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Wildfire dynamics, local people's fire use and underlying factors for wildfires at Liwale District in Southern Tanzania

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Abstract

Fire causes positive effects on the ecosystem if appropriately managed. Unmanaged fire may, however, rather be detrimental. Despite the substantial role the forests play in economics and other ecosystem services in Tanzania, the forest landscape is threatened by wildfires. There is little information regarding wildfires, and available data is too general. Empirical data on wildfires at a local scale is essential for underpinning fire management strategies and policies. This study determined the spatial and temporal dynamics of wildfires in Liwale district, south-east Tanzania. It also examined the interaction between local people and fires regarding fire use, fire occurrences, and the influence of incentives in forest fire suppression. The study used focus group discussion, key informants, archival data, and remote sensing to achieve the objectives. The results show that local people in Liwale district predominantly use fire in farm preparation. The extent of burning was relatively greater in reserve areas compared to community forest. The study has shown that tangible forest benefits may influence the community's willingness to suppress forest fire. The study recommends the government of Tanzania to ensure that the local community realizes the forests' economic values to encourage them to conserve the forests, including undertaking fire suppression.

Keywords: Wildfires, Miombo woodlands, Local people, Qualitative research, Focus Group Discussion, Anthropogenic activities

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Abbreviations

AVLFR	Angai Village Land Reserve
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussion
GHGs	Greenhouse Gases
GIS	Geographical Information System
Ha	Hectare
LDC	Liwale District Council
MNRT	Ministry of Natural Resources and Tourism
MODIS	Moderate Resolution Imaging Spectroradiometer
SLU	Swedish University of Agricultural Sciences
SUA	Sokoine University of Agriculture
TAWA	Tanzania Wildlife Management Authority
TFS	Tanzania Forest Services Agency
URT	United Republic of Tanzania
VNRC	Village Natural Resources Committee
WWII	World War II
VNRC	Village Natural Resources Committee

1. Introduction

1.1. Wildfire/fire: General concept

Wildfire is a global disturbance that affects the forest ecosystem. Fire results from an explosive reaction of three essential combustion elements: fuel, oxygen, and heat. Given its ability to jeopardize some living organisms and cause surviving organisms to be dependent on regular fire, Pyne (2001) regarded fire as a selective force and ecological factor that organizes and shapes evolution and biota. Though other organisms can modify the environment of fire, only humans can willingly start and stop it (*ibid*).

It has been argued that fire on Earth started around 420 million years ago, as the most ancient charcoal fossils date back to this time. The Earth is unique as it holds the three elements of combustion, which may explode to form fire (Pyne 2001). The size and prevalence of fire depend on factors such as climate, elevation, topography, type of fuel and source of ignition (Gould & Siitonen 2007). Climate change would exacerbate the risk of wildfires due to prolonged drought periods and high winds (Katani et al. 2014; Juárez-Orozco et al. 2017).

1.2. The extent of burning in Africa

Evidence has revealed an exponential rise in tropical forests' burning areas due to agriculture activities (Mouillot & Field 2005). The Africa continent experiences the highest burning extent (Hansen et al. 2000; Mouillot & Field 2005; van Lierop & Moore 2019), contributing to 42 % of global burned biomass. The Savanna biome contributes to almost 22 % of the global burned biomass (van Lierop & Moore

2019). The Savanna biome is prone to burning due to the sufficient fuel it produces, which is highly flammable in dry periods (Mouillot & Field 2005).

In Tanzania, the average annual burning area is 11 million ha, approximated at 12.5 % of the total land area (FAO 2013a; Tarimo et al. 2015; van Lierop & Moore 2019). According to Tarimo et al. (2015), 69 % of Tanzania's burned area between 2000 and 2011 was woodland. It is further reported that Tanzania had lost 8,067,000 ha (19.4% of total forest area) from 1990 to 2010 due to various forest disturbances. This loss is an average of 403,350 ha per year. Among other things, forest fires contribute a significant loss of forest in Tanzania (FAO 2011). Anthropogenic activities profoundly contribute to fires in Tanzania woodlands (Tarimo et al. 2015).

1.3. Positive and negative impacts of fires

In agriculture, fire is helpful in farm preparation; it clears the new and existing agriculture land to remove unwanted agricultural and woody debris. Fire also controls diseases and pests (FAO 2013a). Farmers, particularly in Tanzania, prefer burning because ashes are believed to increase soil fertility (Masawe 1992; Katani et al. 2014). Basically, tropical soils have inadequate inorganic nutrients (Tiessen et al. 1994). Studies from tropical rainforest soil have shown that ash from burning increases essential soil nutrients such as N, P, K, Ca, and Mg, temporarily. However, these nutrients start decreasing after a couple of months (Sanchez et al. 1983).

In some local communities in Tanzania, fire is traditionally used in honey harvest, chasing away wild animals, and hunting (Miya et al. 2012; FAO 2013a; FAO 2013b; Rija et al. 2013; Katani et al. 2014; Ngongolo et al. 2015; Hariohay et al. 2020; Kilawe et al. 2021). The use of fire in hunting reduces ground cover, thereby exposing burrows that facilitate catching wild animals (Parker 2015). Prescribed burning maintains the habitat for wildlife and other living organisms (FAO 2013a; Ngongolo et al. 2015). In national parks and game reserves, fire improves visibility which is important for recreation. Fire also improves pasture

quality and productivity (FAO 2013a). Pasture productivity is attained through killing/reducing competing vegetation and through providing a nutrient boost to grasses. Fire helps in breaking the seed dormancy of some plants which depend on fire. Also, fire is essential in speeding up the grass germination process (FAO 2013a).

Unmanaged wildfire may rather be detrimental. Fire may kill plant individuals, thereby diminishing woody plant densities leading to change in species population and structure (Zolho 2005). Fire may also result in loss of nutrients, soil erosion, change soil pH, remove organic matter, and cause soil degradation. At the ecosystem landscape scale, fire can cause forest degradation, destroy riparian ecosystems and recreational values hence undermining ecosystem landscape potential as a carbon sink and other ecological values and functions. Significant fire consequences may lead to the loss of people's lives and destroy food, causing hunger and poverty. Fire may cause climate change and associated consequences such as increased droughts, floods and air pollution through emission of GHGs (FAO 2013a; Rija et al. 2013; van Lierop & Moore 2019).

1.4. Miombo woodlands

Miombo woodland is the deciduous and dominant forest vegetation in Tanzania, where *Brachystegia spp* (*miombo*) is a dominant genus (Munishi et al. 2011; Sunseri 2014). Miombo is profoundly located in the western, central and southern part of the country (Tarimo et al. 2015), occupying 44.7 million hectares, which is 92 per cent of forested area (the forested area in Tanzania mainland is 48.1 million hectares), and 50.4 per cent of the total land area in Tanzania mainland (MNRT 2015). The annual average rainfall in dry miombo is 750 to 1000 mm. The tree canopy cover in miombo is between 20 per cent and 60 per cent and exceeds 15 m in height on rare occasions. Miombo is a green and flowering biome during the rainy season turns leafless during the dry season (Sunseri 2014).

Given its partial tree cover and shortage of marketable trees and its characteristics of accommodating tsetse fly that carry sleeping sickness, German foresters did not consider miombo as important forests in Tanzania during colonialism. In the 1920s, British ecologists revealed that miombo would attain climax as a closed forest when isolated from human interference. Following the economic impacts of WWII, which triggered a high demand for timber coupled with a newly constructed railway that facilitated its exploitation, British officials declared miombo to be exploitable for imperial economic stability in 1951 (Ylhäisi 2003; Sunseri 2014).

Since then, miombo has been valued as important as other vegetation. Consequently, natural forest production is primarily done in miombo woodlands (Sunseri 2014). Miombo provides social-economic benefits such as charcoal, firewood, building poles, thatches, beeswax, honey, resins, ropes, mushroom, vegetables, fodder, medicines and game meat (Mbwambo 2000). Apart from economic benefits, miombo contributes to climate change regulation as a carbon sink (Monela et al. 2000).

When exposed to fire disturbance, the impacts of fire on miombo depend on factors such as tree species, age, fire intensity, fire frequency and burning season. It has been revealed that frequent fires result in a significant increase in species diversity in miombo woodlands (Mganga & Lyaruu 2016). They argue that one of the factors is the elimination of fire intolerant species, thereby creating favourable niches and resources required by colonizing fire-adapted species. On the other hand, repeated fires in miombo woodlands may impede sapling development and hinder tree maturity (Mganga & Lyaruu 2016). Generally, miombo species are resilient to fire disturbance thanks to vegetative regeneration from stumps and resprouts (Chidumayo 2004). This is because regeneration through coppice offers rapid growth due to an efficiently developed root system that recovers more rapidly when exposed to fire than newly established seedlings (Matowo et al. 2019).

Studies show that fire intensity affects miombo population and biomass (Backéus et al. 2006; Ryan & Williams 2011). Frequent late fires may decrease stocking of *Brachystegia*, *Isoberlinia* and *Julbernardia* species specifically at a younger age (Trapnell 1959; Backéus et al. 2006). On the contrary, *Pterocarpus angolensis*, *Diplorhynchus condylocarpon*, *Strychnos innocua* and *Pericopsis angolensis* species are fire-tolerant at a young age (Backéus et al. 2006). Even though *Pseudolachnostylis maprouneifoli*a and *Bridelia cathartic*a species are semi tolerant, they can be affected by late fires during the dry seasons. Generally when miombo is isolated from disturbances, it dominates the plant community (Backéus et al. 2006; Furley et al. 2008).

The long-term studies in miombo have revealed that annual fire regimes, at medium to high intensity would shape miombo vegetation structure by converting them to grassland and scattering shrubs (Furley et al. 2008; Ryan & Williams 2011). On the other hand, a low-intensity fire would maintain the forest cover of miombo woodlands, mainly when miombo has attained height and bark thickness enough to prevent fire damage (Furley et al. 2008). Given the low intensity and early fire at a return interval above one year and less than five years, fire disturbance would enhance miombo tree biomass (Trapnell 1959; Furley et al. 2008; Ryan & Williams 2011).

Trapnell (1959) described early and late fires as burning in the dry season in cold and hot weather, respectively. Early burning may preferably occur in June or July immediately after the rain season. Late burning may occur from August to October before the rainy season. When exactly early and late burning may occur would vary from one region to another depending on climatic conditions. Burning for farm preparation in Tanzania often increases in July, August and September in the late dry season (FAO 2013a). During this period, the fuel load in miombo woodlands is huge and dry and fires may become more detrimental than early fires would.

Early fires have fewer damaging effects on miombo species, allowing regeneration with no severe impacts on resprouts due to low fire intensity because

of high moisture of the fuel (Matowo et al. 2019). Unlike the early fires, late fires in the dry season may severely impact miombo species by changing miombo to grassland with few remaining tolerant species (Miya et al. 2012). Trapnell (1959) observed substantial effects of late fires on the stocking of young trees, shrubs and regenerants of miombo species.

1.5. Influence of human population increase and demand of agriculture products to wildfire occurrence

It has been documented that an increased human population contributes to high demand for agricultural land (Abdallah & Monela 2007). Statistical data shows a significant increase in human population in Liwale district and Tanzania in general (NBS 2003, 2006, 2013). This being the case, clearing the land for agriculture expansion in the country is apparent. According to the national agricultural survey, Lindi region, which Liwale district is part of, is among the top three crop production regions. Lindi region ranks first and second in growing sesame and cashews, respectively. Sesame is the third in nuts and oilseeds production in the country (NBS 2007), and its farming is associated with slash and burning practices.

Following the completion of the Mkapa Bridge across the Rufiji River in 2003, which used to be a limiting factor for goods transportation from southern regions (Milledge et al. 2007), the Bridge has increased access and demand for agricultural products, particularly sesame and cashews from Liwale district to the marketplace in big cities like Dar es Salaam. Increased demand for agricultural products, in line with increased population, may exacerbate wildfires due to land expansion through burning.

Despite the substantial role of the forests in the growth of national income, improving people's livelihood, and other ecosystem services in Tanzania, the forest landscape is profoundly threatened due to persistent forest degradation and deforestation. Wildfires being among the factors for forest threats. Yet, there is no

adequate information concerning the underlying causes of fires specifically, at the local scale. Studies show that protected areas such as forest and game reserves are most affected by fire in Tanzania (FAO 2013a; van Lierop & Moore 2019). However, this information is too general. Therefore, it is essential to determine the spatial and temporal fire dynamics between different land uses at the local scale. Also, it is critical to investigate the relationship between human activities and the occurrence of fires in miombo woodlands. This investigation would help to provide information to support existing strategies for the reduction of wildfires in Tanzania.

The objectives of this study are to (1) determine the spatial and temporal dynamics of wildfires in the study area, (2) examine the relationship between local people and fires in the study area, (3) explore underlying factors for uncontrolled fires in the study area, and (4) investigate the influence of incentives in forest fire suppression in the study area.

The study addressed the following questions; a) What are the temporal and spatial dynamics of wildfire in the study area in recent years? b) How and why is fire used and perceived by the local people in the study area? c) What are the causes of forest fires in the study area? d) How would incentives drive local people to suppress forest fires, and how could forest fires be managed in the study area? Based on these research questions, this study will also address fire management in Liwale district from a broader perspective and propose solutions to prevailing land management challenges.

2. Material and methods

2.1. Study area

This study was conducted at Liwale district, south-east Tanzania. Ngido is the predominant ethnic group in the area. Other small ethnic groups include Mwera, Makonde, Yao, Ngoni and Makua (LDC 2018). The recent national population census shows that, in 2012, Liwale district had 91,380 inhabitants (NBS 2013). The average temperature is about 25°C, and annual rainfall ranges from 503mm to 1220mm (Dondeyne et al. 2003, Dondeyne 2004a; Dondeyne 2004b; LDC 2018; URT 2019). The altitude ranges from 360 m to 900 m above sea level, the land is mostly flat, where a few areas have folded mountains, and the soil is primarily sandy and loamy (Dondeyne et al. 2003; Dondeyne 2004a; LDC 2018).

The total area of Liwale district is 37,800km^2, out of which 58% is covered by Selous Game Reserve (Dondeyne et al. 1998). The forests cover 28,021km^2, where Angai and Nyera-Kipelele are two major forest reserves (LDC 2018). The vegetation is mainly covered by miombo, dominated by *Pterocarpus angolensis*, *Afzelia quanzensis*, *Dalbergia melanoxylon*, *Euphorbia candelabrum*, and *Brachystegia spiciformis* species (Dondeyne et al. 1998; Dondeyne 2004a; LDC 2018).

Angai Village Land Forest Reserve (AVLFR) covers 1400km^2 (Dondeyne et al. 1998). AVLFR became a community-owned forest in 2005 (Mustalahti et al. 2012). Nyera-Kipelele is the national forest reserve covering 984.20km^2 (LDC 2018). It was established during colonial era in 1956 when the Forest Department aimed to expand protected forest (Sunseri 2014).

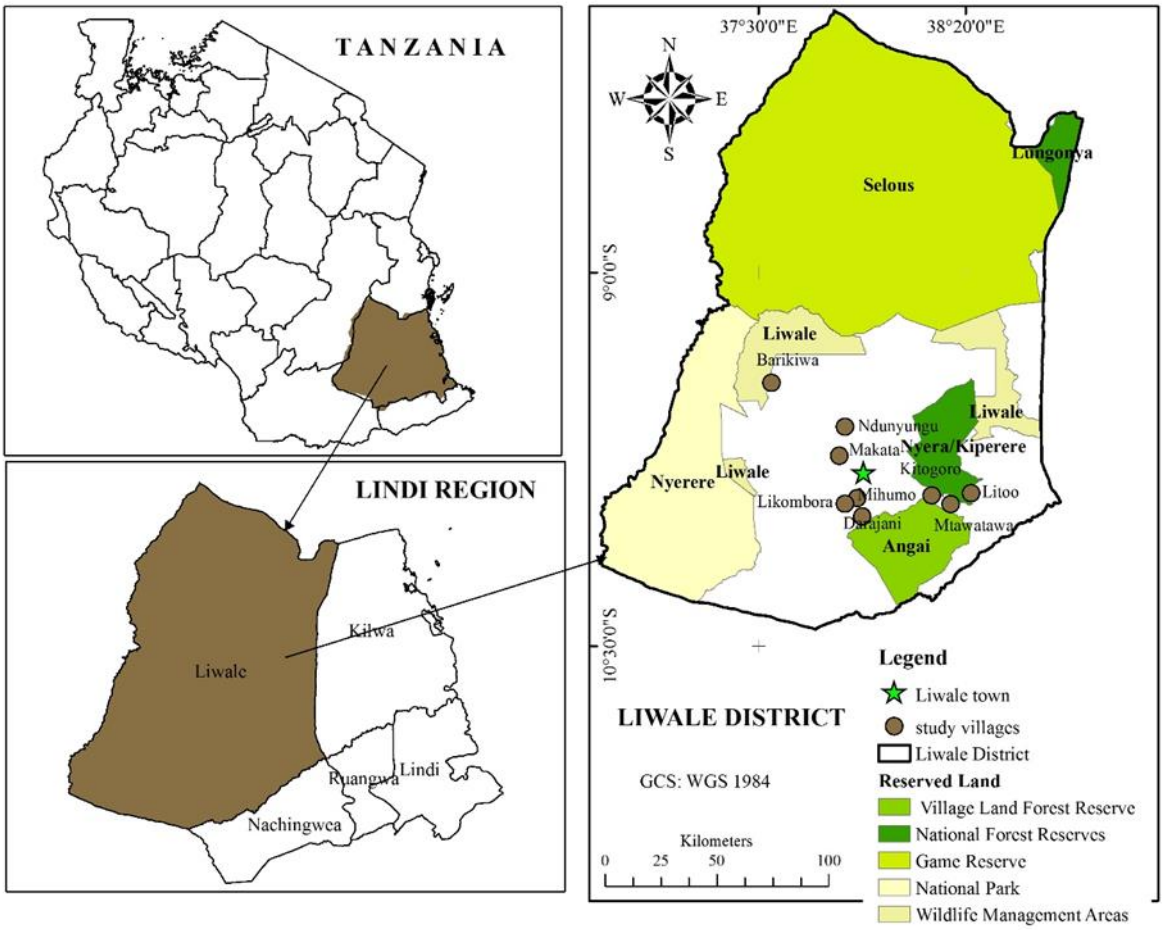


Figure 1: A map showing a study area

2.2. Brief land use and fire history of Tanzania

Before colonialism, the forests were owned communally, and people depended on forest resources for their livelihoods. The community used customary laws to manage the forests involving taboos, beliefs, and customs (Zahabu et al. 2009). In northern Tanzania, indigenous Maasai people used fire traditionally for various purposes such as generating new pastures, controlling pests, deterring dangerous animals and preventing late catastrophic fires (Butz 2009).

German rule began in the late 1880s, and then the British took over in the 1920s. Germans objected to the traditional management of the forests (Ylhäisi 2003). This is because traditional systems involved shifting agriculture which encouraged heavy burning, which was detrimental to the forests (Sunseri 2014). The first forest

ordinance was established in May 1891 to initiate state scientific forestry. Later in the century, field burning was banned. The ban contributed to the Majimaji war in southern Tanzania between 1905 and 1907. Consequently, colonialists suspended the ban, and the forests were protected by cutting fire breaks. Yet, the forests were still vulnerable to intentional fires because peasants were angered by forest reserves' expansion (Sunseri 2014). In 1953, the British established the first forest policy to increase protected areas (FAO 2013b).

After Tanzania's independence in 1961, the colonial forest policy was reviewed in 1963 (URT 1998). Protecting the forests against fire by cutting fires breaks was still an ideal strategy (Sunseri 2014). By the 1970s, the country experienced heavy forest degradation due to extensive commercial agriculture (FAO 2013b). Having adopted a villagization policy in the 1960s that forced people to leave their settlements, field burning increased due to the destruction of former homesteads, stopping people from returning (Ylhäisi 2003; FAO 2013b; Katani et al. 2014). In 1998, a new forest policy was established. The forest policy, among other things, stressed clear ownership of the land, including forests, as a critical strategy to mitigate forests degradation drivers, including forest fires (URT 1998).

2.3. Data collection and analysis

2.3.1. Data collection

Qualitative data cover a broad range of the matter being studied (Seers 2012; Punch 2013). They offer flexibility and comprehensive knowledge of human experience (Hsieh & Shannon 2005; Bohnsack et al. 2010). For that reason, in this study, qualitative data were considered essential to explain a comprehensive relationship between humans and fires.

Socio-economic data were collected between August and September 2020 from 9 villages. Purposive sampling was employed to select 3 villages from each forest management type based on forest proximity ensuring a broad range of human-fire interaction. The forests based on three management types are: The national forest

reserves, where the central government is the owner while the villagers are co-managers of the forests. The village land forest reserve, where the villagers are the owner and managers, and the general land forests located outside the reserved land. The forests on the general land are open access areas but managed by the central government (URT 1998, URT 2002; Mbwambo et al. 2012). Selected villages were: Barikiwa, Makata and Ndunyungu, which represented general land forests; Likombora, Mihumo, and Darajani that represented a village land forest reserve; Kitogoro, Mtawatawa, and Litou represented both a village land forest and national forest reserve.

Focus Group Discussion (FGD), which involved open-ended questionnaires (appendix 1), was employed to gather social-economic data. Adams & Cox (2008) suggested a maximum of 8 members as optimal for a FGD. However, in this study, each FGD consisted of 10 members to maximize the diversity of information. Respondents were farmers who were involved in activities such as crop production, beekeeping and hunting. Groups consisted of 1 village chairperson, 5 adults, 2 young people and 2 village natural resources committee (VNRC) members.

Figure 2. Focus Group Discussion at Mtawawa village. Photo: Richard Mtaki

Key informants, who are believed to be knowledgeable on the study's aspect (Chambers 1992; FAO 1999), complemented FGDs data. Data from the FGDs and Key informants were collected separately. Informants comprised of: 1Village executive officer in each village; 1 District natural resources and land officer; 4 officials from Tanzania Forest Services Agency (TFS) (3 in Liwale district, and 1 from the Headquarters); 2 officials from Tanzania Wildlife Management Authority (TAWA) in Liwale district; 3 Academicians from the Sokoine University of Agriculture (SUA).

Data to determine the extent of burned areas in the Liwale was the MODIS burned area shapefile (MCD64A1) obtained from the ftp server of the University of Maryland.

2.4. Data analysis

2.4.1. Socio-economic data

Socio-economic data collected from FGDs and key informants were transcribed, coded and subjected to content analysis. Coding means splitting the data into functional patterns by changing raw text to research concerns (Auerbach & Silverstein 2003; Bennett et al. 2019). Content analysis refers to sorting, organizing and summarizing data into various themes, meanwhile maintaining original data context (Hsieh & Shannon 2005; Bohnsack et al. 2010; Seers 2012). Document analysis which is essential for gathering retrospective data (Pershing 2002), was employed to analyze information from the previous documentations.

2.4.2. Burnt land at Liwale District

MODIS Burned area data were analysed in the GIS software to determine the extent of burned area for the period 2001 – 2019 and the monthly extent of burned area for 2019 in the reserved areas and general land in Liwale. Before analysis, MODIS burned area data and GIS data (shape files of Liwale district, Selous game reserve, and forest reserves) were projected to WGS 84 zone 37S. This enabled overlaying and clipping of data and quantifying the burned area in hectare (Ha).

3. Results

3.1. Spatial and temporal dynamics of wildfires and miombo at Liwale District

3.1.1. Burnt areas

The average annual burned area from 2001 to 2019 at Liwale was 1,002,013 ha. There was a low peak burnt area in 2006 and 2014. High peaks of burnt areas were observed in 2003, 2005, 2008 and 2009.

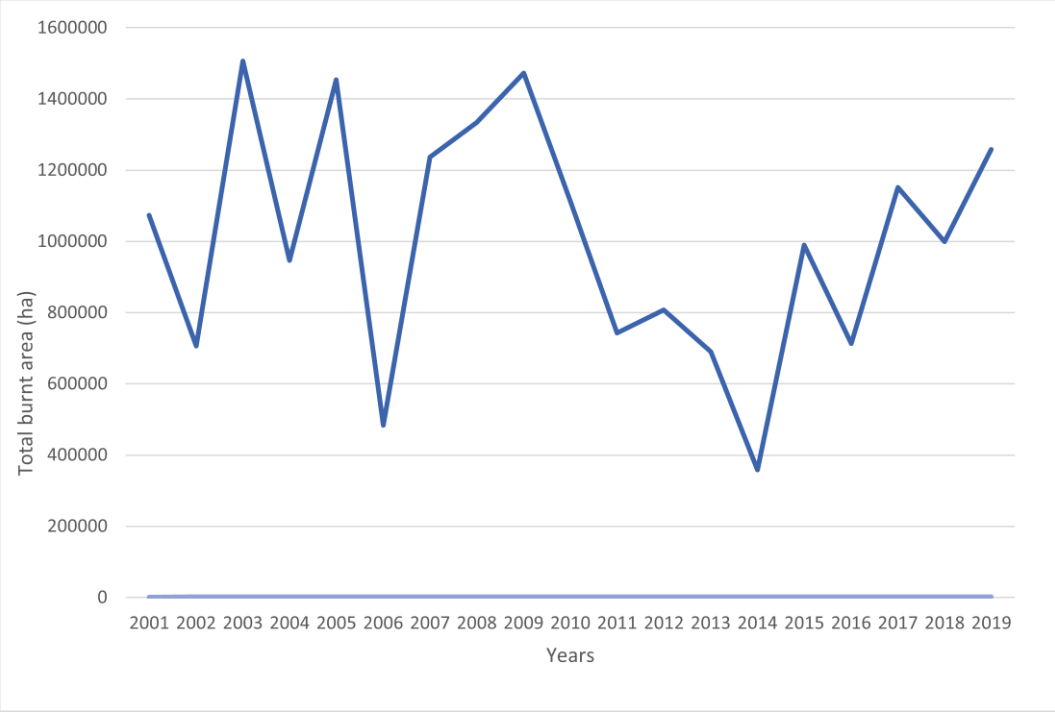
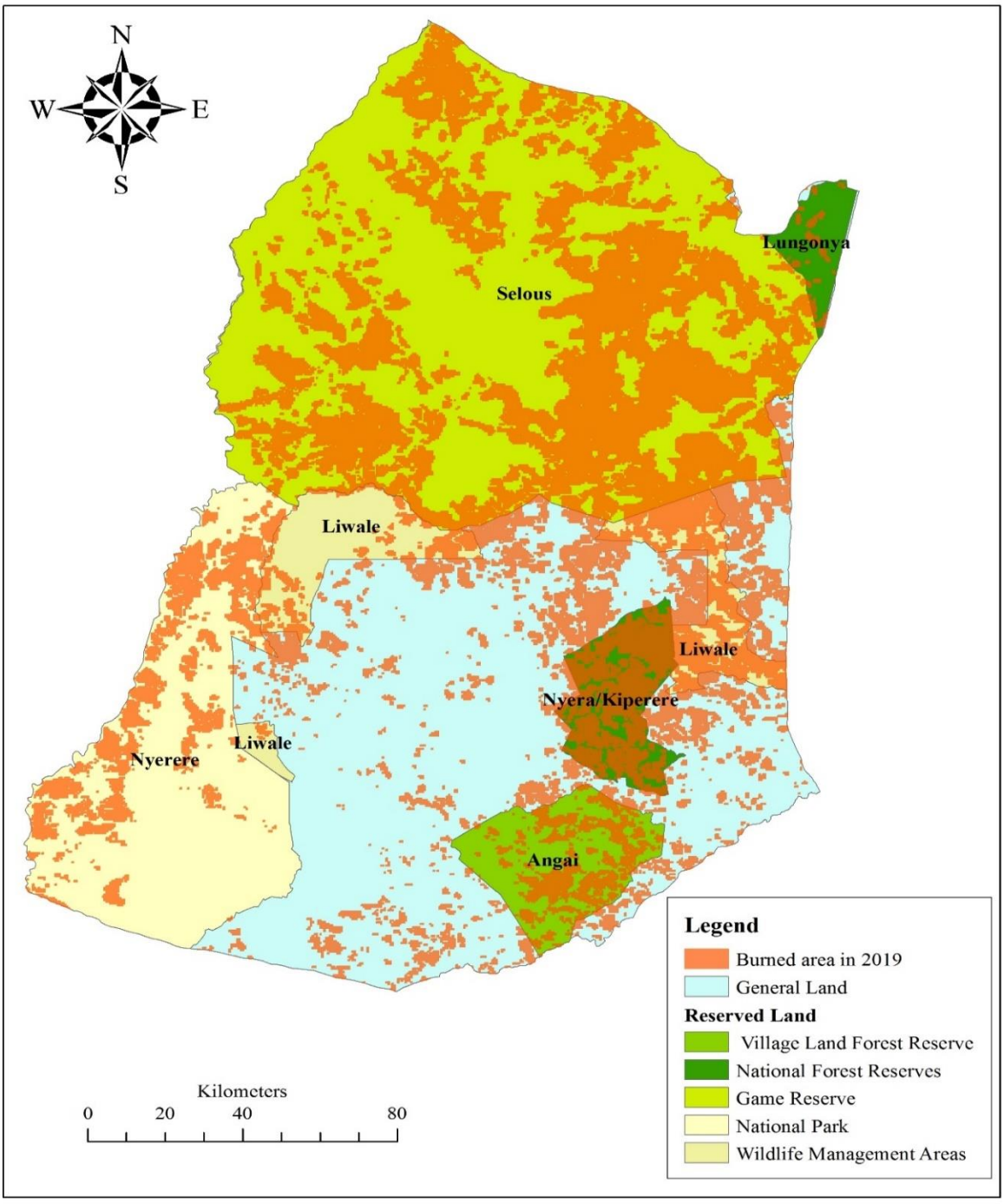


Figure 3. Total burnt areas in recent years at Liwale district (2001- 2019)



In 2019, the highest percent of burnt areas was in Nyera-Kipelele forest, followed by Selous Game Reserve, Angai Village land Forest Reserve and other village areas (figure 4).

Figure 4. Burned areas at Liwale district in 2019.

3.1.2. Months of fire occurrence at Liwale District

Respondents revealed that fire occurs between June and November. The highest fire activity is in October, followed by September and August. Remote sensing analysis of the most recent year (2019) shows that fire occurs between May and November. In May, only 47 ha was burned. More fires were detected from June, which burned (114,583 ha), with the highest peak in July (425,041 ha) followed by August (416,425ha). Fires tend to slow down from September (245 806), October (62 297 ha) to November (463 ha).

3.2. Fire use by local people and game rangers in the wild, the occurrence of wildfires and perception of local people

3.2.1. How and why local people and game rangers use fire in the wild

Fire use by local people in the wild is summarized in Table 1. Game rangers at Selous Game Reserve use fire for ecosystem conservation purposes. Informants reported that Selous in Liwale is largely surrounded by fire breaks such as roads and rivers, which prevent escaping fire. Where natural fire breaks do not exist, artificial fire breaks are prepared. In agriculture, fire is an essential tool in opening new areas and maintaining existing farms to grow cash and food crops.

Table 1. Fire use in the wild by local people in the study area

Forest mgt type	**Forests on general land**			**VLF**			**VLF & NFR**		
Fire use/villages	Barikiwa	Makata	Ndunyungu	Likombora	Mihumo	Darajani	Kitogoro	Mtawatawa	Litou
Farm preparation	YES	YES	YES	YES	YES	YES	YES	YES	YES
Beekeeping	YES	NO	YES	YES	YES	YES	NO	NO	NO
Chasing wild animals	YES	NO	YES	YES	NO	NO	NO	YES	NO
Hunting	NO	NO	YES	NO	NO	NO	YES	YES	NO
Wild fruits gathering	NO	NO	NO	NO	YES	YES	NO	NO	NO
Charcoaling	YES	NO	YES	NO	NO	NO	NO	NO	NO

VLFR = Village land forest reserve. NFR = National/State forest reserve

'YES', means a particular fire use was mentioned during FGDs, whereas '**NO'** means the specific fire use was not mentioned.

3.2.2. Reasons for wildfire occurrences at Liwale District

All respondents reported using fire to manage existing farms and open new areas. Ultimately, fires escape, especially when fire breaks have not been prepared. Cultivation of cashew nuts and sesame were the main economic activities in the study area. All respondents during FGDs mentioned that they grow cashews while more than half of respondents were growing sesame. Other cash crops included millet and sunflower. The latter was mentioned in Mihumo and Darajani villages only. Local people also grow food crops such as maize, beans and peas.

Figure 5. Farm land preparation through burning at Liwale district. Photo: Fabian Balele

Escaping fires in honey collecting was found in Likombora, Ndyunyungu, Barikiwa, Mihumo and Darajani villages. Fires from thrown cigarettes were mentioned in Kitogoro, Mtawatawa, Litou and Ndunyungu villages. These fires eventually spread over larger areas. Ndunyungu and Mtawatawa villages reported escaping fires due to cooking when local people used to attend their farms and timber harvesting.

Chasing away the elephants from crop-raiding was another reason for wildfires. Hunting fires that facilitate capturing animals and getting new pastures for wild animals were found in three villages (Table 1). Informants revealed that most fires occurring in the Nyera-Kipelele originate inside the reserve. Local people conduct early burning in the forest borders, reducing late catastrophic fires, affecting cashews. During field visits, it was revealed that Liwale – Nachingwea main road and forest patrol roads surrounding the Nyera-Kipelele forest act as fire breaks.

Respondents at Mtawatawa village reported wildfires associated with cleaning the village footpaths that reduce grass and shrubs. Wildfires associated with arson was mentioned in Ndunyungu village in which one villager ignited a fire intentionally to destroy his fellow villagers' field crops as revenge due to personal conflicts. Respondents mentioned other reasons for wildfires which include charcoal making and collecting wild fruits (Table 1).

3.2.3. Perception of local people on the use of fire

Local people perceived fire as an essential tool in various activities, especially agriculture. They revealed that fires facilitate farmland preparation by clearing a large land area in a short time with less labour. However, local people revealed that, if not properly managed, the fire would be devastating by causing negative consequences such as loss of cashew plants, forest degradation and death of people. The latter was reported in Likombora, Litou and Ndunyungu villages. Respondents from Litou, Mihumo and Darajani asked agriculture experts to provide alternative means of farm preparation instead of using fires that seem destructive when mismanaged.

3.3. Influence of incentives for forest fire suppression and wildfire management

Local people adjacent to Nyera-Kipelele forest (Kitogoro, Mtawatawa and Litou villages) were reluctant to engage in forest fire suppression in the national reserve

because of inadequate forest economic benefits in the villages. Respondents from Kitogoro village were willing to suppress forest fires in Angai forest rather than Nyera-Kipelele forest if they would be provided with proper gear. Respondents from Makata village were willing to extinguish wildfires if the government would facilitate water service. Local people normally extinguish wildfires around their field crops when fires would seem to affect their cashews. Given the largest forest area, local people perceived that forest fire suppression is practically impossible.

The provision of awareness of wildfires was considered the primary strategy to mitigate wildfires in the study area. This could be done through cinemas and village meetings. Awareness could stress modern beekeeping, cutting fire breaks and early burning. Other identified strategies included the provision of alternative income-generating activities, law enforcement, and using signposts.

4. Discussion

4.1. Spatial and temporal dynamics of wildfire and miombo forests at Liwale District

The annual average burnt area of this study's findings is 340,804ha higher than FAO's findings. FAO (2013a) reported an annual average burnt area of 661,209ha between 2000 and 2011. Though the yearly average burnt areas are not comparable, it is encouraging to compare these two studies' low and high fire peaks. FAO (2013a) found the lowest fire peak in 2001, 2006 and 2011 and the highest fire peak in 2003 and 2005, consistent with this study's findings. Variability of fire prevalence could be associated with climate variability (Katani et al. 2014; Juárez-Orozco et al. 2017; van Lierop & Moore 2019). For instance, climate changes may result in extended dry periods, which cause high fire peaks (Katani et al. 2014). On the other hand, advocacy of anti-fire policies may cause reduced fire prevalence (Butz 2009).

High burning percentages in protected areas in this study are consistent with FAO (2013a) and van Lierop & Moore's (2019) observations. According to informants, hunting and intentional fires by farmers contributed to the substantial occurrence of fires in Nyera-Kipelele forest. Intentional fires could be attributed to the ignorance of local people to understand the impacts of fire on the forest ecosystem. Katani et al. (2014) reported that ignorance of local people on the relationship between wildfires and biodiversity loss led to high fire incidences in national forests in eastern Tanzania miombo forests. Prescribed burning done earlier in June could contribute to a high burning percentage in the Selous Game

Reserve. FAO (2013a) argued that less burning in cropland is due to farmers protecting their crops from fire damage.

Even though Angai Village Land Forest Reserve (AVLFR) constitutes a large proportion of forest reserve to Nyera-Kipelele forest, the percentage of burnt area in AVLFR was relatively lower than that of Nyera-Kipelele. AVLFR is the village forest, whereby the villagers are entitled to own and utilize the forest. Local people revealed that AVLFR contributes to a significant income of the villages. Therefore, these economic benefits motivate them to conserve AVLFR over a national forest reserve. Katani et al. (2014) argued that weak law enforcement contributed to high fire incidences in national forest reserves in eastern Tanzania miombo woodlands. Informants commented that inadequate financial resources attribute to weak law enforcement in Liwale which contribute to fire incidences in Nyera-Kipelele forest.

Analyses of responses from the FGDs were similar to remote sensing analysis regarding wildfire seasons. These findings broadly support other studies in Tanzania that most fires occur in the dry season (FAO 2013a; Katani et al. 2014). A slight difference between the analysis of responses from the FGDs and remote sensing analysis on low and high peak fire seasons could probably be due to discrepancies in respondents' perception and emotions because perception may vary between one individual and another.

The occurrence of fires in the dry season could be interpreted as wildfires being predominantly anthropogenic. This is because natural fires in Tanzania are generally rare, and after all, lightning occurs in the rainy season when the fuel is wet (FAO 2013a). Miombo are green in the rain season and leafless during the dry season (Sunseri 2014). Therefore, in May, there would be little fuel load. That reason explicitly explains the lowest burnt area, which was detected in May. Early rain could reduce the combustibility of the fuel load, hence low fires in November (Katani et al. 2014).

4.2. Uses of fire by local people and game rangers in the wild at Liwale District

Given the vast agricultural land in Liwale, local people practise shifting cultivation where the fire is essential to open new areas. Loss of soil fertility is another reason that influences local people to undertake shifting cultivation. According to informants, local people abandon the previous farmland and shift to another land, at least after every two years. Sesame, which is amongst the cash crops, is fundamentally associated with shifting cultivation involving fires (Ngongolo et al. 2015). Shifting cultivation exacerbates the occurrence of unplanned fires, which threaten the miombo ecosystem. Using fire for clearing the land in agriculture has also been reported by other authors in Tanzania (FAO 2013a; Katani et al. 2014; Kilawe et al. 2021).

Results of this study show that local people use fire to collect honey in the wilderness. According to informants, smokes interrupt the defensive behaviour of bees which facilitate smooth honey harvest. Lighting fires during honey harvest cause wildfires especially when the fire is not properly attended. Beekeeping was associated with villages adjacent to Angai forest due to good vegetation that attracts bees. Using fire in beekeeping is traditional and is still common in Tanzania (FAO 2013b). This implies inadequate modern beekeeping skills. Tanzania Forest Services Agency (TFS) and other practitioners provide skills on modern beekeeping. However, conservation education, including modern beekeeping, is limited by financial and personnel constraints (FAO 2013b; Katani et al. 2014; Kilawe et al. 2021). Having allowed beekeeping activities in the forest reserves in Liwale, the occurrence of wildfires during honey collection would persist if improper use of fire in traditional beekeeping is not adjusted.

Using fire to chase away Elephants was predominantly linked with villages closest to the Selous Game Reserve, Nyerere National Park and Wildlife Management Areas. Liwale district is mainly covered by the Selous Game Reserve, which occupies 58% of the total area (Dondeyne et al. 1998). Elephants, therefore, tend to raid field crops, specifically maizes. Crop fields bordering the game reserve

within < 1 km are more prone to elephants' damage (Hariohay et al. 2020). Having crop fields raided by Elephants, farmers tend to chase away the Elephants by fires. Deterring wild animals using fire in Tanzania was also reported by other authors (Katani et al. 2014; Ngongolo et al. 2015; Hariohay et al. 2020). Since bees bite elephants, it has been suggested that using *Apis mellifera* honeybee fences surrounding the crop fields is the best strategy to deter elephants rather than using fire. Another strategy could be planting chilli adjacent to farm lands (Hariohay et al. 2020).

Hunting fire were mostly reported in villages adjacent to the Nyera-Kipelele forest due to its potentiality of having wild animals and closeness to the villages. Fire in hunting enhances visibility, generates fresh pasture, and drives wild animals into desired areas. Hunted wild animals involve Duiker, Antelopes, Rabbit, Greater kudu, Pygmy antelope, Bushbuck and *Kongowi*. The motivation of hunting is probably due to less livestock keeping (NBS 2007). Local people revealed that less livestock is associated with water scarcity. Liwale is generally faced with water shortage (Mustalahti et al. 2012). Given low livestock numbers, local people may continue illegal hunting in the forest reserves, causing a wildfire outbreak. Using fire for hunting has also been reported by other scholars in Tanzania (FAO 2013a; Katani et al. 2014; Kilawe et al. 2021). On the other hand, the Tanzania Wildlife Conservation Act No. 5 of 2009 prohibits illegal hunting. Legal hunting can be conducted in designated wildlife hunting blocks in game reserves, game controlled areas and wildlife management areas (URT 2009).

Analysis shows that game rangers at Selous conduct prescribed burning to maintain the ecosystem landscape. Early burning is done earlier in June, reducing late catastrophic fires. Late burning is conducted in October and November for grass regeneration. In the absence of early fires, late fires could be devastating due to high fuel load accumulation in Selous. Informants revealed that controlled late fires maintain habitats, essential for seed germination and control pests such as tsetse fly and tick. Moreover, fire is essential to clear bushes enhancing tourism

hunting and patrols. Prescribed burning in Tanzania has also been reported by other scholars (FAO 2013a; Ngongolo et al. 2015).

4.3. Local people's perception of fires

Positive perception of fire by local people in Liwale indicates that fire is an important tool in agriculture activities within the community. Perception of fire may contribute to the increase or decrease of wildfires. For instance, in eastern Tanzania miombo woodlands, local people recognized that ashes enhance soil fertility. Also, they understood that burning is essential to minimise pests attack (Katani et al. 2014). In this regard, fire perceptions would encourage agriculture fires which influence unplanned fires if the proper use of fire is not advocated. On the other hand, it has been reported that field burning has been reduced in northern Tanzania due to the negative perception of the Maasai indigenous people against wildfire, claiming that burning leads to climate changes (Butz 2009). This would generally indicate that wildfire awareness has influences on local people's perception of wildfires.

4.4. Underlying cause of wildfires at Liwale District

Wildfires originating from farm activities are very common in Tanzania (Miya et al. 2012; FAO 2013a; Rija et al. 2013; Katani et al. 2014; Ngongolo et al. 2015). According to FGDs, agriculture fire escapes when it is out of control, and it becomes devastating when fire breaks have not been prepared. If not properly managed, these fires cause severe impacts in the forests (Van Vliet et al. 2012). Section 70 (2) of the Tanzania Forest Act no 14 of 2002 mandates farmers to apply for a permit before field burning. According to informants, ignorance caused local people not to apply for burning permits. On the other hand, law enforcement is unsatisfactorily implemented in Tanzania (FAO 2013a; Katani et al. 2014).

Although local people revealed that farm preparation contributes to significant wildfires, agriculture fires may not necessarily be important for fires in Nyera-

Kipelele forest. Informants mentioned that fires originating inside the reserve contribute to the substantial occurrence of fires in Nyera Kipelele. Fire breaks surrounding a large part of the reserve would mitigate escaping agriculture fires outside the reserve. For that reasons, early fires ignited by farmers in Nyera-Kipelele forest boundaries preventing late catastrophic fires that affect cashews could contribute to fires in Nyera Kipelele forest. According to FGDs, early burning is done locally to avoid the destruction of cashews. Informants commented that early controlled fires would help reduce the severe impacts of late fires in the forests.

Results show that beekeeping was associated with wildfires in three villages adjacent to Angai Village Land Forest Reserve (AVLFR). Respondents in FGDs commented that fire facilitates honey collection in traditional beekeeping. AVLFR management plan allows local people to conduct beekeeping within the reserve. Therefore, beekeeping could contribute to the occurrence of fires within AVLFR. It has been argued that traditional beekeeping is an effective way of managing the forest resources because of the high protection of the sites where beehives are cited (Augustino et al. 2016). This argument could, however, be challenged when inappropriate use of fire is exercised during honey collection.

Findings show that cigarette smokers throw burning pieces of cigarettes in the fields when walking; eventually, wildfire occurs. This result is consistent with Butz (2009), who observed wildfires associated with cigarette smoking within the Maasai community in northern Tanzania. Wildfire outbreak due to cigarette smoking indicates a lack of awareness of wildfires in the community. This problem could be adjusted by awareness creation on wildfires to local people.

Results have revealed that prescribed burning contribute to the significant occurrence of fires in the Selous Game Reserve. However, according to informants, the burning does not cause a substantial occurrence of wildfires outside the reserve. This is due to natural and artificial fire breaks that mitigate the spread of fires outside the Selous.

It was revealed through the FGDs that chasing away the elephants by using fires in the farms contributes to the significant occurrence of wildfires. This is because most fires ignited to chase away wild animals are not controlled, thus, spreading and burning unintended areas. This observation is similar to other studies conducted in Tanzania, which reported that wildfires occurred due to clearing the vegetation cover to chase away wild animals (Katani et al. 2014; Ngongolo et al. 2015; Hariohay et al. 2020).

Illegal game hunting could influence fires in Nyera-Kipelele. This is because two out of three villages (Table 1) borders Nyera-Kipelele forest, where hunting was reported to be associated with wildfires. Katani et al. (2014) have also reported that most fires in eastern Tanzania miombo woodlands originate inside the reserves. Wildfires related to hunting are common in Tanzania (Miya et al. 2012; FAO 2013a; Rija et al. 2013; Katani et al. 2014; Ngongolo et al. 2015).

Even though several scholars have stressed charcoal making to be related to wildfires in most parts of Tanzania (Butz 2009; FAO 2013a; Katani et al. 2014; Ngongolo et al. 2015), this study, however, found that charcoal making was less related to wildfires. This is because local people revealed charcoal to be relatively expensive over firewood. Generally, firewood energy in Lindi region represents 97.66% of total energy, while charcoal accounts for 1.77% (NBS 2007).

Analysis shows that arson was reported in only one village. Local people in Liwale generally perceived arson to be rare. This is because local people considered arson to be destructive in the entire community. In other parts of the country, arson has been reported to be among the factors for wildfires (FAO 2013a; Rija et al. 2013; Katani et al. 2014; Kilawe et al. 2021). During colonialism, arson was used as an instrument of resistance against forest reserve expansion (Sunseri 2014).

4.5. Influence of incentives for forest fire suppression

Though section 71(3) of the Tanzania forest legislation mandates a nearby person to extinguish wildfires (URT 2002), results show that forest fire suppression in the study area was not common and not practised. The reasons include, among other things, that local people were unaware of legislation requirements on forest fire suppression. They generally perceived forest fire suppression as not practical. On the other hand, local people were willing and took part to extinguish wildfires around their field crops. This is because they normally fear that wildfires would destroy their cashews, which are essential to community livelihood (NBS 2007; LDC 2018; URT 2019).

Although forest fire suppression seems not to be common in the study area, local people from Kitogoro, Mtawatawa and Litou showed interest in fire suppression in AVLFR rather than Nyera-Kipelele forest. This is because AVLFR plays a more central economic role in the villages than Nyera-Kipelele forest. This implies that tangible benefits (economic incentives) would motivate local people to suppress forest fires. In a village land forest reserve, the community is entitled to 100% benefits of the forest (Scheba 2018). Of course, lack of or insufficient tangible benefits from the forest cause disappointments to local people adjacent to the forest (Scheba & Mustalahti 2015).

4.6. Wildfire management

Anti-fire policies focusing on fire suppression may create hostility between local people and foresters. In addition, they may lead to adverse effects on the ecosystem by creating late catastrophic fires due to suppressing traditional early burning (Laris & Wardell 2006; Butz 2009). For instance, in western Africa, savanna wildfires have not been reduced regardless of anti-fire policies (Laris & Wardell 2006). However, as Laris & Wardell (2006) suggested, this is not arguing that fire-reduction policies are nasty; instead, its formulation should integrate the local community's knowledge, interests, and other scientific aspects of wildfires management.

The creation and maintenance of fire breaks are among the strategies to mitigate wildfires. It has been argued that fire breaks in the forests would reduce fires outside the reserves (Katani et al. 2014). On that account, the prevention of wildfires should also focus on fires originating inside the forests. Informants revealed that wildfires awareness could help mitigate fires both originating inside and outside the forests. This argument is consistent with Ngongolo et al. (2015), who recommended that wildfires awareness, in line with law enforcement, is a potential strategy to mitigate wildfires. However, extension services in Tanzania have been faced with financial constraints since colonial era (Sunseri 2014). For that reason, informants argued the government to consider the provision of sufficient and sustainable funds for wildfires management.

5. Conclusion and recommendations

Anthropogenic fires, specifically agriculture fires, remain the dominant factors for wildfires at Liwale district. Protected areas experience higher burning percentages due to intentional fires. Given the shortage of water and low livestock keeping in Liwale, local people may continue hunting illegally, thereby using fire irresponsibly. The government may consider solving water shortage in Liwale to influence livestock keeping. Increased livestock may help reduce unintended hunting fires. Creation and maintenance of fire breaks, providing sufficient funds for wildfires awareness, advanced agriculture and supporting alternative income-generating activities such as modern beekeeping and fishing are essential to mitigate wildfires. Local people were willing and took part to extinguish wildfires around their field crops to prevent fire damages in cashews. This evidence explicitly reveals that fire suppression in Liwale was driven by economic benefits rather than forest conservation. In addition to that, local people were willing to suppress fires in AVLFR rather than Nyera-Kipelele forest because they realized the direct economic benefits of AVLFR. For that reason, it is worth saying that the forests' tangible benefits may influence the community's willingness to forest fire suppression. This fact creates an alert that the government has a lot to do, ensuring the local community appreciates the national forests' economic values.

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Appendix 1

Questionnaires

Key Informants

1. What are the fire incidences in recent years?
2. How is fire used in the community?
3. What are the main sources of occurrences of wildfires in the community?
4. In your view, what drives the reasons for these sources of wildfires?
5. Can you rank these sources and drivers according to their frequency of occurrence or influence?
6. How do human activities relate to forest fires?
7. How does the fire frequency change throughout the year, and why?
8. In your view, how would you rank wildfires as an important disturbance relative to other disturbances in the forest?
9. In your view, what have been the effects of wildfires in the community regarding economic, social, and environmental aspects?
10. How much forest area has been affected by fire in recent years?
11. How has the population changed in recent years?
12. In your view, how is the population dynamics related to fire uses?
13. How are the decisions being made in the community when wildfires occur? Who makes a specific decision? How are the community members being involved in preventing/suppressing the fires?
14. In your view, what is the community perception concerning preventing fires? What drives the perception?
15. How do you mitigate the occurrence of wildfires in the forests?

16. What resources are needed by the community, households and individuals to become more successful at preventing the damage and recurring of wildfires?
17. In your view, what is the most effective wildfire combating strategy? Why?

Focus Group Discussion (FGD)

1. How is fire important in your working environment?
2. How do women use fire?
3. How do men use fire?
4. How do you perceive fire generally?
5. What are the main sources of occurrences of wildfires in the community?
6. In your view, what drives the reasons for these sources of wildfires?
7. Can you rank these sources and drivers according to their frequency of occurrence or influence?
8. What are the effects of wildfires in your village?
9. How are the decisions being made in the village when wildfires occur? Who makes a specific decision? How are you involved in preventing/suppressing the wildfires?
10. In your view, are you willing to suppress forest fires? If YES, why and what motivate you to suppress forest fires? And if NO, why?
11. What should be done to mitigate the occurrence of wildfires?

SENASTE UTGIVNA NUMMER

2020:04 Författare: Mikaela Casselgård
Effects of 100 years of drainage on peat properties in a drained peatland forest in northern Sweden

2020:05 Författare: Therese Prestberg
1900- talets skogsbruk i kronoparksskogar – En skogshistorisk studie om Håckren och Bjurfors kronoparker

2020:06 Författare: Nils Södermark
Inverkan av trädslagsval och plantstorlek på tall- och granbestånds anläggningskostnad, skadeutveckling och tillväxt i norra Sveriges kust- och inland

2021:01 Författare: Torben Svensson
Tallsåddens potential för återbeskogning av marker med tjocka humustäcken eller torv i norra Sverige.

2021:02 Författare: Therese Strömvall Nyberg
Vad betyder det att skydda natur? – En europeisk jämförelse av skyddade områden

2021:03 Författare: Oscar Nilzén
The Guardian Forest – sacred trees and ceremonial forestry in Japan

2021:04 Författare: Gustaf Nilsson
Riparian buffer zones widths, windthrows and recruitment of dead wood
A study of headwaters in northern Sweden

2021:05 Författare: Louise Almén
Naturhälsokartan - Hälsofrämjande naturområden i Väster- och Österbotten

2021:06 Författare: Lisa Lindberg
Trait variation of Lodgepole Pine – do populations differ in traits depending on if they are invasive or in their home range?

2021:07 Författare: David Falk
Drivers of topsoil saturated hydraulic conductivity in three contrasting landscapes in Kenya - Restoring soil hydraulic conductivity in degraded tropical landscapes

2021:08 Författare: Jon Nordström
En märr som hette Mor – De sista härjedalska hästkörarnas berättelser från tiden innan skogsbrukets mekanisering.

2021:09 Författare: Roberto Stelstra
Implementation of native tree species in Rwandan forest plantations – Recommendations for a sustainable sector

2021:10 Författare: Kazi Samiul Islam
Effects of warming on leaf – root carbon and nitrogen exchange of an ericaceous dwarf shrub.

2021:11 Författare: Ellika Hermansson
Ett riktigt hästarbete –skogsarbete med häst i sydvästra Sverige, förr, nu och i framtiden

2021:12 Författare: Fabian Balele
Wildfire dynamics, local people's fire use and underlying factors for wildfires at Liwale