AFRICA

The Fire Continent

TERRAFRICA
REGIONAL SUSTAINABLE LAND MANAGEMENT

Foreword

Science tells us that many plant species and ecosystems in Africa benefit from fire and indeed need fire to remain healthy. Traditional farmers recognise this and have for centuries frequently burnt grasslands to stimulate and maintain their grazing potential. However, in the last 150 years, people have changed the fire cycle. They have often increased or decreased both the intensity and frequency of fires in different ecosystems.

With increased development comes the chance of out of control fires damaging property. More recently as a response to climate change, with the desire to build up carbon stocks, there has been a tendency to count the loss of biomass due to fire as a negative. Yet, at the same time, especially in southern Africa we also see a return to using fire as an important landscape management and restoration tool.

This report is aimed at provoking discussions on these issues and reminding us that the right fire management regime is an important element in maintaining the health of different ecosystems. We see this as the start of an important debate on how fire should be used to restore and maintain healthy ecosystems, promote agriculture, and build up carbon stocks to address climate change, while reducing the risks to life and property.

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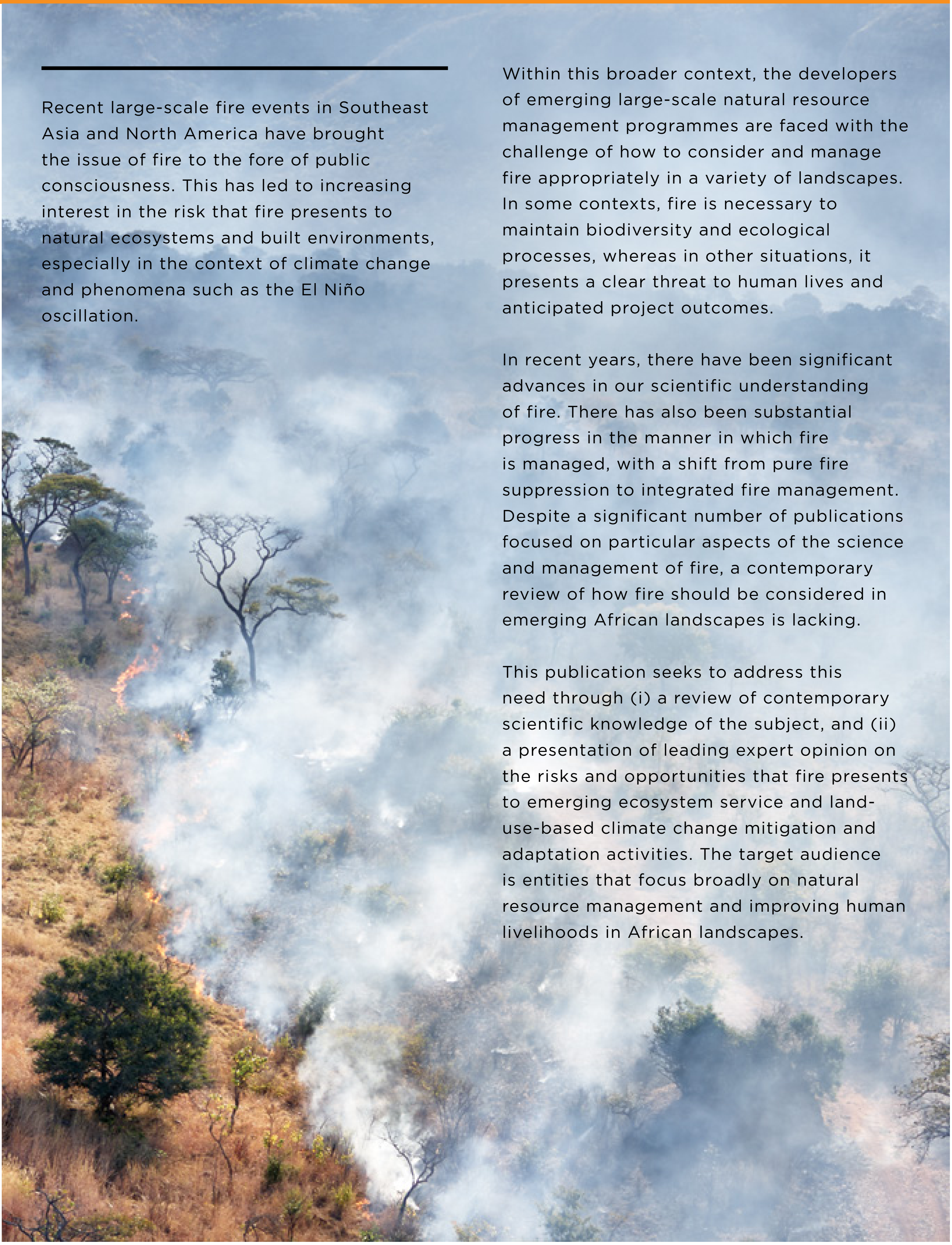


Recent large-scale fire events in Southeast Asia and North America have brought the issue of fire to the fore of public consciousness. This has led to increasing interest in the risk that fire presents to natural ecosystems and built environments, especially in the context of climate change and phenomena such as the El Niño oscillation.

Within this broader context, the developers of emerging large-scale natural resource management programmes are faced with the challenge of how to consider and manage fire appropriately in a variety of landscapes. In some contexts, fire is necessary to maintain biodiversity and ecological processes, whereas in other situations, it presents a clear threat to human lives and anticipated project outcomes.

In recent years, there have been significant advances in our scientific understanding of fire. There has also been substantial progress in the manner in which fire is managed, with a shift from pure fire suppression to integrated fire management. Despite a significant number of publications focused on particular aspects of the science and management of fire, a contemporary review of how fire should be considered in emerging African landscapes is lacking.

This publication seeks to address this need through (i) a review of contemporary scientific knowledge of the subject, and (ii) a presentation of leading expert opinion on the risks and opportunities that fire presents to emerging ecosystem service and land-use-based climate change mitigation and adaptation activities. The target audience is entities that focus broadly on natural resource management and improving human livelihoods in African landscapes.

The subject of fire management is explored through five thematic questions using practical case studies and examples where possible:

1. What is the nature of fire in Africa?
2. To what extent and for what purpose can fire be managed in African landscapes?
3. How would fire management actually occur in vast, populated landscapes?
4. What risk does fire present to the outcome of landscape management ventures?
5. What influence could fire have on emerging natural resource management programmes?

In this paper, we use the term ‘wildfire’ to refer to the uncontained combustion of vegetation, to distinguish it from ‘domestic fire’, the other major source of combustion in Africa, which takes place in millions of enclosed stoves and hearths. ‘Wild’ does not connote ‘uncontrolled’.

The emphasis here is on understanding the nature of wildfire, and the practical management thereof, in contemporary African landscapes, which are often diverse and used by a variety of actors for a range of different purposes.

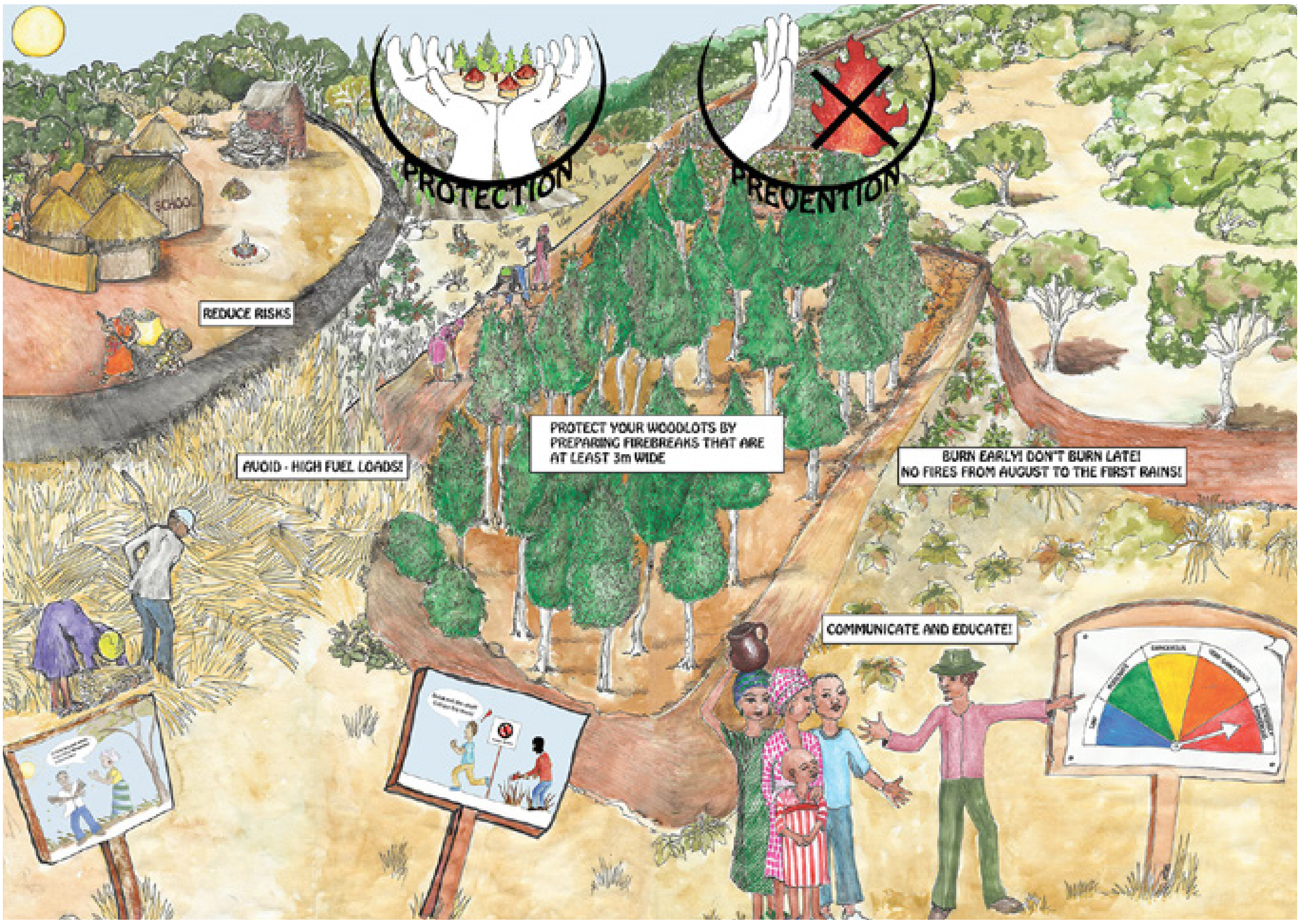
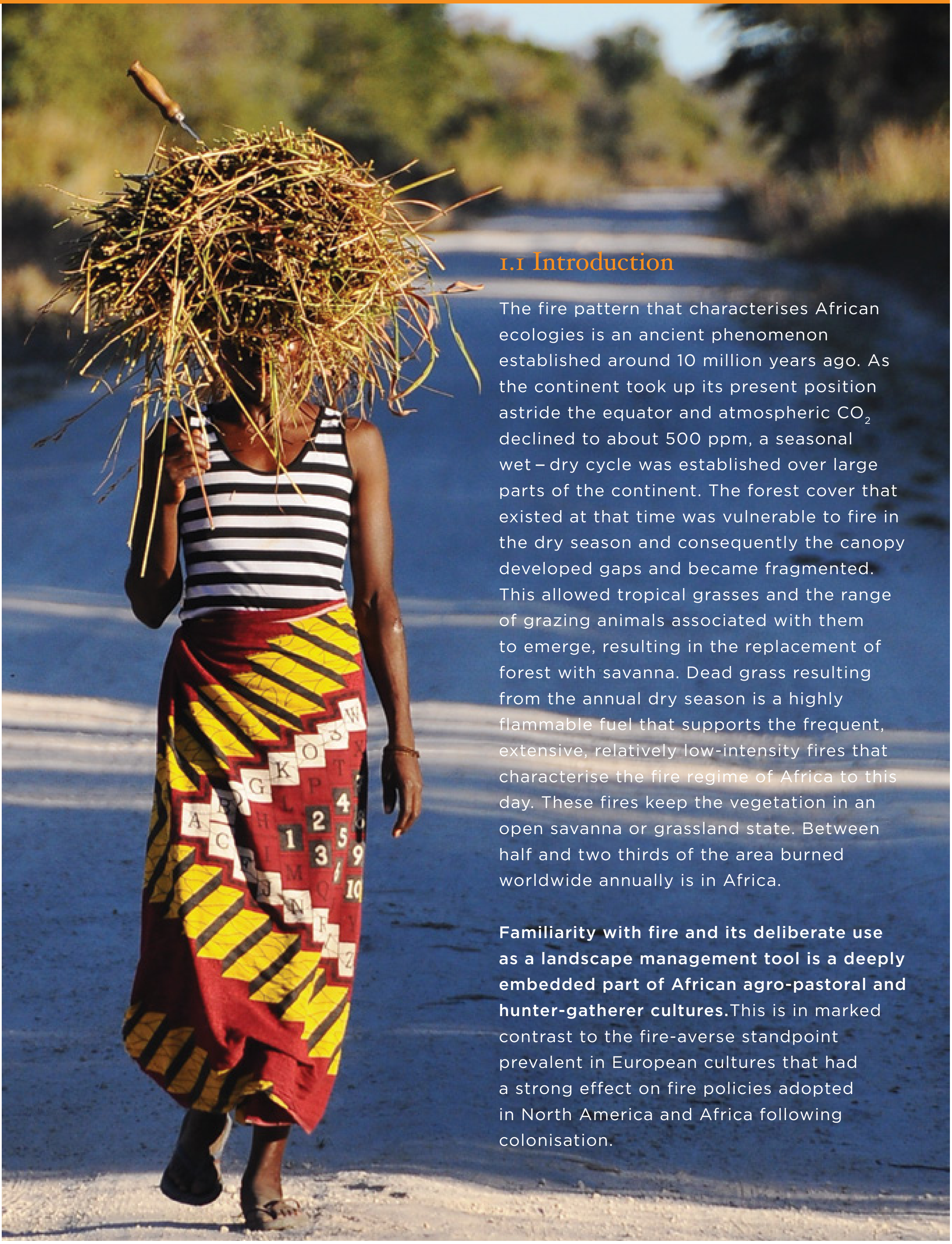


Figure 1. An example of a community engagement poster.

Section 1

What is the nature of fire in Africa?



1.1 Introduction

The fire pattern that characterises African ecologies is an ancient phenomenon established around 10 million years ago. As the continent took up its present position astride the equator and atmospheric CO_2 declined to about 500 ppm, a seasonal wet – dry cycle was established over large parts of the continent. The forest cover that existed at that time was vulnerable to fire in the dry season and consequently the canopy developed gaps and became fragmented. This allowed tropical grasses and the range of grazing animals associated with them to emerge, resulting in the replacement of forest with savanna. Dead grass resulting from the annual dry season is a highly flammable fuel that supports the frequent, extensive, relatively low-intensity fires that characterise the fire regime of Africa to this day. These fires keep the vegetation in an open savanna or grassland state. Between half and two thirds of the area burned worldwide annually is in Africa.

Familiarity with fire and its deliberate use as a landscape management tool is a deeply embedded part of African agro-pastoral and hunter-gatherer cultures. This is in marked contrast to the fire-averse standpoint prevalent in European cultures that had a strong effect on fire policies adopted in North America and Africa following colonisation.

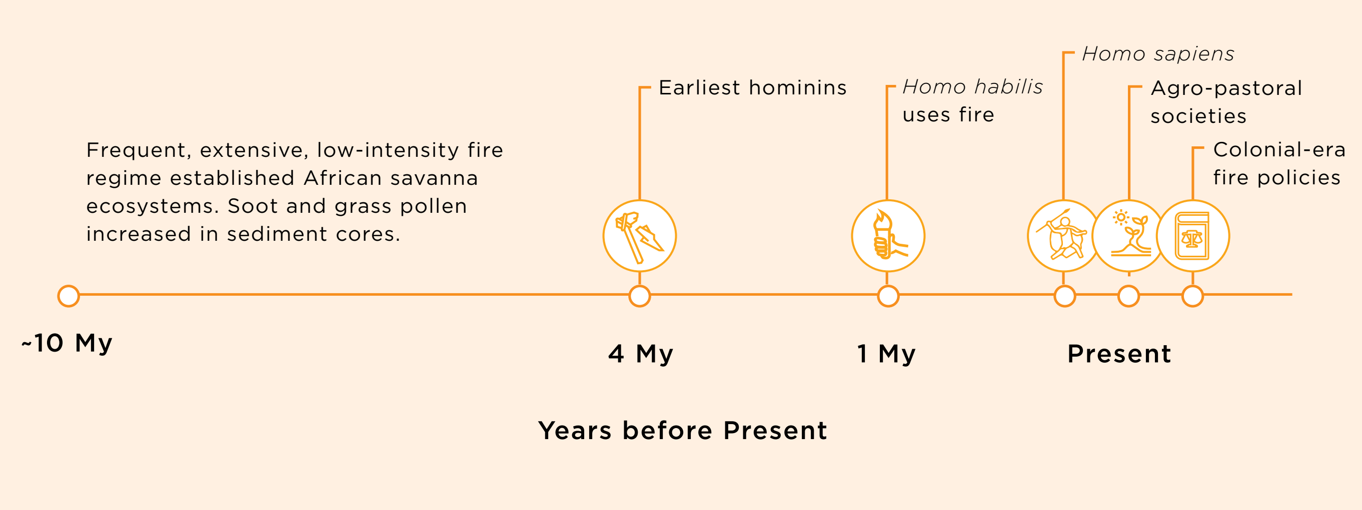


Figure 2. Timeline of fire in Africa. The African fire regime has been in place for many millions of years, but humans have only been the prime source of ignition for about one million years. African agro-pastoral societies co-developed with fire over about five thousand years whereas colonial-era fire policies have been in place for less than a century.

1.2 The extent and type of fire in Africa

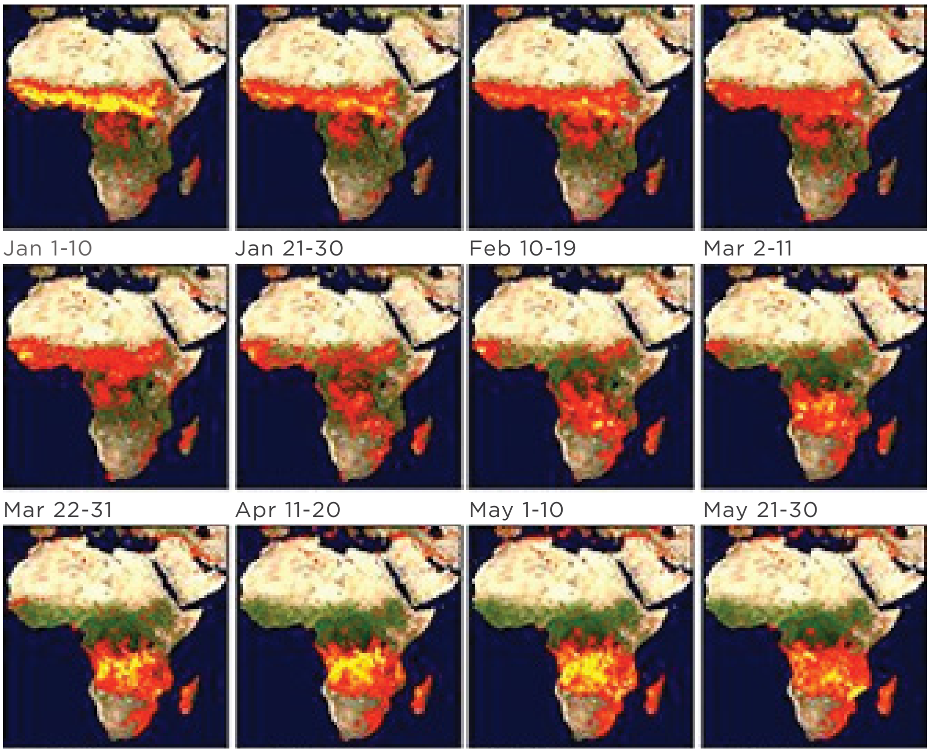
1.2.1 The concept of a fire regime

The nature of fire in a particular landscape is characterised not by a single measure (for example, annual burned area), but by a set of attributes that together constitute a 'fire regime'. Attributes, such as the season, frequency, intensity and type of fire, are commonly applied when describing African fire regimes (Table 1). The regime is a statistical concept that is not applied to a single fire but to many fires observed over a long time or a large area. Each attribute should be considered as a probability distribution function with a range of possible values, rather than as a single value.

Other fire attributes have sometimes been ascribed, for instance whether a fire is anthropogenic (human ignited) or natural, prescribed, accidental or arson. These distinctions are not very informative ecologically, and are hard to operationalise. Some scholars are investigating whether other attributes, such as the size and shape of individual fires, are important in influencing biodiversity outcomes (Martin 1992, Parr & Brockett 1999, Parr & Andersen 2006).

Table 1: The characteristics of fire regimes.

Attributes	Units and values	Comments
Return time	Years	This is sometimes called 'fire frequency', which technically would be 1/return time. Return time is often assumed to be equal to 100/(annual burned area %), but this is not strictly true since fires are not randomly and independently distributed in the landscape.
Intensity	kW/m	A fire is termed 'cool' or 'hot', but actually intensity has little to do with temperature. It has to do with rate of energy release along the burning front, which is controlled by rate of spread of the fire, and fuel load. Intensity strongly influences the ecological and human impacts of a fire as well as the ease with which it can be controlled.
Season	Early-wet, mid-wet, late-wet, early-dry, mid-dry, late-dry	The seasonality of fire is most usefully expressed relative to the rhythm of the ecosystem rather than the human calendar. Seasonality in Africa is mostly controlled by rainfall rather than temperature.
Type	Fore, back or crown, ground, underground	The conventional typology for forest fires is crown, ground and underground fires, but since almost all African savanna fires are ground fires, whether they are burning with the wind (fore) or against the wind (back) is a more useful distinction.

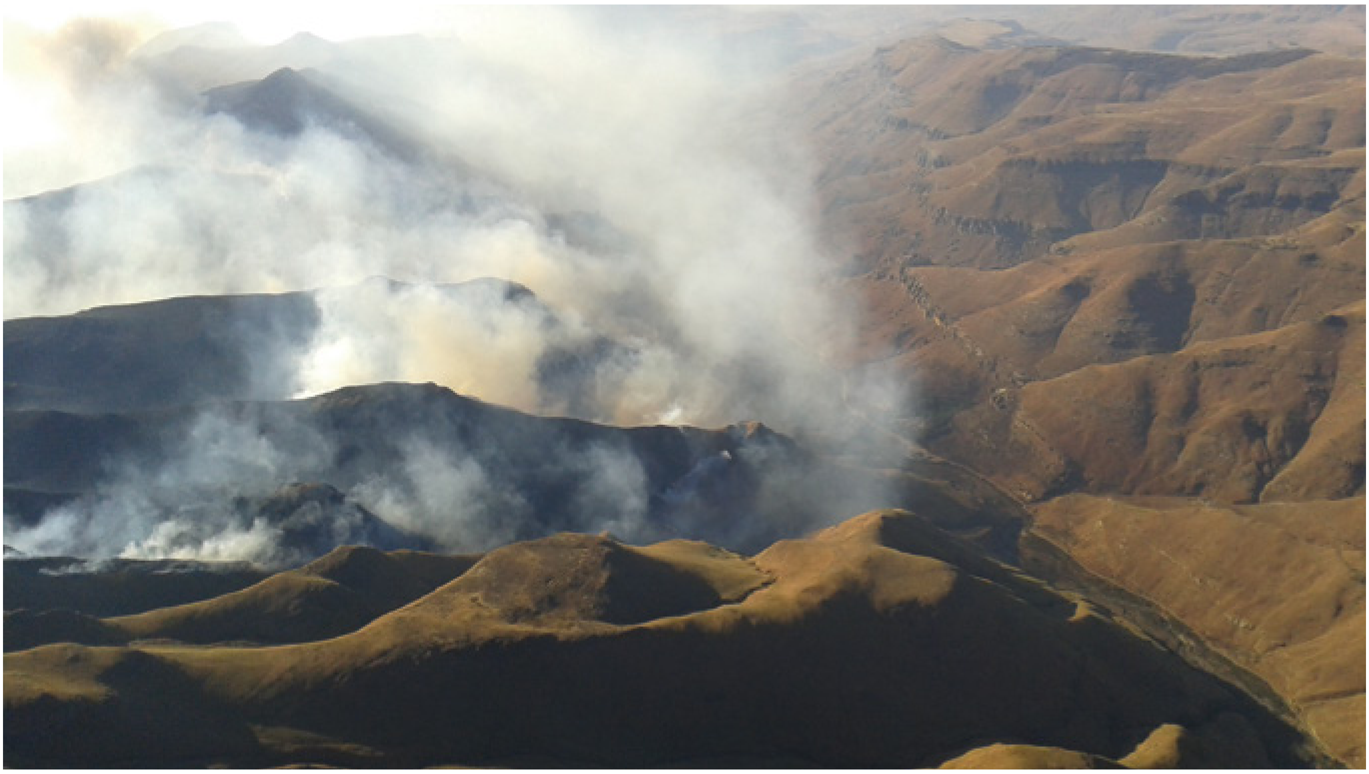

Jan 1-10
Jan 21-30
Feb 10-19
Mar 2-11
Mar 22-31
Apr 11-20
May 1-10
May 21-30
Jun 10-19
Jun 30 Jul 9
Jul 20-29
Aug 9-18

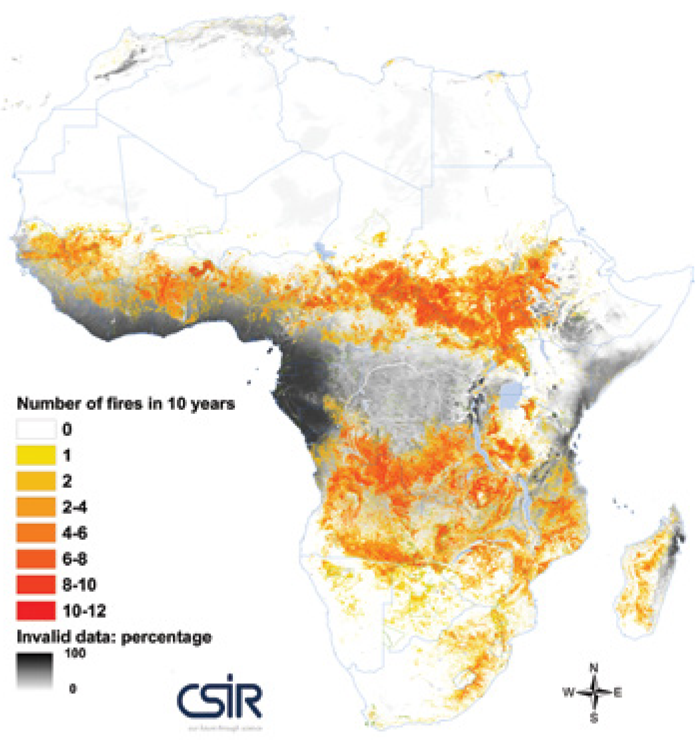
◀ Figure 3. The fire season appears as a distinct wave as it spreads through Africa. It peaks in January in West Africa (the northern hemisphere dry season), and in southern Africa in August (southern hemisphere dry season) (Source: NASA MODIS Active Fire product).

▶ Figure 4. Frequency of fire in Africa for the period 2000 to 2010. Dividing the number of times a pixel was detected as having burned into 10 gives the approximate fire return time, in years (Source: David Roy, NASA & Sally Archibald, CSIR).

1.2.2 Fire return times

Fire in the main fire-prone African ecosystems (dry woodlands, savannas, grasslands and certain shrublands) is extremely frequent by global comparison, which is why the satellite-based active fire detection algorithms show Africa to be permanently ablaze. However, the heat-detecting sensors on the satellites are very sensitive, and they record fire in a pixel covering many hectares when the actual area burning may only be a few square metres. Fire return time based on active fire detection will therefore generally be many-fold over-estimated. Even landscapes such as Miombo woodlands, frequently claimed to burn every year, are typically only 1/3 burned in an average year on an area basis (Scholes et al. 1996, Archibald et al. 2010).





Since about the year 2000, highly reliable satellite-derived products for mapping burned areas with a spatial resolution of about 500 m have been available continent-wide (Giglio et al. 2006, Roy et al. 2008). They sense the darkening of the land surface after a fire has passed, rather than the heat of a fire, and thus give a relatively unbiased estimate of a fire's extent provided the fire is larger than about 25 ha in area. However, this class of product may miss fires burning beneath dense tree canopies, or if post-fire views of the surface are obscured by clouds long enough for the blackened scar to disappear. The most reliable estimates of return time at any given point come from long-term (>50 years) place-based studies in which every fire is accurately mapped and the return time is worked out for every part of the landscape.

Table 2: Key attributes of vegetation wildfires in Africa (Sources: van Wilgen & Scholes 1997, van Leeuwen et al. 2014).

Vegetation type	Burned area fraction %/y	Intensity[a] kW/m	Fuel load kgDM[b]/ha	Completeness[c] %
Forest (Afromontane or Congolean rainforest)	<1	Low	40 000–150 000	Low, 25%
Deciduous dry forests	~5	Low unless crown fire	Usually only grass, <1 000	90% of grass
Moist savannas and woodlands	30–80	Medium to high	1 000–5 000	>90
Semi-arid savannas	10–40	Medium	500–3 000	80–90
Grasslands	20–60	Medium	1 000–8 000	>90
Shrublands (typically drylands)	<10	Low	300–2 000	50–80
Winter rainfall shrubland (called fynbos in South Africa)	10–20	High to very high	5 000–15 000	60–90
Seasonally-dry wetlands (dambo in central Africa, vlei in South Africa)	10–70	High	3 000–15 000	20–90
Short-duration croplands	10–30	Low	300–1 000	50–80
Plantation forests	~2–5	Very high if in crown	10 000–60 000	20–70

a. Low <1 000; medium 1 000–3 000; high 3 000–8 000; very high >8 000 kW/m

b. Dry matter (DM)

c. Fraction of fuel load exposed to fire which combusts

1.3 What controls fire in Africa?

1.3.1 Environmental factors

The attributes that account for most of the spatial variation in the burned area fraction in Africa are environmental: rainfall, its seasonality, temperature, nutrients and topography (Archibald et al. 2009). Different biophysical environments have distinctive fire signatures and this leads to the notion of a 'fire biome', or 'pyrome' (Archibald et al. 2013). Fire prevalence in Africa is fuel-limited rather than ignition-limited. In other words, as there are usually more than enough ignition opportunities, what controls the area burned is the degree to which the fire can spread. This is influenced firstly, by the fuel load, and secondly, by the presence of barriers to fire spread. The potential fuel load is determined by climate and soil – a larger fraction of the area burns in the dry season following a wet year, than in a dry season following a drought year (Archibald et al. 2010). This is in contrast to fires in forests, which are more prevalent in dry years.

1.3.2 Human influence

There is a perception that because the overwhelming majority (approximately 90%) of fires in Africa are ignited by humans, people and their institutions are the determinants of fire. If this were the case, we would expect to see sharp disjunctions across national borders or jurisdictions where different fire policies exist. Such 'unnatural' boundaries are not generally apparent. A key effect of humans is to alter the fire season. Traditionally Africans light 'cool' fires early in the dry season (as soon as the grass will ignite) and continue to do so until a mosaic of burned patches has developed to support the grazing needs of their livestock.

Fire intensity is controlled by fuel load, fuel moisture, air temperature, and wind speed, which vary through the day and year. The strongest effect is air humidity, which acts via the moisture content of the fine grass fuel. Fire intensity is potentially firmly under the control of the person doing the ignition – experienced fire managers can tailor the intensity of the fire quite precisely by choosing the date and time of setting the fire. **However, human attempts to deviate greatly from the fire regime associated with a particular environment will usually be frustrated, and this can lead to highly unfavourable outcomes such as extreme fire risk.**

Dense human settlements typically have a network of roads, fields, settlements and rivers, which impede fire paths through the landscape. **Thus, while the number of ignitions may go up with human population density, the individual fire size goes down.** The net effect on burned area is a substantial reduction at human densities above about 15 people/km^2, and in very densely populated landscapes fires are virtually excluded (Archibald et al. 2009).

1.3.3 The effect of fire policy

The fire system is broadly self-regulating – fire exclusion leads to a build up of fuel, which increases the likelihood of future fire; conversely, frequent fires make it harder for fires to propagate. Where a single landscape has been managed under different fire policies, the long-term effect on the area burned is often surprisingly small. For instance, over the past century, fire policy in the 2 million ha Kruger National Park in South Africa has ranged from prohibition, to prescription, to mimicking natural ignition. Through this period the burned area fraction has hardly changed (van Wilgen et al. 2004). The attributes that do seem to be amenable to policy intervention are the season of burning, the size of individual fires and, to some extent, fire intensity.

1.4 Fire ecology

1.4.1 Fire and ecosystem processes

The main fuels for African wildfires are dead grass, fallen tree leaves, twigs and wood. All of these have had a large fraction of their nutrient content (nitrogen, phosphorus and other essential elements) extracted before senescence[1], thus the fraction of the total ecosystem nutrient stock exposed to individual fires is relatively small.

The non-volatilised N and S, along with most of the Phosphorus and mineral elements such as K^+ and Ca^{2+}, are deposited in ash in a highly plant-available form. This raises the soil pH briefly and provides a short-term nutrient ‘flush’, aided (if the soil is slightly moist) by increased microbial activity stimulated by sun-warming of the darkened surface (Parsons et al. 1996). The post-fire regrowth is much more palatable than the dead, dry grass it replaces, partly because of the nutrient flush, but mostly because the leaves are young. This is the main reason why domestic and wild herbivores flock onto recently burned patches.

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[1] ‘Senescence’ is a term used to describe the process of aging in plants. Following juvenile and maturity phases, the entire plant or only a part thereof (e.g. the leaves) turns brown, dies and eventually falls as litter.

1.4.2 The effect of fire on trees and grasses

Burned grasslands generally have a slightly higher (approximately 25%) productivity in the year after the fire than unburned, ungrazed grasslands, but annually-burned grasslands may show a long-term productivity decline relative to grasslands burned less frequently (Jones et al. 1990, Ouédraogo & Delvingt 2007). This can partly be ascribed to the nutrient effects described in 1.4.1, above, but a large part of the short-term increased productivity is due to reductions in self-shading. If there is a dense canopy of dead grass from previous seasons, the new leaf is in carbon deficit until it can grow into the sunlight, and the productivity of the sward suffers. Where the dead grass is too indigestible to be grazed, fire is an effective tool to reverse this condition.

Fire has very little effect on the survival of established, tall trees in fire-prone African vegetation. They are protected by fire-resistant bark, an absence of leaves in the dry season, and low flammability. Where these defences are breached, for instance by basal scars from injuries, mature trees do eventually succumb to repeated fires. Even then, the fire may not kill them, as many savanna trees re-sprout from the stem or roots following damage. However, while woody perennial plants are short in stature, they are susceptible to fires in the grass layer. These fires kill the aboveground parts of the plants and force them to start again from ground level. If the plants grow through the flame zone before the next fire, they suppress grass growth around them, reducing their fire risk, and the whole system eventually becomes tree dominated.

1.4.3 Fire and animals

Fire is one of the key structuring agents of the wildlife habitat. The animal inhabitants of fire-prone African vegetation (including birds and invertebrates) are highly adapted to survive and benefit from fire. Most move out of harm's way ahead of the fire. Some slow-moving species (such as tortoises) are vulnerable as individuals, but have strategies to survive fire at the population level, for instance, by laying eggs before the fire season that hatch after it is over. Many African species have life-histories explicitly keyed to the fire regime. Examples are birds which nest on recent fire scars, and mammals that give birth in time to use the green flush on recently burned areas to support lactation.

1.4.4 Fire and people

Every year, wildfires in Africa kill several tens of people (accurate statistics are not available), burn homes, crops and livestock accidentally, and in some cases, have a detrimental impact on livelihoods. Nevertheless, traditional African societies accept fire as normal and desirable (Pyne 1997). Wildfire is perceived to have benefits as well as threats, and consequently it is treated with respect rather than fear. There is a long history of indigenous technical knowledge in fire management. Fires are ignited, and where necessary, put out without great fuss but most frequently ignored.

1.5 The effects of African fires on the global atmosphere and climate

Wildfires in Africa are among the largest natural sources of particulate aerosols and carbon monoxide to the global atmosphere (Andreae et al. 1996, 2001, Langmann et al. 2009). Two points are worth noting: they are likely to have been so for millions of years, and emissions from the domestic burning of biomass in Africa are of a similar magnitude (Scholes et al. 2011).

1.5.1 Carbon balance

Wildfires have no net long-term effect on the global atmospheric CO_2 concentration provided that the fire regime is not changed. CO_2 is a major part of the smoke emission, but it is reabsorbed by the vegetation regrowth in the months or years following a fire. If fires become more frequent than in the past, or combust a larger fraction of the fuel, then a net carbon emission will result, and vice versa if less frequent or less intense. This manifests, in the long term, as a change in the aboveground biomass and belowground soil carbon (Jones et al. 1990, Shackleton & Scholes 2000). Deliberate changes in the fire regime may result in additional carbon sequestration, but the amount of carbon thus stored is relatively small per hectare (though it can add up over large areas). Carbon uptake saturates after a few decades, and the accumulated biomass carbon stock is vulnerable to accidental loss back to the atmosphere.

1.5.2 Other greenhouse gases

The non-CO_2 greenhouse gases emitted by wildfires are net emissions because they are not reabsorbed by the ecosystem in the short term. However, they are generally not ‘net anthropogenic emissions’ in the UNFCCC sense, since there is scant evidence that the average emissions have changed in the industrial era. They are best regarded as part of a background natural cycle. The quantities emitted at a whole-continent scale are large (Table 3). Burning early in the dry season, rather than late, has been suggested as a way to reduce greenhouse gas emissions in Australia but it is not clear that this will have the same benefits in Africa (Korontzi et al. 2003), where much burning is early anyway.

Table 3: Emission factors for the main greenhouse gases and particles or their precursors, resulting from dry-season fires in African savannas and grasslands (Sources: Scholes et al. 1996, Scholes & Andreae 2000).

Gas or aerosol	g emitted[a]/ kg dry matter fuel combusted	s.d.	Sub-Sahara Africa emissions[b] (Gigagrams/y)
CO_2[c]	1 613	95	1 290 400
CH_4	2.3	0.9	1 840
N_2O	0.21	0.1	168
NO_x	0.31	0.24	248
CO	65	20	52 000
PM2.5[d]	6	(range 5–50)	4 800

a. On a whole-gas basis

b. Whole-gas basis, assuming a total fuel combusted of 800 Teragrams/y (range is about 716-881 Tg/y)

c. This is an important transient feature of the global carbon cycle, but not a net emission

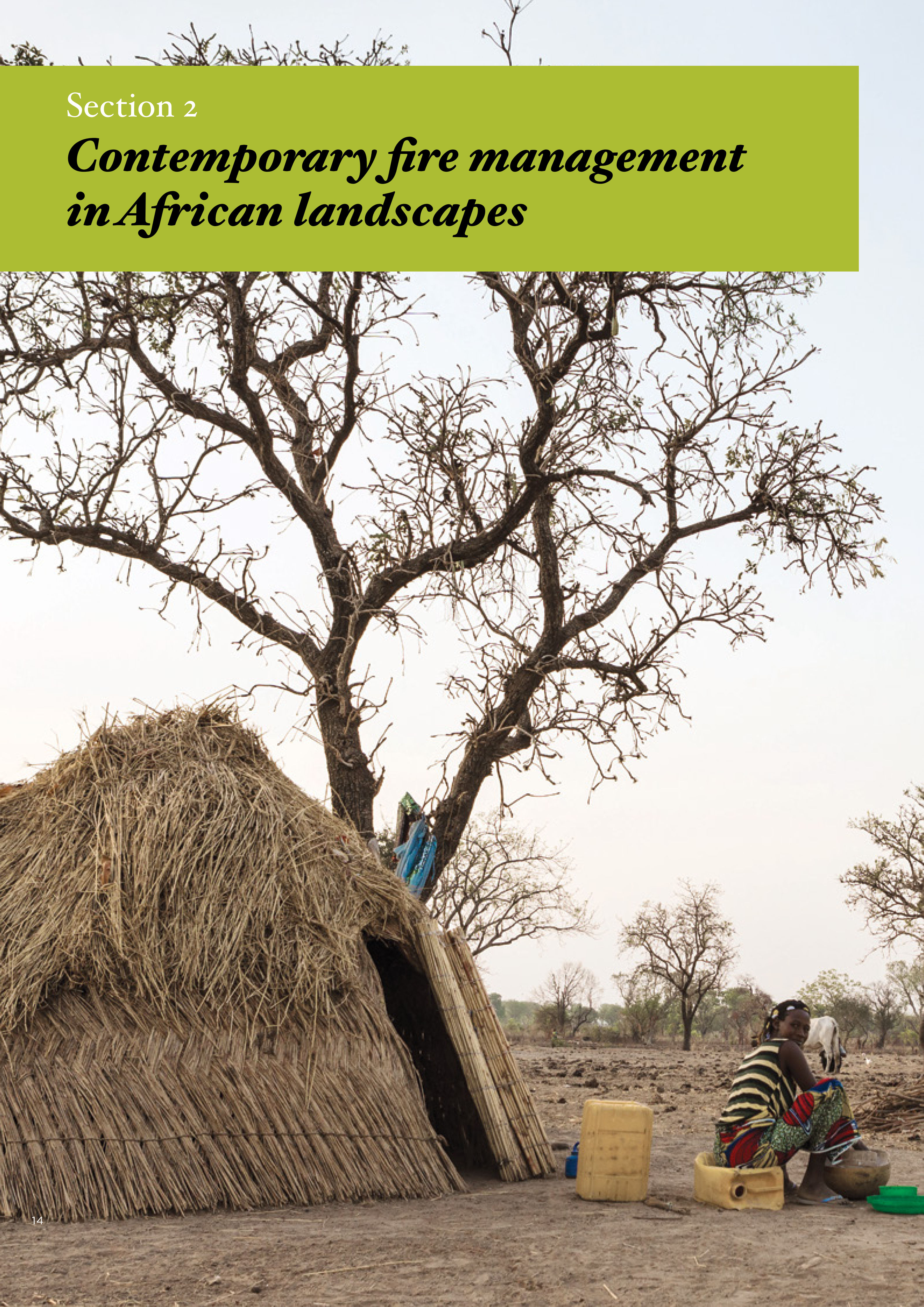
d. Particulate matter of less than 2.5 micrometres in diameter. These are the fine particles that pose the greatest health risk.

1.5.3 Particulate emissions

Much of the visible part of smoke consists of particles that have two important effects. The first effect is pollution – inhalation of smoke particles is injurious to health. Many African people suffer chronic exposure to smoke particles due to the burning of domestic fuels, often indoors, in inefficient hearths. The wildfire contribution to the health burden is small. The second effect is cloud condensation. Water vapour droplets condense into clouds in the presence of smoke particles which act as nuclei. Although such clouds are often associated with wildfires, the resulting increase in rainfall is small since most fires occur in the dry season when there is very little water vapour in the atmosphere.

Section 2

Contemporary fire management in African landscapes



2.1 Emerging African landscapes

Relative political stability and improved access to health care and services are expected to lead to significant population growth and change in African landscapes. Following a period of relative isolation from world markets, considerable areas of the continent are rapidly opening up through expanding road and rail networks and favourable trade agreements. Access, together with demand for resources both locally and internationally, is leading to the expansion of existing small-grower farming as well as the development of agriculture production at scale (e.g. the Southern Agricultural Growth Corridor of Tanzania – SAGCOT). Mining, commercial forestry and urbanisation, and their associated demands on ecosystem services, are broadly in a period of growth in Africa, with associated changes in land cover and demands on ecosystem services.

With this context in mind, Africa has become a focus area for global programmes aimed at reducing deforestation and forest degradation such as the World Bank Forest Carbon Partnership Fund, the UN-REDD+, as well as emerging ecosystem-based climate change adaptation initiatives at landscape scales (Devisscher 2010).

Three considerations are particularly important for future fire management on the continent:

- **Large areas of the landscapes of western, eastern and southern Africa have already been, and continue to be, transformed into a mosaic of differing land-use types that includes commercial agriculture and forestry, mining, urban, peri-urban and other built environments.**
- **Each land-use type within the mosaic has particular fire management needs, ranging from targeted prescribed burning to reduce fuel loads in urban and commercial forestry areas, to the use of fire as a tool to manage grasslands and woodlands in a productive manner.**
- **Due to the close proximity of different land-use types within the mosaic, for example, conservation areas adjacent to urban areas or commercial sugarcane, a shift from isolated fire management exercises to a co-ordinated approach at the scale of the landscape is required.**

2.2 Changes in fire management philosophy

2.2.1 Colonial-era fire policy

The history of people using fire in Africa goes back hundreds of thousands of years. Fire has long been used as a tool to manage pastures, to clear land of vegetation and to prepare fields through slash-and-burn practices. However, the advent of the colonial-era brought with it Eurocentric perceptions of fire together with associated management practices.

The European view of fire as a threat, a danger and a driver of degradation, led to the formulation of fire suppression policies in many countries in western, eastern and southern Africa (Laris & Wardell 2006, Dube 2013). For example, in the Cape Colony, a series of regulations forbidding burning were issued in 1687 that included the threat of hanging for repeat offenders (Hunt & Campbell 2005). Botswana alone had approximately 10 000 km of firebreaks that were maintained until 2009 (Dube 2013).

Over time, the ineffectiveness of this approach became clear. Firstly, the suppression of fire leads to an excessive build up of plant fuels that may result in disastrous wildfires, particularly if they are exacerbated by adverse weather conditions in the form of high temperatures, low humidity and strong winds (Williams et al. 2011). A second issue with the suppression of fire is that it does not suit the ecology of the seasonally-dry African ecosystems (as described in Section 1). Early on, colonial farmers recognised this problem and learnt the art of grassland burning from Khoisan communities (Botha 1924). A third, perhaps more contentious issue, is the true practical effectiveness of fire suppression policy. Evidence from western Africa and elsewhere on the continent questions whether decades of legislation and investment actually resulted in a significant change in the extent of fire (Laris & Wardell 2006, Dube 2013). Decades of effective fire suppression in North America and Australia have led to a situation of heightened fire risk.

With time, the inappropriateness of colonial-era fire policy has become evident. There is growing recognition that an alternative form of fire management is required that complements the ecology of African ecosystems, makes use of traditional knowledge of the subject, and is appropriate to emerging African landscapes and priorities.

2.2.2 Contemporary Integrated Fire Management (IFM)

In many parts of Africa there has been a shift from previous colonial-era fire policies to a more progressive approach based on traditional and emerging concepts where fire is proposed as a tool to manage rangelands and forests (FAO 2001). Focused applied research over the past few decades has led to the development of the concept of Integrated Fire Management (IFM), which embodies the aphorism ‘fire is a bad master but a good servant’. Characterised by its flexibility to local conditions and needs, IFM takes a holistic approach to the ecological, cultural, economic and political aspects of fire. **Importantly, IFM recognises that while large areas of Africa remain under traditional land-use practices, an ever increasing mosaic of different land-use types and priorities needs to be included in planning to avoid adverse, and potentially disastrous, outcomes.**


FIREFIGHTER
WORKING ON FIRE

2.3 Guiding principles and elements of Integrated Fire Management

A set of guiding principles, elements and processes are described here as a means of introducing IFM. Their joint consideration forms the basis for IFM for a particular area.

2.3.1 Defined by the local context and needs

Extensive stakeholder engagement with relevant parties within a landscape is required to ensure that interventions are locally appropriate and accepted. A bottom-up approach, including extensive interviews with local communities, traditional authorities, government officials and commercial enterprises, allows parties to communicate specific needs and concerns. It also provides the developing agency with the opportunity to identify local community entities that could lead, or at least take part in, the implementation of required activities. This approach, which is often shared by community-based natural resource management (CBNRM) and emerging REDD+ programmes, is important to creating a sense of ownership and ensuring the sustainability of the intervention.

2.3.2 Integration at a landscape scale to consider differing priorities and reduce costs

Formal integration across landscapes is necessary to ensure desired outcomes are met and that one part of the greater landscape mosaic does not present a threat to the other areas. For example, prescribed burning around commercial plantations should not present a danger to neighbouring communities or inhibit their own rangeland burning needs.

Integration at a landscape scale further provides opportunity to realise economies of scale, to use capacity and resources more efficiently, and to ensure that awareness and education cover the entire area. The management of fire in urban areas and around high-value assets is likely to require dedicated professionals and associated equipment, vehicles and base premises. Firstly, the cost burden of such capacity can be reduced if implementation occurs at scale, and secondly, it provides the opportunity to support required fire management elsewhere in the landscape. Experience has shown that while community-based approaches to fire management may be appropriate across vast indigenous and subsistence farming areas, additional, external support is occasionally required to undertake large prescribed burns i.e. ‘in safe manner’, especially in remote and mountainous locations.

2.3.3 Active use of fire as a cost-effective tool

For several thousand years, fire has been actively used as a tool to improve livestock production in African rangelands. Over the past century, there has been experimentation in the use of fire to manage bush encroachment, the spread of alien invasive species and the build-up of substantial fuel loads immediately adjacent to rural communities, high-value assets and urban areas (Lykke 2000, Parr 2006, Trollope 2007). The active use of fire is an integral part of IFM and is further described in Section 3, where its application in six typical African contexts is explored.

2.3.4 Informed by comprehensive monitoring and reporting

The effective use of fire in rangeland and forest ecosystems is closely dependent on knowledge of current conditions in the particular area. The development of prescribed burning strategies requires in-depth understanding of the condition of the grass sward, the level of forest regeneration, and the extent of bush encroachment and alien plant infestations. Annual assessments of range condition are therefore a prerequisite for initial planning as well as tracking potential success.

The implementation of regular field assessments provides further opportunity to monitor a broader set of ecological, social and operational parameters that are important for larger programmes and national reporting. It is likely that fire management will be nested within a greater landscape programme (e.g. national REDD+ or regional ecosystem-based climate adaptation interventions). Furthermore, a structured monitoring framework has the potential to provide the information required for the development of national natural resource strategies and for international reporting commitments to the UNFCCC, UNCCD and other parties.

2.3.5 Emphasis on local recruitment, training and equipment

IFM provides an opportunity to create significant skill-development and employment opportunities. Its success as a mechanism through which to create jobs in remote rural areas is one of the principal reasons why the Working on Fire programme is strongly supported by the South African Government.

To create a local sense of ownership and acceptance of the programme as a whole, it is important that residents regionally, if not locally, are employed in professional fire teams as well as included in community-based measures. Effort should be made to ensure that the direct economic benefit of the programme is realised locally to elevate its importance and acceptance among all local parties.

2.3.6 Central co-ordination and institutional considerations

To implement and manage the practical requirements of IFM successfully, it is advisable to have adequate institutional and support structures in place in advance. Co-ordination is required to manage prescribed burning on a year-to-year basis, to coordinate education, awareness and training, to provide parties with required equipment, and to lead responses to large fire outbreaks in a co-ordinated and safe manner.

Experience has shown that failure to attend adequately to this important function often leads to a lack of coherent fire management at scale. The absence of an institutional home tends to inhibit the long-term acceptance and sustainability of programmes, the result of which is an ineffective and inappropriate fire management approach, undertaken in a piece-meal manner.

2.3.7 Awareness and education

A principle element of IFM is ensuring that all parties within the focus area are aware of potential changes in fire management philosophy, and their personal responsibility and role in the process. Including education on the ecology and management of fire in local school curricula has proven to be a successful means of communicating important concepts and messages. Presentations at local farmers' days, community meetings, and to industry are also important to create a common understanding of desired outcomes among all interested parties.

In certain high-risk circumstances, awareness campaigns may need to be supported by day-to-day information on the risk of fire that is communicated in a user-friendly manner. For example, the realisation of the critical role weather conditions play in fire behaviour resulted in the development of a Fire Danger Index (FDI). The FDI is presented as a colour-coded index for communication and management purposes (see section on commercial plantations). It can be displayed on boards on roads or near communal facilities, and broadcast by radio or television.

Section 3

Fire management in typical African landscapes

In this section we describe six case studies that illustrate the practical application of fire management in contemporary African landscapes. The case studies were chosen based on their wide-ranging applicability across the continent. They are grouped according to their particular goal, for example, maintaining timber in production forests or improving grazing capacity in grassland landscapes.

SEMI-ARID RANGELANDS: Improving range condition and preventing bush encroachment through fire management.

About half of the frequently burned area of Africa is semi-arid rangeland located in the Sahel, East Africa and the Kalahari (300–700 mm MAP). This area is home to substantial human populations that are dependent on grasslands for livestock production and a broader suite of ecosystem services. Fire management is aimed at preventing bush encroachment, maintaining biodiversity, removing moribund grass and stimulating 'green bite' (spring grazing).

MOIST GRASSLANDS: Improving water services, biodiversity and livestock production through fire management in higher-altitude, moist, temperate grassland ecosystems.

The grasslands of southern and eastern Africa provide a wealth of ecosystem services to local residents and downstream communities. Well known for their exceptional biodiversity and substantial belowground carbon stocks, these grasslands are positioned at the head of significant watersheds (for example, the Nile), and provide climate-resilient water services to downstream economies. Fire management is aimed at maintaining biodiversity, grassland condition for grazing, and optimal vegetation cover to yield good-quality water.

SUB-HUMID WOODLANDS: Rejuvenating and managing woodland ecosystems.

The sub-humid woodlands (Miombo) of sub-Saharan Africa extend from Angola in the west, through Zambia, Malawi and Zimbabwe to the east coast of Tanzania and Mozambique. These countries are the focus of several national REDD+ programmes. This fire management case study is equally applicable to the dry woodland ecosystems of West Africa and the Sudanian woodland belt. Proactive fire management maintains their biodiversity and protects carbon stocks.

PRODUCTION FORESTS (BOTH INDIGENOUS AND EXOTIC): Protecting growing timber stocks through active fire management.

Fire is viewed as a risk to production forests throughout Africa and is emerging as a threat to indigenous forest, particularly in the context of partially degraded forests and areas that are experiencing unprecedented dry spells as a result of climate change. Fire management forms a vital part of the sustainability of commercial operations and national REDD+ programmes in such locations.

ALIEN INVASIVE SPECIES: Control by means of fire.

Infestation by alien invasive species has led to a significant reduction in livestock production in certain savanna areas of southern Africa (for example in South Africa, Namibia and Mozambique). Fire management techniques may be one of the only cost-effective and sustainable means of addressing this phenomenon.

THE RURAL–URBAN INTERFACE: Managing fire in urban and peri-urban landscapes.

Urban and peri-urban landscapes are increasing in extent in most sub-Saharan African countries. Managing fire and its potential effect on people, property and ecosystem services is among several emerging development challenges that urbanisation presents.

3.1 Semi-arid rangelands

3.1.1 Context

Nearly half of the frequently burned area of Africa is in semi-arid savannas having a mean annual rainfall of 300–700 mm. The main areas include the Sahel (between the Guinean humid savannas and the Sahara desert), the drier areas of East Africa and the Horn of Africa, and the southern African savannas south of the Zambezi River, including the Kalahari semi-desert. The soils of semi-arid lands are generally more fertile than those under moist (sub-humid) savannas, but commercial crop agriculture is only possible above about 600 mm/y, although subsistence cropping can occur down to about 450 mm. As a result, the main land uses of semi-arid rangelands are grazing for domestic livestock, tourism, and hunting of African indigenous wildlife.

3.1.2 Characteristics of fire in this landscape

The fire return period is 3–10 years. Fires occur throughout the dry season, often with a peak towards its end. Fire intensity is generally low-to-moderate because much of the grass fuel is eaten by herbivores. After abnormally high rainfall years, however, and on hot, dry, windy days, the fires can be intense. Individual fires in the pre-modern era would have been large (tens of thousands of hectares), but fires are now fragmented by roads, fields, and firebreaks. A typical fire now burns an area of about 1 000 ha. The fires are almost entirely ground fires that consume the grass layer. Tree leaf litter, fallen twigs, dead wood and dry dung on the ground surface can contribute nearly half of the fuel load.

3.1.3 The objectives of burning in this landscape

The three primary reasons for burning in semi-arid savannas all relate to domestic grazing and wildlife conservation, the main economic land use in such areas:

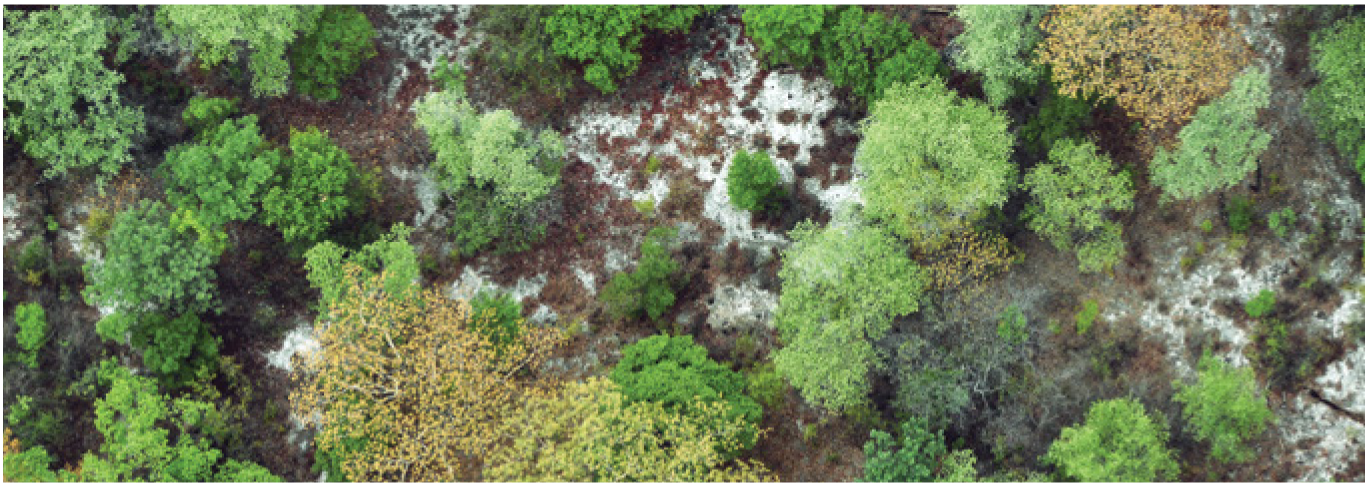
Preventing bush encroachment:

Bush encroachment has two principal drivers, consistent overgrazing and the suppression of intense fires. Intense and frequent fires are the main mechanism keeping these savannas open. If the fires are too cool or too infrequent, tree saplings (which are always present in the grass layer) manage to escape the flame zone. As they grow taller they suppress grass production and may make livestock production unviable. The ecosystem then remains in a bushy state, possibly for many decades. Prevention of bush encroachment requires high-intensity fires (>3 000 kW/m every 3–5 years), preferably in the very late dry season when trees have leaves but grasses have not yet sprouted. Such intense fires require careful management if the hazard to people, animals and assets is to be minimised.

Improving forage quality and quantity by the removal of moribund grass and stimulation of 'green bite':

When dead grass from previous seasons shades out the new grass shoots, this reduces the productivity and palatability of the herbaceous layer. Post-fire regrowth is higher in nitrogen and lower in fibre than mature grass, and much more nutritious and palatable than old dead grass. For millennia, African pastoralists have burned patches to provide quality grazing. Many wildlife species congregate on burned areas during the dry season. Fires to meet this objective can be cool, and ignited in the early-to-mid dry season.

Figure 5. Miombo woodland with patches of white sand showing through the leaf detritus, Western Zambia.



Maintaining biodiversity:
Many African plant and animal species are fire-dependent to some extent for their regeneration and survival. In land areas managed for biodiversity, a diverse fire regime creates opportunities for many species, whereas a uniform regime selects for just a few. To meet this objective the fire frequency, the location of burned areas, the ignition season and the intensity should not be rigid. By recreating the fire regime that has been experienced in the area over the past thousands or millions of years, in all its variability, the biodiversity objective is met.

3.1.4 Fire management

The large extent of semi-arid rangelands in Africa and the low economic margin of the enterprises they support mean that low-cost approaches to management are essential. Fire is one of the key tools available to land custodians, but it can also consume a large fraction of their time. The high inter-annual variability of rainfall in semi-arid climates (>30% CV) means that an inflexible fire prescription is inappropriate. In many years it may be impossible to burn due to insufficient fuel or forage. Conversely, during wet spells it may be desirable to burn several years in succession. Fire response teams are usually small (ten people) and equipped for controlling fires of moderate intensity (<3 500 kW/m).

On commercial livestock ranches, burning is usually done on a rotational basis in blocks corresponding to paddocks, and fires are started early in the dry season and continued throughout the dry season.

To control bush encroachment, however, the application of intense fires, typically in the late dry or early wet season, is necessary. In addition, a ‘hands-off’ approach to accidental or lighting ignitions is adopted unless they pose an imminent threat. The formation of fire management associations at the scale of several tens of thousands of hectares allows equipment and expertise to be shared, and facilitates fire regime management at a more appropriate scale. At a national level it is very helpful to have a regulatory regime that recognises the necessity for fire but devolves fire management authority to local groups or individual landowners.

3.2 Moist grasslands

3.2.1 Context

Significant areas of cool, moist, high-altitude grassland occur at several locations through the Afromontane belt of East and southern Africa. Extending from the Ethiopian Highlands in the north, to the Drakensberg Escarpment in the south, and including, among others, the temperate grasslands of the Uluguru Mountains of Tanzania and the Nyika Plateau of northern Malawi and Zambia, these grasslands are an ancient component of African mountain landscapes (Finch et al. 2009, Finch & Marchant 2011).

The temperate grasslands of the Afromontane region are well known for their exceptional biodiversity, endemism and the broad suite of ecosystem services they provide to local and downstream economies (Egoh et al. 2009). Internationally recognised as a biodiversity hotspot (Myers et al. 2000, CEPF 2012), they provide important water services within the Nile catchment and to urban and industrial hubs in East and southern Africa such as Nairobi, Dar es Salaam, Johannesburg and the cities of South Africa's eastern seaboard.

3.2.2 Characteristics of fire in this landscape

A fire return period of 1–4 years is generally observed within moist grasslands, with fires occurring throughout the prolonged dry season. The grasslands are both fire prone and fire dependent, with evidence from East and southern Africa indicating that these grasslands are a primary, ancient vegetation type (at least 13 000 years old) and not a secondary form that has emerged as a result of human clearing of forests (Finch & Marchant 2011, Bond 2016).

Fire plays several important functional roles within this ecosystem that are important to its long-term resilience. These include the removal of moribund grass biomass that allows both new shoots as well as the species-rich forb component of the grasslands to flourish (O'Connor & Bredenkamp 1997, SANBI 2014).

3.2.3 The objectives of burning in this landscape

Fire is used in grasslands to support the generation of ecosystem services and to suppress the establishment of woody species.

Particular objectives include:

Resilient provision of water services:
Reduction of soil erosion and the regulation of freshwater services (reliability of flow and adequacy of water quality) is closely dependent on the type of ground cover, which controls the rates of water infiltration into the soil and the amount that can be stored and gradually released. An intense rainfall event on bare, compressed, hardened soil leads to sheet erosion, the formation of gullies and a sharp spike in stream flow immediately after the storm. A similar rainfall event on an intact grassland with good basal cover and high soil organic content yields a steadier, more prolonged flow of water with a low sediment content. Although fire may have little short-term direct effect on soil organic content (Manson et al. 2007), the use of low- to moderate-intensity fires at 2–5 year intervals, together with appropriate animal stocking rates, is an important part of maintaining adequate basal cover and the health of soils and the grass sward over time, leading to a gradual build-up of soil carbon.

Livestock and wildlife production:
As in semi-arid rangelands, fire is used in this landscape to remove moribund grass, improve forage quality and to control ticks (Trollope et al. 2013). Fire is further used to control the risk of fire itself to the forage in an entire landscape and to the infrastructure and high-value assets. The emerging trend is to use a patch-mosaic burning pattern, staggered over the dry season, to decrease the continuity of fuel loads across landscapes and thus reduce the risk of large-scale fires.

Biodiversity maintenance in grasslands and indigenous forest patches:
Evidence from field experiments indicates that long-term fire exclusion in temperate grasslands leads to encroachment by tree and shrub species and a decrease in the diversity of grass and forb species (Uys et al. 2004, Titshall et al. 2009, Wakeling et al. 2012). In this fire-dependent ecosystem, burning is required to keep grasslands in an open state and to provide forb species with an opportunity to flourish in the interval after a fire and before they are overshadowed by the growth of grass species (SANBI 2014).

3.2.4 Fire management

A bottom-up participatory approach will initially be required to develop IFM that adequately takes into account the needs of local communities, agriculture and potential conservation agencies, while managing the risk of fire at a landscape scale.

Thereafter, at a local scale, herdsman and commercial farmers may implement fire interventions with the intention of managing forage quality, invasive weeds, basal cover and the encroachment of woody saplings. A rotational or patch-mosaic resting system that allows pasture to rest and recover following burning and grazing pressure is advised (Zacharias 1994, Brockett et al. 2001, Kirkman 2002). At landscape scale, dedicated fire-management personnel (potentially with aircraft support) may be required to implement large open-ended firebreaks in remote montane areas, to undertake high-intensity burns aimed at clearing existing encroachment by woody species, and to control runaway fires.

3.3 Sub-humid woodlands

3.3.1 Context

Sub-humid woodlands occur in two distinct floristic regions – the Guinea-Congolian-Sudanian region extending south of the Sahel from Senegal to South Sudan, and the Zambezian woodlands extending from the coast of Angola to the shores of Tanzania and Mozambique (Fig 7, White 1983, Timberlake et al. 2010). The two regions have similar mean annual rainfall of 700–1 200 mm, and importantly, have clear dry seasons of 5–7 months in which fire may occur. In general, sub-humid woodlands are characterised by a tree canopy that is approaching closure (40–60% tree canopy cover, formed principally of deciduous trees that are 10–25 m in height when mature), together with an underlying grass layer. An intermediate shrubby layer may be present.

The sub-humid woodlands of Africa are home to several million people, who are often reliant on the woodlands for their livelihoods and a rich suite of ecosystem services (Hiepe 2008, Syampungani et al. 2009, Chidumayo & Marunda 2010). Ensuring the sustainable use of natural resources is a priority, especially in regions where growing local and international demand for forest products and land for agriculture is placing increasing pressure on woodland ecosystems. For this reason, the woodlands are a particular target area for REDD+ programmes aimed at reducing further degradation and managing landscapes in a sustainable manner (Kamelarczyk 2009, Burgess et al. 2010).

Figure 6. Seasonal grassy wetlands known as dambos occur in depressions and low lying areas within the Miombo woodlands. Following the rapid growth of biomass during the wet season, these often dry out and burn in drier periods.

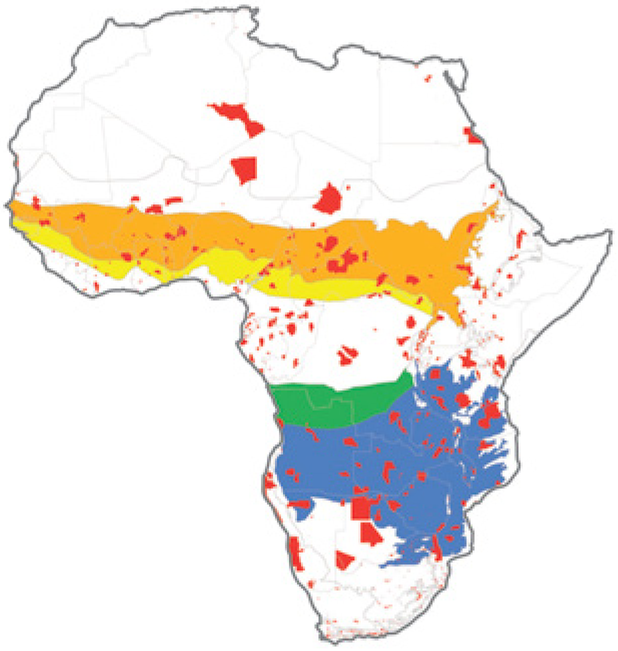


Figure 7. The two main sub-humid woodland regions of Africa: Zambezian (blue – known as Miombo) and Guinea-Congolian-Sudanian (orange). The transition zones between sub-humid woodlands and moist tropical Congo-Guinea forest (green to the south, yellow to the north) have elements of sub-humid type forests that will share similar fire regimes with the main blocks of sub-humid woodland. Protected areas are shown in red.

3.3.2 Characteristics of fire in sub-humid woodlands

Sub-humid woodlands experience fire every 1–4 years, principally in the form of low- to medium-intensity surface fires that consume the grass and litter layers (Swaine 1992, Shea et al. 1996, Walker & Desanker 2004, Williams et al. 2008). Within intact woodlands, grass accumulation is generally suppressed by the presence of a canopy and herbivory, resulting in relatively low fuel loads (4–6 t/ha) and low-intensity fires.

Disturbance of woodlands and, especially, the opening of the canopy, for example, through deforestation and slash-and-burn agriculture, result in an increase in grass production, larger fuel loads and often high-intensity fires that may open up woodlands further and keep them in an open state (Geldenhuys 1977, Chidumayo 1988). The pattern may be reversed through the short-term suppression of fire or the implementation of relatively cool, early season burns that allow resprouting tree shoots to grow beyond a height where they are threatened by surface fires and where they start to suppress grass growth naturally.

3.3.3 The objectives of burning in sub-humid woodlands

There are common reasons for burning in both Guinean and Zambezian woodlands:

To improve livestock production:

The dry-season nitrogen content of grasses in this ecosystem is too low to sustain ruminant livestock. Therefore fire is traditionally used to remove moribund grass, stimulate new shoots, provide grazing for domestic livestock and attract wildlife species to certain areas (Laris & Wardell 2006, Eriksen 2007). In addition, fire is useful for managing ticks and other pests (Swaine 1992). Burning is often implemented in a patchwork manner at different intervals through the dry season to ensure constant availability of new growth.

To improve wood production:

Within communal areas and indigenous timber concessions, early season fires may be used to remove grass fuel loads before more intense fires present a risk to mature woodland or saplings and resprouting stems in recovering stands (Swaine 1992, Chidumayo 2004, Laris & Wardell 2006, Geldenhuys 2009). Furthermore, the germination of several species, including the commercially important *Pterocarpus angolensis*, is dependent on moderate exposure to fire.

To prepare cropland:

The use of slash-and-burn practices to prepare and fertilise fields is widespread within sub-humid regions that generally have infertile soils and where residents seldom have access to commercial fertilisers. Trees and other biomass are felled, burned and turned into the soil to increase the nutrient content and temporarily raise the soil pH.

To manage biodiversity:

The Zambezian floristic region contains some of the world's most extensive formal conservation areas. Here, fire may be used to stimulate new growth and create a mosaic of different forest types and age-classes (stages of succession) to maintain variation and biodiversity at a landscape scale.

3.3.4 Fire management

Sub-humid woodlands are characterised by their exceptional ability to tolerate fire and to recover following intense disturbance events (Chidumayo 2004). Long-term field experiments in Zambia and Tanzania indicated that 70–90% of woody plants resprout following fire or felling, generally leading to the rapid rejuvenation of forest (Fig 8, Luoga et al. 2004, Chidumayo 2002, 2004). This inherent ability to respond to fire has been leveraged by local residents for thousands of years. There is, however, growing awareness of the opportunity to use fire as a tool to improve the productive ability of indigenous woodlands and to manage fire risk at broad landscape scales. Such approaches are currently being pioneered in the Miombo woodlands of Mozambique and Zambia.

3.4 Production forests and plantations

3.4.1 Context

The establishment of commercial forest plantations in Africa started initially in the late 1800s and expanded significantly during the period 1920–1960 (de Ronde et al. 1990, Chamshama 2011). During the 1970s and 1980s there was an expansion of smaller woodlot units, principally in response to concerns regarding deforestation and aimed more at meeting household and local needs such as the curing of tobacco rather than for commercial timber production (Chamshama 2011).

Although there may have been a decline in interest in large-scale, state-owned or commercial forest plantations over the past 20 years, more recently there has been a resurgence of investment in smaller scale, locally-controlled production in eastern and southern Africa with a view to meeting growing local and international demand (Nhantumbo et al. 2013). Current estimates of the area of plantations in Africa vary widely depending on the particular definition used. The area of commercial plantations is estimated to be 3.5–6 million ha, with the total area of planted forest amounting to approximately 16 million ha across the whole of Africa (FAO 2011, 2015, Portin 2012, Jacovelli 2014)

Figure 8. Rapid sprouting of Miombo woodland following intense fires that can reduce trees to ground level (A, B). This early period of regeneration allows many herbaceous species to flourish (C).

3.4.2 Characteristics of fire in the production forest landscape

Outside the moist forests of the Congo-Guinea region, exotic plantations and woodlots are often located in rangeland and grassland ecosystems where mean annual rainfall generally exceeds 700 mm. The establishment of a fire-sensitive asset within fire-prone and fire-dependent ecosystems requires substantial careful additional management to ensure that the investment in plantation woodlots is secure.

The fire return period across the greater rangeland or grassland landscape in which plantations are located generally ranges from 2–4 years (as described in Section 3.1–3.3). Within plantations of timber species the target return time of crown fires (i.e. intense, damaging fires) is ‘never’. The achieved fire return period is typically 20–100 years and can be a principal determinant of the long-term economic viability of the forest-based enterprise (Jacovelli 2014). The establishment of exotic *Pinus, Eucalyptus and Acacia* species plantations creates a large, tall and relatively closely-packed fuel load (40–60 tons biomass/ha or more) that, once ignited, leads to extremely intense fires, often in the form of 'fire storms'. Such fires are exceptionally dangerous and difficult to control, presenting a risk to infrastructure within the broader landscape.

3.4.3 The objectives of burning in production forest landscapes

Fire management within plantation landscapes focuses on four principle objectives:

Protection of growing stock in a cost-effective manner:
Attempting to suppress fire completely, both within the plantation landscape and within the plantations themselves is generally counter-productive, as the gradual accumulation of surface fuels increases the potential likelihood and intensity of fire over time (de Ronde et al. 1990). Prescribed low-intensity burning within plantations, known as under-canopy burning, is used to remove surface fuels through low-intensity burns every 2–4 years.

Preparation of plantation areas and reduction of risk of fire to saplings:
Fire was commonly used to clear new land or remove grass and debris from recent harvesting operations prior to replanting. This practice reduces the threat of wildfire to saplings, suppresses the growth of weeds, and may enhance soil nutrient availability. However, the increasing occurrence of the pine root rot fungus, *Rhizina undulata*, which is promoted by burning prior to planting, and which causes large scale mortality in newly planted pine trees, has made this practice much less prevalent. Where eucalypt plantations are regenerated using coppicing, this practice is avoided because it increases stump mortality.

Management of fuel loads at a landscape scale:
Runaway fires in adjacent grassland and rangeland ecosystems present a clear risk to plantations. These fires often spread at the end of the dry season, on warm days with strong winds and low humidity, and are difficult to control. A landscape-scale patch-mosaic approach is therefore required to manage fuel loads in a strategic manner, considering the needs of all land-users within the greater landscape.

3.4.4 Fire management

In general, there are four components to fire management in this landscape that should be implemented simultaneously.

Prevention:
A broad set of preventative measures is suggested, including education and awareness-building within schools and community forums. This should be supported by the creation of Fire Protection Associations (FPAs) of land users for communication, pooling of resources and facilitation of legal compliance. Early warning through the use of Fire Danger Index (FDI) systems is a further part of creating and maintaining fire awareness during important times of the year (Fig 9).

Protection through prescribed burning:
As described earlier, a regional approach to managing the continuity of fuel loads across the greater landscape is required to limit the probability of runaway fires that may ignite plantations (de Ronde 2011). This may be done through a mosaic approach using natural barriers as boundaries (e.g. riparian areas).

Suppression:
Early detection of wildfires using lookout towers, cameras or satellite-based real-time fire detection is crucial to rapid ground suppression efforts. The satellite-based Advanced Fire Information System (AFIS, www.afis.co.za), which is an African innovation that has been widely adopted globally, provides vital early warning of fire events in close to real time.
The management of wildfire events should be handled by an Incident Command System (ICS) to ensure response measures are co-ordinated, effective and managed in a manner that does not endanger the lives of fire teams (Teie 2009, Calvin 2004).

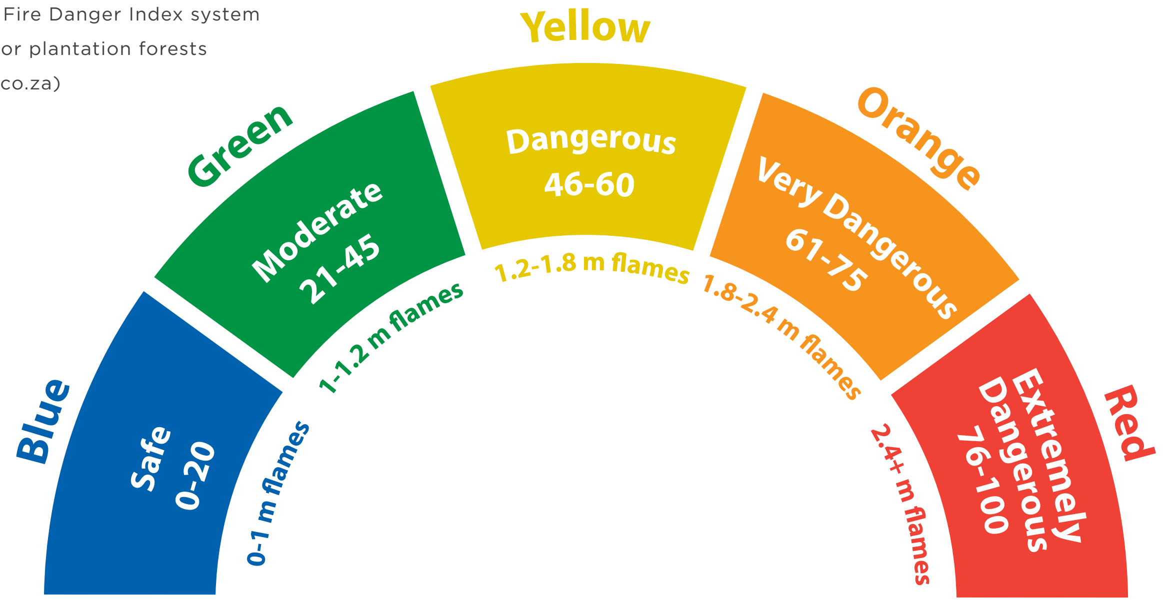
Training, equipment and support:
The suppression of high-intensity plantation fires requires professionally-trained teams that are adequately prepared and equipped for the task. In contrast to the management of grassland and rangeland fires through less costly, low-key measures, the control of intense plantation fires requires substantial investment to ensure effectiveness and safety of personnel.

3.5 Control of invasive alien species

3.5.1 Context

The impact of invasive alien species (IAS) can be profound: indigenous species can be out-competed; ecosystem services such as water supply and grazing reduced; and the risk of fire to natural resources and built environments increased (Ehrenfeld 2010, Le Maitre et al. 2011, Pejchar & Mooney 2009). The economic cost to Africa amounts to several hundred million US dollars each year through lost natural resources and the direct expense of control programmes (Matthews & Brand 2004, McConnachie et al. 2015).

Figure 9. Fire Danger Index system suitable for plantation forests (www.klf.co.za)



Low Fire Hazard. Controlled burning operations can normally be executed with a reasonable degree of safety.	Although controlled burning operations can be done without creating a fire hazard, care must be taken when burning on exposed dry slopes. Keep a constant watch for unexpected changes of wind speed and direction.	Controlled burning is not recommended when the FDI exceeds 45. Aircraft should be called in at the early stages of a fire.	No controlled burning of any nature should take place. Careful note should be taken of any sign of smoke, especially on the up-wind side of a plantation. Every fire that occurs should be attacked with maximum available force including aircraft.	Fire teams, labour and equipment are to be placed on full stand-by. At the first sign of smoke, every possible measure should be taken to bring the fire under control in the shortest possible time. All available aircraft are to be called without delay. All personnel and equipment should be removed from the field.

The effects of IAS on water services, in particular, are well known (for example, reduced regulation of stream flow and increased sediment load). This has led, in South Africa, to the creation of substantial government programmes aimed at clearing IAS and restoring catchments while providing employment in remote rural areas (Turpie et al. 2008).

Within the broad variety of IAS, this report focuses on plant species that may influence fire regimes and that may be effectively controlled through the use of fire. These include woody *Pinus, Eucalyptus* and *Acacia* species that were initially introduced to Africa for timber production, as well as non-woody weed species such as *Chromolaena*, introduced from South America and now widespread throughout southern, eastern and West Africa (Goodall & Erasmus 1996, Osariyekemwen & Igbinosa 2010, Codilla & Metillo 2011).

Chromolaena is an unpalatable creeping shrub. Infestations reduce grass cover, decreasing the grazing capacity of rangelands for both domestic livestock and wildlife species. Since *Chromolaena* is highly flammable, encroachment into forest fringes renders the forest more susceptible to fire damage.

3.5.2. Characteristics of fire in relation to invader species

Encroachment of IAS may change the nature of fuel properties across a landscape (density, structure, flammability), which in turn can affect fire behaviour through changes in fire frequency, extent, intensity, type and seasonality. If an invader species becomes dominant, it may change previous historical fire regimes completely (van Wilgen & Scott 2001, Brooks et al. 2004).

In many African rangeland and woodland ecosystems, invasion by tall, woody species may increase fuel loads five- to ten-fold (Knowles 2011). The result is a shift from low-intensity surface fires to higher-intensity canopy fires that are extremely difficult to control, and that may present a threat to human livelihoods and built environments (van Wilgen & Richardson 1985, Chamier et al. 2012).

Invasion of grasses into arid shrublands (such as the Karoo of southern Africa) and Mediterranean shrublands (fynbos in southern Africa, macchia in North Africa), possibly under the influence of climate change, has the potential to radically alter the seasonality and frequency of fires in these biodiversity hot-spots (van Wilgen 2009).

3.5.3 The objectives of burning for invasive species management

Fire may be an effective tool in the management of IAS at several stages of the invasion and eradication process.

To control early infestations:
Before IAS are well established and able to alter the nature of fuel loads and create substantial seed banks, prescribed burning can be used as an effective tool to clear land and allow indigenous species to flourish.

To clear large invaded areas cost effectively:
In comparison to physical removal and the use of herbicides, fire has been shown to be a cost-effective mechanism for controlling certain species, for example *Chromolaena*, and restoring natural rangelands (Fig 10-11). Appropriate fire interventions are highly dependent on the type of IAS, the stage of infestation, its effect on fuel loads, and the relative ability of the species to resprout post-fire. Good knowledge of the particular IAS and due discretion is required to ensure that fire is used effectively and does not lead to further infestation. Preventing further infestation requires follow-up of post-fire regeneration of the weed species in cases where heat promotes germination of the seed stock in the soil or where the seed is held on the plant in capsules that only open after being subjected to the heat of a fire e.g. *Acacia* or *Hakea* species respectively.

To control potential invasion of landscapes over the long term:
In certain landscapes where seeds may continually be introduced from urban areas or exotic forests, fire may be an important part of a comprehensive management intervention to limit the spread of IAS and to maintain indigenous landscapes over the long term (Alstron & Richardson 2006). This is particularly pertinent in upper catchment areas where exotic plantations can be a continuing source of seeds over time.

3.5.4 Fire management

As indicated above, fire is a cost-effective tool in the control of certain species, for example *Chromolaena*. In contrast, others such as invasive *Pinus* and *Acacia* species are often fire-adapted and may spread prolifically after burning, unless managed appropriately (Le Maitre et al. 2011, van Wilgen et al. 2012).

Brooks et al. (2008) suggest a range of responses, from early season prescribed burning to control minor infestations, to extensive interventions for particularly aggressive invasive plants that are well-established, that have significantly increased the size of the fuel load, and that have the ability to resprout more rapidly post-fire than the indigenous vegetation. In such cases, a combination of interventions over several years including mechanical clearing, the application of herbicides, closely-managed intense burns, and a dedicated post-fire replanting programme may be required to reinstate pre-infestation vegetation.

Figure 10. Severe encroachment of *Chromolaena*, prior to burning.

3.6 Fire at the wildland, urban and agriculture interface

3.6.1 Context

As human populations grow along with the associated demand for land and resources, the focus on fire at the interface between wildlands and developed areas becomes more prominent. This issue is relevant not only to Africa, but is also pertinent in many locations around the globe where changes in demography and the expansion of urban areas and agriculture into fire-prone ecosystems require new forms of management (Hammer et al. 2009, Laurence et al. 2014).

Runaway fires in woodland and rangeland ecosystems present a threat to peri-urban and urban homes, agriculture, plantations and tourism facilities in formal conservation areas. Conversely, urban areas, plantations and agriculture are in themselves potential sources of ignition and fuel as well as invasive alien plants that may alter the fire regime within adjacent wildland areas (Alston & Richardson 2006, van Wilgen et al. 2012, Bowman et al. 2013). This interplay needs to be considered in potential fire management interventions.

Figure 11. Recovery of the savanna six months after the first burn.

3.6.2 Characteristics of fires at the wildland–urban interface

Runaway fires can present a considerable threat to communities resident in remote areas of the woodlands and rangelands of sub-Saharan Africa where wood and thatch are used extensively to construct homesteads and infrastructure. Intense fires towards the end of the prolonged dry season can result in damage to property, crops, livestock and even loss of life. For these reasons, residents often implement burns at stages through the dry season to reduce fuel loads immediately adjacent to infrastructure and croplands.

A growing concern is fire at the wildland–urban interface, where suppression of fire over time and the establishment of IAS lead to the accumulation of large fuel loads immediately adjacent to homes and infrastructure. Once ignited, the resulting high-intensity fires are exceptionally difficult to control. This phenomenon is well publicised and researched in the Cape region of South Africa (Alston & Richardson 2006, van Wilgen et al. 2012) and is likely to become a growing concern in many other areas of Africa as urban areas are established in fire-prone landscapes.

3.6.3 Objectives of burning in the settled landscape

There are several reasons for active fire management within this domain:

- **To protect lives.**
- **To limit the risk that fire presents to homes, infrastructure and agriculture.**
- **To maintain biodiversity, ecosystem functions and services. There may be a significant change in land-cover type from indigenous forms, making the maintenance of ecosystem services in emerging landscapes an important component of future economic development (Bowman et al. 2013).**

3.6.4 Fire management

The wildland, urban and agriculture interface is often characterised by significant heterogeneity in land cover, land use, and the priorities of residents, farmers and other stakeholders, as

well as by the presence of several forms of land tenure and management that may include communal, private and state land.

There are several key elements of fire management in this context:

- **The avoidance of risk through good spatial planning and the enforcement of building and development codes aimed at preventing the placement of valuable, flammable, and inhabited structures in places that will inevitably experience high-intensity fires.**
- **The protection of vulnerable assets using adequate fire breaks, for instance on the edges of settled areas, and a programme of fuel-load reduction in the general landscape, using pre-emptive burning or harvesting.**
- **The establishment of an effective and professional fire response capability. Urban firefighters need to be trained in the combatting of wildfires in vegetation, but also in techniques of prescribed burning that reduce the risk of out-of-control fires.**

A fire management programme would start with extensive stakeholder engagement and an awareness-creation process involving local government officials, homeowners, traditional leaders, and other private entities that may be located within the landscape.

Thereafter, an IFM strategy can be created with additional input on fire ecology and the operational aspects of fire management. An example of this approach is the FireWise Communities Programme that has been adapted to African conditions and applied in South Africa (www.firewisesa.org.za). Begun in 2004, this programme has proved to be a cost-efficient and successful means of managing fire at the rural–wildland interface. The implementation model is principally community-based, to provide local employment and skill-development opportunities, and is supported by extensive awareness and education interventions. Where necessary, external support structures are harnessed to provide early warning systems and specialised equipment and personnel, especially for higher-risk or large prescribed burns.

Section 4

Fire within emerging natural resource management programmes

This review has highlighted the potential benefits of IFM in a set of typical African landscapes. This section focuses on how fire should be considered in the context of Natural Resource Management Programmes, particularly those currently being developed by the World Bank. These include TerrAfrica, the emerging REDD+ Initiative for Sustainable Forest Landscapes (ISFL), and GEF-funded ecosystem-based climate change adaptation initiatives at a watershed scale.

4.1 Considering operational structures and the finances of implementation

One of the key strengths of the IFM process is that it is not a rigid, pre-defined structure that is imposed across landscapes, but rather a progressive approach that allows implementation to be tailored to local environmental and socio-economic needs.

It is envisaged that implementation would occur in a catchment or landscape in order to achieve potential cost-efficiencies and to allow for integrated development, operational support, monitoring and shared use of resources. The development, management, monitoring and communication of the process requires co-ordination over time. Training, administration and despatch facilities must be created and the necessary vehicles and equipment acquired. Facilities and equipment must be sensibly located. A programme would require formal premises for administration and despatch, as well as training facilitates, vehicles and equipment. Training could be undertaken within each landscape or at a central training hub, which may be more cost-efficient and promotes open engagement and learning between regions.

A suitable form of fire management would then be identified for each type of land use and stakeholder group within the landscape (for example, on community lands, the emphasis would be on fire management by local residents aimed at reducing risk to homesteads while stimulating the production of forage for livestock). Thereafter, integration across land-use types is required to address the potential risk of runaway fires and to share resources where possible.

Whereas such flexibility in operations is viewed as a prerequisite for successful implementation, it does present difficulties in providing an accurate estimation of costs without an explicit understanding of the particular region under consideration. The cost per unit area may vary substantially due to the required intensity of operations as well as inter-country variation in salaries, fuel and other primary expenses.

The range in intensity of operations exists on a continuum from low-intensity, community-based implementation in fragmented farming regions where there is a relatively low risk of runaway fires, to high-intensity management of fire in peri-urban and commercial plantation areas where fire needs to be managed by professional fire crews with vehicle and even aircraft support. However, such potential variation in costs should not be interpreted as a source of uncertainty that may inhibit implementation. Once a particular area is identified and the scope (and nature of operations) is broadly defined, a reasonable estimation of costs can be generated based on existing operational data from the region.

In terms of payment, income for operations has generally been dependent, to date, on the national fiscus and private forestry companies. In future, it is anticipated that, in addition to these sources, revenues may be generated through further direct payment by private entities located within the landscape, through payment for climate change mitigation and ecosystem-based adaptation activities, and potentially, from insurance companies that have exposure through clients located within the area.

When considering the economics of implementation, it should be noted that fire management is unlikely to be implemented alone, but rather as one element of a broader set of activities within a sustainable landscape management initiative (for example, a regional REDD+ or catchment management programme). IFM tasks are only likely to occur during certain periods of the year, which allows staff and resources to be utilised in other ways (for example, forest management, erosion and livestock control measures, monitoring and so forth) at other times.

4.2 A source of substantial employment in remote rural areas

An often underestimated element of integrated fire and forest or grazing management is the ability of programmes to create substantial skill-development and employment opportunities locally. Creating economic opportunities is crucial to the success of natural resource management interventions, particular REDD+ programmes in East and southern Africa. Whereas the principal observed direct drivers of deforestation and environmental degradation in Africa are frequently the expansion of small-grower agriculture and the unsustainable production of charcoal and harvesting of wood, the underlying driver is often the need for livelihood opportunities where few alternatives exist. The creation of sustainable alternative livelihood opportunities is therefore one of the most important and difficult challenges for the implementers of IFM and the developers of REDD+ activities in the region.

Fire, forest and ecosystem service management programmes provide at least one mechanism through which to recruit previously unemployed people or provide rural dwellers with alternative sources of income (Blignaut & Moolman 2006). This approach has been pioneered successfully by South Africa's Working for Water, Working on Fire and the associated Expanded Public Works Programmes, and it could be replicated and adapted elsewhere across the continent as a means of addressing poverty and stimulating local economic activity (Turpie et al. 2008).

4.3 Reconsidering the risk of fire to REDD+ programmes

Fire is unlikely to present a substantial risk to the outcome of REDD+ activities in sub-humid forests and to similar emerging protection and restoration programmes in grassland ecosystems (Knowles 2011). Maintaining terrestrial carbon stocks (over a period of at least 30 years, if not in perpetuity) is the measure of success in the context of land-use-based climate change mitigation activities. As fire in these systems takes the form of surface rather than crown fires, it has a limited effect on the total carbon stock.

In open grassland ecosystems, fire may remove aboveground biomass, but the biomass recovers within a period of one to two years, depending on rainfall, soil type and grazing pressure (Everson 1985, Manson et al. 2007). After several years of growth, aboveground dry biomass stocks of approximately 1–4 tons per hectare can be expected (0.5–2.0 tC/ha) (Everson 1985). In comparison, soil carbon stocks within temperate grasslands are in the order of 80–140 tC/ha (to a depth of 30 cm) (Knowles et al. 2008, Knowles & Pienaar 2010). **A fire event may therefore only remove 1–4% of the total carbon pool, which is likely to recover within two to three years.**

Although sub-humid forests have substantially larger aboveground carbon stocks than open grassland, the findings are similar because of the nature of surface fires within this ecosystem. In comparison to exotic plantations or boreal forests where canopy fires may remove a significant fraction of the aboveground woody carbon pool, within sub-humid forests surface fires consume grass, litter and herbaceous plants but generally have little effect on large trees. **As 95–98 % of the aboveground carbon pool is located in the woody component (Frost 1996) and 50–80% of the total carbon stock is within the top 1.5 m of soil (Walker & Desanker 2004), a fire event is likely to release less than 2% of the total carbon pool, which is likely to recover within two to three years (Knowles 2011)**. More intense fires may occur where sub-humid forest has been disturbed, but these situations are often isolated and can be actively managed through prescribed burning. **The net effect on the total amount of carbon sequestered across a vast landscape over a period of 30 or more years would be negligible.**

Conclusion

The objective of this report is to remind World Bank staff and landscape management practitioners of the importance of fire in Africa as a key landscape management tool, in the face of mounting development pressures and climate change. In addition, effectively integrating fire management into landscape management will reduce the loss of life and property from fires and assist in realising the World Bank's vision of eliminating extreme poverty by 2030 by boosting shared prosperity.

Fire has shaped African rangelands for over 10 million years. The occurrence of the prolonged dry season allows fires to occur across the vast grassland, savanna and dry woodland areas of Africa where it has profoundly changed the structure and function of ecosystems over time. Between half and two thirds of the area burned annually worldwide is located on the African continent. Unlike in tropical rainforest, regular fires form a critical component of sound rangeland and ecosystem management in these areas of Africa. Fire maintains the health of ecosystems by promoting seed germination, killing pests, returning nutrients to the soil and improving rangeland productivity. Without fire, the open grasslands and African savanna which support an abundance of herbivores and cattle would become landscapes of thorn trees and woodland. Experience over the last 100 years demonstrates that attempting to suppress fire over long periods of time, other than in commercial plantations, is usually unsuccessful. The reason is that suppression strategies simply delay fire, and when it does inevitably occur, the fire is of a far greater intensity due to the accumulation of biomass/fuel load. There is also no benefit in suppressing fire in the African landscape over the long term in order to promote carbon sequestration for climate change mitigation as these areas will inevitably burn and release carbon. Carbon released from such burning forms part of the natural carbon cycle and so is not responsible for the increase in greenhouse gases. The combustion of fossil fuels, burning of rain forest (which should not take place), and the release of methane from peatland burning and destruction that does not form part of the natural carbon cycle, are the major causes of the increase in greenhouse gases. Traditional African societies accept fire as part of life and use it as a tool to manage rangeland for grazing animals and to prepare fields for crop production, among other purposes. However, African landscapes are undergoing massive change. While traditional crop and livestock production is still prevalent, large areas are being transformed into a mosaic of diverse land-use types that includes urban settlement, mining, plantation forestry and commercial farming.

Each land-use type has its own fire management needs. These range from low-key traditional techniques to manage rangelands for commercial livestock production, to higher intensity implementation by professional fire crews where prescribed burning is required to reduce fuel loads within peri-urban and forestry areas. The close proximity of different land-use types within emerging landscapes requires a shift from isolated fire management interventions to a co-ordinated approach at scale, which has several benefits. Active fire management at scale is able to deliver desired landscape production, ecosystem service and biodiversity outcomes. It may also be more cost effective to implement, as it uses human and institutional capacity more efficiently.

An appropriate next step would be the implementation of integrated fire management at scale in selected landscape programmes in western, eastern and southern Africa. Drawing on the sound expertise and extensive experience in these regions, this initial rollout will have a relatively high probability of success and should provide valuable lessons to inform policy and landscape management in the future.

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