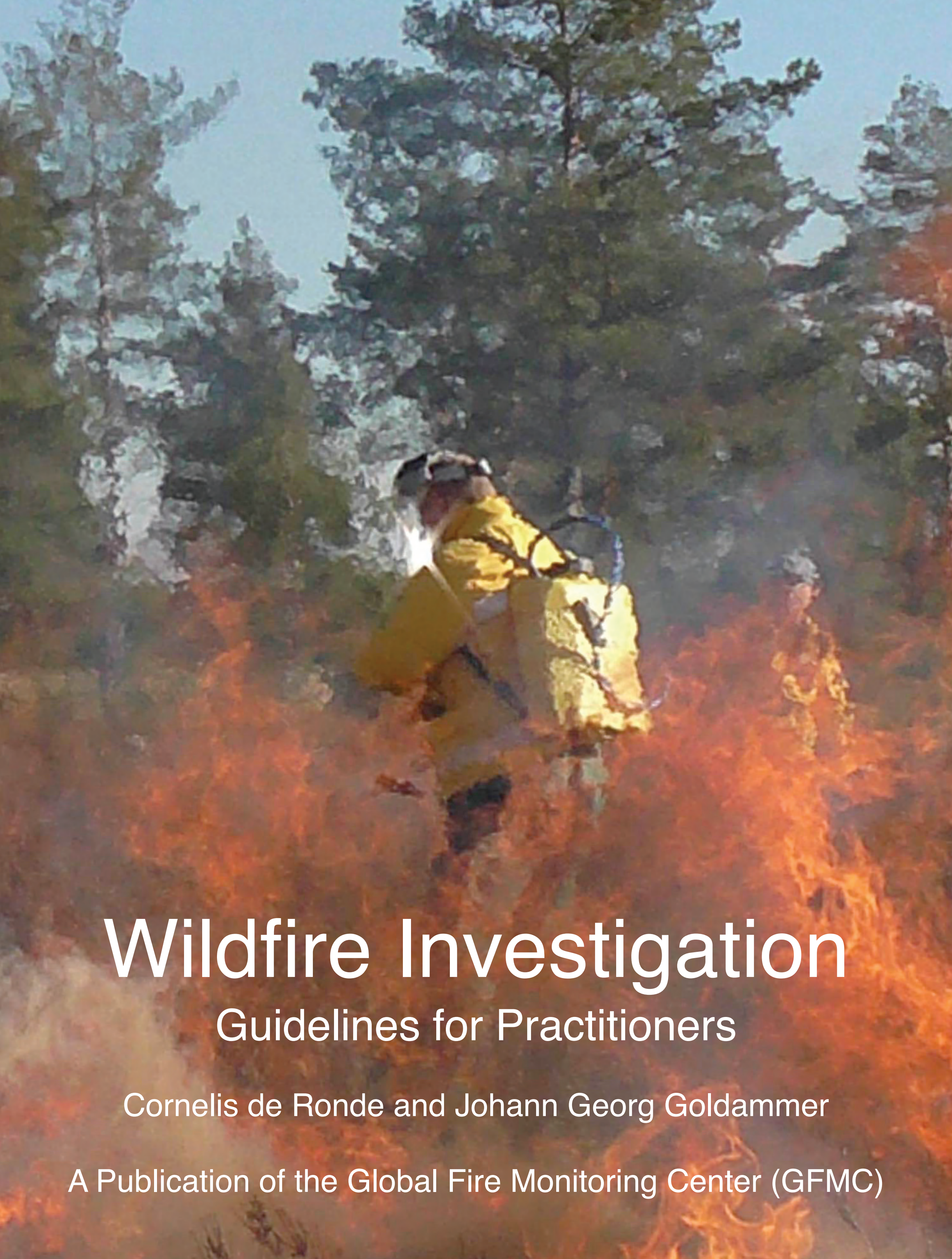

Wildfire Investigation

Guidelines for Practitioners

Cornelis de Ronde and Johann Georg Goldammer

A Publication of the Global Fire Monitoring Center (GFMC)

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Preface

The rationale for the publications of this volume is the motivation of the authors, which have been driven from two different perspectives.

The reason for the first author to initiate writing this book was to share experiences of wildfire investigation in South Africa over two decades. This included private ad-hoc investigations of relative small uncontrolled fires, to the investigation of large wildfires, which crossed a number of properties. Most of these tasks entered either in arbitration processes, settlements between parties (with or without legal assistance), appointments of expert witnesses in high courts, with subsequent court attendances (or settlements), and special investigation tasks conducted for government institutions or insurance companies. The experience gained during this period was very wide, with no single fire being equal to the next, which provided a wealth of information, including specific wildfire reconstructing processes with the use of advanced technology, with the assistance of GIS, satellite-derived information and more. These experiences form the backbone of this volume.

The motivation for the second author to join this book project was the recognition of the need to bring the expertise of the first author to other regions and countries of the world as a contribution to support the endeavor of the United Nations (UN) and its affiliated processes and networks, notably the United Nations International Strategy for Disaster Reduction (UNISDR) and the Global Wildland Fire Network, to reduce the impacts of wildfires at global level for the benefit of the global environment and humanity. The Global Fire Monitoring Center (GFMC), which is serving as secretariat and facilitator of the Global Wildland Fire Network and its representation to the UNISDR, the Wildland Fire Advisory Group, joined the book project in order to enrich national expertise by international insights and bring this to international use and benefit.

In following up the UNECE/FAO Regional Forum on Crossboundary Fire Management (UN Geneva, November 2013), in which representatives of the UNECE and other regions of the world, including Sub-Saharan Africa, met to develop visions and concrete action to enhance efficiency and effectiveness in fire management by exchange of experience and expertise among nations, the International Wildfire Preparedness Mechanism (IWPM) was launched in 2014.[1] The IWPM, hosted by the Global Fire Monitoring Center (GFMC), is a non-financial instrument serving as a broker / facilitator between national and international agencies, programmes and projects to exchange expertise and build capacities in wildland fire management and particularly in enhancing preparedness to large wildfire emergency situations.

1 http://www.fire.uni-freiburg.de/iwpm/index.htm

Wildfire investigation is an essential component of fire management since it contributes to clarify the origins and causes wildfires, but more importantly, to unveil possible deficits in fire management, gaps that should be closed by appropriate capacity building.

Sedgefield (South Africa) and Freiburg (Germany), 31 January 2015

Cornelis de Ronde and Johann Georg Goldammer

Contents

Preface.......5

1 INTRODUCTION.......9
1.1 Fire History and Fire Ecology in South African Biomes.......*9*
1.2 Fire Management in Natural Ecosystems.......*10*
1.3 Fire Management in Agriculture, Game Management and Forestry.......*15*
1.4 The effect of Urbanization and Human-made Fuel Manipulation.......*16*

2 THE ECOLOGY OF FIRE.......18
2.1 Fynbos in the Western Cape and Eastern Cape Provinces.......*18*
2.2 Montane Grassland.......*21*
2.3 Moist Savanna.......*23*
2.4 Dry Savanna.......*24*
2.5 Lowlands, Montane and Coastal (Indigenous) Forest.......*26*

3 FUEL AND FIRE DYNAMICS.......27
3.1 Fuel Characteristics and their Effects on Fire Behaviour.......*27*
3.2 Dynamics of Man-made Fuels.......*29*
3.3 Fuel Combustion and Fire Spread Processes.......*31*
3.4 Fire Behaviour Dynamics.......*32*
3.5 Characteristics of Large and Multiple Fire Spread.......*38*

4 CAUSE AND ORIGIN DETERMINATION.......46
4.1 Determining the Origin of a Fire.......*46*
4.2 Determining the Cause of a Fire through Fire Origin Evidence.......*53*
4.3 Considering the Cause of a Fire.......*63*

5 RECONSTRUCTING WILDFIRE SPREAD.......68
5.1 Fire Reconstruction Procedures.......*68*
5.2 Reconstructing Initial Wildfire Spread.......*74*
5.3 Reconstructing further Wildfire Spread Stages.......*79*
5.4 Investigating and Reconstructing Wildfire Disasters.......*86*

6 FIRE PREVENTION.......93
6.1 South African Standards.......*93*
6.2 Legal Requirements in South Africa.......*94*
6.3 Considering Effective Fire Protection Measures.......*96*
6.4 Responsibilities and Fire Prevention System Control.......*98*
6.5 Capacitating Local Communities in Wildfire Prevention – A Globally Increasing Endeavor to Reduce Wildfire Threats.......*100*

7 FIRE FIGHTING ISSUES....103
7.1 Fire Fighting Capacity....*103*
7.2 Incident Command System....*108*
7.3 Effective Use of Aerial Fire Fighting Support....*109*
7.4 The Role of Working on Fire (WoF) Teams and Equipment....*110*
7.5 Utilization of Private Fire Fighting Teams and Equipment....*112*
7.6 Capacitating Local Communities in Wildfire Self Defense: The International Perspective....*112*

8 CONCLUDING REMARKS: WITNESS REPORTS, DAMAGE CONSIDERATIONS, INSURANCE, ARBITRATION AND MORE....114
8.1 Damage Considerations....*114*
8.2 Expert Witness Reports....*115*
8.3 Investigating a Fire on Insurance Company Instructions....*116*
8.4 Considering Arbitration or Court Action....*116*
8.5 The Role of the Veld and Forest Fire Specialist in Wildfire Investigations....*117*
8.6 Who Qualifies as a Veld and Forest Fire Investigator?....*118*
8.7 Concluding Remarks....*119*

9 GLOSSARY....122

Appendix 1....128
Table of representative custom fuel model examples developed for South African fuel and vegetation types....*128*

1 INTRODUCTION

1.1 Fire History and Fire Ecology in South African Biomes

Africa is a fire continent (Komarek, 1971) and that includes South Africa. The country is characterized by a sub-tropical and temperate climate, and although most of its regions fall within the summer rainfall area, a small (but unique) percentage of the country is situated in the winter rainfall or constant rainfall climate within a temperate climatic environment. Linked to these main regional climatic characteristics, is a contrasting yearly rainfall range, extremes of which differ from <100mm/year in the far NW-part of the Northern Cape Province to >2000mm/year on the highest Western Cape mountain ranges, providing a mosaic of diverse vegetation features across a range of biomes (Kruger, 2004).

This brings me to the occurrence of wildfires in the South African biomes, causing fire damage levels ranging from "rare" to "mostly yearly", each with very specific characteristics. The wildfire investigator needs to understand the basic dynamics of each vegetation base where a wildfire occurred, otherwise he/she will not be in a position to table any meaningful findings of the investigation results.

There exists a chronic rhythm of wetting and drying. Seasonality flows a cadence of rainfall, not temperature. Thus – in the summer rainfall regions – we find wet seasons growing fuels, while dry seasons prepares them for burning, thus presenting a range of wildfire dangers (Pyne et al., 2004). These are called "dynamic fuels". Some vegetation types, however, in other regions (some with different land-uses) do not present such significant contrasting seasons. The latter are mostly called "static fuels" (Rothermel, 1972; Andrews, 1986; Andrews and Chase, 1986; Andrews and Bevins, 2000).

Many ages of early civilization of South Africa did not alter the ecology of the southern-part of the continent significantly for many years, as the country was only sparsely populated by small (mostly migrant) tribes. Lightning remained the most important factor in dictating the maintenance of biodiversity, although man used fire to some extent to assist in some agricultural activities, sometimes using fire to assist in hunting parties as well. However, these did not have a major influence on ecosystem existence and well-being, until such time when European imperialism became the vector for industrialization (Pyne et al., 2004).

As European settlement spread through the country, at times coupled to African migration as agriculture, forestry and industries developed, and in the process urban and other interfaces (such as with agricultural and forestry land) developed. These significantly altered the status of vegetation biomes and the role of fire. Not only was the maintenance of biodiversity threatened, but increased land-use for growing crops reduced ecosystem sizes structures and even existence. These changes in land-use let to not only impacting changes in ecosystems, but also the creation of "new", disturbed, ecosystems and fuels, such as industrial plantations, maize lands, sugar cane and wheat crops with harvesting waste. This created a completely new "fire environment", while newly-created Urban-Interfaces provided new fire protection and prevention challenges for fire managers (Pyne et al., 2004).

The ecology of fire in South Africa ranges from a "rare event" in e.g. the dry Karoo regions, to a 1-2 year occurrence in the wettest regions, such as in e.g. moist montane ("dynamic") grasslands. In Fynbos shrublands in the Western and Eastern Cape Provinces, fire frequency ranges mostly from 10 to 40 years, with (in the winter rainfall areas) most fires occurring during the summer. In the constant (all-year) rainfall areas more fires occur during the winter period, during Bergwind conditions (Edwards, 1984; Pyne et al., 2004). In many Fynbos areas more exposed to wildfires, fire frequency has been reduced significantly, even to a dangerous 4-6-years level, threatening the maintenance of biodiversity (own observations).

In most regions of the summer rainfall area in South Africa, particularly in the vast savanna-grassland biomes, fires are mainly caused by lightning and humans, and these fires are more frequent than in Fynbos. In arid grassland and savanna, grazing alone may suffice to maintain the grass component. Under natural conditions, however, fire is necessary to maintain the vigour of moist, sour, grassland (Edwards, 1984). In savanna grassland, fire is required to maintain a productive and stable savanna (Trollope, 1984).

Undisturbed indigenous forests, only covers a minor percentage of the land, and they are well protected against wildfire damage if left undisturbed. However, as many forest edges are disturbed by fires and/or exploitation in the past, forest edges became extremely vulnerable to fire damage, and are thus mostly reduced in size by regular fires, particularly in broken topography. As a result, surviving forest patches require special protection against fire damage (Geldenhuys et al., 2004; own observations).

1.2 Fire Management in Natural Ecosystems

In South Africa we have been fortunate in having a rich research and developed research history in most of our natural biomes, with recommendations available with regard to optimum fire frequencies, prescribed burning application, season of burn and fire management in general to ensure optimum maintenance of biodiversity. However, many of these recommendations are not applied according to these rules for various reasons such as conflicting management goals, lack of capacity and training, irregular wildfire occurrence, changes in land-use and climate change. Subsequently, in many cases the biodiversity maintenance is being threatened by lack of fuel management control (leading to unchecked fuel accumulation) and resulted in a general increase in wildfire size, intensity and related other negative impacts.[1]

1 Where applicable, fuel model examples will be provided in the text, also referenced in a fuel model set provided in Appendix I.

1.2.1 Fynbos

One of the most dominating features with regard to fire behaviour in Fynbos is its relatively slow fire rate of spread (in relation to dynamic grassland) and regular flaring when large shrubs are present. This flaring can also easily give rise to an abundance of spotting in favourable terrain when burning with a strong wind (own observations).

For the purpose of fuel and fire dynamic studies and assessment in Fynbos, the following examples can be used for fuel classifications and fuel models as part of a wildfire investigation if required (for fuel model detail, refer to Appendix I):

Fynbos types

- Moist Fynbos (uninfested, mature, S aspect, near Caledon and Garcia): Fuel models 64 and 65
- Semi-moist Fynbos (7-10 yr old, W. Cape): Fuel model 68
- Strandveld
- Dry Fynbos-Renosterveld (N-aspect Fynbos, near Garcia and mature Renosterveld, in W. Cape): Fuel models 66 and 67

The history of Fynbos management has an interesting background in the Cape Regions. Before the 1960s the Department of Forestry controlled all mountain catchments and related nature reserves in the region, and Fynbos management was mainly applied by means of regular block burning as well as rotation burning of wide firebreaks on mountain foot slopes on property boundaries. When control over the catchments was handed over to provincial nature conservation authorities, not much change in this fire management policy was experienced at first, because the foresters of these reserves were also transferred to the provincial authorities. As these foresters retired, prescribed burning application became less and less frequent and was eventually not applied at all.

As prescribed burning attempts became less and less, wildfires increased in size and intensity, and nature conservation bodies are at present bringing back prescribed burning application programmes, although at this point in time at a lesser scale as it used to be, because of lack of trained fire managers and reduced capacity (own observations).

1.2.2 Montane grasslands

Most of these grasslands are centered in the Drakensberg Mountains of the Kwazulu-Natal Province and Lesotho and adjoining escarpment. The extent of the grassland is strongly determined by climatic variables, with fire and grazing exerting considerable influence over the boundaries of the grassland biome. In the grasslands' domain, rainfall should be above 600 mm with relative cool temperatures and dry, cold winters and snow common at high altitudes.

If not grazed, the frequency of fires in this grassland – in particularly in the Drakensberg – leads to a yearly fire risk if prescribed burning is not applied before the dry wildfire season. This in turn leads to conflict between the adjoining land managers and conservation bodies, as the first advocates yearly burning of the whole Drakensberg range to avoid wildfire damage. Conservation bodies, in contrast normally recommend a 2-3-year fire rotation, which unfortunately leads to serious wildfire damage at times, also because there is conflict between the application of – and selecting – the optimum burning application season.

Grazing can have a highly significant impact on fire hazard, and when investigating such land, it is important to model grazed vs. non-grazed grassland as fire behaviour between the two fuel types are normally highly significant (fuel models 88, 91 and 92, vs. fuel models 89, 90, 93 and 94).

1.2.3 Kalahari Grasslands and shrublands

Also referred to as the "Kalahari Thornveld", this vegetation is dominated by sand dunes, plains and pans with dry fossil riverbeds. The climate of the Kalahari is semi-arid, where the rainfall ranges from 200 mm/year in the SW to 500 mm/year in the N and E, with drastic seasonal variation in yearly rainfall sometimes experienced between sub-regions.

Very little knowledge is available of fire ecology of the Kalahari, but historic occurrence of wildfires tells us that a few years with above-average rainfall can normally lead to wildfires, particularly in the natural parks (such as the Kgalagadi Trans-Frontier Park, managed by SANParks) where natural grazing is occurring irregularly depending on game stock. Serious (large) wildfires can occur, particularly in the dry riverbed vegetation, where grassland biomass is at its highest (own observation). From the few records available, it appears that wildfire frequency in the Kalahari is approximately 10-15 years, although extreme wildfires normally only occur every 30-50 years, when (particularly) riverbed tree components are mostly all killed (Bond et al., 2004; own observations). During 1977/78, 350 000 ha burnt in the Kgalagadi Park (Trollope, 1984). Fuel biomass situations in these grasslands have been modeled also for the N. Cape region for the purpose of wildfire simulation in these fuels, where this dry savanna was heavily infested with shrubs (e.g. fuel model 100).

1.2.4 Moist Savanna grasslands

These grasslands can mostly be found at altitude ranging from 500 to 1000 m on plateau type of topography, where the yearly rainfall ranges from 500 to 1100 mm (Huntley, 1984). The most desirable burning regime for grazing conditions is annual or biennial application, depending on grazing intensity and grass fuel conditions. However, fire frequency is normally between 3 and 5 years during dry seasons (Trollope, 1984).

While the herbaceous production in Central Africa, in Miombo woodlands, can be as high as 4.8 tons/ha/year, this is much less in South Africa, where the average herbaceous production is about 2.2 tons/ha/year, with a tree component of between 20 and 40 tons/ha/year (Huntley, 1984). One fuel model of the South African moist Savanna Grasslands has been developed (fuel model 98) and one for wetland Savanna Grassland (fuel model 99).

Figure 1.1. Photograph taken a few weeks after a wildfire in the Outenique Mountains near George (South Africa). A = Young Fynbos, unburned; B = Patchy-burned slopes, with non-vegetated rock sheets; C = Low profile Fynbos, burned over; D = Wetland Fynbos burned at high intensity. Photo: C. de Ronde.

Figure 1.2. Ignited prescribed fire in progress in grassland in the KwaZulu-Natal Province of South Africa. Photo: Courtesy Working on Fire.

Figure 1.3. Typical Kalahari grassland (dry savanna) with scattered tree component. Photo: C. De Ronde.

Figure 1.4. View of dry savanna grassland with dense shrub and tree cover, a in the Northern Cape Province. Photo: C. De Ronde.

Figure 1.5. View of dense indigenous forest on the Tsitsikamma plateau, with the N2 national road carving its way through the forest carefully between a few giant Outeniqua Yellowwoods in the background. Photo: C. De Ronde.

Figure 1.6. Early progress of a wildfire in Montane Grassland in the Free State Province. Note the effect of the strong wind blowing from left to right in the picture. Photo: C. de Ronde.

1.2.5 Dry Savanna grasslands

Arid savanna normally occurs in the hotter, drier, lowland valleys, where the rainfall ranges between 250 and 650 mm/year, and where calcrete soils are sometimes a common feature. The vegetation within dry savanna is diverse and includes open sparse grassland with scattered shrubs and short trees as well as dense thorn thickets, in which the herbaceous layer might be insignificant.

Herbaceous biomass production ranges from 500 to 1000 kg/ha, with a typical woody component (biomass) of about 20 tons/ha. Fire is an infrequent but significant component of this biome and damage to large stands of *Acacia* trees can be severe and common. Succession advances towards an open woodland or shrub savanna climax, but under disturbed conditions a dense thicket might develop (Huntley, 1984). No specific fuel models were developed under this heading, but fuel model 100 can be used as a close example.

1.2.6 Montane (coastal and temperate) forest

The forest biome includes the indigenous coastal forests of the coastal lowland and escarpment from the N of the Zululand coast all along the KZN and Eastern Cape coastal land as well as inland into the Drakensberg Escarpment. Montane Forests are fairly dominant on the Cape Provinces' plateau and into the adjoining mountain ranges, where it normally only occurs in smaller isolated (well-protected) patches. These forests cover <1% of South Africa.

Fire is normally not an issue where these forests are undisturbed, but were forest edges have been disturbed by earlier fires and/or exploitation, the forest adjoining the forest edge can be vulnerable to damage when fire is burning in adjoining vegetation. For that reason, forest edges should be protected at all times to save the remaining forests, while unchecked exploitation should also be forbidden (Huntley, 1984; Bond et al., 2004; own observations where wildfires occurred).

1.3 Fire Management in Agriculture, Game Management and Forestry

Land-use is changing rapidly in South Africa, and millions of hectares have been converted to agricultural land in the form of cultivated lands and land used for grazing. Ploughed lands are mostly used for wheat, maize and sugar cane, mostly creating fuels at some stage at or just after harvesting, which could present a serious fire hazard, though mostly for a restricted period of time. Harvesting slash in wheat lands is normally burned by farmers in a systematic manner, but even stubble lands can present a fire hazard, depending on the height at which e.g. wheat fields are cut (own investigation experience). Such cutting heights are sometimes alternated yearly by farmers on purpose, presenting a fire hazard some seasons, and some seasons not (pers. comm. with farmers). One fuel model has been developed to provide an example of hazardous stubble land.

The harvesting of slash from maize lands only presents a fire hazard under local conditions for a very short period of time, only just before harvesting is conducted, and then only if this coincides with very strong winds: Situations, which seldom occur as harvesting (and slash management) is normally taking place before the "strong wind season". As such, fuel situations are extremely variable, and it is recommended that such models are only developed when such wildfires in fact occur, as average models will then be of little use (own assumption).

No grassland fuel model under this category has been developed here, but a typical (rare) example is Kikuyu grass during the dry season when cured, as this is an imported grass cultivar, differing significantly from South African (natural) grasslands. However, such fuel can present a serious fire hazard where it is found.

Most South African agricultural grassland used for grazing can be classified as (i) intensively grazed, as many times found in the rural landscape near rural townships (fuel model 92), (ii) irregularly grazed grassland, such as found on large commercial grazing land (fuel model 91), and (iii) land used for game farming and nature reserves, where very little in terms of prescribed burning is applied. In such situations, mostly non-grazed old grassland is found, mostly in semi-moist to dry savanna, as well as in montane grassland (e.g. fuel models 98 and 100).

Where industrial plantations are grown for commercial purposes, a whole range of fuel models has been provided to cover examples by forest region, species and age groups, for specific silvicultural regimes applied. The fire hazard situation in industrial plantations normally changes significantly over time, after the application of silvicultural treatments (such as pruning and thinning) and after clear felling (when slash is added to existing forest floors). During early stand age, the natural base fuel also significantly adds to fire hazard as the tree stand progresses towards crown canopy closure situation, and the partly closed stands with old natural fuel remnants (such as grass and Fynbos) can then reach extremely hazardous proportions, requiring special protective care. Although not all industrial plantation fuel models could be provided here, some representative fuel models have been provided (fuel models 52 to 63).

1.4 The effect of Urbanization and Human-made Fuel Manipulation

These situations can range from rural farmlands, where homesteads are bordering directly to dangerous fuel lands such as Fynbos, dynamic grasslands or other dangerous fuels, to where informal settlements have been developed inside natural fuel lands or industrial plantations, to the edges of towns and villages, bordering e.g. agricultural land, industrial plantations, nature reserves or game farms. The same can be found where such populations are bordering any form of man-made manipulated fuels.

A classification of urban fire hazard is sometimes available, which can be used for regional integrated fire prevention plans, unchanged or adjusted (as and when required).

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2 THE ECOLOGY OF FIRE

2.1 Fynbos in the Western Cape and Eastern Cape Provinces

2.1.1 Introduction to Fynbos ecology

Fynbos is a vernacular term for fine-leaved shrubs and is a vegetation dominated by evergreen shrubs. These include small-leaved ericoid shrubs, including many species of Ericaceae, but also many shrubs of other families, including several endemic families such as Bruniaceae and Penacae. Mixed with the ericoid shrubs are taller proteoid shrubs (dominated by members of the Proteaceae). Its fire frequency is normally linked to the yearly rainfall recorded in the region where the community is growing, which ranges from ca. 250 mm in the lowlands, to 3000 mm in the highest rainfall areas in the mountain (Bond et al., 2004).

Burning triggers different stages in plant life cycles, including flowering, seed dispersal and seed germination in fire-dependent plants, perennial grasses and herbs, including orchids, lilies and other bulb plants, flower prolifically after they have been burnt, often as a facultative response to light, water and nutrient availability. Seeds only become available after a burn, so that population growth is episodic and stimulated by fire. Burning also stimulates seed release from species with serotinous cone-like structures, which store seeds on the plant for years between fires (Bond et al., 2004).

The fire ecology of Renosterveld is not well understood and we require more knowledge about the subject to conserve this rich flora. The response of Strandveld to burning is even less understood than Renosterveld. The dominant broad-leaf shrubs all sprout after burning but their seedlings are fire avoiders. Frequent intense fires in Strandveld are likely to promote the Fynbos elements at the expense of the broad-leaf shrubs. Strandveld is also very susceptible to *Acacia* invaders threatening their existence on many coastal sites as they can easily result in extreme fire intensities with a long residence time, leading sometimes to a complete absence of plant regeneration (own observations).

The succession after fire in Fynbos follows the following specific succession stages:

- Immediate post-fire phase: The first 12 months after a fire
- Youth phase: 4-5 years after a fire
- Transitional phase: Up to 10 years after a fire
- Mature phase: Up to 30 years after a fire
- Senescent phase: Final stage after a fire

One of the main features of fire exclusion for too long periods of time is that fires can today occur at shorter frequencies during the "youth phase", which can be detrimental for the maintenance of Fynbos biodiversity.

2.1.2 The high rainfall (winter rainfall) regions of the W-Western Cape Province

During the dry summers, south-easterly winds occur frequently, blowing for several successive days. These winds are normally strong, gusting up to more than 50 km/hr (own studies from weather data). Such strong winds many times give rise to fires. In some valleys these winds are more common with the strongest SE winds experienced during the later afternoon and early evening, such as in particular experienced in the Worcester-Wolseley-Tulbagh valley (own observations and weather data studies).

From Hermanus eastwards, foehn-like Bergwinds can occur during the winter period, when dry subsiding air moves off the interior plateau of South Africa in response to strong coastward pressure gradients. Standing waves arise as the air is drawn across the coastal ranges, and strong downwash in their lee, results in warm turbulent winds where the waves reach the surface (Kruger and Bigalke, 1984).

In this region, moist, semi-moist and dry Fynbos (Renosterveld) is found, while on the coastal plateau, Strandveld is common. It is particular in the Strandveld Fynbos, where sometimes heavy infestation with certain exotic *Acacia* weeds can present serious problems, sometimes increasing fire intensities of wildfires more than ten-fold (own observations). In Fynbos growing in mountainous terrain, many other infestation problems occur, such as from *Pinus*, *Hakea* and *Acacia* spp., but these are found in specific areas, such as on the foot slopes of some mountain ranges.

2.1.3 The high rainfall (constant rainfall) regions of the E-Western Cape Province and W-Eastern Cape Province

This region includes the so-called “Southern Cape” and the “Tsitsikamma”, south of the Langeberg, Outeniqua and Tsitsikamma mountains. Rainfall in the region is spread throughout the year. The most dangerous fire season is during the winter season, when strong Bergwinds occur at times, particularly where there is a significant contrast in altitude over short distances, along the southern foothills of the mountains (own observations).

The Fynbos here is mostly found in the mountainous terrain ranging from “moist” along the most-southerly aspects, to “dry” along the most northerly aspects of these mountains. On the plateau, mostly moist Fynbos is found in patches (particularly in the Tsitsikamma), but along the coast, some patches of Strandveld can be found, also growing on the coastal sand dunes (own observations).

An interesting feature of Fynbos characteristics here, is that senescent Fynbos is invaded with the “Kyster fern” (*Gleichenia polypodioides*), which retains fuel moisture very well below its dense fern-leaf canopy. As a result, mats of the species do not burn as easily as surrounding Fynbos does. However, if it eventually burns “it burns like hell” (comments from a US scientist visiting the country).

Figure 2.1. Example of mature, moist, Fynbos on the Tsitsikamma plateau in the W-Eastern Cape Province. Photo: C. De Ronde.

Figure 2.2. Prescribed burning in progress in the Drakensberg Mountains. Photo: Terry Everson.

2.1.4 The high rainfall (summer rainfall) regions of W-Eastern Cape Province

The Fynbos in this region is mostly found in the southern-most mountainous terrain, from around Humansdorp, as far as to the east in the W-Amatole Mountains, in the Hogsback area. East of this area, the natural vegetation changes to more typical montane grasslands.

Because of the climatic change here from the constant to summer rainfall regions, the Fynbos has generally-speaking a lower height profile, which can mainly be attributed to a lower rainfall level (500-750mm/year) than the Fynbos in the Southern Cape and Tsitsikamma, (where the annual rainfall ranges from 750-1200mm/year) and where the rainfall is absent during the winter season. Otherwise, not much is known of this particular Fynbos region (own observation).

2.1.5 Low rainfall Fynbos areas of the SW-Karoo and Little Karoo of the Western Cape and Eastern Cape Provinces

Apart from a "transition phase" of dry (low profile) Fynbos on the most N-aspects of the Southern-most mountain ranges of the Western and Eastern Cape Provinces and semi-moist to dry Fynbos found along the S-aspects of the Swartberg Mountains, most other Fynbos found here can be described as "Renosterveld".

Renosterveld was once also an important component of the Fynbos biome on the more clay-rich soils of the coastal forelands and inland valleys, occupying ca. 20 000 km^2. Most of this vegetation type has been transformed by agriculture, since much of its former area was suitable for crop farming. Today, only small pockets remain in e.g. the extensive wheatlands of the Cape regions (Bond et al., 2004).

One interesting feature of fire effects in Renosterveld, is its spectacular flower display. However, otherwise fire frequency normally exceeds 25 years and if it then burns under typical fire weather conditions, it normally burns in the form of a low profile fire, sometimes resulting only in patchy fire cover as a result of lack of continuous fuel layers (own observations).

2.2 Montane Grassland

2.2.1 Introduction to montane grassland ecology

The two main grassland types found in South Africa are the following:

Climatic climax grassland

Succession does not normally proceed beyond the grassland stage because the climate is too cold to permit the development of woody communities, even in the absence of fire. These are called the "True" grasslands (Acocks, 1988). These are short, sour grasslands dominated by moisture-loving species. Some temperate grass species and Fynbos shrubs also occur here (Tainton and Mentis, 1984). Trees are also rare were the grassland occurs, mainly being restricted to the Highveld, as a result of the dry and extremely frosty winters (Bond et al., 2004). On many climatic climax grassland sites, man-made and natural (lightning) fire occur at yearly or two-yearly intervals, as these grasslands normally produce a biomass of 2.5-3.0 tons/ha/year, sometimes even as high as 4.5 tons/ha/year (Tainton and Mentis, 1984). Two fuel models will be provided (models 89 and 90) to represent one-year and >one year examples.

Fire climax grasslands

These occur where the climate will permit succession to proceed beyond the grassland stage into shrubland or forest, but which are maintained as grassland by biotic factors such as fire and grazing (Huntley, 1984). These grasslands are also referred to as "secondary" or "false" grasslands (Acocks, 1988). Degradation of these grasslands leads to invasion of xerophytic Fynbos shrubs such as *Felicia* spp. When secondary grassland is protected from fire for several years, it is eventually invaded by forest-precursor shrubs, which form a dense thicket. Two fuel models will be provided to represent such fuels (models 88 and 91).

2.2.2 Kwazulu-Natal and Mpumalanga Highveld regions

The natural (protected) grassland catchment areas in these regions are managed primarily for the conservation of water resources, biodiversity and the preservation of the soil mantle. Managers of these areas aim to maintain the ecosystems in their natural state and conserve their genetic resource and diversity. Since sourveld areas do not naturally support large numbers of grazers, removal of top-growth by grazing alone is minimal, except in reserves where there are introductions of non-naturally occurring animals. Fire is therefore the only practical means of managing these areas and is consequently widely used to achieve the major aims.

In commercial agricultural areas, fire is used to maintain the composition and vigour of the grass sward to enhance animal production. The main objectives of burning grazed grassland are to:

- Burn off unpalatable growth left over from previous seasons to provide nutritious regrowth for livestock.
- Maintain the vigour, density and cover of palatable perennial grasses.
- Control the encroachment of undesirable plants in the veld.
- Reduce the extent of patch grazing.
- Protect the rangeland (and farm) from wildfires and accidental fires (Morris, 1998; Everson et al., 2004).

2.2.3 Eastern Free State and N-Eastern Cape Grassland

In the N-Eastern Cape (along the foot-slopes of the S-Drakensberg Mountains) basically the same grassland management is applicable as described in par. 2.2.1, apart for the consideration of a dominant agricultural crop land (maize) and/or industrial plantation interface now present there. This thus now demands more intensive fire protection than in the KZN Drakensberg regions, where natural grassland normally borders grazing grassland areas (own observations). This results in the yearly burning of all the mountain grassland before the fire season, with the exception of certain ecologically sensitive areas, such as natural heritage sites and areas where *Protea* communities are growing. Protection of the latter by means of a rotation burning system of 2-3 years, was achieved by means of management/conservation compromises reached to satisfy both disciplines (own experience).

In the far-eastern Free State, mainly grassland is concerned (farming and nature conservation land) requiring a 2-4 year fire rotation. It has been observed, however, that this is seldom achieved as a result of lack of prescribed burning application, and as a result large (damaging) wildfires do occur regularly in the region (own observations).

2.3 Moist Savanna

2.3.1 Introduction to moist savanna ecology

In the so-called "sourveld" grasslands of moist climates and leached, low nutrient, soils, (which are prevalent in the moist grassland and moist savanna regions), palatability is limited to about four months of the year so that plant material accumulates to provide greater fuel mass and flammability during the dry season.

In the higher rainfall regions, most savanna has a relative high production at 2-5 tons/ha/year and fires can occur as regularly as each 2-3 years. However, flame heights experienced are normally relatively low and close to the ground, although crown fires up to a height of 3-4m can occur. However, during most fires, many of the mature tree components will survive fires, even with sporadic crown fires occurring (Huntley, 1984).

An interesting feature of fire behaviour in savanna, is that bush clumps are very resistant to fire. The surface fires will skirt around the edges of clumps, leaving the centres unburned. This is normally caused by the lack of available grass within bushes, not providing continuous fuel layers necessary for carrying such fires to the centre of a bush. The most desirable burning frequency under grazing conditions in moist savanna is annual or biennial burning, depending on grazing and grass fuel conditions (Trollope, 1984).

2.3.2 Fire management within nature reserves

Where such reserves occur within moist savanna, a significant tree component normally exists, with some shrubs also present. This normally results in ideal conditions for patch burning to be applied on a regular scale, providing a suitable burning mosaic for the maintenance of savanna systems, including the provision of adequate grazing for wild animals, such as grazers (as well as browsers). However, above-average seasonal rainfall can cause above-average grassland biomass development, giving rise to extreme wildfire situations, particularly where fire-application in general has been excluded for some years in reserves. Such conditions can present a serious threat to wildlife as well as grazing provision, while even the mature tree component can be killed in the process, disturbing the whole balance of the savanna.

It is thus clear that grassland biomass should be monitored carefully, and this could also assist in reducing fire risk significantly, by providing external and internal (prescribed burned) buffer zones to avoid such disasters.

Sometimes natural savanna areas change in land-use from cattle and sheep grazing to nature conservation to converting such areas to nature reserves, and then related changes in fire regimes are not applied correctly and extreme fire hazards can develop fast. Managers need to check out such land-use changes by monitoring the grassland biomass status regularly and apply fire selectively but correctly, to meet such challenges (own experience and observations).

2.3.3 Fire and game management

Farming with game at a commercial level in moist savanna is becoming more and more popular, when commercial grassland and savanna is converted to game farming. The most important such changes in land-use can cause, is that intensive grazing (by e.g. cattle and sheep) is changed to irregular grazing by game, causing extreme fire hazard in grassland as well as in savanna communities. Such changes should soon be followed by a well-planned fire management regime incorporating fire-ecological requirements. However, most of such land changes are leading to total exclusion of fire for years, which normally causes extreme wildfires, particularly after above-average rainfall causing above-average grassland biomass.

Although such fire hazards are more common in open grassland than in moist savanna, both can be at risk, although probably less severe at lower altitudes, where the savanna status is found more frequently, creating a lesser fire risk where the tree component is more dominant (own observations).

2.4 Dry Savanna

2.4.1 Introduction to dry savanna ecology

The general fire frequency in dry savanna is at a rotation of about 3-5 years, but this will be for a lower frequency during dry periods. In general, dry savanna has a lower fire frequency than moist savanna, actual frequency being dependent on annual rainfall and linked biomass additions in grassland components (Trollope, 1984).

In some climatic regions, seasonal rainfall can fluctuate more than in others, and in the first the frequency of fires is normally over longer periods than in others. In both, bush encroachment can become a problem if fire is excluded for too long and more regular fire application can be desirable to check such problems before it gets a foothold (own observations).

In some nature conservation areas (such as the Kruger National Park) the use of fire as a management tool was excluded for long periods of time, in the believe that only natural fires (such as lighting) can provide the necessary biomass checks in a mosaic-form. However, this resulted eventually in some abnormal grass fuel accumulations, leading to damaging wildfires at an unacceptable scale, and even the loss of human lives (own observations and experience, e.g. with the 2001 "Napi Boulders" fire during 2001). It makes thus sense that block burning has been brought back in this Park as a regular application of fire.

2.4.2 In the dry North-Western regions

Most of the dry savanna in these regions is found in nature reserves and farming areas where game farming has developed as a major industry. In most of these areas, fire is applied infrequent or not at all, resulting many times in serious wildfire damage to the flora and fauna where such high intensities take place under extreme weather conditions.

The status of the burnable biomass (grass, shrubs and sometimes trees) depends on the intensity and length of grazing history, and where large herds of browsers are found (including elephants), the whole savanna landscape can be altered, making it possible to re-assess the use of prescribed burning (methods, frequency and season of burn). It might in most cases be desirable to integrate firebreaks along strategic boundaries with prescribed burning application as well as mosaic burning allowance, but this depends on the local status of fuels within reserves and game farms (Trollope, 1984).

2.4.3 In the Kalahari savanna

The main regulator of prescribed burning application in the Kalahari, is whether the land is used for farming (cattle, sheep, game) or as nature reserves (such as the Kgalagadi Trans-Frontier Park). On farms, grassland biomass management is normally well applied, although "bumper years" in terms of abnormally-high rainfall and subsequent high grass biomass addition, can lead to wildfires, which can be severe in terms of damage to all above-ground vegetation. One such a wildfire occurred in the Nossop riverbed of the Kgalagadi Trans-Frontier Park during 1977/78, which killed most of the tree component in that area, including trees exceeding 50 years of age (own observations).

Although prescribed burning should be applied selectively in nature reserves in the Kalahari Savanna in tandem with lightning fires, the technique is seldom considered. In contrast, surrounding farms normally have a more systematic approach to grassland management by means of grazing rotation, providing a much better grassland biomass control than is normally present within the nature reserves at times. However, the absence of prescribed burning application on farming land in the region, can give rise to bush encroachment (own observations).

2.5 Lowlands, Montane and Coastal (Indigenous) Forest

These forests are normally seriously threatened by outside wildfire exposure, sometimes seriously damaging the forest edge, particularly reducing forest area size of smaller forest remnants in mountainous terrain. The larger forest units (such as found near Knysna, the Tsitsikamma, Amatole, Kwazulu-Natal coastal areas and Lowveld escarpment in the Mpumalanga Province), are normally better protected against fire damage, provided the forest edges are not damaged by (illegal) timber exploitation (own observations and experiences with wildfire damage investigated in forest areas).

To avoid damage of forest edges, special fire protection regimes should be applied, including selective fire application in surrounding vegetation (e.g. in grassland and Fynbos). Fortunately most timber exploitation has been stopped, but the wildfire problem along forest edges will need special attention to protect the remaining forests in South Africa (own conclusions).

From a wildfire investigation point of view, indigenous forests are normally in the path of a wildfire being investigated and then the damage done by such a fire is normally at stake. Questions such as: "Was the forest adequately protected against wildfires?" and "could damage to an indigenous forest have been avoided?" are foremost in the investigators' program (own experience).

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