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# Intentions behind common and risky fires in south-eastern Tanzania

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Human-set fires are a crucial component of African savannas, affecting ecosystem structure, carbon emissions, local hazards and livelihoods. Yet, most fire research in these ecosystems focuses on the fire ecology of protected areas. Research exploring fire regimes in inhabited landscapes remains limited, undermining opportunities for culturally and environmentally sustainable fire management. To address this gap, we used interviews in Tanzanian farming communities and remote sensing to identify intentions behind fire use and the perceived relative frequency and riskiness of fires set for different purposes. We found that the most common ignitions were intentional and important to livelihoods. Burning was adaptive, responsive to environmental conditions, and optimised for the intended outcome with the perceived riskiest fires intentionally spreading uncontrolled. Remote sensing showed that most of the total burned area was accounted for by fires during the late dry season when people burned for activities, such as field preparation, and when environmental conditions encouraged fire spread. Our findings offer an insight into fire regimes in inhabited landscapes, by exploring how intentions shape the fire regime at the landscape scale. We discuss how understanding these intentions and local priorities, including adaptive uses of fire, is key to sustainable fire management outside protected areas.

**Keywords:** fire behaviour, local ecological knowledge, management (natural resources), miombo woodland, remote sensing

## Introduction

Fire regimes in African savannas and woodlands are made up of individual fires that vary in extent, intensity (temperature), frequency, timing and location (Bowman et al. 2011). Observational and experimental evidence shows that variations in these aspects of fire regimes dictate fire severity and associated impacts on vegetation, litter and soils (Trapnell 1959; Lawton 1978; Kikula 1986; Whelan 1995; Staver et al. 2011). For example, less intense and less frequent fires allow greater tree recruitment and cover (Ryan and Williams 2011). This affects the suite of services provided by ecosystems (arguably, in both positive and negative ways), such as carbon storage, biodiversity and the myriad ways savannas support local livelihoods (Ryan et al. 2016).

Humans modify fire regimes across African savannas with impacts on greenhouse gas emissions and ecosystem dynamics (Archibald 2016; Ramo et al. 2021). Many of these modifications are indirect, as both local land use and global climate change alter wind speed, fuel load, continuity, and moisture (Bowman et al. 2011). In particular, land use change has decreased landscape connectivity over time, causing total burned area and associated emissions to decrease in many human-dominated parts of the world, including the most populated parts of Africa (Archibald 2016; Andela et al. 2017). People also directly impact fire regimes by setting and suppressing fires and, outside protected areas, human ignition patterns have strong influences on

fire regimes (Archibald et al. 2010). Fire is commonly used to support livelihood activities in rural communities, such as to prepare agricultural fields, to promote fresh grazing for livestock, deter pests and create firebreaks (e.g. Kull 2004; Eriksen 2007; Shaffer 2010).

Considerable research over several decades has explored the biophysical aspects of fire management in national parks and conservation areas of different African ecosystems (e.g. Bond and Archibald 2003; Govender et al. 2006; van Wilgen et al. 2007; Ribeiro et al. 2019a). This has informed fire management in protected areas, particularly the use of prescribed burning early in the dry season to reduce fire spread and intensity later in the dry season, which may enhance biodiversity (e.g. van Wilgen et al. 2008, but see also Parr and Andersen 2006). In inhabited African landscapes, studies incorporating local knowledge have found that fire management is influenced by multiple social and cultural dynamics, including historic fire policies (often fire suppression), conservation goals and current fire management best practices (often prescribed burning, based on biophysical studies), local livelihoods (often dependent on burning) and social power dynamics (e.g. Eriksen 2007; Butz 2009 Shaffer 2010; Humphrey et al. 2021; Johansson et al. 2021). Research by Laris explored how human burning practices drive spatial and temporal aspects of the fire regime in southern Mali (2002),

finding that traditional burning created a landscape-level seasonal mosaic with patches of unburned, early burned, and late-burned vegetation. Laris (2013) also found, using interview and remote sensing data, that human burning practices, vegetation cover type and landscape pattern are the primary drivers of the fire regime in this region. Similar landscape-level mixed methods approaches have not been attempted in southern Africa, limiting understanding of human controls over fire regimes here.

Fire management must be resilient to changing needs under shifting environmental and social conditions (McWethy et al. 2019). For example, climate change and associated changes in rainfall, expansion of cropland and urban areas are projected to be important drivers of change in African savannas in future (Dziba et al. 2020). Community-based fire management (CBFiM) is now widely promoted as an approach for environmentally and culturally sustainable fire management, but its roll-out and success has been limited, for example in Tanzania (Kagosi et al. 2020; Kilawe et al. 2021) and Botswana (Dube 2013). Gaining better understanding of local fire use, who initiates burning, how and why people burn, can inform culturally and environmentally sustainable management and policies (Meyers 2006), especially when combined with studies exploring the ecological impacts of fire uses (Colombaroli et al. 2019).

Here, we present a case study of the fire regime in Kilwa, a rural district of south-eastern Tanzania. Kilwa represents a useful case, because of its dominant land cover of miombo woodlands, which extend 2.7 million km<sup>2</sup> across southern Africa, but which have undergone significant land use change in recent decades, with 0.6 million km<sup>2</sup> having been converted to cropland (Dziba et al. 2020). The current wooded area totals approximately 2.0 million km<sup>2</sup> and 0.1 million km<sup>2</sup> is natural non-wooded land. Kilwa is home to a number of fire-based livelihood activities common to other African savannas, including agriculture, pastoralism and charcoal production (Miya et al. 2012), which historically have been significant drivers of change in miombo ecosystems (Dziba et al. 2020). There is a mixture of land management approaches in the district, with active community forest management, which includes protection of community woodlands from fire, in several of its villages (Khatun et al. 2017).

Here we report findings from interviews in rural communities to understand the role fire plays in local livelihoods. We then combine these data with remote sensing to explore linkages between fire intentions and the resulting fire regime. We asked the following questions:

1. What are the main causes of fire (human or otherwise) in Kilwa?
2. What are the human intentions and livelihoods associated with fire use?
3. How do the intentions behind fire use influence fire regimes?

## Materials and methods

### Study site

Kilwa District, in the Lindi Region of south-eastern Tanzania (Figure 1), is dominated by miombo woodlands (Ribeiro et al. 2020), but also includes patches of East African coastal forest (Burgess and Clarke 2000). Precipitation is highest

along the coast and lowest inland, with an estimated mean annual precipitation of  $821 \pm 350$  mm ( $\pm$ SD). Altitude ranges from sea level on the eastern coast to 740 m asl farther inland (McNicol et al. 2018). Typically, the rainy season is from November until May, with intraseasonal droughts usually lasting several weeks between January and March. The dry season is from June until October. The population is approximately 85% rural and primarily dependent on natural resources for their livelihoods (Miya et al. 2012).

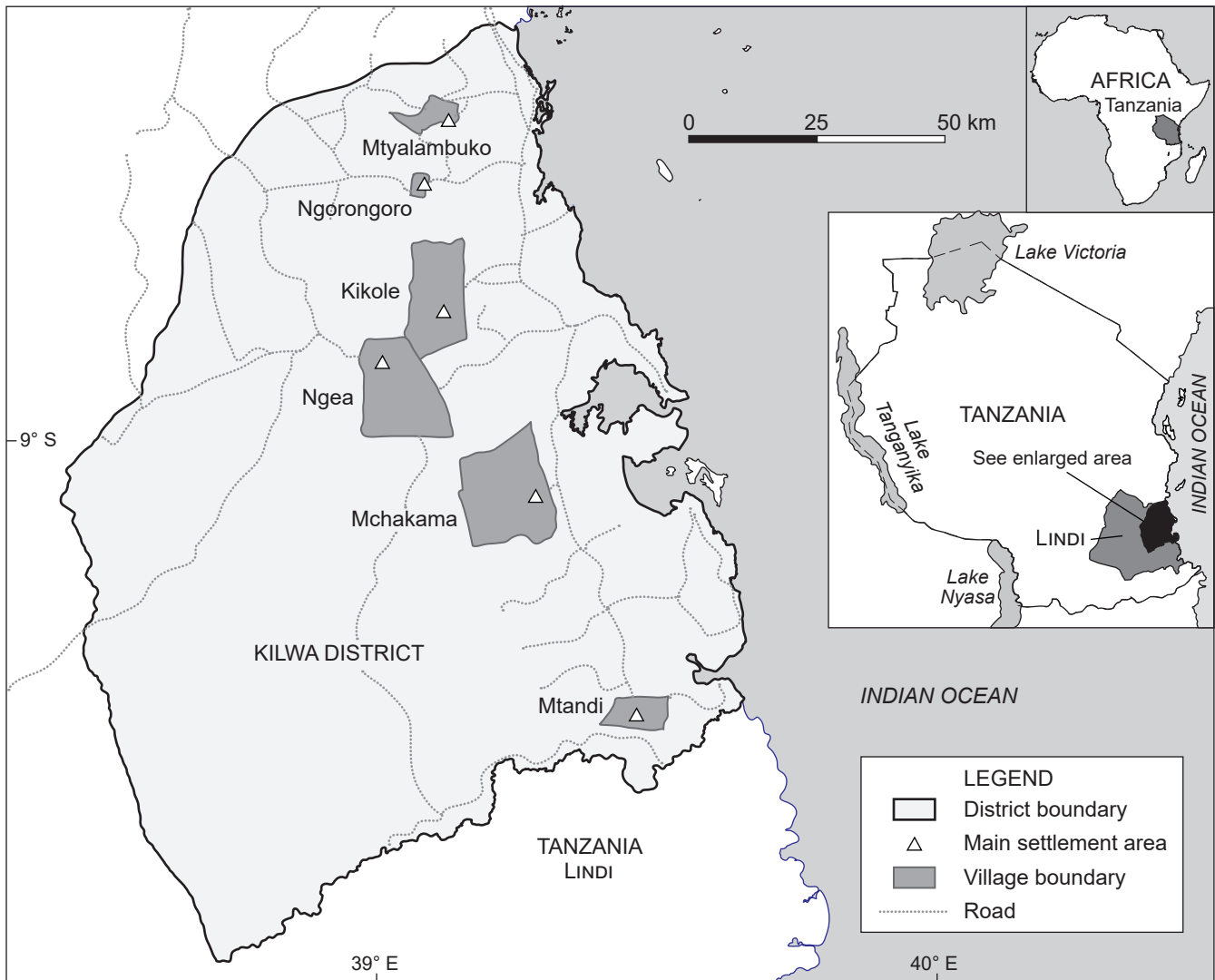
Satellite data were used to determine fire trends across the district, and interview data were collected from six study villages. In the study villages, the majority of people are Muslim, with some Christians, and represent several tribes. The most common tribes include Makonde, Matumbi, Mwera, Ngindo, Nyasa, and Yao. Most families are arable farmers growing a mixture of subsistence and cash crops. Some people are involved in livelihood activities that are (almost always) additional to farming, including hunting, charcoal production, honey collection and logging. Small populations of pastoralists from the Sukuma tribe live in or close to all the study villages, having moved from their traditional northern range and arriving fewer than 10 years ago in most cases. The Sukuma peoples' main livelihood is keeping livestock to sell meat and milk, but most families also grow crops.

The local authority is headed by the Village Executive Officer (a government employee who typically comes from outside of the village) and there are a number of elected committees, including the Village Committee and Village Natural Resources Committee, in each village. Some regulations about fire come from the local and national government, for example people can be fined if an uncontrolled fire they set burns someone else's property. Tanzania's 2002 Forest Act (Parliament of the United Republic of Tanzania 2002) allows people to burn on their own land, but they must seek permission from a government authority (or the relevant land owner), if burning elsewhere. It requires people to fully extinguish fires before they spread to land they do not have permission to burn.

There are designated community woodlands in three of the villages (Kikole, Mchakama and Ngea) established by the local NGO Mpingo Conservation and Development Initiative (MCDI). These villages use prescribed burning around the borders of their community woodland to protect it from later uncontrolled fire, so that timber species can be sustainably harvested and sold, generating funds for the communities (Khatun et al. 2017). Aside from prescribed burning around the borders of these community woodlands, there is no burning organised at the community level in Kilwa.

### Remote sensing

The MODIS Burned Area data product (MCD64A1) was used to identify the dates and extent of burns throughout Kilwa District between 2001 and 2019. This product combines changes detected in 500 m Moderate Resolution Imaging Spectrometer (MODIS) Surface Reflectance imagery with 1 km MODIS active fire observations. The date of burns are identified for 500 m grid cells in each individual MODIS tile as the day of year on which a burn occurred (Giglio et al. 2015, 2018). The MCD64A1 data



**Figure 1:** Location of six study villages in Kilwa, Tanzania

were processed in R (R Core Team 2020) to identify the total burned area for bimonthly periods within Kilwa District between 2001 and 2019, as well as to calculate crude fire return intervals;  $\pm$  indicates standard errors of the mean unless otherwise noted. Figures were produced using R Version 4.0.1 (R Core Team 2020) and the ggplot2 package (Wickham 2016), and QGIS Version 3.10.10 (QGIS Development Team 2019).

#### **Interviews and focus group discussions**

Data were collected over a total period of six months in 2018 and 2019. A village meeting was conducted upon arrival in each of the six villages. Subsequently, data collection involved the following:

##### *September–November 2018*

Two focus group discussions were conducted in each village, one with men and one with women, involving between eight and 13 respondents and lasting between two and three hours. Respondents drew village maps that

included where fires had occurred in the past 12 months, while discussing causes and impacts of those fires.

Additionally, one focus group discussion with five respondents (both men and women) was conducted in each village involved in prescribed burning around the community woodlands. Respondents discussed the process and impacts of prescribed burning. Focus group discussions lasted between one and two hours.

Finally during 2018, some 112 semi-structured interviews (between 16 and 20 in each village) were conducted with individuals and small groups, lasting between 30 minutes and two hours. Interviewees were selected based on characteristics of interest (purposive sampling), in order to build a comprehensive understanding of the fire regime. Interviewee selection was informed by learnings from village meetings, focus group discussions and other interviews, in order to explore research questions that remained unanswered or unverified. Both men and women involved in livelihood activities that use fire (e.g. farmers, hunters, charcoal makers) and those involved in activities

vulnerable to fire (e.g. grass collectors) were interviewed. Those involved in the Village and Natural Resources Committees (indicating involvement in village planning, and more interactions with local environmental NGOs), and those with no involvement in committees were interviewed.

General uses of fire in the village were discussed with all respondents, as well as respondent livelihood activities, their own use of fire and experiences of fire, including uncontrolled fire. Interview topics were flexible, dependent on the areas in which respondents showed particular expertise and interest. Fire use is a sensitive area of enquiry in the study villages, and if respondents were uncomfortable or unsure, the conversation was steered in another direction. Four of the interviews (two with men and two with women) in each village were conducted while walking to locations where there had been recent fire. Across all interviews, 62% of respondents were male, reflecting some of the gendered dimensions of natural resource management and fire use in the study area.

#### *September–November 2019*

Focus group discussions lasting between two and three hours were conducted with two groups of 10 men and women in each village (one group of members from village committees and one with non-committee members) to validate major findings and conduct ranking exercises. Potential causes of uncontrolled fire (intentionally or otherwise) common across all villages that had been identified during the previous field season were verified by each group. These causes were ranked by groups to establish the extent to which ignition sources differ in perceived frequency and riskiness of fires, while discussing reasons for the rankings.

During initial village meetings and informal discussions, and throughout the study period, trust was built with respondents and the research aims and affiliations were clearly explained. The 'outsider' status of the researchers was minimised by travelling by public transport and eating and socialising with villagers. Although several uses of fire were subsequently discussed readily as a result, many respondents were reluctant to discuss fires that are intended to spread uncontrolled, particularly those used in hunting and livestock keeping. The likely reasons for this were discussed with some respondents who suggested this was due to fear of recrimination from neighbours or from the researchers who may be thought to represent the district authority. Therefore, multiple sources of information, gathering both individual perspectives and group consensus, were used to triangulate (validate) results (Nightingale 2020). Informal discussions and observations were also used to verify information and prompt new queries. Data were collected until the point at which new insights related to the research questions stopped emerging (i.e. theoretical saturation was reached) (Charmaz 2006; Bryman 2012).

All interviews and focus group discussions were conducted in English by EW, translated into Swahili with additional questions asked by MM. Respondents were thanked for their time with a payment of 5 000 TZS Tanzanian Shillings (~2 US\$) per interview, following the advice of MCDI staff and a precedent set by researchers who had previously

worked in the study area. The study was approved by the University of Edinburgh School of Geosciences Ethics Committee.

NVivo 12 (QSR International 2018) was used to thematically analyse interview notes. Figures were produced using R Version 4.0.1 (R Core Team 2020) and the ggplot2 package (Wickham 2016).

## **Results**

### ***Overview of spatial and temporal patterns of recent fires***

Remote sensing analysis found that between 2001 and 2019, on average  $4\,890 \pm 158$  km<sup>2</sup> of Kilwa District burned annually, equivalent to  $33 \pm 1\%$  the land area. On average, 99% of the total burned area was burnt between May and November, though fire seasonality varied from year to year (Figure 2). This was corroborated by findings from focus group discussions and interviews as respondents reported that the fire season typically shifts from year to year, depending on the timing of the rainy season. Grasses begin to burn when they are dry enough, following the end of one rainy season and before the start of the next. Respondents noted that there has been no consistent trend of the fire regime starting earlier or later over time, but that it varies between years.

On average, 63% of the total burned area was burnt in the months of July and August alone. Respondents reported that early July is typically the start of the late dry season, when grasses have fully dried and more intense fires burn. Respondents reported that uncontrolled fires are most common during the late dry season.

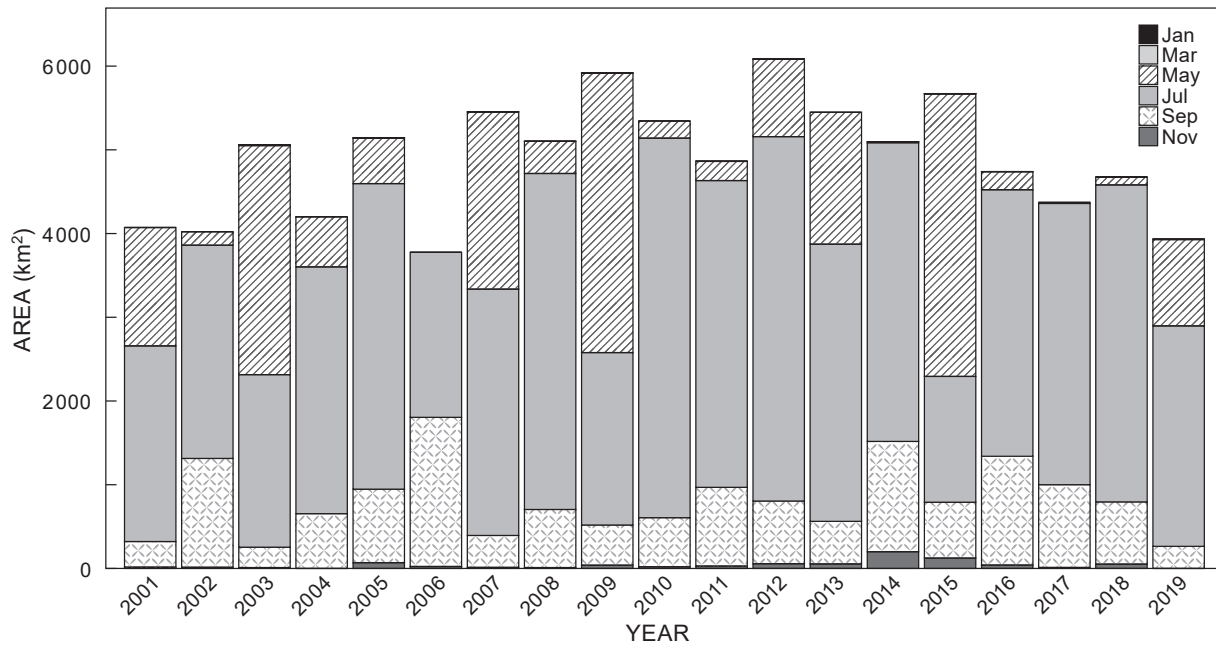
Each year, a larger area burned in the western part of the district, compared with the eastern (including the study villages). There was also typically a gradient of seasonality each year, with earlier fires in the western compared with the eastern part of the district. The spatial patterns of burned area for 2018 and 2019 (the years of interviews and focus group discussions for this study) are shown in Figure 3.

Almost half of Kilwa's land area had a mean crude fire return interval of five years or less during 2001–2019 (Table 1). The fire return interval was 5.6 years on average, across the district, whereas 30% of the land did not burn at all during the 19-year period studied.

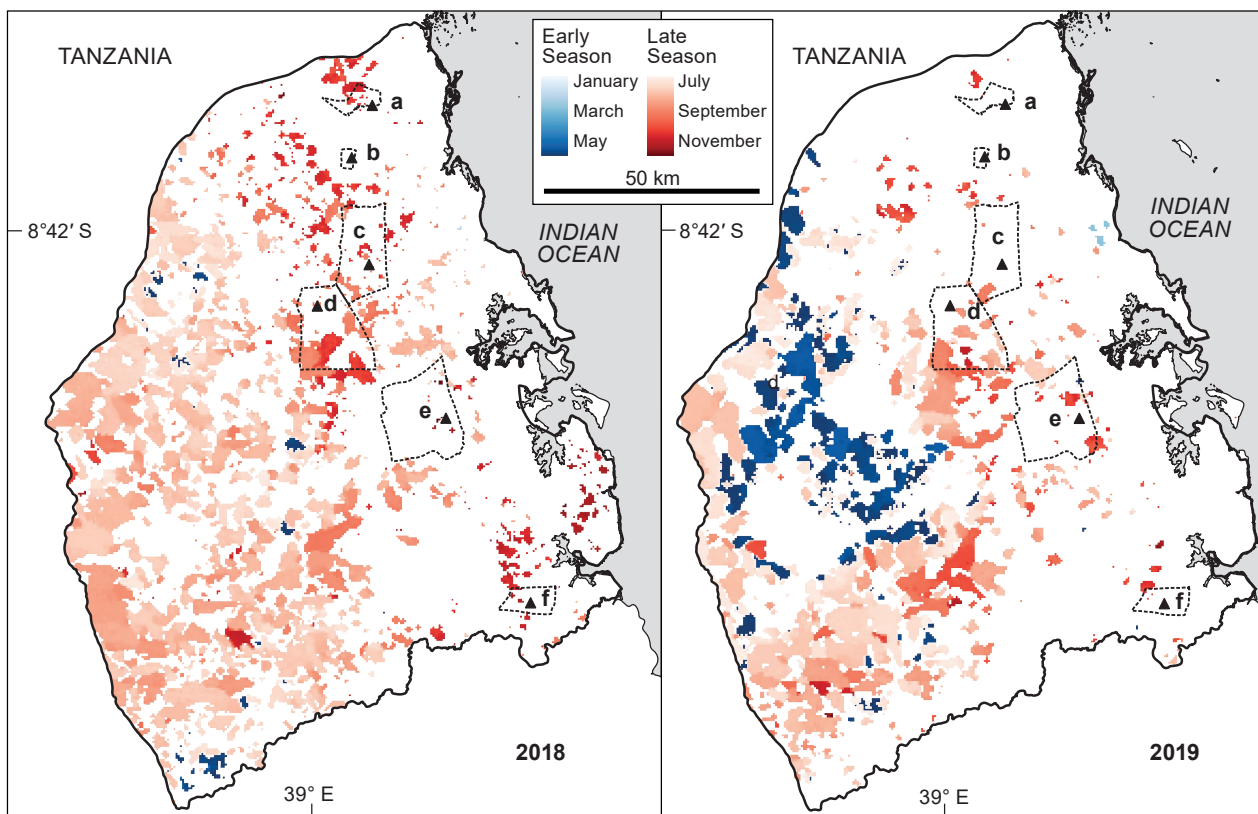
### ***Potential causes of uncontrolled fires***

Ten potential causes of uncontrolled fires (i.e. fires that could spread into the landscape and impact the fire regime), common across all villages, were identified during interviews and focus group discussions in 2018, and verified by focus group discussions in 2019 (Table 2). Most ignitions were intended to achieve specific goals and meet livelihood needs, and fire was considered important to meeting those needs: 'Everyone uses fire... If you are going to talk about uses of fire... one quarter of human life depends on it.' (Respondent at Mchakama Village Meeting 2018).

Decisions to burn for those needs tended to be made by individuals and small groups. Other causes of fire unrelated to livelihood needs included fire caused by lightning, general carelessness or actions considered reckless (often attributed to the inebriated, those who carelessly drop cigarettes, or young children playing with matches) and fire



**Figure 2:** Burned area in Kilwa, Tanzania between 2001 and 2019. Bars show total area burned identified from the MCD64A1 Burned Area data product (Giglio et al. 2015, 2018) and processed in R (R Core Team 2020) for bi-monthly periods. With calendar days numbered from 1 to 365/6, the time periods for non-leap years are January 1st until March 2nd (Jan), March 3rd until May 2nd (Mar), May 3rd until July 2nd (May), July 3rd until September 1st (Jul), September 2nd until November 1st (Sep), November 2nd until December 31st (Nov)



**Figure 3:** Burned area in Kilwa, Tanzania, in 2018 and 2019 as identified from the MCD64A1 Burned Area data product (Giglio et al. 2015, 2018) and processed in R (R Core Team 2020). The village centre (triangles) and boundaries (dotted lines) are shown for (a) Mtyalambuko, (b) Ngorongoro, (c) Kikole, (d) Ngea, (e) Mchakama, and (f) Mtandi. Fires between January and the end of June are shown in blue, fires between July and the end of December are shown in red

**Table 1:** Crude mean fire return intervals between 2001 and 2019 in Kilwa, Tanzania. The total area of land (in km<sup>2</sup>) with a mean fire return interval falling within the ranges given (1–5 years, 6–10 years) is shown. Land area as a percentage of the total land area of Kilwa District is also shown;  $\pm$  indicates standard error of the mean. Burnt pixels were identified from the MCD64A1 Burned Area data product (Giglio et al. 2015, 2018) Data were processed in R (R Core Team 2020)

Mean fire return interval (years)	Area (km <sup>2</sup> )	Area (%)
1–5	7 295.5 $\pm$ 61.8	48.6 $\pm$ 0.4
6–10	1 746.9 $\pm$ 114.7	11.6 $\pm$ 0.8
11–15	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
16–19	1 487.5 $\pm$ 0.0	9.9 $\pm$ 0.0

used to intentionally harm others (arson). Although fire to harm others was said to be very rare, we were told stories of people intentionally burning somebody else's crops or even home out of rage or jealousy, and all focus groups stated that these fires could spread uncontrolled.

Several activities involving fire were carried out mainly by men (Table 2). In the study villages, only the Sukuma people used fire to generate fresh grass growth to feed their livestock (as reported by Sukuma livestock keepers and others). One Sukuma livestock owner reported a traditional method of burning firebreaks around patches of grasses that are favoured by livestock, to prevent those grasses from being burned during the dry season. This is a similar method to burning to clear a firebreak around homes and fields used by the majority of people in the study villages (Table 2).

### Methods to optimise burning

Respondents reported that, depending on the desired outcome, fires were either intended to burn within specific boundaries or to spread uncontrolled (Table 2). Outcomes were achieved by choosing optimal ignition conditions, and using specific methods to set and control fires. Larger fires intended to spread uncontrolled were set in hot, dry and windy conditions, with grasses being the best fire fuel, and strong winds able to carry fires great distances and across potential firebreaks like paths. Fires intended to remain small were set in cool, still conditions, often in the morning when grasses were still wet with dew and likely to burn less intensely.

Other criteria specific to the livelihood activity also dictated the location and conditions of intentional burns. For example, some respondents reported that livelihood activities additional to agriculture, like charcoal production, were more commonly conducted during the dry season when farming is less labour-intensive. This also made activities carried out at this time of year (as well as fires caused by lightning and carelessness) more likely to cause uncontrollable fires, for example if fire escaped charcoal kilns. Conversely, honey was collected soon after flowers had bloomed in the rainy season when grasses were wet and more likely to suppress uncontrolled fire that could result from a dropped smoking branch (Table 2).

If the conditions were risky, but the aim was to avoid the uncontrolled spread of fire, preparations were made like burning or digging a border around a field, or choosing

bare, sandy earth on which to make charcoal. Smaller fires were sometimes monitored until they burned out, and some were extinguished or controlled using green branches (*mafukutu*) and sandy soils. Farmers often told neighbours when they were going to burn their fields, so that they could control the area burned together.

Respondents reported that most of the techniques they used to burn had been taught by their parents and grandparents, or simply that they had always burned this way. Burning agricultural debris in piles rather than burning the whole field was seen as a way to prevent damaging impacts of fire on soils, and this had been taught by government employees, known as *Bwana Shamba* or *Bibi Shamba* (terms used for men and women, respectively), who live in the villages to educate and assist local farmers. Some respondents who had been involved in prescribed burning (*ubabuaji* in Swahili) in Kikole, Mchakama or Ngea reported that involvement in community forestry and prescribed burning may have encouraged the use of similar methods elsewhere (e.g. to clean around homes and fields). However, all stated that methods like these were not new. Several respondents did not know the term *ubabuaji*, and there were a variety of other local names for methods of this type of traditional protective burning: 'You start by cutting down grasses at night and then you burn where you cut down grasses, and because they are wet grasses the fire won't go far away... We call it *ubabaya*, and we have known it since our grandfathers.' (Farmer; former blacksmith and hunter in Mtyalambuko 2018).

Most respondents across the villages stated that the methods of burning had not changed in their lifetimes.

### Common and risky fires

The extent to which ignition sources differ in perceived frequency and riskiness of the resultant fire was explored during ranking exercises in 2019 (Figure 4).

In all villages, fires to clear unwanted vegetation and burn piles of plant residue and debris around homes were reported as common; these fires were used frequently by every household. They were also considered low risk, because of their small size, because they could be easily controlled (and the incentives to do so, to protect the fire user's property, were strong), and occurred in the village centre where there is a low density of flammable grasses.

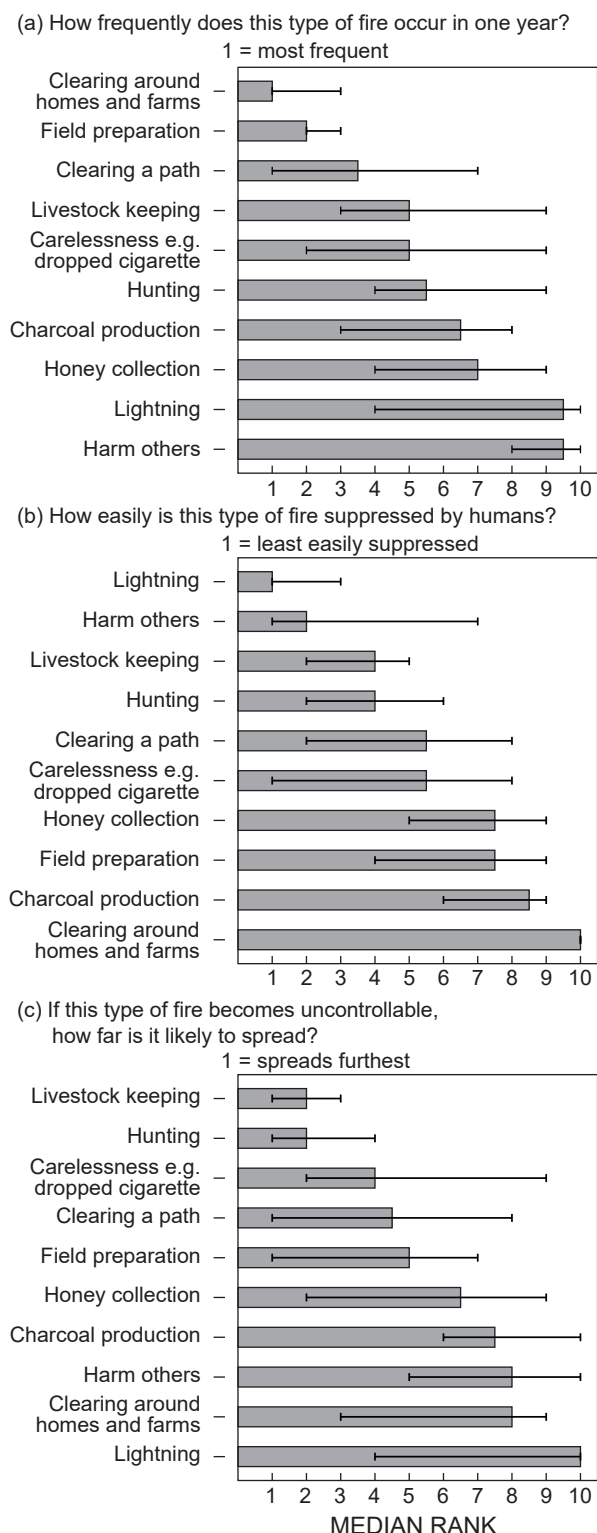
Other fire types were less consistently ranked, likely due to both genuine variation in observed fire between villages and limitations with the ranking exercise. For example, lightning fires were ranked among the three least common fire types in all villages, with most commenting that they only occurred during the rainy season, apart from in Ngorongoro, where the two groups ranked lightning as the fourth and sixth most common cause of fire. It is unclear whether this was because there had been more lightning strikes here or if people were simply more aware of it. In this village, many coconut trees are grown and lightning striking the top of coconut trees is a highly visible and reportedly common occurrence.

Respondents in ranking exercises noted that the intentions of those setting the fire partly determined its perceived riskiness. The two types of fire that spread



**Table 2:** Fire causes and ignition conditions in Kiliwa, Tanzania

Activity related to burning	Ignition description	Ignited by	Intended control	Habitat	Month	Time of day
Human ignition: Field preparation	Burning piles of cleared plant residue, or burning entire field	Men and women, individuals or small household groups and sometimes neighbours	Controlled, but fire can escape intended boundaries	Woodland, fallow, village centre	August until November (dry season)	Middle of the day to burn the entire field, evening or morning for burning piles
Clearing around homes and farms (to prevent later fires reaching these areas)	Burning piles of cleared plant residue and debris, or burning flammable vegetation directly	Men and women, individuals or small household groups	Controlled, but fire can escape intended boundaries	Woodland, fallow, village centre	May until November (dry season)	Evening or morning
Charcoal production	Burning logs in earth kiln	Usually male farmers, as an additional livelihood activity	Controlled, but fire can escape kiln	Woodland	Any month	Any time
Honey collection (to tranquilize bees)	Lighting a smoking branch	Usually male farmers, as an additional livelihood activity	Controlled, but smoking branch may be dropped after use and cause fire to spread uncontrolled	Woodland, village centre	December until April (rainy season)	Evening
Clearing a path (for ease of access and security from wild animals)	Burning grassy areas	Anyone	Spread uncontrolled	Woodland	June until November (dry season), commonly October when traveling to farms outside of village centre	Middle of the day
Hunting (to improve visibility and encourage grass growth)	Burning grassy areas	Usually male farmers, as an additional livelihood activity	Spread uncontrolled	Woodland	June until November (dry season), often later in the dry season	Middle of the day
Livestock keeping (burning off old grasses to encourage fresh growth)	Burning grassy areas	Pastoralists, usually young men and boys are responsible for burning	Spread uncontrolled	Woodland, often areas close to rivers and other water sources that enable grass regrowth	May until November (dry season), often early or late in the dry season, when recent or upcoming rains enable grass regrowth	Middle of the day
Harm others	Burning someone's farm or home	Anyone	Spread uncontrolled	Homes and fields in village centre, woodland	Any month	Any time
Carelessness	Dropping a cigarette or match accidentally	Anyone	None	Anywhere	Any month	Any time
Natural ignition: Lightning	Lightning striking flammable vegetation	NA	NA	Anywhere	January until April (rainy season)	Any time



**Figure 4:** Results from ranking exercises in 12 focus groups in six villages (two groups in each village) in Kilwa, Tanzania. Ten fire causes were ranked three times by each group, answering the questions: (a) how frequently does this type of fire occur in one year? (b) How easily is this type of fire suppressed by humans? (c) If this type of fire becomes uncontrollable, how far is it likely to spread? Median ranks across groups are shown. Error bars show the range of ranks reported across the 12 groups

furthest were those for hunting and livestock keeping (ranked first or second highest by 10 out of 12 and 9 out of 12 focus groups, respectively). Both of these types of fires were intended to spread uncontrolled over large areas. For other fires, the incentives to keep the fire controlled were often strong: 'A charcoal maker wants a benefit, not a loss, so most of the time he'll be checking that the fire hasn't gone uncontrolled and his charcoal hasn't been burned. He wants some money to solve his problems, so he is careful and if the fire goes uncontrolled, it's an accident.' (Respondent during ranking exercises for non-committee members in Ngea 2019).

Respondents said that fires caused by carelessness, for clearing a path, hunting or livestock keeping, to harm others and by lightning could not be controlled easily by directly preventing or extinguishing fires, but discussed how the time and place of ignition could result in indirect controls (Table 2): 'Most of the time lightning happens in the rainy season when the area is still wet and grasses are still wet, so it can't spread far' (Respondent during ranking exercises for non-committee members in Ngea 2019).

However, respondents also noted that intentions did not always match up to the reality of burning and that some people had been careless by allowing controlled fires to become uncontrolled, or simply that some fires can become uncontrollable and that this was unavoidable under certain conditions.

The major causes of uncontrolled fire cited by respondents in interviews varied and included hunting, field preparation, clearing a path, or unknown reasons; those who were deemed careless or irresponsible were also often said to be the cause. Part of the uncertainty over the biggest cause of uncontrolled fires arose because of difficulty in identifying the cause of individual fires.

#### **Perceived biogeophysical impacts of uncontrolled fires**

Respondents reported that uncontrolled fires typically destroy herbaceous vegetation, tree seedlings and saplings, but that large trees have not been harmed by most fires. Fires were not reported to burn into the tree canopy. Many, but not all respondents, reported that uncontrolled fires could cause long-term environmental changes in areas that had been repeatedly burned, by killing trees and turning previously wooded areas to grassland, reducing soil fertility and causing water sources to dry up.

Most immediate impacts of uncontrolled fire had been directly observed. However, the perceived long-term effects were typically reported as having been taught by school teachers, NGOs, Bwana Shamba or Bibi Shamba (government employees assisting farmers, who taught that repeated fire can reduce soil fertility), or as being simply well-known in general. Respondents rarely reported having observed long-term effects of uncontrolled fire in their lifetimes; conversely, uncontrolled fire was reported to have always been a normal part of life, and burnt areas were observed to recover and regrow. Some areas were reported to burn annually: after the start of the rainy season, grasses regrow and the area could burn again the following year.

The benefits of burning for specific livelihood activities (Table 2) were seen by respondents as accruing only to the fire users, whereas the broader environmental impacts of

uncontrolled fire as described above were generally seen as harmful: 'Anything that has good impacts also has bad impacts. For example, you set fire in your field to cultivate, to get crops to sell. But (to do this) you have cut down trees and burn the area, so the land will turn to desert.' (Farmer and charcoal maker in Kikole 2018).

Respondents also noted that fire hazards, when an uncontrolled fire had become dangerous or destroyed someone's property, had affected others in the community. Some who gather resources, such as thatching grasses and palms used to make mats, had lost income when they found these resources were burned. MCDI staff and community members involved in community forest management reported that it was important that the community woodlands, and their valuable timber species, should be protected from fire and that prescribed burning could help achieve this (though not all respondents in Kikole, Mchakama or Ngea had been involved in community forest management or prescribed burning). Therefore there was an unresolved tension between believing that uncontrolled fire has long been a normal and acceptable feature of the environment, and that it causes environmental and social harms.

#### ***Potential shifts in the fire regime over time***

Some respondents noted social and demographic changes that had the potential to influence the fire regime in recent years, however, this was reported inconsistently. Some reported that uncontrolled fires had become more common over time, citing larger village populations and more careless attitudes as causes of this change. Several collectors of thatching grasses and palms reported that these resources had become more difficult to find over time, due to an increase in uncontrolled fires. Others said that through experience and practice in burning for different purposes, environmental education about harms of fire (for example from NGOs), and fear of the law and fines, people had learned to be more careful and there had been fewer uncontrolled fires in recent years. However, the details of the law were in general poorly understood, and many also said that there were no laws or fines related to fire use.

Some respondents noted specific changes in ignitions: for example, claiming that there had been no fires to produce fresh growth for livestock until the Sukuma people moved to the villages. Hunting was also said to be less prevalent than it used to be, due to its criminalisation. In villages close to the Selous Game Reserve, people particularly feared being caught by game wardens and said there was little hunting in the village because of this. Hunting was a highly sensitive topic and only a few respondents across all villages discussed their own hunting activities openly; several respondents noted that trends in fire use for hunting were likely impacted by a range of variables. For example, some respondents reported lower availability of wild animals to hunt, compared with previous decades, reducing hunting activities overall. Many reported that although fire is useful for hunting larger game, some smaller species are best hunted in the rainy season and without fire. There was no correspondingly consistent reporting of changes to uncontrolled fires in living memory and remote sensing data showed no consistent directional trend in total area burned between 2001 and 2019 (Figure 2).

## **Discussion**

These findings contribute to a growing body of research documenting how fires across sub-Saharan Africa are intentionally set by people in rural communities and important to local livelihoods. Many fire uses, such as for field preparation, livestock keeping (rangeland improvement) and honey collection, are common across multiple countries, communities and through time (e.g. Kikula 1986; Eriksen 2007; Shaffer 2010; Ribeiro et al. 2019b). In Kilwa, as in several of these studies, we found that it was often individuals or small groups who made decisions to burn, though elsewhere burning has also been found to be coordinated at the community level. For example, Butz (2009) reported that for the Maasai in northern Tanzania, burning was historically coordinated by elders to meet community needs, such as killing pests, keeping away dangerous wildlife and preventing late-season catastrophic fires, but also found that there has been a decline in this type of fire management.

The most common reasons for ignition reported in the study villages in Kilwa were useful to large proportions of village populations: for field preparation, clearing vegetation and debris around homes and farms, and clearing a safe path through grassland (Figure 4). The latter two of these intentions behind ignition were for direct protective or preventative purposes, mirroring some of the reasons for community burning cited by Butz (2009). However, respondents described the benefits of burning generally as relevant to the individual or small groups setting the fire only. Laris (2002) and Butz (2009) found that in communities in Tanzania and Mali, respectively, decisions to burn resulted in the creation of a landscape-level seasonal mosaic, which the authors argue is less hazardous and more useful than unburned land (though in Mali decisions to burn were not made communally). Here, in contrast, we found little evidence of the creation of a seasonal mosaic. A greater proportion of the land area burned in the later months of the dry season (Figure 2) when many risky fires were set, dictated by the livelihood activities carried out at this time (Table 2), and when conditions encouraged the spread of accidentally uncontrolled fire, which can be hazardous and harmful to people.

Fire seasonality in Kilwa shifted slightly from year to year (Figures 2 and 3), as was found by Cooke et al. (1996) in their study of fire regimes across continental Africa. Fire seasons in southern Africa tend to be consistent across areas with both high and low human influence (Archibald et al. 2010), suggesting that the shifting fire season is dictated by weather variations: grasses begin to burn when they are dry enough. In this study, we also found that year-on-year weather patterns (particularly timings of rainfall) altered people's decisions about when to set fire, i.e. people waited until the conditions are right for the kind of fire they want. Fire management was therefore adaptive and responsive to environmental factors, such as rainfall seasonality, which could affect ignition decisions driving the fire regime in future, e.g. under projected increased rainfall intensity (Niang et al. 2014).

Many respondents suggested that social and demographic shifts had influenced local attitudes towards

fire, and potentially trends in the fire regime, yet recent fire trends were not perceived in a consistent way. For example, population growth was reported by some to have increased ignitions, whereas criminalisation of hunting and education from NGOs was claimed by others to have reduced ignitions. Fear of breaking the law by causing uncontrolled burns was also cited as a potential cause of reduced ignitions, though the details of the law were poorly understood. Tanzania's 2002 Forest Act requires people to seek permission before burning outside of their own land, but respondents were unaware of this and did not seek permissions prior to burning (though people with neighbouring fields often burned them together). Rather, decisions to burn for many activities, such as hunting, livestock keeping and to clear a path were made adaptively and often spontaneously.

The MCD64A1 Burned Area product we used here only goes back to 2001, which may not be a long enough time period to capture any possible trends in response to recent social drivers, for example the arrival of the Sukuma and increased use of fire for livestock keeping. These trends may also not be captured at the landscape-level by the 500 m pixel resolution of MODIS imagery, which misses small fires (Ramo et al. 2021). Comparisons across southern Africa show that high human population densities result in increased ignition frequency and reduced fire spread (Archibald et al. 2010), although the magnitude of the effect of human populations on burned area depends on local conditions (Andela et al. 2017). Even though trends in recent years are not observable at the landscape level in Kilwa, they could still affect local hazards and livelihoods in a meaningful way. For example, collectors of thatching grasses and palms reported that these resources had become more difficult to find over time, due to an increase in uncontrolled fires, resulting in a loss of income from these sources. Potential cumulative impacts of shifts in livelihoods and population sizes on fire regimes should therefore not be underestimated (Eriksen 2007; Butz 2009; Laris 2013).

Kull (2016) distinguishes between the roles of fire as a tool for rural livelihoods, a change agent transforming landscapes and a natural hazard. In this study, we found that the usefulness of fire as a tool understandably took precedence for people in Kilwa (as Kull also found in rural communities in Madagascar) and burning was optimised depending on the desired functioning of the land. Some land needed to be protected from fire (for example community woodlands) and other land had to be burned to be useful (for example some rangelands). The riskiest fires were reported to be those intended to spread uncontrolled, particularly for hunting and livestock keeping, which were usually set in dry and windy conditions (Table 2 and Figure 4). Although respondents generally described wider environmental and some social effects of uncontrollable fire as harmful, there is a trade-off between these potentially harmful impacts and the need to use fire for livelihood activities.

The widespread reporting of the harmful environmental effects of fire was likely influenced by national environmental narratives and teachings from environmental organisations, as also reported by Brockington (2006) and Gross-Camp (2017). Lovett (2003) argues that international conservation initiatives, such as Tanzania's participation in

the Convention on Biological Diversity (CBD) and Reducing emissions from deforestation and forest degradation (REDD+) are highly influential of its national environmental policies, many of which frame fire as harmful. For example, in the National Biodiversity Strategy and Action Plan 2015-2020 (Government of Tanzania 2015) required by the CBD, fire is described as a major cause of biodiversity loss, and burning to prepare fields is labelled as 'unsustainable'. Anti-fire policies in Mali (Laris 2002), northern Tanzania (Butz 2009), and Madagascar (Kull 1999) have been reported to encourage fires to be set anonymously, stifling community-level management and discussions about the best way to burn. Some respondents in this study suggested that environmental narratives may encourage secrecy in burning (EW and MM, pers. obs. 2019), though the data here are insufficient to determine whether this is a substantial issue. However, there was a clear tension between the belief that fires generally harm the environment and the concurrent belief that fire had long been a normal and acceptable part of the environment, supported by observations of land recovering from fires.

The fire management initiated by Mpingo Conservation and Development Initiative, prescribed burning used in some of the study villages in Kilwa, was related to community woodlands only. This type of fire management does not affect uses of fire for other activities and was considered successful by those involved. Elsewhere in Africa, community-based fire management, where attempted, has often had limited effectiveness (e.g. Dube 2013; Kilawe et al. 2021). For example, CBFiM involving training, fire suppression, protection and monitoring, trialled in northern Tanzania, led to initial reductions in fire occurrence, but these were not sustained in the long-term. Kagosi et al. (2020) cite explanations for this including exclusion of community members from the process, limited training due to inadequate funds and the continued use of fire as a tool in activities like hunting, field preparation and honey collection. Fire management in this case undermined livelihood activities requiring the use of fire as a tool, and was therefore in conflict with the priorities of local people. Approaches in CBFiM incorporating local knowledge, and an understanding of the importance of fire for livelihoods, are therefore likely to have better social and environmental outcomes. Aligning those outcomes in inhabited landscapes is likely to be one of the most important challenges for fire management in future.

## Conclusions

This study is the first of its kind using data from interviews, focus group discussions and remote sensing to explore how human decisions drive different dimensions of the fire regime in a lived-in landscape in southern Africa. It is demonstrated that fire ignitions in Kilwa were driven mainly by human intentions, and that local people managed fire regimes in a way that served important livelihood needs. Most local people saw fire as a tool for achieving individual goals, as well as recognising its potentially harmful effects. Fire management was adaptive and responsive to environmental conditions, which are projected to change in future. Understanding how to align local priorities (including adaptive uses of fire) with conservation goals, must form

the foundation for sustainable management of fire regimes in inhabited landscapes. Future field-based studies should explore the ecological impacts of the fire regime as driven by livelihood activities to better understand how to align those goals. Incorporating high resolution remote sensing (Ramo et al. 2021) would also improve understanding of the fire regime, as driven by livelihood activities, at a landscape scale in future.

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