in African savanna-protected areas**

A scoping review was carried out to explore the synthesis questions: (i) how has the integration of Aboriginal fire practices with modern emissions accounting methodologies in Northern Australia influenced proposed fire management strategies in East and Southern African savanna-protected areas? (ii) What are the opportunities and challenges for prescribed EDS burning to achieve primary emissions reductions and carbon sequestration objectives, as well as address equity and rights concerns, and deliver socioeconomic, cultural, and biodiversity co-benefits? Drawing upon the broader literature, a pyro-geographic framework illustrating the interconnectedness of biogeophysical, topographical, and sociocultural conditions with fire was applied to critically analyse the three main assumptions informing the transfer of Australia’s SBEA methodologies to African savanna-protected areas: (i) perceived similarities between nutrient poor mesic savannas marked by distinct wet and dry seasons; (ii) presence of extensive protected area networks (each  $>1000\text{km}^2$ ) which emulate Northern Australia’s savanna rangelands, characterised by low human and livestock population densities and frequent intense wildfires; and (iii) accrue ment of similar fire management strategies practised by indigenous landholders and pastoralists across the two regions and their interest in diversifying income through carbon benefits (Fig. 2). Lastly, given that Africa’s wildfire paradox can be considered as symptomatic of broader socioeconomic, environmental, and political dynamics, these assumptions were assessed against three key contextual challenges that differentiate Australia’s indigenous rangelands from Sub-Saharan Africa’s protected areas: population growth, climate change, and recent colonial history and neo-colonial influences.

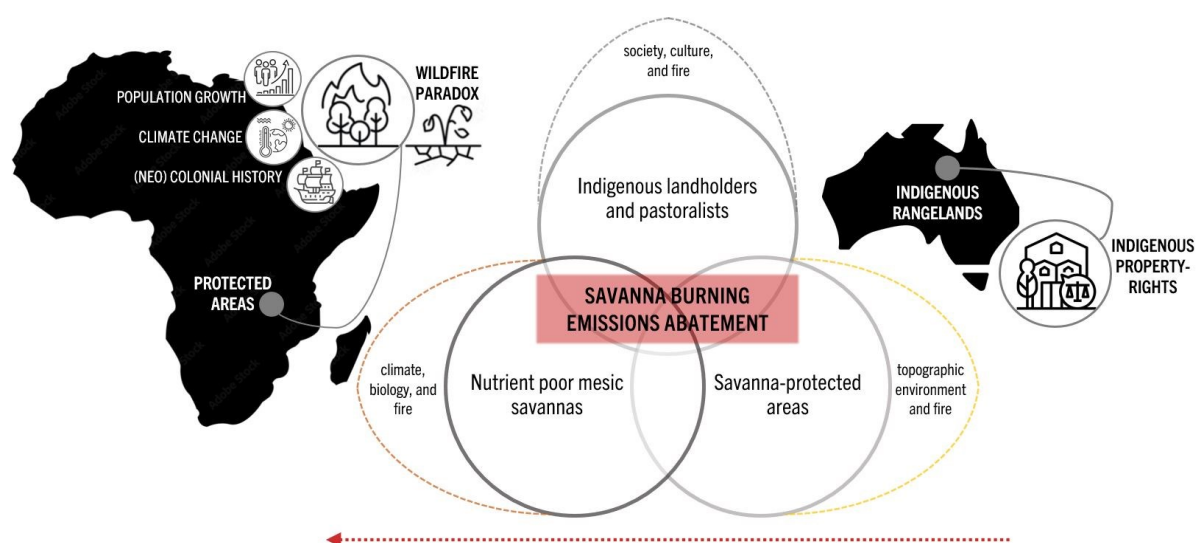


**Figure 2.** Pyro-geographic framework highlighting the interconnectedness of biogeophysical (e.g., “climate, biology, and fire”), environmental (e.g., “topographic environment and fire”), and socio-cultural (e.g., “society, culture, and fire”) dynamics in fire management applied to the three main assumptions informing the transfer of Northern Australia’s indigenous-led savanna burning emissions abatement methodologies to East and Southern African savanna-protected areas: (i) similarities between nutrient-poor mesic savannas; (ii) presence of extensive unpopulated savannas; (iii) presence of indigenous landholders and pastoralists interested in carbon benefit generation. Transferability assumptions need to be considered in relation to the contextual opportunities and challenges that differentiate indigenous rangelands in Northern Australia from protected areas in Africa: population growth, climate change, and (neo)colonial history. Adapted from Humphrey et al., (2021).

### 2.10.1. SBEA scoping review methods

The PICO framework used to address the synthesis question and structure this review consisted of the following components: Indigenous people and local communities (population); SBEA schemes in savanna-protected areas (interest); and East and Southern Africa (context). To specifically address whether SBEA schemes can provide an alternative bottom-up fire management approach in this context, CBFiM was defined as a type of management structure with (i) significant community authority in decision-making that transcends consultation, (ii) proactive community participation in management activities, (iii) community involvement in project establishment, and (iv) funding structures that support long-term self-governance when external support is withdrawn (Croker, Woods & Kountouris., 2023a).

The following search was carried out in Scopus and relevant articles were retrieved using an independent test-list<sup>6</sup> and through the application of a pre-established set of inclusion and exclusion criteria (Table 4):

<sup>6</sup>Corey, B., et al. (2019); Edwards, A., et al. (2021); Laris, P. (2021); Lipsett-Moore, G. J., et al. (2018); Moura, L. C., et al. (2019); Russell-Smith, J., et al. (2013); Russell-Smith, J., et al. (2017); Russell-Smith, J., et al. (2021); Russell-Smith, J., et al. (2015). Tear, T. H., et al. (2021).

TITLE-ABS-KEY (('savanna\*' OR 'fire-prone')) AND (('burn\*') AND ('emissions' OR 'carbon') AND ('abate\*' OR 'offset\*' OR 'reduction' OR 'mitigation') AND ('project' OR 'scheme' OR 'plan' OR 'policy' OR 'model')) AND (('Africa\*' OR 'Angola' OR 'Botswana' OR 'Burundi' OR 'Ethiopia' OR 'Kenya' OR 'Lesotho' OR 'Madagascar' OR 'Malawi' OR 'Mozambique' OR 'Namibia' OR 'Rwanda' OR 'Somalia' OR 'Somaliland' OR 'South Africa' OR 'Swaziland' OR 'Eswatini' OR 'Tanzania' OR 'Uganda' OR 'Zambia' OR 'Zimbabwe'))

Population and interest components 'Indigenous people and local communities' and 'protected areas' were not included in the search syntax due to both the diversity and specificity of terms used to define heterogenous communities and the types of protected areas included in this review. The terms 'savanna\*' and 'fire-prone' were used to determine interest component 'savanna' to provide some flexibility regarding their fire-induced bimodality with forests (Michele & Accatino, 2014), and terms used to determine interest and context components 'SBEA schemes' and 'East and Southern Africa' were applied under field code ALL to avoid omitting studies where SBEA was mentioned within a broader fire management or emissions mitigation context. This also accounted for challenges associated with searching for geographic locations where names often vary (e.g., specificity; language, sociocultural determination) or are absent from publication title, abstract, and keywords (CEE, 2022).

Several papers detailing Northern Australia's Emissions Reduction Fund and carbon accounting methodologies without reference to their development in other tropical fire-prone savanna contexts informed the analysis but were excluded in the screening process (Whitehead et al., 2008; Murphy, Liedloff & Cook, 2014; Parr et al., 2014; Ansell & Evans, 2019; McKemey et al., 2020).

**Table 4.** Inclusion and exclusion criteria applied to review the evidence on savanna-burning emissions abatement schemes in East and Southern African savanna-protected areas based on PICO framework.

| PICO       |                                                    | Inclusion                                                                                                                           | Exclusion                                                                                                                                                                                                                      |
|------------|----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| General    |                                                    | Peer-reviewed                                                                                                                       |                                                                                                                                                                                                                                |
|            |                                                    | Published/translated in English                                                                                                     |                                                                                                                                                                                                                                |
| Population | <b>Indigenous and local people</b>                 | Focus on socio-cultural aspects of savanna burning schemes, e.g., 'indigenous,' 'traditional,' or 'community-based' fire management | Focus on biogeophysical properties of fire with no or limited reference to social aspects, e.g., experiment reports, vegetation assessments, satellite and remote sensing analyses, medical studies, paleo-ecological accounts |
| Interest   | <b>Savanna burning emissions abatement schemes</b> | Prescribed early dry season fires for carbon credit generation based on Northern Australian model                                   | Other fire management strategies where fire is not actively prescribed for carbon credit generation (e.g., prescribed early dry season fires for fuel reduction, but without carbon credit aims)                               |

|         | <b>Savanna-protected areas</b>  | Protected areas as defined by IUCN I-VI (may be locally recognised) and buffer areas                                                                                                | Outside protected areas (IUCN I-VI) and buffer areas (including communal rangelands) |
|---------|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|         |                                 | Savanna ecosystem: savanna; woodland; grassland; veld; mopane savanna                                                                                                               | Non-savanna ecosystem: forest; desert; fynbos; Afromontane forest; Afroalpine        |
| Context | <b>East and Southern Africa</b> | Angola; Botswana; Burundi; Ethiopia; Kenya; Lesotho; Madagascar; Malawi; Mozambique; Namibia; Rwanda; Somalia; South Africa; Swaziland/Eswatini; Tanzania; Uganda; Zambia; Zimbabwe |                                                                                      |

### 2.10.2. Scope of SBEA schemes in East and Southern Africa

The search retrieved 730 published papers, 694 of which were removed during title and abstract screening stages for not examining Kyoto-compliant SBEA schemes. Three additional articles (Ryan & Williams, 2011; Trollope & Trollope, n.d.; Khatun, Corbera & Ball, 2017) identified in reviews retrieved in this search (Nieman, Wilgen & Leslie, 2021; da Veiga & Nikolakis, 2022) were screened. Two were excluded for focusing on the biogeophysical effects of fire on savanna vegetation without reference to local fire management in carbon credit generation (Ryan & Williams, 2011; Trollope & Trollope, n.d.), however were used to inform the transferability analysis. Nineteen papers were removed at full-text screening for not meeting most of the inclusion criteria. These papers and the reason for their exclusion are provided in Croker, Woods & Kountouris (2023b) Supplementary Information. The final sample of 18 papers included in this review are provided in Table A1. These papers exhibited large variation in their aims, focus, and level of detail describing SBEA schemes in the African context.

All papers were published after 2013, corresponding with the publication of two key reviews: ISFMI flagship report highlighting the global potential for indigenous fire management through EDS savanna burning (UNU-IAS, 2015), and Lipsett-Moore et al. (2018) analysis of fire emissions mitigation and revenue generation opportunities for SBEA projects in African Least Developed Countries. Members of the ISFMI and Darwin Centre for Bushfire Research authored eight papers included in this review, five of which did not include authors affiliated with institutions outside Australia. Only seven papers included authors affiliated with institutions in East and Southern Africa.

Most papers focused on the success of commercial SBEA schemes in Australia's compliance carbon market, providing broad recommendations for their development in fire-prone environments globally. These included the opportunities for prescribed EDS burning to mitigate carbon emissions associated with LDS fires and deliver socioeconomic, cultural, and biodiversity co-benefits. However, subsidiary benefits were mostly assumed in feasibility assessments for African savanna-protected areas, overlooking existing challenges that prevent them from being realised in local fire-based emissions projects worldwide, such as difficulties in quantifying the (in)direct effects of fire management on

poverty alleviation, community resilience, biological diversity, and ecosystem restoration, and a lack of data to carry out trade-off analyses (Corey et al., 2019; Edwards et al., 2021). These challenges are summarised in Table 5.

## **2.11. Pyro-geographic analysis of SBEA schemes**

The scoping review on SBEA schemes revealed broad recommendations for the transfer of Australia's SBEA methodologies to African savanna-protected areas to mitigate LDS wildfires. However, the three main assumptions informing these recommendations have not been scrutinised in the literature. Rather, the broader literature describing the biogeophysical, topographical, and sociocultural conditions that characterise Northern Australian and African savannas highlights large discrepancies between the two regions (Lehmann et al., 2014). This information has not been widely incorporated into discussions over the development of community-based SBEA projects in the Africa, thus will likely lead to negative emissions reductions, biodiversity, and livelihood outcomes and trade-offs.

The following sub-sections describe these regional differences and highlight how stated assumptions might implicate opportunities for CBFiM in African savanna-protected areas and lead to unintended outcomes. While this analysis directly addresses SBEA schemes, the discussion provides useful insights for implementation of carbon-based PES schemes more broadly, highlighting the potential benefits and trade-offs of 'community-based' projects which prioritise emissions reductions, and key considerations for their future development.

### **2.11.1. Climate, biology, and fire**

Australian and Southern African savannas have distinct evolutionary histories, distributive limits, faunal and floristic assemblages, functional diversity, and exhibit large variation in biogeophysical dynamics affecting vegetation and fire feedbacks under climate change (Bond, Woodward & Midgley, 2005; Lehmann et al., 2011). However, this information has not been translated into SBEA project design due to the prevailing assumption that climatic and biological processes and their relationship with fire are similar across nutrient poor mesic savannas with marked wet and dry seasons.

The functional role of fire in savanna ecosystems varies across the two regions, having significantly different impacts on soil and vegetation structure, and on the ecosystems' distributive limits across the arid and mesic transition zones. African savannas persist in the absence of fire at the arid end of the continuum ( $<100\text{mm}$  MAP), and there are pronounced disparities between savanna extent and fire occurrence until  $\text{MAP} > 1000\text{mm}$  (Lehmann et al., 2011). Across this arid transition, high soil and vegetation nutrient availability supports large herbivore populations which directly compete with fire to reduce fuel loads, influence tree-grass competition, expose woodlands to grass invasions and maintain open-savanna formations, and distribute nutrients throughout the system to promote spatially

diverse vegetation communities (Asner et al., 2009; Marchant, 2010; van der Waal et al., 2011; Donaldson et al., 2022). Across the mesic transition ( $>1000\text{mm}$  MAP), tree-cover is bimodal and there are extensive climatic overlaps between forests and savannas (Michele & Accatino, 2014). When  $\text{MAP} > 650\text{--}700\text{mm}$ , woody thickening increases, in part due to a reduction in the habitat selection of large herbivores (Luvuno et al., 2018), thus necessitating high intensity fires to prevent ecological succession (Nieman, Wilgen & Leslie, 2021). When  $\text{MAP} > 1500\text{mm}$ , the probability of fire also rapidly declines due to canopy closure and landscape fragmentation (Staver, Archibald & Levin, 2011).

In contrast, Northern Australian savannas are characterised by: (i) higher arid limits ( $>250\text{mm}$  MAP) and dependency on prior fire occurrence, (ii) greater probability of fire occurrence across the precipitation gradient, (iii) strong correlations between fire occurrence and savanna extent, (iii) low mammalian populations, and (iv) higher mesic limits ( $2000\text{mm}$  MAP) where fires persist. This is largely due to the ecological dominance of fire-resistant eucalyptus species capable of growing through fire-mediated recruitment bottlenecks and traps, supporting open canopies under higher MAP (Lehmann et al., 2011; Staver, Archibald & Levin, 2011). These ecological parameters calibrated in Australia continue to inform the expansion of SBEA across fire-prone savannas worldwide, despite the recorded incompatibility of East and African savannas with the biogeophysical requirements for project implementation (Murphy, Liedloff & Cook, 2014).

For example, savannas prone to woody thickening are incompatible with emissions avoidance SBEA schemes due to uncertain feedbacks between climate change, woody component dynamics, fire-weather conditions, and GHG emissions (Russell-Smith et al., 2013; Russell-Smith et al. 2024). Yet, pilot sites are mostly concentrated in semi-arid and mesic African savannas where  $\text{MAP} > 600\text{mm}$  (Lipsett-Moore et al. 2018). The Miombo Woodland has been identified as a key site for SBEA implementation due to its high contribution to LDS fire emissions (Russell-Smith et al., 2021). However, this ecoregion has comparatively high average MAP ( $>1000\text{mm}$ ) and extensive woody plant cover ( $>90\%$  above-ground biomass), and spatiotemporal variability in GHG emissions is strongly associated with edaphic conditions (e.g., frost and soil moisture content) rather than fire, making fire-related emissions calculations unreliable (Ribeiro et al. 2020). In the short-term, LDS fires required to maintain an open-vegetation structure conflict with carbon emissions reductions objectives (Corey et al. 2019; Nieman et al. 2021). In the long-term, their suppression under an exclusive EDS fire regime promotes woody thickening and soil erosion, reducing perennial herbaceous cover and belowground carbon sequestration (Zhou et al., 2022; Coetsee et al., 2023). Consistent with most active fire management projects across East and Southern Africa which aim to eliminate fire and increase forest cover (Parr et al., 2024). SBEA proposals increasingly advocate for the incorporation of complimentary methodologies and the application of voluntary carbon mechanisms (e.g., CDI and REDD+) to account for bio-sequestration through multiple carbon pools

(e.g., above-ground non-living biomass, live woody biomass, and soil carbon) (Khatun et al., 2016; Lipsett-Moore et al., 2021; Tear et al., 2021). While methods for measuring AGC concentrations are well established and practised worldwide, methods for measuring BGC are in their infancy and limited in application, thus are not included in SBEA proposals to date. This can accelerate woody thickening across the savanna ecosystem, having negative consequences on biodiversity and local livelihoods (Edwards et al., 2021; Russell-Smith et al., 2021).

Carbon-based PES schemes commonly create arbitrary divisions between the EDS and LDS to align prescribed burning activities and bio-sequestration methodologies with carbon emissions accounting requirements. However, they do not consider how local biogeophysical dynamics and fires interact to affect combustion efficiency, emissions factors (Russell-Smith et al., 2014), soil health, vegetation structure, and biodiversity (Corey et al., 2019; Nieman et al., 2021), nor how anthropogenic climate change is increasingly shifting wet and dry season in time and space (e.g., prolonged drought conditions, unpredictable rainfall, and fire-weather) (Laris, 2021). For example, SBEA schemes aiming to mitigate savanna-CO<sub>2</sub> emissions by shifting fires from the LDS to the EDS only account for CH<sub>4</sub> and N<sub>2</sub>O emissions (Lipsett-Moore et al., 2018), based on the understanding that CO<sub>2</sub> uptake in post-fire vegetation regrowth replaces CO<sub>2</sub> emitted during biomass burning within a year of ignition (IPCC, 1997). Yet long-term data on CH<sub>4</sub> and N<sub>2</sub>O emissions trajectories in response to land-use and cover change, fire, and changes in soil microbial and decomposer activity is limited across East and Southern Africa. Recent evidence shows that burning in the EDS when soil and vegetation moisture context is high can increase CH<sub>4</sub> emission factors by 50-400% (Laris, 2021). Since CH<sub>4</sub> and N<sub>2</sub>O emissions have higher global warming potential values, this might offset CO<sub>2</sub> emissions reductions achieved through shifting fire seasonality (Maraseni et al. 2016).

Lastly, in accordance with Articles 7 and 8 of the Convention on Biological Diversity, SBEA projects are expected to support multiple facets of biodiversity, where ‘pyro-diversity begets biodiversity’ (Parr & Andersen, 2006), while also generating investment opportunities in protected areas. This includes greater anti-poaching and protection efforts and human-wildlife conflict resolution activities (Lipsett-Moore et al., 2018; Russell-Smith et al., 2021; Tear et al., 2021). The assumption that nutrient-poor mesic African savannas support low mammalian populations akin to Northern Australia has reinforced their perceived compatibility with SBEA implementation (UNU-IAS, 2015), despite being prone to woody thickening. This can result in large biodiversity-emissions trade-offs (Andersen, Woinarski & Parr, 2012). While the importance of metrics calculating potential trade-offs between carbon offsetting methodologies and biodiversity conservation in development projects is acknowledged in the literature, they have not been developed for SBEA projects, largely due to challenges associated with measuring the indirect feedback effects of management interventions on social-ecological outcomes (Tallis et al., 2008; Lindenmayer et al., 2012; Corey et al., 2020). Given that >60% of pyrodiversity research has focused on and been sourced from Australia, compared to

only four from Africa (Jones & Tingley, 2022), there is limited evidence to suggest that the exclusive application of EDS burns in SBEA schemes, which fix multiple fire management variables in time and space to fulfil contractual obligations, can curb biodiversity loss in African savanna-protected areas (Moura et al., 2019; Laris, 2021). Moreover, with the introduction of bio-sequestration methodologies into SBEA schemes and carbon-based PES schemes more generally, projects will likely capitalise on woody thickening, driving further biodiversity loss.

Causality between fire and biodiversity in African savannas has mostly been derived from satellite and decadal-long data, and one-off studies or ecological surveys from other global regions (Perry et al. 2021). However, satellite data may not detect small, fragmented burns which create fine-scale dynamic trophic networks (Russell-Smith et al., 2021). Additionally, species responses to fire over a 10-year interval are likely to exhibit time-lags representative of phenotypic plastic adaptations to decadal environmental variability across the region, largely driven by variation in sea surface temperatures over the Pacific Ocean coupled with warming over the Indian Ocean (Funk et al., 2016; Wang et al., 2023). While biodiversity responses cannot be easily attributed to the adoption of EDS fire regimes (Oostra et al., 2018), the costs associated with developing accredited biodiversity monitoring programmes have hindered progress in assessing biodiversity-emissions trade-offs (Perry et al., 2016; Edwards et al., 2021).

### **2.11.2. Topographic environment and fire**

Northern Australia's savanna rangelands are sparsely populated, remote, unfragmented, and are formally owned or managed by indigenous people under the Aboriginal Land Rights Act 1976 and Native Title Act 1993 (Russell-Smith et al., 2017; Sangha et al., 2021). Statutory recognition of pastoral and indigenous land tenure arrangements (e.g., rangeland ownership, Aboriginal reserves, native land titles, and aboriginal-owned pastoral leases (Edwards et al., 2021)) have enabled landholders to directly benefit from SBEA schemes through the mitigation of LDS wildfires and associated pasture loss, and through the generation of carbon credits either sold back to the Australian government via the Emissions Reduction Fund reverse auction (or increasingly to voluntary and corporate sectors) (Skroblin et al., 2014).

While East and Southern Africa's extensive protected area network (each >1000km<sup>2</sup>) might appear to emulate Northern Australia's rangelands, they are mostly state-owned and governed, highly excludable and subtractable (i.e., no or limited human and livestock habituation), have strict delineated boundaries that are under pressure from surrounding human populations, and are fragmented by tourism infrastructure, human encroachment, and the ecological implications of spatial compression (Veldhuis et al., 2019; Croker, Woods & Kountouris. 2023a). The customary rights of pastoralists are not typically recognised in national legislation, and enduring legacies of exclusion and scepticism towards local fire use, combined with rising migration and conflict challenges (Eriksen,

2007), have prevented indigenous people from securing property rights (Kull, 2002). Hence, opportunities for ‘community-based’ carbon-based PES schemes are limited in this context, particularly considering the UN Convention on Biodiversity’s new Global Deal for Nature which aims to protect 30% and 50% of terrestrial ecosystems by 2030 and 2050, respectively (Dinerstein et al., 2019), and the rapid expansion of privatised large-scale land investments (LSLIs) for commercial developments (incl. SBEA schemes), where contracts drawn between governments and investors are not required to include IPLCs in negotiations, decision-making, or management activities (Bachram, 2004; Cochrane & Andrews, 2021).

### **2.11.3. Society, culture, and fire**

The expansion of carbon-based PES schemes in conservation-development projects has occurred synonymously with the emergence of a global jurisprudence in respect of indigenous land rights and legal empowerment (Fig. 1). This has mounted pressure on African governments, NGOs, and corporations to address structural inequalities in resource governance which have accelerated inter-group conflicts between conservation agencies and customary rightsholders (Fisher et al., 2021; Humphrey et al., 2021). ‘Community-based’ schemes that reconcile traditional fire management with modern market-based approaches present an opportunity for political and economic constituencies in Africa to generate carbon credits while mitigating uncontrolled fires associated with local political resistance and intensifying human-wildlife conflicts (Kull, 2002; Veldhuis et al., 2019). SBEA schemes are contingent on the presence of pastoralists and indigenous landholders who practice traditional fire-stick burning methods and are interested in diversifying their income through carbon benefits (UNU-IAS, 2015; Lipsett-Moore et al., 2018), yet spatiotemporal incompatibilities between SBEA projects and local fire-use practices limit their legitimate participation in carbon-based projects and distribution of benefits.

Local experiential fire knowledges have been left out of SBEA design due to structural asymmetries between global and local fire-use decisions and (in)formal management arrangements, such as between Kyoto-compliant prescribed EDS burning to maximise annual carbon revenue versus intra-annual burning to fulfil socio-cultural aspirations (Radeny et al., 2019; Sangha et al., 2021).

Complexity in global climate policy (e.g., number of actors, variation in values, uncertainty, and high implementation and regulation costs) has necessitated centralised policy design (Dzebo, 2019). This has enabled few powerful entities, mostly based in the Global North, to control decision-making processes and rules governing climate action (Corbera et al., 2016; Biermann & Möller, 2019). For example, the ISFMI carried out an experimental fire exchange in Botswana with Aboriginal rangers to ‘convince fire managers of Botswana that traditional fire management Northern Australian-style was much better than the European-style fire management they had been undertaking’ (ISFMI et al. n.d.). Australian rangers identified local communities using similar fire sticks and inferred homogeneity in

traditional fire techniques which have produced ‘similar heterogenous landscapes from early season burning’ worldwide (UNU-IAS, 2015; ISFMI, 2018), even though fire-stick farming methods, or cultural burns, have divergently evolved over millennia to achieve socio-cultural objectives in specific savanna contexts (Adlam et al., 2022). Prior elicitation of these traditional methods to develop carbon-based projects in state-governed protected areas is missing in the literature, undermining local knowledge that could otherwise contribute to the success of SBEA.

Without formal guidelines that define the roles, rights, and responsibilities of IPLCs in project development and design (Croker, Woods, & Kountouris, 2023a), SBEA projects might be used as a top-down strategy to mitigate conflicts where local activities are considered a threat to conservation-development objectives, ‘heavily influenced by short-term economic needs, which frequently ignore long-term sustainability issues and environmental concerns’ (UNU-IAS, 2015). The absence of formal guidelines also makes these projects more susceptible to elite capture, such that local elites who traverse subsistence, social, and political economies are often employed by the state through the creation of Indigenous ranger positions (McKemey et al., 2020; Millhauser & Earle, 2022), transferring burning responsibilities from Indigenous custodians and customary landowners to Indigenous rangers and other external agencies to implement centralised fire suppression policies and prescribed burning regimes (Fache & Moizo, 2015). These employment trends in SBEA and CBFiM projects more broadly are consistent with the Theory of Predatory Rule where bargaining power of centralised authorities and control over property-rights systems facilitates the expansion of decision-making elites in fire management. This isolates these individuals from the marginalised groups most impacted by policy implementation yet demanded to comply with prescribed activities (Levi, 1981). This can drive a decline in local democratic decision-making and traditional governance systems protecting community rights.

Additionally, carbon-based PES schemes across the region lack formal procedures and distributive processes safeguarding the long-term supply of carbon benefits to IPLCs, creating a highly uncertain environment at the local-level, compounded by price volatility in carbon markets in response to geopolitical risks and climate change. Thus, while the economic benefits of carbon projects accrued at the national-level are recognised in the literature (Russell-Smith et al., 2017; Lipsett-Moore et al., 2018; Tear et al., 2021), it cannot be assumed that local communities benefit from carbon credits or capital diversification.

## **2.12. Further research imperative**

The external construction and governance of CBFiM projects aiming to address wildfire challenges across East and Southern African savanna-protected areas and their potential biogeophysical, environmental, and sociocultural trade-offs necessitate a deeper, more focused research inquiry to explore their meaning, relevancy, and legitimacy at the local level, and to avoid reproducing colonial

legacies in the production of knowledge informing their development. As such, the following chapter details a case-study carried out in southeastern Kenya in 2022.

**Table 5.** *Implementation challenges for Northern Australian SBEA methodologies in East and Southern African savanna-protected areas. Information extracted from review evidence-base, and criteria adapted from Russell-Smith et al. (2017), Nieman et al. (2021), and da Veiga and Nikolakis (2022).*

| Criteria for SBEA projects               | Implementation challenge                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Enabling policy and legislation          | <ul style="list-style-type: none"> <li>▪ Institutional resistance towards including savanna burning as a mitigation strategy in Nationally Determined Contributions.</li> <li>▪ Negative perceptions towards traditional fire use and lack of policy support for local participation in decision-making.</li> <li>▪ No supporting policies and carbon abatement contracts to safeguard local distribution and access to carbon benefits.</li> <li>▪ No legal requirements to include social-cultural aspirations and non-ecological goals in fire management.</li> </ul>                                                                                                                                                               |
| Kyoto Protocol-compliant methodologies   | <ul style="list-style-type: none"> <li>▪ Spatiotemporal discordance between aerial-based Kyoto Protocol compliant methodologies and walking-based adaptive local burning practices.</li> <li>▪ Requirement for secure land tenure and legal access to manage savanna burning projects for <math>\geq 7</math> years.</li> <li>▪ Historical dominance of mid-dry season and future wet season burning overlooked by determination of fire seasons as early- and late-dry.</li> </ul>                                                                                                                                                                                                                                                    |
| Evidence and baseline data               | <ul style="list-style-type: none"> <li>▪ No formal guidelines to determine appropriate pre-project emissions baseline.</li> <li>▪ Lack of long-term scientific evidence and monitoring for robust baseline data underpinning project development (e.g., fire mapping, fuel accumulation, combustion efficiency, site emissions factors, bio-sequestration, and biodiversity responses).</li> </ul>                                                                                                                                                                                                                                                                                                                                     |
| Emissions reductions objectives          | <ul style="list-style-type: none"> <li>▪ Reporting and funding conditions contingent on annual fire performance (burned area and seasonality) rather than multiple fire and ecological dynamics.</li> <li>▪ No accounting for the effects of inter- and intra-annual biogeophysical variability on fire type, occurrence, and associated emissions.</li> <li>▪ No temporal correlation between weather and seasonal cut-off dates for emissions in semi-arid savannas.</li> <li>▪ Increase in CH<sub>4</sub> emissions factors associated with combustion of uncured fuels in early-dry season burning.</li> <li>▪ Uncertain relationship between N<sub>2</sub>O emissions factors and combustion efficiency and fuel type.</li> </ul> |
| Conservation of carbon stocks objectives | <ul style="list-style-type: none"> <li>▪ Uncertain relationship between fire and grazing on future carbon sequestration potential of grass and woody species.</li> <li>▪ Misapplication of voluntary carbon market mechanisms that define forests as having 10-30% woody cover.</li> <li>▪ Expansion of unpalatable and fire-resistant increaser II and invader species not included as applicable vegetation types in savanna burning.</li> <li>▪ Increased long-term wildfire risk and associated emissions.</li> <li>▪ Permanency obligation challenges (i.e., maintaining carbon offsets for 25 or 100 years) in bio-sequestration projects in protected areas.</li> </ul>                                                         |
| Equity and rights of local people        | <ul style="list-style-type: none"> <li>▪ Limited application of FPIC and income diversification opportunities due to the absence of local property-rights in protected areas.</li> <li>▪ Commodification of traditional burning practices in state-mandated Indigenous ranger programmes to meet donor demands and market objectives.</li> <li>▪ Acceleration of power inequities between carbon credit purchasing and producing countries through ‘accumulation by decarbonisation’.</li> <li>▪ Revocation of dry season grazing and resource harvesting rights due to competition with savanna burning for fuel biomass.</li> </ul>                                                                                                  |
| Co-benefits                              | <ul style="list-style-type: none"> <li>▪ Limited assignment of monetary values to additional direct and off-site ecosystem services due to stakeholder diversity and variation in purchasing power.</li> <li>▪ ‘Bio-perverse’ outcomes due to implementation of low-cost extensive burns to maximise annual carbon revenue rather than fine-scale patch-mosaic burning.</li> </ul>                                                                                                                                                                                                                                                                                                                                                     |

- No legislation and allied market incentives to develop an adaptive biodiversity monitoring framework and incorporate biodiversity credits into savanna burning.
- Wildlife conservation trade-offs due to herbivore-fire competition for grass biomass and prevention of intense fires necessary to prevent woody thickening.

|          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Capacity | <ul style="list-style-type: none"> <li>▪ Limited community capacity to address conflicting land-use objectives and fire management due to weak local governance.</li> <li>▪ Requirement for international support and sustained national political will-power to develop and scale-up projects.</li> <li>▪ Limited public support and transparent financial systems for the establishment of taxpayer-funded Emissions Reduction Fund (eq.) for fire management.</li> <li>▪ Requirement for large attitudinal change of public and private investors to realise sustainability of carbon revenue over short-term development aid.</li> </ul> |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

### Chapter 3. Realities on the ground – a Kenyan case study

Systematic reviews of the literature revealed several issues regarding the contestable framing and theoretical nature of bottom-up that have prevented its meaningful implementation to date (Croker, Woods & Kountouris, 2023a; Croker, Woods & Kountouris, 2023b). Hence, there was both an ethical and scholarly imperative to take a participatory case-study approach to understand whether and how equitable fire management and policy frameworks can be practically realised in local contexts.

Fieldwork was carried across the Tsavo Conservation Area (TCA) in Kenya between July and December 2022 and was largely evidence-led, drawing upon the theoretical frameworks described in Chapter 1 to exploratorily address the aims and objectives of this research.

Previous systematic reviews and contextual investigations helped identify specific units-of-observation to be measured and collected during fieldwork to help understand fire management in the research context. However, the specific unit-of-analysis these units-of-observation seek to explain is much more difficult to delineate using formal logic in social-ecological systems research (Damsa & Jornet, 2020). While formal logic uses inference to deduce conclusions from sets of known or assumed facts, social-ecological systems are inherently complex, path-dependent, and unknown, existing as multiple nested ‘panarchies’ where adaptive cycles interact across multiple spatiotemporal scales (Holling, 2002; Ostrom, Janssen & Anderies, 2007; Garmestani et al., 2023). Additionally, the boundaries of any given social-ecological system vary depending on the individual and context determining its conceptualisation but are always open to transfer energy and material from surrounding systems (Martín-López et al., 2017; Martín-López et al., 2020). Considering these limitations, an ecological rather than formal logical approach was taken to define the specific unit-of-analysis studied in this research. Ecological logic gives credence to empiricism as a condition for scientific rigor by spotlighting how prior assumptions and individual interpretations of the research context can lend rhetorical force to the research process, output, and reproduction of subjective interpretations of local reality (Croker et al. 2022). Thus, it foregrounds developmental enquiries, relational experience, dialogue, and field observations to realise how system variables interact across multiple spatiotemporal scales and what they mean to different (Chilisa, 2019; Damsa & Jornet, 2020). As a result of this process, inter-subjective understandings of the research context can be used to form a social-ecological unit-of-analysis where practical management and policy solutions for addressing wildfire challenges can be realised (Berkes, 2017).

This study employed a mixed qualitative and semi-quantitative methods approach consisting of questionnaires, interviews, focus groups, and an inter-cultural workshop to exploratorily address the aims of this thesis and assist in the development of the Belief Network described in Chapter 6. The following sub-sections detail the aims and objectives of carrying out fieldwork, research support, ethical considerations and positionality, and research collaborations. Then I describe field site

considerations, methodologies (design, data collection, and analysis), and challenges and considerations. The results are presented and discussed in Chapters 4 and 5.

### **3.1. Aims and objectives**

Conservation landscapes across Sub-Saharan Africa are inherently complex and competitive, characterised by large variation and contestation between individual or group strategic behaviours and attitudes towards fire management. Land-use values attached to conservation, pastoralism, agriculture, and other land-use types vary considerably across stakeholders and rightsholders, largely depending on accumulative historical interdependencies that have fostered asymmetrical biopolitical relationships in natural resource governance structures worldwide (Bluwstein, 2018). For example, wildlife conservation is typically valued higher by individuals who benefit from their establishment (e.g., national governments with protected area coverage targets) than individuals who have been displaced from their ancestral lands. At the local-level, competing land-use values and, in turn, management practices, are constantly changing as individuals and groups continuously renegotiate with their ecological, social, economic, and political environment (Crocker, Woods & Kountouris, 2023b). Actors that appear to share similar agendas, such as conservation organisations, governmental agencies, and local communities also hold competing land-use values and objectives. This demands a critical systemic investigation into what, how, and why existing beliefs over fire management exist, reinforcing and emerging narratives, and opportunities and challenges for alternative landscape-scale approaches that foster equitable multi-group cooperation and long-term sustainable outcomes (Berkes, 2017).

As such, fieldwork aimed to: (i) provide an in-depth understanding of TCAs pyro-geography and local fire-use values, including the historical, current, and likely future systemic drivers and impacts of the dominant fire regime; and (ii) explore opportunities for the development of an equitable and sustainable bottom-up fire management approach to address wildfire challenges across a highly contested savanna conservation area. To achieve this, a mixed-method data triangulation approach was adopted to: (i) elicit diverse perceptions and attitudes towards fire, its significance in the landscape, and its systemic drivers and impacts; (ii) identify inter- and intra-group conflict and opportunities for multi-group collaboration in fire management; and (iii) understand the meaning of bottom-up fire management to diverse stakeholders and rightsholders in the local context, including its governance structure and application, enabling conditions (considering existing fire suppression policy and exclusionary property-rights), and potential outcomes.

While this thesis seeks to address the colonial legacies in fire management, it cannot be assumed that local communities who have been subject to different (neo)colonial influences are predisposed to the same or their pre-colonial beliefs. Such considerations are particularly important where traditional governance systems have weakened, the roles of traditional authorities have changed, livelihoods are

in a state of transition, and strong anti-fire narratives are continuously perpetuated through government agencies and conservation-development and religious organisations. As such, fieldwork also aimed to explore how (neo)colonial influences over fire-use values and management are reinforced by members of the local communities.

### **3.2. Research support**

This study was granted funding support by the Leverhulme Centre for Wildfires, Environment, and Society (Ref. No: LWFS04), and the Science and Solutions for a Changing Planet DTP, Grantham Institute – Climate Change and Environment, Imperial College London.

A comprehensive risk assessment was carried out through the Imperial College Safety Department and a Fieldwork Outdoors First Aid training course completed. Insurance and travel health considerations were also arranged through Imperial College London.

### **3.3. Ethics and positionality**

Fieldwork was conducted in an ethical and reflexive manner, acknowledging and iteratively addressing my positionality as a British researcher in the local context, and how my ontological and epistemological assumptions affect the research process, outcomes, and interpretations. Croker et al. (2022) and Croker and Ford (2022) detail key questions and concepts drawn upon during fieldwork to ensure that principles of decolonising methodologies were applied throughout this study. The Centre for Biodiversity Information Development (BID-C) at Strathmore University, Kenya, hosted me while I was conducting fieldwork, facilitating collaborations with local researchers and longer-term institutional partnerships (e.g., Croker et al. 2024).

This study was reviewed by Imperial College London's Science Engineering Technology Research Ethics Committee (SETREC) on 26<sup>th</sup> April 2022 and given favourable opinion on 16<sup>th</sup> May 2022 (SETREC No: 22IC7618). The Research Governance and Integrity Team granted full approval of the study on review of the study protocol, participant consent forms and information sheets, interview and questionnaire documents, and recruitment materials. This study was also reviewed by the National Commission for Science, Technology and Innovation (NACOSTI), including institutional affiliation letters from Imperial College London, UK, and Strathmore University, Kenya, a grant letter, research proposal, and ethical approval certification (SETREC), and was granted a research license on 25<sup>th</sup> June 2022 (License No: NACOSTI/P/22/18078). This license permitted research to be conducted in Kajiado, Kilifi, Kitui, Kwale, Machakos, Makueni, Nairobi, Taita-Taveta, and Tana River on the topic.

### **3.3.1. Participant information**

All participants of this study were provided with a comprehensive information sheet detailing the purpose of the study (incl. use for academic purposes only), how the study will be conducted, and the potential (dis)advantages of taking part so that they could make an informed decision on whether to participate. They were also provided with a consent form confirming that they had read and understood the information sheet, agreed to take part in this study, were happy for interviews to be audio recorded for transcription and direct quotes to be pseudonymised and used in this thesis and any related publications, and understood that they were free to withdraw from the study at any time without explanation. Given that fire use is criminalised under national law (e.g., 2013 Wildlife Conservation Management Act (WCMA) and 2016 Forest Conservation Management Act (FCMA)), and study participants included local fire-users from communities considered marginalised and vulnerable, all data was anonymised and safely stored to ensure confidentiality. All transcript files and field notes were stored in private files and never distributed, complying with data protection legislation.

Since most participants did not speak English as their first language or did not speak English at all, all research activities were carried out with local research collaborators and English-speaking members of the community who verbally explained the details of the study, and the data anonymisation and consent process to participants in their first language (mostly Swahili and, in rural areas, the first language shared by the ethnic group). If participants agreed to participate, oral consent was used over written consent in most cases due to three main reasons: (i) many participants were illiterate or functionally illiterate and, therefore, might not have been able to verify signed forms; (ii) to reduce the research costs imposed on members of the local community who were employed to distribute and orally administer questionnaires across large geographical areas and numerous participants; and (iii) to foster an informal open environment where participants who might feel threatened by sharing their knowledge on fire and fire-use practices feel at ease to express themselves.

### **3.3.2. Research collaboration**

Collaboration through research exchange with local communities, researchers, or institutions is a key principle of decolonising methodologies to enrich our understanding of the research context, reflectively engage in perspective taking processes, and potentially reveal new transdisciplinary areas of exploration (Crocker and Ford, 2022). Therefore, prior to fieldwork, institutional collaborations were established between the Centre for Environmental Policy, Imperial College London, UK, and the BID-C, Strathmore University, Kenya. A local researcher supported by BID-C also intended to carry out fieldwork across TCA between July and December 2022 to map fire hotspots, thus becoming my local research collaborator (LRC). We ensured that the research exchange was mutually beneficial, for

example through translation, resource and knowledge sharing, and harmonising methodologies, as well as through longer-term institutional connections (Crocker et al., 2024).

### **3.3. Study site – Tsavo Conservation Area, Kenya**

The Tsavo Conservation Area (TCA) is located across southeastern Kenya along the border with Tanzania. It spans Kajiado, Makueni, and Taita-Taveta counties and borders the Amboseli Ecosystem. TCA encompasses Tsavo East, Tsavo West, and Chyulu Hills National Parks, the Taita-Taveta ranch and conservancy complex, and the Maasai Group Ranches. The Amboseli Ecosystem neighbours TCA on its western boundary and was included in this research to account for continuity across the conservation landscape.

TCA was selected as the case-study site due to meeting several social-ecological and practical requirements. Firstly, TCA primarily consists of grass-dominated savannas in the semi-arid lowlands, and woody-dominated mesic savannas in the highlands. Savannas in the highlands climatically overlap with forest ecosystems, requiring regular fire disturbances to maintain an open-canopy structure. Secondly, TCA has a complex pyro-geographic landscape, characterized by: (i) an expansive network of exclusionary state-governed national parks, ranches, and conservancies with contentious property-rights systems; (ii) the presence of bioculturally diverse Indigenous and local communities with competing land-use values and claims to resources, and who are experiencing rapid livelihood transformations, and (iii) increasing international interest, presence, and influence over land-use, -cover, and -tenure. Thirdly, TCA's fire regime is dominated by the wildfire paradox, and strong colonial legacies over fire suppression and conservation management continue to be reinforced in landscape management plans and governance. Lastly, because of TCA's social-ecological complexity and diversity, information gathered through fieldwork might be relevant in similar research contexts globally, thus promoting transferability. In the context of this study, this data can be abstracted to draw conclusions over fire management across East and Southern African savanna-protected areas.

Additional criteria that influenced the selection included: (i) establishing a partnership with a local institution willing to facilitate this research; (i) the presence of a local Swahili-speaking research collaborator; and (ii) accessibility from Nairobi.

The study site is described in detail in Chapters 4 and 5.

### **3.4. Methodology**

A mixed-method data triangulation approach was used to comprehensively address the aims of this study and was iteratively adapted throughout the research process in response to practical challenges in the field. Considering the exploratory nature of this thesis, data triangulation, including both

qualitative and semi-quantitative methods, helped to elicit diverse knowledges and identify systemic variables that (in)directly affect the fire regime and management. Additionally, this approach enabled the cross-examination of multiple sources of empirical data (questionnaires, interviews, focus groups, and inter-cultural workshop) to identify consistencies and divergences between results, thus contributing to the validity of the findings (Gibson, 2017).

A pilot study was carried out followed by four field-site visits between August and November 2022, each visit focusing on a different area of TCA and lasting between 4 and 10 days. Duration in the field was largely dependent on organisational matters (e.g., resource requirements and funding), logistical arrangements (e.g., distance to local towns) and the prior commitments of LRCs, as well as in-situ conditions which either lengthened or shortened time spent in the field.

### **3.4.1. Model contributions**

Recent efforts to create a globally standardised approach to bottom-up fire management have prevented equitable fire management approaches from being realised in East and Southern Africa (Croker, Woods & Kountouris, 2023a; Croker, Woods & Kountouris, 2023b). Fixing multiple fire management variables in time and space (e.g., season, frequency, and intensity of burning) based on some external understanding of ‘traditional fire management’ has provided an operationalisable approach for the main constituencies that dominate environmental management in Africa: national governments; international aid bureaucracies and multi-lateral institutions; land managers and park authorities; and specific scientific research groups (Eriksen, 2007). Therefore, including diverse local actors in the development of SAV BN was important to increase representation in the model’s algorithm and mitigate some of the risks associated with reinforcing asymmetrical understandings of bottom-up fire management and inequitable governance structures (Hulme, 2016; Croker and Ford, 2022).

SAV BN is designed to provide a locally legitimate and useful decision-support tool for evaluating alternative fire management strategies relevant in the local context, while also providing a broader framework that can be adapted for fire-prone savanna-protected area landscapes globally. As such, the methodologies presented in this chapter were designed to facilitate participatory futures thinking and model development. The results presented in Chapters 4 and 5 were semi-quantitatively and thematically analysed to assist in parameterising the network, such as determining nodes, edges (interactions), and edge values (interactions strength), and further develop fire management and socioeconomic-climate scenarios modelled in SAV BN. Taking a mixed-methodological approach also helped to understand and interpret modelled outcomes, for example by enabling a cross-examination of results to resituate modelled ‘abstracts of reality’ in their real-life context (Patton, 2002).

The contribution of fieldwork data to the construction and development of SAV BN is detailed in Chapter 6 and the final set of model interactions and fire management and joint socioeconomic-climate scenarios are publicly available online at Croker (2024a).

### 3.4.2. Pilot week

A pilot study was conducted the week commencing the 25<sup>th</sup> of July 2022 to assess the research landscape, resource and practicality requirements, and intended methodological approach, and to establish contacts with local decision-makers, stakeholders, and rightsholders across TCA who might participate in this research. We were assisted by a local researcher working for the African Wildlife Foundation (AWF) who helped us navigate the landscape, identify key sites and local communities, and establish research connections. Most of these connections were established during a World Rangers Day commemorative event held at Kasigau Wildlife Conservancy, hosted by multiple organisations previously identified as key informants (e.g., TTWCA, KWS, the County Government of Taita Taveta, KWCA, AWF, and Wildlife Works), and attended by staff and rangers from across the National Parks, ranches, and conservancies, and by diverse Indigenous and local communities who engage in a range of agricultural and pastoral livelihood activities. This proved very important when returning to the field in late-August, such that local people had some idea of who we were and our research objectives and intentions, thus were more willing to openly participate in this research.

The pilot week facilitated a stronger understanding of the social, cultural, political, and economic context in which we would be researching, thus enabling us to carry out fieldwork in a contextually sensitive manner. This included an awareness of existing inter- and intra-group relations, inter-tribal conflicts, political and religious factions, and competing socioeconomic activities. It also raised several practical considerations which would affect how we carried out our research methodologies: gaining permission from local Chiefs and elders to engage with local communities; high rates of (functional) illiteracy and language barriers; inter-personal trust; and time and resource constraints. Firstly, permission from local Chiefs or, in their absence, elders, to administer questionnaires and carry out focus groups with members of their local communities was largely contingent on whether they viewed us as independent researchers, such that they trusted they would not be criminalised for sharing information on fire-use practices and management. On permission from the Chief, we would need to employ and provide transport and subsistence (e.g., motorbikes and food) to trusted members of community to verbally administer the questionnaires in each sampled village. This enabled questionnaires to be verbalised in the communities' native languages and administered across rural locations, and increased participation and open expression due to greater inter-personal trust between research assistants and participants. NGO and protected area staff assisted in identifying these individuals based on previous employment experiences, sharing their standard protocol for carrying out similar assignments and providing recommendations over employment practicalities and

expectations, such as establishing a clear time-frame, having a clear communication strategy, and arranging remuneration considering research expenses, time, and inconveniences, as well as cautioning against paying too much to avoid (de)incentivising individuals (e.g., might not cooperate in the future unless paid) or creating wealth disparities in the local economy. Employing trusted individuals mitigated later challenges associated with randomly selecting research assistants, including potential defection after payment, haphazard administration to reduce time taken (e.g., not following sampling protocol, skipping over questions), and the number of unreturned or uncompleted questionnaires.

### **3.4.3. Questionnaires – a landscape approach**

Questionnaires provided a semi-quantitative landscape-scale approach to explore demographic trends and diverse understandings of and attitudes towards fire in the landscape and wildfire mitigation strategies (research objective 2) (Bhattacharjee, 2019). Considering the size and topography of TCA and resource constraints, questionnaires provided a time and cost-efficient method to ensure that diverse actor groups, including more marginalised communities in rural locations, were represented in this study. Additionally, their structured format facilitated a standardised analysis to understand opportunities for bottom-up fire management, revealing dominant perceptions and attitudes towards fire, convergences and divergences between actor groups, and conflictual relationships between park authorities and local people.

#### **Questionnaire design**

Questionnaires were divided into two main sections, consisting of closed-ended questions to provide a structured elicitation approach. Section A elicited demographic information through multiple-choice questions, and Section B elicited attitudes and beliefs over wildfires through a series of independent Likert- and rating-scale questions (Jr & Boone, 2012). Only two open-ended questions were included to facilitate further elaboration on key aspects of this research while acknowledging methodological, analysis, and interpretation challenges associated with this approach: administration across large geographic area; representation bias due to likely exclusion of illiterate, marginalised, or time-constrained individuals; interpretation bias when analysing results in the absence of participants (e.g., unable to ask questions or clarify meanings); and limitations on quantitative analysis to produce standardised results (Baxter & Eyles, 1997; Patton, 2002). Key informant interviews methodologically overlap with open-ended questionnaires but provide a more in-depth discussion and analysis, leading to more relevant results. Hence, combining closed-ended questionnaires with semi-structured interviews facilitated macro- and micro-systems analysis and understanding of the fire landscape across TCA.

The difference between fires and wildfires was clearly stated to all participants in the introduction prior to completing the questionnaire to avoid inconsistencies and conflation between regenerative savanna fires and high intensity wildfires. In this study, fires were defined as *‘intentional, controlled, and mostly small-scale, used as a land management tool’*, and wildfires as *‘unintentional, uncontrolled, very large, and intense, exceeding natural fire variability levels.’*

In Section A, demographic variables were selected using a social-ecological systems framework and drew upon multiple equality and human and social capital indicators. For example, socioeconomic attributes and norms are important in distinguishing between different actors in the network (Wellman, 1983; Laumann & Pappi, 2013), and age, gender, identity (e.g., indigeneity; ethnolinguistic group; economic activities), level of education, and employment (e.g., sector; type of organisation; length) are critical components of gender and racial equality, poverty, and human development (UN, n.d.; UN, 2023; UN, 2024). Additional analysis variables were added to the dataset, including participant location, presence of REDD+ (e.g., none, Kasigau, or Chyulu Hills REDD+), and primary and secondary grouping ‘types’. Participants were assigned a primary group type depending on whether they were a (1) member of an Indigenous or local community living in proximity to Tsavo East, Tsavo West, or Chyulu Hills National Parks, (2) ranger, or (3) member of protected area staff. Participant types were further refined into secondary groups to account for intra-group heterogeneity and enable a more in-depth analysis of belief factors. Secondary groups included distinct Indigenous and local communities (1-4), and rangers and staff employed within conservancies and ranches (5 and 7, respectively) and national parks (6 and 8, respectively).

In Section B, 90 independent Likert-scale questions – presented as fire perception items - were included on a five-point scale: ‘strongly agree’ (1), ‘agree’ (2), ‘neutral - neither agree nor disagree’ (3), ‘disagree’ (4), and ‘strongly disagree’ (5). Cells were left blank if the participant did not know or did not understand the question. Where Likert-scale questions solicited further explanation, or where questions targeted knowledge over a specific component of the fire regime, either open-ended or multiple-choice questions were provided. For example, if participants (strongly) agreed that ‘other policies, other than fire suppression, are effective in wildfire management’, they were then asked to ‘state or describe these other policies’; if they were asked ‘when do wildfires occur’ or ‘when are prescribed controlled burns carried out’, they were presented with a choice between early dry season, late dry season, early wet season, late wet season, and not applicable (no prescribed burns). Participants could select any number of responses, hence the total sum for each choice was used in the analysis. Open-ended questions were considered in the thematic analysis and development of fire management scenarios (Chapters 5 and 6).

Fire perception items were divided into nine distinct categories to explore local attitudes towards wildfires and the broader social-ecological context in which they occur (Table 6). The number of

questions in each category varied, largely depending on the complexity of the subject matter or perceived importance in addressing the aims of the study. These categories were also used to assist in parameterising the Belief Network model.

**Table 6.** *Categories structuring Likert-scale questions to explore local attitudes towards wildfires and broader social-ecological interactions and address key areas of model development.*

| Category (qs.no)                                             | Main evidence                                                                                                      | Model contribution (overview)                                                                                                             |
|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Wildfires and physical climate change (13)                   | Salience and influence of climate change on wildfire conditions.                                                   | Parameterisation of climate and environmental variables (e.g., interactions and edge values).                                             |
| Wildfires and local environment (12)                         | Attitudes towards savanna ecosystems and the role of fires.                                                        | Fire management scenario development (e.g., forestation versus savanna conservation).                                                     |
| Causes of wildfires (12)                                     | Attribution of (wild)fires to natural and (un)intentional socioeconomic, cultural, and political activities.       | Parameterisation of fire-related activity variables (e.g., interactions and edge values).                                                 |
| Wildfire suppression policies (6)                            | Knowledge of and attitudes towards current fire management.                                                        | Fire management scenario development – building ‘top-down’ scenarios.                                                                     |
| Capacity in wildfire management (12)                         | Presence and effectiveness of wildfire management strategies pre, during, and post fire event.                     | Fire management scenario development – defining and parameterising intervention measures.                                                 |
| Wildfire management mitigation strategies (11)               | Knowledge of and attitudes towards reactive versus proactive fire management and specific mitigation strategies.   | Fire management scenario development – defining and parameterising intervention measures.                                                 |
| Communication and information management (4)                 | Experience of communications and information sharing for effective fire management and policy development.         | Fire management scenario development – defining and parameterising intervention measures.                                                 |
| Interactions between park rangers and local communities (12) | Inter-group relationships, cooperation, and fire management rights in the protected areas                          | Fire management scenario development – defining and parameterising permission and intervention measures.                                  |
| Local knowledge recognition (8)                              | Attitudes towards traditional fire management and the incorporation of burning practices into wildfire management. | Fire management scenario development – building bottom-up scenarios and defining and parameterising permission and intervention measures. |

Lastly, Section B included four rating-scale questions and two open-ended questions. Rating-scale questions were on a scale of 1 (minimum) to 10 (maximum) to assess individuals’ experiences and observations of wildfire, such as how frequent, intense, and severe wildfires are, and how large is the area burned by wildfires in their locality. Wildfire intensity was characterised by size, heat, fuel consumption, rate-of-speed, and severity by the negative impacts of wildfire on soil and vegetation.

Open-ended questions included *'please state any specific plant and animal species that are negatively affected by wildfire. If they are of importance or value to you, please state why'*, and *'please share any additional comments you have on this research.'*

## **Data collection**

Questionnaires were widely distributed across TCA to capture a large sample of the population, specifically those who were not being interviewed or attending focus groups. The sampling strategy varied depending on the participant group (Indigenous and local communities; rangers; protected area staff) and type of land tenure (e.g., communal land, conservancies and ranches, and national parks).

### **i) Indigenous and local communities across communal land:**

For Indigenous and local communities living across communal land, a cluster sampling methodology was used for two main reasons: large, widely dispersed, and often inaccessible target population; and evidence of internal heterogeneity in settlement areas (used as clusters) (Clegg, 1983; Alvi, 2016). Considering time, resource (e.g., access to specialised vehicle to access some areas), and funding constraints, as well the practicalities of carrying out simple random sampling across the entire study area (e.g., employment of local people to verbally administer questionnaires), clusters were established to best reflect diversity across the overall population. Using Google Earth engine, we mapped a 5km radius around the national parks, conservancies, and ranches, and identified villages within this range via satellite imagery (e.g., clusters of settlements). Through conversations with key informants and protected area staff, we then overlaid the map with sociocultural information to identify, based on ethnolinguistic-lines, where different Indigenous and local communities were clustered. Across the identified villages, clustered communities included Bantu-speaking Kamba, Giriama, Duruma, Taita (including WaDawida, WaSagalla, WaKasighau sub-groups), and Taveta peoples, Nilotic-speaking Maasai peoples, and Cushitic-speaking Waata peoples. Other Indigenous peoples who have migrated to TCA in more recent history were also identified as being more widely dispersed across mapped clusters, therefore contributing to population heterogeneity. As such, Kikuyu, Luhya, Meru, Kalenjin, Luo, Pokot, and Somali peoples were represented in this study where they resided or worked in sampled clusters. To some extent, selecting village clusters based on geographical and ethnolinguistic considerations, rather than taking a randomised approach, risks creating a more homogenous and biased reflection of the overall population, thus mitigating some of the benefits associated with cluster sampling (e.g., high external validity). However, explicitly accounting for ethnicity was important in this study to ensure that socio-culturally diverse Indigenous and local populations, as well as the more vulnerable and marginalised members of the population, were represented in this study.

We did not set a limit on the number of villages to be sampled in this study, aiming to maximise representation and sample as many villages as possible. Rather, practical considerations imposed

some external limits. Six villages were sampled in total. Approximately 20 questionnaires were administered in each identified village. Individuals were randomly selected based on village size and settlement distribution. For example, if the village had approximately 100 settlements, 1 in 5 households located in proximity of one another were randomly selected to be sampled. 127 questionnaires were returned, representing three different Kamba communities, two different Taita communities, and a Duruma and Waata community. Due to challenges encountered during administration and transport (e.g., not labelled and mixed up), we cannot distinguish between the two Taita communities (Msorongu and Maktau). Individuals from the Kibwezi Community Forestry Association administered the questionnaires amongst Kamba communities across three main locations: Kibwezi, Nguumo, and Utiithi. In each location, individuals were sampled from 27 sub-locations, therefore representing a broad range of local people rather than a specific cluster. While this was not the intended sampling strategy, these disparities highlight some of the difficulties in carrying out specific methodologies in practice, particularly across complex social-ecological landscapes.

ii) Protected area staff in ranches, conservancies, and National Parks:

For protected area staff (i.e., ‘non-uniformed’) that were not interviewed, no sampling strategy was used due to very low numbers. In most locations, staff did not exceed 10 people. Therefore, the number of questionnaires distributed at each location matched the total number of staff. In the case of many of the ranches and conservancies, the manager was the only full-time employed member of staff – and they were interviewed during the focus group. Questionnaires for staff were distributed at Tsavo East, Tsavo West, and Chyulu Hills National Park, Kasigau Ranch Headquarters (oversee the Kasigau Corridor), and LUMO Conservancy (who had a comparatively larger body of staff due to their volunteer and tourism enterprises).

iii) Rangers in ranches, conservancies, and National Parks:

For rangers, a simple random sampling strategy was used, though no formal sampling frame was constructed due to three main reasons: incomplete or unlocatable formal documentation listing all employed rangers; to minimise time and other logistical costs imposed on individuals tasked with distributing questionnaires (e.g., creating the sampling frame and locating selected individuals), and; to maximise participation given potential disinterest, loss of questionnaires in the field, and the remoteness of field stations where a large number of rangers are posted during the dry season due to increased incidences of human-wildlife conflict, illegal activity (e.g., poaching, resource harvesting), and wildfires (Flick, 2014). As such, all rangers were made aware of the questionnaires located at their respective head office via team meetings and communication platforms. The sampled ranger population included those who, while on duty, collected and completed the questionnaire. The number of questionnaires distributed at each location (i.e., ranch, conservancy, or national park) depended on the total number of rangers employed – largely corresponding to the size of the protected area. For

Amaka, Cholongo, Kasigau, Marangu Hill, Mbale, and Wushumbu ranches and conservancies, questionnaires were provided to the managers at a focus group meeting in Voi. For national parks, they were provided to senior KWS officials during key informant interviews. These individuals oversaw the distribution of questionnaires amongst their rangers. They were given one week to distribute and recollect the completed questionnaires to attach a sense of high priority to participation, therefore mitigating some of the challenges associated with procrastination or abandonment of the task when participants are given longer time-frames (Hua, 2016). Ranch and conservancy managers shared how they visited Voi for official and personal business matters several times a month, therefore all completed questionnaires were returned to and collected from the AWF office in Voi. In the case of the national parks, questionnaires were collected personally from the site during the next field site visit. In the case of LUMO Conservancy and Luaiyeni Ranch, questionnaires were taken to the site, distributed amongst rangers, and returned while we conducted semi-structured interviews with the managers. Any outstanding questionnaires were photocopied and returned via email or were brought to Nairobi by contacts we had made in the field and/or by local delegates (incl. other managers and organisational representatives) attending the Decolonising Fire Science Workshop (see section 3.4.6).

Most rangers and protected area staff were proficient in reading and understanding English, therefore questionnaires were self-administered and/or discussed between individuals where at least one participant could read and speak English. However, in Kamungi Conservancy, ‘community scouts’ are recruited from the local community and employed by the NGO managing the conservancy, fulfilling the same job responsibilities as government-appointed rangers. Unlike rangers, community scouts often have low or below average education qualifications and are functionally illiterate. Therefore, conservancy management organised for two enumerators (*‘youth’*) who had previously collected data on their behalf to administer the questionnaire in digital format (using Google Forms) to community scouts, using technologies provided by the NGO. Enumerators were reimbursed for their time and expenses in line with the NGO’s payment policies.

### **Data analysis**

To assist in exploring local understandings of and attitudes towards fire regimes and management across TCA, as well as support the development of the Belief Network and modelled scenarios, individual fire perception questions were analysed as Likert-type items and the median (*Mdn*), mode, and frequency values were used to describe the results. These values were used in two ways. First, to critically analyse interview and focus group data discussed in Chapter 5, providing greater insights into what extent diverse actors agree, disagree, or are uncertain over specific statements or broader themes expressed or evoked by interviewees, respectively. Secondly, to determine edges and edge values between direct cause-and-effect systems variables in the Belief Network.

Demographic data describing the sample population was statistically summarised to make explicit some of the underlying contextual factors that underpin this study's empirical claims and outcomes. Given that sample data was used to make inferences about the entire population across TCA, this was important to increase the study's transparency and the trustworthiness and generalisability of results. This data was also analysed to infer how specific social, economic, political, and governance systems variables (e.g., rule-making-organisations, property-rights, repertoire of norms and strategies), and the socioeconomic attributes of different actors, might influence perceptions, beliefs, and behaviours towards fires across TCA (Table 1), therefore resulting in opportunities and challenges for alternative fire management futures. As such, a generalised regression model was used to evaluate the influence of independent demographic factors over certain perceptions or beliefs present in the population (i.e., the relationship between predictor values and a dependent response variable). A Poisson link function was used to account for the ordinal values of the dependent variable (Faraway, 2016; Jones & Stafford, 2021; Hui et al., 2022). Analysis of Variance (ANOVA) calculations were performed using chi-squared calculated p values to evaluate the model. The deviance (or variability) explained by each predictor variable was calculated to demonstrate how much of the observed variability in each perception or belief can be explained by each significant demographic factor. Significant demographic factors were analysed further to determine which sub-groups within the population were more likely to agree or disagree with fire perception items. For continuous predictor variables (e.g., age and education level where coded values increase linearly), this was determined from ANOVA output and by plotting the results (e.g., regression line). For categorical predictor variables (primary group code, REDD+, employment organisation, and ethnolinguistic identity), pairwise comparisons were carried out between sub-groups using estimated marginal means.

Six demographic factors were included as predictor variables (Table 7). These factors were selected based on various sources of empirical evidence suggesting their power or relative importance in influencing land governance arrangements across conservation areas, social epistemologies, and land-use values:

- Group membership can affect decision-making power, autonomy, and rights (Crocker, Woods & Kountouris, 2023a) with more powerful actors having a larger influence over the production of knowledge informing resource management, mobilising certain narratives or use policy interventions (incl. economic incentives) to achieve group objectives (Crocker et al., 2024; Smith et al., 2024).
- REDD+ projects often define forests as having as little as 10% canopy cover and have significant influence over local institutions, land-use values, and resource governance and management decisions (Bayrak & Marafa, 2016; Nantongo, Vatn & Soka, 2024; Parr, te Beest & Stevens, 2024)

- Processes of biocultural hysteresis have resulted in a loss of traditional knowledge amongst younger generations (Lyver et al., 2019; Croker et al., 2024), yet strong cultural heritage values, social norms, and political partisanship amongst older generations might affect capacity to adapt to or willingness to implement change (Fung, 2013).
- Education increases human and social capital and enhances adaptive capacity, such as the ability to make informed decisions over management under joint socioeconomic-climate change (Feinstein & Mach, 2020).
- Organisational culture can influence individual behaviours by defining the rules governing action situations, therefore shaping attitudes, values, and accepted norms, of which are often followed to avoid guilt, feel group belonging, maximise instrumental pay-offs, and strategically navigate the social landscape (Morris et al., 2015; Midjord, Rodríguez Barraquer & Valasek, 2021).
- Ethnolinguistic identity is strongly associated with distinct land and resource governance systems, politico-ritual leadership structures and spiritual beliefs, cultural heritage and land-use values, and specific socioeconomic activities (Gil-Romera, Turton & Sevilla-Callejo, 2011; Moura et al., 2019).

**Table 7.** Demographic factors included in the generalised regression model. ‘Primary group type’ and ‘REDD+’ were deciphered by the researcher based on participant ID and location. ‘Age’, ‘education level’, ‘employment organisation’, and ‘ethnolinguistic identity’ were answered by the participant and left blank if the participant did not identify or associate themselves with any of the stated sub-categories.

| Demographic factor                               | Sub-categories                                                                                                                               |
|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Primary group type                               | Indigenous or local community member; Ranger (protected area); Staff (protected area)                                                        |
| REDD+ (participants within project jurisdiction) | Not present; Kasigau Corridor REDD+; Chyulu Hills REDD+                                                                                      |
| Age                                              | 18-25; 26-35; 36-45; 46-60; 61-80; 80+                                                                                                       |
| Education level                                  | No formal education; Primary level; Secondary level; Diploma certificate; Bachelors (undergraduate); Masters (postgraduate); Doctorate (PhD) |
| Employment organisation                          | Government agency; NGO; Private sector; Community organisation; Religious organisation                                                       |
| Ethnolinguistic identity                         | Bantu; Nilotic; Cushitic                                                                                                                     |

Fifteen fire perception items were included in this analysis, each individually analysed to assess whether any of the six demographic factors have an influence over certain attitudes and beliefs present in the population which might affect future fire management (Table 8). Items were selected based on their generalisability, such that they broadly covered other items not included in this analysis (e.g., ‘there are good relationships between park authorities and local communities’ broadly encompasses beliefs over whether ‘park authorities trust local communities’, and ‘local communities trust park authorities’, and so on), and their direct relevance to current or potential future fire management. For

example, it can be useful to know which demographic factors significantly influence certain attitudes and behaviours towards fire management in the study context and, therefore, will likely play a larger role in determining opportunities and challenges for the development of alternative fire management approaches.

**Table 8.** Likert-scale statements presented as fire perception items in a generalised regression model. All items were responded to on a five-point scale: ‘strongly agree’ (1), ‘agree’ (2), ‘neutral - neither agree nor disagree’ (3), ‘disagree’ (4), and ‘strongly disagree’ (5). The ‘attitude’ column explains how a response of 1, ‘strongly agree’, might be perceived given that statements were not standardised (i.e., in this study, a response of 1 does not consistently show a positive or negative attitude).

| Fire perception item                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Savanna ecosystems are of ecological and social importance and value                                                                                  |
| Some large fires are good for preventing woody encroachment and maintaining an open grass-dominated savanna ecosystem                                 |
| Savanna ecosystems are degraded forests and need to be restored to their forest state                                                                 |
| Current fire suppression policies are effective in wildfire management                                                                                |
| Fire suppression policies have contributed to large wildfires due to fuel accumulation                                                                |
| Other policies, other than fire suppression, are effective in wildfire management                                                                     |
| Prescribed controlled patch mosaic burns promote habitat diversity                                                                                    |
| More information and training on the benefits and methods of prescribed controlled burning for wildfire management are required before implementation |
| There are good relationships between park rangers and local communities                                                                               |
| The ancestral land rights of local communities are respected across the Tsavo Conservation Area                                                       |
| Traditional fire management strategies carried out by local communities are considered in current park and conservancy management plans               |
| Traditional fire management strategies carried out by local communities should be considered in future park and conservancy management plans          |
| Fire suppression policies reinforce negative views towards all fires                                                                                  |
| Fire management is a source of conflict between park authorities and local communities                                                                |
| Wildfires are fuelled by conflicts between communities and park authorities                                                                           |

Spearman’s rank correlations were also carried out on fire perception items to evaluate the relationship between certain perceptions and beliefs which might have future policy implications. For example, a statistically significant positive relationship between participants who perceive savanna ecosystems as degraded forests which need to be restored to their forest state, and those who believe that prevention and suppression of all large wildfires is effective in promoting tree growth in savanna ecosystems, implies that forestation schemes that invest in greater suppression operations might expand across savanna conservation areas. Additionally, when analysed alongside the total number and status (i.e., influence in resource governance) of participants who agreed with each of these statements, we can begin to assess the likelihood of specific fire management interventions being implemented in the future. These results (p-value and correlation coefficient (rho)) are presented in Chapter 5 to support the thematic analysis.

### 3.4.4. Semi-structured interviews – key informants

Semi-structured interviews were used to dialogically, discursively, and experientially elicit knowledges and belief systems to develop a robust understanding of the fire context and identify opportunities and challenges for alternative fire management approaches, including the systemic challenges influencing inter- and intra-group conflict and creating barriers for decentralised fire governance (research objective 2). This interview format provided an adaptive evidence-led approach to acquire in-depth information on existing and future alternative policies for addressing wildfires across social-ecologically complex savanna-protected areas (Tedlock, 1991; Hampshire et al., 2014; Magaldi & Berler, 2020).

#### Interview design

The interview rubric was split into four main sections to provide a broad thematic framework to semi-structure discussions while also enabling interview data to be compared and analysed (Table 9). This framework provided scope for combining structured and unstructured conversations, such that participants were delivered the same questions, but in different orders and using different phrasing to facilitate open conversation, opportunities for asking additional questions, and for sharing new information which had not previously been considered. Additionally, having a set of predetermined questions was important to reduce the likelihood of asking leading questions which might embed observer biases into the results, hence unstructured conversations were a result of encouraging interviewees to clarify and elaborate on their responses considering the wider systemic context (Lofland et al., 2022).

**Table 9.** *Semi-structured interview rubrics*

| Section                                                   | Question overview                                                                                                 |
|-----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| General                                                   | About yourself                                                                                                    |
|                                                           | Interest in Tsavo Conservation Area                                                                               |
| Fire                                                      |                                                                                                                   |
| Fire policies and rules                                   | (In)formal institutions, rules, policies, and legislation governing fire use and management                       |
|                                                           | Current fire suppression and prevention policy and its impacts                                                    |
| Fire knowledge and practices                              | Fire in the landscape                                                                                             |
|                                                           | Fire practices – objectives, decisions, and outcomes                                                              |
|                                                           | Fire practices – changes over time                                                                                |
|                                                           | Intentional controlled fires versus unintentional uncontrolled fires – characteristics and consequences           |
| Wildfires                                                 | Events and characteristics                                                                                        |
|                                                           | Physical and human causes and consequences                                                                        |
|                                                           | Management and risk mitigation strategies (pre, during, and post event)                                           |
|                                                           | Management capacity (incl. data collection and use)                                                               |
|                                                           | Inclusivity in fire management (incl. firefighting)                                                               |
| Spatial and temporal drivers of change in the fire regime | Physical and human drivers of change (e.g., fuel loads, biogeophysical wildfire conditions, socioeconomic trends) |
|                                                           | Local governance systems and fire-use practices                                                                   |

|                                 |                                                                                                                                     |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Systemic influences and impacts | Relationship between the fire regime and broader macro-scale and systemic processes (e.g., society, economy, politics, environment) |
| Community-based fire management |                                                                                                                                     |
|                                 | Existence and meaning                                                                                                               |
|                                 | Opportunities and requirements                                                                                                      |
|                                 | Challenges (incl. institutional, political, and legislative barriers)                                                               |
| Social-ecological futures       |                                                                                                                                     |
|                                 | Protected area conservation model                                                                                                   |
|                                 | Inter-group relationships                                                                                                           |
|                                 | Future management                                                                                                                   |
|                                 |                                                                                                                                     |
| General                         | Additional comments                                                                                                                 |

## Data collection

Prior to fieldwork, a stakeholder mapping exercise was carried out to contextualise the social landscape and identify actors (incl. stakeholders and rightsholders) who might provide a richer understanding of the research area through semi-structured interviews. Additionally, this exercise helped identify individuals who hold decision-making power, can lobby on behalf of local communities, influence the production of knowledge and how information flows throughout the social network, or who are excluded from resource governance yet comply with, or rebel against rules-in-use.

This exercise drew heavily on the research frameworks described in Chapter 1 (SES and historical institutionalism) for three main reasons:

- i) Ecosystems transcend human-made borders, and local, national, and international social and political-economic institutions are continuously interacting and renegotiating rules-in-use and property-rights (WRI, 2018; Croker, Woods & Kountouris, 2023a).
- ii) Local land governance systems and the global market economy are interconnected through transformation activities that add market value to common-pool resources, introducing new actor networks and disrupting existing power hierarchies (Birdsall & Nellis, 2003; Marshall, 2015; Gunter & Wilcher, 2020).

Therefore, (i) and (ii) make it difficult or inappropriate to map actors based on delineated jurisdictional boundaries in landscape governance.

- iii) To maximise the representation of different actors living and working across TCA, therefore encapsulating diverse epistemologies and land-use values in the data, and avoiding reproducing hegemonic discourses over local fire governance (Croker, Woods & Kountouris, 2023a).

TCA and the Amboseli Ecosystem formed the unit-of-analysis, providing an unbounded geographical policy domain to map known external and internal forces on the system and their potential impacts on outcomes of interest (Arias-Arévalo, Martín-López & Gómez-Baggethun, 2017; Damsa & Jornet,

2020; Berkes, 2017). External forces were considered as the macro-scale social, economic, political, and interconnected ecological systems dynamics that interact with internal forces to influence management preferences, attitudes, and strategic behaviour at the local-level. As such, internal forces were considered as the actors within the immediate political arena who have power, influence, and decision-making capacity (WRI, 2018). These actors, typically referred to as the ‘context setters’ (high power-low interest) and ‘players’ (high interest-high power), have competing principles, land-use values (e.g., preferences over resource extraction), and priorities (e.g., goals, interventions, and activities), thus were included as key informants in this study. Across the study domain, identified groups included government and parastatal agencies and state corporations (e.g., KWS; KFS; Taita-Taveta, Kajiado, and Makueni County Governments; KEFRI; NEMA; Kenya Water Towers Agency), individual conservancies and ranches and umbrella associations (e.g., KWCA, TTWCA, and AET; Tsavo Conservancy; Maasai Group Ranches), carbon-financing institutions (e.g., Chyulu Hills REDD+ and Kasigau Corridor REDD+), international development and donor agencies, private businesses (e.g., Wildlife Works LLC), and a broad range of international, national, and local NGOs and NPOs who, by far, constituted the largest proportion of stakeholders present in TCA (incl. African Conservation Centre; African Wildlife Trust; Amboseli Trust for Elephants; Big Life Foundation; David Sheldrick Wildlife Trust; Maasai Wilderness Conversation Trust; Tsavo Heritage Foundation; Tsavo Trust). Prominent NGOs funded by multi-lateral and international donor agencies were identified as important informants in this study given their high degree, closeness, betweenness, and Eigenvector centrality in the network, acting as important intermediaries between government agencies and local people, and exhibiting large influence over political-economic agenda and property-rights (WRI, 2018). State agencies were also identified as key informants due to their central position in the network with regards to their authoritative power in implementing rules-in-use. However, questions were raised over how effectively these agents can use their central position to influence policy change given resource, financial, and technological constraints.

While high-power actors can determine action situations and possible outcomes, the long-term effectiveness of fire management is highly contingent on local socioeconomic dynamics and inter- and intra-actor relationships. This research also considered rightsholders as actors within the immediate political arena, such as those who possess little or no power to subvert dominant policy narratives but have a legitimate and urgent claim over resources and can affect realised policy outcomes (Mayers, 2005). These actors are often referred to as ‘subjects’ (low power-high interest) or the ‘crowd’ (low power-low interest); the former often comprised of local Indigenous and subsistence-based communities who are directly affected by resource management decisions such as changes in property-rights and rules-in-use. ‘Subjects’ often have large social and community networks and are the dominant fire-users across African conservation landscapes. Hence, their ability to mobilise in response to political action and increasing use of fire as a form of everyday agrarian resistance makes

them critical actors in future fire management (Kull, 2002; Croker, Woods & Kountouris, 2023a). Key informants from local Indigenous and subsistence-based communities were identified during fieldwork and their participation in this study largely depended on established research networks, such as being introduced through organisation representatives trusted by the local community, their ability (e.g., having sought permission from local chiefs and elders) and willingness to talk to us about fire challenges, access to meeting places, and timely communication.

The ‘crowd’ were not included as key informants in this study and were not interviewed. These actors are often ‘outsiders’ who have no ties with the land and stay in the area for a short period of time. They are commonly perceived as engendering ‘crowding externalities’ by over-exploiting or unsustainably extracting resources, such as burning indiscriminately to achieve immediate individual benefits. While they might present a threat to natural resource management, they move transiently throughout the landscape and do not play a sustained role in policy implementation (Kyriakopoulou & Xepapadeas, 2021). However, as ‘outsiders’ increasingly settle across TCA, the ‘crowd’ will likely become ‘subjects’ with competing land-use values and management practices, hence eliciting their attitudes through questionnaire data was important for futures thinking.

Key informants were invited to participate in this study via email, WhatsApp, or in-person. ‘Context setters’ and ‘players’ were initially contacted via email. In few cases, interviews were conducted online via Zoom and lasted approximately one hour on average. However, response rate was low and limited to international NGO representatives. The pilot study revealed that WhatsApp is the primary means of communication across TCA and Kenya more generally, often used interchangeably with email. Kenya has the highest percentage of WhatsApp users globally, largely due to limited access to Wi-Fi and computer technologies, the dominance of the informal economy and associated unregulated communication networks, and the continuous exchange of phone numbers to carry out financial transactions (e.g., M-PESA). Phone numbers were collected and shared during the pilot week (e.g., at International Rangers Day) and succeeding field visits, and interviews were organised via WhatsApp at a time and location convenient for the interviewee.

Twenty-eight interviews were conducted, including 58 individuals in total. The number of interviewees per semi-structured interview ranged from one to six, while for focus group interviews, between four and ten. In some cases, interviews started with one or two key informants, but increasingly grew in numbers as colleagues joined the discussion. The duration of the interview varied accordingly, lasting between one and four hours. Verbal consent to audio record the interviews were given by the initial interviewees beforehand, and any individuals who joined the discussion were made aware of the recording before sharing their opinions. Interviews were held across a range of locations, including park headquarters, conservancy board rooms, Chief offices, Maasai bomas,

community meeting places (e.g., under large trees, village halls), roadside cafes, and hotels in urban centres.

Several key informants identified as both stakeholders and rightsholders, for example local chiefs and protected area officials who hold formal positions in government or land management but are also members of the local community and engage in subsistence-based activities. Most interviewed on behalf of their agency or organisation, rather than as an individual rightsholder, however typically expressed greater sensitivity towards local communities and their socioeconomic hardships. Only 8 interviewees identified as exclusively rightsholders, of which all but one were interviewed during focus group meetings.

Given the sensitive nature of the research and perceived cultural implications, questions were delivered depending on the individual interviewee (e.g., community elder versus international NGO representative) and their observed behaviour in the first few minutes of the interview to mitigate some of the validity challenges associated with social desirability bias and the Hawthorne effect (Randall, Paul Huo & Pawelk, 1993; Ross & Zaidi, 2019). For example, where interviewees expressed reluctance, discomfort, or in contrast, over-zealousness, questions of a more general or less sensitive nature were asked first, such as asking interviewees to describe how national parks, ranches, and community lands are governed, or to share observed impacts of climate change across the region. The level of detail and richness of the discussion following pre-determined questions largely depended on the importance value individuals attached to aspects of the question, their own person experiences, and how much they were willing to share with us.

### **Data analysis**

Since English was a second or third language to all but one interviewee, and conversations were often fragmented or difficult to understand due to large variation in local dialects and accents, hesitation and emotive interjections, and heavy background noise, all interviews were personally transcribed by hand from audio recordings. Notes were taken during interviews conducted outdoors or in loud public settings to assist in later transcription. At the end of each interview, these notes were checked with the interviewee(s) to make sure they accurately restated their words without unintentional researcher subjectivities. While this approach was more time consuming than using AI-transcription software and could result in greater human error, it mitigated potential challenges associated with erroneous documentation and, in-turn, misinformation and misinterpretation, especially considering existing ethnicity-related biases in automated speech recognition (Sayers et al., 2021; Wassink, Gansen & Bartholomew, 2022). Additionally, given the practical aims of this research and ongoing communications with local stakeholders involved in fire management, the production of incorrect results could have negligible policy implications at the local level. Transcriptions were read alongside original audio recordings to ensure they were printed verbatim. If certain sentences could not be

understood due to background noise or language barriers, they were checked with my LRC and/or not included in the transcription.

Following the transcription of interviews and focus groups, a thematic analysis conducted within a constructivist framework was performed on NVivo. Thematic analysis provides a useful method in social-ecological systems research where the studied system is analytically, ontologically, and epistemologically complex and uncertain, therefore raising questions over how and why knowledge, understanding, meaning, culture, norms, and values come to shape resource governance in specific locations (Biggs et al., 2015). This analysis aimed to explore and systematically interpret and represent participant perspectives, attitudes, and behaviours towards fires regimes across TCA (Crabtree & Miller, 1999; Nowell et al., 2017), therefore revealing themes and patterns in the data, similarities and differences between individual actors and groups, and unanticipated insights into the research context (Braun & Clarke, 2006). Both deductive (theoretical) and inductive approaches were taken to thematically code the data, assigning perceptions and attitudes to distinct codes related to pre-established and emergent themes. Themes established prior to fieldwork were representative of main discussion points elicited from previous systematic reviews (see Chapter 2) and used to structure interviews and focus groups, hence were derived using deductive logic based on existing knowledge of the broader research context, rather than local experiential realities. While deductive analysis provided an initial structure to systematically code data in accordance with research objectives, as well as generating interesting insights into how far current framings and understandings of bottom-up fire management are relevant in real-world contexts, it provides a less rich description of the local research context. Hence, an inductive content analysis was also carried out to provide a more constructionist way of identifying realities in the data itself, thus revealing emergent themes related to diverse truths and knowledges of the system (Patton, 2002; Braun & Clarke, 2006). This was particularly important in the context of this research given that established fire management structures informed by Western forestry and preservationist ideals have engendered and are increasingly failing to mitigate wildfire challenges across conservation landscapes. Therefore, inductive analysis revealed rich narratives within the broader researcher enquiry to facilitate blue sky thinking and normative future scenario development (Biggs et al., 2015; Johansson, 2021).

It is important to note that constructivist approaches to thematic analysis are not rid of epistemological assumptions and subjectivities, such that the researcher coding the data determines the analysis, makes judgements over the coding and theming, and decontextualises and recontextualises the data through coding and interpretation (Starks & Trinidad, 2007). The data itself is also an abstract of reality, representative of dialectical, transactional, and subjective relationships between the researcher and interviewees (Croker et al. 2022). Explicitly stating the assumptions that inform thematic analysis can increase the rigor and trustworthiness of the results and coherently underpin the study's empirical

claims (Holloway & Todres, 2003; Nowell et al., 2017). The positionality of the researcher is discussed in Chapter 1 and was iteratively reflected upon throughout the analysis.

Each transcript was read at least twice to mitigate misinterpretation. The themes that emerged during this analysis and detailed participant accounts of the research context are presented and discussed in Chapter 5.

### **3.4.5. Focus groups - participatory futures thinking**

Focus groups were used to explore convergences and divergences in group attitudes towards, and knowledges, of fire regimes, governance, and management practices (research objective 2). An informal semi-structured interview format was followed by a fuzzy cognitive mapping (FCM) exercise to graphically represent heuristic, less rigorous, and more judgemental and perceptive understandings of the studied system (Kosko, 1986; Kontogianni, Papageorgiou & Tourkolias, 2012). FCMs facilitated inclusive, in-depth, and open dialogue and conceptual knowledge sharing, leading to participant-led discussions and conflictual consensus (Prochazka & Hajek, 2015; Devisscher, Boyd & Malhi, 2016). In this process, participants identified interactions between macro- and micro-scale systems variables that (in)directly affect fire, fire management decisions, and changes in attitudes and behaviours, and discursively explored alternative future scenarios and opportunities for cooperation to address landscape-scale wildfire challenges.

#### **Focus group design**

‘As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality’ – Albert Einstein

Fuzzy cognitive mapping exercises were designed to facilitate open discussion for social learning and the emergence of diverse epistemological understandings related to the research question. While FCMs can reveal conceptual and experiential knowledges of complex system dynamics unique to specific individuals and groups, their structure provides a formal means of translation to analyse conceptual cause-and-effect relationships between systems variables. In this way, FCMs serve as boundary objects to maximise inclusivity and transparency in the construction of a single Belief Network modelling savanna fire management approaches (Star & Griesemer, 1989). Therefore, they represent a form of distributed intelligence, incorporating multiple perspectives into the formulation process and providing more salient and locally legitimate information for policy and management development (Cole & Persichitte, 2000; Papageorgiou & Salmeron, 2013; Gray & Zanre, 2014).

Fuzzy logic was used during mapping exercises to explicitly account for the ‘fuzziness’ of human knowledge as a source of information and of ascribing causality between complex systems dynamic, therefore structuring uncertainty into the model algorithm. A series of ‘if-then’ rules were used (e.g.,

‘if parent node  $Y$  increases, what happens to child node  $X$ ?’) to guide unstructured dialogue between participants to verbally describe and map their conceptual knowledge of the studied system (Kosko, 1986). Participants used arrows to indicate the direction of causal relationships and plus and minus signs to distinguish between mathematically positive or negative interactions e.g., an increase in  $Y$  results in an increase (+) or decrease (-) in  $X$ . These interactions were described using fuzzy linguistic statements closer to their natural languages and thought processes (e.g., ‘never’, ‘not really’, ‘sort of’, ‘likely’, ‘certainly’), indicating certainty over the interaction (i.e., agreement between group participants) and the magnitude of change (i.e., effect of  $Y$  on  $X$ ) (Frías et al., 2017). FCMs were later used to define edges and edge values in SAV BN using processes of defuzzification i.e., establishing a fuzzy set with values ranging between  $[0,1]$  to represent beliefs over causal interactions and the magnitude of their effect.

There are two main differences between FCMs and Bayesian Belief Networks (BBNs) that required consideration before fieldwork: (i) cognitive maps do not distinguish between direct and indirect causal relationships due to unstructured thought processes where interactions may not necessarily be ordered; (ii) cognitive maps include feedback loops which violate the directed acyclic graphical (DAG) structure of BBNs. Feedback loops might not be relevant in the modelled time-frame and can be unintentional due to diverse interpretations of what constitutes cause-and-effect, therefore leading to erroneous conclusions (Liu et al., 2015; Azar & Mostafaei Dolatabad, 2019; Guan et al., 2020). While BNs overcome some of the limitations associated with traditional BBNs, such that they enable feedbacks within the modelled system, causal interactions and feedback loops included in FCMs to be clarified in the model time-frame and checked to ensure intentionality.

## **Data Collection**

To facilitate open discussion and normative futures thinking, participant ‘groups’ were defined based on some shared socioeconomic or cultural attributes, while also considering structural power hierarchies and inequalities present across TCA (Johansson, 2021). Shared attributes and hierarchies were identified through pre-fieldwork contextual reviews, stakeholder mapping exercises, and in the field through conversations with key informants and local people, largely determining which individuals were invited to participate in group research, and how the meetings were facilitated. This approach was important in the study context due to prominent legacies of systemic injustice and layered power relations which continuously reinforce the exclusion of Indigenous and local people in decision-making processes. In inter-cultural inter-group settings designed to facilitate knowledge co-production and understanding between different groups, dominant voices are more likely to be heard, leaving little room for marginalised groups to challenge the status quo. Hence, outcomes are more likely to be exploratory rather than normative in nature, representing the interests and objectives of actors already in positions of power (Johansson, 2021; Croker et al., 2024).

In total, three focus groups were carried out; two with rightsholders, and one with stakeholders. Rightsholders were divided into two main sub-groups: those with decision-making power (community elders), and those without decision-making power (women and youth). Given that any given Indigenous or local community is characterised by institutional and power and hierarchies, socioeconomic heterogeneity and conflicting land-use values, and a range of diverse attitudes towards fire and fire management, separating decision-makers from the more marginalised members of the community gave the latter an opportunity to openly discuss their beliefs in a safe environment and share their views over the conceptualisation of, opportunities for, and challenges facing the development of ‘bottom up’ fire management approaches. This format also facilitated a comparative analysis of group responses, identifying similarities and differences in importance values and how community-based fire management might materialise in the future, depending on the transfer of management vs exclusion rights and who constitutes ‘community’ in project establishment and decision-making processes (Croker, Woods & Kountouris, 2023a).

Following semi-structured interview discussions, FCM aims and methodologies were explained to participants who were then asked to map components of the social-ecological system which influence or are influenced by (wild)fires, following ‘if-then’ rules and using fuzzy linguistic statements to draw connections between mapped components. Groups engaged in collaborative discussions to create their maps. These discussions were translated back to me by my LRC during both rightsholder-based focus group meetings.

i) Rightsholder focus groups

Rightsholder-based focus groups were carried out with (a) community elders ( $n=4$ ) and (b) women and youth ( $n=4$ , 2 women, 2 youth) from two agricultural Taita communities residing in two distinct villages bordering Tsavo West National Park. Focus groups were held at a time and location convenient for the participants – an elders meeting room and village hall - and refreshments were provided. Neither group spoke English. As such, all conversations were translated between English and Swahili by my LRC.

ii) Stakeholder focus group

The stakeholder-based focus group was held at a local hotel in Voi on Wednesday 19<sup>th</sup> October with eight ranch managers and two board officials representing nine ranches and conservancies in total from across Taita-Taveta County. Four of these ranches are Directed Agricultural Companies, four are private ranches, and one is a group ranch, thus vary considerably in governance and membership. All these ranches are members of the Taita Taveta Wildlife Conservancies Association (TTWCA) who have a significant influence over landscape-scale governance and management strategies, boasting strong partnerships with several influential international NGOs and funding agencies. While these individual stakeholders hold diverse experiential knowledges and occupy action landscapes

configured by dynamic social and biocultural interactions, as members of the TTWCA, they have all adopted defined membership role, accepted the same norms, and are bound to the same formal behavioural expectations (Grothe-Hammer & la Cour, 2020). Considering the vastness of the county's ranching landscape, a focus group meeting was the most practical approach for interviewing individual ranch managers and exploring areas of convergence and divergence in their attitudes towards fire and fire management. Recognising the invisible costs of participatory research, all travel expenses were reimbursed, and refreshments were provided throughout the workshop (Crocker and Ford, 2022). All participants spoke fluent English and most had attained certificates or diplomas of Higher Education. Working across the community-protected area interface, ranch managers were able to share detailed insights into the challenges they have experienced and expect to see in the future with regards to inter-group conflict and the expansion of wildlife conservancies across the ranches. As members of the local communities themselves, they also provided a less biased perspective, or rather a more balanced argument, regarding local fire-use practices and wildfires.



**Figure 3** Focus groups held with community elders (left) and women and youth (right). Tsavo Conservation Area, 2022.

### Data analysis

Focus group interviews were analysed in the same format as semi-structured interviews. While FCMs provided some insights into conceptual understandings of systems interactions, several methodological challenges limited the relevancy and legitimacy of mapped outcomes. Firstly, the aims and objectives of the approach were lost during translation from English to Swahili, and participant questions were not consistently translated back to English. The methodological approach was not fully understood by the LRC or participants, resulting in a lot of direction and, therefore, researcher bias in terms of interactions and edge values. These biases were evident in the maps, such that they all displayed similar structures consisting of similar variables and edges. Considering these limitations, FCM discussions were transcribed in the same format as the rest of the focus group interview. They were not analysed as FCMs for the construction of the BN, given that they did not necessarily represent diverse stakeholders and rightsholders' 'fuzzy' understandings of the studied system.

### 3.4.6. Workshop

A two-day inter-cultural workshop titled ‘Fire Management Across Contested Landscapes’ was convened at Strathmore University, Kenya, in collaboration with the BID-C as part of the Decolonising Fire Science workshop series described in Chapter 1. This workshop aimed to: (i) apply decolonial methodologies identified as useful in building inter-subjective interpretations of the research context, thus contributing to more equitable forms of participant engagement; and (ii) meaningfully contribute to ongoing research with locally-relevant outcomes in the Kenyan context. The motivation for this workshop largely came from my interview data, where participants had emphasised the urgency for the development of an integrated fire management policy to address ongoing wildfire challenges:

*‘We need an integrated approach to managing the landscapes.’ ‘We need to create bi-annual forums – once every two years, to bring scientists and practitioners to just share. [...] Planning platforms which bring these people together means that they can plan in their own way, [...] based on the realities on the ground. [...] Then we can bring the government and these people together, to sit at a table and agree on the direction we need to take, a coordinated direction that we have all agreed on. [...] At the moment, the problem is inertia to plan’.*

Therefore, this workshop brought together diverse stakeholders and rightsholders living and working across Kenya’s fire-prone conservation landscapes to engage in a series of participatory activities that facilitated knowledge sharing and open discussion (Crocker et al. 2022; Crocker and Ford, 2022). Activities included rich pictures, world café discussions, participatory art, and the co-development of a Joint Declaration signed by workshop participants to show their commitment towards supporting the development of equitable fire policy. To our knowledge, it was the first inter-cultural workshop to explicitly address fire challenges in Kenya, actively interrogating colonial legacies in fire management and exploring normative future scenarios which foster equitable governance structures and outcomes.

While this workshop directly contributed to the development of this thesis, specifically addressing research objective 2 (i.e., revealing opportunities for multi-group collaboration in the development of alternative fire management approaches and current barriers to implementation) and, therefore informing subsequent discussions presented in Chapters 4 and 8, and the development of fire management scenarios presented in Chapter 6, it was an independent event with broader, long-term, institutional objectives. As such, the workshop is not detailed in this thesis. Instead, we point readers towards the full published workshop report:

- (i) *'Decolonising Fire Science by Reexamining Fire Management across Contested Landscapes: A Workshop Approach.* (Croker, A. R., Ford, A. E. S., Kountouris, Y., et al. 2024).

Reference: Croker, A. R., Ford, A. E. S., Kountouris, Y., et al. (2024) Decolonising Fire Science by Reexamining Fire Management across Contested Landscapes: A Workshop Approach. *Fire*, 7(3), 94. <https://doi.org/10.3390/fire7030094>

### 3.5. Challenges and considerations

Several contextual and methodological challenges were experienced in the field that required adapting to, or where this was not possible, acknowledging as a potential limitation of this study and key consideration for future research.

Fieldwork was planned to commence on August 8<sup>th</sup> 2022 to pre-empt key informants being engaged in firefighting or conflict resolution activities as the LDS progressed. This was delayed due to Kenya's general election which took place on August 9<sup>th</sup>. We were advised not to travel in the lead up to, during, or two-weeks after the election based on historical experiences of post-election conflict and ethnic-based violence. Additionally, where people move back to their home counties during the election and remain there until the post-election environment has stabilised, sampling the population in TCA at this time might have led to unreliable results.

Kenya was amid a La Niña-induced multi-year drought event at the time of fieldwork, resulting in three consecutive failed rainy seasons – the third due to commence in October-November. This accelerated existing socioeconomic vulnerabilities and security challenges across the region, compounded by the 2019-2020 locust plague, 2020 unprecedented flood events, and 2020-2022 COVID-19 pandemic. Inter-group conflict and ethnic- and gender-based violence became a noticeable threat, particularly in rural urban areas where we were perceived as possessing money and resources. As a result, and informed by our own ethical standpoint, such that it seemed insensitive to try and engage local people in research when they were experiencing huge livelihood challenges, field visits in October were terminated early, and we did not return to the field in November. Where hardships were particularly pronounced, such as across the Maasai Group Ranches, engagement with this research was minimal (e.g., low return of questionnaires; low number of community focus groups).

With regards to specific methodologies, Chiefs were often away from their villages on administrative business, thus it was difficult to attain permission to administer questionnaires or carry out focus groups with members of their communities. The participation of local people was also limited by scepticism, such that they were reluctant to take part in the study out of fear of being criminalised for sharing information about burning practices. While questionnaires and focus group meetings did not

ask individuals about *their* burning practices or whether *they* had caused wildfires, as external researchers, some Chiefs and elders expressed concerns over our connections with the KWS and other government agencies and how we might communicate this data to them. In these instances, interviewees were less open with us and were more likely to express social desirability bias. While having a Kenyan LRC might have offset some of these challenges in specific instances, he was considered an ‘outsider’ in the research context. Rather, being present in TCA and building interpersonal trust with stakeholders and rightsholders was more important in facilitating open and honest dialogue.

Applying a mixed-method data triangulation approach enabled us, to some degree, to flexibly adapt to these challenges and continue collecting data to address the aim of this thesis and research objective 2. These challenges revealed how prescribed methodologies can be limited in their application in complex fieldwork environments, as well as the potential benefits of carrying out longer-term ethnographic studies where the research question itself necessitates a good level of trust and understanding.

## Chapter 4. Results

This chapter describes demographic data elicited through questionnaires and reports on the results of the generalised linear regression analysis (section 3.4.3), therefore contextualising the discussion presented in Chapter 5.

### 4.4.1 Questionnaires

**All questionnaire data is publicly available online – see Croker (2024b).** Missing data was considered as Missing Completely at Random or Missing at Random where participants did not respond out of choice (e.g., uncertainty or reluctance), or out of error (missing questions) (Berg, 2005; Glas, 2010). The online database and results presented below make explicit potential biases in the data, increasing the transparency of the findings.

In total, 225 questionnaires were completed by members of Indigenous and local communities (n=127), namely Waatha, Giriama, Duruma, Kamba, and Taita communities, and by rangers (n=78) and staff (n=20) employed in the ranches, conservancies, and national parks. 213 participants identified as Indigenous to Kenya, belonging to agriculturalist Bantu (n=182), and (agro-)pastoralist Cushitic (n=25) and Nilotic (n=11) ethnolinguistic communities. This sample is largely representative of Kenya’s larger Indigenous landscape (see Oyori Ogechi, 2019, pg. 115). Only two participants identified as non-indigenous to Kenya, both employed as rangers in community conservancies. Bantu, Nilotic, and Cushitic peoples have distinct sociocultural and political-economic histories, hold competing land-use values and claims to land and resources, engage in different livelihood practices,

and possess different understandings and forms of local accountability, institutional legitimacy, and empowerment. Therefore, it is important to recognise that at the macro-level, the results from survey data will be biased towards the attitudes and perspectives of Bantu peoples who form the majority of the sample. At the micro-level, diverse Bantu communities compete, engage in conflict, and cooperate (Etefa, 2019; Amutabi, 2023). The discussion presented in Chapter 5 seeks to untangle some of these complexities to understand opportunities for bottom-up approaches.

Recognising the importance of equitable representation in bottom-up fire management, such that vulnerable groups are included in project governance to avoid elite capture and increasing socioeconomic disparities, gender equality was an important consideration in this research and was discussed with research assistants administering the questionnaires. In total, 64% of participants were male ( $n=143$ ) and 34% female ( $n=77$ ). Two-percent did not state gender. For Indigenous and local communities, the ratio of males to females was almost equal. While research assistants cautioned that the sample would likely be biased towards men given their household status, many were at work (e.g., farming, labouring, or herding) when questionnaires were administered. There was greater gender inequality amongst ranger and staff participants, with 79% and 65% being males, respectively. Park wardens and NGO representatives shared how difficult it would be to ensure gender equality when distributing the surveys in the conservancies, ranches, and national parks, given that most positions are held by men:

*‘Our work - it is very gender discriminative. The conditions are deliberately discriminatory because one, we work in one of the harshest places. [...] In our culture, our norms and gender roles, there are some roles women can’t afford. [...] There are inconveniences for us too; we take women, and they need some conveniences, but men can comfortably work without these conveniences. [...] In 2010 we tried to implement 30% recruitment of women, [...] but the nature of the work is purposefully discriminative.’ ‘The landscape is discriminative’. ‘In Tsavo East, [...] we have less than 10 women for the uniformed positions – that is the rangers - out of a total workforce of 350. [...] In the mechanics workshop, we have two ladies out of a team of about 84. It’s generally male.’*

The population sampled in this research was largely representative of population dynamics (e.g., age, education, and employment) across TCA and Kenya more broadly. Participants varied between the ages of 18 and 80+. The average age of the sample population was 36-45 ( $n=50$ ), with 42% participants being younger than 36 ( $n=95$ ), and 34% being older than 45 ( $n=76$ ).

Education attainment was generally low. Fifty participants had received no formal education, 80 had received primary-level education, and 68 secondary-level education. Only 10% of participants had received tertiary education, including a diploma certificate ( $n=15$ ), undergraduate degree ( $n=6$ ), postgraduate degree ( $n=1$ ), and doctorate ( $n=1$ ). NGO representatives emphasised how their

corporate social responsibility (CSR) projects aiming to ‘*create social benefits*’ through education programmes mostly target youth below 17-years old who are still of school age, rather than tertiary institutions. These results are consistent with recorded employment trends; national statistics show that over 80% of Kenya’s total workforce are employed in the informal sector (not including small-scale agriculture and pastoralist activities), of which >60% are youth between the ages of 18 and 35 – a large demographic in this study - who are moving out of educational institutions straight into informal employment due to limited job opportunities in formal public and private sectors (Muchiri, n.d.; Murunga, Muriithi & Wawire, 2021; KNBS, 2024). In this study, 50% of participants identified as being employed in the formal sector, while 42% in the informal sector. However, in conversation with participants, we learned that the percentage of individuals employed in the informal sector is likely to be much greater than this due to casual- or temporary-based workers (e.g., for casual labour and extinguishing fires) responding as being formally employed. Since, the informal sector is characterised by low job security, income, productivity, and poor working conditions, yet continues to grow due to high levels of corruption in governance, liberalisation and privatisation policies that have reduced job opportunities in the formal public sector, and rising tax burdens, poverty, inequality, and the prevalence of illicit trade networks and counterfeiting activities are likely to increase in the long-term, weakening economic growth (Schneider & Enste, 2000; Schneider, 2005; Dijkstra, 2011; Dianah, Joseph & Wawire, 2014). This can present large mitigation and adaptation challenges, including a lack of resources to invest in management interventions and resolution measures addressing conflicts related to declining socioeconomic and environmental conditions.

67% participants identified as being employed by a community organisation ( $n=54$ ), private sector organisation ( $n=38$ ), governmental agency ( $n=31$ ), NGO ( $n=15$ ), or religious organisation ( $n=13$ ), with the average length of employment lasting approximately 6-10 years. Most participants have been employed for between 1 and 5 years. Those employed by community organisations ( $n=76$ ) included staff and rangers from LUMO Community Wildlife Conservancy, rangers from Marungu Hill Community Association, and members of Indigenous and local communities. This included 100% of the surveyed Duruma population residing near Chalongo Ranch, whom of which are recognised nationally as both a minority ethnic group and marginalised community, mostly lacking political representation, economic empowerment, proof of citizenship, and in-turn, access to rights (NGEC, 2017). Private sector employment included rangers employed across private and directed agricultural company ranches, such as Amaka, Chalongo, Kasigau, Lualenyi, Mbale, and Wushumbu ranches. Some rangers from Wushumbu ranch stated that they were employed by a community organisation, likely due to the ranch being a member of the TTWCA. In total, 39 participants were employed by a group, private (incl. directed agricultural company) or co-managed ranch. Governmental agency and NGO representatives mainly consisted of National Park authorities (staff and rangers) ( $n=33$ ) and Community Scouts working in Kamungi Conservancy, respectively. 77% of individuals employed by

religious organisations were from a local Waata Community residing near Marungu Hill Conservancy, whom of which have strong religious and spiritual values and are identified as the second most marginalised and minority group in Kenya.

Across Kenya's drylands, rural communities have diversified their livelihood practices to adapt to and buffer themselves against ecological uncertainty, processes of socioeconomic change, and environmental and economic shocks (Kirui et al., 2022). Hence, the diversification of livelihoods is a strategy defined by opportunity (Bostedt et al., 2023), with individuals increasingly engaging in a mixture of livestock and agricultural production, and low- and high-return economic activities (Lind et al., 2020). Participants were asked to select up to three economic activities that best describe their livelihood strategies and/or employment. These results are presented in Table 10.

**Table 10.** *Economic activities practiced by participants in this study. Six participants stated 'other' but did not provide further information.*

| Economic activity                                                                                                                                                      | No. of participants |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| Arable (crop) farming                                                                                                                                                  | 133                 |
| Wildlife conservation                                                                                                                                                  | 89                  |
| Settled livestock farming (e.g., ranching)                                                                                                                             | 79                  |
| Mobile livestock farming (e.g., pastoralism)                                                                                                                           | 62                  |
| Apiculture (beekeeping/honey harvesting)                                                                                                                               | 44                  |
| Forestry; Tourism and hospitality                                                                                                                                      | 33                  |
| Public services (incl. police, fire services, security, healthcare, education)                                                                                         | 13                  |
| Artisan (e.g., carpentry, pottery, textiles, jewellery, art, crafts, leather goods); Cash-crop production (i.e., crops for export); Poultry farming; Social enterprise | 9                   |
| Fossil-fuel energy development (e.g., mining)                                                                                                                          | 8                   |
| Other                                                                                                                                                                  | 6                   |
| Fishing                                                                                                                                                                | 5                   |
| Casual labour; Informal trade                                                                                                                                          | 4                   |
| Charity                                                                                                                                                                | 3                   |
| Materials extraction (e.g., ballast; fuelwood)                                                                                                                         | 2                   |
| Carbon tree farming; Green energy development; Missionary work                                                                                                         | 1                   |

Sixty-percent of surveyed participants (n=135) responded to the open-ended question, '*please state any plant and animal species that are negatively affected by fire, and if they are of importance or value to you, please state why*'. Sixty-eight of respondents were from Indigenous and local communities, 56 were rangers (51 from ranches/conservancies; five from national parks), and 11 were protected area staff (three from ranches/conservancies; eight from national parks). Their responses were analysed in relation to 'primary group type' (see Chapter 3), land tenure (community land; ranch/conservancy; national park), and the presence of REDD+ (i.e., within the jurisdictional boundaries of the Chyulu Hills or Kasigau Corridor REDD+ projects). These results, along with fire perceptions analysed as Likert-type items, are presented and discussed in Chapter 5.

#### 4.4.1.1. Generalised linear regression

Results from the GLM analysis revealed that certain demographic factors included in this study in-part explain perceptions present within the population. However, they only explain a small percentage of model deviance (up to 35%), suggesting that other factors not included in this study have a significant influence over perceptions of fire – perhaps related to individual experiences. These results are presented in Table 11. For significant categorical predictor variables, estimated marginal means are presented in numerical order, where:  $1 \leq x < 3$  shows positive perception (strongly agree and agree);  $x = 3$  shows uncertainty or no opinion; and  $3 < x \leq 5$  shows negative perception (strongly disagree and disagree). For REDD+ results, mean values represent the likelihood of participants within project jurisdictions (e.g., Chyulu Hills or Kasigau REDD+) to agree or disagree with the fire perception item.

**Table 11.** Results of generalised regression model evaluating the influence of independent demographic factors over dependent fire perceptions items. Results of the sub-group analysis for significant predictor variables are described in column 4.

| Fire perception item:<br>Likert-scale question                                                                                                        | Mdn,<br>mode | Significant predictor variable:<br>Demographic factors (%<br>deviance explained) | Sub-group analysis<br>(likelihood of agreement or disagreement with fire perception item)                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Savanna ecosystems are of ecological and social importance and value                                                                                  | 2 (1)        | Ethnolinguistic identity (16%)<br>REDD+ (9%)<br>Education level (6%)<br>Age (4%) | <ul style="list-style-type: none"> <li>▪ Bantu (avg. 1.68) and Nilotic (avg. 2.09) agree; Cushitic (avg. 3.76) uncertain/disagree.</li> <li>▪ Chyulu Hills REDD+ (avg. 1.25) agree; Kasigau REDD+ (2.70) agree/uncertain.</li> <li>▪ Higher education level - greater agreement.</li> <li>▪ Higher age - greater disagreement.</li> </ul> |
| Some large fires are good for preventing woody encroachment and maintaining an open grass-dominated savanna ecosystem                                 | 3 (5)        | Ethnolinguistic identity (18%)<br>REDD+ (12%)                                    | <ul style="list-style-type: none"> <li>▪ Cushitic (avg. 1.88) agree; Bantu (avg. 3.37) and Nilotic (avg. 3.91) uncertain/disagree.</li> <li>▪ Kasigau REDD+ (avg. 2.42) agree; Chyulu Hills REDD+ (avg. 4.45) disagree.</li> </ul>                                                                                                        |
| Savanna ecosystems are degraded forests and need to be restored to their forest state                                                                 | 2 (2)        | <i>No significant predictor variables.</i>                                       |                                                                                                                                                                                                                                                                                                                                           |
| Current fire suppression policies are effective in wildfire management                                                                                | 2 (1)        | Employment organisation (15%)                                                    | <ul style="list-style-type: none"> <li>▪ Religious organisations (avg. 1.00), community organisations (avg. 2.31), NGOs (avg. 2.36), private sector organisations (avg. 2.46), and government agencies (avg. 2.80) agree.</li> </ul>                                                                                                      |
| Fire suppression policies have contributed to large wildfires due to fuel accumulation                                                                | 3 (2)        | Ethnolinguistic identity (6%)<br>REDD+ (5%)<br>Age (4%)                          | <ul style="list-style-type: none"> <li>▪ Bantu (avg. 2.73) agree; Nilotic (avg. 3.10) uncertain; Cushitic (avg. 4.16) disagree.</li> <li>▪ Chyulu Hills REDD+ (avg. 2.23) agree; Kasigau REDD+ (avg. 3.27) uncertain.</li> <li>▪ Higher age - greater disagreement.</li> </ul>                                                            |
| Fire suppression policies reinforce negative views of all fires                                                                                       | 3 (3)        | <i>No significant predictor variables.</i>                                       |                                                                                                                                                                                                                                                                                                                                           |
| Other policies, other than fire suppression, are effective in wildfire management                                                                     | 3 (3)        | Education level (4%)                                                             | <ul style="list-style-type: none"> <li>▪ Higher education level - greater agreement.</li> </ul>                                                                                                                                                                                                                                           |
| Prescribed controlled patch mosaic burns promote habitat diversity                                                                                    | 2 (3)        | <i>No significant predictor variables.</i>                                       |                                                                                                                                                                                                                                                                                                                                           |
| More information and training on the benefits and methods of prescribed controlled burning for wildfire management are required before implementation | 1 (1)        | <i>No significant predictor variables.</i>                                       |                                                                                                                                                                                                                                                                                                                                           |
| There are good relationships between park rangers and local communities                                                                               | 2 (1)        | Ethnolinguistic identity (9%)                                                    | <ul style="list-style-type: none"> <li>▪ Cushitic (1.12), Nilotic (2.00), and Bantu (avg. 2.46) agree.</li> </ul>                                                                                                                                                                                                                         |
| Wildfires are fuelled by conflicts between communities and park authorities                                                                           | 3 (3)        | Ethnolinguistic identity (9%)<br>Age (7%)                                        | <ul style="list-style-type: none"> <li>▪ Nilotic (avg. 2.73) agree; Bantu (avg. 3.03) uncertain; Cushitic (avg. 4.48) disagree.</li> <li>▪ Higher age - greater disagreement.</li> </ul>                                                                                                                                                  |
| Pastoralists unintentionally cause wildfires when burning for pasture regrowth                                                                        | 2 (1)        | REDD+ (11%)                                                                      | <ul style="list-style-type: none"> <li>▪ Kasigau REDD+ (avg. 1.93) agree; Chyulu Hills REDD+ (3.33) uncertain.</li> </ul>                                                                                                                                                                                                                 |
| Traditional fire management strategies carried out by local communities should be considered in future park and conservancy management plans          | 2 (3)        | Ethnolinguistic identity (11%)                                                   | <ul style="list-style-type: none"> <li>▪ Nilotic (avg. 1.91) and Bantu (avg. 2.41) agree; Cushitic (avg. 4.24) disagree.</li> </ul>                                                                                                                                                                                                       |
| Traditional fire management strategies carried out by local communities are considered in current park and conservancy management plans               | 3 (3)        | REDD+ (7%)                                                                       | <ul style="list-style-type: none"> <li>▪ Chyulu Hills REDD+ (avg. 2.17) agree; Kasigau REDD+ (avg. 3.63) uncertain.</li> </ul>                                                                                                                                                                                                            |
| Fire management is a source of conflict between park managers and local communities                                                                   | 3 (3)        | Primary group code (10%)<br>Ethnolinguistic identity (10%)                       | <ul style="list-style-type: none"> <li>▪ Indigenous and local communities (avg. 2.87) agree; protected area staff (3.00) and rangers (avg. 3.14) uncertain.</li> <li>▪ Cushitic (avg. 1.64) and Nilotic (avg. 2.36) agree; Bantu (avg. 3.25) uncertain.</li> </ul>                                                                        |
| The ancestral land rights of local communities are respected across the Tsavo Conservation Area                                                       | 3 (3)        | Primary group code (1%)                                                          | <ul style="list-style-type: none"> <li>▪ Protected area staff (avg. 2.47) and rangers (avg. 2.51) agree; Indigenous and local communities (avg. 3.14) uncertain.</li> </ul>                                                                                                                                                               |

Overall, the results show that ethnolinguistic identity and the presence of REDD+ projects have the largest influence over perceptions towards fire across TCA. Participants within the Chyulu Hills REDD+ project area expressed stronger beliefs than those in Kasigau, with mean response varying between 1.25 and 4.24, compared to between 1.93 and 3.63. Similarly, participants who identified as Cushitic expressed greater conviction and polarity in their responses (between 1.12 and 4.24), such as simultaneously agreeing that there are good relations between park authorities and local communities and that fire management is a source of conflict. Whereas those who identified as Bantu generally expressed greater uncertainty (between 1.68 and 3.37). This is likely explained by the large sample of Bantu participants in this study who span different ‘group types’, while Cushitic participants were mostly from a single Indigenous Waata community, thus have to some degree, express the same repertoire of norms and strategies. Age, education, primary group type, and employment organisation have less influence over perceptions towards fire. Generally, age and education were negatively and positively correlated with agreement over fire perception items, respectively; older participants typically disagreed with the notion that savannas are social-ecologically important ecosystems, and that fire suppression policies have contributed towards wildfire events, while higher educated participants typically agreed that savannas are important ecosystems and that other policies, other than fire suppression, are effective in wildfire management.

## 5. Complex pyro-geographies

This chapter provides an in-depth discussion of the fieldwork results described in Chapters 3 and 4. Qualitative results are supported by semi-quantitative data (e.g., median (*Mdn*), most, and frequency values, spearman rank correlations, and GLM results) to provide a detailed and critical account of diverse actors’ perceptions of fire and their significance in the landscape, the drivers and impacts of wildfire events, and current and future fire management approaches. It draws on the broader literature to describe the political-economic, sociocultural, and legal conditions that contextualise fire management across TCA. A pyro-geographic framework was loosely applied to structure this discussion and increase readability and coherency (see Chapter 2). However, due to complex interconnections between fire and climatic, biological, topographic, and sociocultural conditions across multiple spatiotemporal scales, there are significant overlaps between each section, thus results should be interpreted holistically, rather than in isolation.

While the data discussed in this chapter is specific to TCA, macro-scale conditions and (neo-)colonially inherited policies, governance systems, and knowledges present similar opportunities and challenges in local resource governance settings across Sub-Saharan Africa and the tropics more globally. Thus, much of the information provided in this section can be considered in other research and management contexts.

## 5.1. Climate and biology, topographic environment, and fires

Understandings of savanna ecosystems, biogeophysical wildfire conditions<sup>7</sup>, and the ways in which they interact to affect social-ecological systems have significant influences over management interventions and outcomes. This section describes participants' perceptions of fire in relation to the physical environment, such as the key drivers of wildfires, their spatiotemporal variability, and how current and future land-use, -cover, and -tenure change affects biogeophysical conditions across TCA. In doing so, this section aims to provide an in-depth understanding of how, why, and the extent to which certain narratives over fire exist, and to contextualise further discussions presented in sections 5.2, 5.3, and 5.4.

### 5.1.1. Regional biogeophysical conditions

Anthropogenic climate change is increasingly shifting the timing of seasons (e.g., onset and termination of wet and dry seasons) and driving large inter- and intra-annual rainfall variability (*Mdn: 1*). Dry seasons are lengthening in duration (*Mdn: 1*) and droughts are becoming more frequent and intense (*Mdn: 1*). Interspersed with 'heavy' or 'good' rainfall seasons, drought conditions have resulted in large, highly flammable fuel loads, creating unpredictable fire regimes dominated by wildfires. 68% of participants observed wildfires in the LDS when strong winds enhance wildfire spread (*Mdn: 1*), with the most extreme wildfires being observed in dry seasons immediately succeeding 'good' rains. Only 34% and 7% of participants observed wildfires in the EDS and wet season, respectively. Generally, participants agreed that climate change has increased the frequency (*Mdn: 2*), intensity (*Mdn: 2*), and total burned area (*Mdn: 2*) of fire events, and strongly agreed that climate change has affected fire severity (*Mdn: 1*), having greater negative impacts on soil and vegetation structures<sup>8</sup>. With the earlier onset and later termination of the dry season and rising temperatures, biomass 'is completely dry. It is like kindling.' However, ongoing declines in MAP, increases in the number of dry versus wet years (*Mdn: 2*), and the intensification of multi-year droughts caused by double and triple La Niña events - of which have accelerated in the last 25 years (Anderson et al. 2023; Geng et al. 2023; Wang et al. 2023) – have reduced the frequency of wildfires across TCA: 'There are no wildfires when the rains fail. The last major wildfire was in 2020 because in 2019 we had rain for a whole year. The grass grew, so when we entered the dry season, it was tinder. You can tell the wildfire cycle as you have the conditions that precede the big ones.' These trends were further evidenced in the scale-ranking data, such that most participants have observed

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<sup>7</sup>Including: temperature; relative humidity; rainfall; soil moisture and composition; vegetation moisture, structure, and diversity; wind; and geomorphological features.

<sup>8</sup>Frequency (e.g., shorter return interval); intensity (e.g., larger flames, hotter flaming front, greater fuel consumption, faster rate of spread); severity (e.g., greater negative impacts on vegetation and soil); total burnt area.

high intensity (*ranked 10/10*) and severe (*ranked 8/10*) fires in their local jurisdictions, however at low frequencies (*ranked 1/10*).

The persistence of multi-year La Niña events across East Africa are particularly pronounced following strong El Niño events characterised by above-average rainfall (DiNezio & Deser, 2014; Wu, Okumura & DiNezio, 2019). Additionally, a positive correlation between La Niña and *n*IOD events, of which typically occur during the late-autumn winter months (Lim & Hendon, 2017; Song & Ren, 2022; Huang et al., 2024), favours drought conditions in the short-rainy season under future climate change (Anderson et al., 2023; Tao et al., 2024). Hence, the intensification and of the ENSO and IOD and their teleconnections under global warming can accelerate a *'negative wildfire cycle'* whereby less frequent, high intensity, and severe wildfire events are succeeded by prolonged drought conditions, driving long-term savanna degradation and large reductions in available biomass (Endris et al., 2019). Participants highlighted how the failure or later onset of the rains has negatively affected vegetation growth, such that the thermal response of plants to begin development at the onset of the wet season means that they are increasingly growing under water- and heat-stressed conditions, resulting in slower growth rates, declines in primary productivity and plant diversity, woody encroachment, and extensive bare-ground coverage (Lobell & Burke, 2008; Palmer et al., 2023). This has exacerbated inter- and intra-specific competition between wildlife, livestock, and humans for natural resources, further driving ecological degradation and socioeconomic vulnerabilities.

Vegetation serves as a windbreak or ecological buffer across the landscape, preventing water, soil, and further vegetation loss by wind erosion. Thus, changes in surface albedo due to defoliation and soil degradation can, in-part, explain why participants are increasingly experiencing large fluctuations in daytime and nighttime temperatures and stronger winds which facilitate rapid fire spread (Rutherford et al., 2017; Western et al., 2021; Malongweni & van Tol, 2024). This has created disagreements over when and how to fight wildfires. Most participants agreed that firefighting should be carried out during the day *'because the winds increase at night in semi-arid areas. However, high temperatures in the day also create challenges.'* Conversely, park authorities maintained that it *'is common knowledge that the best time to fight fires is at night, not during the day; because of the amount of wind – it is strong. It is making it difficult to fight fires.'*

Some participants attributed *'significant declines in rangeland production'* to *'issues mainly centered around settlement'*, rather than climate-induced changes (e.g., rainfall patterns and seasonality); *'if you look at historical trends, [...] there have been insignificant changes in rainfall production'*, but there has been *'increased sedentarisation across the landscape and over-utilisation of land - uniformly used in the wet and dry seasons. There is no movement and fallow periods for land to recover.'* While settlement patterns have a perceptible influence over land-cover change and, for many participants in this study, transitioning towards a more sedentary livelihood is both a tangible and

lived experience, long-term precipitation trends are often less known to local people. This can in part be attributed to complex global teleconnections and variation in the local drivers of decadal and inter-annual climatic variability across the region (Palmer et al., 2023), resulting in anomalous patterns of wetting and drying in the rainy seasons, and oscillations between extreme wet and dry events (Kotikot, Smithwick & Greatrex, 2024). Such variability, compounded by a lack of long-term data due to the absence of well-resourced and functioning weather stations across the region (MacLeod et al., 2021; Tzachor et al., 2023), as well as a decline in traditional ecological knowledge, might have created disparities in local understandings of climate change and its effects on the environment.

### 5.1.2. Natural causes of wildfire

Wildfires originating from ‘natural’ disturbances such as lightning and physical weathering are unknown or considered rare across TCA (*Mdn: 3*). Most participants attributed wildfire events to ‘human interference’, thus physically-induced fires were speculated to occur only in areas with low resource availability and reduced human populations, for example in Misani where *‘there is not much there and a lack of human presence, but there are still fires. It is extremely dry and hot, so a slight friction could easily ignite a fire.’*

Natural fire activity has been observed in the LDS (late July to early October) when regional biogeophysical conditions favour ignition and fire spread. However, discrepancies between participants’ understanding of ‘natural fires’ was consistent with long-standing debates over the concept of ‘natural’ versus ‘anthropogenic’ fire regimes in Africa (Bowman et al., 2011; Archibald, Staver & Levin, 2012). Natural fires were generally understood as a product of enhanced biogeophysical wildfire conditions in the LDS, irrespective of human ignition sources (incl. technological hazards): *If it’s a dry season, it’s a dry season, you cannot have lightning. If it rains, they are tropical and heavy, so you cannot have fire.* Most did not perceive fires as existing independently from humans – *‘we don’t have lightning as a cause of wildfire in Kenya’* – despite contrary evidence (Komarek, n.d.; Cardoso et al., 2008; Nyongesa, 2015). Understandings of the relationship between climatic and weather phenomena and wildfires have mostly been informed by global comparisons (e.g., Australia and South Africa), where evidence from other tropical fire-prone environments have been used to make assumptions over fire dynamics in East African savannas (Crocker, Woods & Kountouris, 2023b). Given its comparatively close geographical location, fire management literature sourced from South Africa continues to inform understandings and practice in East African savanna-protected areas, despite the regions’ evolutionary distinct ecological and social characteristics and climate patterns, often exhibiting non-linear and inverse effects (Plisnier, Serneels & Lambin, 2000; Sazib, Mladenova & Bolten, 2020; Pooley, 2021; Doi, Behera & Yamagata, 2022).

### 5.1.3. Local topographies

Localised biogeophysical conditions in TCA - largely attributed to human activities, ignition sources and the structure of wild and domestic herbivore communities - have created discernible differences in the spatiotemporal distribution and characteristics of wildfires across the landscape. Wildfires are typically less frequent but greater in size (i.e., burned area) and intensity across the semi-arid savanna lowlands in Tsavo than in the mesic savanna-woodland-forest habitats in Chyulu Hills (Muriuki et al., 2011a). Vegetation growth across much of Tsavo is 'precipitation-limited' (see Chapter 2), therefore fires tend to follow the *'negative wildfire cycle'*. While this can increase their predictability, – *'if you have good rain for three or four months, there's fuel. So, you can predict them to the dot.'* - Tsavo's continuous grasslands facilitate rapid fire spread and larger wildfires. In recent years, the encroachment of woody shrub and weed species have made it challenging to fight fires, resulting in larger burnt areas.

In contrast, Chyulu Hills rises to over 2000m above sea-level and is characterised by porous volcanic lava rock and a mesic savanna-forest vegetational structure, serving as the main water catchment for the surrounding area (Scoon, 2018). The generally wetter environment, denser vegetation structure, and higher proportion of woody plants, bushes, and shrubs relative to herbaceous species prevents rapid fire spread and, to some extent, reduces the overall flammability of biomass. Though mesic savannas in Chyulu Hills are 'disturbance-driven', historical fire suppression policies have resulted in widespread bush encroachment. *'Wildfires do not spread as fast in Chyulu and they do in Tsavo, but they can persist because people cannot access fire sites to extinguish them.'* Therefore, similar challenges regarding firefighting are experienced in both Chyulu and Tsavo where the cover and density of woody plants is increasing.

Wildfires are more frequent and sporadic in Chyulu Hills than in Tsavo, occurring intra-annually with larger events concentrated in the LDS. Population growth in this region far exceeds the national average, and the number of people living in absolute poverty is increasing (Muriuki et al., 2011a). Participants have observed large declines in vegetation in areas densely settled by Kamba communities and across the Maasai Group ranches due to over-grazing. This is exerting forms of habitat compression on Chyulu Hills (e.g., ecological degradation within the park boundary), thus driving local people and their fire-use practices further towards the core (often inaccessible) areas of the park in search of resources. Fire ignitions were specifically attributed to pastoral Maasai communities *'who have to burn without knowing it will rain'*, agricultural Kamba communities *'who light fires'* and *'do not co-exist with wildlife'*, and *'outsiders'* who *'do not see the reason to continue to conserve pasture in the protected areas'* (see sections 5.2. and 5.3) (Muriuki et al., 2010). Given the park's woody vegetational structure and increasingly fragmented landscape, this rise in ignition number has not, to the participants' understanding, translated into a larger total area burnt (Archibald,

2016). However, participants view ignitions as being symptomatic of ever-growing socioeconomic vulnerabilities, including poverty, food insecurity, and a lack of livelihood options, therefore threatening the long-term ecological viability of Chyulu Hills.

The presence of wild and domestic herbivores has a large influence over the type, structure, and availability of biomass in the wet and dry seasons inside and outside the protected areas. Multi-year drought conditions following the 2020 wildfires in Tsavo contributed to large declines in wildlife and an unprecedented number of livestock deaths (UN OCHA, 2023). Participants expressed how wildebeest in the Mara *'create a very fertile ground for generation.'* However, Tsavo *'barely has wildlife or livestock. The few you find are concentrated in water-source landscapes, so those areas are highly degraded while others are tinder boxes for fire.'*

In TCA, dry season grazing areas are typically moist-dystrophic (nutrient-poor) savanna ecosystems, only utilised by herbivores when water sources and pasture have depleted in the more arid nutrient-rich savannas. However, due to observed declines in wildlife, as well as the inability for livestock to functionally replace bulk-feeding herbivores (e.g., elephants, buffalo, rhino, and hippo) in terms of fuel utilisation and consumption (Archibald & Hempson, 2016), these areas have accumulated large amounts of biomass and are identified as wildfire hotspots, including Olgulului-Ololarashi, Imbirikani, and Eselenkei group ranches, and lower areas of Chyulu Hills (Mramba, 2022). An increase in tsetse fly (*Glossina pallidipes*) populations within and surrounding mesic protected areas, partly due to the KWS' *'duty to protect all animals'* and subsequent ban on applying population control strategies (e.g., odour-baited targets), also reduces the habitat selection of herbivores across these areas (Gachoki et al., 2023). However, due to temperature and precipitation-driven declines in tsetse fly populations and increasing drought conditions (Moore & Messina, 2010; Nnko et al., 2017; Nnko et al., 2021; Cecilia et al., 2021), dry season grazing areas are under pressure from greater utilisation by both wildlife and herders and their fire-use activities. In the short-term, this presents a large wildfire risk. In the long-term, increasing human, livestock, and wildlife concentrations reduces vegetation continuity and density, thus suppressing fires irrespective of ignition number

Most of Tsavo's productive rangelands are situated within the protected areas where *'no human interventions'* have contributed to the dominance of panicum grasses up to 2m tall – noted for being attractive to tourists because they *'take a nice photo'* and, therefore, have been left unmanaged. Increasing security operations and electric fences preventing and suppressing human and natural disturbances (e.g., livestock grazing and fire) have *'over-protected the landscape'*, resulting in large surface fuel loads and high intensity wildfires in Tsavo National Parks. Wildlife is generally concentrated in locations where water continuously flows from porous volcanic rock, such as the Mzimi Springs in Tsavo West (Nyingi, Gichuki & Ogada, 2013; Muñoz, Orlando & Zuñiga-Feest, 2021). As such, *'fuel during the dry season is minimal'*, but when fires break out in these areas *'it can*

*take weeks before they go out. You feel like you have put it under control, only to realise tomorrow that you see smoke.*’ This is likely due to the greater likelihood of smoldering wildfires across volcanic landscapes where fractured and weathered zones in the rocks support nutrient-rich, deep organic soils which favour smoldering combustion (Stracher, Prakash & Rein, 2015; Scholten et al., 2021; Olivares-Martinez, Gomez-Tagle & Mataix-Solera, 2023).

In Chyulu Hills, greater security enforcement has had the opposite effect. Electric fences have concentrated wild animals within the woody-dominated protected area, increasing herbivory pressures and reducing surface fuel loads (Diplock et al., 2018). Fire suppression, drought conditions, and water-stress have promoted woody thickening across the mesic savannas, resulting in an increase in drought-tolerant shrub and weed species outcompeting native grass species, further reducing vegetation continuity and, in-turn, fire spread (Otieno & Kinyamario, 2017; Mganga, 2023). In the foothills of the Chyulu Range where the park meets the Maasai group ranches, herbivore-vegetation-fire dynamics are akin to those observed in Tsavo, particularly within the Chyulu Hills REDD+ project area where above-ground biomass accumulation is financially incentivized.

Outside park boundaries in the savanna lowlands and foothills, overgrazing, settlement, and land-use and cover change have increased bare ground coverage and soil erosion:

*‘You can tell where the electric fence is without seeing it. After the fence, you have trees and shrubs, but no grass. The problem with tree cover is that it suppresses grass – there are the perennials, but not the annuals; it drives erosion and kills the savanna. Inside the fence you have a lot of grass but no trees.’ ‘They always have issues with fire within these establishments. Two months after the rain, they are dealing with fire.’*

Based on regional climate patterns and local biogeophysical wildfire conditions, participants generally agreed that *‘you would not have wildfires if farmers were empowered because you could predict them’*; fires would occur in the LDS immediately succeeding good rainy periods, and as the number of drought years increases, the likelihood of wildfires decreases due to increased competition for limited biomass.

#### **5.1.4. Wildfire-Biodiversity Interaction Pathways**

Population growth coupled with large-scale land reforms have accelerated processes of sedentarisation, urbanisation, and agricultural intensification across TCA, blocking ecological corridors and increasingly concentrating wildlife populations into smaller fragmented parcels of land (see section 5.2). Participants consistently attributed biodiversity loss to interactions between LDS wildfires, vegetation structure, and herbivory inside spatially-compressed protected areas. The individual and synergistic effects of these interactions on biodiversity and future wildfire conditions varies across the landscape, depending on tree-grass dynamics, the presence and structure of herbivore

communities, and park security operations. While this variation is extremely nuanced at the local-level, three main ‘Wildfire-Biodiversity Interaction Pathways’ emerged in the data and are summarised in Table 12. These pathways assume that human activity is spatiotemporally homogenous across the landscape (i.e., drivers of spatial compression are the same in Tsavo and Chyulu). Pathways 1 and 2 assume that herbivores are equally distributed across the ecosystem, while Pathway 3 assumes that herbivores are highly concentrated within a dry season grazing area. Participants did not specify the time-period or the specific biogeophysical and socioeconomic conditions that contextualise these pathways. For example, illegal encroachment is increasing in the parks in and is strongly associated with deforestation – directly through fuel harvesting and indirectly through burning - and increased human-wildlife conflict. While not presented in Table 12, human presence can either intensify or weaken stated feedbacks (see section 5.3). Hence, these Interaction Pathways should be treated as abstracts of reality and considered alongside broader discussions presented in this thesis to help understand wildfire-biodiversity feedbacks.

**Table 12.** *Wildfire-Biodiversity Interaction Pathways in spatially-compressed savanna-protected areas where fire suppression is the dominant management approach.*

|   | Pathway                        | Dominant savanna type     | Security operations | Pathway description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Human-wildlife conflict |
|---|--------------------------------|---------------------------|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| 1 | <b>Savanna grasslands</b>      | Semi-arid (mostly grassy) | No electric fence   | Wildfires drive wildlife out of protected areas into community lands. Declines in herbivore communities drives woody encroachment due to reduced nutrient supply and distribution (plant heterogeneity) (Monk, 2024). Woody encroachment and increased canopy density limits future fire spread and reduces habitat selection of large herbivores, driving further biodiversity loss.                                                                                                                                                                                                                                                                           | Direct                  |
| 2 | <b>Savanna woodlands</b>       | Mesic (mixed, woody)      | Electric fence      | Security operations concentrate wildlife inside protected areas, preventing movement between parks and community lands. Dense herbivore communities drive declines in above-ground biomass (trees and grasses) due to increased competition, over-grazing, and movement throughout the ecosystem, reducing surface fuel loads. In the short-term, increased vegetation continuity can favour rapid fire spread. Wildfires increase pressures on vegetation and contribute to total plant reductions, driving further biodiversity loss. In the long-term, overgrazing can favour the growth of unpalatable and fire-resistant increaser II and invader species. | Indirect                |
| 3 | <b>Dry season grazing area</b> | Semi-arid (mostly grassy) | No electric fence   | Prolonged dry conditions drive higher concentrations of wildlife into wetter, nutrient-poor grazing areas, typically consisting of high grassy fuel loads. Wildfires drive wildlife out of protected areas into community lands. Declines in herbivore communities from dry season grazing areas results in large surface fuel loads, increasing wildfire risk and creating ‘wildfire hotspots’.                                                                                                                                                                                                                                                                | Direct                  |

Under socioeconomic-climate change, all three pathways directly (Pathways 1 and 3) or indirectly (Pathway 2) accelerate human-wildlife conflict. Wildfires consume a large proportion of above-ground biomass in protected areas, driving wild animals into community lands and increasing negative human-animal interactions, such as crop raiding by elephants, livestock depredation, and loss of property and livelihoods (see section 5.3). Elephants were frequently cited as being negatively impacted by wildfires; however, participants were primarily concerned with the economic consequences of declining megafaunal populations due to human-wildlife conflict. Since wildlife conservation is a dominant economic activity in TCA (Table 10), declines in tourism and related revenue streams are projected to have significant implications on the local economy, accelerating social vulnerabilities where livelihoods increasingly rely on *'foreign exchange.'* Additionally, participants expressed concern over the impacts of wildfire on ground-nesting birds and smaller species such as reptiles (particularly snakes, lizards, and tortoises), amphibians, and burrowing and hibernating mammals who *'cannot escape fires'*. *'Nowadays, people are interested in the smaller species. So, those groups oppose fires in conservation areas. Fire can be beneficial for larger mammals, but it might not be for the smaller ones.'*

Although increased security operations (e.g., fencing, outposts, ranger patrols) are perceived to have generally reduced poaching across the region, they have increased tensions between local communities and conservation agencies due to the stricter enforcement of exclusionary property-rights. The challenges presented in Pathway 2 are pronounced in Chyulu Hills due to the establishment of an electric fence around the park, exacerbating resource-based conflicts and illegal activity (see sections 5.2. and 5.3).

#### **5.1.5. When is a savanna a forest?**

Savanna ecosystems support a high proportion Sub-Saharan Africa's population, most of its rangeland and livestock biomass, and Earth's last remaining extant megafauna (Roy, Saugier & Mooney, 2001; Kibet et al., 2021). They are of ecological, social, and economic importance to people across TCA (*Mdn:2*), particularly to Bantu agriculturalist and 'settled' Nilotic agro-pastoralist communities who require access to healthy savanna ecosystems to carry out their economic activities, of which significantly contribute towards local and national economic development and regional security (Tables 10 and 11). Thus, livelihood resilience under future socioeconomic-climate change is highly contingent on the adaptive resilience of savanna ecosystems and their ability to respond to disturbances and support ecological processes characteristic of the ecoregion's natural variability range (Galvin & Reid, 2010; Marchant, 2010). Despite these strong importance-values, only two participants alluded to the ecological role of fire in savanna vegetation regeneration – mostly in relation to pasture for livestock.

Fires are negatively perceived across TCA, having little or no positive impacts on savanna biodiversity. Rather, *‘all plants and animals are negatively affected by wildfire’*; fires kill all plant species and, in-turn, animal species who *‘suffer from a low and bad quality diet when fresh plants burn’*, and *‘when the grass burns, animals starve.’* Vegetation regeneration was mostly attributed to ecological factors other than fire, including rainfall, herbivory, and edaphic conditions, and participants were generally uncertain over the role of fire in preventing woody encroachment and maintaining an open grass-dominated landscape (*Mdn: 3*) - however most strongly disagreed. Participants who agreed that savannas are socially-ecologically important typically disagreed that fires are important in maintaining their ecological health, further evidencing a disconnection between savanna ecology and fire disturbances [ $p = 4.893e-0.5$ ,  $\rho = -0.267$ ]. This disconnection was particularly pronounced across the Chyulu Hills REDD+ area, possibly due to ongoing challenges with wildfires associated with illegal activity (Table 11).

While 77% of participants attach high importance values to savanna ecosystems, only 8% believe that tropical grassy biomes are intrinsically valuable and ecologically distinct from forest ecosystems, experiencing their own patterns of degradation, including woody thickening. 73% of participants perceive savannas as degraded forests that require restoration [*Mdn: 2*], advocating for fire suppression and prevention to promote tree growth [*Mdn: 2*;  $p\text{-value} = 4.936e-0.8$ ,  $\rho = 0.354$ ]. This suggests that individuals concurrently hold divergent views: savannas are socially-ecologically important ecosystems but are also degraded forests that need to be restored. These contentions in the data are consistent with long-debated and politically salient questions regarding ‘when is a savanna a forest?’, ‘what is a tropical dry forest?’, ‘are tropical forests undergoing savannization?’, and ‘are forests *treed* savannas?’, which have and continue to have large implications on land-use and management decisions (Ratnam et al., 2011; Stark et al., 2020).

Most participants do not perceive plant nor animal species in TCA to be fire-adapted. Rather, they highlighted the negative impacts of fire on soil microorganisms and how this propagates throughout the ecosystem, initiating a negative trophic cascade:

*‘There are no fire-resistant trees. Fire has killed the microorganisms that trees depend on. That is the biggest loss.’ ‘You kill the ants; you kill the termites... you kill the soil. Soils lack the ability to regenerate.’*

Knowledge of fire-adapted plant species did not translate into positive perceptions of fire in savanna ecosystems. For example, participants who believe that some large fires are necessary in maintaining an open-canopy also believe that savannas are degraded forests [ $p\text{-value} = 0.003$ ;  $\rho = 0.194$ ], and participants who believe that savannas are degraded forests also typically believe that some plant species are adapted to fire [ $p\text{-value} = 0.04633$ ;  $\rho = 0.1329778$ ]. Most participants who acknowledged that some plant species are adapted to fire commonly understood

‘fire-adapted’ as ‘fire-resistant’ or ‘drought tolerant’, identifying several tropical agro-forestry species (TASs) that can withstand fire events or prolonged drought conditions rather than plant species whose evolutionary and life histories (e.g., germination, reproduction, recruitment, growth), functioning, adaptive cycles, and competitive relationships depend on fire disturbances (e.g., herbaceous spp.) (Scogings, 2023; Parr, te Beest & Stevens, 2024).

Figure 4 summarises the divergent beliefs held by participants regarding the nature of savannas, their fire ecologies, and how they should be managed. Overall, these results imply that participants generally associate fire with the preservation of secondary savanna vegetation structures at the expense of primary closed-canopy forest structures, reinforcing Clementsian views of vegetation succession and semantic challenges rooted in colonial-inspired degradation narratives (Butz, 2009; Pollini, 2010).

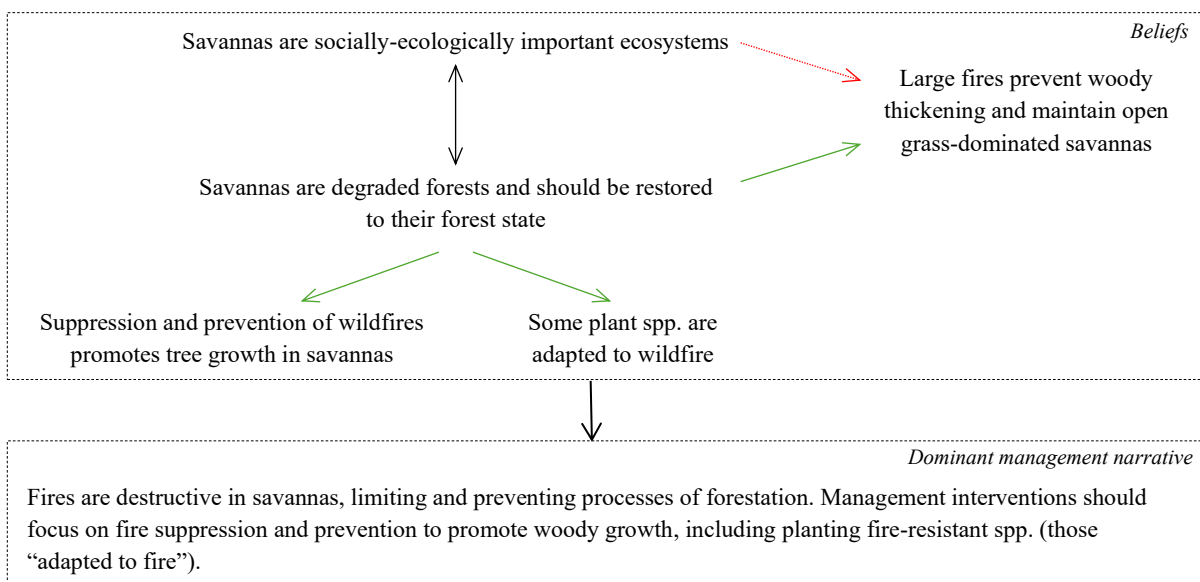


**Figure 4.** Beliefs over savanna ecosystems and biodiversity and their management implications. Green arrows show statistically significant positive correlations between beliefs, and red arrows show negative correlations.

### 5.1.6. Tropical agroforestry species in *Acacia-Commiphora* savannas

Indigenous and local communities, and protected area staff and rangers, expressed concerns over the negative effects of wildfires on native savanna tree species important for improving soil fertility, preventing soil erosion, and providing wind breaks, shade, and food and shelter for wild and domestic animals across the savanna lowlands (Feyisa et al., 2018). Identified species included: Bird plum (*Berchemia discolor*), *Acacia tortilis* (now the umbrella thorn acacia, *Vachellia tortilis*), *Acacia mellifera*, and *Commiphora schimperi*. Taita communities residing along Tsavo West’s boundaries expressed greater concern over the impacts a reduction in the range and productivity of *Acacia-Commiphora* savanna bushlands might have on browsing livestock populations (e.g., mostly camels

and goats) under intensifying drought and wildfire conditions. They highlighted how livestock deaths can amplify food security challenges and, in turn, incidences of livestock rustling and agrarian resistance. These concerns are likely widespread across the tropics as rural communities increasingly shift from cattle to goat and camel farming to increase the resilience of meat and dairy production under climate change (Rahimi et al., 2022; Ndona et al., 2024). (Rangers on the other hand, were more concerned over the impacts of wildfires on wildlife and tourism, identifying endangered species, tree-nesting birds, and the ‘big five’ (mostly elephants and buffalo) as being most at risk. While the term ‘big five’ was first introduced by colonial hunters to refer to the largest, most dangerous species to hunt on foot, rangers now identify the big five as keystone species and one of the main *‘tourist attractions that empower our economy.’* Their plight is *‘a big loss to the conservancy,’* thus rangers highlighted the need to invest in *‘the proper mitigation of bushfires – spearheading bushfire control through training, equipment, and necessary support, including increased technologies,’* to prevent the *‘loss of habitats and many animals.’* Settled agro-pastoral Giriama and Waatha, and agricultural Kamba communities within the broader distributive limits of the Chyulu Hills and Kasigau REDD+ projects noted how Acacia species *‘important for carbon offsetting’* are negatively impacted by wildfires, resulting in a reduction in carbon credits which *‘help to educate our children’* - in

To mitigate wildfire challenges across the Acacia-Commiphora savannas ecosystems, while simultaneously contribute towards achieving higher agricultural output and carbon emissions offsetting objective, ‘fire-adapted’ TASs - mostly understood as ‘fire-resistant’ or ‘drought tolerant’ in this context - are increasingly prioritised in protection and planting schemes. Rangers, protected area staff, and representatives from conservation agencies promoted species such as Siamese Senna or ‘Ikengeta’ trees (*Senna siamea*), Neem or ‘Mwarubaini’ trees (*Azadirachta indica*), ‘Mukau’ or ‘Kirumbutu’ trees (*Melia volkensii*)<sup>9</sup>, Mango trees (*Mangifera indica*), and Desert date or ‘Mulului’ trees (*Balanites aegyptiaca*) for ongoing plantation across TCA. However, this is *‘changing the landscape’*; *‘bushes and trees are growing’* and *‘you barely find well established grass.’* While many of these species are relatively drought resistant, such as being able to withstand prolonged drought conditions with low rainfall (e.g., 300 MAP for Desert date, Mukau, and Mango trees) and high temperatures (e.g.,  $\geq 40^{\circ}\text{C}$  for the Neem tree), they are not fire-adapted. Only Siamese Senna and Neem can withstand some fires as adults, however their saplings are vulnerable to fire, and neither species are native to Kenya. Only Mukau and Desert date trees are native to Kenya (see Agroforestree database).

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<sup>9</sup> “Mukau” to Tharaka, Kamba, and Kikuyu people. “Kirumbutu” to Digo and Taita people.

Members of Indigenous and local communities identified several of these TASs and maize (*Zea mays* L) and pawpaw (*Carica papaya*) as being critical for their livelihoods<sup>10</sup> but negatively affected by wildfires. Agro-pastoral and agricultural communities within REDD+ project areas reiterated the importance of TASs in providing direct health benefits and food security to large proportions of the rural population (>80% in developing countries (Chérif et al., 2023)), as well as sourcing products that are locally and commercially traded (e.g., timber). As such, wildfires threaten local food security (particularly a decline in maize and honey) and future income opportunities. Communities living outside REDD+ project areas identified the Baobab tree (*Adansonia digitata*), cactus (*Opuntia* spp.), and *Erythrina brucei* as ‘not being affected by wildfire’, ‘drought resistant’, and ‘bringing a source of food to animals’, recommending their prioritisation in future forest restoration and agro-forestry projects implemented in fire-prone areas. Conversely, rangers working within REDD+ identified Baobab trees and cactus, as well as Mesquite (*Prosopis juliflora*), as being negatively impacted by wildfires, and staff from Tsavo East National Park further identified *Macaranga conglomerate*. Participants advocated for increased fire mitigation to protect these species.

These results reveal that different actors (e.g., context setters, players, and subjects) hold divergent understandings of specific plant ecologies. Thus, depending on their specific management objectives and influence over future rules-in-use, these actors can have significantly different influences over future fire regimes, long-term savanna health, and local livelihoods across TCA, such as by selecting species prioritised in fire mitigation strategies (incl. planted as firebreaks) and ecosystem restoration projects (e.g., achieving climax communities). The next sub-section considers participants responses to provide a management case-study, outlining the effects different priorities and implemented pathways might have across TCA.

#### 5.1.6.1. Management case-study

The prioritisation of Baobab trees in restoration efforts will likely have long-term positive impacts on the local environment under intensifying wildfire and drought conditions. Baobabs are native to Kenya’s hot arid lowlands, exhibit fire-resistant (e.g., bark and stem physiology) and drought-tolerant traits, and provide a range of ecosystem services, including nutrient cycling and increased soil fertility, soil erosion prevention, and the provision of food, medicine, shelter, and shade for humans and wildlife. Studies show that in more xeric savanna environments (<750mm MAP), stand-alone, widely spaced, and small groups of scattered Baobabs can increase herbaceous-layer productivity by up to 95% by reducing solar radiation and soil temperatures (reducing evapotranspiration) and increasing organic matter concentrations. Similarly, native *Acacia* spp. (e.g., *Acacia totillis*) have been

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<sup>10</sup>Identified TASs provide food (e.g., fruit, nuts, oils), firewood, medicine, fodder, charcoal, timber for construction materials, textile fibres, farm and household tools, gums and resins, tannins and dyestuffs, and forage for bees, can act as windbreaks and live fences around farms and homesteads, and provide shade and increase soil fertility on farms.

shown to have comparable positive effects on grassland productivity across Tsavo (Belsky et al., 1993; Belsky, 1994; Gebauer et al., 2016).

On the other hand, the long-term social-ecological implications of planting exotic species such as *Erythrina brucei* are largely unknown. *Erythrina brucei* has recently been introduced in Kenya as a fast-growing (mitigating some of the risk fires present to saplings), drought-tolerant TAS due to having observed benefits on surrounding plant communities in its native environment (Ethiopia) through nitrogen fixation and soil fertilisation. In Kenya, there is potential for this species to outcompete native species, altering local biotic interactions. Moreover, *Opuntia stricta* (well established across Taita-Taveta) and *Prosopis juliflora* are recognised invasive alien species (IASs) (Hussain et al., 2020; Bibi et al., 2023), termed ‘among the worst invasive species globally’ and ‘world’s worst woody invasive plant’ in savanna grasslands, respectively (Wells et al., 2023). These species can outcompete native herbaceous and indigenous tree species (Mwendwa et al., 2020), consuming large quantities of water, forming shrubby thickets, promoting woody encroachment and soil erosion, and causing livestock infections and mortality. While *Opuntia spp.* are noted as having ‘fleshy’, ‘edible’ cladodes consumed by ‘elephants during the dry season’ or when their dietary preferences have been ‘consumed by fire’ in protected areas (Theimer & Bateman, 1992; Owen-Smith & Chafota, 2012), studies suggest that the net negative effects of elephants and other large herbivores on *Opuntia spp.* through suppression (e.g., physical disturbance – uprooting, consumption, trampling) outweighs the net positive effects through facilitation (e.g., seed dispersal). These results suggest that savanna degradation, biodiversity loss, and livelihood vulnerabilities will rapidly accelerate where megaherbivore populations able to support ecological resistance to *Opuntia* invasions are declining (e.g., Pathways 1 and 3 (Table 12)), and fire management interventions aiming to protect these species are implemented (Shackleton et al., 2017).

Rather than addressing these challenges, woody shrub and bush encroachment across TCA is driving a transition from cattle herding to sheep and goat production (herein referred to as ‘shoats’). While one adult cow is considered 1.0 animal unit equivalent (AUE)<sup>11</sup>, one adult shoat is considered 0.2 AUE. Hence the ratio of cows to shoats that can be sustainably supported in a defined spatial area is 1:5; an attractive proposition for agro-pastoralists, particularly where livestock not only contribute towards rural food and nutrition security, but are an economic asset (Pica-Ciamarra et al., n.d.; Engida, Guthiga & Karugia, 2015), such that they provide cash income or represent the fundamental currency (e.g., are directly traded rather than money, demonstrating wealth and status) (Rigby, 1992; Quinlan et al., 2016), and constitute a form of savings (e.g., capital growth through herd growth) and insurance against emergencies (Varijakshapanicker et al., 2019). Goats are increasingly preferred over other ruminant species due to their resilience to climate change (e.g., thermal and drought tolerant) and low-

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<sup>11</sup>Animal Units (AUs) standardise stocking rates across animals of different shapes and sizes.

input demands, presenting a lower-input higher-output agricultural system than cattle. Participants highlighted how goats are opportunistic feeders *‘that eat the shorter grasses and shrubs’*, as well as being able to access tree leaves due to their bipedal stance, surviving on poorer-quality vegetation which other ruminants find difficult to consume (e.g., woody plants and plant roots). In the short-term, increasing shoat populations might appear as an effective strategy to mitigate rural food insecurity under climate change - as advocated and resourced by multiple international aid agencies across the tropics, resulting in the proliferation of local shoat-rearing schemes. Rather than addressing the root causes of woody encroachment, livelihoods are adapting to this change by stocking shoats at higher densities, thus reinforcing the expansion of IASs and savanna degradation: *‘unlike cattle which graze the surface layer of grasses, shoats utilise grasses to the root, therefore driving soil erosion and limiting grass regeneration when rains come.’*

### 5.1.7. Prioritising plantations – is history repeating itself?

The negative effects of fire on *‘economically-valuable’* plantation species were a common concern across all participants surveyed and interviewed in this study. *‘Planting exotic species for the regeneration of degraded sites and to contribute towards reforestation [...] is an emergency. [...] This can ensure we maintain and exploit forests in a sustainable manner.’* However, on plantations, *‘fires can burn big areas’*, threatening the provisioning of timber, firewood, and the generation of carbon credits. As such, participants emphasised the *‘critical’* need to *‘prevent and fight fires since they consume valuable natural resources, time, and money [...] – firefighting is the second emergency’*, and recommended planting fire-resistant TASs *‘between live plantations’* to reduce fire spread and severity.

Plantation species have been prioritized in forestation schemes in Taita Taveta since the 1960s when the KFS<sup>12</sup> began establishing eucalyptus (*Eucalyptus saligna*), cypress (*Cupressus lusitanica*), pine (*Pinus patula*), black wattle (*Acacia mearnsii*), umbrella tree (*Maesopsis eminii*) and silky oak (*Grevillea robusta*) plantations to meet growing domestic and global demands for wood and industrial products, and to alleviate pressures on indigenous species undergoing large-scale deforestation, thus contributing to total forest cover (Pellikka et al., 2009; Omoro, Starr & Pellikka, 2013). Prior to the arrival of the British East Africa Company in Kenya in 1888, deforestation was mostly attributed to agricultural expansion and natural resource harvesting (e.g., firewood and charcoal production) in the mesic highlands, consistent with *‘human population growth and an increase in permanent settlements across the hilltops’*. After 1895 when the British government declared a protectorate over British East Africa (present-day Kenya), the deforestation of indigenous forests was routinised to source large-scale industrial and construction developments (e.g., Uganda Railway and tannin industry), and to

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<sup>12</sup> KFS, formerly the Kenyan Forest Department (1902-2005).

facilitate European settlement and agricultural expansion (e.g., White Highlands). This continued through independence where new leaders trained in European institutions pursued an ‘industrialisation first’ development policy, resurrecting anti-burning policies and implementing ‘modernisation projects’ (Kull, 2002; Mwinyihija & Killham, 2006; Pooley, 2021; Pooley, 2022).

Between 1955 and 2004, more than 50% of indigenous tropical cloud forests in Taita-Taveta were converted to agriculture and bushland (Pellikka et al., 2013), largely due to the failures of the shamba system first introduced in Kenya by the colonial government in 1910 which increased incidences of illegal logging and land grabbing for political expediency (Kagombe & Gitonga, 2005; Witcomb & Dorward, 2009; Ototo & Vlosky, 2018). However, total forest cover only decreased by 2% over this period; post-independence governments sought to manage forests based on the European forestry ‘principle of the sustained yield [...] to obtain the best returns on its capital value’<sup>13</sup> (Sessional Paper No. 1 of 1968: A Forest Policy for Kenya). Aiming to increase ‘the economic production of sufficient forest produce to satisfy the requirements of the community and to provide for exportable surpluses’, and drawing upon ‘experience over the past 30 years’ which showed ‘that Kenya is fortunate in being able to grow exotic tree species, particularly softwoods, at a cost and in a period which should enable the resulting timber to be placed on the world market at competitive prices’, plantations expanded across Taita Taveta, replacing degraded indigenous stands.

Since independence, a series of policies and presidential decrees have been established to reify forestry management practices that aim to prevent further deforestation and degradation. These include the 1977 and 1998 bans on logging indigenous timber without a license, 2009 Forest Charcoal Rules, 2018 ban on logging in public and community forests (Teucher et al., 2020; Wekesa et al., 2020; Gambo, Sola & Ingram, 2022), 2024 ban on livestock grazing and grass harvesting in public forests, and the 2016 FCMA which imposes strict fire suppression measures to limit burning on agricultural lands adjacent to and inside protected areas (previously articulated in the 1955 Agriculture Act, 1962 Forests Act, and all later revisions). However, the criminalisation of customary forestry and fire practices have driven local opposition towards protecting indigenous species, such that they have little or no incentive to plant indigenous species which they are prohibited from accessing or utilising (Teucher et al., 2020). Instead, local communities are increasingly planting exotic species on their farms (e.g., *Maesopsis eminii* and *Grevillea robusta*), of which they are permitted to utilise. As livelihoods transition ‘from cattle to corn’ (Lind, Okenwa & Scoones, 2020), humans are increasingly moving towards the mesic highlands where there is more fertile land for agriculture, occupying land surrounding plantations. Observed reductions in human-wildlife conflict (e.g., crop raiding) due to

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<sup>13</sup>This was first formerly articulated in Sessional Paper Number 7 of 1957: Report of the Game Policy Committee and, following the enactment of the 1962 Forests Act (revision of 1942 version), was restated in 1968 by the independent Government of Kenya in Sessional Paper Number 1 of 1968: A Forest Policy for Kenya.

low habitat selection of native species in monocultural plantations have accelerated this trend (Siljander et al., 2020), resulting in greater land-use and cover change.

*Maesopsis eminii* and *Grevillea robusta* were introduced in the 1970s and 1980s to support small-scale farmers and alleviate pressures on indigenous forests (Pellikka et al., 2013; Mwendwa et al., 2020). These plantation species, promoted as drought-tolerant, fast-growing, and low-input high-out TASs which provide a range of ecosystem services including fuelwood, fodder, construction materials (e.g., timber), shade on farms, and bee habitats (for honey harvesting), remain among the most frequently planted exotic species across small-farms in Kenya. However, they are pioneer species, able rapidly colonise newly disturbed sites (e.g., after a fire event) and environmentally degraded habitats (e.g., farmlands) across areas of high native biodiversity values in the savanna-forest transition zone, accelerating processes of woody encroachment, soil erosion, and creating an unstable environment (Siljander et al., 2020; Gairola, Bahuguna & Bhatt, 2023).

### 5.1.8. Towards the future

In comparison with multi-layered indigenous forests worldwide, exotic plantations are characterised by increased water demands, lower total biomass and sparser understoreys, higher percentages of bare-ground cover, reduced organic matter concentrations and carbon sequestration potential (Omor, Starr & Pellikka, 2013), lower biodiversity (e.g., species richness, abundance, and composition), and limited pollinator populations (e.g., insects and avian frugivore assemblages). The latter due to a reduction in native plant species and increased use of chemical pesticides and artificial fertilisers, thus further limiting opportunities for native seed dispersal (Otieno et al., 2011; Nyingi et al., 2018).

Participants highlighted the imperative to continue expanding plantations across TCA to alleviate anthropogenic pressures on indigenous forests and promote socioeconomic resilience. They recommended planting fire-resistant TASs '*between live plantations*' to mitigate wildfires, highlighting how this is already underway in many areas where 'community-based' CSR projects (e.g., see section 5.2) aiming to increase local climate resilience and food security are assisting communities to procure their seeds. In the long-term, this presents several challenges which compromise social and ecological management objectives. For example, plantations impose forms of habitat compression on indigenous forests, further reducing patch size and accelerating fragmentation. Additionally, the expansion of non-native fire-resistant trees on privately-owned farms has increased bare-ground coverage, initiating a positive feedback loop between the further invasion of exotic species, increased woody encroachment and changes in the local energy budget, reduced MAP and increased surface dryness, and aridification (Nair, Rao & Buck, 2004; Nair, 2007; Pooley, 2021). Participants have experienced increasing '*challenges in maintaining the boundaries between farm and forest. [...] You find that the seeds from trees growing in the forest are used by communities on their farms*', and considering increasing illegal fire-use activities and wildfires within the protected areas,

TASs grown on farms are increasingly colonising disturbed sites. Landscape homogenisation across latitudinal and longitudinal gradients and has made *‘it difficult to decipher between farms and forests.’*

Today, Taita Taveta’s indigenous forests are described as ‘islands in a sea of savanna’ (Pellikka et al., 2013) increasingly isolated by ‘hostile’ land types as agricultural frontiers expand further across the savanna-forest transition zone (Habel et al., 2023). Agricultural frontiers are closely associated with wildfires across African and tropical savannas globally, as expansive fires lit to clear land for agricultural and livestock production in higher rainfall areas unintentionally spread out of control<sup>14</sup>. Drivers of agricultural frontier development in TCA can partly be envisaged by the forest transition model used to describe how economic development influences competing land-use values and forest cover change, such that as the economy grows, there is a shift from net forest loss (e.g., deforestation) to net forest gain (e.g., investment in conservation, reforestation, and afforestation) (Mather, 1992; Barbier, Delacote & Wolfersberger, 2017). However, TCA is experiencing increasing rates of poverty, unprecedented socioeconomic-climate pressures, and rapid declines in natural resources. This is driving net forest loss across the mesic highlands where MAP supports some crop production and the land-use value for agriculture to meet the energy demands of a growing population outcompetes that of protecting forests. Participants identified controlled fires ignited on private farms to quickly clear and prepare land and manage crop residues, as well fires related to increasing livestock production in the highlands, as leading sources of uncontrolled wildfires across plantation and indigenous forests, particularly where fires have been suppressed, and livestock grazing, and fuel harvesting have been banned under government policies.

## 5.2. Society, culture, and fires

To mitigate the wildfire paradox, it is important to understand the contentious sociopolitical domain in which it has come to symbolise and in which future fire management will be developed. This section describes these conflicts within their broader systemic context, revealing several multi-dimensional challenges that will affect the future fire regime and effectiveness of management interventions. The ways in which participants perceived these conflicts as affecting fire-use practices (legal and illegal), wildfires, and opportunities for bottom-up fire management are presented in subsequent sections 5.3 and 5.4.

### 5.2.1.1. Claiming conservation areas

Kenya’s tourism industry accounts for approximately 10.4% of national GDP, 4.2% of National Gross Fixed Capital Formation (Tourism Research Institute, 2022), and is believed to have positive direct,

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<sup>14</sup>Similar challenges regarding agricultural frontier development are unfolding across the South American Chaco, Brazilian Cerrado, much of Southeast Asia, and the Miombo Woodlands.

indirect, and induced multiplier effects on rural social-economies, such as through providing employment and revenue opportunities, and recirculating tourist expenditures (e.g., hotels purchasing food from local suppliers) and spending earnings (Brida, Disegna & Osti, 2014; Comerio & Strozzi, 2019; Ma, 2020). However, East and Southern Africa is the least competitive region for travel globally (Rogerson<sup>1</sup>, 2007; Croker, Woods & Kountouris, 2023b), and Kenya is heavily reliant on foreign visitors due to its high park entry fees which are largely unaffordable to nationals<sup>15</sup>. Conservation is, therefore, vulnerable to political unrest, external shocks, and crisis (e.g., COVID-19 pandemic) (Musavengane, Woyo & Ndlovu, 2022), and has increased competition, limited business opportunities, and created large uncertainties in long-term economic growth (Tear et al., 2021). At the local level, these challenges have had large equity implications, reducing the degree to which citizens support and attach value to the parks.

Local people hold strong '*feelings of historical injustice*' in TCA, believing that '*park managers value wildfire more than their livestock, [...] and more than human lives*'. '*Tsavo East and Tsavo West take up around 64% of the county*', the ranches and conservancies occupy a further 24%, leaving the community with only 12% of the land to live on, of which is '*mostly inhabitable rocky hills*' and inclusive of gazetted forests. Considering the amount of land dedicated to conservation and ranching in TCA, local employment opportunities are perceived as disproportionately low, thus are a major source of conflict. While Amboseli, Tsavo East, and Tsavo West National Parks contribute towards a large proportion of total park revenue in Kenya (Ministry of Tourism and Wildlife, 2022), participants repeatedly shared that '*the wildlife tourism industry is not considered as a resource to be shared with local communities, so 100% of the profits go to the government*'. '*There is that notion that tourists going to the National Parks fund the park*', such that it is reinvested in restoration projects, building infrastructure, and resilience mechanisms (e.g., security and local livelihood schemes) to achieve joint conservation-development objectives. However, the parks are highly degraded and '*run at a loss. [...]* *So how do you share the revenue?*' (Ministry of Tourism and Wildlife, 2022).

These feelings are particularly pronounced in jurisdictions along the eastern border of Chyulu Hills National Park, specifically Mtito Andei, Makindu, and Kibwezi, where up to 43% of the population live below the poverty line (Government of Makueni County, 2020; 2022). Despite being considerably smaller than the Tsavo parks, occupying approx. 9% of Makueni County, it is among the '*least visited*', lowest revenue generating, and most degraded parks in Kenya<sup>16</sup>. Since the park was gazetted in 1983 to protect the region's primary '*water tower*', '*people who lived across this land*

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<sup>15</sup>Gate fees for entering Kenya's protected areas rank second highest globally for international tourists. On average, they are thirty-times more expensive than gate fees in high-income countries, consistent with their relatively low-price elasticities (Pagiola et al 2002; IUCN WCPA, 2019).

<sup>16</sup>In 2021, the total number of tourists visiting Tsavo west (61,309) was more than 100-times greater than the total visiting Chyulu Hills (595) (Ministry of Tourism and Wildlife, 2022).

*have been continuously evicted*’, and *‘the revenue it has collected vis-à-vis the budget we have spent to conserve it is not even 1%. [...] It has not been a revenue generating park.*’ Low visitation rates and paucity in revenue have increased the perceived and realised socioeconomic costs imposed on local communities excluded from accessing natural resources (Briedenhann & Wickens, 2004). Strong feelings of *‘hate’* towards conservation and the KWS are heightened among these *‘sections of the community who feel left out and not getting any benefits’* – contesting that *‘if fires consume parts of the forests, you [park authorities] have the right answer from god.*’ As such, Chyulu hills experiences *‘serious challenges’* attributed to encroachment and uncontrolled fires (Ministry of Tourism and Wildlife, 2022).

### 5.2.1.2. ‘Tribal’ conflict

Dispossession by external dictate is often considered the main driver of resource-based conflict. However, participants attributed competition between communities who hold divergent land-use values and requirements to historical inter-tribal conflicts that emerged during colonial rule (Wily, 2011). Whereas prior to European colonisation, culturally diverse tribes occupied a range of social-ecological niches (d’Errico et al., 2017), the demarcation of nation states, protected areas, and native reserves by colonial governments, introduction of forced relocation and villagisation schemes by post-independence governments, and more recently, the expansion of large-scale private investment projects across savanna rangelands, have concentrated distinct communities into smaller, often resource-depleted geographical areas. As such, TCA consists of diverse (non)Indigenous communities with competing livelihood practices, each of whom claim a stake to the park and its revenue<sup>17</sup>. Participants expressed how, over time, the arrival of different communities with *‘very different ways of life’* and *‘targeting the same scarce natural resources’* has resulted in clear *‘winners and losers’* in resource governance and has contributed a *‘loss of tribal culture’*. This has expedited resource conflicts between and within the communities themselves, and *‘as social and climatic pressures increase, tolerance wanes, and there are increasing conflicts between groups.*’ In some cases, these conflicts have surpassed negative relationships with government agencies and NGOs; local people are increasingly becoming *‘informers to partners, [...] informing and sharing information on who is participating in illegal activity, checking on who is doing what.*’ This is likely due to individual ambition and the perceived benefits of working with these organisations (e.g., increased access to resources), further evidencing growing sociocultural antagonisms at the local level and presenting several dilemmas regarding the decentralisation of management rights.

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<sup>17</sup>Inclusive of Giriama, Kamba, Kikuyu, Maasai, Somali, Taita (Wadawida, Wasagalla, and Wakasighau), Waata, and Wataveta peoples.

### 5.2.1.3. Colonially inherited ‘community-based’ ranching

Non-state protected areas legally-recognised under the WCMA (2013) are expanding across Taita Taveta, with an increasing number of ranches leasing land to conservancies to diversify their revenue through tourism. For many participants, the introduction of ‘*new rules*’ to facilitate such land-use change is viewed as an emerging facet of historical land acquisition challenges which have and continue to reconfigure the spatial contours that define local grazing systems (Scoones, 2021). The introduction of powerful membership organisations such as the KWCA and introduction of new transnational actor networks are shifting existing tenure arrangements in space and time, driving new forms of (re)territorialisation and greater mutual exclusivity over natural resources, and increasing land-based conflict between conservation and competing non-conservation land-uses (Hall et al., 2017; Pas & Cavanagh, 2022). *‘For some members of the ranches, there is a sense of ownership over that space’*, thus greater perceived benefits associated with converting the land. However, most members *‘feel that they do not benefit’* from conservancies having willingly *‘donated’* their ancestral lands, and non-members with no legal claims to the land *‘feel left out’* altogether. Several ranch board members shared that they *‘did not know of a single ranch that said they wanted a conservancy. [...] It is not a locally-based idea; people,’ ‘mostly scientists based on literature,’ ‘just came and told them that the model works without asking, ‘what works for you?’*” These antagonisms are evidenced in the data, such that staff and rangers employed in protected areas and, therefore, directly benefit from their operations, typically agreed that the ancestral land rights of local communities are respected across TCA. Indigenous and local people typically disagreed (Table 11).

Negative perceptions towards formalised land registration across Taita Taveta’s ranching landscape are deeply-rooted in colonial and post-independence policies which have repeatedly failed to meet commitments over addressing land-based inequalities. Ongoing processes of land adjudication and commodification across Kenya can be traced back to the 1954 Swynnerton Plan (Haugerud, 1989), introduced to consolidate and register land to expand commercial cash-crop farming, encouraging the individuation of tenure and issuance of indefeasible land titles to native Kenyans who had previously been excluded from obtaining property rights (Onguny & Gillies, 2019; Ndungu Kungu, Chacha & Gichobi, 2022). Though portrayed as an agricultural policy, the plan emerged at a time when acute land grievances were coalescing into broader liberation movements, such as the Mau Mau Rebellion (1952-1960). By institutionalising private property rights and creating opportunities in agricultural production for native Kenyans, the colonial government sought to distract individuals who might have otherwise joined the rebellion (Boone, Lukalo & Joireman, 2021). Agricultural land was divided into high versus low areas, which typically meant that it divided large-scale farms held by settlers in the White Highlands from small-scale farms held by Kenyans across Native Reserves where there were no formal claims to land ownership (e.g., under informal customary tenure). As a result, the plan created a class of wealthy white landed farmers who could acquire and register more land, and a class

of Kenyan poor landless farmers (Place & Migot-Adholla, 1998), thus serving to maintain colonial boundaries established along ethno-linguistic lines to achieve ‘divide and rule’ policies (Crocker, Woods & Kountouris, 2023a)

Participants shared how the current ranches were established from former colonial hunting blocks in the 1960s and 1970s following the articulation of the 1966 Lawrence Mission Report. The report sought to address the failures of the Swynnerton Plan – landlessness, ‘*inequitable distribution of resources*’, and ‘*resource competition*’ – by introducing formal grazing systems into former Native Reserves and hunting blocks registered under group ownership titles, therefore enabling groups of local people to jointly hold freehold titles to the land. The plan was enacted by the 1968 Group Ranch Representatives Act (GRRA) and associated policies (e.g., 1967 Land Act and 1968 Land Adjudication Act), sanctioning the development of two types of ranching systems, either commercial or pastoral, of which were to be adopted based on the local context and existing sociocultural organisations (Coldham, 1978; Wayumba, 2017).

‘*Maasailand*’ was frequently cited as a model example of how ‘*greater agreement over conservation*’ can be achieved to mitigate land-based conflicts. Participants referred to the Maasai’s adoption of pastoral ranching systems (i.e., group ranches) following the GRRA which, to some, extent, has enabled them to maintain a ‘*traditional land tenure system*’ based on ‘*collective resource ownership*’, as well as increase their traditional wealth base – livestock – through the provision of basic services such as water and veterinary care. Additionally, group ownership titles have secured land from non-Maasai ‘*outsiders*’ by preventing individual land sales. However, the ‘*ranching landscape in Taita Taveta is very different*’; participants stated that those proposing the ‘*Mara model*’ ‘*don’t understand the conservation landscape*’ in Taita Taveta.

At independence, the county primarily consisted of Trust Lands (i.e., lands held on a fiduciary basis by the local council), including former native reserves occupied by diverse Indigenous communities with no firm claims to landownership (Kang’ee & V, 2013; Chomba et al., 2016). After the opening of the White Highlands in 1960, the new government allocated large high-potential agricultural farms to individuals from the Kikuyu, Meru, and Embu tribes; a decision which has long been criticised as an act of corrupt ethnic favouritism and political patronage<sup>18</sup> (Jones, 1965; Boone, Lukalo & Joireman, 2021). In a bid to secure land from external communities and displaced white settlers, senior officials and politicians in Taita Taveta took advantage of the laxity in land claims and registered commercial ranches, granting themselves land leases as individuals, partners, or shareholders in private

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<sup>18</sup>The allocation of high-potential agricultural land to members of the Kikuyu, Meru, and Embu tribes have been attributed to the fact that the Prime Minister and soon to be President of independent Kenya was himself, a Kikuyu. However, this might have also been a salute to these communities who had been socioeconomically marginalised from their ancestral lands – the White Highlands – and formed the majority of the Mau Mau rebels which ultimately boosted the campaign for independence.

companies<sup>19</sup> (Chomba et al., 2016). While Directed Agricultural Companies (DACs) were established as ranches for the rest of the community (i.e., those not registered as individual or private companies), individuals had to purchase shares in the company to become a member, therefore membership has been and remains only accessible to the minority elite. *‘These shareholders receive individual benefits, such as dividends from the company’*; as net profit increases, individual shareholders receive higher dividends, often in the form of increased shares in the company. Often, *‘shareholders stay away from the area [...] and it’s hard to get them to accept community projects. [...] They aren’t interested in the land in terms of ties – they don’t understand it.’*

Today, ranches designed to convert ‘land into a valuable asset that can leverage capital and stimulate rural development and poverty reduction’ are (Matende, 2021), instead, viewed as a *‘colonial construction to establish collective ownership’*, Rather, than *‘addressing challenges associated with resource competition and distribution,’* they have accelerated land-based conflict, inequalities and poverty challenges, illegal activity, and political-based violence.

Considering these historical inequalities embedded with Taita Taveta’s ‘community-based’ ranching system, some participants expressed concern over ranches collaboratively leasing land to conservation clients and *‘shifting the management focus from livestock rearing to conservation’*. While the *‘ranch benefits financially – receiving a portion of the profit made through conservation and tourism’*, the benefits are not distributed across the individual ranch members or to the local communities surrounding the conservancy. Conservancies are *‘just private farms who have their own security. [...] Gate entry fees bring a lot of money to the conservancy’*, but this fails to reach the communities. *‘The conservancy board keeps the benefits. [...] It benefits the wealthier members of the community.’ ‘It does not benefit the young people – so they are just going around poaching.’* In the dry season, when *‘there is no grass – no pasture for livestock’*, ranch members and landless pastoralists often want to *‘reclaim their property’* and ancestral lands in the conservancies and ranches, respectively, therefore *‘are fighting to get into the parks. [...] Even just a month after the rains, the communities are cutting the fields and fences to put their cows there, [...] because there is nothing in terms of grass on community lands.’*

While Article 102 of the WCMA (2013) makes provisions for local herders to access ‘national parks for purposes of grazing and watering of livestock in times of drought and other natural disasters’, there are large disparities in the implementation of *‘gentlemen’s agreements’* across southern Kenya (Crocker et al. 2023a). In TCA, local herders feel *‘disempowered’* and *‘mistreated by the KWS’*. *‘If they catch a local, they mistreat the local more than they would an outsider.’* They are *‘arrested, put into*

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<sup>19</sup>Kambanga ranch, a Directed Agricultural Company, was established ‘by the request of one of the Taita leaders who had overheard governments plan to allocate the vast chunk of land in the rangelands to retired army generals.’

*holding pens, and penalised about 500Ksh per head.* 'So, there is no way they can appreciate the park.' However, in the Maasai Mara National Reserve, the *'Maasai are allowed to graze their cows inside the park'*. In Amboseli, *'co-existence challenges'* due to the failure of the *'1974 agreement to close the parks boundaries'* and construct a pipeline carrying water from the park to the surrounding Maasai rangelands have prompted conservation agencies to grant *'watering rights to the local communities for their livestock, [...] allowing park neighbours to enter during prolonged dry seasons.'* Participants believe that such agreements are important in fostering *'common interests'* and *'reciprocal relationships'*, yet due to their *'ad-hoc implementation'*, they have engendered large *'confrontations between and within communities, because people feel that the government favours some people over others'* – *'why are the Maasai in the Mara and Amboseli allowed to graze in the parks but not in TCA?'* There is a *'need to align these policies so that they are not selective'* and do not accelerate conflict (Croker et al. 2024).

#### **5.2.1.4. Fire in the 'fattening zone'**

Taita Taveta is *'a fattening zone'*; *'the country's biggest and major beef supplier.'* Hence, many of the challenges related to illegal grazing in the protected areas are related to commercial herders – *'wealthy politicians and rich people who bring their livestock here for fattening before shipping them abroad. This is just a fattening zone.'* Participants referred to herders from outside the county as *'nomads'*; leasing lands for short periods of time before finally exporting their livestock to Asia. They do not have *'ancestral or cultural ties'* to the land, thus do not adhere to traditional authorities, rules, or community regulations, and possess little or no incentive to sustainably extract resources to conserve pasture in the long-term.

Since Taita Taveta received 'disease-free' certification under the government's Disease-Free Zones (DFZ) Programme, Taita Taveta has experienced a 'massive intrusion of livestock from outside' the region (LUMO Conservancy Management Plan, 2022<sup>20</sup>). The programme was launched in 2010 to increase meat (particularly beef) and other animal product exports in alignment with nationwide industrialisation and development goals (State Department of Livestock, 2011). With an existing commercial-based ranching system and being within proximity to the port of Mombasa, conservancies have sought to leverage the county's disease-free certification to maximise revenue streams and improve economic wellbeing, dividing their lands into conservation and tourism, livestock production, and wildlife conservation zones.

However, participants highlighted how conservancies and ranches have perpetuated issues of social differentiation and ecological degradation in this context; whereas many local herders hold thin, poor-framed breeds which are typically kept for economic insurance reasons and as a sign of pride – selling

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<sup>20</sup> I was provided with this draft document during fieldwork, due to be published.

them at market in times of hardship, external grazers (‘outsiders’) in the ‘fattening zone’ often hold breeds bred to maximise meat production and associated export revenues, thus are the primary beneficiaries of leasing agreements<sup>21</sup>. Today, they comprise ‘more than 50% of livestock herders in Taita Taveta’. On one hand, conflicts are increasing between local herders and ‘outsiders’ because ‘locals can only enter the ranches at a fee; they are accommodated on the condition they pay a levy’. On the other hand, locals are not employed in the ranches and conservancies because ‘they don’t want to herd the livestock. Most of them have this mentality that if you have been to university or college, you go for white-collared jobs in the County or National Government,’ and ‘ranching is not considered a white-collared job’.

In some cases, political alliances are forged between park authorities and eminent cattle barons ‘from far-off counties such as Wajir, Garissa, and Mandera’ who ‘bribe leaders and wardens within the protected areas for access rights; providing a financial incentive to allow them entry’ (Hall, Scoones & Tsikata, 2015; Gilleard & Higgs, 2020). This loss of grazing lands available to local people, coupled with the need to counter environmental variability and uncertainty (Butt, 2011), have precipitated forms of ‘nocturnal agency’ across Kenya’s conservation areas. Illegal grazing and other activities are increasingly practiced at night when security operations are weaker (e.g., decreased visibility) to circumvent and resist existing conservation arrangements (Hall et al., 2017). These challenges are increasing where management interventions permit the construction of temporary bomas in conservation zones at night to assist herders in fattening steers after daytime grazing - helping them to meet market requirements while also maintaining the conservancy’s tourism value (i.e., visitors do not want to see human infrastructure in the conservancy) (e.g., LUMO Conservancy Management Plan 2022-2027). Herders are ‘increasingly living near the park and along its edges so it’s easier to encroach at night’, then staying in the park on the pretence that they have been granted entry and are fattening livestock for export. This poses another form of habitat compression on the protected areas, reinforcing environmental degradation narratives and, therefore, reducing the willingness of authorities to redress access restrictions and rights (Pas & Cavanagh, 2022).

Social-ecological challenges in the ‘fattening zone’ have been discussed based on the understanding that Taita Taveta is ‘disease-free certified’. However, there are several issues embedded within the DFZ programme itself which undermine the determination of ‘disease-free’ zones, thus risk accelerating existing resource-based conflicts and engendering new challenges where conservancies capitalise on and incorporate livestock production into wildlife conservation management.

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<sup>21</sup>In LUMO Community Wildlife Conservancy, there are an increasing ‘number of retired former civil servants who have opted to save their retirement benefits in livestock.’ Since the conservancy falls within the ‘disease free zone’, management plans are focused on the development of this zone, ‘because livestock production forms an important cog in the success of the overall plan and the economic development of the area at large.’ However, livestock numbers are growing beyond the carrying capacity of the rangeland.

Firstly, the programme's main goal was to enter new international markets and increase foreign exchange in the coastal zone where local livestock owners (incl. pastoralists) were purported to be direct beneficiaries. In doing so, the plan would contribute towards food security and reduce the percentage of the population living below the poverty line from 44% to 28% within five years of its initial inception in 2010, assuming that macroeconomic trade policies would provide financing opportunities to local people to carry out livestock production operations (State Department of Livestock, 2011). The programme's roll-out corresponded with increasing demands in Asia for African-sourced meat products, particularly among the Gulf Cooperation Council (GCC) member states who, over the last ten years, have invested over \$100 billion (approx. 30% of total outward foreign direct investment) in agricultural land and export-oriented food production systems<sup>22</sup> (Shahid & Ahmed, 2014; Bani, 2018). Hence, in 2021, Kenya's top partners in meat exports included several of the GCC states, whom of which release vast amounts of finance very quickly due to having fewer regulatory requirements than Western financial institutions (Hanieh, 2018). While the programme's success at the national-level might be measured by the increasing number of bilateral trade and long-term lease deals made with GCC states, at the local-level, >57% of Taita Taveta's population live in absolute poverty, contributing towards >52% and 58% of Kenya's total urban and rural poor, respectively (County Government of Taita Taveta, 2019). As local food systems rapidly orient themselves towards the export market, commercial herders will continue to compete local pastoralists – the assumed 'beneficiaries' who are increasingly '*losing out*', resulting in new forms of sub-altern politics and conflict.

Secondly, 'disease-free' certification was never achieved in Taita Taveta. The County Government Integrated Development Plan (2023-2027) spotlights how resource and funding constraints faced by the County Government have resulted in poor livestock management and inadequate extension services, of which were supposed to be addressed between 2010 and 2014 under the DFZ programme. While county governments have been devolved political autonomy in Kenya under the 2010 Constitution, thus possess the power to raise their own revenue, control their budgets, and secure resources, the National Government retains land administration functions and has little obligation to share national wealth. As such, ethnic-based land grievances and political corruption (e.g., clientelism) have thwarted local development (Boone et al., 2016; Boone, Lukalo & Joireman, 2021).

Thirdly, the DFZ programme required each county to establish quarantine stations at entrance points to regulate livestock movements and control the reintroduction of pathogens. However, these were

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<sup>22</sup>Demand for food is rising synonymously with continuous population growth across 'capital-rich' yet 'food insecure' GCC states (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates) - threatened by hyper-aridity, water scarcity, poor soils, declining agricultural land, and low agricultural productivity. Due to large deficits between current biocapacity (resources generated) and ecological footprint (resources consumed), GCC states have increased agricultural investment abroad, importing >80% with >70% of food consumed domestically (Shahid and Ahmed, 2014; Bani, 2017).

never established in Taita Taveta, nor were many of the other requirements necessary for the programme's implementation. These governance loopholes have eased cross-border livestock movements, enabling '*nomads*' to capitalise on the county's growing commercial-based livestock system without having to undergo lengthy security procedures (Taita-Taveta County Government, 2023). Participants directly attributed a rise in resource-based conflicts across TCA to '*Somalis arriving from northeastern Kenya*' with large camel caravans; previously limited to the colonially established Northern Frontier District, since the collapse of the Somali state in 1991 and ongoing political-economic instability and environmental degradation, millions of Somalis have taken refuge in Kenya, moving their camel production systems across the border and expanding along the coastal regions to access export terminals (Scharrer, 2018; Agwanda, 2022). Perceived as 'enemies' of the Kenyan state due to ongoing inter-ethnic conflict along the Kenya-Somalia border (Otunnu, 1992), Somalis have 'ambiguous citizenship' and are typically omitted from participating in the formal livestock sector (Lochery, 2012; Scharrer, 2018). As a result, they have developed informal livestock trade networks across the country, successfully evading government regulations over the movement and trade of livestock (Ng'asike, Stepputat & Njoka, 2020). Given Taita Taveta's lax border controls, the arrival of Somali herders and camel populations are projected to increase, potentially driving the commercialisation of camel farming across the region given their competitive edge under future climate change (e.g., drought tolerant, opportunist feeders, and able to produce large quantities of quality milk and meat). However, this might result in greater competition for depleting vegetation and water resources, the introduction of new pathogens and increased likelihood of transmitting zoonotic diseases (e.g., MERS coronavirus), and growth in the illicit transnational production, trade, and consumption of animal products, particularly where livestock rustlers exploit weak intra- and international cross-border regulations and coordination between authorities (Gumba et al., 2019; Jori et al., 2021).

Despite multiple allegations against illegal '*nomads*' and their '*destructive*' practices in the parks, '*there is limited or no concrete evidence*' to formally support these claims. Meanwhile, '*desertification due to overgrazing*' is a salient challenge across the group ranches, thus refocusing the blame on '*local pastoralists, such as local Maasai and Pare from Tanzania*' for ecological degradation within the parks. As such, conservancies continue to lease land to commercial herders to achieve integrated livestock-wildlife production objectives, while remaining strongly opposed towards the decentralisation of grazing rights to local pastoralists to support socioeconomic development and addressing rising poverty and food insecurity challenges (Karanja, 2017.; Pulido-Chadid, Virtanen & Geldmann, 2023). Considering the plethora of land-use values and livelihood activities across TCA, participants highlighted how the introduction of grazing rights could spark resentment among non-pastoral communities and exacerbate existing resource-based conflicts. Additionally, given the diversity of reasons people illegally enter the protected areas, '*you wouldn't be able to decipher*

*between a genuine herder and a poacher.* 'The cost of living is increasing', and there are greater demands for *'poachers selling bushmeat at lower prices'*, hence you might find herders *'doing just the same or similar activities, [...] you find they might poach.'* TCA's proximity to the port of Mombasa - one the world's major hubs for illegal wildlife trafficking between Africa and Asia (Clarke & Babic, 2016; Walker, 2016; Meteti, 2022) – makes it highly vulnerable to international poaching activities, and while the enforcement of anti-poaching measures is perceived as *'very effective in controlling poaching'*, it has inadvertently increased the gap between demand and supply for poached products (Challender & MacMillan, 2014). Thus, acknowledging existing law enforcement challenges and *'failure to identify hardcore poachers'* and the *'drivers of illegal activity'*, and rising tensions due to a lack of employment opportunities in the ranches and conservancies, participants expressed concern over granting communities grazing rights at a time when poaching might be perceived as a *'low-risk high-profit'* trade (Chege, 2015). Instead, they recommended a *'fences and fines'* approach to conservation to limit community activities and associated biodiversity loss (Peluso, 1993; Adams & Hulme, 2001), assuming that the national and County government have the capacity, will, and internal legitimacy to effectively enforce central control.

#### **5.2.1.5. Reconfiguring the frontiers – from within**

In many developing countries, community lands have proved more relevant than other land tenure systems in supporting large agrarian economies (Alden Wily, 2018). The 2016 Community Land Act (CLA) was introduced to assist in securing customary tenure for local communities who identify based on their common ancestry, culture, or socioeconomic interest, enabling them to collectively own and govern their land, providing that their rights and practices align with existing national legislation. The law states that all lands held under customary tenure are to be formally adjudicated, registered, and governed by an elected community assembly, and that any unregistered community land will be held in trust by the county government until it is formally registered or compulsorily acquired by the state or other external actors for public or private development. However, the specific responsibilities of the County Government as a 'trustee' are not specified and given that registration can take up to several years to complete, unregistered community lands are at risk from state and private acquisition for the development of LSLI projects (Boone et al., 2019; Rahma, 2023). Once community lands have been registered under the CLA, community tenure is still not secure; a great deal of power is invested in community assemblies established to set the rules and regulations governing registered community lands, including how land is used, allocated, and potentially alienated, with little provision for the wider communities' input. Additionally, corruption in the State Department for Lands, lack of political will, institutional frameworks, and financial commitments to enforce the law, and reluctance on the part of the Kenyan government to surrender lands to

communities – defining community lands under customary tenure as public - have led participants to believe that the 2016 CLA is just the latest manifestation of land adjudication and commodification in Kenya (Alden Wily, 2018; Rahma, 2023).

Based on historical experiences of ‘development-driven-displacement’ under policy reforms designed to address land-based inequalities in TCA (e.g., landlessness and social stratification) (Ferrando, 2013), coupled with ongoing processes of rangeland degradation under intensifying socioeconomic-climate pressures, the CLA has catalysed the sub-division of customary lands as individuals rapidly seek to secure access to competitive and depleting natural resources. Additionally, the act is commonly viewed as the latest institutional tool in legitimising the *‘transfer of community lands’* to private landowners or local elites; the establishment of county assemblies under the Act embeds *‘elite capture into community-based structures’* in the same way that the creation of Local Native Councils in the 1920s and 1930s suppressed local autonomy and facilitated state control over rural affairs and (Okoth-Ogendo, 1972), in independence, elected county councils exercised absolute power over Trust Lands, re-allocating high potential lands to political elites and more influential tribes. Thus, sub-division has emerged as a symbol of local resistance towards the formalisation of communal tenure.

*‘Sedentarisation is increasing across the landscape’* because *‘people are settling so they have a share in the rangelands’*. As such, the fragmentation of rangelands into smaller, higher-value parcels of land registered as freehold or leasehold continues to reconfigure local grazing, agricultural, and conservation systems. In the ranches where *‘community lands are required to re-register and new members are being appointed, [...] ranch leaders and existing members are opting for sub-division and privatisation to secure their individual land rights’*, capturing the economic benefits of livestock production at the household level, or selling off their land to wealthier members of the community or external investors at competitive prices. This is particularly pronounced across the Maasai Group Ranches where *‘the Maasai would rather sell an acre than a cow’*, and across the Taita Taveta ranches where individual members who *‘feel left out’* from conservancy leasing agreements believe that by owning land, they can directly benefit from selling or leasing it to commercial livestock producers. Participants highlighted how, *‘under freehold title arrangements, landowners can use their land as they choose, provided they act in accordance with national laws and regulations. However, in the absence of these laws – or more like weak enforcement – sub-division can drive land scrambles and further misunderstandings in the legal framework.’*

#### **5.2.1.6. Reconfiguring the frontiers – from without**

East Africa’s semi-arid pastoral rangelands have become hotspots for international activity amidst the global rush for land and resources (Lind et al., 2020). Previously considered as low potential and unproductive, the implementation of long-term development policies by African governments have reimagined and revalued ‘untapped’ rangelands as new ‘frontiers’ of global capital (Blejer and Khan,

1984), stimulating private investment and fragmentation (Wily, 2012; Lind, Okenwa & Scoones, 2020). Rangelands continue to be reterritorialized by LSLI projects<sup>23</sup> owned by private (non-listed) companies<sup>24</sup> with self-constituted and flexible regulatory requirements, stock exchange-listed firms, investment funds, state-owned entities, and individual entrepreneurs (Nolte, Chamberlain & Giger, 2016), turning land ‘into a pure commodity, devoid of its cultural and spiritual values’ (Barume, 2010; Cotula, 2013). Being in proximity of the port of Mombasa and holding key trade routes (e.g., Mombasa Highway and Arusha-Holili/Taveta-Voi Road), TCA is particularly susceptible to LSLIs which deliver ‘*commercial benefits*.’

Participants emphasised the difficulties in addressing ‘*ongoing gazettement*’ as it cannot be attributed to a single factor, rather it is a symptom of macro-scale economic and geopolitical conditions and subsequent transformations in local livelihoods (e.g., transition from social- to market-based economic activities). In Kenya, frontier development long preceded the 2016 CLA, during which time there were no legal or institutional barriers for converting lands under customary tenure to statutory tenure. As such, land sub-division has been taking place since the mid-1970s when ‘*outsiders*’ were enlisted as members in the ranches, prioritising individual wealth gain by selling off land to foreign investors.

Since ‘*the group ranches established in 1960 never obtained their objectives, similar communal establishments under the 2016 Community Land Act are negatively perceived*’, therefore accelerating, rather than mitigating land sub-division across the rangelands.

Situating the CLA within its historical and broader political-economic context, three main challenges prevent equitable land tenure from being realised under its provisions. Firstly, the Act assumes that community-based arrangements can strengthen customary laws and practices to achieve socioeconomic justice and equality across rural societies without considering the (neo)colonial legacies embedded with community-based structures. Additionally, it ignores how sociocultural, political, and economic relationships are continuously renegotiated at the local level, driving critical livelihood transitions, changes in land-use value, and complex and often contentious intra-society relationships (Lind, Okenwa & Scoones, 2020; Croker, Woods & Kountouris, 2023a). Secondly, key requirements for its implementation have not been met due to a lack of institutional will, capacity, or clear framework to action them (Alden Wily, 2018). The government retains ‘*a lot of power and control over what happens in the rangelands*’ (Croker et al., 2024) and given that collective titles have proved ineffective in increasing investment, asset accumulation, and rural development in the rangelands, the establishment of a robust nation-wide implementation plan is perceived as ‘*far-*

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<sup>23</sup>In Kenya, LSLIs are mostly directed towards conservation, renewable energy, resource plantations, cash-crops and intensive agricultural systems, fossil fuel exploration, and infrastructural developments.

<sup>24</sup>International private companies account for more than half of the concluded land deals in Africa.

*fetched*<sup>25</sup>. Lastly, the formal procedure to legally recognise communal tenure is often inaccessible to rural communities and can take several years to complete - during which time the County Government retains authority over the land. Even after registration, county assemblies can decide to alienate land (in adherence with the law), or land can be seized via compulsory acquisition by the state. Given that African national governments are key shareholders and retain a high degree of influence in listed companies, as well as economically and politically benefitting from the income generated from leasing land to non-listed private investors (Blejer & Khan, 1984; Nolte, Chamberlain & Giger, 2016), LSLIs have and will continue to take place across both registered and unregistered customary lands.

### 5.2.1.7. Reconfiguring conservation

*'There's no concept of ecosystem connectivity; everyman is just in it for himself. These are the impacts of sub-division.'* It is *'having negative consequences'* on conservation, *'blocking wildlife corridors between biodiversity reserves and migratory routes'*, and imposing forms of habitat compression on the protected areas. *'This has been a particular challenge within the Ngai Ndethya National Reserve'*<sup>26</sup> where local communities living within its designated boundaries are sub-dividing their land and selling it to *'outsiders'*.

Acknowledging the inevitability of future land sub-division across TCA and rapidly declining relations between conservation agencies (incl. KWS) and local communities, participants stated that sub-division needs to be formally managed to ensure the coexistence of multiple land-uses. The Amboseli Ecosystem Management Plan 2020-2030 (AEMP) recognises that for many local communities, land-use change is an economic imperative to secure direct benefits from agriculture in the absence of indirect benefits from conservation activities and tourism (AET, 2020). Therefore, the management committee overseeing the plan (comprised of NGO, County Government, and government agency representatives) *'advises local communities on the best way to sub-divide their land'* – this is the establishment of a *'zoning scheme'* that separates land-uses that are compatible with conservation from those that are not. *'The scheme includes a settlement zone, cultivation zone, pastoralism development zone, and conservation zone which facilitates tourism.'*

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<sup>25</sup>Between 2016 and 2020, less than 10 communities had registered community lands under the CLA due to 'a lack of interest from relevant government agencies', resulting in deadlines for the recognition of land rights being missed and increased excisions of customary lands for conservation purposes (RRI, 2021).

<sup>26</sup>Ngai Ndethya National Reserve ranks highest for vulnerability to potential climate impacts (habitat change, species loss, and resource pressures) and lowest for adaptive capacity (low tourism demand, infrastructure risk, and low potential for expansion) (WWF, 2021).

The plan is centered around creating nucleated human settlements whereby local communities are concentrated into designated settlement and cultivation areas to support the modernisation and commercialization of the agricultural industry as stipulated in the Kenya Vision 2030 development programme (Government of the Republic of Kenya, 2007), and to make land available for pastoral and conservation activities. While the benefits of collective settlement and farming are evident in the literature (Kariuki & Place, 2005; Shiferaw et al., 2009; Andersson & Gabrielsson, 2012), specific case studies or rational concepts have informed assumptions over their applicability in socio-culturally and politically distinct contexts worldwide. The AEMP assumes that nucleated settlements can contribute towards social equality, improved living standards, agricultural productivity, and increased exports by concentrating on improving social and agricultural amenities<sup>27</sup> and resource provisioning in ‘Community Service Centers’ and across delineated rain-fed and irrigated agricultural lands (AET, 2020). However, there is limited inspection of existing challenges that have prevented these benefits from being realised to date, such as under-funding, donor conditionalities, government corruption, and institutional failures. Additionally, the capacity for County Governments, NGOs, and other development agencies to provide these services is increasingly limited by rapid population growth and urbanisation. Participants highlighted how *‘most of the youth go to urban areas looking for employment opportunities’*, increasing rates of rural-urban migration, rangeland abandonment, and rapid urbanisation across TCA and Kenya more broadly<sup>28</sup>. However, population growth rate is outstripping infrastructural capacity and employment opportunities. This has centered informal economic activities in urban areas; increasingly characterised by high income inequality, poverty, and low living standards (Hope, 2012). *‘People in TCA are financially insecure, and all insecurities are related to financial security’*, *‘so people will engage in illegal activities.’* Thus, the expansion of informal settlements and low-return economic activities might preclude improved infrastructure, services, and employment opportunities across nucleated zones, putting undue burdens on these agencies, and intensifying socioeconomic vulnerabilities, conflict, and illegal activity.

Additionally, the official allocation of land in different zones to enable individuals to practice their livelihood activities and participate in local economic development is determined by the existing ranch officials who possess *‘the power to manage resources in the ranches, [...] make decisions on behalf of the communities, decide on land-use and resource allocation, [...] devise by-laws for grazing systems and, in the case of wetlands conducive to agriculture, how land is sub-divided and allocated to members of the community.’* While collective settlement and farming might encourage individuals who have previously lost out from communal tenure arrangements to adopt this plan,

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<sup>27</sup>Amenities include administrative services, education and health facilities, accommodation, access to water and agricultural markets, development infrastructure, new enterprises and employment, modern farming technologies, supply chain management systems, extension services, processing plants, and storage facilities.

<sup>28</sup>Urbanisation increased from 14.3% in 1999 to 25% in 2009 across TCA (Teucher et al., 2020).

historical experiences of ranch officials allocating themselves to high-potential agricultural lands and grazing pastures provides a cautionary tale (Place & Migot-Adholla, 1998; Wayumba, 2017). As land bordering protected areas becomes increasingly valuable to tourism and commercial agricultural production developers, participants perceive land sub-division to be a politically expedient strategy driven by local elites; on one hand, they want to protect their own claims to land against increasing threats of appropriation by internal and external actors (Mwangi, 2007), at the same time as benefitting from entering political-economic coalitions with commercial investors by selling off or leasing large parcels of their land at premium rates (Kimiti et al., 2018).

The nucleation of settlements is assumed to facilitate the establishment of community farming cooperatives to scale-up production, overcoming some of the challenges individual small-scale farmers have experienced with accessing credit to cover the large capital outlays required for commercializing their production (Balana & Oyeyemi, 2022; Dhillon & Moncur, 2023). For example, many small-scale farmers have been locked out of gaining credit from financial lending institutions due to high interest rates and not being able to meet collateral requirements, such as where wealth is not in the form of liquid assets (e.g., where livestock is their main wealth-base), they do not hold formal land titles, or they do not hold title deeds to support their ownership claims (Njuguna & Nyairo, 2015). Hence, by pooling finances and collectively purchasing, marketing, and processing produce, farming cooperatives are believed to increase local bargaining power, access to credit and resources, and enter export-based markets (Bizikova et al., 2020; Mwambi, Bijman & Galie, 2021; Ma, Marini & Rahut, 2023). However, the deployment of nucleated settlements to enhance export-based production systems shares a strong resemblance to Ujamaa policy pursued in post-independent Tanzania which ultimately left poor farmers in a more impoverished situation. Similar to the zonation plan, Ujamaa was a cooperative economics strategy centered on prescribed villagisation, where nucleated settlements consisting of individual dwellings - each with a small plot of land to cultivate for subsistence purposes - were established amid larger communal farms aimed at catalyzing the modernisation and commercialisation of agricultural production. The policy aimed to collectively benefit the community and national government by mitigating ‘tribalization’ and making it easier and more cost effective for the government to distribute common resources, modern technologies, and development services to rural populations (Hunter, 2008; Guthrie, 2014; Jennings, 2017). However, the policy failed due to several challenges which persist in Kenya’s resource governance arrangements today, including the inadequate provisioning of extension services to rural populations to enable them to participate in long-term modernisation and development, and the exploitation of poorer farmers by political and economic elites (Jaimungal, 2019). The latter potentially facilitated through the institution of farming cooperatives under the zonation plan. This is because economic and political elites are often the main actors in cooperatives since they possess greater bargaining power and access

to government and social resources, thus can act as intermediaries between transactions with the financial sector, large-scale investors, and markets (Li et al., 2023).

Land reforms always create ‘*winners and losers*’ - the winners being the elites who have existing tenure rights in the ranches and collectively pursue agricultural intensification and commercialisation through sub-division. The ‘*local communities are the first losers*’ – those who do not have secure tenure and possess little in the way of bargaining power, thus are often left out of farming cooperatives. The replacement of local agricultural systems with export-based systems is contributing to declines in local economic empowerment, rising poverty rates, and food insecurity (Alden Wily, 2018; AET, 2020), all of which were identified as among the main drivers of inter-group conflict and illegal activity.

#### 5.2.1.8. Reconfiguring biocultural diversity

Land sub-division has ‘*driven a decline in communal life. There has been a loss of tribal culture*’ due to the ‘*the arrival of other tribes to the area who are buying land*’, and rapid decoupling of biological, linguistic, and cultural systems that have co-evolved over millennia. A decline in communal life is both an outcome of and driving force behind the biocultural hysteresis, such that the breakdown of traditional land governance systems and cultural institutions have accelerated the loss of distinct identities, social structures, heritage values, and ecologically and culturally rich ecosystems (Lyver et al., 2019; Millhauser & Earle, 2022). This further reduces opportunities for inter-generational knowledge transmission, therefore fire practices that are deeply embedded in cultural and spiritual traditions are increasingly lost, forgotten, or rendered ‘*obsolete*’, contributing to global patterns of cultural extinction:

*‘Fire is a tool for rangeland management that can capture traditional knowledge. [...] But land is becoming more and more sub-divided, resulting in a decline in savanna burning on the rangelands. Because of increasing population growth, livestock densities, and sub-division, the role of fire has changed. The use of fire as a management tool has become obsolete. What fire used to do is no longer standing.’*

While settlement areas and ‘development frontiers’ are playing out differently in local contexts depending on existing forms of sub-altern politics across distinct agrarian societies (e.g., societies both resist and accelerate agricultural intensification depending on local governance systems, regulations, and resilience under climate-socioeconomic change) (Ioris & Fernandes, 2023), they are increasingly considered as contentious biopolitical spatial configurations which overlap with and erase local worldviews and claims to land and resources based on ancestral precedence, cultural histories, and adaptive livelihoods (Rasmussen & Lund, 2018). Participants stated that for as long as external actors and local elites capture the benefits of land sub-division across TCA at the expense of

local communities who are '*continuously excluded and marginalised*', '*financially insecure*', '*desperate*', and are '*suffering the most*' from climate change, '*landscape conflicts*' will continue intensifying. With all parties acting in self-interest and on the periphery of the law, Kenya's rangelands are increasingly layered with violent territorial claims and acts of resistance as local communities stake claims to their ancestral lands in the absence of traditional governance systems and regulations.

### 5.2.1.9. Promises of partner networks

The KWS are '*hated and liked in equal measures*' by members of the local communities. Despite believing that the KWS are '*ruthless when they visit the locals*', '*slow at responding to human-wildlife conflict*', '*make no provisions for communities to access resources*', and perceive '*wildlife as belonging to them*', most participants agreed that there are good relationships (Mdn: 2) and mutual trust (Mdn: 2) between park rangers and local communities - '*we still want the KWS to stay in our villages*' because their *employees contribute to economic value* by '*shopping in our shops, [...] employing local people for casual labour, like building fences, [...] and assisting with bursaries*'. Positive attitudes towards the KWS were mostly expressed in relation to their perceived connection with NGOs, such that where the KWS are present, NGOs '*who employ locals [...] and provide support for those living around the parks*' are present.

Conservation agencies are increasingly required to reexamine the benefits local communities receive from the establishment of state-governed protected areas to mitigate ongoing processes of ecological degradation and biodiversity loss attributed to inter-group conflict under socioeconomic-climate change. Participants expressed that '*there will always be resistance*' from the local communities, however, '*you will get more support where people benefit more*'. Historically, NGOs served primarily as service delivery organisations to African states (Nega & Schneider, 2014). However, there has been a marked trend in the prominence of Western NGOs in international politics since the end of the Cold War where centralised administrative control over rural poor communities is limited by low governance capacity, corruption, and weak internal legitimacy (Peluso, 1993; Croker, Woods & Kountouris, 2023a). NGOs have evolved into political institutions and key '*environmental and conservation partners*' in decision-making processes; working with governments, donors, and the private sector to deliver governance reform and privatisation policies, joint multi-lateral programmes with cross-sectoral outcomes, and promote socioeconomic transformation in rural development through policy advocacy and action (Norton-Griffiths, 2010; Lewis, 2020). In Kenya, more than 12,000 registered NGOs operate across different sectors and investment significant amounts of money into local- to regional-level projects, providing opportunities for skills development, creating thousands of salaried and voluntary employment opportunities (>71,000 in 2021-2022), and significantly contributing to total GDP (NGOs Co-ordination Board, 2023). '*We have a large*

*influence over management and governance of natural resources and conservation, [...] working in collaboration with other organisations [...] to provide a range of community services and projects' and engage in 'advocacy work' over matters of land use and tenure.*

In TCA where most subsistence-based farmers earn less than \$15 USD a month (Hagen, 2022), NGOs have played an important role in fostering collaborative working relationships - serving as *'a community voice'* in conservation decision-making – to deliver *'livelihood projects'*, resulting in *'reduced conflict'* and *'creating a new group of custodians in protecting wildlife'*. Participants representing conservation agencies suggested that these projects are contributing towards achieving long-term conservation objectives by aligning inter-group land-use values, *'giving back to the society'*, increasing the *'number of benefits reaching the local people'*, and *'making louder the message of conservation'*.

Livelihood projects were mostly understood by Kenyan participants as corporate social responsibility (CSR) projects, whom the responsibility for implementation lay with donor-funded (inter)national NGOs not limited by government finance and resource allocations. Consistent with global trends, *'community-based'* CSR projects are rapidly increasing across Kenya, shaped by divergent understandings of their key dimensions<sup>29</sup> and expected outcomes (Sahlin-Andersson, 2006; Dobers & Halme, 2009; Jamali & Karam, 2018); participants from the local communities stated that it is the role of NGOs, as *'separate'* non-governmental entities, to *'create value chains across TCA that economically support communities – looking at opportunities for local enterprises'* which diversify income, generate *'commercial benefits'*, and, in turn, empower local communities and create a sense of agency in conservation management. In this way, *'local people feel part of the project – so they own it.'* Participants from governmental agencies understood CSR projects as a top-down conflict mitigation tool - *'only focusing on areas close to the parks, [...] because these are the people that are impacted by the negative consequences of human-wildlife conflict'* – to align local behaviours with national conservation objectives and reduce illegal activity. These participants emphasised the important role of REDD+ in conservation management; *'reducing human-wildlife conflict'* through the reinvestment of carbon credits in CSR projects which focus on *'enlightening communities'* on *'modern practices'*, thus enabling them to *'assist in conservation.'* Generally, participants agreed that were there *'are less projects and greater resistance'*, there will be *'higher incidences of poaching and human-wildlife conflict'* and *'increased illegal activity.'*

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<sup>29</sup>Participants understood CSR projects as any of the following: development of water infrastructure, construction and resourcing of schools and health facilities; creation of employment and fundraising opportunities; provision of training courses in wildlife conservation; human-wildlife conflict mitigation measures; allocation of bursaries.

### 5.2.1.10. Paucity and privation in partner networks

The benefits of (inter)national partner networks in achieving sustainable development and conservation objectives at the national level are well recorded in the literature, hence play an important role in future conservation efforts in many developing countries (DeSombre, 2006; Dong, Yang & Li, 2018). However, Norton-Griffiths, (2007) describes the relationship between the KWS – the ‘Kenya state conservation monopoly’ – and international agencies as an ‘unholy alliance’, perpetuating policy instruments which divert conservation benefits away from local communities – their supposedly new group of ‘*custodians in protecting wildlife*’ – and towards the central government, county governments, and ‘tourism cartels’.

Local communities generally ‘*feel oppressed by the government*’ and ‘*hate the KWS rangers for not helping them much – only employing them on a casual or temporary basis*’, and ‘*not prioritising them in skilled roles*’. ‘*The KWS are the enemy due to increasing incidences of human-wildlife conflict, [...] such as elephants raiding farms*’ – ‘*they take too long to respond to*’, and ‘*the communities receive no compensation*’. Compensation ‘*is extremely hap-hazard*’ and ‘*selective, for example only including certain animals like elephants and predators, not snakes and other animals*’ (WCMA, 2013). Given increasing political instability, civil conflict, and human population and climate-driven pressures across the region (Gooch, 2011), the KWS and KFS are limited in their operations because ‘*funding and resource priorities are being directed towards security, rather than conservation.*’ ‘*The KWS do not have resources. [...] The government and corruption have hollowed out the system*’ and that while ‘*KWS should do more CSR to assist the communities*’, they have to ‘*follow bureaucratic processes*’ and are ‘*highly dependent*’ on government financing and resourcing. Aware of these limitations, several participants voiced frustration over the communities’ negative attitude towards the protected areas, stating that the relationship is ‘*amicable, but they [the communities] generally have a perception that the park is a solution to all their needs, from CSR projects, employment, money from tourists, resources like firewood, grazing, water...*’ And ‘*the problem with the community is that they will always be asking for more. You can never satisfy them. They have a dependency syndrome. You give them this, they want something else next time. It goes on. A reel of requests.*’ Local chiefs recognised the grievances of their local communities, but since they hold ‘*an office of the President*’, such that they are appointed by the National Government to assist at the county level, they typically remained more neutral in their opinions towards KWS, looking more towards conservancies and private investors for providing employment opportunities.

NGOs have evolved from ‘implementors’ of local projects in the 1990s to ‘peripheries of power’ in the twenty-first century (Shivji, 2007), serving as ‘*partner organisations*’ to ‘bureaucratic alliances’ crafted between powerful (inter)national public and private organisations to promote government agenda in rural affairs. As such, they have been criticised for reinforcing missionary paternalistic

approaches to local development (Hearn, 2007; Manji & O’Coill, 2002), such as the need to empower and educate local communities (Nelson, 2003), rather than strengthening existing local governance systems and building capacity in management (Croker, Woods & Kountouris, 2023a). For example, NGO representatives expressed how their organisations aim to *‘promote community engagement by changing perceptions and attitudes towards wildlife’, ‘break down traditional wisdoms’, ‘educate the community [...] on the relevance of conservation’,* and in-turn *‘bring empowerment.’* KWS representatives shared that where *‘NGOs have done enough advocacy work’,* local behaviours are changing and *‘we are able to see the benefits.’*

Several participants criticized NGOs for speaking on behalf of rural communities to advance foreign and governmental agenda, insinuating elite minority views in conservation-development policy which, in the long-term, can lead to conflicts related to legitimacy and undermine effective political action (Parks, 2008); *‘there has been no valuable community input into landscape management plans – no genuine, serious discussion about how it will benefit the communities, or any discussion with the communities over how management will be done – how it will be organised.’* Local communities *‘do not feel empowered’* because *‘they are continuously excluded and marginalised’* in resource governance. They *‘still engage in illegal activities’* in the parks because of *‘the economic realities and challenges’* they are facing. However, direct employment opportunities with NGOs are limited by organisational requirements and the local demographic context. For example, *‘most of the professionals leave the region – to Nairobi or Mombasa. So, only a few professionals from Taita Taveta are employed by us. [...] Mostly, skilled positions will be filled from outside the region.’*

The number of NGOs operating across Kenya is increasing at an unprecedented rate<sup>30</sup>, each with their own institutional policies and conditionalities imposed on them by foreign and multi-lateral donors who seek to export Western environmental and social standards (and costs) and, in turn, increase the competitiveness of certain industries such as forestry management vis-à-vis conservation (Kogan, 2004). NGO representatives shared how rapid growth in the *‘partner network’* has created several organisational challenges related to distrust, conflict, and competition, stymying opportunities for effective cooperation in resource governance management (KIPPRA, 2021). Firstly, due to a *‘scarcity of resources among donors’* and limited national investment in environmental research and development, NGOs are competing for investment (or renewed investment) from the same pool of donors seeking to fund conservation projects with similar objectives (Stephenson et al., 2017). As such, NGOs are reluctant to share environmental data with one another, especially considering existing data availability, access, and usability challenges which have contributed to large gaps in recorded information on African biodiversity (Siddig, 2019). Despite that *‘private foundations are an*

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<sup>30</sup> In 1974, 125 NGOs were operating in Kenya. In 2006, over 4,200 NGOs had been registered with the government. This has risen to over 12,000 in 2024 (The National Council of NGOs, 2024).

*important source of funding for fire management and conservation, this largely tracks the USA economy and can be restrictive, such as imposing rules on local management systems and increasing vulnerability to shocks in the USA's economy.* For example, the socioeconomic downturn experienced across TCA due to the COVID-19 pandemic revealed regional vulnerabilities to external shocks affecting established, though somewhat ad-hoc, funding streams, as well as the communities' reliance on 'community-based' CSR projects which were temporary inhibited by lockdown restrictions.

Secondly, the greater the number of NGOs active in the partner network, the higher the risk any given NGO exits a multi-level management agreement (often including local communities) during implementation. In such instances, participants have observed an *'increase in incidences of elite capture and corruption'* due to a shift in priorities and responsibilities or the emergence of governance loopholes. These challenges likely cascade from the top-down where regional organisations *'partner with different agencies and NGOs, all of which have competing interests and funding requirements, as well as different regulations and governance structures.'* Participants expressed how this issue of transparency among partners had previously compromised their own operations. Over the last decade, there have been large fluctuations in the number of active NGOs formally registering their activities, such that between 2021-2022, only 31% of NGOs complied with the Non-Governmental Organizations Co-Ordination Regulations Act (1992) by submitting their annual report to the Board. Hence, in the Board's 2022 Annual Report, they state that *'it has been difficult to get reliable data on the actual contribution of NGOs to the economy due to low compliance levels'* and, despite the sector *'increasingly becoming a major player in the provision of basic services'*, *'its expansion also brings high risks of potential abuse both for the public who interact with these NGOs on a day-to-day basis as well as overall national security and economic stability.'*

Fiscal strains at the local level have resulted in county governments demanding higher returns from park revenue, hence impeding opportunities for reinvestment in conservation. In light of these governance and capacity challenges, KWS officers shared how they are increasingly looking directly towards large international development agencies for assistance in delivering their objectives, rather than channelling donor funds and resources through tertiary NGOs. In the KWS's Strategic Plan 2024-2028, they state the international development partners will play an important role in *'provid[ing] financial and technical assistance'*, to *'capacity building development'*, to *'participat[ing] in policies development'* (KWS, 2024). Amid growing fears that the world's focus on net-zero, carbon, and climate change is diverting resources away from biodiversity, they have called upon these agencies who have a great deal of power in international environmental policy development to *'develop conservation models for the global South'* which *'put a voice for biodiversity'* (KWS, 2024b).

### 5.2.1.11. Opportunities for community-based governance

Recognising the importance of empowerment and environmental stewardship in mitigating deforestation and forest degradation (Mbuvi, Musyoki & Ongugo, 2015), the Kenyan government introduced Participatory Forest Management (PFM) in 1997 to decentralize forestry management and achieve national forestation targets. PFM was later formalised under the Forest Act (2005), requiring local communities to form and register Community Forestry Associations (CFAs) under the provisions of the Societies Act (1968) before entering management agreements with the KFS and county governments (Humphrey, Moses & Tsingalia, 2014). As a result, PFM arrangements are diverse in structure and implementation, largely reflecting the interests of participating local communities and their traditional user-rights (Forest Conservation and Management Act, 2016, Article 48-52), as well as the forestry management goals of government authorities. In TCA, the Mwambo CFA has recently been established to enter a ‘*collaborative management agreement*’ to implement Mwambirwa-Mbololo (Mwambo) PFM Plan 2020-2024. The Mbololo Forest - the largest extant fragment of indigenous Afromontane Forest in Taita Hills - was gazetted as a National Forest in the 1990s and has remained under the jurisdiction of the KFS. The Mwambirwa forest, however, is a county forest<sup>31</sup>, and given that the non-consumptive income opportunities of forests have not been seen by many rural communities across Kenya, as well as resource and law enforcement constraints experienced by the County Government, it is undergoing rapid rates of encroachment and degradation (refs): ‘*where devolved areas aren’t gazetted, the KFS have no legal backing to support their activities and there are conflicts and unsustainable resource use.*’

Several studies suggest that only ‘*gazettement could preclude further forest degradation and loss*’ (Aerts et al., 2011; Wekesa et al., 2020). Yet, KFS representatives shared how they are often ‘*met with resistance in some areas where forests are gazetted because the locals do not accept it*’. Across the Mwambo project location, some farmers have resisted the plan due to higher land-use values being attached to agriculture than forest protection, expressing concern over the negative impacts of increasing tree cover on crop growth. As such, the KFS are pursuing a ‘Least-Cost Forest Connectivity Model’ to maximise tree plantations across the lowest possible number of farms to connect the two forests, as well as providing law enforcement training to community scouts, helping farmers procure seeds and seedlings, and raising awareness over the benefits of biodiversity conservation.

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<sup>31</sup> County forests include forestland (i) within public land as defined by the Land Act (2012), the Land Registration Act (2012), and Forest Conservation and Management Act (2016); (ii) transferred to the County by way of sale, reversion or surrender; and (iii) in which no individual or community ownership can be established by any legal process (Nyeri County Forest Management and Conservation Policy, 2020).

While PFM provides opportunities for community input in resource management in Kenya, variation in their governance structures, rules-in-use, and agreed distribution of benefits to local communities presents several challenges that require addressing to avert future conflicts. Firstly, CFA members are required to pay a monthly or annual membership fee affirming their support and commitment to protecting the forest. This is based on the understanding that they will receive a direct stake in forest management, decision-making processes, and the sustainable utilisation of forestry resources.

However, the KFS retain forest resource ownership rights and can withdraw the agreement at any time, preventing the decentralisation of management to local communities and their ability to lobby, initiate rural development, and participate in conflict management (Ongugo et al., 2008). Furthermore, membership fees limit participation to wealthier, politically prominent individuals, hence land declared as a County Forest upon the recommendation of the County Government and collaborating CFAs risk reinforcing inequitable power hierarchies in resource governance, commensurate with the transfer of exclusion rather than management rights to local communities (Taita-Taveta County Environment and Forest Bill, 2018; Croker, Woods & Kountouris, 2023a):

*‘Community-based structures are vulnerable to politics’. ‘Where the local government and communities are supposed to share the land, resources are often taken by a few, such as wood and charcoal. It is political because politicians use and exploit the ecosystem.’*

Secondly, CFAs are inadequately funded and over-rely on NGO and governmental support. As such, ‘collaborative management agreements’ can reinstitute external control over rural affairs through the introduction of green conditionalities, strict top-down rules-in-use, and the establishment of ‘community-based’ CSR projects focusing on law enforcement training and community awareness to increase the effectiveness of exclusionary ‘fences and fines’ approaches to conservation and align land-use values and objectives.

The KFS, NGOs, and the local government are working towards the formulation of a Taita Taveta Forest Conservation and Management Policy to establish formal legislation in the county’s forestry sector, including the future role of CFAs and sustainable management practices. The success of this policy and long-term ecological resilience of the savanna-forest transition zone will depend largely on the extent to which local communities acquire real decision-making power vested in legitimate institutions – so that they ‘accept’ the plan, ‘appreciate’ the forests, and feel enfranchised in sustainable resource governance (Mbuvi, Musyoki & Ongugo, 2015; Croker, Woods & Kountouris, 2023a).

### 5.3. Wildfire attribution

The ‘anthropogenic fire regime’, or ‘ecological-biocultural wildfire paradox’, that characterises TCA was strongly attributed to human activity inside national parks (*Mdn*: 2) and community

conservancies and ranches (*Mdn: 2*), and across communal lands immediately surrounding the protected areas (*Mdn: 2*) (Fig. 5). Participants noted how the capacity for fire activities to spread into wildfires is largely controlled by an ecological fire spread threshold determined by surface fuel load and connectivity (Archibald, Staver & Levin, 2012; Keeley & Pausas, 2022).

*‘Sources of fire are from normal activities like charcoal and bee harvesting that happen every day. But when there is fuel, that interaction becomes deadly.’*

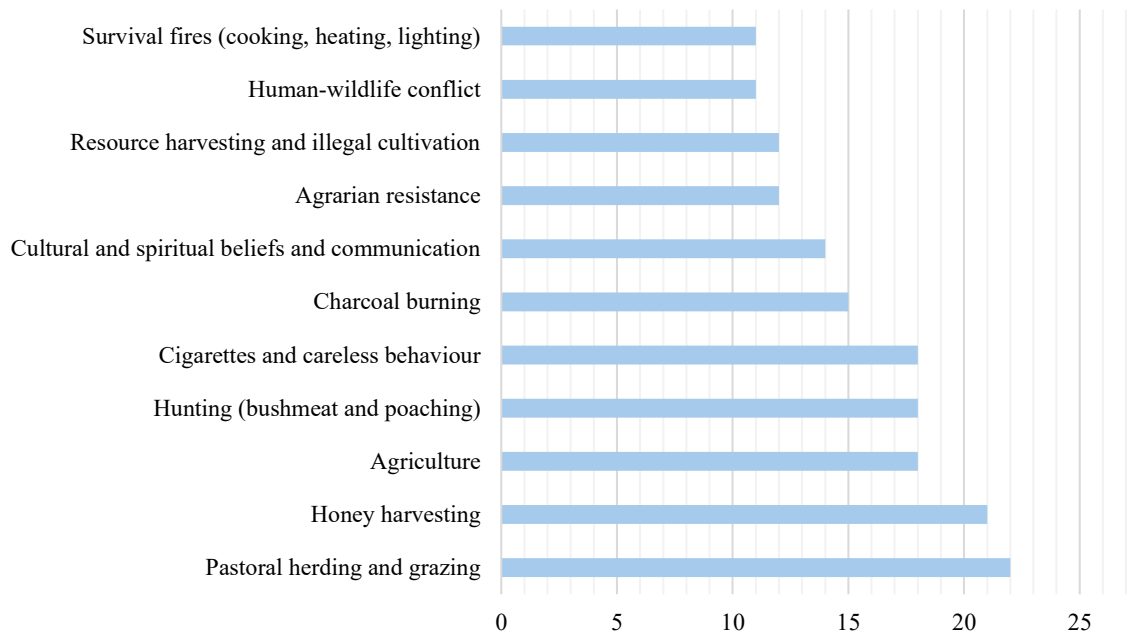


**Figure 5.** Attribution of wildfires to local human activities. Data: 28 semi-structured interviews conducted across the Tsavo Conservation Area, Kenya, 2022.

These observations are typical across state-governed conservation landscapes globally where long histories of exclusionary property rights and fire suppression are increasingly coming into conflict as livelihood vulnerabilities intensify under socioeconomic-climate change (Tedim, Leone & McGee, 2019). The preceding sections (5.1 and 5.2) described the interrelated physical and human components of the fire regime, detailing macro- and micro-scale systemic influences of wildfire and the conditions in which they increasingly synthesise and are symptomatic of. Considering the complex actor network that characterises TCA, this section describes the fire-use activities identified by participants as leading causes of wildfires in the protected areas. These activities should be considered within their systemic physical-human context (e.g., sections 5.1. and 5.2).

While local causes of wildfire are widely documented in the literature (e.g., see Croker, Woods & Kountouris, 2023a, Text S3 and Table S4), this analysis situates burning practices within their broader political-economic context, critically analysing additional landscape and regional-level conditions that

directly influence current and potential future fire-use activities. Participants frequently differentiated between fire regimes and wildfires experienced along the eastern (Makueni County, Taita Taveta County) and western (Kajiado County) boundaries of Chyulu Hills and Tsavo West National Parks where agricultural Kamba and Taita communities and pastoral Maasai communities with conflicting land-use objectives reside, respectively. The distribution of fire is, therefore, inextricably linked with local forms of sub-altern politics across distinct geographies. At the same time, fire-use activities cannot be attributed to one group, rather they are practiced in parallel by multiple groups depending on the individual, context, and rules-in-use. Exploring these aspects of the fire regime can assist in identifying and addressing gaps in knowledge that affect opportunities and challenges for alternative bottom-up fire management.

### 5.3.1. Pastoralist herding and grazing

Pastoral-based livestock production within or immediately surrounding the protected areas was the most cited cause of wildfire in Tsavo (Fig 5), particularly across the parks' western boundaries. 67% of participants believe that wildfires are often unintentionally ignited by agro-pastoralists when they intentionally burn pasture to encourage vegetation regrowth (*Mdn: 2*), eradicate livestock pests, or facilitate movement throughout the landscape. This is *'their traditional way of thinking'*, *'burning purely because they want their livestock's welfare to be taken care of.'* For example, following periods of heavy rainfall, participants have observed an increase in pastoral-related fires to reduce the density of less palatable moribund materials and promote the regeneration of nutrient-rich grass species. They believe these traditional ways of thinking to be *'unfortunate'* as *'they do so much damage.'* Others viewed these traditional fire practices as *'myths'*: *'burning manure because it's infested by ticks - it's a myth to burn to get rid of pests'*. 19% of participants do not perceive herders as having *'anything to do with it. Herders will not participate in causing fires because pastures are integral to their economy.'* This removes fire as a key disturbance event in the savanna adaptive cycle, inferring that other processes are important in pasture regeneration.

Participants residing or working within the jurisdiction of the Kasigau Corridor REDD+ project expressed greater conviction over the connection between wildfires and herding activities than those within the Chyulu Hills REDD+ project area (Table 11). This might be due to the dominance of agricultural Giriama and Duruma communities in the Kasigau area who are more likely to blame pastoral herders for wildfires, particularly considering the socio-economic costs a reduction in carbon credits might have on local farming initiatives and income. Additionally, members of a pastoral Waata community who are not the primary beneficiaries of the REDD+ project also strongly believed in this connection, possibly providing an honest account of their own practices and experiences due to the anonymity of this research, and/or some deep-rooted tensions regarding their subsumption into

dominant pastoral groups during the establishment of colonial Native (or Tribal) Reserves (Kassam & Bashuna, 2004).

Pastoral fires occur intra-annually across TCA but are more common *'in Tsavo East and Tsavo West - the only reason we have those fires, the huge ones, is because of livestock grazing in those areas'* - and in the LDS when herders light fires to regenerate *'lush green grass readily available for their livestock'* at the onset of the rains. Therefore, greater uncertainty regarding the connection between wildfires and herding activities within the Chyulu Hills REDD+ project area is likely due to the comparatively low number of herders in Chyulu Hills National Park than in Tsavo and observed increases in other illegal activities strongly associated with wildfire (e.g., honey harvesting, hunting, agriculture, and illegal cultivation and resource harvesting). While herders typically *'come to Chyulu as a last resort'* due to its *'bushy landscape'*, socioeconomic-climate change and declining tsetse fly populations are increasing the number of pastoralists present within the park who use fire to facilitate livestock production.

Controlled fires applied to reduce fuel loads *'can easily burn out of control'* across the savanna lowlands due to the expansion of non-fire adapted woody shrub species and increased biogeophysical wildfire conditions. Additionally, LDS burns are becoming more expansive due to the commercialisation of livestock ranching across the region. When expansive burns are followed by *'failed rains'*, *'all the livestock die'* due to increased forage competition between wild and domestic herbivores. Historically, people *'burned one area and grazed in another. The grass would sprout, and they would come back to it. Now there are people occupying everywhere, and everyone is wanting to burn.'* Herders *'start fires every year, often when wildfires, or killer fires as we call them, have already broken out in the protected areas, particularly in extremely dry years when the parks are already dealing with multiple challenges.'*

Some participants interchangeably referred to prescribed burns and pastoral fires, thus reinforcing negative perceptions towards prescribed fire as a rangeland management strategy. *'Rather than burning as a land management tool, [...] they should use mulching'* to reduce wildfire risk. Others suggested that pastoralists burn in the wet season when *'it is a bit safer because it won't burn all the grass'*, however this does not consider the social-ecological importance of higher intensity dry season fires for savanna regeneration and pastoral livelihoods.



**Figure 6.** Rangers and NGO staff fighting a wildfire in Tsavo West National Park believed to be caused by illegal herders. Tsavo Conservation Area, 2022.

### 5.3.2. Honey harvesting

*‘One of the main challenges related to wildfires within the protected areas is traditional honey harvesting practices’* that take place both within and outside their boundaries, mostly carried out by agricultural Kamba communities along the eastern border of Chyulu Hills National Park and, to a lesser degree, Taita communities along the eastern boundary of Tsavo West (Table 10). Participants revealed that approximately 30-40% of Taita communities harvest honey, while for Kamba people, it is a *‘cultural activity’*, it is *‘part of Kamba culture’*. For example, honey has historically been used as a form of dowry, presented to the bride’s family in a bucket and to community elders in the form of a traditional brew – *‘kimee’* – as a symbol of appreciation and respect. While many of these practices were suppressed by Christian missionaries, honey remains an integral food source and symbol of cultural heritage.

The gazettement of *‘Chyulu Hills resulted in a lot of displacement’*, resulting in large Kamba populations *‘living in the periphery of the park’*. The Ngulia, a minority sub-tribe of the Kamba community, live in these areas and have retained their traditional hunter-gatherer sociocultural identity, rarely participating in economic activities now practiced by the majority Kamba community.

The Ngulia are typically poorer, have low literacy skills, and limited access to government services, constituting most of the squatter population across the Kibwezi-Chyulu Hills National Park interface (Muriuki et al., 2011). Hence, they are likely to be *‘the beekeepers inside’*. While *‘people have been taken for training in beekeeping and the use of modern technologies for harvesting honey’*, *‘most of them continue to use traditional beekeeping methods’*:

*‘The WWF have given modern beehives – the Langstroth beehives – so that during harvest, farmers don’t need to use fire. This is one of the preventative measures to mitigate wildfires, but they are reluctant to take the modern beehives. To them, the traditional ones are more effective.’*

As such, illegal honey gatherers are entering the protected areas and lighting fires to *‘smoke out the bees’*. *‘All of a sudden, they have spread into wildfires’*. They mostly do not have the knowledge or resources to extinguish these larger fires, hence *‘tend to run away’* as *‘they do want to be the culprits.’* Despite being primary beneficiaries of the Chyulu Hills REDD+ project and ascribing strong importance-values to savanna ecosystems (Table 11), participants have observed members of the Kamba community intentionally igniting uncontrolled wildfires to *‘burn within the park and drive bees out towards their hives’*, resulting in large-scale ecological degradation and loss of carbon credit revenue.

Across communal lands, honey harvesting tends to be concentrated around exotic Sisal (*Agave sisalana*) and Moringa (*Moringa oleifera*) trees due to their flowers’ high nectar content. Traditional log hives are typically placed in trees surrounding the plantations and bees are smoked out of during the night to avoid detection (Li, 2014). Taita Taveta hosts one of the largest private sisal estates in the world, established under colonial rule and mostly employing external individuals to avoid potential conflicts with local people who hold (informal) ancestral land rights (Minoia, 2020). Additionally, *Moringa oleifera* plantations are increasing across Makueni County under a large-scale TAS plantation project aiming to increase tree cover and address sustainability challenges related to food insecurity and malnutrition, as well as under a new Makueni Agroforestry Carbon Project (VCS/4325). The commercialisation of these species is negatively affecting the fire regime by replacing native fire-adapted species with non-fire adapted TASs. Hence, the placement of hives around plantation borders and increasing incidences of agrarian resistance regarding ancestral land and resource rights increases the wildfire risk associated with traditional honey harvesting activities.

### 5.3.3. Agriculture

Considering TCA’s large agricultural population and concentration of *‘fertile areas for farming and agricultural activities’* being around protected areas, most participants identified subsistence-based agricultural practices as a source of wildfire within their boundaries (*Mdn: 2*). Fire is a quick and

cheap landscape management tool utilised by rural poor farmers to clear vegetation and prepare land in the LDS before the onset of the rains. Participants noted '*crop residue burning*' – where fire is used to '*remove stubble and residues in preparation for planting*' - to be '*a large issue*', particularly along the eastern border of Chyulu Hills National Park and the '*north-eastern part of the Group Ranches*'. While they acknowledged that burning can be beneficial in land management, '*it is more on the agricultural side of things*' and '*is not beneficial to wildlife*', explicitly referring to the negative impacts of slash-and-burn practices on deforestation and ecological degradation.

Historically, rules governing fire-use advised against burning between 3-4pm; '*people were told to be extra cautious [...] because fires can spread quickly.*' Prior to burning, people were required to establish fire-breaks to mitigate the risk of fires escaping on to neighbouring farms. However, with the breakdown of traditional land governance systems and increasing resource competition, people are acting in self-interest rather than on behalf of the wider community. Without these rules, fires frequently '*exceed*' or '*go beyond their control*', spreading into neighbouring farms and '*spilling over into the parks.*'

Participants warned that agricultural-related wildfires are likely going to increase in the future because '*there is a lot of crop failure due to climate and weather conditions. For the last three years, we haven't harvested anything. Someone has pumped inputs into their farm and the rains have failed. You are at square zero. So, when the next rains come, you look for quick ways to prepare your farm – often using fire.*' Additionally, as humans increasingly settle in higher altitude savanna-forest areas due to declining resources and land suitable for agriculture in the lowlands, they will likely need to apply higher intensity fires for clearance and cultivation purposes. In some cases, people have been observed clearing land within the parks' perimeters to expand agricultural production. Due to ongoing challenges with deciphering between '*farm and forest*', participants shared how they are unable to identify, prevent, and penalise these activities.

Agriculture-caused wildfires were also attributed to an increase in commercial traders in the region who burn extensive plots of land to facilitate intensive production. This is having knock-on-effects as subsistence-based farmers adopt cash-crop agricultural practices, redirecting produce to export markets. There have been observed forms of local resistance against commercial traders, mostly where local produce is used solely to feed families and communities. Hence, they '*do not want to sell their produce*' to commercial traders. But because of widespread food insecurity across the country, the produce delivered by commercial traders is in high demand among other traders and non-farming communities. In these instances, traders have '*burned the forest to force local people to sell their produce.*'

### 5.3.4. Hunting: bushmeat and poaching

‘Bushmeat hunters’ and ‘poachers’ were often referred to interchangeably as a cause of wildfire in TCA, for example stating ‘*bushmeat poachers*’, or defining bushmeat hunting as ‘*small game poaching*’ rather than ‘*big game poaching*’. All hunting is illegal under Kenyan law, yet the drivers of and scale and operations for carrying out bushmeat and poaching activities vary significantly. As such, this study, consistent with the existing literature, considers bushmeat hunting as subsistence-based, carried out by local people for immediate consumption, thus is strongly linked with poverty, economic disempowerment, and food insecurity challenges (Lindsey et al., 2013). Poaching, on the other hand, is considered as commercial-based harvesting, often carried out by local or external individuals who are part of or have entered into agreements with transnational organised crime networks, typically involving international third parties (Wyatt, van Uhm & Nurse, 2020). Participants stated that ‘the biggest fires’ in TCA are the uncontrolled fires are intentionally ignited in the protected areas to facilitate hunting for ‘*self and commercial purposes*’. Fires are used to: ‘*distract rangers*’ and ‘*draw attention away from their hunting sites*’, such that rangers ‘*are no longer concentrating on catching the poacher but instead are putting out the fire*’; regenerate ‘*fresh shoots*’ and ‘*softer grasses*’ to attract game to areas ‘*they have set up snares*’; drive game towards their hunting sites by burning large areas of the parks and smoking out predators from their dens; clear bushes for increased visibility and mobility; process bushmeat; and ‘*dispose of the evidence of them being the area.*’

Bushmeat hunting is particularly prominent on the eastern side of Chyulu Hills where a high percentage of Kamba people live in absolute poverty in informal urban areas and are extremely vulnerable to declining agricultural productivity. Pastoralists shared how their cultural practices and beliefs have fostered a symbiotic relationship with wildlife for many years, thus condemning Kamba people for lighting fires in Chyulu Hills to carry out bushmeat hunting. However, as La Niña events intensify across the region and multi-year droughts and crop failures become frequent events, participants recognised that *'people have no alternative. They have no source of income, so they start sourcing for wild animals. Hunting under such circumstances is viewed as a 'form of necessary evil.'*



**Figure 7.** Rangers and NGO staff extinguishing a wildfire in Chyulu Hills National Park which spread from a camp established by bushmeat hunters. Tsavo Conservation Area, 2022.

Poaching activities are *'transforming Chyulu to grassland. There are many fire scars across the landscape.'* In recent years, poaching has declined, largely due to the establishment of an electric fence around the national park, increased *'anti-poaching patrols'*, and the introduction of *'heavy*

*penalties for poaching*’ as articulated in the 2013 WCMA<sup>32</sup>. Participants emphasised the importance of investing in security operations to mitigate wildfires, explaining how wildfires are a consequence of illegal activities in the parks, rather than being an independent challenge.

While poaching rates have decreased in Kenya over the last decade, a resurgence in terrorism and increase in the number of transnational organised crime networks operating across the Western Indian Ocean threatens regional geopolitical and economic security (Kumar, 2023), particularly considering the recent establishment of trade relations between East Africa and GCC states (Pandey & Gurudatt, 2023). Wildlife traffickers are likely to take advantage of the weaker and fragile maritime environment, while local people who are *‘are financially insecure’* are more likely to engage in poaching activities to generate income (Somerville, 2017). Participants highlighted how these challenges might be particularly pronounced in TCA in the coming years due to the redistribution of resources and rangers to Boni Forest in Lamu County and other counties along the Somalian border where Al Shabab are an ongoing threat.

### 5.3.5. Charcoal burning

Charcoal burning is a *‘big source of bush fires’* in TCA, symptomatic of local socioeconomic conditions and rural poverty, *‘especially during the dry season when people have no other source of income.’* This is particularly common along the eastern border of Chyulu Hills where local Kamba communities *‘have to turn to charcoal burning for survival.’* *‘People do it in a hurry and leave it burning’*, and the *‘fires are just left to spread.’*

Government bans introduced on resource harvesting to protect tree species have had inverse effects by impacting prices along the value chain, financially incentivising local people to produce and illegally sell products to traders and consumers. The 2018 Charcoal Ban significantly weakened the institutional power of formal Charcoal Producers Associations (CPAs) (e.g., lack of mandate regulating harvesting) and raised the value of charcoal at the certified producer, intermediate, and consumer levels (Wekesa et al., 2023). This contributed to a decrease in purchasing power, having knock-on socioeconomic effects throughout the value chain, and provided a financial opportunity for illegal charcoal producers and members of CPAs to increase their own charcoal production activities, directly selling to traders along the Highway and at other market centres for reduced prices (refs). These activities have been eased through liberalisation of the motorcycle industry in 2008 (Kivoi, 2022), enabling local people to engage in commercial trade networks.

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<sup>32</sup>Penalties include fines up to 20 million KSH and more than 10 years imprisonment for possession of wildlife resources such as horns, skins, and ivory.

*'Rampant wildfires' related to charcoal burning are 'distinct to Chyulu Hills' where 'there are more trees for charcoal burning'. When local agriculturalists 'are not busy on their farms' and 'are desperate', participants have observed them turning to charcoal burning and other illegal activities to earn a living: 'the charcoal issue might take time to mitigate, because unless they are given alternative livelihoods, they will continue doing this.'*

Charcoal production presents a *'large environmental problem'* across the country, resulting in 0.087-1.33 million hectares of deforestation annually (Kiruki et al., 2017; Senelwa et al., 2023). Over 99% of charcoal producers in Kenya use inefficient earth-mound charcoal kilns to process harvested wood (Njenga et al., 2023), *'cutting down a lot of trees'* - mostly targeting mature hardwood trees with large basal areas (Ndegwa et al., 2016). Participants have observed an increasing number of *'motorbikes carrying lots and lots of charcoal'* between Taita Taveta, Kwale, and Kilifi counties, particularly around Mackinnon Road and Kilibasi where there are high rates of poverty. *'You will see these people sneak into our ranches' and 'fell trees for charcoal burning.'* Since charcoal production is illegal, *'most of them practice this away from their homes and leave the kilns burning. These kilns often collapse and lead to fire outbreaks.'*

To suppress charcoal production in the parks, authorities have *'tried chasing out the charcoal burners'* and have *'destroyed their kilns.'* However, this is not a long-term solution; rather than *'going after'* the producers, participants highlighted the importance of fostering sustainable livelihoods which are *'compatible with conservation'*, do not *'contribute towards wildfires'*, and generate alternative sources of local revenue sources.



**Figure 8.** Ranch ranger destroying earth-mound charcoal kiln illegally constructed in a private ranch in Taita Taveta. Tsavo Conservation Area, 2022.

### 5.3.6. Resource harvesting and illegal cultivation

Fires are used for a variety of reasons when people are ‘*illegally accessing, and harvesting, and cultivating resources*’ inside the protected areas, for example to distract authorities while extracting fuelwood, medicinal plants, honey and other food sources, and construction materials. The latter including sandalwood which is protected under CITES. These activities are closely associated with declining environmental conditions across community lands and socioeconomic hardship. ‘*There is a link between COVID-19, and increased fire occurrences related to illegal resource harvesting. This is due to a decline in youth employment. Perennial criminals serve their term and then get back to business, lighting fires.*’

The illegal cultivation of khat/miraa (*Catha edulis*) and production of bhang (*Cannabis sativa*) are leading causes of wildfire in Chyulu Hills National Park, where intentional controlled burns used to clear land, residues, and promote regeneration often spread out of control. Increased MAP and cooler temperatures promote the natural growth of miraa across Chyulu Hills and in specific areas in Tsavo East National Park (Mwaura, Kiringe & Warinwa, 2016). Illegal miraa harvesting is mostly attributed

to Kamba communities who *'burn annually at the start of the rainy season, or after it has been harvested to regenerate miraa buds that are then later harvested to sell.'* Local people often harvest miraa for themselves, to chew as a stimulant. However, (inter)national demand for miraa and its large-scale commercialisation across East Africa have driven an increase in market-based production amongst Kenyan farmers seeking to diversify their income (Carrier, 2008; Gebissa, 2010). At the same time, countries such as the UK who have previously benefitted from miraa imports (e.g., profiting £2.5 million p.a. in taxes on the trade) have banned consumption and classified it as an illicit drug, putting many local farmers out of business (Klein, Beckerleg & Hailu, 2009; Carrier, 2014). While changes in international demand for miraa and its consequences at the local-level are uncertain, exposure to the stimulant and potential addiction might increase its value on the black market, hence fires associated with harvesting miraa are likely to become more frequent and less controlled. Aerial patrols have been somewhat successful in suppressing production in the park, however *'the remnants of those plantations'* remain, and *'when it rains, the wild khat will sprout. We are not able to stop that. [...] We are not able to cut it.'*

Bhang does not grow naturally in TCA, rather it *'is specifically farmed'*. This is mostly carried out in government-owned areas due to the threat of having freehold land forfeited to the government if caught growing bhang (Carrier, 2008; Carrier, 2014). *'Whole areas are cleared using fire to plant bhang.'* Participants highlighted how bhang is equally *'difficult to mitigate'*; *'we still have those remnants of bhang, and we are clearing them every year.'* However, *'this is a forest, so seeds disperse. And every time you have fires, you have fresh shoots of bhang plantations.'* Bhang is an invasive species in Kenya, thus should be considered in the development of a broader invasive species management programme to prevent further degradation in Chyulu Hills. However, efforts to manage bhang at the local-level are likely to be futile if national action fails to control increasing domestic consumption and the number of trafficking syndicates present in Kenya who are trading bhang across international borders.

### 5.3.7. Survival fires

All illegal activities in protected areas are associated with survival fires, referring to fires used for cooking, lighting, and heating. Most participants attributed wildfires to the *'careless'* *'mismanagement'* of survival fires, often *'left unattended'* and *'spreading very quickly'* into wildfires (Mdn: 2). These fires are prominent in the dry season due to increased illegal activity in the parks and the movement of pastoralists to their dry season grazing areas, establishing temporary bomas and lighting fires to *'to keep warm and avoid predators'* as they traverse the landscape. In Chyulu, survival fires are typically associated with *'people who enter the park and spend time chewing miraa'*, or by poachers who light fires in their camps and *'do not do away with it properly'*, *'leaving fires to burn out of control'* as they swiftly flee hunting sites to avoid criminalisation.

Survival-related wildfires often spread from community lands into the protected areas ‘*when groups cook and roast meat*’, ‘*meet for discussions*’, and ‘*warm themselves during the cold season*’, leaving fires unattended. Additionally, a large percentage of the population - up to ‘*100% of the communities*’ in certain areas (e.g., around Shirango and Kamungi conservancies) - use open three-stone-stoves for cooking. ‘*It is an open fire-oriented cooking method and is highly energy consuming, requiring a lot of fuel to cook a small amount of food.*’ While these fires often ‘*spread out of control*’ and cause wildfires, it is their indirect impact on the environment which is of greater concern. The harvesting and production of firewood and charcoal to meet the growing demands of the rural poor population have accelerated ecological degradation, biodiversity loss, and wildfires within the protected areas. Participants advocated for attaining coal-energy cooking stoves to mitigate these challenges – ‘*maybe that is something we should look at in the future.*’



**Figure 9.** Rangers and NGO staff fighting a wildfire in Chyulu Hills National Park believed to be caused by illegal herders scaring off predators. Tsavo Conservation Area, 2022.

### 5.3.8. Human-wildlife conflict

Human-wildlife conflict is an extremely multi-faceted challenge in TCA, both a symptom and driver of ecological degradation and livelihood vulnerabilities across multiple spatiotemporal scales, and a direct and indirect cause of wildfire. Fires ignited as a nightly routine for security reasons, mostly to

*'scare off wild animals', 'keep elephants away from homesteads', and provide 'night herders vision to be able to spot predators', were identified as leading causes of 'large bushfires'. Participants were particularly concerned over the 'traditional belief' that lighting elephant dung releases a 'smell that repulses elephants'. An increasing number of farmers are spreading ignited elephant dung across their farms and 'leaving it to burn overnight when people go to sleep' to mitigate large nighttime crop raiding events. Because of its 'high lighting potential', it is difficult to extinguish once ignited, thus resulting in large uncontrolled wildfires. Fires are also used to 'chase away wildlife. [...] This is the easiest and most traditional way to mitigating human-wildlife conflict.'* However, *'if just a small piece of fire falls on dry grass, then it automatically becomes wildfire.'* Increasing incidences of human-wildlife conflict across TCA have driven local communities to retaliate against park officials, burning their own pasture *'to make sure there is no pasture left for wildlife in their ranches and farms.'* *'They are basically saying 'if you allow wildlife to come and feed on our pasture, we will burn the pasture, so elephants and other species don't come to our farms'.* However, this is accelerating rangeland degradation, imposing forms of habitat compression on the protected areas and, in-turn, increasing inter-specific competition between humans and wildlife for natural resources, thus reinforcing a positive human-wildlife conflict feedback loop.

However, many participants did not extrapolate a connection between human-wildlife conflict and wildfires: *'fires are not an issue of discussion. Normally it is about human-wildlife conflict.'* Instead of focusing on wildfires, they are looking for *'mechanisms to mitigate human-wildlife conflict'*, such as the creation of *'beehive fences along park fences'* to prevent wildlife crossing into community lands. Such disconnection between human-wildlife conflict and wildfire challenges will likely exacerbate both issues in the future. For example, given that the uptake of modern beekeeping technologies is limited across TCA, mitigation measures that promote honey production might increase future wildfire risk.

An increasing number of 'community-based' CSR projects are focusing on mitigating human-wildlife conflict, such as establishing compensation schemes to alleviate some of the challenges of living with wildlife. However, schemes are inconsistent across the landscape; compensation schemes do not cover all communities or species, for instance only covering livestock deaths from depredation rather than crop raiding. Additionally, there is limited discussion over the systemic issues driving increased conflict, as well as their long-term impacts, such the migration of farming communities to high altitude savanna-forest transition areas that surround highly flammable plantation sites.

### 5.3.9. Cultural and spiritual beliefs and communication

*'Fires are strongly associated with culture, beliefs, and traditions. It is very rooted in the hearts of the people.'* Participants expressed how *'cultural beliefs are normal around the world – clear and burn, clear and burn.'* However, *'this was a very scientific in a different landscape in time. It is not practical now.'* And *'nowadays, some of those cultural beliefs – scientifically you cannot prove.'* Participants reiterated the challenges they are facing regarding the specific belief that *'if you burn the forests,' 'the gods will release rain to put out the fire.'* This idea that *'once fires burn' - 'not just burn, but PROPERLY burn' – 'rains arrive'*, is believed to remain *'deep-seated in the hearts'* of many agricultural Taita and Kamba communities, resulting in large wildfires across TCA's highlands and widespread environmental degradation.

Historically, these rain ceremonies took place at the end of the dry season in high altitude forests across Taita Hills, *'communicating with people down the hill that rains were coming.'* Cultural norms governed these practices, such as *'cautiously use firebreaks'* to prevent deforestation. However, without these norms and increasing incidences of wildfire, participants contemptuously referred to this tradition as a *'miracle belief'* used to justify *'people just heading into the parks and burning'*. This belief was likely informed by natural seasonality dynamics, such that agricultural fires are typically lit in the LDS to prepare land ready for the wet growing season. While *'they thought their burning brought the rain'*, it is in fact, when *'the rain season starts.'* Rain ceremonies are predicted to increase over the next decade as multi-year drought conditions intensify livelihood vulnerabilities. However, when preceded by *'failed rains'*, *'that's degradation of the land – the whole environment, completely.'*

### 5.3.10. Cigarettes and careless behaviour

Wildfires are largely attributed to the careless behaviour of herders, traders, visitors, and general members of the communities across all land-use types, mostly due to careless cigarette butt disposal (Mdn: 2). Cigarette-induced fires were less attributed to Kamba communities due to a lack of vegetation across their settlement areas, rather they *'burn refuse'* in residential estates that directly border the park. On the other hand, *'some of the herders who enter the conservancies are serious smokers'*, particularly the wealthy cattle barons who have no ancestral ties to the land, thus drop cigarettes as they traverse the ranches.

A single cigarette butt was purportedly the cause of *'the last major fire'* in Tsavo in 2020, based on its point of ignition being along the Mombasa Highway. The (semi-)arid Tsavo lowlands are one of Kenya's, and the region's, main transit routes, hence *'people just carelessly throw cigarettes out of their vehicle windows'* and *'cigarettes quickly light fires'*. These challenges tend to be concentrated in Tsavo because Chyulu Hills *'is not connected to the highway'*, yet tourists have been observed to

*'come to Chyulu and throw cigarettes'*, despite it being a punishable offence under the 2016 Forest and Conservation Management Act<sup>33</sup>.

Participants shared how *'cigarettes are frequently bought in market centres distributed along the highway'* where they are often sold at cheaper prices. This is likely related to the Kenyan government's acceptance of the WHO Protocol to Eliminate Illicit Trade in Tobacco Products to address the country's growing illicit tobacco industry, introducing higher taxes on smoking products. However, this has made legal cigarettes unaffordable to most of the population, resulting in >70% of Kenyan consumers buying counterfeit goods from neighbouring Tanzania and Uganda (Roberts, 2021). These activities tend to be concentrated in border towns, including those situated along the southern boundaries of Kajiado and Taita Taveta counties. Given weak local enforcement and the failure of the East African Community (EAC) to enact an Anti-Counterfeit Bill to enhance regional cooperation and legally come down on the illicit trade (Kieyah, Shibia & Gitonga, 2014; Ross, 2017), cigarette-related fires are likely to increase across TCA.

### 5.3.11. Agrarian resistance

Participants expressed a range of beliefs as to whether wildfires observed across TCA are a form of everyday agrarian resistance, political protest, or arson (*Mdn: 3*). This is likely representative of their own personal experiences regarding culturally and institutionally embedded forms of violence, subjugation, and exclusion (e.g., members of marginalised communities), or exposure to feelings of injustice and resentment (e.g., conservation employees working with local people). For example, ethnolinguistic identity had a significant influence over whether an individual held these beliefs, with members of Bantu and Nilotic communities more likely to agree or express uncertainty over the connection between agrarian resistance and wildfire events, and Cushitic communities more likely to (strongly) disagree (Table 11). While the Waata are a marginalised Cushitic community in Kenya, the individuals surveyed in this study have been absorbed into the Marungu Hill Conservation Association, thus are less likely to resist conservation (Kassam & Bashuna, 2004).

On the other hand, park authorities who primarily identified as Bantu and Nilotic are at the forefront of dealing with these challenges. Representatives from conservation NGOs highlighted how, in recent years, *'landscape conflict due to the exclusion of people from the parks'* has resulted in large, intentionally ignited, uncontrolled wildfires across TCA. With limited adaptive capacity to respond to compounding socioeconomic-climate challenges due to processes of biocultural hysteresis, fires are increasingly lit by members of the communities as an act of resistance against government agencies

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<sup>33</sup>2016 Forest and Conservation Management Act, Article 64: Except under a licence or permit or a management agreement issued or entered into under this Act, no person shall, in a public or provisional forest— (d) smoke, where smoking is by notice prohibited, or kindle, carry or throw down any fire, match or other lighted material; (j) set fire to, or assist any person to set fire to, any grass or undergrowth or any forest produce.

who they feel *'stand in the way of their livelihoods'* and *'value wildlife more than their livestock'*. *'Until you empower the communities, they will not stop burning the park.'* Thus, wildfires increasingly symbolise the *'unstable political situation'* that characterises the conservation area, particularly in light of recent land sub-division reforms. In some instances, *'local political and community leaders take advantage of the unstable situation and incite local livestock herders to get what they want'* - for their own political-economic expediency.

When park management changes hands, existing clandestine agreements between individual authorities and members of the local community are often quitted, hence the removal of herders, hunters, resource harvesters, and charcoal burners from the parks results in more *'retaliatory fires'*. Since *'their intention is to cause damage, they burn strategically'*, having *'more of a negative effect'* on the environment. These fires are mostly concentrated between May and August in the protected areas when resources are scarce across community lands, with their frequency and intensity exhibiting a *'positive relationship'* with *'changes in wardens and officers in charge of the management system'* and subsequent interventions. *'Retaliatory fires'* were also attributed to farming communities who have had their crops raided by elephants and received no compensation.

*'One of the main issues with addressing illegal activity is the lack of evidence. When it comes to fire, there are so many allegations, but now, the question is, do we have sufficient evidence? [...]* Retaliatory fires – we get those reports. But much of them are more about perception, because proving it will not hold water.' But for illegal activity and burning, *'it is an offence, and we will arrest you.'*

Increased security operations in the parks and well-enforced legislative criminal procedures can directly reduce illegal activities across TCA, for example by developing surveillance capacities and increasing the number of ranger patrols. However, *'when people are chased away from food, wood harvesting, or collecting miraa inside the protected areas, they retaliate by lighting fires.'* *'Whenever bushmeat poachers are threatened with arrest, they light a fire.'* *'Charocal burners who illegally encroach burn intentionally when rangers remove them from the protected areas.'* When there is pasture scarcity and *'rangers do not allow'* or *'force'* herders out of the parks, *'they light fires just to create malicious damage.'* With regards to external grazers, *'fire is not an issue for them. They often light fires and do not follow procedures. So, when they are chased away from the ranches by scouts or their livestock are impounded by the KWS, they will retaliate.'* When a member of the local community *'is arrested for illegal activity, [...] arsonists light fires out of revenge or retaliation, especially when they know'* the individual.

These accounts provide an interesting insight into the future effectiveness of protected area-based conservation where increased militarisation tactics are used in response to illegal activity. While

paramilitary conservation organisations such as the KWS<sup>34</sup> and KFS are key mandates in disaster management and (National Disaster Management Policy, 2010) (Kinoti, 2019), therefore, are often revered for their services in times of natural disaster (e.g., responding to large wildfire events) (Dutta & Simlai, 2022), their use of militarised force against perceived threats reinforces environmental legacies inherited from their former colonial power (Jones, 2021), thus risk inciting local uprisings and acts of rebellion (Massé & Lunstrum, 2016); causing the very crises they strive to mitigate.

## 5.4. Fire policy and management

Considering TCA's complex pyro-geographic landscape described in sections 5.1, 5.2, and 5.3, this section explores participants' experiences of and attitudes towards fire management, including current fire suppression, and understandings of and opportunities for future alternative bottom-up approaches. As such, this section directly addresses the main aim of this thesis and attempts to overcome structured inequalities in the production of knowledge on 'community-based' fire management (Chapter 1 and Chapter 2).

### 5.4.1. 'Paper plans'

Unprescribed fire was identified as a main management priority in the TCA Management Plan 2008-2018 due its perceived negative effects on Acacia-Commiphora bush/grasslands (KWS, 2007). The plan laid out three main action points: (i) raise awareness of fire risk and the ecological impacts of unprescribed fire, including the implementation of fire warning signs and raising community awareness of fire prevention and best practices; (ii) improve management response and firefighting capacity, including the establishment of fire preparedness guidelines in liaison with the KWS Rapid Response Unit (RRU) (by December 2008), a TCA RRU, and fire watchtowers; (iii) implement improved and coordinated fire management measures by carrying out a pilot prescribed burning programme (by September 2008) to improve ecological health and achieve conservation objectives.

However, the management plan is *'just a document. [...] People do not stick to these plans.'* The plan states that *'people should prepare for fire, but there are no defined guidelines'*. *'At the moment, there is no wildfire management plan'* or *'common centre for wildfire'*. The TCA RRU was never instituted; the TTWCA are currently *'in the process of establishing a Rapid Response Unit that specifically focuses on wildfire management.'* Nor was the pilot burning project. None of the participants, including protected area managers, had ever heard of the project. *'This has never been implemented in*

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<sup>34</sup>KWS rangers attend the KWS Law School Enforcement Academy to undergo training in military operations. The KWS was established in 1989 as a state corporation with a paramilitary training wing for anti-poaching activities, including training ranchers in drills for conservation. The Law Enforcement Academy was established in 1990 and relocated to Tsavo West National Park in 2011. Today, the academy is overseen by chief instructors and acting commandants, mirroring a military structure, and trains personnel in a range of cross-sector security-oriented duties. In recent years, international NGOs (e.g., IFAW and AWF) have been involved in updating the curriculum to include operations for addressing human-wildlife conflict and wildlife crime and trafficking.

*the landscape. People want to move away from using fire to manage vegetation in Tsavo'. The pilot project was planned for implementation in 2008. However, 'the new 2013 Wildlife Conservation and Management Act made no provisions for fire. There have also been some amendments made to the 2013 Act in 2019, like higher prosecution for fire use.'*

Since the publication of the TCA Management Plan, the AET released the Amboseli Ecosystem Management Plan 2020-2030 which aims to develop a fire preparedness and response strategy to 'guide stakeholders in fire prevention and suppression' (AET, 2020). This expands upon earlier plans that focused on the enhancement of firefighting operations and capacity building (AET, 2008), rather than considering alternative approaches that proactively and holistically address the wildfire paradox. Similarly, the LUMO Community Wildlife Conservancy Management Plan (2022-2027) identifies charcoal and firewood harvesting as key threats to Commiphora grasslands and woodlands but does not include any additional details on fire management.

#### **5.4.2. Inheritance: fire suppression and prevention**

*'A fire suppression and response model - mostly firefighting - has been the dominant model in the past and remains the dominant model in the present' (Mdn: 2).* Fire suppression is generally perceived as an effective strategy (Mdn: 2), partly by reinforcing anti-fire sentiments [ $p = 0.003$ ;  $\rho = 0.196$ ]. Individuals employed by religious organisations expressed the greatest conviction over this belief. Given that most of these individuals were Waata people<sup>35</sup>, this could be attributed to the observed negative effects of wildfire on their main economic activities (e.g., mobile livestock herding and forestry, Table 10), or the portrayal of hell as 'the fire' in the Quran<sup>36</sup>. Government agencies expressed greater uncertainty over its effectiveness, likely due to their exposure as first respondents to wildfire events in the protected areas.

Considering most participants perceive savannas as degraded forests, positive attitudes towards fire suppression were also related to its effectiveness in promoting tree growth [ $p = 2.706e-07$ ,  $\rho = 0.342$ ]. *'The standard of fire suppression which has dominated in the last couple of years is a good standard'*, believed to have reduced the frequency of wildfires across TCA (e.g., ranked 1/10). And observed increases in wildfire intensity [ $p\text{-value} = 6.35e-05$ ;  $\rho: 0.267$ ] and severity [ $p\text{-value} = 0.008$ ;  $\rho: 0.191$ ] are a result of climate change (Mdn: 2, 1, respectively), rather than policy. Since decision-makers typically do not attribute wildfire challenges to ineffective, or rather, a lack of policy and management, they are unlikely to prioritise developing fire-specific management strategies to

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<sup>35</sup>Afro-Cushitic Sunni Muslims who have a complex and problematic relationship with the Kenyan state and wider Christian public (Ndzovu, 2022).

<sup>36</sup>For example, 'and fear the Fire which is prepared for the disbelievers.' (Quran 3:131); 'They will long to leave the Fire, but never will they leave there from; and theirs will be a lasting torment.' (Quran 5:37).

address the wildfire paradox. This also creates challenges for advising these actors when resources are limited:

*'Unless you change our perspective, we think that fire is a threat. We have never advocated for the use of fire, and unless we get new information that advises early burning or intentional burning for management, when fires occur, we will suppress them. This could change in the future with an increasing understanding of fire as being somewhat effective in land management.'*

While only 12% of participants believed that fire suppression is ineffective in wildfire management, most participants agreed that suppression policies have contributed to an increase in large wildfire events due to the accumulation of flammable biomass, particularly following higher rainfall periods [ $p = 3.737e-07$ ,  $\rho = 0.338$ ]. This association was stronger amongst participants who perceive savannas as intrinsically valuable and ecologically distinct from forests [ $p\text{-value} = 0.001$ ,  $\rho = -0.233$ ], as well as those who do not perceive fires as having any beneficial role in maintaining an open-canopy landscape [ $p\text{-value} = 7.526e-06$ ,  $\rho = -0.297$ ]. Contrasting beliefs over the effectiveness of fire suppression policies support the results displayed in Fig. 11., and are also partly influenced by where participants attribute blame, for example to human causes such as agrarian resistance [ $p\text{-value} = 0.001$ ,  $\rho = 0.228$ ], rather than natural phenomenon [ $p\text{-value} = 0.008$ ,  $\rho = -0.180$ ] (i.e., greater effectiveness in mitigating human- rather than naturally-induced wildfire events; the latter generally not perceived in TCA). Furthermore, ethnolinguistic identity and the presence of REDD+ had a significant influence over how the relationship between fire suppression policies, fuel accumulation, and savanna fire ecology was perceived by participants. Participants within the Chyulu Hills REDD+ project area were more likely to agree that fire suppression policies have resulted in higher fuel loads and consequent wildfires, at the same time as (strongly) disagreeing with the notion that fires are beneficial in managing savanna ecosystems. They also agreed that the current suppression model considers traditional fire-use practices and knowledge (Table 11). 63% of these participants were agricultural Kamba peoples who are members of the Kibwezi Forest CFA, hence are exposed to persisting (inter)national anti-fire sentiments through their close working relationships with conservation agencies and organisations (Croker, Woods & Kountouris, 2023a). This is further evidenced in the data, such that Nilotic-speaking peoples within the project area were almost all KWS staff and rangers who typically advocated against fire as a land management tool. Meanwhile, members of Duruma, Giriama, Taita, and Waata communities living outside the Chyulu Hills REDD+ project area and not part of a CFA were more likely to disagree with the notion that anti-fire suppression narratives are representative of local fire-use knowledges [ $p = 4.44e-11$ ;  $\rho = 0.426$ ]. These results support evidence showing that the subsumption of local communities into centralised resource management structures and their long-term exposure to external influences can drive processes of biocultural hysteresis and, in-turn, reinforce colonially inherited environmental

degradation narratives from the bottom-up (Kull, 2002; Butz, 2009; Kamau & Medley, 2014; Kneas, 2016).

Despite recognising the ineffectiveness of fire suppression in managing fuel loads, participants who stated that ‘other policies’ are effective in wildfire management only highlighted aspects of the existing suppression model, rather than considering normative scenarios. These included: education and awareness programmes that limit local burning practices; community mobilisation protocol in firefighting; the creation and expansion of firebreaks; increased security operations within the protected areas to limit illegal activities (incl. shutting down ‘*illegal honey communes*’); and existing fire regulations laid out in the 2016 FCMA and 2013 WCMA. One participant stated ‘*anti-smoking campaigns*’, addressing a broader systemic challenge related to fire. Few participants, mostly from local communities, broadly stated traditional and cultural fire policies mandated by the area Chief (e.g., rules of clearing land). Since the position of Chief became an ‘*office of the President*’ under the colonial government, these regulations now reflect existing suppression policies. Limited or no acknowledgement of normative strategies beyond fire suppression further evidences processes of biocultural hysteresis and a loss of traditional knowledge. It might also infer that decision-makers are more likely to adopt exploratory fire prevention approaches in the future, including fuel reduction strategies such as vegetation harvesting and grazing schemes, and carbon-based PES schemes to financially benefit from woody fuels.

Preferences towards exploratory fire suppression approaches rather than alternative normative scenarios might also have been influenced by the launch of the Kenyan government’s 10-year National Landscape and Ecosystem Restoration Strategy (2022) to achieve commitments made under the African Landscape Restoration Initiative (AFR100). This strategy aims to reduce GHG emissions, stop and reverse deforestation, and restore 5.1 million hectares of deforested and degraded landscapes, thus demanding that 1.5 billion trees are planted annually across public, private, and community lands to achieve 30% tree cover by 2032. Consistent with the rise of carbon-based PES schemes globally (Chapter 2), ‘community-based’ CSR projects in Kenya are increasingly prioritising the expansion of fire-resistant woody species (often exotic TASSs) that limit the growth of fire-adapted herbaceous species, further reinforcing Clementsian views of ecological succession and the importance anti-burning policy.

Aligned with the environmental stress-gradient hypothesis, these projects are accelerating woody encroachment across mesic and (semi-)arid savannas in different ways. Across the mesic transition, fire suppression is accelerating the net competitive effect trees exhibit on sub-canopy grass production, instigating a regime shift (Dohn et al., 2013; Pringle et al., 2016). Across the arid transition where grass competition can significantly reduce the growth and demographic transition of tree species, direct (e.g., afforestation) and indirect (e.g., fire suppression) management interventions

that reduce total grass biomass, density, and diversity, are favouring the expansion of woody species. This is notably the case where overgrazing has promoted the growth of woody increaser species at the expense of productive decreaser species, accelerating ecosystem degradation (Riginos, 2009).

### 5.4.3. Building on the basis: current fire management

Three main themes describing current fire management operations emerged in the interview data, largely akin to several of the fire perception categories used to analyse questionnaire data: (i) fire management systems (incl. command, communications, community involvement, education and community sensitisation, wildfire data and monitoring, and compensation for wildfire damages); firefighting activities (incl. firefighting operations, command, and community participation); and firefighting capacity (incl. firebreaks, fuel reduction strategies, infrastructure, equipment, trained personnel). This section sets out to provide a deeper understanding of the current fire management and policy domain in which future approaches might be developed.

#### 5.4.3.1. Fire management systems

Fire management was understood as a reactive strategy to wildfires after they have broken out, mostly led by conservation agents. There was greater uncertainty as to whether interventions are proactively applied before<sup>37</sup> and after<sup>38</sup> fire events (*Mdn: 3*), and whether local communities are involved or cooperate in fire management (*Mdn: 3*). Considering the circularity of fire management, such that post-fire management interventions feedback to pre-fire activities and enabling conditions, actions taken at one stage ultimately strengthens or weakens the overall management approach and capacity to address wildfire challenges (e.g., see Tedim, Leone & McGee (2019), ‘Shared Wildfire Governance framework’). For example, post-fire assessments of losses and immediate needs, and investigations into the causes and impacts of wildfire, can technically inform the development of a locally appropriate fire management approach and alleviate immediate and long-term socioeconomic and ecological vulnerabilities. Additionally, data collection and monitoring protocols that include both pre- and post-fire information can be managed and analysed together to inform adaptive management strategies based on real-time observations.

*‘It is mandatory to report on fires on a daily basis’ and ‘you must compile a report on a fire event within 24 hours of the fire being extinguished to send to the Nairobi Headquarters’.* However, only

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<sup>37</sup>Pre-fire interventions include: ignition avoidance (e.g., fuel reduction, firebreaks, community sensitization and education programmes, increased park security operations); data collection and hazard identification (e.g., formal ecological monitoring framework); emergency planning (e.g., early warning signals); and sharing information on fires.

<sup>38</sup>Post-fire interventions include: investigations into causes of wildfire; assessment of losses and immediate needs (i.e., imminent post-fire threats to human lives and ecological systems); data collection on hazards and impacts (incl. social, ecological, and economic factors) to inform technical recovery processes and future management plans.

information on date, time, and GPS location are recorded, and there is no central database to upload information. Formal investigations into the causes of fire and pre- and post-fire conditions are subject to long bureaucratic procedures and require sustained inter-group collaboration. The latter reportedly limited by competition for donor funding and lack of transparency within the partner network. Without social-ecological data, post-incidence reports written to inform future fire management are mostly ‘fantasy documents’; they do not address the root causes of, enabling conditions, and long-term solutions to the disaster, but instead are published to prove that authoritative actors have ‘done something’ about it. Hence, are just *‘put on the shelf’* (Birkland, 2009).

In the event of a wildfire, 68% of participants perceive there to be crisis communication (e.g., via WhatsApp channels) and firefighting protocols in place to respond to the event (Mdn: 2). However, they expressed greater uncertainty as to whether this response strategy is well resourced and coordinated between park authorities and local communities (Mdn: 3). Participants typically agreed that *‘there is no is no coordinated management approach or common command on wildfires,’* rather fires are treated as an emergency or disaster, rather than as an issue of management. The KWS are viewed as being responsible for coordinating fire management across TCA, however different agencies have their own command system (e.g., KFS conservator who declares the fire season), and protected areas are developing individual ecosystem management plans. WhatsApp channels are utilised as *‘forums for rapid response’* across multiple actors (incl. government agencies, NGOs, and community Chiefs) to share information and communicate on wildfires *‘once they occur’*. However, this is inconsistent across TCA (Mdn: 3) and not necessarily available or understandable to local communities (Mdn: 3). Aligned with the results presented in Chapter 2, community participation is mostly limited to local elites who communicate with park agencies and possess some authority over determining operational rules-in-use, or to firefighting activities where local people provide most of the voluntary labour force and/or are temporarily employed to carry out labour-intensive tasks that *‘don’t require any skills’*, such as constructing firebreaks. In this regard, local communities do not receive compensation for fire damages or injury incurred whilst firefighting (Mdn: 5), whereas employed rangers, particularly from higher revenue-generating protected areas, are believed to be provided with medical insurance:

*‘You will be going behind bars and get fined if you light a fire. But if you're affected, there is no compensation. Across Kenya generally, hearing of cases where people have been compensated for fires, no.’*

Participants expressed that they *‘need a coordinator’* and were optimistic about the establishment of a RRU in TCA focusing specifically on wildfires, where *‘one commander will take charge of the command centre and all fire operations. This will create a uniform communication network’* and assist in *‘procuring aerial and other resources’*. However, sixteen-years on from when the TCA RRU and

fire preparedness guidelines were set to be established (KWS, 2007), and two-years on from these interviews, there are no signs of a TCA RRU or fire guidelines. Participants shared how fires burn every year, but *'the last major wildfire was in 2020'*. In the wake of this event, (inter)national media attention raised the issue of fire management as a priority area in political agenda. However, aligned with broader trends in media reporting, crisis management action, and long-term policy solutions (Nikolakis & Roberts, 2022), *'catastrophic fire events and seasons are usually followed by blame games and reactive and short-lived bursts of activity by governments and organisations'* (Tedim, Leone & McGee, 2019, pg. 193):

*'Wildfires are on the news for a period of time, and everyone wants to create plans for the future. But as soon as that wildfire is over and it leaves the news, it just forgotten about. And that's a global problem with this kind of wildfire.'*

Considering the natural *'wildfire cycle'* described in section 5.1, participants expressed how they know in advance when pre-fire mitigation strategies should be implemented, including *'preparing fire breaks', 'training firefighters', and 'implementing education and awareness programmes with communities'*. However, *'there are no resources for fire management. The government and corruption have hollowed out the system.'* Consistent with global trends where limited resources are continuously redirected towards waging *'war on fire'*, rather than into pre- and post-fire management actions, Kenya has fallen into a *'firefighting trap'*, leaving little or nothing to invest in proactive management activities that actively address the underlying social-ecological causes of wildfire (Tedim, Leone & McGee, 2019). *'We are very reactive. We just go with what we think works. We're not sufficiently organised to deal with these things.'* *'After the situation the teams disintegrate, and everyone works on their own.'* The availability of resources, however, does not necessarily translate into increased proactiveness. Myopic preferences among citizens and policymakers have reinforced *'quick-fix'* response strategies. For example, large-scale firefighting increases the perceived political salience of wildfires, thus the public are more likely to view the government favourably for addressing these challenges (Sheffer, Loewen & Lucas, 2024). Meanwhile, long-term policy solutions often generate benefits that are intangible or less visible in the short-term and are realised under successive governments. Hence, they might be viewed by the public as inertia to act, thus presenting a strategically disadvantageous strategy to policymakers who are seeking to maximise their support base.

Participants highlighted how *'communities understand the traditional ways used for mitigating fire'*. Yet very few expressed that *'there is a big opportunity'* to include local people in wildfire management, and this was mostly in reference to top-down interventions seeking to maximise local support and limit subsistence-based fire-use:

*'In terms of fire management, we need to dispel that burning notion among the communities through teaching and education. We need to bring them to the light that these fires are destructive to wildlife. We need to enlighten them'.*

For example, 65% of participants agreed that park rangers support wildfire management across the community conservancies, ranches, and community lands (*Mdn: 2*), mostly because fires *'end up crossing to our side'*, and unless you *'support the communities, whatever we are doing on our side can only be temporary.'*

Forty-four percent and 26% of participants (strongly) agreed that park rangers and local communities receive some level of training in fire management, respectively. Greater conviction over the belief that rangers receive training might be explained by the formal versus informal nature of training opportunities. For example, it's far more perceptible when rangers (do not) attend training courses ran by the KWS Law Enforcement Academy or the TTWCA and partner organisations, than when members of the local communities optionally attend *'ad-hoc'* barazas mostly run by government agencies to *'educate communities'* on the *'importance of wildlife'* and *'the parks'*, to *'raise awareness of fire'* and their *'consequences and effects'*, and to *'remove negative perceptions'* of the KWS. Additionally, the importance of training and continuous learning opportunities for ranger workforces have received increasing international attention since the adoption of the Kumming-Montreal Global Biodiversity Framework which aims to achieve '30 by 30' (Duffy et al., 2019; Büscher, 2024). As such, ranger training or recognition days receive a lot of media attention in Kenya, attracting a lot of (inter)national investment and significantly influencing government agenda (Behr & Iyengar, 1985). Given this inflow of investment towards conservation and, more broadly, security, the government are more likely to scale-up management opportunities for rangers which align with national objectives, rather than for local communities where intercultural-exchange might lead to discursive approaches in fire management. However, with regards to firefighting, participants shared how training *'has not been intensive, just the basics'* with a couple of rangers from each conservancy.

Community education and sensitisation schemes run by conservation agencies and REDD+ are believed to have an important role in sharing *'knowledge on wildfire management'*, educating communities on *'the disadvantages of fire and the benefits of the forest'*. Participants shared how this is beginning to take effect in the ranches because *'some fires spill over into the ranches where people keep their livestock – one of the mainstream economies in the area.'* So, they are beginning to take *'issues of fire'* more seriously. Additionally, a local Chief shared how he *'would like REDD+ to be implemented here'* because it is *'good at opening the eyes of the community to conservation of landscapes and resources'* and *'in punishing those that destroy it.'* These results show the success of carbon-based PES and community education schemes in reinforcing anti-fire sentiments among diverse actor groups, resulting in a loss of social, cultural, and intellectual legacy in resource

governance and, therefore, limiting opportunities for future CBFiM approaches (Pearson, Jackson & McNamara, 2023).

#### 5.4.3.2. Firefighting

Fire management is predominantly reactive across TCA, mostly consisting of firefighting operations (Mdn: 2). Participants who perceived fire management to be reactive also understood it to be proactive [ $p = 1.31e-06$ ,  $\rho = 0.316$ ]: *'on the aspect of proactiveness, we have daily patrols of the park, and the moment smoke is sighted, a team is dispatched. So, the issue of fire is taken holistically.'* *'Another aspect of proactive management is capacity building in terms of training personnel. Staff from the parks are trained in firefighting, 'like backburning' – 'where you burn the front' or 'against the fire to act as a break'.* *'Another preventative measure would be boreholes and water points', so there are 'water sources which aid in putting out the fires.'* *'One of the main proactive measures is firebreaks', so 'with very well-established firebreaks done by tractors, the approach is changing from being reactive to proactive.'* While these activities might proactively strengthen firefighting capabilities, they do not extend beyond the current suppression model. Thus, prioritising what is perceived to be 'proactive' in this context risks reinforcing the 'firefighting trap' and associated social-ecological challenges (Essen et al., 2023).

The 2014 National Emergency Response Plan set out Standard Operating Procedures (SOPs) to establish a clear command in disaster response and outline how resources should be allocated (NDMU, 2014). County Fire Departments were identified as the heads of firefighting in their jurisdictions, providing services (incl. equipment and trained personnel) and building capabilities to fight urban, rural, and wildland fires in alignment with other relevant laws and regulations<sup>39</sup>. However, *'equipment is kept at headquarters and can be slow to respond.'* *'It is not strategic'* and their management activities do not consider fire risk in the ranches and conservancies.

Fires are treated as emergencies, so there is little in the way of risk reduction activities. Because there is *'no management or policy guidance for responding to fire, we use instinct.'* *'When we receive information about smoke', 'the current administrative system'* is used to establish an Incident-Command System to coordinate the response strategy – where local chiefs and park wardens communicate to mobilise people and resources. *'In locations where there are emergency response committees, they assist in sharing information, but they have no tools or knowledge.'* This chain of command describes how information is communicated, rather than a strategic firefighting response system. Response is *'informal'* and *'ad-hoc'*, such that when fire breaks out, information is shared with neighbouring partners so that they can *'collectively pull resources and act in the shortest possible*

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<sup>39</sup>Relevant laws include: Grass Fire Act, Cap 327; Kenya Forest Act 2005 (now the Forest Conservation and Management Act 2016); The Agricultural Act, Cap 318; Wildlife Conservation and Management Act 2013.

time', appointing *'ad-hoc coordinators'* to lead the response and coordinate multiple actor groups across large geographical areas: *'fighting fires in Chyulu was uncoordinated and doesn't work as a strategy. It involved many partners including NGOs, and the county ends at the top of the hills in Chyulu, one side is Kajiado, the other is Makeni'*, increasing the number of responsible and/or interested parties requiring coordination.

The TTWCA have *'a risk management policy that recognises the risk of fires'*, and in 2023, launched a community disaster and risk management plan under the Sustainable Management of Tsavo Landscapes project (see USAID, 2023) to set out prevention and mitigation measures for common risks. However, recognition of wildfire challenges has not, to date, translated into a *'wildfire management policy that cuts across all members.'* TTWCA representatives shared that *'with climate change, the world is burning. We need a strategic management approach. The reason why more than 30,000 acres burned is because of poor coordination, there is no one in charge of firefighting.'*

Since firefighting is a *'collective responsibility'*, there is *'a lot of the support from the communities neighbouring the park'* who volunteer in extinguishing wildfires when they exceed the rangers' capacity (Mdn: 2). However, the willingness of local communities to engage in firefighting is variable and highly dependent on four main *'perception pathways'*: the perceived immediate risk of fire on the community's primary socioeconomic and livelihood activities; the perceived long-term risk of fire on natural resources which the community depend upon (e.g., *'the effects of fire on the ecological balance in the region'*, including water sources, forests, and pasture); the perceived direct and indirect benefits of engaging in firefighting; the perceived direct costs of engaging in firefighting. Engagement based on immediate risk tends to be concentrated among neighbouring agro-pastoral communities where wildfires present high economic and food security challenges, particularly under prolonged drought conditions. Engagement based on long-term risk largely depends on whether and to what extent the communities already have access to natural resources (e.g., property rights). For example, participants highlighted how *'through CFAs, communities assist in managing wildfires because they are aware of the benefits the forest provides.'* Engagement based on the indirect benefits received through firefighting was mostly attributed to the *'benefits the community get from the KWS'*, such as *'accruing benefits from conservation'* in their jurisdiction. On the other hand, engagement based on direct benefits was mostly attributed to incentives – *'bread and milk'*:

*'When communities are invited to join the firefighting teams, bread and milk are given out. You realise that no one will work without a fee'. 'Unless incentivised, there is less willingness to fight fires, because if they didn't start the fires, they don't see it as their responsibility.'* This is especially true in *'areas where people are hungry. They will rarely work for free. The voluntary aspect is not there because of the economic realities or challenges we are facing in this region.'*

Participants emphasised the importance of voluntary assistance, only providing communities with immediate tangible benefits, rather than financial incentives. *‘If you pay members of the local community to fight fires, they will be burning’*. For example, where the direct financial benefits of igniting uncontrolled wildfires in the parks and engaging in subsequent firefighting operations outweighs the risk of being caught and penalised for igniting the fire in the first place, total number of fires are predicted to exponentially increase. Considering high unemployment and poverty rates across TCA, this could *‘style of payment’* could result in rapid, large-scale ecological degradation. Instead, providing food during the event is viewed as a strategy to increase local support for conservation in times of environmental and socioeconomic hardship. Coupled with the immediate risk of fire across neighbouring farms, this can increase willingness to participate in firefighting. On the other hand, as drought conditions worsen under future climate change and subsistence-based communities are threatened with critical food insecurities, the provisioning of food and drink might alone provide an incentive to burn.

Engagement based on direct costs was mostly related to the risk of death during the activity. Since most members of the communities have received no formal training and have no equipment or protective gear – mostly using traditional methods including tree branches, sticks, leaves, and whistles to communicate to one another - *‘firefighting is very risky. It can consume peoples’ lives’*. Participants recommend training members of the community alongside KWS rangers and community scouts *‘to give them the knowledge and skills to effectively fight fire’*.

#### 5.4.3.3. Firefighting capacity

Ranches, conservancies (*Mdn: 4*), and local communities (*Mdn: 5*) are ill-equipped to manage wildfires, lacking basic resources, funding, and trained personnel (*Mdn: 5*). Most participants, particularly in the Chyulu Hills jurisdiction, also perceived national parks to have limited capacity, in-part due to having no employed fire management specialists (*Mdn: 3*). Each park has a small fire station where firefighting equipment<sup>40</sup> provided by partner organisations (incl. DWST, AWF, Tsavo Trust) is located. While *‘some of the equipment has been upgraded’* in response to the 2020 wildfires, investment into pre- and post-fire intervention measures has not been achieved. Across the Taita-Taveta ranches and conservancies, fire equipment has been distributed to the *‘the eight hotspots’*<sup>41</sup>. However, given the increasing intensity of wildfires *‘fire beaters barely work’*, and there are *‘no water sources to aid in putting out fires.’* The County Government is expected to assist in firefighting by providing fire engines, however *‘there is no water to operate these.’* Participants expressed how

<sup>40</sup> Equipment includes protective gear, mobile towing trucks with water bowsers, fire beaters and flaps *“in many quantities”*, fire rakes, and pickaxes.

<sup>41</sup> LUMO Conservancy and Lualyeni, Mgeno, Choke, Rukinga, Maungu, Kambanga, and Wangala ranches.

efforts to distribute knapsacks and water bowzers across the ranches is futile if *'the issue of water is not addressed first'*. Additionally, access to vehicles required to transport firefighting teams is highly contingent on partner organisations and on receiving financial aid to cover the cost of fuel. To date, this has been informally organised and often ineffective, requiring significant scaling-up to deal with contemporary wildfire challenges.

The establishment of fire warning signs and watchtowers were key strategic aims of the Tsavo Conservation Management Plan (2008-2018). However, they have not been constructed across TCA due to resource constraints. Participants requested that fire warning signs are established in strategic locations *'along the park fences to remind people that now is not the time to burn.'* On the other hand, they expressed how *'man-made watchtowers'* are *'not necessary anymore'* because mobile technologies are used to communicate about fire, rather than ground surveillance.

Fuel reduction strategies and the construction of firebreaks are inconsistent across TCA. Participants shared how firebreaks should be established around existing *'zones used to manage grazing. If each zone had firebreaks, this would prevent the spread of fire'* and *'contain it within blocks.'* Existing roads and patrol routes can also act as fire breaks providing that they are maintained by *'mowing the grass'* using the recently acquired tractor-grader. This grass can also be used to *'make bales stored as dry season fodder'*, thus providing a win-win solution. However, *'there are no resources to maintain firebreaks'* and *'no one thinks in advance about when we will have fires.'* The tractor-grader has *'not been seen creating firebreaks due to a lack of resources' – 'they don't have fuel to fuel the grader.'*

#### 5.4.4. Reimagining fire management

*'The person who controls the fire, controls the ecosystem. When you do not control the fire; you are just fighting it. When you over-protect the landscape, there is a lot of fuel. Then when wildfires occur, they are far more destructive'.*

Participants identified five main alternative fire management approaches, mostly focusing on exploratory scenarios that build on existing management practices to anticipate outcomes ranging from 'business as usual' approaches (e.g., increased fire suppression) to more bottom-up approaches (e.g., fuel harvesting and grazing schemes). Participants did not imagine normative fire management approaches that challenge existing governance structures and norms, thus were prompted to discuss solutions that radically address structural inequalities in resource management (e.g., CBFiM) (Gilbert & Lennox, 2019; Johansson, 2021).

These fire management approaches informed the development of the final scenarios modelled in SAV BN (Croker, 2024) to increase the saliency and relevancy of this research, and the legitimacy of modelled outcomes in the local context (Zorrilla-Miras et al., 2018). The following sections detail participants' perceptions of alternative fire management approaches. Drawing on previous reviews

(Chapter 2) and the contextual challenges highlighted in Chapter 5, key implementation challenges requiring additional consideration are also discussed.

#### 5.4.4.1. General prescribed burning

Regulations for burning vegetation on private and community land adjacent to national reserves were first articulated in the Control of Grasses Fires Ordinance (1941). Since then, different sectors have instituted policies, *‘each imposing penalties for people burning vegetation.’* The WCMA (2013) and FCMA (2016) being the latest to ban fire-use within and surrounding forests and protected areas. As such, *‘there is no permission for fire use in the law for prescribed burning. We have it in our plans, in our technical reports. Burning is there, like early burning, but it is not practiced’* (Crocker et al., 2024). Having no knowledge of the 2008 pilot prescribed burning project, or of increasing international interest in the implementation of SBEA schemes in African savanna-protected areas, most participants did not perceive prescribed burning as a likely fire management approach to manage fuel loads:

*‘In Kenya, you do not find prescribed burning in the form of fire management. It is banned by the government. [...] Proactively, we don’t do fire management.’ ‘There is no knowledge of formal prescribed fire here.’ ‘If you go to Tanzania, they practice prescribed burning to remove unwanted biomass. But we are the ones who suffer because those fires sometimes go beyond their control where firebreaks aren’t active, crossing on to our side.’*

Participants frequently understood prescribed fires as livelihood burning practices, such as those used to achieve agricultural and pastoral land management objectives (Crocker, Woods & Kountouris, 2023a), or as backburns ignited to fight fires. Given that participants strongly attribute wildfires to these livelihood activities, they argued that *‘prescribed fire is not used as a management tool’* because *‘it is too traditional’*. Across the arid savanna transition zone, *‘grazing should be used instead’* because *‘there is so much livestock that gets rid of the fuel. The vegetation we have here dries out almost completely, so this would make it difficult to control fire. It’s windy and dry.’* Across the mesic savanna transition zone, *‘there is no prescribed burning [...] because there is not a high fuel load in the forests. The communities have other uses for fuel, like harvesting grass’*.

Additionally, *‘increasing climate change and livestock populations’*, and rising incidences of unplanned and extreme fire events, *‘limit the potential for fire use.’* As such, participants advocated for greater preventative measures rather than active burning: *‘wildfires will occur, so how we prepare for them as a disaster is important. We need a disaster mitigation tool’*. Some participants recognised that *‘from a scientific perspective, fire is a rangeland management tool and can capture traditional knowledge.’* However, they stated that *‘the problem with scientists is that they are looking in a certain direction and give you this sort of information when the reality on the ground is not that’* – is burning appropriate to *‘remove dead materials’* when *‘grazing also removes dead material’* but without

*‘removing carbon’ and ‘destroying microorganisms’.* *‘By burning, we decarbonise the soil. So, what shall it be?’* Such understandings remove fire from its ecological context, repudiating the role of fire in the savanna adaptive cycle and influence over long-term BGC concentrations.

In few cases did participants recognise that *‘when done correctly’*, *‘prescribed fire could be good’* to address ecological degradation across the ranches where *‘there is no new vegetative growth because the old grass is overgrown’*. However, they too expressed concerns over the impacts of fire on *‘crawling animals who cannot escape quickly’*, and on *‘microorganisms that play a big role in maintaining the ecosystem at the soil level’*. Considering the long history of fire suppression and shift in attitudes towards fire-use practices, the costs associated with prescribed burning seemed to outweigh the perceived benefits of challenging the status quo. As such, most participants strongly agreed that more information and training on the benefits and methods of controlled burning is required before it can be considered in ecosystem management (*Mdn: 1*).

#### 5.4.4.2. REDD+

Kenya’s commitment to the development of REDD+ projects across the country is clearly stated in its National REDD+ Strategy (2022), constitutionally endorsed by the Climate Change (Amendment) Act (2023) and Climate Change (Carbon Markets) Regulations (2024). These policies present a governance and institutional framework for regulating projects active within the carbon market economy, including the establishment of a National Carbon Registry which encompasses all REDD+ projects (due to be operational late 2025). REDD+ projects have historically been the top issuer of carbon credits in Africa, thus developing transparent trading budgets (e.g., stricter measurement, reporting, and verification (MRV) protocol) and a carbon registry is expected to increase Kenya’s presence in the global carbon marketplace and assist in achieving national climate goals and mobilising additional funding for NDC implementation. Coupled with the launch of the Government’s 10-year National Landscape and Restoration Strategy (2022), REDD+ projects are expected to be scaled- and doubled-up with ARF100 projects over the next decade. Aligned with the IPCC guidelines on reporting national GHG inventories, forests are defined in Kenya as an area >0.5ha with >15% canopy cover and vegetation height of >2m (IPCC, 2006). As such, Kenya is working towards nesting site-scale projects within a national REDD+ institutional architecture to increase central access to funding and develop its compliance market, as well as address existing challenges related to double-counting, additionality, and leakage (Smith et al., 2024).

Individual REDD+ projects selling carbon credits on the voluntary carbon offset market (VCM) have diversified financial revenue streams for conservation, reducing some of the sector’s vulnerability to exogenous political-economic and environmental shocks (Tear et al., 2021). Additionally, CSR projects run through the projects are *‘supporting communities’* and increasing the perceived benefits of wildlife to local communities so that *‘they partner with us in the conservation of the ecosystem.’*

This is mostly achieved through top-down education schemes which aim to *‘impart knowledge to communities about reducing pressures, [...] to change attitudes, and [...] to stop burning.’* Some participants stated that *‘we need more projects like REDD+ in Kenya’* to *‘achieve our main aim, to reduce deforestation and degradation’*, as well as include *‘that element of social and cultural benefits.’*

However, REDD+ projects vary considerably in terms of community participation and management rights. For example, ranch officials who hold group ownership titles in the Maasai Group Ranches, *‘have a park account – it is registered’*, and partner with NGOs (e.g., MWCT and BLF), *‘receive their share of the carbon revenue directly to manage as they wish.’* However, *‘on the eastern side, the Kamba don’t have any formal set up in terms of engaging them, so we only give bursaries.’* Considering that a high percentage of these communities - *‘from Kiboko to Mtito Andei’* - live in absolute poverty, bursaries have, in some cases, increased local support for wildlife conservation.

Individual REDD+ projects and other carbon reduction schemes, including the Kajiado Rangelands (VCS proj.4714) and Makueni Agroforestry (VCS proj.4325) projects<sup>42</sup>, do not require legislative change. Therefore, management plans can be drafted by local actors specifically for the project area and implemented without undergoing long bureaucratic procedures, providing they are aligned with national legislation. Since burning is prohibited and fires are perceived to *‘disrupt carbon storage – degrading the soils and reducing carbon sequestration’*, REDD+ pursues total *‘fire suppression and prevention to gain carbon credits.’* Carbon revenue can be reinvested into developing more robust fire management systems which, to date, has mostly been aimed at fire prevention and firefighting. Additionally, revenue has contributed to increased security and law enforcement around protected areas to quell illegal activities which accelerate ecological degradation.

The effectiveness of REDD+ in driving ideational shifts across local fire-user communities might not depend on their legitimate participation in project governance, but rather how governing actors frame perceived benefits. Since communities are already excluded from state-governed protected areas, the perceived benefits generated from REDD+ projects likely outweigh the perceived trade-offs, at least during the projects’ initial scoping and development stages when the costs associated with increased security operations and unequal distribution of benefits have not yet been realised. These types of ideational change are evident in local communities’ gradual transition towards favouring fire suppression across areas where REDD+ projects are active.

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<sup>42</sup>Kajiado Rangelands (VCS proj.4714) and Makueni Agroforestry Carbon Project (VCS proj.4325)<sup>42</sup> aim to restore perennial grasslands through rapid rotational grazing systems and expand perennial agroforestry tree species across agricultural lands, respectively.

However, there are several challenges with this approach which limit opportunities for bottom-up governance in fire management and can accelerate savanna degradation. Firstly, *'there are challenges with the distribution of benefits'* to communities who are not *'formally organised'* (i.e., do not hold collective ownership titles or have not formally registered communal land), such that they possess little or no agency to challenge *'how carbon credits are allocated and used.'* As such, those already identified as the *'winners'* from ongoing land adjudication processes are also emerging as the *'winners'* from REDD+. Where carbon benefits are directly transferred to landholders, political and economic elites have attained greater exclusion rights over resource governance, deciding on who benefits and how they benefit, but mostly resulting in the accumulation of carbon benefits among these individuals. These challenges are projected to increase under a 'nested' REDD+ architecture which extends central control over rural governance systems. Secondly, high costs associated with MRV requirements to legally enable projects to issue carbon credits provides little market incentive for the adoption of additional regulatory and safeguarding frameworks for monitoring biodiversity and social goals. Where additional frameworks appear to have been adopted, their implementation remains ambiguous, especially where biodiversity objectives present trade-offs with annual carbon emissions objectives. For example, both the Kasigau Corridor and Chyulu Hills REDD+ projects apply VCS and CCB (managed by VERRA) Double Gold Standard Level (Climate, Biodiversity) standards, yet REDD+ actively promotes forestation across grassy savanna ecosystems, accelerating long-term biodiversity loss. Thirdly, there are large uncertainties over the long-term success of market-based carbon projects revenue due to price volatility in international carbon markets in response to geopolitical risks and climate change, as well as due to unintended increases in uncontrolled fire-use surrounding project areas (Johansson, Andersson & Fischer, 2024; Smith et al., 2024).

#### 5.4.4.3. Fuel harvesting scheme

The establishment of CFAs in accordance with the provisions of the 2016 FCMA have permitted certain users the rights to harvest wood, grass, and other forest products for community-based industries (FCMA, 2016), thus reducing fuel loads while simultaneously addressing socioeconomic challenges associated with declining resource availability<sup>43</sup>. Some participants argued that *'livestock are not allowed in the national parks because they spread diseases and herders are disorganised. Where grazing is not allowed, biomass builds up.'* In this instance, *'communities can be granted permission to enter the protected area, collect the grass, and take it back to their livestock. This is a*

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<sup>43</sup>Livestock grazing, fire-use, and resource harvesting remain strictly prohibited under the WCMA (2013). 'Harvesting' is defined as the felling, trimming, docking, splitting, debarking, extracting, or uprooting of any plant or plant substance in the protected area, and is classified as an activity under 'poaching'. 'Poaching' is any means of illegal hunting, illegal capturing, and illegal harvesting of any wildlife but does not include the control of species widely and commonly regarded as pests or vermin, as listed in the Act.

*participatory fuel reduction strategy. [...] Firewood harvesting also reduces the fuel load that burns during fire events.* While fire use is banned under the WCMA (2013), conservation organisations and local communities increasingly find it inappropriate to burn vegetation when they have observed a *‘large increase in bare ground cover and desertification.’* As such, management plans collaboratively developed between CFAs, government agencies, and conservation partners can define harvesting rights and practices, including the establishment of a zoning rotation, issuance of harvesting quotas, and enforcement of an access and rights fee paid by individuals seeking to *‘cut-and-carry grass’* in the protected area. Participants reiterated that these harvesting activities must only be practiced for personal rather than commercial purposes, with individuals only permitted to harvest the amount they can carry without assistance and/or machinery. Additionally, harvesting zones should be established between grazing blocks and identified *‘wildfire hotspots’* to create natural firebreaks across TCA. In instances where by-laws do not permit the community access to the parks, conservation agencies are required to harvest the grass and distribute it to the surrounding communities, including any hay bales created through the establishment of firebreaks.

Fuel harvesting schemes are perceived as incompatible with grazing and prescribed burning projects due to competition for biomass. Hence, participants advocated for increased fire suppression and prevention operations to reduce the risk of wildfires and their harvesting supplies, as well as suggesting that future carbon-based PES schemes incorporate harvesting activities into their methodologies to reduce ground litter and increase primary productivity, removing moribund materials which result in self-shading and dormancy (Zimmermann et al., 2010).

The challenges associated with this approach are detailed in section 5.2.1.11. In addition, participants have observed fee-paying individuals in other protected areas in Kenya sell their harvests at premium rates to Somali herders in the northern counties who are suffering from intensifying drought conditions. This is driving the commercialisation of and an illicit trade in harvested grass, with an increasing number of non-paying individuals taking advantage of the slightly laxer access rights to protected areas. Lastly, where fuel harvesting is carried out in the absence of fire, this is promoting woody encroachment and creating a water-stressed environment, resulting in long-term savanna degradation.

#### **5.4.4.4. Grazing scheme**

Despite legal provisions for grazing in protected areas *‘in times of drought and other natural disasters’*, there is no legal framework to implement this, resulting in *‘ad-hoc’ ‘gentlemen’s agreements’* in protected areas and large confrontations between park authorities and herders excluded from accessing pasture. Acknowledging the historical compatibility of pastoral herding with biodiversity conservation, participants recommended developing grazing schemes for implementation

within the protected areas based on the current ranching model, thus providing an integrated wildlife-livestock fire management approach:

*'We are getting to understand very well that the only way to keep protected areas is to integrate livestock as a management tool, to mimic nature - buffalos and antelopes. The reason grass is so high is because we don't have enough herbivores to eat it. It is tinder'.  
'It's a threat to biodiversity. But the thing we can use easily to control the fuel is livestock.'*

Grazing schemes present an opportunity to reduce surface fuel loads in protected areas while simultaneously improving relations between park authorities and local herders who are granted permission to access pasture and water resources. Though previously recognised as sites of significant ecological degradation due to overgrazing, trampling, and the expansion of woody increaser II and invader species, participants recommended establishing permanent water points throughout the parks to *'bring a lot of wildlife and livestock to those areas, so there would be nothing to burn. That would control wildfire and provide a solution for shrub encroachment.'* Based on the perception that herbivores and fires compete for consumable biomass across savanna ecosystems (Archibald & Hempson, 2016), they also advocated for increasing fire suppression and prevention operations to maximise pasture available to livestock. *'Burning an acre, from a greenhouse gas emissions point of view, is the equivalent to 6,000 cars. There are better ways of doing it. Can we bring in more livestock? Can we use livestock as a management tool?'*

Since livestock grazing is banned under the WCMA (2013), grazing schemes require national laws to be amended. Similar to CFAs, grazing committees consisting of governmental and conservation agencies and elected community representatives (e.g., ranch officials) need to be established to collectively govern pasture resources. The committee is responsible for devising by-laws which align with the given park's conservation objectives and regulate grazing operations and management, specifying the rights, liabilities, powers, and duties of officers and members, the grounds for the scheme's dissolution, the regulations governing routine conduct and activities, and the distribution of benefits. Specific management plans unique to the local context should also detail the issuance of seasonal grazing permits, livestock stocking rates and density quotas, fodder production guidelines, burning regulations and conditions, and the implementation of a rotational grazing system.

Participants emphasised the importance of adopting a periodical *'graze and rest'* system based on local environmental conditions under a landscape-scale zonation plan, promoting pasture regeneration. Though negatively perceived by most participants, permitting prescribed burning in grazing schemes to facilitate pastoral fire-use practices would require additional amendments to national legislation and by-laws. This might be the case if grazing schemes were to consider the long-term facilitative interactions between fires and herbivores – both acting as critical disturbance events

in the savanna adaptive cycle across the precipitation gradient (Van de Vijver, Poot & Prins, 1999; Van Langevelde et al., 2003; Smit & Coetsee, 2019).

There are several challenges with this approach, particularly regarding its long-term impacts on savanna health. Firstly, permitting select members of the community greater access to pastures inside the protected areas will likely exacerbate existing challenges related to illegal livestock ‘intrusions’, particularly amongst herders excluded from grazing schemes and, therefore, are more likely to engage in forms of ‘nocturnal agency’ (see 5.2.1.4). Additionally, ‘select’ members are often ranching elites who sit on the grazing committees and grant themselves access to the best resources, thus reinforcing the transfer of exclusion rights in yet another approach designed to address land-based inequalities (see 5.2.1.3). Due to the failure of the DFZ Programme to establish county-wide control fences regulating the movement of livestock into Taita Taveta, park authorities might be faced with increasing challenges preventing external entities (e.g., political and business elites) from entering the protected areas. However, this assumes that local law enforcement is limited by resource capacity only, when in fact, park authorities might be presented with even more lucrative bribes by external agencies as resources decline across the country. Lastly, as conservancies increasingly adopt integrated wildlife-livestock systems, commercial livestock production will expand across Taita Taveta, resulting in greater herd sizes and stocking densities. This is driving widespread woody encroachment, defoliation, and soil erosion, particularly around water sources and where goats are stocked at higher densities. Immediately outside protected areas, semi-commercial ranching activities are expanding due to the perceived benefits of increased access to pasture, increasing forms of habitat compression (Veldhuis et al., 2019). As such, wildlife and livestock are increasingly competing for consumable biomass, putting additional stress on vegetation under drier conditions.

#### 5.4.4.5. CBFiM

While CBFiM could present a ‘blue sky thinking’ approach in state-governed savanna protected areas, participants exploratorily imagined CBFiM within the current legal and political framework, likely due to their systematic exclusion since parks were first established and, therefore, inability to imagine radically different futures. Acknowledging the historical interconnectedness of humans, their local fire-use practices, and savanna biodiversity, and the emergence of ‘wicked problems’ where these connections have been disrupted, some participants noted that *‘people who lived in the savannas had methods of positively using fire, and these methods were passed on. So, where there are more fires, we need to question ‘what are the effects of current governance?’*”

However, due to a long history of exclusion, fire suppression, and perpetuation of anti-fire rhetoric, CBFiM was considered as an extension to existing CFA structures, such that individuals from the local communities who are interested in fire can form specific ‘user-groups’ to work with government agencies to collaboratively manage fires in the parks. Considering the diversity of land-use values and

associated fire practices across TCA, these ‘*user-groups*’ might represent different livelihood activities, such as agriculture, grazing, and resource harvesting, with group members lobbying on behalf of their wider communities for the introduction of fire-related practices in savanna-protected areas. Participants shared how existing CFAs provide an avenue for engaging members in fire management because they have vested interests in protecting natural resources, thus recommended that members of newly established CBFiM ‘*user-groups*’ also pay a fee. The development of CBFiM within this existing framework is perceived as a realisable approach in state-governed protected areas, providing an opportunity for culturally diverse local communities to advance their issues and ambitions:

*‘The integration of community-based natural resource management and community-based conservation could help reconcile rural development and conservation. This requires a joint livelihood-conservation approach.’* However, *‘the National Parks [...] are no go zones for the community, so there would need to be dialogue about establishing community-based associations.’*

For fire management to be effective, ‘*communities need to benefit from the policy*’, and ‘*the best way to manage fires and understand their impacts on species is to incorporate local and traditional knowledge, looking at traditional institutions and their ways of predicting environmental change*’ A CBFiM approach formally recognises local communities in decision-making processes, legally permitting certain (elected or fee-paying) individuals to define operational rules-in-use (e.g., who, what, when, and how burning takes place) and govern burning activities in a somewhat flexible manner depending on local ecological and socioeconomic conditions. This demands large changes in national legislation to make provisions for fire-use activities in protected areas (incl. grazing, agriculture, resource harvesting), and the establishment of additional by-laws that clearly define the rules, regulations, and responsibilities for burning in the local context.

While participants recognised the indirect benefits community ecological knowledge has on the ecosystem, they shared how ‘*they don’t use that knowledge to benefit wildlife. It is more on the agricultural side of things. They use fire if it benefits them.*’ Though this has historically contributed to the evolution of diverse savanna ecosystems, several participants expressed how climate change, the breakdown of traditional land governance systems, and biocultural hysteresis has resulted in a ‘*loss of traditional ways of life*’ and knowledge, with fire increasingly regarded ‘*in a negative way. The youth do not have the knowledge*’ and certain ethnic-groups ‘*have no special way*’ of managing fire.

Large uncertainties over the constitution of and opportunities for CBFiM in protected areas raise several challenges, of which are discussed in detail in Chapters 2 and 8. These include structural asymmetries between locally legitimate and policy relevant governance institutions in protected area management, where institutional and tenure barriers and over-reliance on external agencies for

funding and resourcing limit the role and autonomy of local communities in decision-making processes. This can increase incidences of elite capture whereby exclusion rights rather than management rights are decentralised to specific members of the community who pay a fee to participate. Additionally, the centralised retention of ownership and management rights limits opportunities for legitimate community participation by (i) setting the policy domain in which local people can act and make decisions, limiting opportunities for shared learning experiences and normative fire management development, (ii) enabling state agencies to withdraw from community-based agreements at any time, preventing local people from lobbying and initiating rural development, and (iii) driving processes of biocultural hysteresis which further limits opportunities for CBFiM, for instance due to the loss of traditional fire knowledge and replacement of harmonious management arrangements with individualistic fire regimes, making authorities less likely to decentralise management rights. This is compounded by socioeconomic-climate change, with communities transitioning towards more sedentary (high- and low-return) market-based activities and increasingly moving away from burning due to observed short-term trade-offs with livestock grazing and resource harvesting. Lastly, increased access to the protected areas is perceived to increase the risk of illegal and other-fire related activities that are not permitted under the agreed management plan.

## **Chapter 6. Belief Network Model**

This chapter details the development of a Belief Network (BN) (herein referred to as SAV BN – ‘Savanna Belief Network’) probabilistically model the social-ecological network effects and outcomes of alternative fire management approaches implemented in East and Southern African savanna-protected areas under future socioeconomic-climate change. BNs are a relatively recent adaptation of traditional Bayesian Belief Networks (BBNs) for modelling complex systems dynamics in uncertain environments (Dominguez Almela, Croker & Stafford, 2024). SAV BN was developed from Stafford, Williams & Herbert (2015) in R Software and is the first model of its kind in this field, including multiple climate, environmental, socioeconomic, and policy variables which interact across delineated spatial boundaries across a conservation area.

Empirical data derived from multiple methodologies was used to construct and refine SAV BN. While the latter used information specific to TCA to provide a locally-relevant decision support tool, the network was constructed based on information related to fire-prone savannas across East and Southern Africa and the tropics more broadly. As such, SAV BN provides a macroscopic tool that can be adapted to inform management and policy decisions in specific savanna contexts globally.

Here I discuss the opportunities and challenges for BBNs in social-ecological systems modelling before explaining why and how SAV BN was developed for this research and its novelty within the

field. I then detail how SAV BN was constructed, developed, and modelled, including important considerations for the interpretation of modelled results and future research.

**The full dataset for the SAV BN developed during this thesis is publicly available online at Croker (2024a).**

Reference: Croker, A. R. (2024) *Belief Network: fire management in African savanna-protected areas under future socioeconomic-climate change*. Figshare. Dataset.

<https://doi.org/10.6084/m9.figshare.26885743.v1>

This dataset includes: (i) a **comprehensive list of nodes** and their descriptions (incl. representation status and location); (ii) **all direct interactions** between parent and child nodes ('edges') and their integer and probability values ('edge values'); (iii) detailed descriptions for **fire management and policy intervention measures** implemented under different scenarios (input variables); and full narratives, descriptions and supporting evidence for (iv) **fire management** (incl. information applicable across carbon-based PES schemes) and (v) **joint socioeconomic-climate scenarios** developed and modelled in SAV BN.

This information was made available online for three main reasons: size and complexity of data (too large to be presented in-text in this thesis); facilitate future model development, cooperation, and adaptations based on research and management contexts; enable access and use at policy-relevant scales to inform management decisions.

This chapter draws on three peer-review journal articles (one published, two *in review*) I was involved in over the course of this thesis, mostly in reference to methodologies:

- (ii) 'Evaluating optimal solutions to environmental breakdown' (Stafford et al., 2020)
- (iii) 'Creating simple predictive models in ecology, conservation and environmental policy based on Bayesian belief networks' (Almela, Croker & Stafford, 2024).
- (iv) '2024 UK General Election manifesto commitments: implications for the economy, environment, and society' (Stafford et al., 2024).

All authors of the articles have agreed on their inclusion in this thesis.

## 6.1. Traditional Bayesian Belief Network

‘Wicked problems’ are contributing to the degradation of global public goods (e.g., biodiversity and natural resources) (Sills & Jones, 2018). To date, management solutions addressing these challenges have largely been ineffective, thus demanding evidence on alternative and novel policy interventions to mitigate future social-ecological and economic risks. BBNs provide an effective process-structuring tool for dealing with ‘wicked problems’ and their mitigation and adaption challenges in environmental management (Barton et al., 2012; Allison et al., 2018). Their structured networks represent probabilistic dependencies among a set of known system variables, able to integrate quantitative and qualitative data to accommodate uncertainty and, to some extent, data-limited conditions (Cooper, 1990; Phan et al., 2016). The network consists of direct interactions between systems two variables (‘nodes’) where each interaction is defined by an ‘edge’ - a fixed parameter showing how the effect variable ( $X$ ) (‘child node’) responds to changes in the cause variable ( $Y$ ) (‘parent node’) (Almela, Croker & Stafford, 2024). As such, BBNs can be used to understand causal inference within the modelled system, for example by exploring the effects given the causes (e.g.,  $P(X|y)$ , where  $y$  is each discrete state of parent node  $Y$ ), and how variables interact throughout the network to influence outcomes (Aguilera et al., 2011). In this way, network analyses provide two main insights: (i) most likely set of conditions for and probability of achieving desired outcomes, and (ii) impacts on outcomes of changes elsewhere in the system (Newton, 2009), including which variables have the greatest positive or negative effect on the outcomes (Barbrook-Johnson & Penn, 2022). Sequenced direct causal pathways can also reveal the potential impacts of a single event on multiple systems variables, revealing indirect and often unknown interactions within the system. Given that it is generally easier to evaluate different management options based on a finite set of outcomes (i.e., selecting a management option based on potential outcomes) than it is to accurately predict ecosystem outcomes (Geary et al., 2020), BBNs can provide a decision-support tool for evaluating the potential outcomes of alternative policy interventions to address complex social-ecological challenges (Hulme, 2016).

Aguilera et al., (2011) provide a detailed overview of the benefits of using BBNs in environmental science. These include: ability to encapsulate uncertainty and risk through a probabilistic representation of the modelled system; provide opportunities for participatory scenario development and futures thinking across multiple stakeholders and rightsholders groups (Johansson, 2021); draw on multiple information and knowledge sources in model parameterisation and evaluation; easily modified considering new information. The participatory nature of BBN modelling and graphical representation of the system also increases model transparency (e.g., visualisation) and assists in building trust and effective engagement between scientists and decision-makers, resulting in more timely and contextually appropriate policy action (Lacey et al., 2018; Dominguez Almela, Croker & Stafford, 2024). These benefits have led to their widespread application in environmental sciences to

assist in decision-making (see Appendix III), for example to measure risk, the delivery of ecosystem services, impacts of land-use and climate change, species populations dynamics, habitat availability, alternative management decisions, adaptive capacity, and to inform the development of impact assessments (Newton, 2009; Barton et al., 2012; Landuyt et al., 2013).

Due to a long history of fire suppression in East and Southern Africa and its embeddedness within forestry sciences, fire management approaches have mostly been informed by dominant perceptions of savannas as ‘degraded forests’ (Parr, te Beest & Stevens, 2024; Smith et al., 2024). With limited evidence on or knowledge of alternative approaches in African-savanna protected areas, BBNs provide a useful tool for evaluating a range of predictive, exploratory, and normative ‘what if’ fire management scenarios under future socioeconomic-climate change (Johansson, 2021).

Transdisciplinary knowledge, expert opinion, and experience from a range of similar environmental, sociopolitical, and economic contexts worldwide can be incorporated into these scenarios and model parameterisation, thus providing a more holistic understanding of the system and assisting in understanding potential policy trajectories (Allison et al., 2018; Dominguez Almela, Croker & Stafford, 2024). The participatory nature of BBN development and interpretability of model results are also important in the context of this research where a lack of property-rights and continuous marginalisation of Indigenous and local people have contributed to unsustainable resource extraction and chaotic fire regimes (Croker, Woods & Kountouris, 2023a).

### **6.1.1. Limitations of traditional Bayesian Belief Network**

Several challenges limit the use of traditional BBNs when modelling complex social-ecological systems characterised by non-linear processes, ecological thresholds, and alternate stable states, particularly under ecologically-relevant timescales (Stafford, Williams & Herbert, 2015). These include their (i) directed acyclical structure, (ii) large data requirements, and (iii) risk of signal loss (Barton et al., 2012; Almela, Croker & Stafford, 2024).

The directed acyclical structure of BBNs does not allow for the inclusion of feedback loops in the modelled system. This discounts the effects of two-way interactions on systems outcomes, such as mutualistic, facilitative, and competitive relationships, self-reinforcing cycles, and long-term ecological responses (Barbrook-Johnson & Penn, 2022).

The development of conditional probability matrixes required to structure BBNs restricts their application in data-limited conditions (McDonald, Ryder & Tighe, 2015). For example, the believed effect that each discrete state of parent node ( $Y$ ) has on child node ( $X$ ) - where each discrete state ( $y$ ) represents the current state of a systems variable and how it might change under a given scenario (e.g., high or low, present or non-present - increasing or decreasing, emerging) - requires numerical parameterisation (e.g., assigning an edge value to each interaction). As the number of nodes in the

network increases, the conditional probability matrix requiring parameterisation grows exponentially and becomes unworkably large (Trendowicz & Jeffery, 2014; Sucar, 2021), imposing practical challenges (e.g., time and effort) on modelling complex systems (Madihi, Shirzadi Javid & Nasirzadeh, 2023). This also increases the likelihood of there being limited knowledge or evidence over a specific interaction, resulting in guesswork over model parameters rather than true beliefs. This can jeopardise model reliability and the usefulness of results (Dominguez Almela, Croker & Stafford, 2024).

BBNs calculate the joint probability distribution based on the chain rule of probability for each system variable, given information on other directly interacting system variables. Therefore, as changes propagate throughout the network, BBNs are prone to signal loss. This increases when a large number of nodes and layers (i.e., number of intermediary nodes) required to model complex systems are included in the network. This can lead to underestimating the impacts of given interventions and/or disturbances (Lee & Rieman, 1997), reducing the model's explanatory insights (Allison et al., 2018). To address the risk of signal loss, BBNs are recommended to be designed with few layers and short lengths between input and outcome nodes (Newton, 2009; Landuyt et al., 2013).

While the advantages of simple model structures are well known (Marcot, 2006; Marcot et al., 2006), their parameterisation often represents a single scientific discipline and risks over-simplifying the realities of the system. This can threaten public and political acceptance of BBN models, the validity and usefulness of results, and the reliability of interpretations in a practical setting (Landuyt et al., 2013). Since fires present a 'wicked problem' for decision-makers due to their interconnectedness with climate and biology, the topographic environment, and society and culture (Croker, Woods & Kountouris, 2023b), future management strategies require transdisciplinary thinking and an understanding of complex multi-scalar interrelationships that drive and are driven by changes within the system (Allison et al., 2018).

In addition to these challenges, BBNs are typically non-spatial and non-temporal models, mostly considering the impacts of a given intervention or disturbance within a specific, often assumed to be homogenous area under present day conditions. For instance, modelling alternative futures by altering management-related input nodes but not biogeophysical-related input data, therefore superimposing alternative management strategies on the current biogeophysical system (May et al., 2019). In well-studied 'data rich' regions, spatially-explicit data which shows territorial features can be incorporated into Spatial BBNs to simulate ecological processes across the modelled landscape (Liedloff & Smith, 2010; Gonzalez-Redin et al., 2016). Spatiotemporal BBNs have also been developed to model how spatial dynamics change over time (Cain, 2001; Aalders, 2008; Bashari, Boali & Soltani, 2024), such as how different types of forest fire impact vegetation at each evolutionary burning phase (Giretti, Carbonari & Naticchia, 2012). However, the integration of simulation models and traditional BBNs

requires specific systems modelling and computer programming expertise, comprehensive datasets to parameterise models (e.g., remote sensing or GIS data), and longer timeframes available to developers. Hence, spatiotemporal BBNs are at odds with the well-documented benefits of applying traditional BBNs in environmental sciences, such as their low development costs, application in data-poor situations, and simple interface for managers and non-modellers to use and interpret.

## 6.2. Adapted Belief Networks

Belief Networks (BNs) present a simple probabilistic cause-and-effect modelling approach based on traditional BBNs (Stafford, Williams & Herbert, 2015). BNs maintain several aspects of Bayesian inference, such as the inclusion of diverse knowledge and information sources in model parametrisation, and the ability to encapsulate uncertainty through probabilistic representations of the modelled system. They also include address several of the challenges highlighted in section 6.1.1., making their application more intuitive in social-ecological systems dynamics modelling. BNs have a simple design and allow for the inclusion of (i) feedback loops and two-way interactions, (ii) systems variables where knowledge of direct interactions between nodes are unknown (e.g., in poorly studied and data-poor systems) and not required, and (iii) a larger number of nodes without jeopardizing model functioning and the validity of results (Almela, Croker & Stafford, 2024). This makes it possible to model complex systems and analyse the potential outcomes of and emergent challenges arising from different management approaches under future socioeconomic-climate change.

In natural systems, there tends to be greater certainty over large events and their impacts, and greater uncertainty over smaller events and their emergent properties (Stafford, Williams & Herbert, 2015). For example, extreme wildfire events are more likely to occur under increased fire weather conditions and where fuel loads had accumulated. In this regard, BNs relate magnitude of change (effect) to certainty between sources (agreement) (Stafford et al., 2020). Because this information is captured in the edge values defining cause-effect interactions and can lead to potential uncertainties and inconsistencies in assigning values, sensitivity analyses can be carried out to identify sensitive edges that require additional scrutiny (Almela, Croker & Stafford, 2024).

BNs simple design allows them to be easily updated considering new information and divergences between epistemic communities that challenge existing beliefs, or to be adapted to represent similar complex systems worldwide (Castelletti & Soncini-Sessa, 2007). In this way, they can provide a platform for collective learning across interest groups with diverse socio-cultural and management aspirations, and be used as transparent decision-support tools for the development of adaptive management frameworks in rapidly changing environments (McCann, Marcot & Ellis, 2006).

All conditional independence assumptions (i.e., direct cause-effect interactions defined by edge values) for known variables in the system are recorded in a conditional probability matrix ( $P(X|Y_i)$ ),

where an increase in the variable in the row ( $Y_i$ ) results in an increase ( $0.6 \leq r \leq 0.9$ ) or decrease ( $0.1 \leq r \leq 0.4$ ) in the variable in the column ( $X$ ). The value ( $r$ ) assigned to the interaction  $[0,1]$  indicates the degree of belief in an increase or decrease in  $X$ , given an increase in  $Y$ . Since the matrix only records known variables and interactions, it allows for the presence of unknown (latent) variables in the model, for example where there are uncertainties over or a lack of knowledge of direct causal interactions (e.g., in data poor systems). Indirect effects are an outcome of the modelling process.

Fixed edge values are based on Bayesian inference, although some non-Bayesian processes are used to enable the inclusion of feedback loops and reciprocal relationships, and to prevent signal loss as change propagates throughout the network, ensuring that any available prior knowledge is maintained and, in-turn, leads to more meaningful predictions (e.g., Almela, Croker & Stafford, 2024).

Probabilities for intermediate and outcome nodes increasing given interactions with other nodes in the network are calculated using the following Bayesian equation:

$$[1] \quad P(X_i|Y) = [P(X_i|Y_i) * P(Y_i) + P(X_i|Y_d) * P(Y_d)]$$

where  $X$  is the node in question (child node), and  $Y$  (parent nodes) are the interacting nodes.

Subscripts  $i$  and  $d$  indicate increasing or decreasing, respectively. Probabilities were calculated for each interacting node in the network (Stafford, Williams & Herbert, 2015).

Where there is no knowledge of an increase or decrease in parent node  $Y$  (prior value of 0.5), this node is not included in the equation. As such, no prior information on child node  $X$  is included in the calculation. Because traditional BBNs require conditional probability matrices to be built when multiple edges act on a node (i.e., more than one parent), any lack of prior information can result in greater uncertainty propagating through the network. However, including prior information - particularly when knowledge is limited, and prior values are determined through guesswork - is often not suitable for making predictions over systems variables when conditional independence assumptions are already encapsulated in the matrix. This can encode greater uncertainty in the network and modelled outcomes.

To ensure prior knowledge is maintained in the BN and to accommodate feedback and reciprocal relationships, overall posterior probabilities for each of the systems nodes were calculated in two ways. Firstly, by ensuring that additional information on interactions between nodes add to the certainty provided by the prior, and secondly by discounting prior values if additional information provides more certain information than the prior value (e.g., value further away from 0.5):

$$[2] \quad \text{Post}(X_i) = P(X_i) + |1 - P(X_i)| * [\sum_{1-n} (P(X_i) * (P(X_i|Y) - 0.5)) / n]$$

and

$$[3] \quad \text{Post}(X_i) = [\sum_{1-n} (P(X_i|Y))] / n$$

where  $n$  is the number of interactions with child node  $X$ . The final value of  $\text{Post}(X_i)$  is the value displaying the highest level of certainty, such that it is the furthest (positive and negative) in magnitude from 0.5. Further iterations of the model are run to allow information to propagate through the network, but with updated prior probabilities:

$$[4] \quad P(X_i) = \text{Post}(X_i)$$

At this stage, after the first iteration of the model, knowledge of a change in parent node  $Y$  is included in equation [1], hence there is some prior knowledge of a change in child node  $X$ .

The number of model iterations might depend on the aims of the study, the complexity of the system being modelled, and the timeframe over which the results are being modelled, e.g., increasing the number of iterations to model outcomes over long periods of time (Almela, Croker & Stafford, 2024). Though BNs are also non-spatial models, their simple design, user-friendly interface, and inclusion of two-way interactions and feedback loops facilitates the incorporation of spatial dynamics into the network structure.

### 6.2.1. Savanna-Protected Area Belief Network

SAV BN was developed to model the effects of alternative fire management approaches in savanna-protected areas on multiple system variables under future socioeconomic-climate change. Specifically focusing on the opportunities and challenges for reducing wildfires and increasing long-term savanna health inside protected areas and strengthening local resilience across broader conservation landscapes.

SAV BN is currently parameterised to represent a semi-arid to mesic (750-1500mm MAP) African savanna conservation landscape based on conditional independence assumptions for known (or identified) variables up to 2100. Model parameters can be locally modified (i.e., alteration of a specific node or direct interaction) to represent more arid African savannas (<750mm MAP), or restructured and revised to represent savannas across similar geographical contexts worldwide.

## 6.3. Methodology

Over the course of this study, I was involved in developing a new package for R software (BBNet) to provide a user-friendly interface for researchers and practitioners to develop predictive Belief Network models. This information, including detailed methodologies to practically develop and model BNs in R software, is provided in (Almela, Croker & Stafford, 2024). BBNet was finalised towards the end of this study, thus was not used in the development of SAV BN. However, model coding and methodologies are mostly the same. Future BN development (incl. SAV BN) should

consider using the BBN framework to enable decision-makers with or without modelling experience to assess (un)specified outcomes under various management interventions.

SAV BN and modelled scenarios were constructed throughout the course of this study, including data from literature reviews (Chapter 2) and broader literary sources, semi-quantitative and thematic analyses of fieldwork data (e.g., Chapters 3, 4, and 5), expert opinion, and sensitivity analysis. The following sections detail the construction and development of SAV BN and modelled fire management and socioeconomic-climate scenarios, explicitly stating the beliefs and assumptions implicit within the model and informing modelled outcomes.

### 6.3.1. Joint Socioeconomic-climate Scenarios (SSPX-Y)

**Full details for SSPX-Y scenarios are available online at Croker (2024a).**

Wildfires are both a human and physical phenomena, synthesising both local vegetation and regional geophysical dynamics. Therefore, as humans increasingly manipulate vegetation and soil composition through changes in land-use and cover (e.g., agricultural intensification, land sub-division and sedentarisation, rapid urbanisation, and large-scale land development projects), land and fire-related policies (e.g., fire suppression, carbon-based PES schemes), and ignition patterns (e.g., seasonality, diurnality) (Giglio, Csiszar & Justice, 2006; Andela et al., 2017), fire management approaches that appear effective under current socioeconomic-climate conditions will likely be ineffective in the future, possibly requiring far more radical intervention measures. The anticipated impacts of alternative fire management approaches on wildfires, savanna health, and local livelihoods need to be considered alongside changing biogeophysical conditions, land-use values and fire-use activities, and resulting political and economic actions (Bowman, O'Brien & Goldammer, 2013; Tedim, Leone & McGee, 2019; Pyne, 2020).

Three joint socioeconomic-climate scenarios were developed to model the effects of fire management approaches under best, intermediate, and worst-case warming and mitigation and adaptation pathways up until 2100: (i) 'Green Climate Ambition' (GCA), (ii) 'Climate Delay and Inequality' (CDI), and (iii) 'Fossil-fuelled Climate Denial' (FFCD). The IPCC Shared Socioeconomic Pathways (SSPs), and Representative Concentration Pathways (RCPs) were used to build a scenario matrix which incorporated climate forcing pathways, anthropogenic drivers of climate change, mitigation and adaptation activities, economic strategies, and political trends. The SSPs provided a broad narrative on socioeconomic development in the absence of additional climate change and climate policy, such as trends in GDP, population growth, urbanisation, and technological progress (e.g., see O'Neill et al., 2014; O'Neill et al., 2017; van Vuuren et al., 2017; Riahi et al., 2017), while the RCPs provided approximate radiative forcing trajectories up to 2100, including the quantification of future GHG emissions concentrations, aerosol emissions, and land-use and cover changes. The IPCC presented

five core SSPX-Y scenarios in its Sixth Assessment Report (AR6) (IPCC, 2021). *X* is the SSP used to explain the emissions pathway and *Y* is the approximate RCP reached by 2100, integrating socioeconomic trends with resulting emissions: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5. Additional SSPX-Y scenarios have also been used in the literature to explore alternative socioeconomic narratives and variation in radiative forcing trajectories across the century (Harrison, 2019). These include SSP4-3.4, SSP4-6.0, SSP3-7.0-low NTCF (Near-Term Climate Forcer), and SSP5-3.4 OS (overshoot). For example, SSP4-3.4 presents an inequality narrative where there are low challenges for mitigation (e.g., global high-tech economy and progress) yet high challenges for adaptation (e.g., regional low-tech economy and progress), thus is relevant to many African countries where poverty and weak or corrupt institutions prevents local adaptation. SSP5-3.4 OS is also important in the African context where fossil-fuel intensive industries continue to grow up until 2040 to assist in economic development, after which strong climate policies are implemented due to increasing residual costs of climate change (Frankhauser & Tol, 1996; Narain, Margulis & Essam, 2011), resulting in large net-negative emissions to reach low forcing levels post-2100 but having severe short term consequences on social-ecological systems (IPCC, 2021; Meyer & Trisos, 2023). Considering the relevance of these additional SSPX-Y pathways in East and Southern Africa, they were integrated with core IPCC pathways to construct GCA, CDI, and FFCD scenarios.

Table 13. provides an overview of these scenarios, including: scenario type (best, intermediate, worst-case depending on climate policy action); mitigation (efforts to prevent GHG emissions and limit future warming) and adaptation (actions to manage climate change risk and impacts) challenges; and degrees of global warming (above pre-industrial levels) in 2100 based on RCP radiative forcing trajectories and their SSPX-Y equivalents. A brief warming summary was developed for each scenario to provide a descriptive overview of the quantitative data used in their construction, for example their estimated temperature range based on policy action and population dynamics, aerosol emissions concentrations, projected frequency of hot temperature extremes, agricultural and ecological drought events, and heavy precipitation events in the wet season under each degree of warming (IPCC, 2021), and GDP and market trajectories (D Finney et al., 2019; WMO, 2019).

Each scenario has a distinct narrative that qualitatively details the socioeconomic dynamics that both drive and result from projected future climate change. Existing global SSP narratives provided the foundation for each scenario's narrative (e.g., global and macro-scale drivers of regional socioeconomic change: <https://iiasa.ac.at/models-tools-data/ssp>), and a range of additional sources specifically describing trends across East Africa provided further detail to increase the relevancy of the model and modelled outcomes in the research context. For example, several IPCC reports and WMO (2021) provided information on land-use, cover, and tenure change, food security, biological invasions and infestation events, processes of desertification, and the impacts of tropical cyclones on marginalised communities across Africa's drylands. GECHS (2008) detailed systemic mitigation and

adaptation challenges, future differential vulnerabilities, and emergent risk related to low institutional and technological capacities, poverty, conflict (incl. legacies of historical conflict), urbanisation, agricultural intensification and commercialisation, water scarcity, and market reforms. IPBES (2019) provided data on the socioeconomic impacts of biodiversity loss and land degradation across the region, and a range of published articles described compound events, the impacts of intensifying ENSO and Indian Ocean Dipole (IOD) events, and how the costs of residual damages limit opportunities for local adaptation (e.g., Hulme et al., 2001; Warner & van der Geest, 2013; Engelbrecht et al., 2015; Hao et al., 2020; Weber et al., 2020).

Final scenarios were sent to range of experts researching aspects of the modelled system to assess their relevancy and how well they represent projected futures. The breadth and richness of information gathered during this process was used to identify and detail the complex network of systems variables that construct SAV BN.

**Table 13.** Overview of Joint Socioeconomic-Climate Scenarios developed for this research. Global warming values in 2100 are based on pre-industrial levels.

| Scenario Title                       | Scenario Type                                                                  | Mitigation and Adaptation Challenges        | Global warming value | Equivalent SSPX-Y Scenarios      | Brief Warming Summary                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------|----------------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Green Climate Ambition</b>        | Best Case Scenario – additional climate policy action                          | Low mitigation and adaptation challenges    | 1°C - 2°C            | SSP1-1.9 and SSP1-2.6            | <p>Increased, strong, and united climate ambition holds warming to approx. 1.5 °C, though more generally it stays below 2°C warming in 2100 after slight overshoot (exceeding 2°C). In the medium- and long-term, overshoot might reach up to 2.6°C across East Africa, making it difficult to achieve warming below 2°C. This scenario implies reaching net-zero emissions after 2050. Annual GDP across East Africa will decline by approximately 2-4.5% per year and there will be greater dependency on external markets.</p> <p>The frequency of hot temperature extreme events over land (global average for drying regions) increases from 4.1 times in a 10-year period under 1.5°C of warming to 5.6 times under 2°C of warming, causing a temperature increase of +1.9°C to +2.6°C (1850-1900 baseline). Similarly, agricultural and ecological drought events are 2 and 2.4 times more likely to occur under 1.5°C and 2°C, respectively.</p> <p>In the wet season, heavy precipitation events are 1.5 and 1.7 times more likely to occur under 1.5°C and 2°C of warming, causing an increase in wetness by +10.5% and +14.0% respectively.</p>                                                                |
| <b>Climate Delay and Inequality</b>  | Intermediate Case Scenario – current policy action                             | Medium mitigation and adaptation challenges | 2°C - 4°C            | SSP4-3.4, SSP2-4.5, and SSP4-6.0 | <p>Little progress to develop current climate policies or implement additional policies increases warming to at least 2.7°C by 2100. Globally divergent approaches to environmental policy and increased inequalities, combined with reinforcing climate feedbacks, likely accelerate warming in the second half of the century. Warming of 3-4°C by 2100 is very likely.</p> <p>Annual GDP across East Africa will decline by approximately 4.5-11.2% per year and there will be greater dependency on external markets.</p> <p>The frequency of hot temperature extreme events over land (global average for drying regions) increases from 5.6 times in a 10-year period under 2°C of warming to 9.4 times under 4°C of warming, causing a two-fold temperature increase of +2.6°C to +5.1°C (1850-1900 baseline). The number of warm nights could increase by 50%.</p> <p>Similarly, agricultural and ecological drought events are 2.4 and 4.1 times more likely to occur under 2°C and 4°C, respectively.</p> <p>In the wet season, heavy precipitation events are 1.7 and 2.7 times more likely to occur under 2°C and 4°C of warming, causing a two-fold increase in wetness by +14% and +30.2% respectively.</p> |
| <b>Fossil-Fuelled Climate Denial</b> | Worst Case Scenario – no additional policy action/retraction of certain policy | High mitigation and adaptation challenges   | 4°C - 6°C            | SSP7-3.0 and SSP5-8.5            | <p>Lack of climate policy action and an acceleration of fossil fuel extraction and energy use, combined with increasing population growth, drives warming to 3°C by mid-century and 5°C by 2100. Reinforcing feedback loops might cause warming of 6.3°C by 2100, however increases in aerosol emissions in East Africa might have a slight cooling effect, keeping warming to below 6°C. Annual GDP across East Africa will decline by more than 11.2% per year, with an exponentially increasing rate of decline for every 0.1°C of warming. By 2050, this figure could reach more than 15% per year. There will be greater dependency on external markets.</p> <p>Under 6°C of warming, the frequency and intensity of hot temperature extreme events over land, agricultural and ecological droughts, and heavy precipitation events in the wet season over a 10-year period, are likely to be double or even triple that experienced at 4°C.</p>                                                                                                                                                                                                                                                                     |

### 6.3.2. Fire Management Scenarios

**Full details for fire management scenarios and intervention measures are available online at Croker (2024a).**

Seven discrete fire management scenarios were developed based on information provided by previous systematic reviews (Chapter 2), participatory research processes involving stakeholders, rightsholders, and practitioners (Chapters 3, 4, and 5; section 5.4.4), and conversations with and recommendations provided by experts working across related disciplines in Sub-Saharan Africa and other tropical savanna regions worldwide (e.g., Brazil, North Australia, South Asia). To summarise each scenario and facilitate comparative analyses, eight key management factors with a defined set of responses were identified and are summarised in Table 14.

Fire management scenarios represent a diverse range of potential fire management futures, some more exploratory (i.e., ‘what could happen based on the current political-economic context?’), while others more normative (i.e., ‘what should happen beyond current societal structures and values?’). Most scenarios integrate both exploratory and normative futures (i.e., ‘what should and what could happen, considering historical institutionalism, complex social-ecological systems, and contextual implementation requirements?’) (Johansson, 2021). Participants frequently applied back-casting approaches to identify interventions that connect the desired future to the present (Robinson et al., 2011). The desired future often demands changes to or the establishment of policies, institutions, governance frameworks, and/or accounting methodologies, requiring long-term planning and political-economic willpower (e.g., the establishment of an internationally-accredited national burning accounting methodology). Hence, this approach was favoured by scientists, stakeholders, and rightsholders who do not hold management or decision-making positions. Policy and management actors were generally more conservative in their approach, identifying areas of improvement and development within existing structures (e.g., increasing firefighting capacity through procuring resources). While SBEA, flexible prescribed burning, holistic grazing, and fuel harvesting schemes have the potential to reinforce exclusionary governance structures, participants identified opportunities for the decentralisation of management rights to local communities in their approach, contingent on the scheme’s objectives and perceived risks associated with granting local communities greater access rights. In these cases, scenarios were modelled twice, each run with a distinct set of prior nodes to account for both centralised and decentralised approaches in their implementation.

This information is captured in the scenarios’ full narratives which detail their main approach, benefits, trade-offs, challenges, requirements, and opportunities for greater community involvement, and in the ‘intervention measures’ constructed to model fire management scenarios (Croker, 2024). Intervention measures were included as input nodes in SAV BN to control for greater investment and resourcing in management interventions prioritised under each approach.

In practical settings, fire management approaches and intervention measures exist along a continuum, and elements from different approaches and measures are likely to be tested or adopted together. Similarly, key management factors and interventions are likely to be more nuanced and varied in application, largely depending on how relevant actors perceive them. For modelling purposes and to provide a comparative overview of the impacts of each scenario on systems dynamics, this study discretises each fire management approach and their intervention measures. This also ensures transparency and consistency in understanding modelled outcomes, particularly when interpreting effects of, for example, an increase in ‘firefighting capacity’ under a decentralised SBEA approach. In practical applications, SAV BN and modelled scenarios can be modified to evaluate nuanced approaches, combining elements of each scenario and incorporating changes to other variables within the system.

**Table 14.** Overview of alternative fire management scenarios for implementation in East African savanna-protected area. All scenarios invest in and resource intervention measures: fire management systems, firefighting capacity, and law enforcement.

| Fire management scenario                                      | Scenario approach                                      | Key management factors                         |                                                 |                              |                                             |                                      |                                                           |                                                                                                                    |
|---------------------------------------------------------------|--------------------------------------------------------|------------------------------------------------|-------------------------------------------------|------------------------------|---------------------------------------------|--------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
|                                                               |                                                        | Burning policy                                 | Dominant view of fire                           | Dominant management strategy | Main fuel reduction strategy                | Ecological objective                 | Finance mechanism                                         | Opportunities for community-based approach                                                                         |
| <b>Fire suppression and prevention</b>                        | Centralised                                            | No policy change or by-laws                    | Negative [disaster]                             | Mostly reactive              | Wildlife; [possible incorporation of fire]  | Forestation                          | n.a.                                                      | Very limited [community involved in firefighting]                                                                  |
| <b>REDD+ project</b>                                          | Centralised (+ BGB)                                    | No policy change or by-laws                    | Negative [disaster]                             | Mostly reactive              | Wildlife; [possible incorporation of fire]  | Forestation                          | Carbon-based PES scheme                                   | Very limited [community involved in firefighting]                                                                  |
| <b>SBEA scheme: Emissions Avoidance and Bio-sequestration</b> | Centralised (+ BGB)<br>Decentralised (+ BGB; flexible) | Requires policy change and creation of by-laws | Positive [regenerative];<br>negative [disaster] | Mostly proactive             | Fire                                        | Savanna conservation;<br>forestation | Carbon-based PES scheme                                   | Very limited; [community involved in implementing prescribed burns]                                                |
| <b>Flexible prescribed burning</b>                            | Centralised (+ BGB)<br>Decentralised                   | Requires policy change                         | Positive [regenerative]                         | Mostly proactive             | Fire                                        | Savanna conservation                 | n.a.; [possible incorporation of carbon-based PES scheme] | Limited [community involved in implementing prescribed burns; possible decentralisation of some management rights] |
| <b>Holistic grazing scheme</b>                                | Decentralised                                          | Requires policy change and creation of by-laws | Negative [disaster]                             | Mostly proactive             | livestock; [possible incorporation of fire] | Forestation                          | n.a.                                                      | Yes [possible decentralisation of some management rights]                                                          |
| <b>Fuel harvesting scheme</b>                                 | Centralised<br>Decentralised                           | Requires creation of by-laws                   | Negative [disaster]                             | Mostly reactive              | Ground litter harvesting                    | Savanna conservation;<br>forestation | n.a.; [possible incorporation of carbon-based PES scheme] | Yes [possible decentralisation of some management rights]                                                          |
| <b>CBFiM</b>                                                  | Decentralised                                          | Requires policy change and creation of by-laws | Positive [regenerative]                         | Mostly proactive             | Livestock; fire                             | Savanna conservation                 | n.a.; [possible incorporation of carbon-based PES scheme] | Yes [decentralisation of management rights]                                                                        |

### 6.3.3. Matrix and parameterisation

The development of BNs depends on the purpose and complexity of the model, time available to model developers, and necessary robustness to meet the aims and objectives of the study. Simple BNs can be developed relatively quickly using ‘best guess’ estimates to experimentally test hypotheses (Stafford, Williams & Herbert, 2015). SAV BN, however, is parameterised to represent dynamic (unstable), uncertain, and unknown interactions between systems variables across a large spatial area (conservation landscape) over a long period of time (up to 2100). In the research context, there is little or no evidence on the outcomes of alternative fire management approaches. And while predictions made over future socioeconomic-climate change use best available data, incomplete understandings of interdependent Earth’s systems dynamics and difficulties in forecasting forward to assess the cumulative impacts of anthropogenic forcings on social-ecological systems (incl. disturbance events, critical thresholds, and regime shifts) imbeds uncertainty into the modelled system. Individual interactions between systems variables might be supported by empirical data, but the modelled system cannot be easily understood, hypothesised, or empirically tested.

To address these challenges, SAV BN was constructed over an iterative four-step model development and parameterisation process (Fig. 10), enabling critical considerations to be made over included nodes, edges (interactions), and edge strengths (weighted interactions), gaining insights and knowledge from a range of sources.

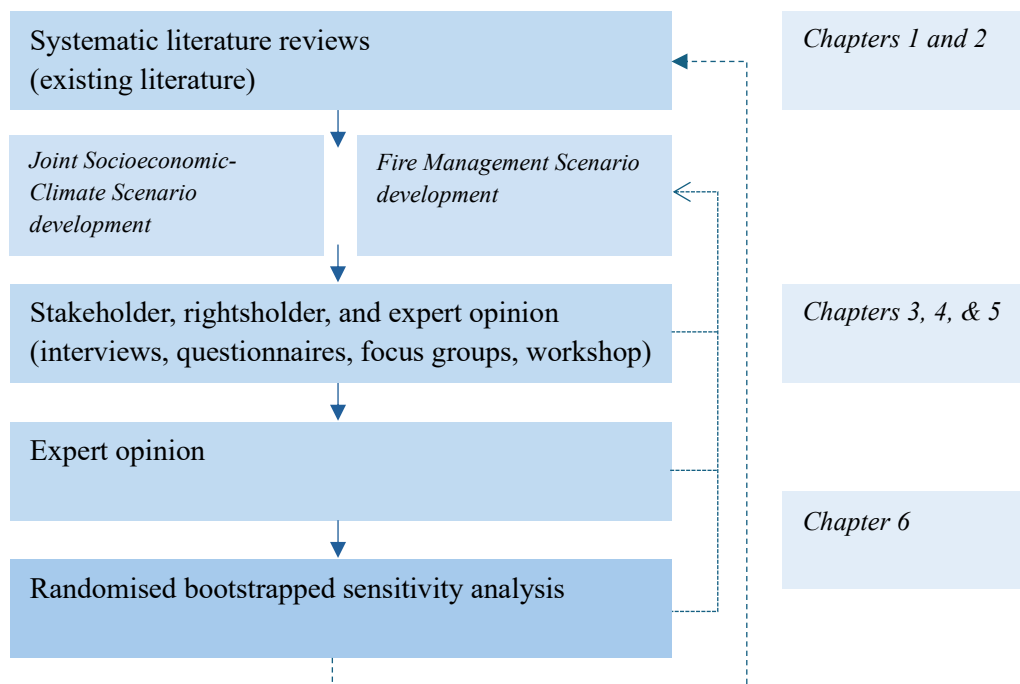


**Figure 10.** Iterative four-step model development and parameterization process.

Like most traditional BBNs, SAV BN is a discrete network structured on interactions between multiple nodes. Each node represents a random systems variable (discrete or continuous), and each direct relationship is defined by a fixed mathematically positive or negative edge value (Trendowicz & Jeffery, 2014). SAV BN includes a range of identified systems variables (nodes), representing multi-level climate patterns and biogeophysical wildfire conditions, and multi-systemic trends across social-ecological conservation landscapes spanning multiple land-use and -tenure types. Nodes were also included based on their ability to capture diverse aspects of the joint socioeconomic-climate and fire management scenarios.

### 6.3.3.1. Model development

In this section, apostrophised words refer to specific aspects of SAV BN, such as a specific model, scenario, or node. Full node descriptions are available online at Croker (2024a).

Three versions of SAV BN were created to effectively model both non-carbon based and carbon-based fire management scenarios: (i) ‘no carbon’ model, (ii) ‘carbon’ model, and (iii) ‘carbon + plant diversity’ model. The latter two including a ‘carbon credits’ node to account for their generation under a carbon-based financing mechanism, and the third including an edge between ‘plant diversity’ and ‘carbon credits’ (set to +4 (0.9)) to facilitate an exploratory analysis of carbon-based PES schemes if they account for soil organic carbon sequestration via below-ground biomass (BGB) in their accounting methodologies. The edge value defining the relationship between ‘forestation’ and ‘carbon credits’ was set to +3 (0.8) in the ‘carbon + plant diversity’ model, compared to +4 (0.9) in the ‘carbon model’. Otherwise, all three models were structured on the same interaction matrix. This distinction was important due to the direct relationship between ‘wildfires’ and ‘forestation’ with ‘carbon credits’, as well as the feedback effects ‘carbon credits’ have on various aspects of the system, such as funding ‘state development projects’ and ‘CSR projects’, and in some cases, decentralising a degree of ‘management rights’ where generated carbon credits are paid directly to registered community accounts for local officials to manage (e.g., Maasai Group Ranches).

The inclusion of a ‘carbon + plant diversity’ model was important to explore normative scenarios that account for BGB in their methodologies, especially considering recent evidence suggesting that >70% of total soil organic carbon (SOC) is derived from grasses in tropical African savannas, with below-ground carbon significantly increasing in frequently burned savannas (Handavu et al., 2021; Zhou et al., 2022; Zhou et al., 2023). As such, the inclusion of BGB accounting in fire management can have long-term implications on savanna health (structure, functioning, biodiversity, and distribution), sequestration potential, and in-turn, voluntary and compliance carbon markets and national GHG emissions inventories (Forfora et al., 2024). However, differentiating between a ‘carbon’ and ‘carbon + plant diversity’ model was important because methods for measuring BGB carbon stocks are still in their infancy, and there is no standardised approach for applying these methods across different land-

use systems. Hence, they are less frequently applied, and when they are applied, have been criticised for providing inaccurate estimates due to the exclusion of fine roots (<2mm in diameter) which cannot be easily differentiated empirically from soil organic matter (Ravindranath & Ostwald, 2008).

### 6.3.3.2. Node categorisation

Each node was categorised as a ‘climate and environmental’, ‘wildlife’, ‘socioeconomic’, ‘protected area fire management and policy’ or ‘outcome’ node. Climate and environmental nodes typically represent regional or large-scale phenomena, whereas wildlife and socioeconomic nodes typically represent more landscape-scale processes, influenced by larger-scale phenomena. Protected area fire management and policy nodes represent local aspects of the system, though were designed to be translatable to other tropical fire-prone conservation landscapes globally. Management and policy nodes were further broken down into sub-categories to make explicit the different constituents of each fire management scenario and their implementation within a savanna-protected area. Sub-categories included: ‘permission measures’ (action permitted to take place), ‘financing measures’ (market-based funding mechanism applied), ‘intervention measures’ (management intervention invested in and applied), ‘legal fire-related activities’ (local livelihood-based burning activity permitted to take place), ‘illegal fire-related activities’ (local livelihood-based burning activity not permitted to take place), and ‘other fire-related activities’ (local burning activity associated with agrarian challenges and negligible outcomes). Nodes categorised as ‘permission measures’ and ‘intervention measures’ were included as input nodes (i.e., ‘parentless’ or ‘root’ nodes), thus their prior values were manipulated to model specific scenarios.

To prevent endless feedbacks in the network and address the aims of this study, all ‘fire-related activity’ nodes were parameterised so that they only directly interacted with  $\geq 1$  of the following nodes: ‘regenerative fire’ (direct outcome of local fire use), ‘surface fuel load’ (biogeophysical wildfire condition and indirect effect on savanna health), ‘biodiversity’ and ‘forestation’ (direct effect on savanna health), and ‘wildfire’ (outcome). Legal, illegal, and other fire-related activity nodes were separated to differentiate between activities that are and are not permitted under a given scenario (‘legal’ and ‘illegal’, respectively), and those that symbolise broader agrarian challenges (‘other’).

Legal activities are directly controlled by ‘permission measures’, enabling model-users to evaluate the effects of allowing different community-based activities to take place inside the protected area. On the other hand, because illegal and other fire-related activities are affected by a range of socioeconomic variables included in the network (e.g., GDP per capita, resource availability, and food security), each ‘illegal’ and ‘other’ fire-related activity node’s posterior probability is an outcome of the modelling process. Several activities can be legal or illegal depending on the given scenario’s permission measures (e.g., ‘pastoral herding (legal)’ and ‘pastoral herding (illegal)’). It was important to incorporate both nodes in the network to account for the fact that even when an activity is legal and

formally regulated under a given scenario (e.g., pastoral herding permitted under a holistic grazing scheme), permitting community access to the protected area to carry out this activity will inevitably result in the activity and other activities being carried out illegally outside the regulations of the given scenario (e.g., increased encroachment from illegal herders not included in the grazing scheme). To capture this differentiation in the model (i.e., increased likelihood of illegal activity if legal activity is permitted), a ‘community access allowed’ permission measure was added to the network, directly linked to all illegal and other fire-related activities. This facilitates the evaluation of the possible indirect (potentially adverse) effects of legal fire-related activities in the protected area. Unlike illegal fire-related activities, ‘other’ activities cannot be legal under a specific scenario since they represent forms of fire-use associated with agrarian challenges and unsustainable resource extraction.

As discussed in Chapters 2 and 5 (Crocker, Woods & Kountouris, 2023b), legal, illegal, and other fire-related activities also differ in terms of the level of control exercised over the burn, the intentionality of the burn, and its regenerative potential. When an activity is permitted in the protected area, burns are more likely to be intentional and controlled to achieve a specific land management or livelihood objective, thus having a higher regenerative potential. When the same activity is illegally practiced in the protected area, less care, consideration, and time is invested in making sure that the burn does not spread out of control, often unintentionally leading to wildfires. ‘Other’ activities (e.g., ‘agrarian resistance’, ‘poaching’, and ‘human-wildlife conflict’) are associated with intentional uncontrolled fires, often ignited to cause disruption (e.g., political protest) or distract authorities while carrying out an illegal activity, or are a result of careless behaviour where individuals have no ancestral ties to the land or perceived reasons to conserve resources (e.g., ‘external grazing’). These fires are not associated with the regeneration of fire-adapted savanna species.

All fire-related activities present varying levels of wildfire risk, even when the activity itself does not require burning (e.g., ‘ground fuel harvesting’). This is because all community activities within protected areas are associated with survival fires (e.g., fires used for cooking, heating, light provisioning, and safety). Additionally, human presence is associated with other behavioural traits that can lead to wildfires, such as smoking (cigarette butt disposal) and playing (e.g., mimicking burning practices), and general negligence (see Chapter 5, section 5.3).

### **6.3.3.3. Model spatiality**

To date, BNs have mostly been used to model localised species interactions and population dynamics (e.g., Stafford, Williams & Herbert, 2015), and to evaluate policy outcomes consistent with current political and economic conditions (Stafford et al., 2020; Stafford et al., 2024). Having proved effective in modelling outcomes across small spatial and temporal scales, SAV BN expands upon the model developed in Stafford, Williams & Herbert (2015) to evaluate the effects of alternative fire management scenarios across a large geographic area consisting of multiple land-use and tenure types

over a long period of time (up to 2100). Additionally, the main outcomes of interest are spatially explicit, such that we are interested in the effects of different scenarios on wildfires and savanna health within the protected area, and the overall resilience of local livelihoods across the broader conservation landscape. In this model, ‘protected areas’ refer to state-governed or exclusionary national parks and conservancies. ‘Community lands’ refer to ranches, agricultural lands, and rangelands under freehold, leasehold, group, or communal tenure arrangements or customary rights.

To account for this spatiality in the modelled system and understand how change flows and propagates across the conservation area, each node was assigned a single fixed geographical distribution. Nodes were assigned as being ‘All’, ‘PA’ (protected area), or ‘CL’ (community lands) nodes, depending on their location in the network. ‘All’ nodes were present across ‘PA’ and ‘CL’ locations, while ‘PA’ and ‘CL’ nodes were only present inside protected areas or across surrounding community lands, respectively. ‘Climate and environmental’ and ‘wildlife’ nodes included ‘All’ and ‘PA’ nodes, ‘socioeconomic’ nodes included ‘All’ and ‘CL’ nodes, and ‘protected area fire management and policy’ nodes included only ‘PA’ nodes, except for ‘carbon credits’ (classified as an ‘All’ node). Outcome nodes (i.e., dependent variables) were geographically distributed as follows: wildfires (‘PA’), savanna health (‘PA’), and local livelihoods (‘All’). ‘All’ nodes mostly represent large-scale phenomena and processes that transcend human-made boundaries (e.g., ‘temperature’, ‘consecutive dry days’, and ‘agricultural and ecological drought’), or systems variables that might be considered as spatial in nature, but in the context of this study, could not be delineated due to their transboundary effects (e.g., ‘human population’, ‘GDP per capita’, and ‘external markets’). ‘PA’ nodes mostly represent ecological dynamics within the protected area (e.g., ‘soil erosion’, and ‘large herbivores’), as well as aspects of fire management approaches aiming to mitigate wildfires (e.g., ‘controlled burning allowed’, and ‘law enforcement’). ‘CL’ nodes mostly represent socioeconomic processes or human aspects of the system that impact ecological dynamics within the protected area and across the broader conservation area (e.g., ‘water availability’, ‘GHG emissions’, and ‘spatial compression’), but do not typically take place within the protected area. While these geographical boundaries might be less clear or difficult to establish in practical and/or different conservation contexts, they were critical to address the aims of this study considering that BNs are typically non-spatial models.

The network was structured to model the flow of interactions between systems variables and evaluate their impacts across different land tenures and on the three main outcome nodes (wildfires, savanna health, local livelihoods). As such, ‘All’ nodes can directly affect and be directly affected by ‘PA’, ‘CL’, and other ‘All’ nodes. ‘PA’ nodes can directly affect ‘All’ and other ‘PA’ nodes, and be directly affected by ‘All’, ‘CL’, and other ‘PA’ nodes. ‘CL’ nodes can directly affect ‘All’, ‘PA’, and other ‘CL’ nodes, and be directly affected by ‘All’ and other ‘CL’ nodes. ‘PA’ nodes categorised as ‘climate and environmental’ or ‘wildlife’ nodes could not directly affect ‘CL’ nodes, rather they might indirectly

affect ‘CL’ nodes through ‘All’ nodes. For example, in the carbon model, ‘forestation’ (‘PA’ node) directly affects the generation of ‘carbon credits’ (‘ALL’ node) which, in-turn, affects the implementation of ‘state development projects’ and ‘CSR projects’ (both ‘CL’ nodes). This flow of interactions across the conservation landscape explicitly addresses the spatial aspects of the modelled system and aims of the study.

#### 6.3.3.4. Representation status

Given the complexity of nodes included in the network, as well as the number of discrete nodes that are not typically quantified or easily measured (e.g., many of the socioeconomic and protected area nodes), each node was strictly defined based on an extensive literature review, and careful consideration was made over what an increase or decrease in each node represents. As such, each node was assigned a ‘representation status’, stating what a change (increase or decrease) in its prior (i.e., value set to model a specific scenario) or overall posterior value (i.e., outcome of the modelled scenario) represents (Croker 2024). These included: ‘level’ (process or trend), ‘extent’ (geographical coverage), or ‘occurrence’ (event or activity) (Croker, 2024). Having strict definitions, clear geographical locations, and prior representations was important to increase transparency and consistency during the parameterisation process, especially where node titles are not necessarily intuitive, appear to be repetitive, or represent similar processes or events inside and outside the protected area. For example, ‘temperature’ infers relative humidity, and ‘rangelands’ represent the ‘extent and continuity of productive rangelands’ (encompassing processes of land fragmentation, woody thickening, and soil erosion across community lands).

#### 6.3.3.5. Parameterisation and model temporality

Edges (interactions) and edge values (interaction strengths) defining direct cause-effect relationships were based on knowledge of the current system until 2100. Since BNs are typically non-temporal models, the temporal dimension was captured through increasing the `rep()` function value in R and incorporated into the parameterisation of edge values constructing the matrix.

Values between -4 and 4 were used to indicate the degree of belief that an increase in a parent node will directly cause an increase (mathematically positive relationship) or decrease (mathematically negative relationship) in a given child node over a 75-year timeframe (until 2100) under a ‘business-as-usual’ trajectory (i.e., no additional socioeconomic-climate change or fire management intervention). Blank cells in the probability matrix indicate no direct interaction between the two nodes. The direction of the interaction was defined by a + (positive) and - (negative) value. The strength of the interaction was defined by a value between 1 and 4, accounting for magnitude (effect) and certainty (agreement) (see section 6.2). For example, an edge value of (+/-) 4 indicates high certainty over a greater magnitude of change in each node, while a value of (+/-) 1 indicates low

certainty over a lesser magnitude of change in each node. While current predictions following ‘business-as-usual’ trajectories for 2100 show greater magnitudes of change (e.g., larger events and greater impacts), there are also greater uncertainties over future systems dynamics, particularly in unstable ecosystems characterised by reinforcing feedback effects, critical thresholds, and regime shifts (Kinzig et al., 2006; Bodin & Wiman, 2007). Therefore, edge values might be less extreme than if the study was constructed to model a shorter timeframe. To ensure consistency throughout the parameterisation process, Table 15 was adapted from Dominguez Almela, Croker & Stafford, (2024) to provide guidance on assigning edge values and prior nodes.

**Table 15.** *Parameterisation of edge and prior values in SAV BN.*

| Integer value | Probability distribution value | Edge value                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Prior value                                                             |
|---------------|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| 4 (or -4)     | 0.9 (0.1)                      | Strong relationship between parent and child node, with clear cause-and-effect relationship. High (> 95%) agreement between sources supporting the relationship.                                                                                                                                                                                                                                                                                           | Large magnitude of change (75-100%) under modelled scenario.            |
| 3 (or -3)     | 0.8 (0.2)                      | Strong relationship between parent and child node, with clear cause-and-effect relationship. Moderately high (>75%) agreement between sources supporting the relationship.<br>OR<br>Moderate relationship between parent and child node, with some difference detectable (might not be obvious) in cause-and-effect relationship. Full agreement (>95%) agreement between sources supporting the relationship.                                             | Moderate to large magnitude of change (50-75%) under modelled scenario. |
| 2 (or -2)     | 0.7 (0.3)                      | Moderate relationship between parent and child node, with some difference detectable (might not be obvious) in cause-and-effect relationship. Moderately high (>75%) agreement between sources supporting the relationship.<br>OR<br>Weak relationship between parent and child node, with difference detectable (might not be significant) in cause-and-effect relationship. Full agreement (>95%) agreement between sources supporting the relationship. | Small to moderate magnitude of change (25-50%) under modelled scenario. |
| 1 (or -1)     | 0.6 (0.4)                      | Weak relationship between parent and child node, with difference detectable (might not be significant) in cause-and-effect relationship. Moderately high (>75%) agreement between sources supporting the relationship.                                                                                                                                                                                                                                     | Small magnitude of change (1-25%) under modelled scenario.              |
| 0             | 0.5                            | No relationship, or large disagreement between sources.                                                                                                                                                                                                                                                                                                                                                                                                    | No direct change.                                                       |

Edges parameters were defined over several steps (Fig. 10). Firstly, the researchers drew on previous systematic reviews, additional literature searchers, and their own knowledge to define edges and edge values (together, ‘edge parameter’), iteratively revising parameters over the course of the study period in light of new evidence and research (approx. two years) (Choy, O’Leary & Mengersen, 2009).

Secondly, empirical data collected in Kenya was semi-quantitatively (questionnaires) and qualitatively (interviews and focus groups) analysed to identify additional nodes in the network and define edge parameters. For example, where Likert-scale data highlighted direct causal relationships

between two systems variables, such as between ‘biogeophysical wildfire conditions’ and ‘wildfires’, ‘wildfires’ and ‘biodiversity’, and ‘inter-group conflict’ and various ‘fire-related activities’, median values were used to help determine edge values. For example, a median value of 2 (‘agree’) for ‘pastoralists unintentionally cause wildfires when burning for pasture regrowth’ was expressed as a positive edge value of 2 or 3 between ‘pastoral herding (legal)’/‘pastoral herding (illegal)’ and ‘wildfire’.

Thematically coded interview data also provided detailed insights into cause-effect relationships between systems variables included in this model, such as the drivers and impacts of inter-group conflict, sedentarisation, and land sub-division, as well as the extent to which wildfires can be attributed to various local burning practices. Edge parameters deduced through thematic analysis were numerically valued based on the number of times a given interaction was mentioned and the stated magnitude and/or conviction over the interaction. For example, 22 and 14 interviewees strongly attributed wildfires inside protected areas to illegal grazing practices and cultural practices, respectively. Hence, edges were valued to reflect these beliefs.

Edge parameters were independently derived from different methodologies. For instance, edge parameters derived from questionnaire analyses did not influence those derived from interview data, and they were recorded in three separate ‘calibration columns’ in the model database (initial; questionnaire analysis; thematic analysis). Lastly, experts were invited to participate in parameterising SAV BN to help identify systems variables and direct causal pathways deemed the most important or influential (Aguilera et al., 2011). Experts were not required to have full scientific knowledge of the modelled system, rather aspects of the system or knowledge of similar geographical contexts worldwide.

#### **6.3.3.6. Expert elicitation**

The benefits of eliciting expert knowledge to parameterise BBNs are widely reported in the literature, particularly when data is limited and experts can assist in identifying additional systems variables to more accurately represent the modelled system (Cain, 2001; Choy, O’Leary & Mengersen, 2009; Newton, 2009; McDonald, Ryder & Tighe, 2015). However, best practices for eliciting this knowledge are often not discussed. There is a growing body of evidence supporting structured elicitation protocols in the development of predictive models to minimise contextual biases and the effects of anchoring and overconfidence on belief judgements, and improve model accuracy and transparency (Brady, 2015; Hemming et al., 2018; Burgman, Layman & French, 2021).

In many cases, BBNs are used to model complex systems which require many input variables and interactions to be parameterised to effectively represent real-life systems. This can place a large burden on experts, increasing cognitive loads, risk of fatigue, and, subject to existing cognitive biases,

result in rapid, informal, and random quantification and inconsistencies (Hassall et al., 2019; Barons, Mascaro & Hanea, 2022). Experts often do not have the resources (e.g., time) to engage in formally structured elicitation protocols used to parameterise such complex networks, therefore are more likely to opt out of the study (Landuyt et al., 2013). While BNs address some of these challenges, requiring experts to only state conditional independence assumptions for known variables and interactions in the system, the sheer amount of information presented to experts can counteract these benefits. To increase participation and remove some of this cognitive load, a draft codebook (now database available at Croker (2024a)) including a comprehensive list of defined nodes and edge parameters calibrated in stage one (literature review) was sent to a wide range of experts spanning multiple disciplines and research contexts. No formal structured elicitation protocol was applied (a potential limitation of this study), rather experts who were known to the researchers, have authored related papers or been involved in related studies, or have featured previously in this study (e.g., systematic reviews), were invited to participate, and snowball sampling was encouraged.

The decision to send experts a codebook including existing edge values rather than asking them to value interactions independently came down to a question of how expert knowledge was being used in this study – was it to construct, develop, or validate the model? Since SAV BN was already constructed through previous calibration stages and incorporated several features that are atypical of BBNs (e.g., space, time, and multiple socioeconomic and policy nodes difficult to quantify), providing a full list of existing edge values was perceived as being more beneficial to increase participation. For example, by significantly reducing time commitments, cognitive loads, and minimising potential errors or discrepancies likely resulting from individual biases (Pitchforth & Mengersen, 2013). While this approach might in itself have created biases by influencing experts responses (e.g., anchoring and framing bias), experts were encouraged to draw on their own knowledge base, highlighting areas of agreement and disagreement with existing and edge parameters, and stating additional nodes or interactions that should be added to the network. In cases where experts disagreed with the existing edge parameters, they were asked to state why they disagreed and reference conflicting evidence. All individual responses were standardised using a ‘certainty x magnitude matrix’ (Table 15) to derive a singular edge value for each interaction included in the network. While there were no large disagreements between experts, or with existing edge values, minor disagreements were reflected in the node’s final value (e.g., greater disagreement equates to less certainty over the interaction), therefore helping to minimise bias and false relationships (Martin et al., 2012).

All new nodes and edges added to the network during calibration stages 2, 3, and 4 were cross-checked in the literature. Final edge values were determined by calculating the mode value for each interaction across the four calibration stages. Since ‘expert knowledge and empirical data exist on a continuum of subjectivity, [...] Both require validation’ (Martin et al., 2012). As such, SAV BN was

later validated via means of a randomised bootstrapped sensitivity analysis to assess how probabilities propagate throughout the network (Barons, Mascaro & Hanea, 2022). This is a particularly important step in the development of BNs with a large number of uncertain interactions and where absent edge values imply conditional independence.

#### 6.3.4. Scenario priors

To model the effects of each socioeconomic-climate and fire management scenario, several nodes ('prior nodes') that best represented or captured the scenario were selected (e.g., where change is known or projected to occur), and their prior values were changed to a value between -4 (0.1) and 4 (0.9). Prior values indicate the belief that a given node may increase ( $P(X_i)$ ) or decrease ( $P(X_d)$ ) under the scenario of interest, and the sum of the probability of an increase and decrease must equal 1. For example, under a CDI scenario, global warming is projected to increase to between 2-4°C above pre-industrial levels in 2100, and annual GDP is expected to decline by approximately 4.5-11.2% per year (Croker, 2024). Therefore, prior values for 'temperature' and 'GDP per capita' were set to 3 (0.8) and -3 (0.2), respectively.

Tables 16, 17, and 18 provide a full list of prior nodes altered for each scenario. For other nodes in the network, there was no prior knowledge of them changing under the specific scenario, thus their prior value was set to 0 (0.5). The effects of each scenario on systems variables were determined by the model as change in their prior nodes propagate throughout the network. This was calculated using the following Bayesian equation:  $P(X_i|Y) = [P(X_i|Y_i) * P(Y_i) + P(X_i|Y_d) * P(Y_d)]$ , where  $X$  is the node under consideration and  $Y$  are the interacting nodes. Probabilities were calculated for each interacting node in the network (Stafford, Williams & Herbert, 2015). A semi-quantitative scale based on the certainty-magnitude matrix used to parameterise edge and prior values was applied to evaluate the modelled outputs, ensuring some consistency in the interpretation of results (Table 19) (Varis, Rahaman & Kajander, 2012; Almela, Croker & Stafford, 2024). Modelled probability distribution values were not converted back to their equivalent integer values in this study; however, this can be included in future studies using the new BBN Package on R software (Almela, Croker & Stafford, 2024).

Prior nodes 'temperature' and 'human population' were also included as input nodes in SAV BN due to certainty over their consistent increase across best, intermediate, and worst-case scenarios. All other prior nodes were included as intermediate nodes, forming the basis of each modelled scenario (i.e., change in prior value), but also changing to reflect positive and negative interactions with other nodes in the network. Prior nodes selected to model fire management scenarios mostly consisted of 'permission measures' and 'intervention measures'. However, 'fire suppression and prevention' and 'holistic grazing scheme' also included socioeconomic variables as prior nodes. The former included 'management rights' considering strong evidence suggesting that fire suppression prevents the decentralisation of management rights to local communities (e.g., no formal 'community regulations' developed) (Croker, Woods & Kountouris, 2023b), and the latter included 'cattle – livestock' and 'sheep – livestock' due to evidence on the commercialisation of livestock production systems when lease agreements are established between park authorities and herders (Chapter 5).

**Table 16.** Joint Socioeconomic-climate Scenarios (SSPX-Y)

| Scenario                      | Priors                      | Prior integer | Prior value |
|-------------------------------|-----------------------------|---------------|-------------|
| Green climate ambition        | Temperature                 | 2             | 0.7         |
|                               | Human population            | 1             | 0.6         |
|                               | GDP per capita              | -1            | 0.4         |
|                               | State development project   | 2             | 0.7         |
|                               | Large-scale land investment | 1             | 0.6         |
|                               | Inter-group conflict        | -1            | 0.4         |
|                               | Marginalisation             | 1             | 0.6         |
| Climate delay and inequality  | Temperature                 | 3             | 0.8         |
|                               | Human population            | 2             | 0.7         |
|                               | GDP per capita              | -3            | 0.2         |
|                               | Large-scale land investment | 1             | 0.6         |
|                               | Inter-group conflict        | 4             | 0.9         |
|                               | Rapid urbanisation          | 3             | 0.8         |
| Fossil-fuelled climate denial | Temperature                 | 4             | 0.9         |
|                               | Human population            | 3             | 0.8         |
|                               | GDP per capita              | -4            | 0.1         |
|                               | Large-scale land investment | 4             | 0.9         |
|                               | Inter-group conflict        | 4             | 0.9         |

**Table 17.** Fire Management Scenarios

| Scenario<br>(c) centralised<br>(dc) decentralised | BN Model          | Priors                   | Prior integer | Prior value |
|---------------------------------------------------|-------------------|--------------------------|---------------|-------------|
| Fire suppression and prevention                   | No carbon credits | Management rights        | -2            | 0.3         |
|                                                   |                   | Plantations              | 2             | 0.7         |
|                                                   |                   | Law enforcement          | 2             | 0.7         |
|                                                   |                   | Firefighting capacity    | 3             | 0.7         |
|                                                   |                   | Fire management systems  | 1             | 0.6         |
| REDD+                                             | Carbon credits    | Plantations              | 4             | 0.9         |
|                                                   |                   | Law enforcement          | 3             | 0.8         |
|                                                   |                   | Firefighting capacity    | 3             | 0.8         |
|                                                   |                   | Fire management systems  | 2             | 0.7         |
| SBEA scheme<br>(c)                                | Carbon credits    | Prescribed EDS allowed   | 3             | 0.8         |
|                                                   |                   | Plantations              | 3             | 0.8         |
|                                                   |                   | Law enforcement          | 3             | 0.8         |
|                                                   |                   | Firefighting capacity    | 3             | 0.8         |
|                                                   |                   | Fire management systems  | 4             | 0.8         |
| SBEA scheme<br>(dc)                               | Carbon credits    | Community access allowed | 1             | 0.6         |
|                                                   |                   | Prescribed EDS allowed   | 3             | 0.8         |
|                                                   |                   | Plantations              | 3             | 0.8         |
|                                                   |                   | Law enforcement          | 3             | 0.8         |
|                                                   |                   | Firefighting capacity    | 3             | 0.8         |
|                                                   |                   | Fire management systems  | 4             | 0.8         |
|                                                   |                   | Community regulations    | 1             | 0.6         |
| Flexible prescribed burning<br>(c)                | No carbon credits | Prescribed EDS allowed   | 3             | 0.8         |
|                                                   |                   | Prescribed LDS allowed   | 2             | 0.7         |
|                                                   |                   | Prescribed WS allowed    | 1             | 0.7         |
|                                                   |                   | Law enforcement          | 3             | 0.8         |
|                                                   |                   | Firefighting capacity    | 4             | 0.9         |

|                                     |                   |                            |   |     |
|-------------------------------------|-------------------|----------------------------|---|-----|
|                                     |                   | Fire management systems    | 4 | 0.9 |
| Flexible prescribed burning<br>(dc) | No carbon credits | Community access allowed   | 1 | 0.6 |
|                                     |                   | Prescribed EDS allowed     | 3 | 0.8 |
|                                     |                   | Prescribed LDS allowed     | 2 | 0.7 |
|                                     |                   | Prescribed WS allowed      | 1 | 0.7 |
|                                     |                   | Law enforcement            | 3 | 0.8 |
|                                     |                   | Firefighting capacity      | 4 | 0.9 |
|                                     |                   | Fire management systems    | 4 | 0.9 |
|                                     |                   | Community regulations      | 2 | 0.7 |
| Flexible prescribed burning<br>(c)  | Carbon credits    | Prescribed EDS allowed     | 3 | 0.8 |
|                                     |                   | Prescribed LDS allowed     | 2 | 0.7 |
|                                     |                   | Prescribed WS allowed      | 1 | 0.7 |
|                                     |                   | Law enforcement            | 3 | 0.8 |
|                                     |                   | Firefighting capacity      | 4 | 0.9 |
|                                     |                   | Fire management systems    | 4 | 0.9 |
| Holistic grazing scheme<br>(dc)     | No carbon credits | Community access allowed   | 3 | 0.7 |
|                                     |                   | Grazing allowed            | 4 | 0.8 |
|                                     |                   | Law enforcement            | 3 | 0.8 |
|                                     |                   | Firefighting capacity      | 3 | 0.8 |
|                                     |                   | Fire management systems    | 2 | 0.7 |
|                                     |                   | Community regulations      | 3 | 0.8 |
|                                     |                   | <i>Cattle livestock</i>    | 2 | 0.7 |
|                                     |                   | <i>Shoats livestock</i>    | 2 | 0.7 |
| Fuel harvesting scheme<br>(c)       | No carbon credits | Fuel harvesting allowed    | 4 | 0.8 |
|                                     |                   | Law enforcement            | 3 | 0.8 |
|                                     |                   | Firefighting capacity      | 3 | 0.8 |
|                                     |                   | Fire management systems    | 2 | 0.7 |
|                                     |                   | Community regulations      | 1 | 0.6 |
| Fuel harvesting scheme<br>(dc)      | No carbon credits | Community access allowed   | 3 | 0.8 |
|                                     |                   | Fuel harvesting allowed    | 4 | 0.8 |
|                                     |                   | Law enforcement            | 3 | 0.8 |
|                                     |                   | Firefighting capacity      | 3 | 0.8 |
|                                     |                   | Fire management systems    | 2 | 0.7 |
|                                     |                   | Community regulations      | 3 | 0.8 |
| CBFiM                               | No carbon credits | Community access allowed   | 4 | 0.9 |
|                                     |                   | Controlled burning allowed | 4 | 0.9 |
|                                     |                   | Law enforcement            | 3 | 0.8 |
|                                     |                   | Firefighting capacity      | 3 | 0.8 |
|                                     |                   | Fire management systems    | 3 | 0.8 |
|                                     |                   | Community regulations      | 4 | 0.9 |

**Table 18.** *Additional Fire Management Scenarios*

| Scenario<br>(c) centralised<br>(dc) decentralised | BN Model       | Priors                   | Prior<br>integer | Prior<br>value |
|---------------------------------------------------|----------------|--------------------------|------------------|----------------|
| SBEA scheme<br>(dc); greater (dc)                 | Carbon credits | community_access_allowed | 3                | 0.8            |
|                                                   |                | prescribed_EDS_allowed   | 3                | 0.8            |
|                                                   |                | plantations              | 3                | 0.8            |
|                                                   |                | law_enforcement          | 3                | 0.8            |

|                            |                |                          |   |     |
|----------------------------|----------------|--------------------------|---|-----|
| SBEA scheme (dc); flexible | Carbon credits | firefighting_capacity    | 3 | 0.8 |
|                            |                | fire_management_systems  | 4 | 0.8 |
|                            |                | community_regulations    | 4 | 0.9 |
|                            |                | community_access_allowed | 1 | 0.6 |
|                            |                | prescribed_EDS_allowed   | 3 | 0.8 |
|                            |                | prescribed LDS allowed   | 2 | 0.7 |
|                            |                | plantations              | 3 | 0.8 |
|                            |                | law_enforcement          | 3 | 0.8 |
|                            |                | firefighting_capacity    | 3 | 0.8 |
|                            |                | fire_management_systems  | 4 | 0.8 |
|                            |                | community_regulations    | 4 | 0.6 |

**Table 19.** Semi-quantitative scale used for scenario analysis of modelled outcomes.

| Modelled probability distribution value | Equivalent integer value | Representation status (i.e., what an increase or decrease in overall posterior value represents) under modelled scenario |
|-----------------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------|
| 0.9 (0.1)                               | 4 (or -4)                | Large magnitude of change (75-100%)                                                                                      |
| 0.8 (0.2)                               | 3 (or -3)                | Moderate to large magnitude of change (50-75%)                                                                           |
| 0.7 (0.3)                               | 2 (or -2)                | Small to moderate magnitude of change (25-50%)                                                                           |
| 0.6 (0.4)                               | 1 (or -1)                | Small magnitude of change (1-25%)                                                                                        |
| 0.5                                     | 0                        | No change                                                                                                                |

### 6.3.5. Intervention measures

‘Intervention measures’ were included as input nodes in SAV BN to model the effects of greater investment in, resourcing, and the prioritisation of various management interventions under different approaches. A combination of intervention and permission measures were used to model each fire management approach. Intervention measures, including ‘law enforcement’, ‘firefighting capacity’, ‘fire management systems’, and ‘community regulations’, are difficult to quantify using traditional metrics and do not typically represent discrete random variables (Barton et al., 2012; Varis, Rahaman & Kajander, 2012). ‘Plantations’ is the exception in this model, such that an increase or decrease in this node can be understood as the extent of plantation coverage inside the protected area under a given carbon-based scheme or economic policy. Each of the other intervention measures can represent or include a range of variables depending on the management approach and broader systemic context. This makes it increasingly difficult to draw on relational reasoning as the modelled system gets larger and more complex, subsequently resulting in erroneous discretisation assumptions with significant influence over causal links within the network (Barton et al., 2012). For example, when using BBNs to conduct an exploratory (rather than normative) scenario analysis for policy impacts on ecosystem services or species populations across a small geographical area (e.g., Varis & Fraboulet-Jussila, 2002; Stafford, Williams & Herbert, 2015; May et al., 2019), it is generally easier to draw upon existing data and empirical evidence (e.g, published ecosystem management plans and case-study-specific

qualitative and quantitative data) to define what an intervention measure, such as law enforcement, represents.

Given the size and complexity of SAV BN, ‘intervention measures’ implemented within a savanna-protected area often require a landscape approach. For example, increasing firefighting capacities to mitigate wildfire challenges inside protected areas requires the development of good communication networks and cooperative relationships across all actors (incl. local communities), as well as invested support for the establishment of trained community firefighting brigades to assist park rangers when wildfires exceed their capacities. Technically, there is no one understanding of intervention measures included in this model, such that they include a range of actions that could be implemented.

Considering these ambiguities, a detailed narrative was constructed to explain each intervention measure and the range of possible actions that could be taken to implement them, thus promoting transparency and consistency in the interpretation of modelled outcomes. Fieldwork data described in Chapter 5, section 5.4, had a strong influence over the development of these narratives (see Croker, 2024).

#### **6.4. Sensitivity Analysis**

Model validation is a critical process in predictive modelling to assess its accuracy, robustness, and generalisability, thus can help determine how reliable and capable the model is in making accurate predictions in real-life contexts. Validation assessments can help identify which interactions have the largest influence on model outcomes and, therefore, should be subject to closer scrutiny (McDonald, Ryder & Tighe, 2015), requiring a greater amount of data or higher certainty (and agreement) to parameterise, such as through additional literature searches and empirical research (Smith et al., 2024).

Robust model validation tools are often not discussed or absent from BBN studies, despite the broad range of validation techniques available to researchers. Where model validation has been conducted, data-driven techniques have mostly been applied (Barton et al., 2012; Landuyt et al., 2013), such as testing how well the model can predict a data set that has previously been excluded from the data set used to estimate the parameters (e.g., (Stafford, Williams & Herbert, 2015)). However, in data-limited environments, or where the model is being used to predict future scenarios or scenarios that have never taken place, or at least observed (e.g., new policy outcomes or future environmental change), data-driven techniques are limited in their application (Barton et al., 2012). Without supporting data, BBNs have commonly been perceived as subjective, inaccurate, or ‘unscientific’ (Busch et al., 2012; Landuyt et al., 2013), restricting their use in many environmental contexts worldwide. More recently, expert and stakeholder-based validation techniques or sensitivity analyses that do not depend on existing data but instead draw on empirical evidence, theoretical knowledge, and information from related disciplines and similar geographical contexts, have been conducted to validate BBNs across

environmental disciplines. This has and continues to require the validity of models to be considered in a wider context, beyond that of quantitative data analysis, including the degree to which a model's network reflects the findings of existing publications and understandings of the system's causal interactions and pathways (Barton et al., 2012).

Since BNs relate magnitude of change to certainty between sources, and that 'confidence' in the network structure is both a statistical fact and a subjective belief, it is difficult to distinguish between a probability of increase or decrease (agreement), and a magnitude of increase or decrease (effect). If an increase in a system variable is likely to be large, it is typically more likely to occur than a small increase. Similarly, if a decrease is likely to be small, it is less likely to occur than a large decrease. Considering the interrelatedness of certainty and magnitude, and inherent uncertainties in the network (incl. variation in the 'confidence' of stated beliefs), computational sensitivity analyses can identify interactions which have significant impacts on the model outcomes, therefore revealing where subjectivities require additional scrutiny (Stafford et al., 2020).

#### **6.4.1. Randomised bootstrapped sensitivity analysis**

A randomised bootstrapped sensitivity analysis was conducted using R software to determine overall changes to posterior node values (Almela, Croker & Stafford, 2024). The bootstrap method is used in predictive systems dynamics modelling as a resampling approach to account for uncertainties in the data and absence of unidentified systems variables. Bootstrap samples are generated from the original data set by resampling with replacement, generating bootstrap replicates (i.e., resamples of the original data set) used to estimate the variability of a data point (e.g., edge parameter) model (Dogan, 2007; Rahmandad, Oliva & Osgood, 2015). This approach is applied to assess the overall accuracy of the model, including how information flows through the network and influences model outcomes, understand inherent uncertainty arising from the parameterisation of edge values and priors (e.g., interrelatedness of certainty and magnitude), and help justify assigned directions and strengths of causal interactions (Dominguez Almela & Stafford, 2024).

Initial bootstrapped sensitivity analyses were carried out during the development of socioeconomic-climate and fire management scenarios to assess the model's functioning when prior nodes were changed, checking whether the modelled outcomes broadly met expectations.

The final sensitivity analysis was conducted on all three models ('no carbon', 'carbon', and 'carbon + plant diversity') to provide a list of the most important edge parameters with the highest cumulative impact on outcome nodes, with importance increasing with numerical value (i.e., frequency number<sup>44</sup>)

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<sup>44</sup>Frequency number states how many times a modified interaction between two nodes appears as having a significant effect on changes to the specified outcome nodes. For example, edge parameters were counted as important every time they were changed in the analysis, hence were in the 25% of bootstrapped cases which had the largest effects on model outcomes.

(Almela, Croker & Stafford, 2024). This analysis involved bootstrapping the outputs of the model to create probability distributions centered at the observed result (i.e., assigned edge value), selecting 10% of the network interactions and adjusting their conditional probability edge values by a randomly determined amount of up to  $\pm 0.1$  (Stafford et al., 2020). This process was run 50-100 times for the initial exploratory analyses, and 1000 times for the final analysis, and 95% confidence intervals were calculated by removing the lowest and highest 2.5% of values for each posterior node (e.g., Crawley, 2012). These confidence intervals were applied to the actual values (without adjustment) calculated by the model using the initial interaction matrix. Thirty-three edge parameters (approx. 10% of the total number of edges) were identified as having the highest cumulative impact on outcomes nodes and were checked in the literature and with independent experts (Wang, Robertson & Haines, 2009). This was repeated for each model.

To additional sensitivity analyses were conducted on (i) a ‘reduced carbon model’ to test the robustness of the model when a random 10% of systems variables were removed from the network<sup>45</sup>, and (ii) the ‘carbon’ model to test the model’s performance under a randomly generated scenario. An online random sampling tool ([dcode.fr/random-sampling](https://dcode.fr/random-sampling)) was used to select 10% of network’s nodes and adjust their prior values to a number between -4 and 4 (converted to probability distribution values for the analysis (Table 15))<sup>46</sup>. This random scenario did not represent a real-life situation, but the results were used to assess the model’s robustness to subjective interpretations of modelled scenarios (i.e., when prior nodes and values are selected by researchers to model a given scenario), as well as how well the modelled outcomes agree with existing beliefs and understandings of the system’s causal pathways.

#### 6.4.2. Sensitivity analysis results and modifications

Initial exploratory analyses revealed a couple of issues that required addressing before running the final sensitivity analysis. Firstly, unlike most traditional BBNs, several of the nodes in BNs are both input and output nodes, such that they are included as prior nodes to model scenarios but should also change to reflect positive and negative interactions with other nodes in the network. By changing the value of prior nodes by a fixed amount to model a given scenario (Tables 16-18), you are essentially fixing the node, such that interactions with other nodes in the system (incl. feedback effects, reciprocal relations, and potential emergent dynamics) were mostly negated, particularly where the prior node had a low number of parent nodes (e.g., only one node directly affecting it). In cases where  $\geq 1$  node directly affected the prior node, some additional change in the prior node was observed,

<sup>45</sup>Removed variables included: water availability, agricultural intensification and commercialisation, cattle - livestock, sedentarisation, firefighting capacity, community access allowed, grazing allowed, land-use – agriculture (legal), cultural practices (illegal).

<sup>46</sup>Randomly selected variables included: temperature (-3), vegetation continuity (-2), human population (-4), human development conditions (3), agricultural intensification and commercialisation (2), technological resources (-4), bushmeat hunting (legal) (-1), subsistence harvesting (legal) (1), and illegal cultivation (4).

however this was insignificant and mostly affected confidence intervals rather than the value of the node increasing or decreasing under the given scenario. As such, nodes for each of the socioeconomic-climate and fire management scenarios were added to the model as scenario nodes (input nodes), with each scenario node directly linked to each of its assigned prior nodes, and edge values between the scenario node and assigned prior nodes representing this fixed increase or decrease. To model a given scenario (e.g., ‘fire suppression and prevention’ under ‘FFCD’ future), the prior values of the relevant scenario nodes were set to 5 (1), and all other node values were set to 0 (0.5). Only scenario nodes can be assigned prior values of 5 to model their effects on the network and avoid some signal loss. All edge values been interactions constituting the network, and prior values of nodes not included as scenario nodes (e.g., if modelling a nuanced scenario and selected nodes within the network to represent the scenario), must retain integer (probability distribution) values between -4 and 4 (0.1-0.9).

Secondly, the results raised questions over ‘what constitutes cause and what constitutes effect’ between modelled interactions. The results highlighted important, yet absent edge parameters, self-reinforcing feedback loops in the network, and nodes that simply served as intermediaries between other nodes that could be directly linked, thus having diluting effects as change propagated throughout the network. Some additional edge parameters were added to the network in this process in light of emerging evidence. For example, between ‘inter-group conflict’ and ‘carbon credits’ to account for the reported effects of international insecurity, a resurgence in nationalism, disparity in economic growth, and a lack of democratic legitimization on economic policy uncertainty and associated volatility shocks in financial and carbon markets (Dhakal, 2009; McAfee, 2012; Stephan & Lane, 2014; Blum, 2020; Adekoya, Oliyide & Noman, 2021).

Eleven nodes were identified as being already accounted for or inferred by other nodes in the network, thus were removed and explicitly incorporated into these existing nodes. In this regard, their existing edge parameters were considered in the included node, and node descriptions were updated to make explicit how included nodes represented removed nodes (see Croker, 2024). This information is provided in Appendix IV, including a short justification explaining why these nodes were amalgamated. All included nodes were re-checked in the existing literature and with independent experts.

A total of 115 edge parameters were identified across the five (three model and two additional) final analyses as having the highest cumulative impact on the outcome nodes. Seven edge parameters were identified across  $\geq 1$  of the sensitivity analyses conducted on the three network models: (i) ‘resource availability  $\rightarrow$  poaching’, (ii) ‘large herbivores  $\rightarrow$  vegetation continuity’, (iii) ‘fire management systems  $\rightarrow$  biocultural hysteresis’, (iv) ‘subsistence harvesting (legal)  $\rightarrow$  surface fuel load’, (v) ‘inter-group conflict  $\rightarrow$  land sub-division’, (vi) ‘rangelands  $\rightarrow$  agropastoralism’, (vii) ‘resource availability

→ agrarian resistance’. All identified edge parameters, particularly recurring edge parameters and those defined to model scenarios (e.g., scenario and linked prior nodes), were carefully checked in the literature, fieldwork data, and with independent experts. Considering the strong network effects of scenario and their linked prior nodes, these edge parameters were also scrutinised against their respective narratives. The full set of results are displayed in Croker (2024a) (worksheet ‘Node Interaction Matrix’).

Neither of the two experimental analyses significantly altered model outcomes and only eight edge parameters were altered after justification in the literature, fieldwork data, and via expert opinion, therefore demonstrating the robustness of the model: (i) ‘GDP per capita → human development conditions’ (from 0.9 to 0.8), (ii) ‘CSR project → human development conditions’ (from 0.8 to 0.7), (iii) ‘CSR project → human-wildlife conflict’ (from 0.2 to 0.3), (iv) ‘CSR project → charcoal burning’ (from 0.2 to 0.3), (v) ‘prescribed EDS burning → surface fuel load’ (0.2 to 0.3), (vi) ‘prescribed WS burning → ghg emissions’ (0.2 to 0.3), (vii) ‘controlled burning allowed → pastoral herding (legal)’ (0.6 to 0.7), and (viii) ‘controlled burning allowed → subsistence harvesting (legal)’ (0.6 to 0.7). Changes to (vi) and (viii) were made in keeping with changes made to interactions identified in the sensitivity analysis, rather than being directly identified in the analysis.

## 6.5. Final model runs

The three joint socioeconomic-climate scenarios (GCA, CDI, FFCD) were run independently to assess potential changes in systems dynamics and modelled outcomes under no additional fire management (i.e., ‘no policy’ scenario). This provided a baseline to compare opportunities and challenges for alternative fire management approaches against the current suppression and response model (with no additional intervention). Fifteen fire management scenarios were run in total: seven discrete fire management scenarios (Table 14) and eight further iterations of these discrete scenarios to model changes in their governance structure (e.g., centralised versus decentralised) or application (e.g., no carbon versus carbon finance mechanism). This included:

- ‘No carbon model’: fire suppression and prevention; flexible prescribed burning (centralised and decentralised); holistic grazing scheme (decentralised); fuel harvesting (centralised and decentralised); CBFiM.
- ‘Carbon model’: REDD+; REDD+ (+ plant diversity); SBEA (centralised and decentralised); SBEA (+ plant diversity); SBEA (flexible burning/+ plant diversity); flexible prescribed burning (centralised); flexible prescribed burning (+ plant diversity).

Each scenario was run under each of the three joint socioeconomic-climate scenarios to evaluate their effectiveness in mitigating wildfires, improving savanna health, and supporting resilient local livelihoods resilience up to 2100. Considering dynamism and uncertainties in the modelled system,

95% confidence limits were calculated from 1000 bootstrap replicates for every scenario. Edge parameters were not adjusted in the first run of each modelled scenario. This result is presented as the ‘increase’ value for each node in the network. The increase value and bootstrapped 95% confidence limits show the probability distribution of a node increasing or decreasing in response to an implemented fire management approach under future socioeconomic-climate change.

An ‘increase’ value of 0.5 (no change) for any given node under a fire management and socioeconomic climate scenario suggests that the node is largely characteristic of present-day conditions. This result might be due to the node not being affected by the modelled scenario (i.e., not relevant or activated), or imply that the node exhibits a degree of resilience or plasticity under future GCA, CDI, and FFCD conditions. To tell the difference between no affect and resilience, the former’s confidence limits will also be 0.5, whereas the latter’s will vary.

These results are presented and discussed in Chapter 7, consistently referring to the database (Crocker, 2024) and previous discussions presented in Chapters 2, 4, and 5.

## 6.6. Considerations

Several considerations require explicit acknowledgement to effectively interpret the results and for future model use and development. To probabilistically evaluate alternative fire management approaches, scenario and prior nodes need to be fixed. This assumes, to some extent, that these interactions are known. However, given the complexity (e.g., dynamic savanna ecosystem) and temporality (e.g., edge parameters based on current knowledge and projections up to 2100) of SAV BN, non-linear processes and emergent behaviours currently unaccounted for might occur as a result of intricate causal relations across meta-coupled systems over space and time (Hill & Hanan, 2010; Ratter, 2012; Liu, 2017). Therefore, it is important to treat outcomes as probabilistic dependencies to inform future management, subject to some variation. Additionally, Chapters 2, 4, and 5 reveal the multi-systemic challenges that (in)directly affect wildfires and their management across conservation landscapes. As such, specific changes in policy and management in other sectors will impact the modelled system and outcomes. For example, the effective implementation of the DFZ programme in Kenya, increased charcoal regulations, crackdown on the illicit tobacco and wildlife trafficking industries, and new trade relations and market reforms will reconfigure the policy domain in which wildfires are governed.

These challenges also influence savanna health and local livelihoods. Since this study models alternative fire management scenarios, thus directly controls for fire-related intervention measures which (in)directly affect savanna health and local livelihoods, these outcomes are largely a result of systems dynamics, rather than targeted policy. As such, the results presented in Chapter 7 reveal potential opportunities for fire management to address ecological degradation and livelihood

vulnerabilities, but also where fire-focused management approaches fall short. Through further network analyses, we can identify systems variables affecting these outcomes and, therefore, areas requiring further research and targeted policy and management.

Lastly, including ‘intervention measures’ as input nodes to model fire management scenarios (Tables 16-18), where in the case of ‘firefighting capacity’ and ‘fire management systems’ directly affect ‘wildfire’, can have fixing effects on modelled outcomes. While this was important to increase model transparency in the context of this research and provide a landscape-scale comparative analysis (see section 6.3.5), it also reduces the complexity of these variables and potential feedbacks within the system resulting from their implementation. Hence, future studies focusing on a specific protected area where there is knowledge of existing management actions and plans, might consider breaking these down into multiple, more focused nodes.

## Chapter 7. SAV BN: an analysis of alternative fire management approaches

In total, SAV BN generated 48 sets of results. Each set of results presents the ‘increase’ value and confidence limits for each of the 82 and 83 nodes included in the ‘no carbon’ and ‘carbon’ networks, respectively. The full set of modelled results are available on request. Considering this high volume of data, one iteration for each of the seven discrete fire management scenarios was selected to be presented and discussed in this thesis (Table 20).

**Table 20.** Key Fire Management Scenarios visualised in this thesis.

| Fire Management Scenario                       | Implementation Approach | Model             | Reason                                                    |
|------------------------------------------------|-------------------------|-------------------|-----------------------------------------------------------|
| Fire suppression and prevention                | Centralised             | No carbon credits | Likely approach                                           |
| Holistic grazing scheme                        | Decentralised           | No carbon credits | Locally-relevant approach                                 |
| Fuel harvesting                                | Decentralised           | No carbon credits | Locally-relevant approach                                 |
| CBFiM                                          | Decentralised           | No carbon credits | Proposed bottom-up approach                               |
| REDD+                                          | Centralised             | Carbon credits    | Increasing across conservation landscapes                 |
| SBEA                                           | Decentralised           | Carbon credits    | Proposed carbon accounting methodology in protected areas |
| Flexible prescribed burning (+plant diversity) | Centralised             | Carbon credits    | ‘Blue sky thinking’ scenario                              |

These scenarios were selected based on their likelihood of being implemented in an East African savanna-protected area, local relevance, current political-economic salience, and potential ecological benefits. Consistent with the aims of this thesis, where fire scenarios present opportunities for both centralised and decentralised management approaches, the decentralised iteration was selected for further analysis. Results generated from other iterations of the modelled scenarios are discussed

alongside the seven key results if changes in their governance structure or application significantly affected modelled outcomes.

Table 21 provides a comparative overview of the main modelled outcomes ('increase' value) of alternative fire management approaches implemented within a savanna-protected area under future socioeconomic-climate change.

**Table 21.** Main modelled outcomes of key fire management scenarios under future socioeconomic-climate change: wildfire (W), savanna health (SH), and local livelihoods (LL). Centralised (c) and decentralised (dc) fire management scenarios were modelled: fire suppression and prevention (FSP), REDD+, savanna burning emissions abatement scheme (SBEA), flexible prescribed burning strategy (FPB) which accounts for below-ground biomass in its carbon accounting methodologies (+), holistic grazing scheme (HGS), fuel harvesting scheme (FHS), and community-based fire management (CBFiM). 'No policy' scenario represents the current fire suppression and response model. Red and blue cells represent the magnitude and certainty of an increase (0.5-1) or decrease (0-0.5) in modelled outcomes under the given scenario, respectively. Blank cells represent no change (0.5). Green text represents more favourable outcomes compared to the 'no policy' scenario.

| Fire Management Scenario | Green Climate Ambition |        |        | Climate Delay and Inequality |        |        | Fossil-fuelled Climate Denial |        |        |
|--------------------------|------------------------|--------|--------|------------------------------|--------|--------|-------------------------------|--------|--------|
|                          | W                      | SH     | LL     | W                            | SH     | LL     | W                             | SH     | LL     |
| No policy                | 0.7719                 | 0.4151 | 0.5080 | 0.9403                       | 0.3560 | 0.1655 | 0.9611                        | 0.3505 | 0.1539 |
| FSP (c)                  | 0.3948                 | 0.2263 | 0.3800 | 0.3948                       | 0.1562 | 0.1959 | 0.3948                        | 0.1457 | 0.1879 |
| REDD+ (c)                | 0.3344                 | 0.1494 | 0.5080 | 0.3344                       | 0.1133 | 0.2195 | 0.3344                        | 0.1084 | 0.1930 |
| SBEA (dc)                | 0.4896                 | 0.1987 | 0.5516 | 0.4896                       | 0.1397 | 0.4160 | 0.5172                        | 0.1327 | 0.4129 |
| FPB (c) (+)              | 0.4904                 | 0.4509 | 0.5080 | 0.5201                       | 0.3560 | 0.2040 | 0.5301                        | 0.4228 | 0.1982 |
| HGS (dc)                 | 0.3344                 | 0.3143 | 0.6468 | 0.3344                       | 0.1980 | 0.4520 | 0.3344                        | 0.1798 | 0.5000 |
| FHS (dc)                 | 0.3344                 | 0.3265 | 0.6468 | 0.3344                       | 0.2046 | 0.4516 | 0.3344                        | 0.1857 | 0.5000 |
| CBFiM (dc)               | 0.3816                 | 0.3339 | 0.6945 | 0.2816                       | 0.2028 | 0.4680 | 0.2816                        | 0.1855 | 0.5501 |

The results show that if the current 'fire suppression and response model' which has dominated fire management in Sub-Saharan Africa since the 1890s continues to be implemented, or rather there continues to be a lack of resourcing and investment into fire management, wildfires will intensify across savanna-protected area landscapes. As global temperatures rise from 1°C (minimum warming value under a GCA future) to 6°C (maximum warming value under a FFCD future), wildfires progressively become more frequent, intense, and severe. Under a GCA future, strong global climate ambition and gradual shifts towards inclusive development and equitable resource management can mitigate some of the social challenges that determine the type, frequency, and distribution of fire ignitions and wildfire events. For example, by redressing exclusionary property-rights regimes and, in-turn, reducing agrarian resistance and inter-group conflict. However, temporary overshoot up to 2.6°C in the medium to long-term will intensify biogeophysical wildfire conditions (0.657), resulting in wildfires that increasingly outstrip current firefighting capacities in savanna-protected areas. A

rapid increase in the probability of wildfires occurring under CDI and FFCD futures is likely due to higher temperatures and increased biogeophysical wildfires conditions when minimal or no additional climate policies are implemented. Additionally, where population growth is coupled with large disparities in economic opportunities and reduced human-development conditions, resource-driven conflicts between park agencies and rural poor and marginalised communities are projected to intensify. This can drive illegal fire-use activities in the parks, as well as incidences of agrarian resistance and human-wildlife conflict across the broader landscape.

As the number of compound extreme events increase under future socioeconomic-climate change and savanna-protected areas experience significant losses in topsoil and biodiversity (e.g., 0.370 and 0.326 under CDI and FFCD, respectively), savanna integrity, intactness, and resilience are projected to decline. Additionally, the resilience versus vulnerability of local people to joint human-climate pressures across the conservation landscape are projected to stay relatively stable under a GCA future despite human population growth and declining resource availability (0.440). This is largely due to some progress in promoting local adaptive governance in resource management and increased investment in the area, such as through state development (0.709) and CSR projects (0.540), large-scale land investments (0.6), and tourism (0.578), which (in)directly influence human-development conditions (0.510). However, local livelihoods become rapidly more vulnerable under CDI and FFCD futures where interconnected challenges associated with more intense climate (e.g., ENSO) (0.777) and compound extreme (0.889) events, and greater inter-group conflict (0.9) and elite capture in resource management (0.859) limits local communities' capacity to adapt to socioeconomic-climate change.

Compared to the current *'fire suppression and response model'*, all alternative fire management approaches are predicted to decrease the frequency and intensity of wildfires experienced in savanna protected-areas under future socioeconomic-climate change. Most approaches appear somewhat effective in reducing the frequency, intensity, and extent of wildfire events inside protected areas. This can mostly be attributed to the direct effects of developing of integrated pre-, during- and post-fire management systems and greater investment in building firefighting capabilities (see 'Intervention Measures', Croker (2024a)). While in practical settings, wildfire frequency, intensity, and extent would be measured as three independent phenomena, and intervention measures would be dissected to model more nuanced applications (see section 6.6. 'Considerations'), a modelled reduction in wildfires – defined as *'unintentional, uncontrolled, very large, and intense, exceeding natural fire variability levels'* – implied that they were less frequent, burned at lower intensities and were associated with lower concentrations of GHG emissions, and had fewer negative ecological impacts across the protected area.

There was much more variability in their ability to address savanna degradation and livelihood vulnerabilities. For example, under CDI and FFCD futures, a centralised flexible prescribed burning (FPB) strategy might be less effective in mitigating wildfires but more effective in maintaining savanna health. Under a FFCD future, decentralised SBEA schemes are also comparatively less effective in mitigating wildfires but might provide greater livelihood benefits.

No alternative fire management approach positively benefited savanna health, thus reducing the ecosystem's ability to maintain structure, functioning, biodiversity, and distribution under future socioeconomic-climate change. In-turn, this can prevent adaptive ecological processes that characterise the system's natural variability and dynamism, thus affecting its ability to respond to disturbance events. Though several approaches are perceived as win-win solutions for mitigating wildfires and increasing biodiversity, these results show that management approaches that prioritise fire in their activities e.g., prescribed burning to mitigate LDS wildfires, or fuel harvesting and grazing to reduce surface fuel loads, do not address ecological degradation under greater environmental stress in the medium- to long-term. For example, woody encroachment and declines in plant diversity were observed under most modelled scenarios, accelerating paralleled processes of forestation and the expansion of bare-ground coverage inside protected areas. Outside protected areas, desertification is projected to occur across large areas of community lands before 2100. These results highlight the need to develop additional management interventions alongside wildfire measures that focus on improving savanna health and biodiversity outcomes, such as developing adaptive biodiversity monitoring frameworks or incorporating biodiversity credits into carbon-based PES schemes (Croker, Woods & Kountouris, 2023b). Additional biodiversity interventions should extend their scope beyond the protected areas to ensure beneficial landscape-scale outcomes.

Variability in local livelihood outcomes is largely consistent with the baseline scenario. This infers that the future ability of local people to address causes of vulnerability and sustain or improve livelihood opportunities, wellbeing, and human-development conditions is predominantly influenced by socioeconomic-climate changes rather than specific fire management interventions. Under a GCA future, decentralised fire management approaches that involve local people in developing regulations and in decision-making processes (e.g., determining collective rules-in-use), and permits them access to the protected areas to carry out fire-related and fuel reduction activities, have greater livelihood benefits than centralised approaches. CBFiM approaches have the largest potential for increasing livelihood resilience, while increased fire suppression and prevention operations that centralise fire management in national disaster risk reduction strategies can accelerate livelihood vulnerabilities. Strong anti-fire rhetoric coupled with a decline in management rights can reinforce processes of biocultural hysteresis (e.g., 0.855 under a FFCD future), limiting opportunities for decentralised fire management approaches. Livelihood vulnerabilities are typically worse under CDI than FFCD futures. This is largely due to interrelated challenges associated with declining resource availability,

rapid urbanisation, and increasing inter-group conflict. High rates of rural-urban migration increasingly limit opportunities for human development (e.g., decline in job opportunities) and exacerbate poverty challenges, particularly in rural areas where communities are heavily reliant on remittances. While large-scale land investments are projected to exponentially increase under a FFCD future and replace small-scale agricultural practices, an increase in CSR projects and tourism might financially benefit local communities, provide human-development opportunities, or mitigate some inter-group and human-wildlife conflicts.

Overall, a centralised flexible prescribed burning strategy that accounts for below-ground carbon in its accounting methodologies performed best under a GCA future, effectively mitigating wildfires and improving local livelihoods, albeit very marginally. Though savanna health continued to decline in the protected area, this was the only scenario that improved savanna health compared to the baseline scenario up to 2100. Determining which fire management approaches performed best under CDI and FFCD futures was more difficult due to contrasting outcomes in savanna health and local livelihoods. Overall, CBFiM and decentralised fuel harvesting schemes appeared to have greater benefits across the three outcomes under a CDI future, reducing the frequency and intensity of wildfires and building some livelihood resilience relative to the baseline scenario. However, savanna health was projected to significantly decrease under both fire management approaches to a similar degree. In this respect, centralised flexible prescribed burning might provide a better alternative, limiting ecological degradation in the protected area to what is expected under current conditions. CBFiM and decentralised fuel harvesting and holistic grazing schemes resulted in comparatively better outcomes under a FFCD future, respectively. All three approaches are projected to effectively mitigate wildfires and significantly improve local livelihoods relative to the baseline scenario. While CBFiM might improve local livelihoods under a FFCD future, fuel harvesting and holistic grazing schemes neither improve nor diminish local livelihoods based on present day experiences, despite large increases in regional conflict and insecurity, elite capture in resource governance, and large declines in resource availability and GDP per capita. This is likely because they all decentralise some level of management rights to local communities through the co-development of formal fire regulations in protected area management, permitting varying levels of access to the parks to carry out management activities. Enabling these activities might promote biocultural heritage and diversity which, in-turn, reinforces positive social-ecological interactions and long-term sustainable resource extraction. However, none of these approaches address ecological degradation in savanna protected areas.

These results show the importance of assessing the benefits and trade-offs of different fire management approaches implemented in savanna-protected areas, and how permission and intervention measures propagate throughout the network to identify systems variables influencing these outcomes. In this way, challenges requiring additional attention (e.g., specific interactions

between systems variables) or areas necessitating additional policy or development which are not (in)directly affected by fire management, can be identified.

The following sections detail the outcomes of each modelled scenario. Charts created to visualise these outcomes plot the mean ('increase' value) and upper and lower 95% confidence intervals. Confidence intervals were calculated by subtracting the mean from the upper confidence limit, and the lower confidence limit from the mean, respectively. Network diagrams were generated on R to assess how modelled scenarios propagated throughout the network, including nodes which had the highest probability of increasing or decreasing under the given scenario. Dark circles represent an increase (closer to 1) and lighter circles a decrease (closer to 0). The darker/lighter the circle, the higher/lower the probability of the node increasing/decreasing. Black circles represent scenario nodes. As socioeconomic-climate change worsens (e.g., from GCA to FFCD scenario), systems variables are predicted to experience higher magnitudes of change, for example shifting towards 1 and 0. To account for this increasing complexity in network diagrams, thresholds were adjusted for best, intermediate, and worst-case scenarios, only visualising nodes within the specified limits: GCA ( $<0.35, >0.65$ ), CDI ( $<0.3, >0.7$ ), FFCD ( $<0.25, >0.75$ ). Red arrows indicate a mathematically positive relationship between parent and child nodes, and blue arrows indicate a mathematically negative relationship. Arrow width indicates the strength of the relationship between two nodes (i.e., the magnitude of effect).

## 7.1. Modelled scenarios: fire suppression and prevention and REDD+

Increased fire suppression and prevention (FSP) operations (Fig. 11) and REDD+ projects (Fig. 12) are projected to have similar impacts on wildfires, savanna health, and local livelihoods under future socioeconomic-climate change. Both scenarios negatively perceive fire (e.g., disaster), promote exclusionary resource governance, prioritise reactive over proactive fire management measures, and promote forestation by reinforcing colonially inherited understandings of savannas as degraded forests maintained by fire. The results for both FSP and REDD+ scenarios show that greater investment in law enforcement and firefighting operations to reduce illegal activity in the parks and build stronger fire response mechanisms can effectively reduce wildfires in protected areas. Investment in pre- and post-fire management activities that aim to mitigate fires through preventative and reactive strategies, including the procurement of modern firefighting equipment, establishment of Incident-Command Systems and trained firefighting brigades (including members of the local communities), creation of firebreaks, warning signs, and watchtowers, and implementation of community education and sensitization programmes to limit livelihood burning practices, can contribute towards mitigating wildfires up to 2100.

The current '*suppression and response*' model lacks funding, resourcing, and formal guidelines directing operations across multiple actors and jurisdictions. While stronger FSP approaches might address some of the current shortfalls that render the current model ineffective, variability in the results show that its contribution to mitigating wildfires under intensifying biogeophysical wildfire conditions and human pressures might be incremental (95% CI: 0.379-0.448 under a CDI future). Hence, future wildfire challenges experienced under strong FSP operations might be akin to what is experienced today under weaker operations. On the other hand, REDD+ projects might invest greater amounts of resources into increasing law enforcement, firefighting capacity, and more comprehensive fire management systems than FSP approaches to protect their carbon base. In turn, carbon credits generated through above-ground carbon sequestration can be reinvested into developing more robust fire management systems and security operations, further increasing their capacity to mitigate increasing wildfire challenges.

Savanna health and local livelihoods rapidly decline under all socioeconomic-climate futures when FSP is implemented, and in the case of savanna health, consistently decreases under stronger fire FSP operations. Similar trends are experienced when REDD+ projects are implemented, except under a GCA future where local vulnerabilities are projected to reflect present day conditions. While the generation of carbon credits can positively impact local communities within REDD+ project areas by increasing investment in state development and CSR projects, as well as by decentralizing some management rights when credits are transferred directly to community associations and landholder groups, local livelihood outcomes are the same as if no additional fire management approach is implemented. This is likely explained by the feedback effects of increasing security operations and reinforcing anti-fire rhetoric, reinforcing processes of biocultural hysteresis and elite capture in resource management which further limits opportunities for local participation in decision-making processes over fire-use practices. This can intensify forms of agrarian resistance and related challenges across the conservation landscape.

These challenges significantly increase the vulnerabilities of local people to future socioeconomic-climate change, but also interact with environmental variables driving rapid declines in savanna health. Where fire suppression approaches and REDD+ projects prioritise the expansion of woody species in alignment with traditional forestry conservation objectives, declines in herbaceous plant diversity and large herbivores, coupled with hydrological drought conditions, widespread soil erosion, and processes of woody thickening and forestation, are projected to drive severe savanna degradation. These environmental factors are resulting in large declines in rangeland conditions and, in turn, increasing land sub-division where individuals are seeking to secure access to declining resources, thus further reinforcing processes of biocultural hysteresis. Under a FFCD future, the expansion of large-scale land investments also has a significant influence over agricultural intensification across community rangelands and elite capture in resource management, thus further impacting savanna

health and livelihood vulnerabilities. Variability in the results show that under all socioeconomic-climate futures, FSP operations and REDD+ projects might cause grass dominated-savanna ecosystems to exceed their social-ecological threshold, thus shifting into an alternative state (i.e., forest) (95% CI: 0-0.287 [FSP]; 0-0.261 [REDD+] under a FFCD future). Similar variability in the results for local livelihoods show that increased exposure to socioeconomic-climate pressures and limited adaptive capacity can increase vulnerabilities to such an extent that local people might be forced to migrate from the conservation area (95% CI: 0.052-0.385 [FSP]; 0-0.346 [REDD+] under a FFCD future).

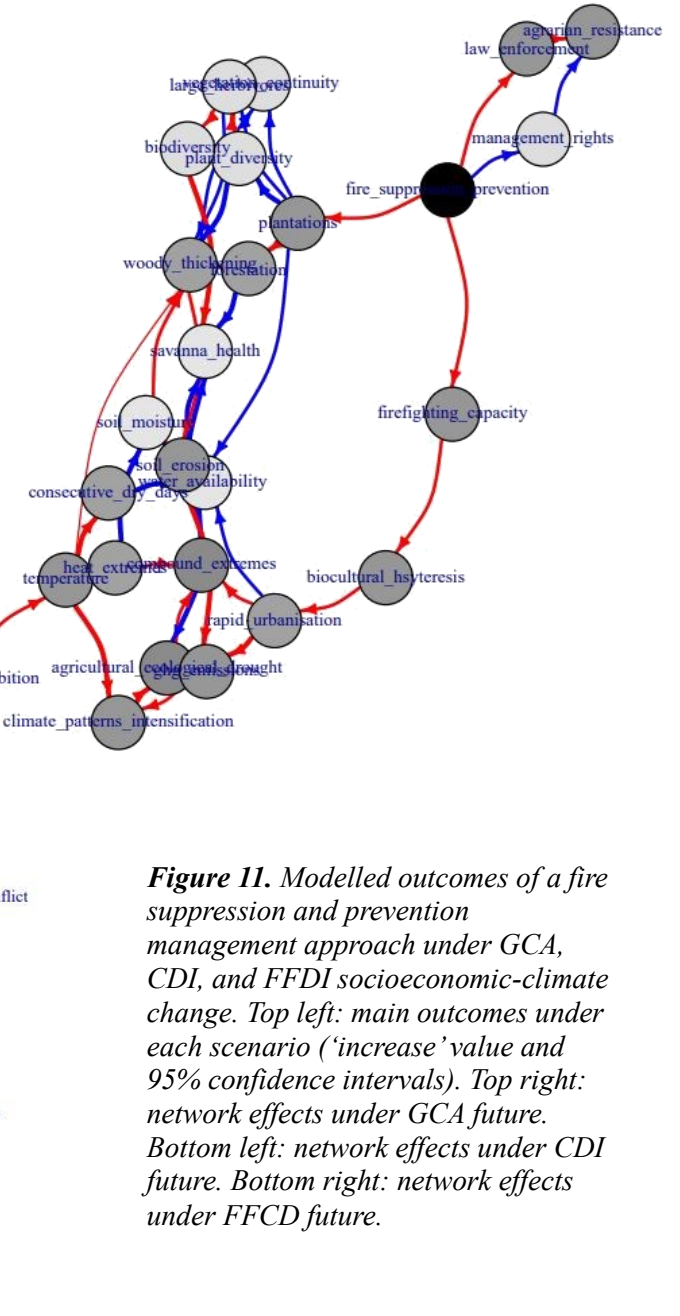
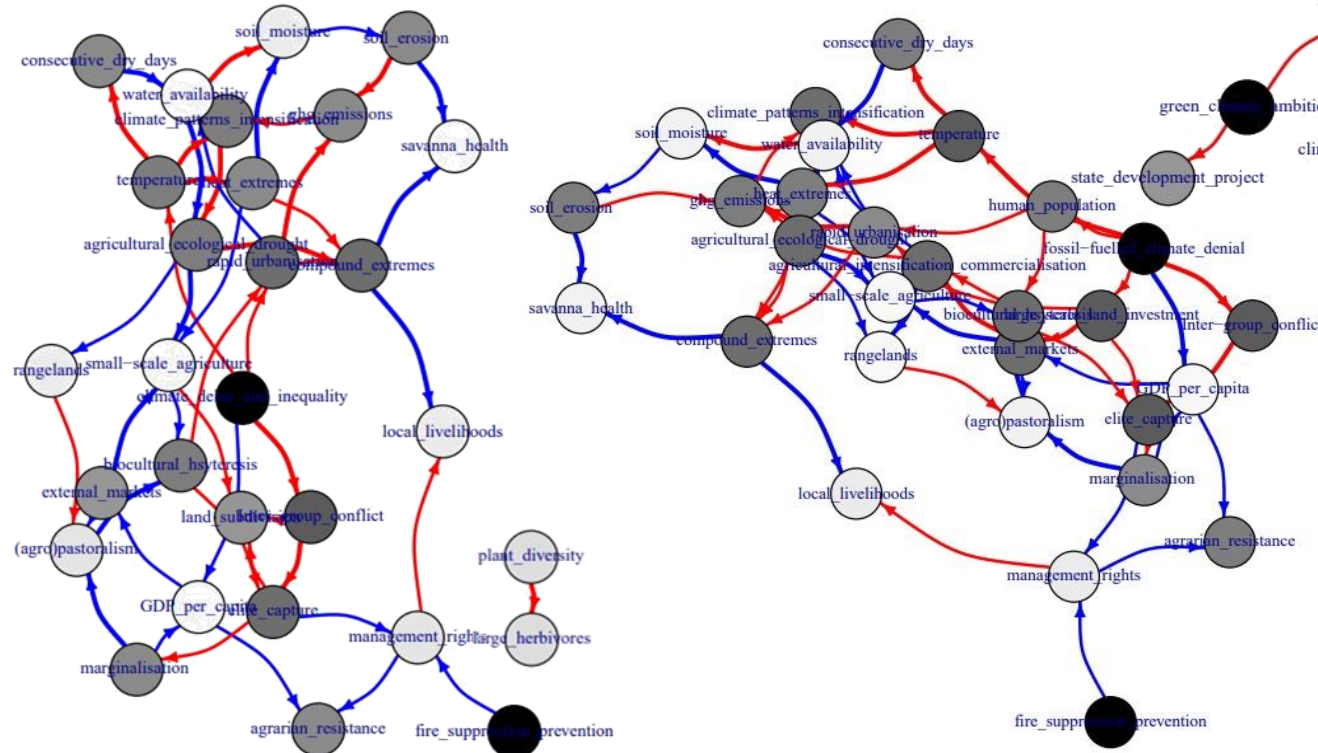
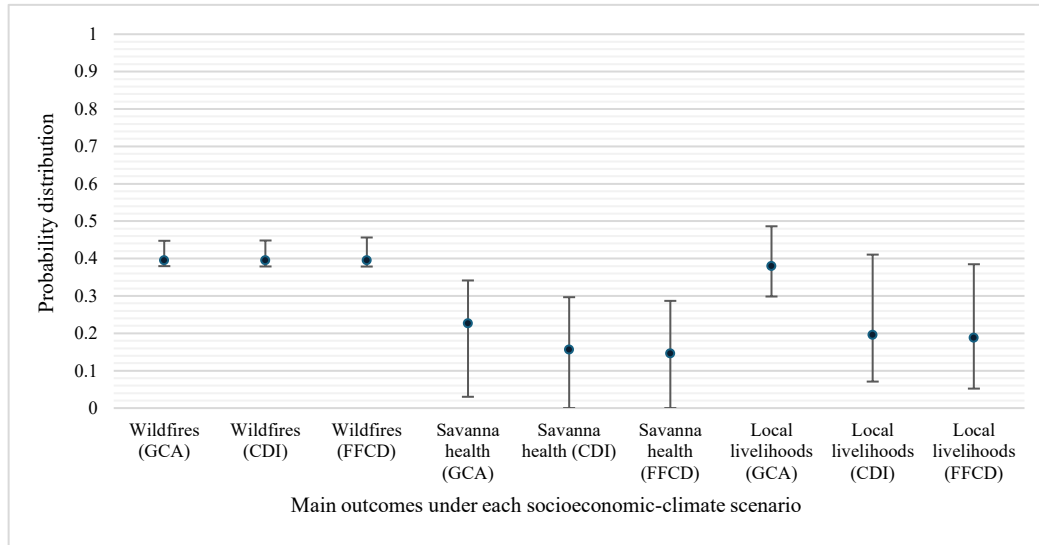


**Figure 11.** Modelled outcomes of a fire suppression and prevention management approach under GCA, CDI, and FFCD socioeconomic-climate change. Top left: main outcomes under each scenario ('increase' value and 95% confidence intervals). Top right: network effects under GCA future. Bottom left: network effects under CDI future. Bottom right: network effects under FFCD future.

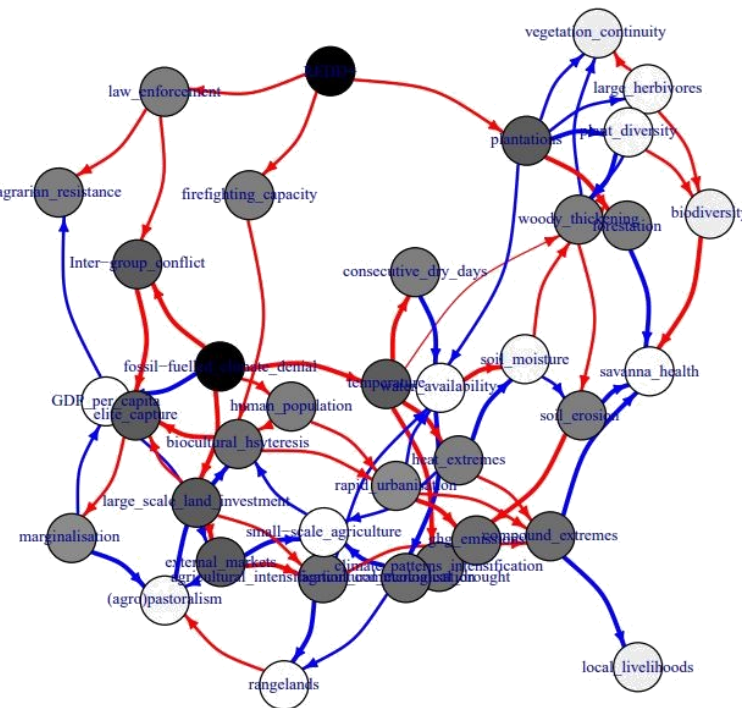
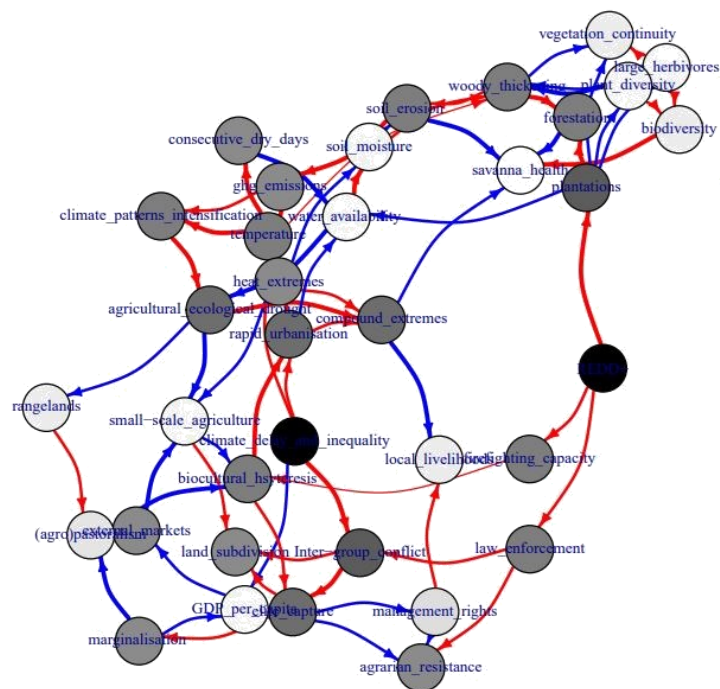
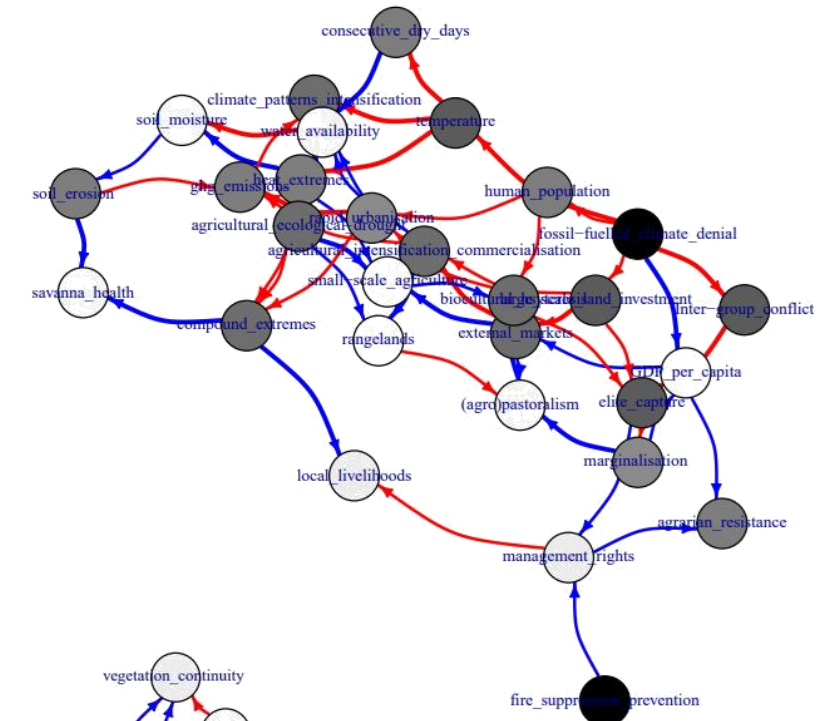
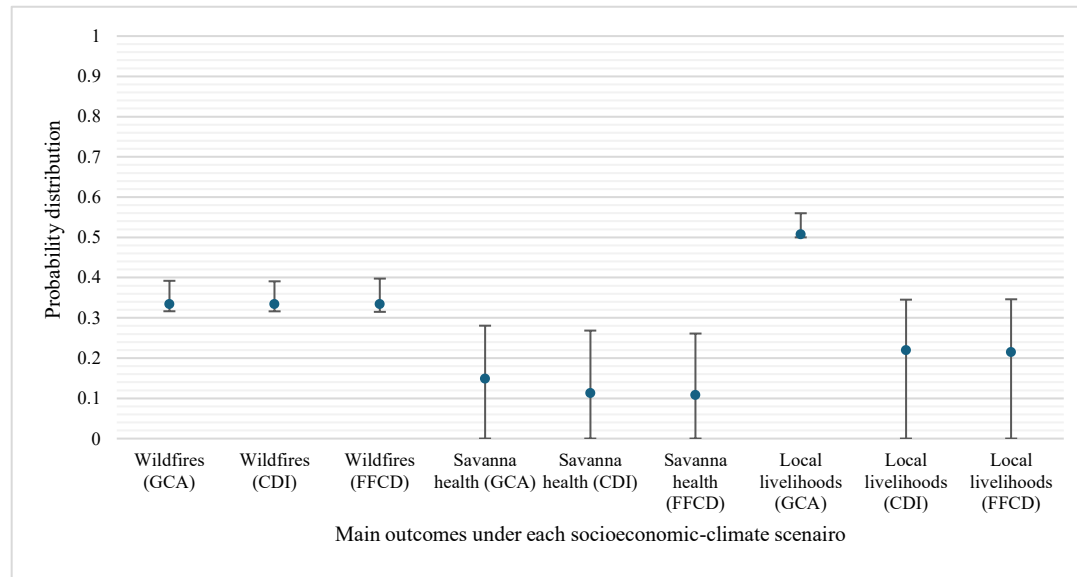


**Figure 12.** Modelled outcomes of REDD+ projects in fire management under GCA, CDI, and FFCD socioeconomic-climate change. Top left: main outcomes under each scenario ('increase' value and 95% confidence intervals). Top right: network effects under GCA future. Bottom left: network effects under CDI future. Bottom right: network effects under FFCD future.

## 7.2. Modelled scenarios: decentralised SBEA scheme

SBEA schemes that decentralise some management rights to local communities to carry out EDS prescribed burns or reduce fuel loads inside the protected areas appear less effective in mitigating wildfire challenges than other modelled fire management approaches. Under a FFCD future, wildfires are predicted to increase in frequency and intensity, likely due to the direct fire risk associated with burning in the EDS under more intense biogeophysical conditions.

Variability in the results across all three socioeconomic-climate futures (e.g., 95% CI: 0.444-0.5 under a CDI future) show that wildfire events might persist under a SBEA management approach despite increased investment in firefighting capacity and fire management systems, thus compromising emissions objectives and assumed biodiversity and livelihood co-benefits. This is likely explained by trends in livelihood resilience and vulnerability. Under a GCA future, broader trends in inter-group collaboration in resource management and the establishment of state development projects to support sustainable development can increase local resilience to socioeconomic-climate change, largely depending on the level of investment in human development conditions (95% CI: 0.518-0.609). However, the decentralisation of management rights and legitimate involvement of local people in the governance of SBEA projects is restricted by the enactment of strict Kyoto-compliant emissions accounting methodologies. Furthermore, under CDI and FFCD futures and increased law enforcement, inter-group conflict and the continued marginalisation of vulnerable communities might preclude the equitable distribution of carbon benefits. Compounded by declining socioeconomic conditions across the conservation landscape, such as a reduction in GDP per capita and increased reliance on external markets, the replacement of small-scale agriculture with commercial production systems, and rangeland degradation and land sub-division, permitting local people access to the protected area to carry out prescribed burns will likely increase incidences of illegal activity. These include illegal herding, resource extraction, poaching, and charcoal burning, of which present a direct wildfire risk.

Consistent declines in savanna health and variability in the results show that the adaptive resilience of savanna ecosystems might be severely compromised, thus risk exceeding their ecological threshold and undergoing a regime shift (95% CI: 0-0.301 under a CDI future). Network diagrams reveal that the inclusion of bio-sequestration methodologies in SBEA schemes are largely responsible for modelled declines in savanna health (Croker, Woods & Kountouris, 2023a). This is due to intentional (e.g., via management intervention) and climate-driven processes of woody thickening across grass-dominated savannas, of which is correlated with a reduction in soil moisture, loss of top-soil and expansion of bare-ground cover, reductions in plant diversity, and declines in herbivore species due to habitat selection behaviours. Low-intensity EDS burns can further exacerbate woody encroachment, promoting the colonisation of non-endemic fire sensitive or resistant shrub, bush, and weed species,

thus limiting below-ground carbon sequestration potential (February, Pausch & Higgins, 2020; Dobson et al., 2022; Coetsee et al., 2023; Zhou et al., 2023). To mitigate these challenges, SBEA schemes might incorporate some LDS fires into their methodologies, however this is unlikely given that LDS fires conflict with annual carbon emissions reductions objectives. This model shows that if schemes incorporated some prescribed LDS fires into their accounting methodologies and accounted for BGC (e.g., decentralised SBEA scheme (flexible burning/+ plant diversity)), savanna health outcomes might slightly improve ('increase' value of 0.217 under a GCA future, rather than 0.199). However, this increase is incremental, thus necessitating further research into the ratio of EDS versus LDS burning, as well as WS burning, that might be required to achieve better savanna health outcomes.

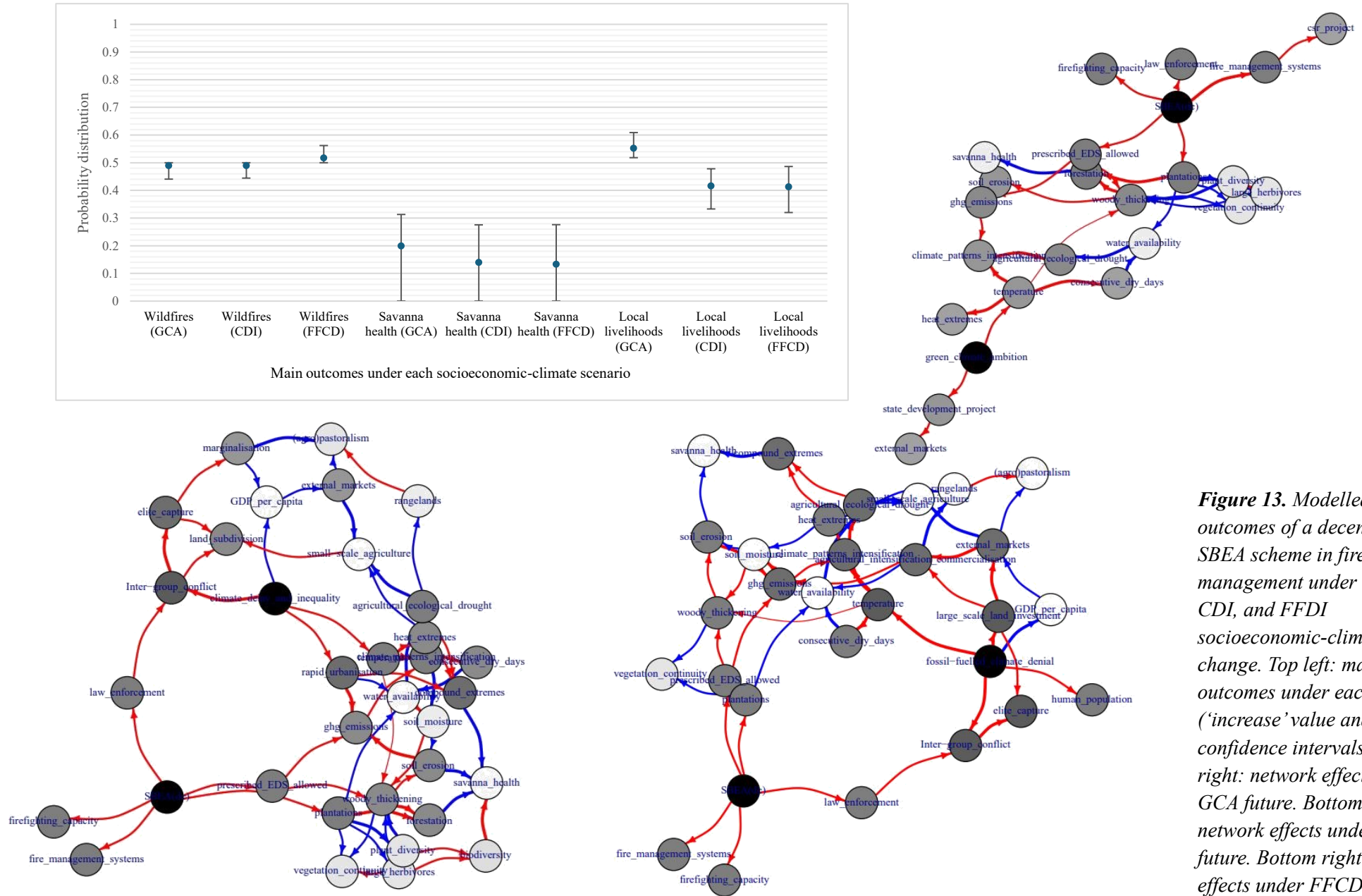


**Figure 13.** Modelled outcomes of a decentralised SBEA scheme in fire management under GCA, CDI, and FFCD socioeconomic-climate change. Top left: main outcomes under each scenario ('increase' value and 95% confidence intervals). Top right: network effects under GCA future. Bottom left: network effects under CDI future. Bottom right: network effects under FFCD future

### 7.3. Modelled scenarios: centralised flexible prescribed burning strategy

A flexible prescribed burning (FPB) strategy that accounts for BGC in its carbon accounting methodologies is a highly normative scenario in the research context, radically challenging the current status quo. This strategy builds upon current SBEA proposals while addressing some of their identified shortcomings (e.g., Table 5). Anti-fire rhetoric is perpetuated by agencies running carbon-based PES schemes based on the notion that fire threatens AGC stocks, contributing to global warming and forest degradation. Flexible burning approaches challenge this rhetoric by acknowledging the beneficial role of heterogeneous fire regimes in the adaptive cycle of savanna ecosystems, contributing to the regeneration of C4-dominated grasslands able to maximise photosynthetic efficiency under global warming and, therefore, sequester large amounts of BGC (Beerling & Osborne, 2006; Maurin et al., 2014; Handavu et al., 2021). These results show that the incorporation of adaptive prescribed LDS and WS burns into fire management frameworks can increase the mortality of non-endemic fire-tolerant and -resistant shrub, bush, and weed species, and reduce post-fire seedling recruitment. In this way, FPB might, to some extent, mitigate savanna degradation.

Under a GCA future, plant diversity and large herbivores might increase, woody thickening decrease, and overall savanna biodiversity stay relatively consistent with present-day conditions. Under CDI and FFCD futures, woody thickening continues to decline, but so might biodiversity, albeit marginally compared to other fire management approaches, therefore contributing to better savanna outcomes. Considering the negative impacts of macro-socioeconomic and environmental change on systems variables under CDI and FFCD futures, these results highlight the importance of assessing which variables are missing from the network which might impact modelled outcomes (e.g., low magnitude of change but high impacts on child nodes). Larger declines in savanna health under a CDI future are likely related to processes of increased inter-group conflict and rapid urbanisation and their network effects on systems variables already under pressure from worsening socioeconomic-climate conditions and exclusionary resource governance arrangements, such as increased hydrological drought conditions, heat extreme events, and biocultural hysteresis.

An FPB approach was the least effective fire management scenario included in this analysis for mitigating wildfire challenges. Wildfires are projected to decrease under a GCA future but increase or stay consistent with current wildfire trends under CDI and FFCD futures. This can be attributed to two main reasons: direct wildfire risk from carrying out prescribed burns under increasing biogeophysical wildfire conditions, particularly high-intensity LDS burns; centralisation of project governance and increased investment in firefighting, fire management systems, and law enforcement. This approach does not readily facilitate the decentralisation of management rights, with all decision-making rights and burning responsibilities reserved for relevant authorities. This is largely due to the

costs and technical and operational requirements for developing FPB strategies and additional adaptative biodiversity monitoring frameworks necessary to inform their activities (e.g., spatiotemporally diverse fine-scale patch mosaic burns at different intensities). Thus, prescribed burning programmes are typically carried out by experts employed by governmental or specialist agencies globally.

While local livelihoods remain relatively stable under a GCA future which prioritises inclusive human development, most likely due to greater investment in CSR projects and increased generation of carbon credits, livelihood resilience rapidly declines under CDI and FFCD futures, consistent with increasing wildfire events. This is largely explained by the feedback effects of greater investment in law enforcement and firefighting capacity. Increased security operations can intensify forms of agrarian resistance when local communities are further excluded from accessing resources in protected areas, as well as exacerbate inter-group conflict and elite capture in resource governance. Coupled with intensifying climatic conditions and increases in compound extreme events, these challenges are projected to accelerate land sub-division across the conservation area as local people rapidly seek to secure access to diminishing resources, thus further creating divides between the landed and landless. Associated socioeconomic vulnerabilities (e.g., large declines in GDP per capita and human development conditions) increases the likelihood of illegal activities inside the protected areas and incidences of human-wildlife conflict. Greater investment in firefighting operations might mitigate some of the direct risks associated with LDS burning. However, these results show that when local people are educated and trained in centralised burning programmes, they are more likely to experience processes of biocultural hysteresis, thus increasing wildfire challenges.

Landscape-level flexible prescribed burning strategies that are not included in carbon-based PES projects and, therefore, are not required to account for annual carbon emissions, might consider decentralising some management rights to members of the local communities to develop inclusive fire management plans and participate in prescribed burning (e.g., FPB strategy (dc)). Under all futures, this might have similar wildfire and savanna health outcomes to a more centralised carbon-based strategy, yet significantly improve local livelihood outcomes (e.g., increase value of 0.599 under a GCA future and 0.468 under a CDI future).

#### **7.4. Modelled scenarios: decentralised holistic grazing and fuel harvesting schemes**

Holistic grazing and fuel harvesting schemes are projected to have similar effects on wildfires, savanna health, and local livelihoods under all socioeconomic-climate futures. Both fire management approaches negatively view fire in the landscape, therefore focus on fuel reduction strategies to mitigate wildfire challenges, rather than prescribed burning activities. Livestock grazing and fuel

harvesting can contribute to a reduction in surface fuel loads across all socioeconomic-climate futures, and increased investment in firefighting operations and fire management systems (e.g., community education programmes to limit local fire-use practices) can effectively mitigate some of the increased fire risk associated with permitting livestock herding and fuel harvesting in the protected areas. For example, when herders ignite fires to regenerate pasture or kill livestock pests, or when both herders and harvesters use fire for survival (e.g., for cooking, heating, and lighting) when carrying out activities in the parks. Though pastoral fire-use has regenerative potential in maintaining open-canopy grass-dominated savanna ecosystems, it is mostly banned under a holistic grazing scheme based on the premise that fire and livestock compete for consumable biomass in the immediate term, overriding longer-term considerations over their facilitative relationship. Furthermore, the implementation of zoning plans to manage grazing in a localised manner and focus fuel harvesting activities across fire hotspots can reduce vegetation continuity and serve as natural firebreaks in the protected areas, further reducing wildfire risk.

The decentralisation of some management rights can reduce or stabilise (based on present-day conditions) livelihood vulnerabilities under future socioeconomic-climate change, despite rapid population growth, poverty challenges, inter-group conflict, and declining rangeland productivity and availability. This is likely explained by increased support for conservation when local communities are enfranchised in resource governance, acquiring real decision-making power vested in legitimate institutions and promoting the equitable distribution of resource benefits. However, management rights are mostly transferred to elected members of the local community who sit on grazing management committees to oversee and collectively govern pasture resources inside the protected areas, and to paying members of formal community associations (e.g., CFAs) who form specific interest groups to collaboratively manage fuel harvesting activities. Therefore, both models of management are susceptible to elite capture, where the decentralisation of management rights might be better described as the transfer of exclusion rights to wealthy economic and political elites. The redistribution of bargaining power to local elites can enable them to redefine the operational rules governing natural resources for individual political and economic expediency and promote an authoritarian governance regime (Crocker, Woods & Kountouris, 2023b).

Both schemes contribute to progressive declines in savanna under all socioeconomic-climate futures, and under CDI and FFCD futures, savanna ecosystems risk exceeding their ecological threshold (e.g., 95% CI: 0-0.301 [HGS]; 0-0.302 [FHS] under a CDI future). Where holistic grazing schemes promote higher livestock stocking densities for commercial production, and influence the expansion of (semi-)commercial ranching activities around the protected areas due to the perceived benefits of increased access to pasture, processes of desertification are projected to accelerate across the conservation area, amplifying the risk of compound extreme events and ecological collapse. Without fire, overgrazing can accelerate the growth of woody fire-resistant increaser species, resulting in woody thickening, a

loss of plant diversity, and overall biodiversity loss. Additionally, investment in law enforcement activities to effectively implement grazing and fuel harvesting management plans might increase inter-group conflict and associated incidences of elite capture in resource governance. This can have feedback effects on processes of land sub-division, increased reliance on external markets and declines in small-scale agriculture, and rapid urbanisation, all of which interact with environmental variables such as water availability and soil moisture to affect long-term ecological integrity, intactness, and resilience. Under both fuel reduction approaches, savanna-protected areas are predicted to experience increased woody encroachment and widespread soil erosion, while community lands are predicted to experience large-scale desertification.

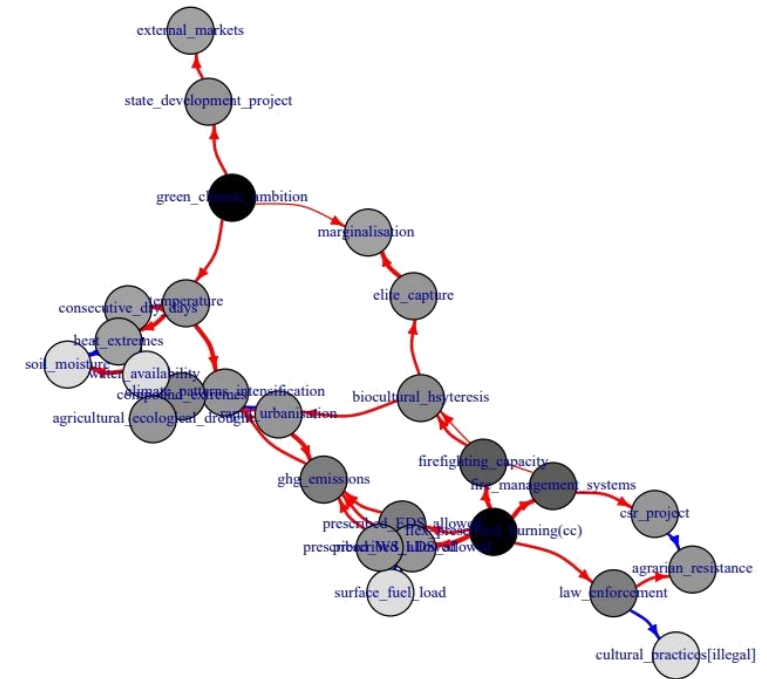
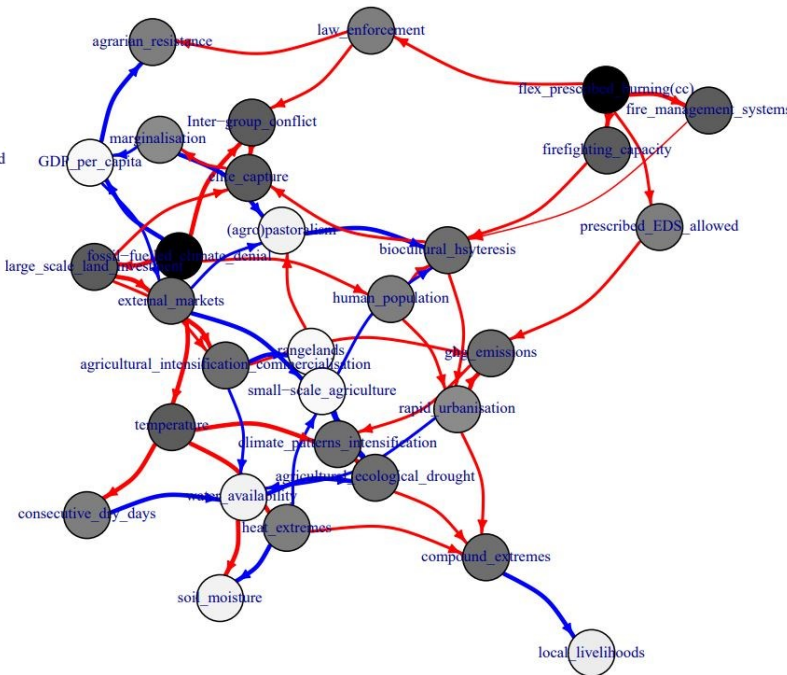
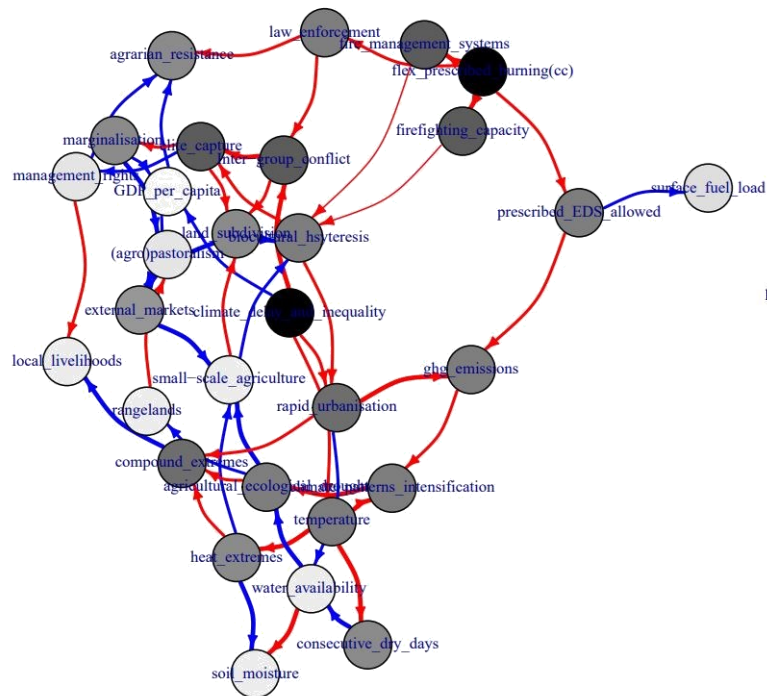
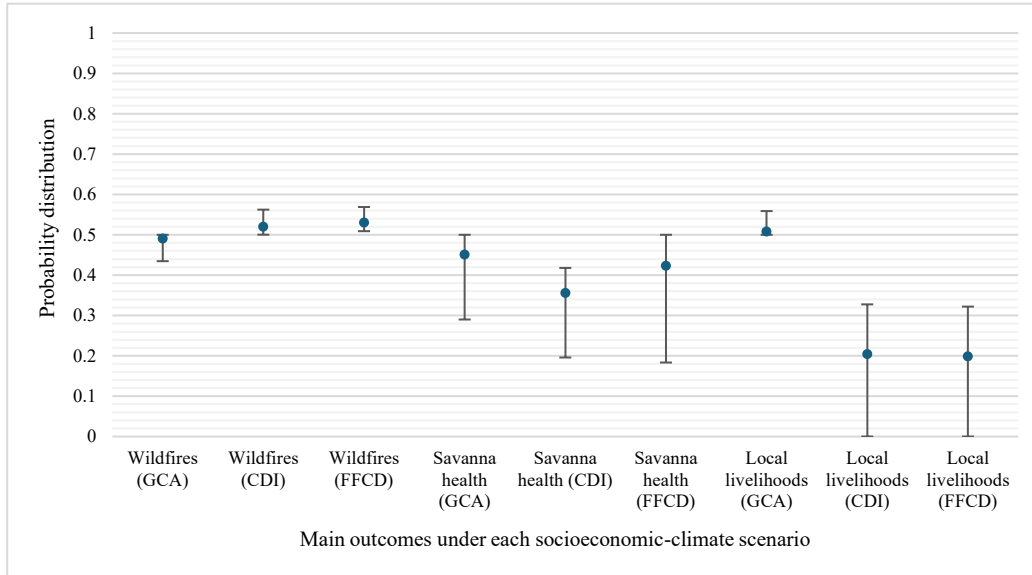


**Figure 14.** Modelled outcomes of a centralised flexible prescribed burning strategy (accounting for below-ground biomass in its accounting methodologies) in fire management under GCA, CDI, and FFCD socioeconomic-climate change. Top left: main outcomes under each scenario ('increase' value and 95% confidence intervals). Top right: network effects under GCA future. Bottom left: network effects under CDI future. Bottom right: network effects under FFCD future.



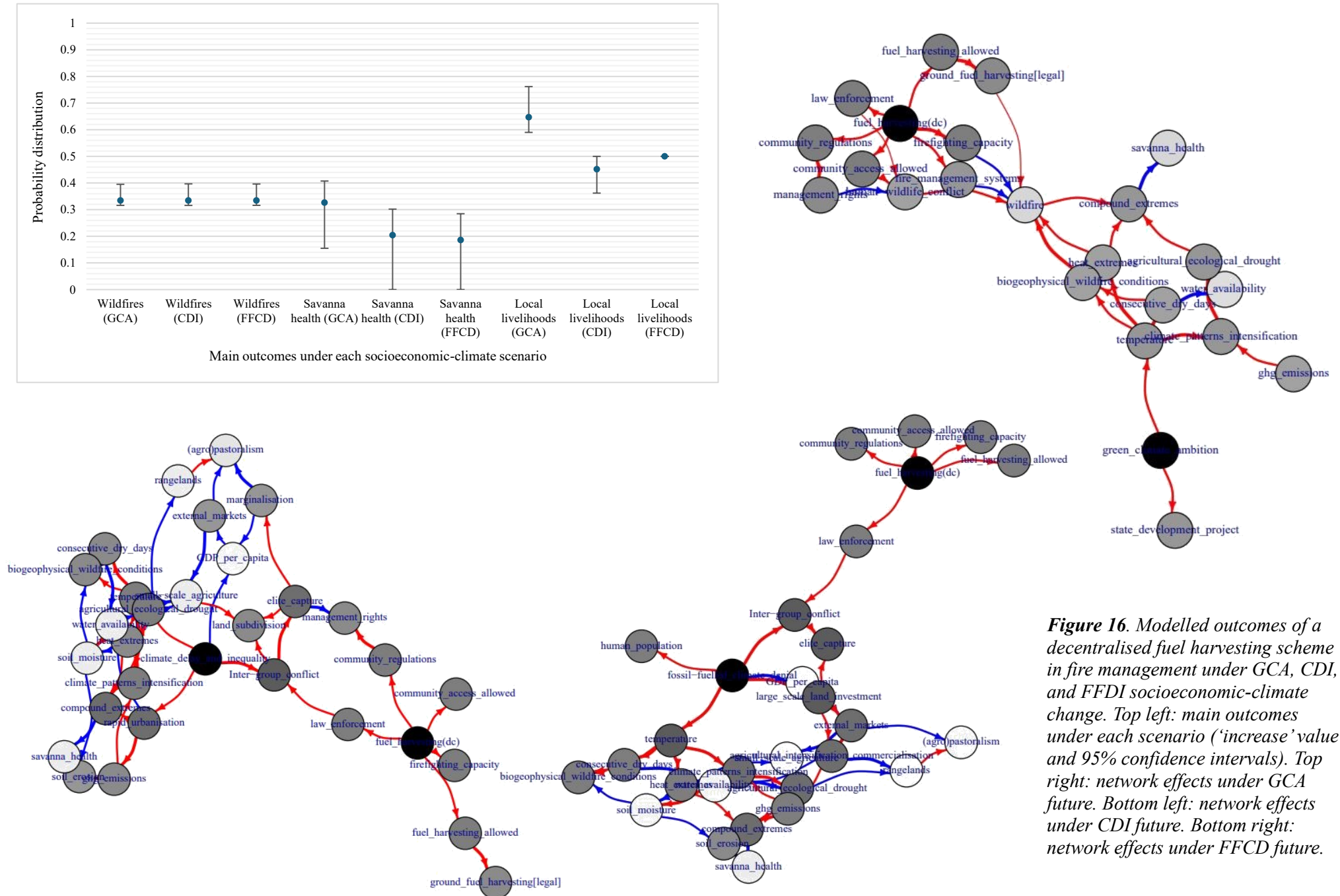


**Figure 16.** Modelled outcomes of a decentralised fuel harvesting scheme in fire management under GCA, CDI, and FFCD socioeconomic-climate change. Top left: main outcomes under each scenario ('increase' value and 95% confidence intervals). Top right: network effects under GCA future. Bottom left: network effects under CDI future. Bottom right: network effects under FFCD future.

## 7.5. Modelled scenarios: CBFiM

CBFiM presents a highly normative approach in state-governed savanna protected areas, projected to contribute towards wildfire mitigation and increased livelihood resilience. With regards to local livelihoods, CBFiM performs better than other modelled fire management scenarios, and variability in the results show that under a FFCD future, the decentralisation of management rights to local communities to govern fire-use activities within the protected areas can reinforce biocultural diversity and heritage values, significantly increasing the resilience and adaptive capacity of local people under socioeconomic-climate change (95% CI: 0.5-0.717). Given that communities benefit from natural resource management under a CBFiM approach, legal fire-use activities are likely to be intentional and controlled, thus contributing to long-term sustainable resource use. Network diagrams show that community regulations governing fire-use activities and increased management rights might mitigate some of the challenges associated with permitting communities' greater access to the protected areas, such as illegal grazing, subsistence harvesting, and cultivation. Under a GCA future, fire management systems that invest in CSR projects to educate communities on the benefits of wildlife conservation can also contribute to declines in poaching and charcoal burning. A small decline in local livelihoods under a CDI future can be attributed to increasing inter-group conflict and elite capture in resource governance, exacerbated by increased investment in law enforcement to effectively implement CBFiM projects and ensure compliance with agreed regulations. Where CBFiM institutions are established by external authorities and management rights are decentralised to local elites, marginalised community groups possess increasingly diminishing power to engage in collective action, thus increasing livelihood vulnerabilities under future socioeconomic-climate change.

CBFiM is considered an alternative bottom-up approach to achieve joint social-ecological outcomes, recognising the evolutionary relationship between local fire use practices and biodiverse savanna ecosystems. However, savanna health progressively declines under global warming and intensifying human pressures. While an increase in regenerative fires associated with local fire-use practices can limit woody encroachment across savanna protected areas, intensifying meteorological drought conditions, heat waves, and agricultural and ecological drought events are projected to drive large declines in savanna biodiversity under CDI and FFCD futures. These events increasingly occur simultaneously, increasing the risk of compound extremes which have large negative consequences on savanna health and local livelihoods. These results show that while CBFiM can effectively contribute towards a reduction in wildfires and increased livelihood resilience, controlled livelihood burning practices which have historically contributed towards maintaining biodiverse savannas cannot, without additional targeted management measures, mitigate ecological degradation under increasing socioeconomic-climate pressures.

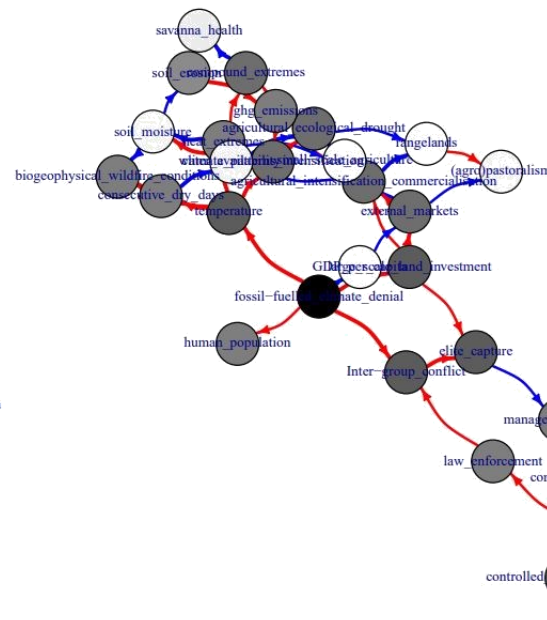
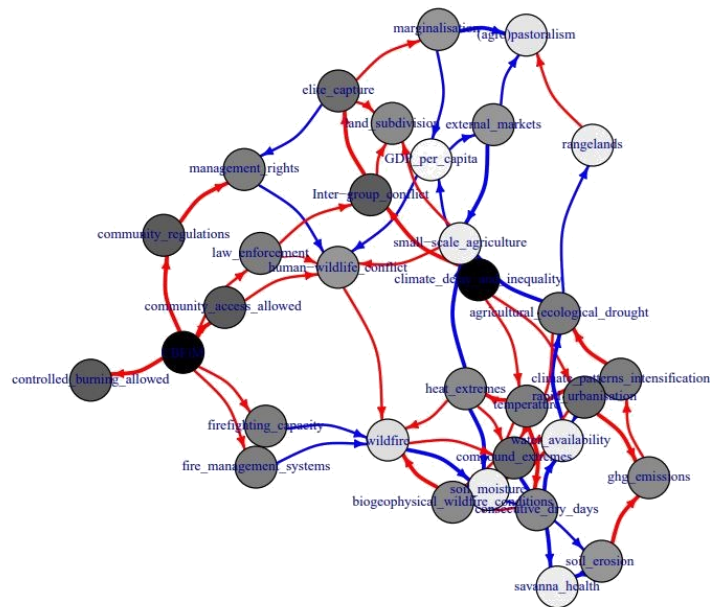
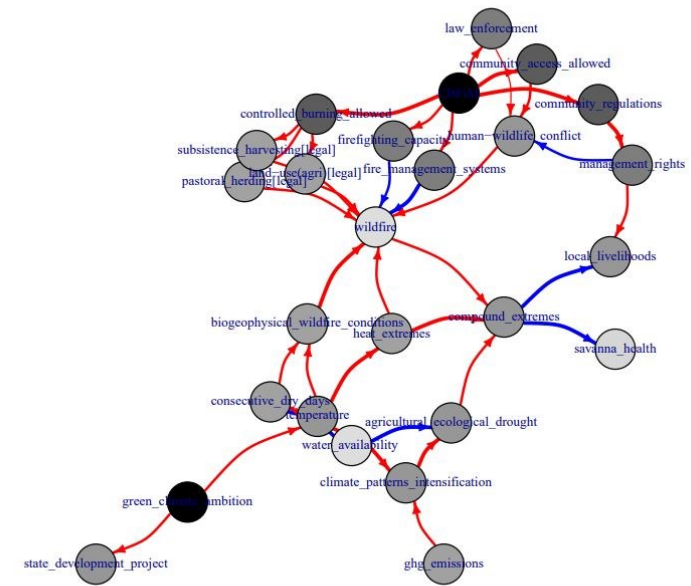
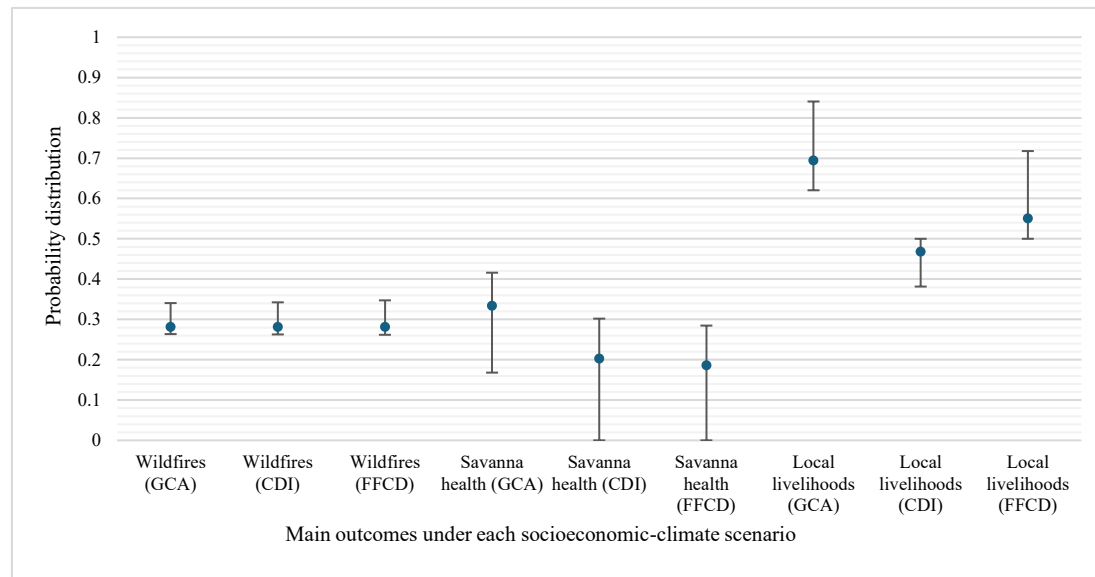


**Figure 17.** Modelled outcomes of a CBFiM approach in fire management under GCA, CDI, and FFCD socioeconomic-climate change. Top left: main outcomes under each scenario ('increase' value and 95% confidence intervals). Top right: network effects under GCA future. Bottom left: network effects under CDI future. Bottom right: network effects under FFCD future.

## Chapter 8. Final discussion and conclusions

There is an ever-increasing imperative to develop bottom-up fire management approaches to equitably and effectively address increasing wildfire challenges, acknowledging both the dual role of fire in savanna ecosystems and the importance of heterogenous self-organising governance systems at the local level. However, the reinforcement of environmental degradation narratives in increasingly carbon-oriented conservation-development projects, imposition of external governance systems in local contexts, and lack of property-rights in savanna-protected areas, have prevented IPLCs from legitimately participating in fire management. As such, this thesis set out to explore the opportunities and challenges for the implementation of alternative fire management approaches in East and Southern African savanna-protected areas, explicitly assessing their ability to mitigate wildfires, improve savanna health, and reduce livelihood vulnerabilities under future socioeconomic-climate change. Key findings relating to each of the three main research objectives are summarised below, however should not be treated independently. Emergent results informed the trajectory of this thesis and subsequent analyses, providing a richer understanding of the pyro-geographic landscape that increasingly characterises conservation frontiers. As such, results related to a specific research objective are often discussed vis-à-vis other objectives to highlight their interconnectedness and broader implications.

### 8.1. Reimagining the ‘wildfire paradox’

**First, this thesis provides a deeper understanding of the wildfire paradox in an East and Southern African savanna-protected area context.** I highlight how the type, frequency, and distribution of fire ignitions and wildfire events are symptomatic of, often seemingly tangential, interactions across path-dependent, meta-coupled, human-physical systems, mostly centered around land- and resource-based inequalities. Hence, I propose that the wildfire paradox is reimagined as a joint ecological-biocultural phenomenon to more comprehensively conceptualise fire challenges across exclusionary conservation landscapes, therefore leading to more relevant interdisciplinary research and cross-sectoral management solutions. For example, future analyses examining the impacts of emerging trade networks, liberalisation and privatisation policies, rising tax burdens, migration, and resource harvesting regulations—particularly in the context of escalating socioeconomic and climate change—can provide deeper insights into the policy landscape shaping wildfire governance.

Furthermore, considering ecological and biocultural hysteresis as a singular positive feedback loop foregrounds the unresolved dichotomy between the physical and social aspects of the fire regime at the core of research inquiry. While current conceptualisations of the wildfire paradox ascribe some responsibility to colonially inherited fire suppression policies across exclusionary land tenure

arrangements, they have mostly failed to situate these policies in their historical institutional context. To date, management solutions have overlooked questions related to power, legitimacy, and the evolution of institutions and rules, such as how they are continuously renegotiated at multiple spatial-temporal scales, determine specific action situations and options available to diverse actors to participate in resource governance, and structure human behaviour, attitudes, and norms. This has resulted in reductionist approaches that narrowly focus on reducing fuel loads to mitigate LDS wildfires and associated GHG emissions, in-turn reinforcing processes of ecological-biocultural hysteresis.

## 8.2. Interrogating colonial inheritance

**Secondly, this thesis examines scientific knowledge on ‘bottom-up’ fire management through a historical institutionalist lens, illustrating how (neo)colonial influences and interventions persist in shaping policy and management strategies within local conservation contexts.**

Both external (scientists, international organisations, government agencies) and internal (members of Indigenous and local communities) actors imagine and construct alternative bottom-up fire management approaches within existing exclusionary natural resource management frameworks where opportunities for local decision-making are institutionally constrained (Twyman, 2000). These approaches are mostly harnessed by state conservation and forestry departments, international NGOs, private actors, and political-economic elites to extend bureaucratic power in local fire governance (Kull, 2002; Dube, 2013), pursue individualistic ambition, mitigate inter-group conflict along park boundaries, and align behaviours (e.g., limiting ‘careless and damaging’ indigenous fire practices) with national conservation and emissions reductions objectives (Laris & Wardell, 2006). Where fire management approaches decentralise some level of management rights to the local communities, they are often state-mandated and governed by public and private organisations, and community participation is mostly tokenistic. Meanwhile, members of the local community who form select committees are required to define fire management objectives in compliance with government and private agencies who primarily aim to control, prevent, and suppress fire, and increase above-ground woody biomass and carbon stocks. Modelled outcomes from SAV BN show that such fire management approaches are projected to accelerate savanna degradation under future socioeconomic-climate change (Archibald, 2016; Parr, te Beest & Stevens, 2024).

The incorporation of traditional fire knowledges into modern management frameworks to ‘revitalise cultural burning’ is increasing across the world, particularly in carbon-based PES schemes. However, the prevailing assumption that prescribed EDS burning is representative of traditional fire-use worldwide does not pay attention to the historical ecology and institutional evolution of this approach (Petty et al., 2015; Humphrey, Gillson & Ziervogel, 2021), or to the distinctive sociocultural trajectories of (agro-)pastoral societies and their heritage and land-use values across time and space

(Croker, Woods & Kountouris, 2023b). As such, while some bottom-up fire management approaches modelled in SAV BN proved more effective in mitigating wildfires and supporting livelihood resilience, the latter was marginal and strongly dependent on broader socioeconomic-climate conditions, rather than on the benefits directly accumulated through the management approach.

In the case of Kenya, and more generally in other East and Southern African countries with a recent colonial history, it is important to recognise that the concentration of absolute decision-making power in fire management among external actors (primarily the ‘players’ and ‘context setters’) is reinforced not only through top-down mechanisms but also through bottom-up dynamics. While it is typically believed that independent states previously exposed to a British colonial regime and common law traditions offer greater opportunities for decentralising management rights to IPLCs in resource governance, such that they are better able to pursue representational, procedural, and distributive justice than states previously exposed to a French regime, the results presented in this thesis suggest otherwise.

For example, the devolution of management rights to County Governments in Kenya has increased the vulnerability of ‘community-based’ governance frameworks to elite capture. County Governments suffering from irregular disbursement of devolved funds from the national government, low revenue collection, and weak and uncoordinated planning, are increasingly entering coalitions with local political and economic elites (including traditional authorities and elected officials) to strengthen their control over rural affairs and promote congruence in fire management (Saito-Jensen et al., 2010), particularly where agrarian resistance fires threaten protected area management objectives (conservation or ranching) (Antona et al., 2004; Agrawal and Ostrom, 2001). Additionally, where power over land administration functions is retained by the central government, colonially inherited land adjudication and registration policies supposedly designed to address land-based inequalities have, and continue to, divide communities along wealth and ethnolinguistic lines. The enforcement of common law in Kenya would, to some degree, infer that the customary rights of local communities have been strengthened in resource governance, enabling local people access to natural resources critical for their livelihoods and biocultural heritage. However, as highlighted by the recent 2016 CLA, many rural communities do not have access to the formalisation procedures required to legally recognise communal tenure, and even after registration, county assemblies (mostly consisting of political and economic elites) and the state hold authority to alienate and seize communal land via compulsory acquisition. As such, the opportunity for members of local communities who do not hold formal land titles to participate in resource governance and fire management is limited at best.

This study also reveals large resemblances between (i) 21<sup>st</sup> century militarised conservation systems and land reforms across East and Southern Africa, and (ii) 11<sup>th</sup> century feudalism and Forest Law in England (see Chapter 2), raising further questions over the adoption and enforcement of common law

and opportunities for decentralisation in ex-British colonies. In both cases, power and social control is founded on formalised land tenure, allowing state agencies, local elites, and private organisations authority over the redistribution of land, how it is used, and who benefits. Under 11<sup>th</sup> century Forest Law in England, and the 2013 WCMA in Kenya, local people who held/hold ancestral land rights to protected areas were/are classified as illegal trespassers and poachers, subject to heavy punishments.

Interestingly, participants in this study perceived fuel harvesting and grazing schemes as alternative bottom-up fire management approaches, recommending their implementation in savanna-protected areas to simultaneously mitigate wildfires and support livelihood resilience through increased access to natural resources. Both approaches require the establishment of governing committees made up of elected community officials who work with government agencies to devise-by-laws and establish strict regulations governing harvesting and grazing activities. Additionally, membership fees or one-off ‘cut and carry’ harvesting fees are recommended under both fuel harvesting schemes and CBFiM projects, thus granting rights based on payment. These recommendations bear a strong resemblance to local ‘rights’ established under Forest Law, such as agistment (right to pasture livestock), estover (right to collect firewood), and turbary (right to cut turf for fuel), of which were permitted in protected areas subject to being granted a license and/or payment. As such, bottom-up approaches as understood by local participants in this study reflect exclusionary property-rights prior to the articulation of the Magna Carta in 1215 and later evolution of Charter of the Forest in 1217 which provided the early foundations of British common law. While these approaches are perceived to improve livelihood outcomes under future socioeconomic-climate change, a historical institutional lens would suggest that they are likely to contribute towards future land- and resource-based conflicts. As the landed become wealthier, and the landless poorer, fire is increasingly reemerging as a symbol of agrarian resistance as it did in Medieval Europe.

The transfer of exclusion rights to select members of the community redistributes bargaining power to local elites who can redefine operational rules, adjudicate land, and manage natural resources for individual political-economic advantage, thus promoting an authoritarian governance regime (Thompson & Homewood, 2002; Nygaard, 2008). As observed in carbon-based PES schemes (Crocker, Woods & Kountouris, 2023b), this can drive privatization and the accumulation of benefits amongst a privileged minority (Kapoor, 2002). Where historically rooted forms of community governance and social rules are present, legal frameworks to transfer management rights to local communities and regulate elite behaviour could facilitate self-organisation in democratic decision-making over fire use (Epstein et al., 2013; Arnall et al., 2013). However, without secure tenure rights, and where ‘new’ community-based institutions (i.e., rules) established or appropriated by external authorities do not account for local forms of accountability and legitimacy, community members possess little power to challenge traditional authorities and opportunities for collective action are limited (Mutua & Kiruhi, 2021).

Western interpretations of Indigenous communities as homogenous and territorially bounded social organisations continue to shape understandings of pre- and post-colonial local land management systems (Kumar, 2005; Neale et al., 2019). This ignores how the disruption of local power dynamics between land chiefs, religious leaders, and community members under both indirect and direct colonial regimes have accelerated processes of biocultural hysteresis and instituted various challenges in the decentralisation of management rights over fire-use. The (un)intentionality of these interpretations requires questioning, such that they have enabled external agencies to consistently restrict local participation in resource governance while adjudicating on the validity of local knowledge (Kull, 2002; Croker, Woods & Kountouris, 2023a), resulting in the decentralisation of responsibilities (i.e., labour and time) and transfer of exclusion rather than management rights (Schafer & Bell, 2002; Ndumeya, 2019). This research highlights how conflicts between local people over fire-use objectives have preclude harmonious management arrangements, promoting a chaotic fire regime and ecological hysteresis across East and Southern African savannas (Bloesch, 1999). As such, we need to question whose knowledges are represented in externally governed bottom-up approaches (Reyes-García & Benyei, 2019), how far local knowledges can be regarded as traditional or pre-colonial, and what the purpose is, or implications are, of seeking out this knowledge in local contexts.

### 8.3. Leaving legacies

**Thirdly, this thesis presents a probabilistic evaluation of the social-ecological network effects of exploratory and normative fire management approaches under future socioeconomic-climate change.** Despite wildfires being increasingly recognised as ‘wicked problems’ that emerge from and interact with multiple nested social-ecological panarchies, reactive Incident-Command systems for firefighting continue to be reinforced due to the risks wildfires pose on commercial resources and GHG emissions targets (Tedim, Leone & McGee, 2019). Fire management activities understood as proactive are, contrarily, mostly preventative, including interventions aimed at reducing fuel loads to eliminate fires from the landscape, and the establishment of firebreaks to contain fire spread and limit total area burned. These perspectives are largely shaped by current conceptualisations of the wildfire paradox; the most apparent strategy for addressing the paradoxical effects of fire suppression on fuel accumulation and, in-turn, extreme wildfire events, is to reduce the fuel load. Hence, proposed fire management approaches mostly focus on engineering the vegetational conditions, rather than proactively addressing the underlying social-ecological causes of wildfire (Tedim, Leone & McGee, 2019). Since no approach modelled in SAV BN effectively considered both the social and ecological conditions wildfires synthesise, they failed to provide win-win-win solutions that simultaneously mitigate wildfires, improve savanna health, and increase livelihood resilience. Management approaches aimed at suppressing fires, increasing above-ground woody biomass, offsetting emissions,

and reducing fuel loads can effectively reduce the frequency, intensity, and extent of wildfires under future socioeconomic-climate change, do not address accelerating savanna degradation and, in most cases, engender livelihood trade-offs.

This study shows that the adoption of a pyro-diverse, intra-annual, mixed-intensity flexible prescribed burning approach that accounts for BGC in its accounting methodologies can provide comparatively better outcomes for savanna health in the future. However, this is a highly normative scenario, challenging the dominant perception of savannas existing as degraded forests which continues to be reinforced by external, and increasingly internal, actors, often through carbon-based PES schemes and ‘community-based’ CSR projects aiming to limit local fire use, increase AGC, and expand economically-valuable plantation species (Parr, te Beest & Stevens, 2024). Additionally, semantic understandings deeply rooted in colonial-inspired degradation narratives, such as interpreting ‘fire-adapted’ as ‘fire-resistant’ and ‘drought-tolerant’, have created a complex epistemological environment in terms of savanna fire ecology and the development of ecologically sound management interventions.

Modelled savanna outcomes revealed how fire management alone cannot provide a solution for addressing savanna degradation. On the contrary, they suggest that for as long as savanna management is considered within fire management frameworks institutionally embedded within forestry sciences, they will be managed as anthropogenic ‘species-poor’ ‘sub-climax’ grasslands. To limit savanna degradation and biodiversity loss under future socioeconomic-climate change, actors need to identify the systemic drivers of fire and their distribution and impacts across the landscape, in-turn assisting in developing cross-sectoral policies and ecologically relevant management interventions. This necessitates long-term cooperation across (inter)national partner networks in resource sharing, data collection, and adaptive management.

Livelihood outcomes displayed greater variability and were mostly related to broader socioeconomic-climate conditions, rather than specific fire management interventions. Across all scenarios, local resilience to anthropogenic pressures was strongly influenced by the degree to which IPLCs are decentralised management rights and their ability to interact with their environment, reinforcing biocultural diversity and heritage values. However, recent literature aiming to highlight the benefits of pyro-diverse indigenous burning necessary to counter strong anti-fire wisdoms has inadvertently contributed to the formalisation of EDS patch-mosaic burning in community-based and indigenous-led fire management approaches (Parr & Andersen, 2006). While this might show a step in the right direction towards recognising the social-ecological importance of fire use, this approach closely resembles colonial fire experiments developed within protected areas throughout the 20th century and is indicative of colonial and more recent global climate policy which seeks a systematic approach to fire management (Laris & Wardell, 2006; Tedim, Leone & McGee, 2019). In local contexts, the strict

prescription of early-dry season burns based on arbitrary seasonal boundaries might be considered a neo-colonial intervention in controlling indigenous fire-use and can raise trade-offs between wildfire and emissions mitigation objectives and local biodiversity adapted to diverse fire regimes (Corey et al., 2020; Laris, 2021; Laris & Jacobs, 2021).

#### **8.4. Last remarks and recommendations**

Consistent with the broader literature on CBNRM, this research shows that land tenure and access to resources is critical to the success and legitimacy of alternative fire management approaches. However, East and Southern Africa's colonial history, population growth, and climatic changes create challenging conditions for the development of bottom-up fire management approaches. Implemented, proposed, and modelled scenarios do not actively address the historical and institutional barriers that prevent IPLCs from accessing and owning land in protected areas (Agrawal & Gibson, 1999; Swatuk, 2005; Measham & Lumbasi, 2013; Cassidy, 2021). Instead, they all imagine fire management futures where decentralisation corresponds with the transfer of exclusion rights to local political and economic elites. Currently, no East and Southern African country has ratified the ILO Convention 169 on Indigenous and Tribal Peoples (ILO, 1989) which makes provisions for Free, Prior, And Informed Consent (FPIC) for the development of carbon-based PES projects on Indigenous and community lands (Russell-Smith et al., 2017). Additionally, the convention is not legally binding and does not apply in state-governed protected areas where consent to develop public-private REDD+ and SBEA schemes is exercised by central authorities (Edwards et al., 2021). Considering the rapid proliferation of carbon-based PES schemes across the region, opportunities for bottom-up fire management are increasingly limited by expansion of exclusionary property-rights and ongoing processes of social-ecological and biocultural hysteresis across savanna ecosystems.

Addressing these challenges requires a long-term, historical social-ecological perspective and interrogation of the strong (neo)colonial legacies that influence received wisdoms, resource management, and power hierarchies (Petty et al., 2015). Particular attention needs to be given to how our understanding of 'community' has been constructed and what institutional legitimacy and empowerment means to IPLCs in specific local contexts (Clover & Eriksen, 2009). To do this, the dominant focus on community needs to shift towards a focus on institutions, exploring how political-economic relationships are continuously renegotiated at the local level and interact with national and international resource politics (Berkes, 2017; Nygaard, 2008). This can expose asymmetries between political institutions and local land governance systems that prevent resource benefits being acquired and equitably distributed at the community level and, in-turn, highlight opportunities for external institutions to provide capacity building support for long-term community fire management (Krah et al., 2020; Fisher, Donnelly & Adams, 2022).

For example, carbon-based PES schemes can utilise scale-dependent advantages, such as technical expertise and equipment, resource allocation, and institutionalised market opportunities, whilst prioritising local, non-expert knowledge, interpretations, and practices in project design, decision-making, and implementation. Making technologies available to local communities can also assist in empowering democratic self-governance and long-term support for fire management schemes, including the development of formal regulatory incentives and metrics for biodiversity conservation, as well as reducing operational costs that might compromise economic objectives.

Such approaches need to be supported through tripartite environmental justice frameworks (e.g., distributional, recognition, and procedural) to address ongoing challenges associated with the lack of political autonomy and negotiating power currently held by Indigenous and local people in fire management and the reproduction of colonial hegemonies in climate governance (incl. facilitating elite capture at the local level).

Decentralisation of fire management rights can assist in creating new narratives in climate policy development which are of greater use and relevancy at the local level and contribute towards achieving national climate, environmental, and social objectives in the long-term. However, it is also important to recognise how processes of (neo)colonialism and the contemporary land rush in sub-Saharan Africa have and continue to impact local agrarian livelihoods, forcing societies to not only renegotiate their relationship with the state and private actors, but also within and between one another. This has created new challenges at the local level which can prevent equitable decentralisation in resource management and accelerate distributional inequalities in fire management and the carbon economy. Understanding the wildfire paradox as an ecological-biocultural phenomena can assist in identifying challenges that might preclude sustainable fire management at the local-level and, in-turn, the political and legal reforms necessary to equitably formalise customary land titles and the development of locally legitimate and inclusive bottom-up fire management arrangements (Domínguez & Luoma, 2020).

If these challenges continue unabated under future socioeconomic-climate change, fires might decline in parallel with a decline in available biomass. Yet, the underlying social-ecological challenges remain. And will likely materialise into an even more complex ‘wicked problem’ across conservation frontiers.

## 9. References

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## Appendix I.

**Table A1.** Final sample of papers retrieved in a systematic review of the published literature on the development of Northern Australian savanna burning emissions abatement schemes in East and Southern African savanna-protected areas.

| Author, (date)                          | Title                                                                                                                                                          |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cassidy, L., et al. (2022)              | ‘Too much, too late: fires and reactive wildfire management in northern Botswana’s forests and woodland savannas.’                                             |
| Corey, B., et al. (2019)                | ‘Better biodiversity accounting is needed to prevent bioperversity and maximize co-benefits from savanna burning.’                                             |
| da Veiga, R. M. and W. Nikolakis (2022) | ‘Fire Management and Carbon Programs: A Systematic Literature Review and Case Study Analysis.’                                                                 |
| Edwards, A., et al. (2021)              | ‘Transforming fire management in northern Australia through successful implementation of savanna burning emissions reductions projects.’                       |
| Laris, P. (2021)                        | ‘On the problems and promises of savanna fire regime change.’                                                                                                  |
| Lipsett-Moore, G. J., et al. (2018)     | ‘Emissions mitigation opportunities for savanna countries from early dry season fire management.’                                                              |
| Lipsett-Moore, G. J., et al. (2021)     | ‘Response to: Problems and promises of savanna fire regime change.’                                                                                            |
| Maraseni, T. N., et al. (2016)          | ‘Savanna burning methodology for fire management and emissions reduction: A critical review of influencing factors.’                                           |
| Moura, L. C., et al. (2019)             | ‘The legacy of colonial fire management policies on traditional livelihoods and ecological sustainability in savannas: Impacts, consequences, new directions.’ |
| Nieman, W. A., et al. (2021)            | ‘A review of fire management practices in African savanna-protected areas.’                                                                                    |
| Russell-Smith, J., et al. (2013)        | ‘Managing fire regimes in north Australian savannas: Applying Aboriginal approaches to contemporary global problems.’                                          |
| Russell-Smith, J., et al. (2017)        | ‘Can savanna burning projects deliver measurable greenhouse emissions reductions and sustainable livelihood opportunities in fire-prone settings?’             |
| Russell-Smith, J., et al. (2014)        | ‘Developing a savanna burning emissions abatement methodology for tussock grasslands in high rainfall regions of northern Australia.’                          |
| Russell-Smith, J., et al. (2021)        | ‘Opportunities and challenges for savanna burning emissions abatement in southern Africa.’                                                                     |
| Russell-Smith, J., et al. (2015)        | ‘Deriving multiple benefits from carbon market-based savanna fire management: An Australian example.’                                                          |
| Sangha, K. K., et al. (2021)            | ‘Assessing the value of ecosystem services delivered by prescribed fire management in Australian tropical savannas.’                                           |
| Tear, T. H., et al. (2021)              | ‘Savanna fire management can generate enough carbon revenue to help restore Africa’s rangelands and fill protected area funding gaps.’                         |
| van Wilgen, B. W., et al. (2022)        | ‘An analysis of the recent fire regimes in the Angolan catchment of the Okavango Delta, Central Africa.’                                                       |

**Table A2.** Summary of the reasons indigenous peoples and local communities (**IPLC**), and park officials (**PO**), use fire as identified in the published evidence-base on CBFiM in savanna-protected areas (Crocker et al. 2023a).

| Reason for burning                                        | Description                                                                                                                  | Reference                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Vegetation Management</b>                              |                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Pasture regeneration and maintenance of pasture resources | <b>(IPLC)</b>                                                                                                                | Bloesch (1999); Kull (2002); Nangendo et al., (2002); Jurvélius (2004); Butz (2009); Mapaire et al., (2009); Shaffer (2010); Eriksen (2007); Gil-Romera et al., (2011); Trollope (2011); Dube (2013); Kamau and Medley (2014); Alvarado et al., (2015); Russel-Smith et al., (2017); Alvarado et al., (2018); Ekblom et al., (2019); Moura et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021) |
| Preventing bush encroachment                              | <b>(IPLC; PO)</b>                                                                                                            | Kull (2002); Eriksen (2007); Butz (2009); Mapaire et al., (2009); Shaffer (2010); Gil-Romera et al., (2011); Trollope (2011); Kamau and Medley (2014); Alvarado et al., (2018); Moura et al., (2019); Ribeiro et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021)                                                                                                                              |
| Habitat creation and management                           | <b>(IPLC; PO)</b> (I) habitat extension; (II) micro- and edge-habitats; (III) maintenance of landscape features              | Bloesch (1999); Eriksen (2007); Butz (2009); Shaffer (2010); Gil-Romera et al., (2011); Alvarado et al., (2018); Ekblom et al., (2019); Moura et al., (2019); Ribeiro et al., (2019); Humphrey et al., (2021)                                                                                                                                                                                                   |
| Biodiversity and wildlife                                 | <b>(IPLC; PO)</b> (I) diverse fire regime; (II) species selection and avoidance; (III) soil memory for biodiversity hotspots | Bloesch (1999); Kull (2002); Nangendo et al., (2002); Eriksen (2007); Shaffer (2010); Gil-Romera et al., (2011); Trollope (2011); Kamau and Medley (2014); Alvarado et al., (2018); Ekblom et al., (2019); Moura et al., (2019); Humphrey et al., (2021)                                                                                                                                                        |
| <b>Visibility</b>                                         |                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Maintain open landscape*                                  | <b>(IPLC; PO)</b>                                                                                                            | Bloesch (1999); Eriksen (2007); Shaffer (2010); Gil-Romera et al., (2011); Dube (2013); Kamau and Medley (2014); Alvarado et al., (2018); Moura et al., (2019); Ribeiro et al., (2019);                                                                                                                                                                                                                         |
| Tourism*                                                  | <b>(PO)</b> (I) attract game                                                                                                 | Eriksen (2007); Gil-Romera et al., (2011); Trollope (2011); Kamau and Medley (2014); Alvarado et al., (2018); Ribeiro et al., (2019); Humphrey et al., (2021)                                                                                                                                                                                                                                                   |
| Game meat hunting                                         | <b>(IPLC)</b> (I) attract game; (II) Donaka – hunting wild zebus                                                             | Bloesch (1999); Nangendo et al., (2002); Eriksen (2007); Shaffer (2010); Gil-Romera et al., (2011); Dube (2013); Kamau and Medley (2014); Russel-Smith et al., (2017); Moura et al., (2019); Humphrey et al., (2021)                                                                                                                                                                                            |
| Tracking                                                  | <b>(IPLC)</b>                                                                                                                | Humphrey et al., (2021)                                                                                                                                                                                                                                                                                                                                                                                         |

|                                                        |                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trophy hunting                                         | <i>(PO)</i>                                                                                                                                                                                                 | Trollope (2011); Humphrey et al., (2021); Russel-Smith et al., (2021)                                                                                                                                                                                                                            |
| Predator detection and removal                         | <i>(IPLC)</i>                                                                                                                                                                                               | Butz (2009); Shaffer (2010); Kamau and Medley (2014); Humphrey et al., (2021)                                                                                                                                                                                                                    |
| Topographic hazard protection                          | <i>(IPLC)</i>                                                                                                                                                                                               | Butz (2009)                                                                                                                                                                                                                                                                                      |
| ‘Avoid arrest by rangers’                              | <i>(IPLC)</i>                                                                                                                                                                                               | Kamau and Medley (2014)                                                                                                                                                                                                                                                                          |
| <b><i>Land Clearance</i></b>                           |                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                  |
| Livestock agriculture                                  | <i>(IPLC)</i>                                                                                                                                                                                               | Kull (2002); Eriksen (2007); Butz (2009); Shaffer (2010); Gil-Romera et al., (2011); Trollope (2011); Dube (2013); Kamau and Medley (2014); Alvarado et al., (2015); Alvarado et al., (2018); Moura et al., (2019); Ribeiro et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021) |
| Arable agriculture                                     | <i>(IPLC)</i> (I) crop field clearance and preparation; (II) crop field fertilisation and sterilisation or soil enrichment; (III) crop residue burning before harvest*; (IV) creation of compost fertiliser | Bloesch (1999); Kull (2002); Eriksen (2007); Shaffer (2010); Trollope (2011); Dube (2013); Kamau and Medley (2014); Alvarado et al., (2015); Alvarado et al., (2018); Ekblom et al., (2019); Moura et al., (2019); Ribeiro et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021)  |
| Removal of moribund                                    | <i>(IPLC; PO)</i>                                                                                                                                                                                           | Bloesch (1999); Kull (2002); Eriksen (2007); Butz (2009); Shaffer (2010); Trollope (2011); Kamau and Medley (2014); Alvarado et al., (2018); Ribeiro et al., (2019); Humphrey et al., (2021)                                                                                                     |
| Infrastructural development                            | <i>(IPLC; PO)</i> (I) homestead development; (II) corporate enterprise development                                                                                                                          | Butz (2009); Eriksen (2007); Shaffer (2010); Kamau and Medley (2014)                                                                                                                                                                                                                             |
| Swidden agriculture (‘slash-and-burn’) e.g., Chitemene | <i>(IPLC)</i> (I) ‘slash-and-burn’ by immigrants;                                                                                                                                                           | Bloesch (1999); Kull (2002); Eriksen (2007); Shaffer (2010); Trollope (2011); Dube (2013); Russel-Smith et al., (2017); Moura et al., (2019)                                                                                                                                                     |
| Resource extraction and transport routes               | <i>(IPLC; PO)</i>                                                                                                                                                                                           | Kamau and Medley (2014)                                                                                                                                                                                                                                                                          |
| Movement of pastoralists and livestock                 | <i>(IPLC)</i>                                                                                                                                                                                               | Butz (2009); Kamau and Medley (2014);                                                                                                                                                                                                                                                            |
| <b><i>Disease and Pest Control</i></b>                 |                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                  |
| Kill and control pests                                 | <i>(IPLC; PO)</i> (I) control ticks; (II) kill rinderpest; (III) control locusts                                                                                                                            | Bloesch (1999); Kull (2002); Eriksen (2007); Butz (2009); Shaffer (2010); Trollope (2011); Dube (2013); Kamau and Medley (2014); Russel-Smith et al., (2017); Alvarado et al., (2018); Moura et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021)                                |
| Prevent disease and control tsetse flies               | <i>(IPLC; PO)</i>                                                                                                                                                                                           | Kull (2002); Eriksen (2007); Butz (2009); Mapaure et al., (2009); Trollope (2011); Dube (2013); Kamau and Medley (2014); Humphrey et al., (2021)                                                                                                                                                 |

|                                                             |                                                                                           |                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Control weeds                                               | <i>(IPLC; PO)</i>                                                                         | Eriksen (2007); Dube (2013)                                                                                                                                                                                                                                                          |
| <b>Wildfire Mitigation</b>                                  |                                                                                           |                                                                                                                                                                                                                                                                                      |
| Prevention of large late dry season fires                   | <i>(IPLC; PO)</i>                                                                         | Bloesch (1999); Eriksen (2007); Butz (2009); Mapaure et al., (2009); Dube (2013); Kamau and Medley (2014); Russel-Smith et al., (2017); Alvarado et al., (2018); Moura et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021)                                          |
| Fire breaks*                                                | <i>(IPLC; PO)</i>                                                                         | Bloesch (1999); Kull (2002); Eriksen (2007); Butz (2009); Mapaure et al., (2009); Shaffer (2010); Dube (2013); Alvarado et al., (2018); Moura et al., (2019); Ribeiro et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021)                                           |
| Fuel management*                                            | <i>(IPLC; PO)</i>                                                                         | Kull (2002); Eriksen (2007); Jurvélius (2004); Eriksen (2007); Butz (2009); Mapaure et al., (2009); Shaffer (2010); Gil-Romera et al., (2011); Trollope (2011); Dube (2013); Russel-Smith et al., (2017); Moura et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021) |
| <b>Natural Resource Management</b>                          |                                                                                           |                                                                                                                                                                                                                                                                                      |
| Subsistence: firewood                                       | <i>(IPLC)</i>                                                                             | Eriksen (2007); Shaffer (2010); Kamau and Medley (2014);                                                                                                                                                                                                                             |
| Subsistence: fuel wood and/or charcoal                      | <i>(IPLC)</i>                                                                             | Bloesch (1999); Kull (2002); Eriksen (2007); Butz (2009); Shaffer (2010); Kamau and Medley (2014); Alvarado et al., (2018)                                                                                                                                                           |
| Subsistence: medicine*                                      | <i>(IPLC)</i> (I) healing rituals;(II) extracting and preparing medicinal plant materials | Eriksen (2007); Butz (2009); Shaffer (2010); Dube (2013); Kamau and Medley (2014); Humphrey et al., (2021); Russel-Smith et al., (2021)                                                                                                                                              |
| Subsistence: apiculture                                     | <i>(IPLC)</i>                                                                             | Eriksen (2007); Butz (2009); Shaffer (2010); Gil-Romera et al., (2011); Kamau and Medley (2014); Russel-Smith et al., (2017);                                                                                                                                                        |
| Subsistence: protection of valuable tree species            | <i>(IPLC)</i>                                                                             | Bloesch (1999); Kull (2002); Eriksen (2007); Shaffer (2010); Gil-Romera et al., (2011); Kamau and Medley (2014); Ribeiro et al., (2019);                                                                                                                                             |
| Subsistence: encouraging ethnobotanically important species | <i>(IPLC)</i>                                                                             | Eriksen (2007); Butz (2009); Moura et al., (2019);                                                                                                                                                                                                                                   |
| Subsistence: harvesting forest and veld products            | <i>(IPLC)</i>                                                                             | Bloesch (1999); Kull (2002); Eriksen (2007); Shaffer (2010); Trollope (2011); Dube (2013); Kamau and Medley (2014); Russel-Smith et al., (2017); Humphrey et al., (2021)                                                                                                             |
| Subsistence: construction material                          | <i>(IPLC)</i>                                                                             | Kull (2002); Eriksen (2007); Butz (2009); Shaffer (2010); Trollope (2011); Dube (2013); Russel-Smith et al., (2021)                                                                                                                                                                  |

|                                                             |                                                                                            |                                                                                                                                                                       |
|-------------------------------------------------------------|--------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Subsistence: food sources                                   | <i>(IPLC)</i>                                                                              | Bloesch (1999); Eriksen (2007); Butz (2009); Shaffer (2010); Trollope (2011); Dube (2013); Moura et al., (2019); Humphrey et al., (2021); Russel-Smith et al., (2021) |
| Subsistence: caterpillar breeding                           | <i>(IPLC)</i>                                                                              | Eriksen (2007)                                                                                                                                                        |
| Commercial: sura production                                 | <i>(IPLC)</i>                                                                              | Shaffer (2010)                                                                                                                                                        |
| Exploitative: khat/miraa ( <i>Catha edulis</i> ) production | <i>(IPLC)</i>                                                                              | Kamau and Medley (2014)                                                                                                                                               |
| Exploitative: bhang ( <i>Cannabis sativa</i> ) production   | <i>(IPLC)</i>                                                                              | Kamau and Medley (2014)                                                                                                                                               |
| <b><i>Carbon Sequestration</i></b>                          |                                                                                            |                                                                                                                                                                       |
| Reduction of GHG emissions through early dry season burning | <i>(PO)</i>                                                                                | Russel-Smith et al., (2017); Moura et al., (2019); Russel-Smith et al., (2021)                                                                                        |
| Savanna-burning emissions abatement schemes                 | <i>(PO)</i>                                                                                | Russel-Smith et al., (2017); Moura et al., (2019); Russel-Smith et al., (2021)                                                                                        |
| <b><i>Other: Social Behaviour</i></b>                       |                                                                                            |                                                                                                                                                                       |
| Religion and spirituality                                   | <i>(IPLC)</i> (I) communication with ancestors*                                            | Shaffer (2010); Gil-Romera et al., (2011); Humphrey et al., (2021)                                                                                                    |
| Rituals and ceremonies                                      | <i>(IPLC)</i> (I) healing                                                                  | Gil-Romera et al., (2011); Moura et al., (2019); Humphrey et al., (2021)                                                                                              |
| Symbolism                                                   | <i>(IPLC)</i> (I) symbol of manhood                                                        | Humphrey et al., (2021)                                                                                                                                               |
| Communication                                               | <i>(IPLC)</i> (I) communication in the bush                                                | Gil-Romera et al., (2011); Dube (2013); Kamau and Medley (2014); Moura et al., (2019); Humphrey et al., (2021);                                                       |
| Knowledge transmission                                      | <i>(IPLC)</i>                                                                              | Shaffer (2010); Gil-Romera et al., (2011); Humphrey et al., (2021)                                                                                                    |
| <b><i>Other: Survival</i></b>                               |                                                                                            |                                                                                                                                                                       |
| Cooking                                                     | <i>(IPLC)</i>                                                                              | Butz (2009); Shaffer (2010); Dube (2013); Kamau and Medley (2014); Humphrey et al., (2021)                                                                            |
| Heating                                                     | <i>(IPLC)</i>                                                                              | Dube (2013); Kamau and Medley (2014);                                                                                                                                 |
| Light provision                                             | <i>(IPLC)</i>                                                                              | Humphrey et al., (2021)                                                                                                                                               |
| Safety*                                                     | <i>(IPLC)</i> (I) guarding livestock; (II) guarding crop fields; (III) guarding homesteads | Butz (2009); Eriksen (2007); Shaffer (2010); Kamau and Medley (2014); Moura et al., (2019); Ribeiro et al., (2019); Humphrey et al., (2021)                           |

|                                               |                                                                                                             |                                                                                                                                                       |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Human-wildlife conflict reduction*            | <i>(IPLC)</i> (I) drive herbivores off crop fields; (II) drive predators away from livestock and homesteads | Shaffer (2010); Humphrey et al., (2021)                                                                                                               |
| Local products production                     | <i>(IPLC)</i> (I) pottery; (II) smelt iron; (III) woody carving                                             | Jurvélius (2004); Shaffer (2010); Dube (2013); Kamau and Medley (2014)                                                                                |
| ‘Chief’s order!’                              | <i>(IPLC)</i>                                                                                               | Eriksen (2007)                                                                                                                                        |
| <b><i>Other: Anti-social</i></b>              |                                                                                                             |                                                                                                                                                       |
| Intentional: political protest and resistance | <i>(IPLC)</i> (I) resistance in agrarian politics linked to subsistence economies                           | Bloesch (1999); Kull (2002); Mapaire et al., (2009); Alvarado et al., (2018); Kamau and Medley (2014); Moura et al., (2019);                          |
| Intentional: arson*                           | <i>(IPLC)</i>                                                                                               | Kull (2002); Butz (2009); Mapaire et al., (2009); Shaffer (2010); Dube (2013); Kamau and Medley (2014); Alvarado et al., (2018); Moura et al., (2019) |
| Intentional: poaching                         | <i>(IPLC)</i>                                                                                               | Eriksen (2007); Mapaire et al., (2009); Shaffer (2010); Dube (2013)                                                                                   |
| Intentional: intra-group conflict             | <i>(IPLC)</i>                                                                                               | Kull (2002); Kamau and Medley (2014)                                                                                                                  |
| Intentional: cattle theft                     | <i>(IPLC)</i> (I) hiding evidence of theft;                                                                 | Alvarado et al., (2018)                                                                                                                               |
| Unintentional: cigarette butts                | <i>(IPLC)</i>                                                                                               | Butz (2009); Shaffer (2010); Dube (2013); Kamau and Medley (2014)                                                                                     |
| Unintentional: children playing with fire     | <i>(IPLC)</i>                                                                                               | Shaffer (2010); Dube (2013)                                                                                                                           |

*\*Reasons for burning identified as spanning multiple categories – categorised based on their primary objective.*

## Appendix II.

**Table A3.** Comparison of projected temperature change (estimated range and median value) globally versus over East Africa (1850-1900 baseline) and the number of consecutive dry days (CDD) estimated for East Africa in the near, medium, and long-term under increasing SSPX-Y scenarios. Annual median temperature changes are the same as median temperatures estimated for the dry fire season in East Africa (April to October) across all scenarios except SSP2-4.5 between 2081-2100 (*italicised in brackets*). Temperature ranges present ‘very likely’ temperature changes calculated by the IPCC AR6-WGI (2021) using 5<sup>th</sup> and 95<sup>th</sup> percentile values. Project range and median values for annual CDDs across East Africa were extracted from the AR6-WGI report (2021) and Interactive Atlas.

|                                    |                                                                                            | SSP1-2.6            | SSP2-4.5                    | SSP3-7.0            | SSP5-8.5            |
|------------------------------------|--------------------------------------------------------------------------------------------|---------------------|-----------------------------|---------------------|---------------------|
| <b>Near-term<br/>(2021-2040)</b>   | East Africa: Range of Temperature Change, Median Temperature Change (°C)                   | 1.3-2.0°C,<br>1.6°C | 1.2-1.9°C,<br>1.6°C         | 1.1-2.0°C,<br>1.5°C | 1.3-2.0°C,<br>1.6°C |
|                                    | Global: ‘Very Likely’ Range of Temperature Change, ‘Best Estimate’ Temperature Change (°C) | 1.2-1.8°C,<br>1.5°C | 1.2-1.8°C,<br>1.5°C         | 1.2-1.8°C,<br>1.5°C | 1.3-1.9°C,<br>1.6°C |
|                                    | East Africa: Annual Range of CDDs, Annual Median of CDDs (Days)                            | 40.3-110.8,<br>76.5 | 41.5-110.2,<br>76.0         | 39.9-108.1,<br>76.6 | 40.6-109.5,<br>75.7 |
| <b>Medium-term<br/>(2041-2060)</b> | East Africa: Range of Temperature Change, Median Temperature Change (°C)                   | 1.4-2.5°C,<br>1.9°C | 1.7-2.7°C,<br>2.1°C         | 1.8-2.9°C,<br>2.3°C | 2.0-3.1°C,<br>2.5°C |
|                                    | Global: ‘Very Likely’ Range of Temperature Change, ‘Best Estimate’ Temperature Change (°C) | 1.3-2.2°C,<br>1.7°C | 1.6-2.5°C,<br>2.0°C         | 1.7-2.6°C,<br>2.1°C | 1.9-3.0°C,<br>2.4°C |
|                                    | East Africa: Annual Range of CDDs, Annual Median of CDDs (Days)                            | 41.1-113.1,<br>76.3 | 39.9-113.1,<br>76.0         | 39.8-109.7,<br>76.4 | 39.0-112.5,<br>75.3 |
| <b>Long-term<br/>(2081-2100)</b>   | East Africa: Range of Temperature Change, Median Temperature Change (°C)                   | 1.4-2.6°C,<br>1.9°C | 2.3-3.9°C,<br>2.9°C (3.0°C) | 3.1-5.2°C,<br>4.0°C | 3.5-6.3°C,<br>4.8°C |
|                                    | Global: ‘Very Likely’ Range of Temperature Change, ‘Best Estimate’ Temperature Change (°C) | 1.3-2.4°C,<br>1.8°C | 2.1-3.5°C,<br>2.7°C         | 2.8-4.6°C,<br>3.6°C | 3.3-5.7°C,<br>4.4°C |
|                                    | East Africa: Annual Range of CDDs, Annual Median of CDDs (Days)                            | 40.6-111.9,<br>75.6 | 38.7-112.9,<br>75.1         | 37.2-109.6,<br>73.0 | 36.8-109, 71.5      |

### Appendix III.

A short review carried out on Scopus to explore the application of BBNs in the environmental sciences revealed a >100% increase in the number of published articles from 2015-2024 ( $n=271$ ), relative to 2005-2014 ( $n=115$ ). The search on ‘Bayesian Belief’ was conducted under the topic subject of Title, Abstract, and Keywords, and was limited to journal articles within the ‘Environmental Science’ subject area. Sub-categories include but were not limited to ecological modelling; ecology; global and planetary change; management, monitoring, policy, and law; and nature and landscape conservation. No time restrictions were imposed on this search. 408 articles were retrieved, published between 1990 and 2024. Only five articles were published before 2000. 66% of articles were published in the last 10 years (2015-2024) ( $n=271$ ), with the number of environmental science articles related to BBNs overtaking computer sciences and mathematics (Aguilera et al., 2011). This exponential increase in the application of BBNs in environmental sciences corresponds with several key events: the Millennium Ecosystem Assessment launched in 2001 to promote research into the social-ecological drivers of and responses to environmental change, popularising the term ecosystem services and their inclusion in systemic policy development (Carpenter, Bennett & Peterson, 2006; Carpenter et al., 2009); the 2010 Bonn Challenge and global movement for ecosystem restoration by 2030 (Maes et al., 2024; Parr, te Beest & Stevens, 2024); the adoption of RCPs in the IPCC Fifth Assessment Report (AR5) published in 2014 to model future GHG emissions concentrations and climate change; the 2015 Paris Agreement and push to increase research into alternative science-based policies to limit global warming to 1.5°C above pre-industrial levels (Schleussner et al., 2016; Aleluia Reis et al., 2023); and the UN Decade on Ecosystem Restoration (2021-2030) launched to address environmental breakdown (climate change, biodiversity loss, and pollution), accelerating research into the importance of incorporating complex systems science into environmental management (Moreno-Mateos et al., 2020; Fischer et al., 2021).

### Appendix IV.

**Table A4.** Nodes integrated following initial SSPX-Y and fire management scenario sensitivity analyses (50 bootstraps), accounting for controlled variables under each scenario and redundant feedback loops.

| Removed node                | Included node (integrated) | Location | Controlled under scenario |
|-----------------------------|----------------------------|----------|---------------------------|
| Primary productivity        | Plant diversity            | PA       | N                         |
| Atmospheric CO <sub>2</sub> | Temperature                | All      | Y                         |
| Predators                   | Large herbivores           | PA       | N                         |
| Bare ground                 | Soil erosion               | PA       | N                         |
| Ground cover degradation    | Rangelands                 | CL       | N                         |
| Human migration             | Human population           | CL       | Y                         |
| Rural-urban migration       | Rapid urbanisation         | CL       | N                         |
| Agricultural productivity   | Small-scale agriculture    | CL       | N                         |

|                                                 |                              |     |   |
|-------------------------------------------------|------------------------------|-----|---|
| Market opportunities                            | Human-development conditions | CL  | N |
| International cooperation                       | Inter-group conflict         | All | Y |
| Local governance and traditional fire knowledge | Biocultural hysteresis       | All | N |

The node ‘predators’ represented the total number and diversity of predators in the protected area (incl. lion, leopard, cheetah, hyena, wild dog, and crocodile). ‘Predators’ only directly affected ‘large herbivores’ (-1) and aggregate node ‘biodiversity’ (+3), while ‘large herbivores’ already affected ‘biodiversity’ and other nodes important for determining savanna health and biogeophysical wildfire conditions (e.g., ‘vegetation continuity’ and ‘woody thickening’). Given that large herbivore and predator interactions typically exhibit predator-prey density dependence in the long-term, an increase in ‘biodiversity’ attributable to changes in large herbivore populations over the modelled time-period can infer a level of trophic stability. While this study recognises that, in-reality, predator-prey interactions are highly complex and stochastic, influenced by multiple density dependencies and changing (a)biotic contexts, modelling such intricate local-level trophic interactions was beyond the scope of this study, and the sensitivity analysis revealed no change on the outcome nodes when ‘predators’ was removed and integrated with ‘large herbivores’.

Moreover, the node ‘bare ground’ represented the geographical extent of soils in the protected area not covered by any vegetation (e.g., due to processes of xerification), therefore was integrated with ‘soil erosion’ which represents a loss of fertile top-soil. Similarly, ‘ground cover degradation’ represented the same processes as ‘bare ground’ for outside the protected area, and only directly interacted with ‘rangelands’ (e.g., increase in ground cover degradation caused a decreased in rangelands). Since ‘rangelands’ represents the extent and continuity of productive rangelands, where productivity can be measured by soil moisture and palatable vegetation cover, a decrease in this node already infers a reduction in vegetation continuity, increased woody thickening, and soil erosion, thus already incorporates ground cover degradation.

Multiple socioeconomic nodes were also integrated, such as ‘rural-urban migration’ with ‘rapid urbanisation’, given that processes of de-agrarianisation are strongly associated with the rapid expansion of urban areas and increase in informal settlements; ‘market opportunities’ with ‘human-development conditions’, given that access to diverse local markets contributes to overall human and social capital through employment, income diversification, and engagement in economic activity; and ‘international cooperation’ with ‘inter-group conflict’, such that a decline in inter-group conflict can infer greater cooperation, coordination, and collaboration between governments, multi-lateral institutions, and international governance systems and market networks.