The impact of change in climate, human demography, and other social factors on the fire regime of the Kogelberg Nature Reserve

by

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Abstract

Background. Fire is a dominant ecological factor in the Fynbos Biome in the Western Cape, and changes in the fire regime have important consequences for the biodiversity conservation of the landscape. Fire regimes in the Western Cape are known to have changed over the past decades due to factors such as changing climate, resources for fighting fires, sources of ignition and human demography. Fire regimes at any given site are never fixed, occurring at varying intervals, in different seasons and at different intensities. Each event is therefore unique and the ecological consequences will depend on both the burn parameters and the nature of the fires that preceded it. Over time, it has been difficult to accurately and consistently quantify fynbos fire regimes and the impact of change in climate, human demography and other social factors because of the unavailability of accurate fire data and records. An understanding of the trends in fire regime and the impact of changes in climate, human demography and other social factors is important to maintain biodiversity and the co-existence of species. There is an urgent need to find effective approaches for assessment of fire regime conditions that balance scientific credibility, spatial continuity and quick delivery. This study seeks to determine the trends in the fire regime (frequencies, return interval, veld age and seasonality) of the Kogelberg Nature Reserve and the impact of changes in climatic patterns, fire-fighting resources, sources of ignition and population increase.

Methods. The study site was the Kogelberg Nature Reserve in the Western Cape Province because of its exceptional conservation significance. It is regarded as the floristic heart of the globally unique Cape Floral Kingdom since it appears to have the highest levels of plant species richness and endemism in the Fynbos Biome. Fifty-four years of fire data records were analysed to determine the trends in the fire regime. The study period was divided into two management periods; 1952-1980 and 1981-April 2006 for analysis of the historical fire regime, with the former being a period when there was less pressure of human settlement and before the reserve was proclaimed a mountain catchment area. The latter period was when the reserve had been declared a nature reserve and more people were settling in the neighbouring towns, the fire risk was increasing and allegations of climate change were being made. To test for the impact of climate change on the fire regime of the Kogelberg Nature Reserve, weather data (temperature, wind speed, relative humidity and rainfall) from a weather station in the vicinity of the nature reserve were analysed to determine fire danger indices for a period of 33 years. The United States of America National Fire Danger Rating System as adapted for South African conditions was used to formulate burning indices from the weather data. A relationship between the fire days and the fire data was established. To test for the impact of the changes in fire fighting resources and sources of ignition, data were obtained from the fire records. To investigate the impact caused by population increase on the fire regime of the Kogelberg Nature Reserve population, data were obtained from Statistics South Africa. Available records for each factor were analysed to test for changes in that factor, and each factor was compared with the trends in fire frequency in the study site. Logistic regression was used to test for the relationships in the changes in fynbos fire regimes and its adaptation to changes in climate and social factors. A multivariate analysis was done to tie the four causing variables namely; fire numbers, fires sizes with population density and burning indices.

Results. Analysis of data indicated a significant increase in the frequency and size of fires during the period 1981-2006 compared to the period 1952-1980. There has been an increase in the burning of veld younger than 6 years, and the total area burnt has increased significantly in the period 1981-2006 coupled with an increase in the number of fires. However, the size per individual fire has decreased significantly in the period 1981-2006. This study found that the conditions for starting fires improved significantly during the period 1989-2005, due to burning indices increasing from the period 1989-2005 which resulted in conditions for starting fires becoming more conducive than the previous era although fires in the reserve started under all environmental conditions. The population size of people staying in the neighbouring towns and villages has more than doubled during the period 1996-2006. Multivariate analysis showed that there was a significant correlation between number of days when fires burnt and area burnt and population with numbers of fires. Finally, since 1988 CapeNature has not been able to comply with the minimum requirements for fire prevention due to lack of capacity and resources.

Conclusions. The Kogelberg Nature Reserve has been negatively impacted by the increased conditions of ignitions associated with climate change, increased unplanned fires associated with increase in population growth and lack of capacity and resources to prevent and control veld fires. These results could negatively impact biodiversity of the Kogelberg Biosphere Reserve if no actions are taken to address these shortfalls.

Key words: CapeNature, Climate, Fire regime, USA National Fire Danger Rating System, Sources of ignition, Fynbos Biome, demography, fire fighting resources

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1.1 General introduction

The Western Cape Province is situated at the southern tip of the African continent between latitudes 31˚00′ and 34˚30′ S (Goldblatt and Manning, 2002) and occupies a small area at the extreme south-west of the southern African sub-continent (van Wilgen, 1981). It stands alone in South Africa in terms of its rich natural heritage (Goldblatt, 1978). The Western Cape hosts two of six world plant kingdoms, the Cape Floral Kingdom and the Palaeotropic Kingdom (Mucina *et al*., 2006). Of particular significance is the Fynbos Biome, also known as the Cape Floristic Kingdom (Kruger, 1977), or "Capensis" region (Taylor, 1978). The Cape Floral Kingdom (CFK) is the smallest of the six floral kingdoms of the world, covering 0.04% of the earth's surface (Takhtajan, 1969), yet it contains 8 920 species of vascular plants, of which 69% are endemic (Goldblatt and Manning, 2000).

The Western Cape Province is internationally renowned for its unique floristic diversity and houses two of the world's biodiversity hotspots –the Fynbos Biome and the Succulent Karoo Biome (Mittermeier *et al*., 1999). There are only 34 biodiversity hotspots worldwide (www.biodiversityhotspots.org), and it is unsurprising that the conservation status of the Western Cape enjoys the highest international status (Cowling and Heijnis, 2001). Hotspots are characterised by the fact that they contain more than 0.5% of the world's endemic species and have had more than 70% of their original areas transformed (Myers *et al*., 2000).

The Cape Floristic Region is home to the greatest non-tropical concentration of higher plant species in the world, with more than 8 200 plant species found in a relatively small land area (www.biodiversityhotspots.org). According to Goldblatt and Manning (2000) an incredible 5 682 (69%) of these species are found nowhere else, ranking it amongst the richest of temperate and tropical floras and one of twelve mega diversity areas in the world (Rebelo, 2001). The Cape Floristic Region has long been recognised as a global priority for conservation (Lombard *et al*., 2003). It has been listed as a centre of Plant Diversity (WWF and IUCN, 1994), and a Global 200 Eco-region (Olson and Dinerstein, 1998).

According to Rouget *et al*., (2003) approximately 30% of the Cape Floristic Region is currently transformed by cultivated land including forestry plantations (25.9%), urban areas (1.6%), and dense stands of invasive alien trees (1.6%). Only 25% of the original extent of the Cape Floristic Region remains intact (Cowling *et al*., 1997). The biggest threats to the biodiversity of the region are habitat fragmentation due to agriculture and urbanisation, invasion by alien species and harvesting of plant products from the wild. The misuse of fire by burning in the wrong season or too frequently threatens certain species (Low and Rebelo, 1996). Alien species have invaded 36% of Mountain and Lowland Fynbos, altering natural fire frequencies, diminishing mountain-derived water production and ultimately eliminating native species (Dalgliesh *et al.*, 2004).

Midgley *et al*., (2001) suggested that climate change might also have serious implications for the Fynbos Biome over the next 50 to 100 years. The northern arm of this biome may disappear altogether and many of the drought-sensitive fynbos plants will be lost since the biome has a very high proportion of endemic species. Any loss of range may result in extinctions.

1.2 Aims of fynbos management

According to van Wilgen (1984) fynbos shrublands cover the mountain catchment areas of the Western Cape Province of South Africa and are managed for a variety of goals; most importantly being sustained yields of high quality stream flow, nature conservation, fire hazard reduction, afforestation, grazing, and the provision of tourism and recreational opportunity.

Since 78% of the Fynbos Biome and 73% of the Succulent Karoo Biome are located in the Western Cape Province, the primary responsibility for the conservation of these areas lies with the Western Cape Nature Conservation Board (Le Roux *et al*., 2000). The Western Cape Nature Conservation Board trading as CapeNature is directly responsible for managing 736 839 ha, and indirectly an additional 1 661 338 ha. According to Le Roux *et al*. (2002) 10.7% of the Western Cape's land surface falls under statutory conservation areas, while an additional 7.7% falls under privately owned conservation land.

1.3 Variation in climate of the Western Cape

The climate of the Western Cape is largely Mediterranean, strictly so in the west, while the eastern half of the Cape Floral Region (CFR) receives substantially more summer precipitation (Goldblatt and Manning, 2002). The Mediterranean climatic zone in southern Africa originated 3-6 million years ago (Deacon, 1983) when the present pattern of ocean circulation became established. Fuggle and Ashton (1979) claim that the CFR is characterised by two pronounced climatic gradients that are superimposed on the mountainous topography to give the region a complex mosaic of spatiality diverse climates.

Following the Köppen classification, the fynbos biome has **Cs** (temperate warm climate with winter rainfall), **Cf** (humid temperature warm climate with sufficient rainfall in all seasons) and **Bs** (arid/steppe climate with cold, dry winters), which makes it a fire prone region by this classification (van Wilgen, 1984). However, Boucher and Moll (1980) argued that a true Mediterranean climate (**Cs** and **Cf**) is restricted to the area from Saldanha Bay on the west coast to the Breede River mouth on the south coast penetrating inland to the first mountain ranges. The eastern and western parts of the Cape Floral Region are considered to be under fundamentally differing climatic controls, probably a long enduring pattern that has affected the evolutionary histories of the areas resulting in their distinctive floras and faunas (Cowling and McDonald, 1999).

Since the climate is Mediterranean, rainfall occurs mainly in the winter months while summer months are hot and dry and the rainfall is lower in the west than in the east (Goldblatt and Manning, 2002). Winter rainfall forms an integral climatic unit, with various implications for those managing the natural environment. On the west coast the rainfall ranges from very low (near desert conditions) to medium and high rainfall in the south-western and southern Cape respectively.

Rainfall in the mountainous regions of the South Western Cape has the highest range in the country and accounts for 76% of water yield for the province (Rutherford and Westfall, 1994). Moll (1990) alleges that the size of the winter rainfall zone has fluctuated considerably in geological time, as have the climatic parameters. The most recent trend is that the extent of the winter rainfall zone is contracting and the climate in general is becoming drier (Deacon and Lancaster, 1984).

The west coast forelands receive 400 mm rainfall and the adjacent mountains receive an excess of 2 000 mm (Schulze, 1972). In areas of low total rainfall, the average monthly precipitation distributed in the summer months may be higher, notably in the Little Karoo. Due to more favourable precipitation/evaporation ratios, effective rainfall is still recorded mainly in winter and on south facing mountain slopes benefiting from summer moisture in the form of rain or fog from the south-east trade winds (Goldblatt and Manning, 2002). The rainfall is mainly cyclonic and orographic, although thunderstorms may occur (on average about five occasions per year) and hail is rare on the coastal forelands. Snow falls on the adjacent mountains in winter and occasionally on the lower foothills in the Cango Valley (Boucher and Moll, 1980). Although snow sometimes occurs at high altitudes, the province has the mildest climate in the country (Rutherford and Westfall, 1994).

Strong southerly winds can blow for several successive days during the summer months, particularly in the south-western region of the province, drying out the vegetation (Kruger and Bigalke, 1984). In addition, hot Föhn like “berg winds” precede cyclonic weather systems during winter in the south-eastern parts of the province. These winds are both associated with extremely high temperatures and low relative humidity readings of between 5 and 25%, which lead to high fire risk conditions (Edwards, 1984).

According to the South African Weather Bureau (1965) the average daily maximum temperature is 28^{o} C in midsummer and about 17^{o} C in midwinter, but extreme maxima can reach 43^{o} C and 30^{o} C respectively. The average daily minimum temperature was about 15^{o} C in January and 6^{o} C in July, with extreme minima falling to 4^{o} C and - 5^{o} C respectively depending on altitude and situation. Frost is rare on the coastal flats (Boucher and Moll, 1980).

In relation to fire regime, van Wilgen (1987) describes the climate over large areas of the Western Cape Fynbos Biome as Mediterranean, with dry warm summers and cold wet winters. In the east, rainfall is more evenly distributed throughout the year. The eastern inland regions have high summer evapo-transpiration and this effectively induces a winter rainfall regime. Fires in the western and inland eastern areas will therefore tend to be concentrated in summer. The south-eastern coastal areas experience relatively even average climate in terms of fire danger, and fires can occur during relatively rare suitable conditions that can occur in summer or in winter.

1.4 Fire Climate Zones of the Cape Floristic Region

Van Wilgen (1984) conducted a study on the climate of the Western Cape in relation to fire potential. Areas that experience similar climatic conditions and have the same potential for fire risks were classified into the following groups:

a) **Western Coastal Zone** - this is a fairly narrow stretch of land along the Cape Peninsula in the south and west and stretching northwards along the west coast. It is characterised by low mean fire potential in winter with fires most likely under extreme conditions of high temperature, low relative humidity and high wind in summer.

b) **Western Inland Coast -** this area connects the Western Coastal Zone with the two towns of Barrydale and Sutherland and north of the Langeberg Mountains. It is characterized by strong seasonal trends in fire potential in summer months with large areas burnt.

c) **Southwestern Coastal Zone** - a zone that extends from the Western Coastal Zone to south of the Hottentots-Holland, Riviersonderend and Langeberg mountains to Mossel Bay in the east.

d) **Eastern Inland Zone** - A zone that extends from the Western Inland Zone eastwards. It experiences rainfall throughout the year but is classified as a winter rainfall area because of the high evapo-transpiration in summer.

e) **Southeastern Coastal Zone** - This zone extends from Mossel Bay eastwards and south of Outeniqua and Kouga mountains. It is characterized by a fire potential that is bimodal, i.e. fire experienced under occasional suitable conditions in both winter and summer.

1.5 Variation in vegetation (fuel) of the Western Cape

In the past, all shrublands in the Cape's Mediterranean climate zone were treated as being biogeographically and ecologically similar (Moll, 1990). However, the vegetation of the fynbos biome is heterogeneous and the variation in structure is extreme (van Wilgen, 1987). Far from having uniform vegetation, the Cape Region encompasses five biomes and several distinctive vegetation types, each with its own suites of species and physical characteristics (Rutherford and Westfall, 1994). Goldblatt and Manning (2002) briefly describe the most common and distinctive vegetation as Heathland Fynbos, Renosterveld, Succulent Karoo and Evergreen Forest. Moll (1990) and Mucina *et al.* (2006) recognise the vegetation of the Cape Region as represented by islands of Afromontane Forest that are scattered throughout the region, and true Mediterranean vegetation types that comprises four distinct shrubland types known as Renosterveld and Strandveld with Succulent Karoo occurring on the more arid fringe and a true Heathland Fynbos as the core.

1.5.1 South African Mediterranean Shrublands

Acocks (1953) recognised several types of shrubland formations occurring in the Mediterranean climate of South Africa and these include West Coast Strandveld, Coastal and Mountain Renosterveld, coastal Macchia and Macchia. Moll and Jarman (1984) recognised two basic shrubland formations that occur in the Mediterranean climate zone of the south-western Cape Province which they note as true Heathlands or Cape Fynbos communities which belong to the Cape Floristic Kingdom. The two subtypes are Mountain Fynbos (Macchia) and Lowland Fynbos (Coastal Macchia). The second formation is a non-heath, truly Mediterranean Shrubland formation that consists of Cape Transitional Small Leafed Shrublands with essentially Cape/Karoo-Namib phytogeographic affinities locally known as Renosterveld, and Cape Transitional Large Leafed Shrublands with essentially Tongaland-Pondoland/Cape/Karoo-Namib phytogeographic affinities known locally as Strandveld. These two non-heath shrublands have both Cape and Palaeotropic Floristic Kingdom affinities.

1.5.2 Heathlands

1. **Fynbos** - this Heathland comprises communities which once occupied 20% of the Cape, and now less than 17% as some areas, particularly in the east which have been cleared for agriculture (Moll, 1990). Fire is the most important ecological factor determining the structure and composition of fynbos and is therefore the most important management tool (Kruger and Bigalke, 1984). In relation to fire, van Wilgen (1987) further divided fynbos into three categories:

a) **Dry or mesic mountain fynbos -** Available fuel amounts to 50-100% of the aboveground biomass and have stands with post-fire ages of less than four years that do not normally have enough fuel to support a fire, whilst large amounts of litter accumulate in old stands and fires are usually possible under even mild conditions in older vegetation.

b) **Wet mountain fynbos -** This type of fynbos is characteristic of southern coastal mountain ranges and has relatively high biomass and less litter than the mesic mountain fynbos. Fires do not burn as easily as in the drier fynbos types under moderate climatic conditions but fire intensities can be high under suitable weather conditions.

c) **Coastal fynbos** - This type of vegetation is structurally similar to either dry or mesic mountain fynbos.

1.5.3 Non-Heath Mediterranean Shrublands

A. **Renosterveld -** this type of vegetation occurs throughout the region, often fringing the fynbos communities but is restricted to the more nutrient rich shale and granite derived soils (Boucher and Moll, 1980). During prehistoric times 12% of the region comprised Renosterveld, but because this vegetation occurs on the nutrient rich soils and on gently sloping land, < 7.5% remains due to agricultural clearing for cultivation

(Moll and Bossi, 1984). What remains is now dominated by *Elytropappus rhinocerotis*, the Renosterbos from which it derives its name. In relation to fire Renosterveld contributes only a very small proportion of the remaining natural vegetation of the Fynbos Biome and is therefore not currently important in landscape-level fire patterns; although it would have been in prehistoric times (van Wilgen, 1987).

B. **Strandveld -** this vegetation type is restricted to the more calcium rich deep coastal sands of the winter rainfall region. It once occupied 2% of the region. Like Renosterveld, almost half of it has been cleared for agricultural purposes. A Strandveld fire tends to be limited to patches of a few hectares in extent (Moll, 1990). It is also likely to carry fire less often than fynbos because of lower fuel loads, sparse canopy and relatively more succulents (Kruger and Bigalke, 1984).

C. **Succulent Karoo**: This is by far the most extensive Shrubland, covering 65% of the region (Moll, 1990). These dwarf open shrublands are dominated by succulent-leafed plants and were once thought to have had a significant grass component (Acocks, 1953). Because this area is arid, very little of the vegetation has been cleared for agriculture. However, it is grazed extensively by sheep and this has a major impact on the floristic and structural composition of the vegetation (Vlok and Yeaton, 2000).

Moll (1987) states that the importance of the distinction between Heathlands and Non-Heathlands, which in the Cape coincidentally occupy the Mediterranean climate zone, is that both respond differently to fire and other environmental factors. He further lists the differences as described in the Table 1.1.

Table 1.1: Differences between Heathlands and Non-Heathlands

HEATHLAND	NON-HEATHLAND SHRUBLAND
Soils oligotrophic or dystrophic	Soils mesotrophic or dystrophic
Plants essentially evergreen with few annuals; except at the semi-arid fringe	Plants mostly evergreen, a deciduous component is conspicuous and occasionally prominent. Many annuals occur
Leaves generally iso-bilateral	Leaves dorsiventral
Mainly C3 grasses	C3 and C4 grasses are co-dominant
Fairly stable composition	Major vegetation changes in last 2000 years
Geophytes restricted	Geophytes widespread, common and even locally abundant
Restioid, ericoid and proteoid growth forms diagnostic	Growth forms shrubs, succulents, annuals, etc. Restioid, ericoid and proteoid forms generally absent
Most woody plants obligate re-seeders after fire	Most woody plants re-sprout after fire
Mostly intact today	Mostly cleared for agriculture
All endemic Cape families occur here	Many endemic genera and species but no families
All species belong to the Cape Floristic Kingdom	Species belong to the Cape and Palaeotropic Floristic Kingdoms

1.5.4 Afromontane Forest

This vegetation type occupies 1% of the Cape Region, particularly the warm temperate all year rainfall zone in the east (Milton, 1987) and is floristically poor with a total of about 1 000 forest species of which less than 5% are endemic and few are threatened (Geldenhuys, 1989). According to Moll and Bossi (1983), this type of vegetation generally consists of three strata; a closed canopy of evergreen sclerophyllous leptophyllous trees to 30 m with *Podocarpus* spp., *Ocotea bullata*, *Olinia cymosa* and *Olea* spp. being the most widespread and common. Beneath this canopy is a poorly developed short tree and shrub layer and finally there is usually a well developed herbaceous understorey often dominated by ferns. The biggest single block of Afromontane Forest occurs in the Knysna region and covers 900 km^2. The remaining area of forest occurs as scattered small islands, usually on south-facing slopes of the coastal mountains as far west as the Cape Peninsula (Geldenhuys, 1989). In relation to fires Afromontane vegetation does not burn except under severe conditions and despite concerns that regular burning would erode forest patches, there is little information on their sensitivity to repeated fire (Van Wilgen *et al*., 1990).

According to Van Wilgen *et al*., (1990) fires in forest patches can be either crown fires or surface fires, and usually the crown fires are sustained by the surface fires below them. However, under severe conditions fires can advance through the crowns of trees leaving the surface fire some distance behind. They further argue that whether or not forest patches in fynbos will burn depends on whether or not crown fires can develop.

1.6 History of fire in fynbos ecology

The pastoralists of 1652 - 2000 burnt the vegetation on a regular basis to provide pasture for their cattle (Bands, 1977). Van Wilgen (1981) cited Botha (1924) as saying Cape farmers learnt the practice of veld burning from the Hottentots in the early days. Thus, the advent of the European settlers and permanent farmers resulted in marked increase in the frequency of burning. The government of the time was against this practice and passed a law in 1658 prohibiting burning during the dry season (Edwards, 1984). In 1687, another law provided scourging as a penalty for a first offence and death by hanging for a second offence. Thus, nobody was able to burn any grazing, wheat land or forest without permission (Edwards, 1984).

Edwards (1984) noted that the ban on burning was not for conservation but for protecting houses, grain and other possessions of the inhabitants against fire and to prevent the depletion of wood supplies. Botha (1924) noted that little attention was given to these laws and to subsequent re-enactments during the 17th, 18th and 19th centuries under both the Dutch and British governments.

According to Bands (1977), the Department of Forestry adopted a policy of protection of mountain areas from fire when entrusted with the land through the Forest Act of 1913 and in the case of Cederberg since 1876. This policy proved unsuccessful (Kruger, 1974) and uncontrolled fires burnt large areas of fynbos vegetation. The accumulation of evidence indicated that complete fire protection of mountain fynbos was not only impracticable and costly but also undesirable as a conservation measure ultimately resulted in the Department of Forestry adopting prescribed burning as a catchment management and ecosystem conservation tool (van Wilgen, 1981).

According to van Wilgen (1981), in a memorandum drawn up in 1968, the policies of the Department of Forestry were revised and the principle of using prescribed burning as a management tool was accepted and rotation and application would vary from place to place and research into these questions would be tackled in earnest.

Some policies for fynbos management include the application of fire as a natural agent of regeneration (Bands, 1977). However, Moll *et al*., (1980) argued that these policies were controversial since there were few well established theories upon which to base a choice among several alternative prescribed regimes. Below is a list of historical events relating to burning practices as adapted from Edwards (1984) and van Wilgen *et al.,* (1994):

1652 - European settlements- severe penalties for indiscriminate burning
1658 - Burning forbidden during the dry season
1687 - A new law provided for scourging as a penalty for a first offence and death by hanging for a second offence. Nobody had the right to burn any grazing, wheat land or forest without permission. Edwards (1984) notes that these laws were not purported for conservation as such but to protect grain, houses and other possessions of the inhabitants against fire and to prevent the depletion of the wood supplies. Deliberate burning was common early in the dry season but often indiscriminate with regards to season. The veld was burnt as often as possible to provide fresh grazing for stock and as insurance against accidental fires.

1707 - Governor Willem Adriaan van der Stel recommended burning if needed in February to prevent damage to grass roots.

1854 - Colonial botanist Pappe warned against destruction of forests by fire after the introduction of injudicious cutting of the evergreen forests and use of fire.

1865 - Colonial botanist Brown advised that burning be restricted on the crown forest lands. Edwards (1984) alleges that little attention was paid to these laws and to subsequent re-enactments during the 17th, 18th and 19th centuries under both the Dutch and British governments.

1924 - Royal Society of South Africa meeting condemned veld burning and that resulted in the ban on all fires and suppression of all wildfires.

1942 - Initiation of hydrological research on effect of veld fires at Jonkershoek whose results showed that veld fires caused temporary increase in stream flow but had no effect on erosion.

1945 - Publication of the report on the preservation of the vegetation of the south-western Cape and that proposed the first formal prescribed burning on an eight year cycle.

1948 - Initiation of ecological research on veld fires at Jonkershoek, which resulted in the early understanding of regeneration mechanisms

1949 - Documentation of the minimum age for seed production in *Protea repens*-which led to the understanding of the minimum interval between fires

1962 - Renewed realisation that species need fire after a wildfire swept through a senescent *Serruria florida* stand and resulted in profuse regeneration.

1968 - First prescribed burn in a fynbos catchment after concerns about the senescence and loss of *Orothamnus zeyheri* populations, which triggered a decision to set deliberate fires.

1970 - Mountain catchment Act passed by parliament which resulted in private land being managed by prescribed burning for catchment protection with alien control

1970 - The first guidelines for prescribed burning where a fire interval of 8 years was proposed for the Marloth Nature Reserve near Swellendam.

1974 - Department of Forestry stepped up research into fynbos fire ecology, which increased the understanding of fynbos ecology.

1978 - Initiation of the Fynbos Biome Project, which led to an increased understanding of fynbos ecology.

1979 - Report on the conservation of the Kogelberg State Forest, which resulted in the "rule of thumb" for assessing the minimum fire interval for fynbos.

1980 - Introduction of the "natural zone" management in the southern Cape that led to a departure from the rigid approach to prescribed burning.

1992 - Development of a computer based system for managing fynbos catchment areas that facilitated the objective of decision making based on rules that incorporate ecological and practical considerations.

1.7 Role of fire in fynbos ecology

Fire has occurred in fynbos for a long time. People have influenced the incidence of fire in fynbos for at least the last 150 000 years (Deacon, 1986). Fires of human origin have occurred at least for 2 000 and possibly even as much as 250 000 years and perhaps longer (Kruger, 1976). Archaeological evidence suggests that hunter-gatherers manipulated the vegetation through the use of fire - whether to attract herbivores to palatable fresh plant growth or perhaps to increase the productivity of geophytes in genera such as *Watsonia, Chasmanthe* and *Gladiolus* can only be conjectured (Parkington, 1977).

Most fynbos plant species need fire to reproduce, as their seeds need fire stimulation (through the smoke, heating or clearing of vegetation cover) in order to germinate (Cowling and Richardson, 1995). This is particularly important for non-sprouters, but even re-sprouters and bulbs need fire to stimulate fresh sprouting, to stimulate their seeds to germinate so that they can colonise new areas. Some examples of non-sprouters are species of *Protea*, *Leucadendron* and *Aulax*, which store their seeds in woody cones (i.e. serotinous fruits); species of *Mimetes, Leucospermum, Paranomus, Serruria, Agathosma*, *Diosma*, *Muraltia*, *Cliffortia*, *Penaea*, *Podalyria* and *Liparia,* which drop their seeds that ants then bury (i.e. myrmecochorus seeds); some species of *Leucadendron* and *Cannomois*, which produce seed that are buried by rodents (i.e. cached fruits); and the smaller seeded genera *Erica, Metalasia,* and *Passerina* (Cowling and Richardson, 1995).

Mediterranean-climate ecosystems are commonly cited as showing convergent evolution in vegetation structure and function, as all these landscapes are dominated by sclerophyllous evergreen vegetation that dries sufficiently during long summer droughts to produce a predictable and extended fire season (Bond and Keely, 1997). There is evidence that species in these communities have evolved to exploit fires for population expansion and have adapted to these disturbances to the extent that they are 'fire-dependent' for completion of their life cycle (van Wilgen *et al*, 1992). Many species regenerate primarily in the first year or two after fire, either because fire stimulates flowering or seed release from serotinous cones or breaking of seed dormancy by heat or from chemicals in charred wood or smoke (Bond and Keely, 1997). The interaction between fire and regeneration in fynbos plays a dominant role in maintaining the ecosystem structure and function and especially in maintaining community diversity (Viviers, 1983).

1.7.1 Regeneration from seed

Fynbos can burn at intervals from five to forty years and many species are killed by fire and regenerate only by seed (Kruger, 1977). Despite the hazards of a total reliance on seeds for survival, such as accumulation of sufficient seed reserves and seedling survival through the long summer drought, obligate seeders, especially of the Proteaceae frequently dominate the overstorey of fynbos communities. Resprouting shrubs are comparatively rare although such a mechanism would appear to be safer for fire survival (Bond *et al*., 1984).

1.7.2 Fire-dependent germination

According to Keeley and Fotheringham (2001), fire causes a multitude of changes in the environment that enhances site quality for seedling recruitment and thus provides the selective impetus for fire-dependent germination. For fire dependent species, fire may be required for seedling recruitment and may trigger seed regeneration directly through the opening of serotinous fruits or cones, or by inducing the germination of dormant soil-stored seed banks. Fire may also indirectly initiate seedling recruitment by opening gaps in closed vegetation, thus providing conditions suitable for colonization.

1.7.3 Adaptive strategies

Kruger (1977) suggests that plants had developed adaptive seed strategies in the form of seed as follows:

a) Bradyspory or serotiny - retention of the seed in a capitulum until the death of the plant: e.g. some Proteaceae and Bruniaceae).

b) Seed protection through hard coats e.g. Fabaceae, which survive fire on or in the soil and germinate readily after fire.

c) Abundant seed production: e.g. some Orchidaceae, Asteraceae and Ericaceae. Here the seeds are not protected in any notable way but show symptoms of dormancy and because of their abundance, they survive fire to re-establish the population.

d) Seed dormancy that relies on a number of cues: e.g. water, temperature, fire, and leaching of allelopaths.

e) Barochory - seeds that are adapted to remain in the vicinity of the parent populations and

f) Myrmechochory - the seeds have a fatty eliaosome attached to the outer coat which is carried off by ants to their nests. It is protected from fire underground, and only germinates when conditions are suitable after the fire.

1.7.4 Fire-stimulated germination

A study conducted by Brown (1993), on the promotion of seed germination in the fynbos fire ephemeral, *Syncarpha vestita*, by plant-derived smoke and aqueous smoke extracts derived from stem and leaf material of the ericoid-leaved shrub, *Passerina vulgaris* confirmed the concept of fire stimulated germination.

1.7.5 Fire related germination cues

Moll and McKenzie (1994) conducted research on the germination ecology of six fynbos shrubs. The study was aimed at explaining the recruitment and coexistence of species that establish after fire. This study predicted that each species would have different germination cues for different regeneration niches. When the species were subjected to natural fire frequencies of ten to twenty years, the result was fire related cues, seed dormancy, extended longevity and fire-related germination cues.

1.7.6 Senescence in fynbos

Bond (1980) presents evidence that shows that a burn in fifty year old fynbos in Southern Cape resulted in very poor regeneration of seeding species. He suggests that this is due to degradation of the seed of the seed pool with advancing age and senescence of the vegetation. When Kruger and Lamb (1979) described the five fire successional phases in fynbos, he noted that over long fire free periods many species become senescent and die, surviving only as propagules in the soil.

1.7.7 Fires contribution to stages of fynbos development

According to Kruger (1974), fire plays a role in rapid growth of fynbos and that both canopy and basal cover reached seventy to ninety percent of original levels within 25-30 months after fire compared to an area that had not been burnt.

1.7.8 Maintenance of species diversity

Fire is implicated in the maintenance of species diversity because it prevents competitive exclusion of species that would exist if the community reached equilibrium, without the periodic, marked disturbance of fire (Kruger, 1983). This richness is possibly maintained by the creation of transient niches in fires, and recurrent fires could be the driving force in fynbos speciation (Cowling, 1987). If species diversity and community structure and processes are to be maintained, then the disturbance regime under which the species evolved should be emulated as closely as possible.

1.7.9 Evolution of traits

According to Cowling (1987), fire has played an important role in the evolution of traits and life histories of fynbos and is an important disturbance factor of the shrublands and an important selective agent at all levels of biological organization. Fynbos requires periodic fires to stimulate recruitment and to retain maximum species richness (De Villiers *et al.,* 2005).

1.7.10 Formation of gaps

According to Dunn and DeBano (1977) fire is responsible for removal of vegetation (formation of gaps) resulting in an increase in irradiance at ground (seedling) level and a reduction in compensation for water. Additional to that, fire accelerates the mineralization of organic matter, making inorganic nutrients more readily available. Fire is also associated with a reduction in herbivore populations by direct mortality and indirectly by opening the habitat and making herbivores more vulnerable to predators (Quinn, 1994).

1.7.11 Effect of fire cycles on cover and densities of sprouting species

According to Vlok and Yeaton (2000), the fire regime of Mediterranean shrublands can affect the proportion of sprouting to non-sprouting species in a community. This is attested to by Cowling and Lamont (1987) who suggested that a general increase in fire frequency coupled with cool spring burns in Mediterranean type shrublands of South Africa and Australia may cause local extinction of non-sprouting species.

1.7.12 Soil nitrogen and the role of fire as a mineralizing agent

Fire is an effective mineralizing agent in soils of the coastal fynbos and has substantial effects on the concentration, form and distribution of low nitrogen reserves (Stock and Lewis, 1986).

1.7.13 Sustained stream flow and water quality

Fynbos shrublands are managed for a variety of goals, one of the most important being maintaining sustained yields of high quality stream flow. According to van Wilgen *et al*., (1990), stream flow can be increased by frequent burning in some cases and the actual magnitude of such increases depends largely on structural and other features of vegetation. Bosch *et al*., (1986) found that fire causes an initial increase in stream flow by reducing the evapotranspiration and eliminating water loss due to interception of rainfall by the vegetation canopy.

1.8 Fire Regimes in Mediterranean climate regions

A fire regime is a statistical characterization of recurring fire in an ecosystem and parameters that are often measured include fire interval, size, intensity and season (Moritz *et al.,* 2004). Mediterranean-climate regions occupy less than 5% of the earth's surface, yet they contain 20% of the world's flora (Cowling *et al*., 1997). Mediterranean ecosystems are often characterised by occurrence of wildfires and summer droughts (Pausas, 1999). In Mediterranean areas, wildfires constitute one of the most relevant environmental problems because they are frequently considered a major cause of soil degradation and desertification (De Luis *et al.*, 2001).

Mediterranean regions are centres of human growth and thus anthropogenic causes of fire that impact on natural ecosystems are a matter of concern. This is because of the potential for introducing new disturbances or altering the frequency and intensity of the existing ecosystems (Pausas, 2001). The drivers of fire regimes, and changes in fire regimes, have been studied in detail in Africa, Europe, Australia and the United States of America. Examples of the different fire regimes of the different parts of the world are discussed below.

1.8.1 Fire regimes of Australia

A study by Bradstock (2010) indicates that patterns in fire regimes across Australia exhibit biogeographic variation in response to four processes. Variations in area burned and frequency result from differences in the rates of switching of biomass growth, availability to burn, fire weather and ignition. Therefore, differing processes limit fire in differing ecosystems. Results of the study indicated that fire regimes are primarily related to fluctuations in available moisture and dominance by either woody or herbaceous plant cover. The study also indicates that the main sources of ignition is predominantly human in tropical open forests, lightning in temperate grassy woodlands whilst a combination of both human and lightning are found in Arid woodlands and Temperate dry sclerophyll and lightning in Cool temperate wet sclerophyll forests.

The range of inter-fire intervals for Tropical open forests is 2-5 years (Williams *et al.*, 2002), for Temperate grassy woodlands more than 10 years and Arid woodlands range between 10 and 80 years (Hobbs, 2002). Temperate dry sclerophyll forests are 5-15 years (near urban areas), 10-25 years (in remote areas), whilst that of cool Temperate wet sclerophyll forests is more than 20 years (Gill and Catling, 2002).

The average number of Very High to Extreme fire weather days per annum for Tropical open forests is more than 30 (Williams *et al.*, 2002), 23 for Temperate grassy woodlands (Lucas et al., 2007), more than 60 for Arid woodlands (Williams *et al.*, 2001), 7.6 for Temperate dry sclerophyll forests (Lucas *et al.*, 2007) and 2 for Cool temperate wet sclerophyll forests (Lucas *et al.*, 2007).

The fire season for tropical open forest is winter-spring, summer-autumn for arid woodlands, spring-early summer (south-east), summer-autumn (south-west) for Temperate dry sclerophyll forests and late summer-autumn for Cool temperate wet sclerophyll forests.

1.8.2 Fire regimes in Europe

In study conducted by De Luis *et al.*, (2001), wildfires constitute one of the most relevant environmental problems and are frequently considered a major cause of soil degradation and desertification in western Mediterranean shrublands. They describe the western Mediterranean as having the world's highest density of cyclogenesis. Their study revealed that there is decreasing precipitation in the western Mediterranean, particularly during summer and an increased variability of the rainfall distribution.

Other studies of western Mediterranean climate based on meteorological records have also observed a trend towards decreasing precipitation in southern Europe since the 1930s (Maheras, 1988). Palutikof *et al.*, (1996) shows that an agreement between model predictions and observations suggests that this trend could be associated with global warming.

De Luis *et al*., (2001) concludes that in western Mediterranean climatic trends between 1961 and 1990 show a particular decrease in the average annual precipitation and may have favoured droughts and fire frequency and reduced productivity in the water- limited ecosystems of the Region of Valencia.

Moreno *et al*., (1998) suggests that despite the increase in fire prevention and fire suppression efforts during the last decades, the number of fires in various parts of the European continent continued to grow markedly. Pausas (2001) concludes that the sudden increase in fire occurrence and area burned in European countries during the mid 1970s cannot be explained by climatic parameters alone because socio economic issues should be considered.

1.8.3 Fire regimes of Chile and Southern California

Montenegro *et al*., (2004) compared fire regimes of two Mediterranean-climate regions; Chile (mattoral) and the southern area of California (chaparral). Results showed that with the mattoral, all fires are driven by anthropogenic activities whereas lightning fires resulting from thunderstorms are frequent in the chaparral. Their results indicate that in both regimes, fires are frequent in summer due to high accumulation of dry plant biomass for ignition.

In Chile and California, Mediterranean landscapes have been altered by replacing vast stretches of continuous wild ligneous vegetation for patches of vegetation dispersed in a mosaic interspersed with less flammable agricultural, weedy herbaceous communities and suburban vegetation as well as non-flammable urban developments (Lepart and Debussche, 1992).

Keeley, (1987) showed that although the fire frequency had increased in both regions, there was no explanation for the differences in the total area over the same period in Chile and in California. Minnich (1989) concluded that fire prevention is less effective in Baja California and thus due to human ignitions, fire frequencies are up to five times greater than in Southern California.

Minnich (1983) argues that most fires in the northern Baja California are driven by onshore northern-western breezes and these have a different capacity for fire spread than fires driven by Santa Ana winds which argument is disputed by Keeley and Fotheringham (2001) who dispute by the fact that these winds diminish the further south of the border one goes. On the other hand, Freedman (1984) concludes that massive Southern California fires are commonly driven by Föhn-type Santa Ana winds that diminish south of the border.

1.8.4 Fire regimes of Southern Africa

According to a study conducted by Archibald *et al.*, (2009) in Southern Africa, human activities have little effect on fire regimes and climatic factors either limit or promote widespread fires. Their results indicate that climatic and environmental conditions are likely to override human attempts to prevent fire unless tree cover increases to 40% or more. Archibald *et al.,*(2009) concluded that Southern Africa is characterised by high inter-annual variability in rainfall and because all other factors influencing burn area on the continent change slowly at decadal time scales, inter annual variability in burnt area is likely to be driven largely by variation in rainfall and dry season length.

In the same study, Archibald *et al.*, (2009) concluded that the drivers of frequency of ignitions in Southern Africa limits or promotes burnt area in the region. Lightning frequency over the fire season came out as one of the least important predictors of land tenure. They concluded that high human densities (>10 people per square kilometre) resulted in less area being burnt, probably because of the effect that people have in fragmenting the landscape through cultivation, grazing livestock, fuel-wood collection, roads or possibly suppressing fires.

1.8.5 Fire regimes in the Fynbos Biome

Research on the fire regime of the Fynbos Biome has been carried out by several researchers on the different conservation sites of the Western Cape Province and below are some of the conclusions drawn about the fire regime of the Fynbos Biome.

The Table Mountain National Park

Forsyth and van Wilgen (2008) concluded that the mean fire return interval of the Table Mountain Park is 22 years and the incidence of short intervals (equal or less than 6 years) had increased more than four times in the last twenty years and a shift away from the practice of prescribed burning in winter and spring to autumn could have contributed to an increase in the number of fires burnt in autumn. Most of the fires were of unknown origin (63%), 23% from prescribed burning and only 1% from natural causes (falling rocks, lightning).

Cederberg Reserve, greater Hottentots-Holland, Jonkershoek, Groenlandberg, Theewaters, Haweqwa and Waterval reserves, greater Swartberg area, greater Swartberg area, Towerkop, Gamkaskloof reserve, Swartberg East Reserves, greater Outeniqua area, greater Outeniqua area, Doring Rivier and Witfontein reserves.

In a study carried out by Southey (2009) in almost all the reserves managed by CapeNature except the Kogelberg Nature Reserve, conclusions drawn by quantifying the seasonality of fire and fire frequency showed that most fires burn in summer except the reserves in the southern Cape where there was less of seasonality trend. The differences in the seasonality are ascribed to seasonal differences in weather between the regions.

In this study, fire return intervals analysis showed that there was a longitudinal gradient with regards to fire frequency where the Cederberg and Hottentots Holland have a greater frequency of fire intervals between 10 and 20 years. This indicates that fires are more frequent in the western areas compared to the eastern sides.

Bontebok National Park

Most fires in the Bontebok National Park as described in a study by Kraaij (2010) were caused by prescribed burning (70%) and the remaining 30% were said to be accidental. There is a mean fire return interval of 5.8 years instead of the expected 4 year interval for similar vegetation to the Bontebok. This could be a reflection of fuel that has accumulated as a result of a prevailing grazing regime to support a fire under weather conditions suitable for prescribed burning (Bond, 1997).

In this study, most of the fires fell in the ecologically acceptable fire season (December to April). Large proportions of total area burnt were by large fires that are a cause of concern, particularly in light of the limited size of the park. The majority of prescribed fires occurred late in the prescribed burning season (March and April) which is a relatively cooler season hence the fires tend to be smaller.

Until a few years ago when CapeNature compiled an accurate record of the fires that burnt in their reserves, few areas in the Fynbos Biome had good fire records which made it almost impossible to construct the historic (or pre-historic) fire regime in the biome. Fire regimes at any given sites are never fixed and they occur at varying intervals, in varying seasons and at different intensities. Each fire is therefore unique and its effects will depend on both its own parameters and the nature of fires that preceded it (van Wilgen, 1987).

1.9 Sources of ignition

The variety of physical causes of fire ignition in vegetation includes falling boulders, earthquake activity, spontaneous combustion and volcanic action which is absent in South Africa (Edwards, 1984). Lightning is the main natural source of ignition of vegetation in the Western Cape but sparks from rolling quartzite also cause veld fires (Kruger and Bigalke, 1984). Bond and van Wilgen (1996) cite human action as the main cause of contemporary veld fires and with increasing population levels, the relative importance of humans as a source of ignition will continue to increase.

Fires in fynbos are caused by lightning, trains, prescribed burning, camp fires, squatters, arson, smokers, honey hunters and rolling rocks (Le Roux, 1979 and Edwards, 1984). Falling rocks from earth tremors can also cause fires and numerous fires were observed after severe earth tremors at Ceres (Department of Forestry, 1969/70 as cited by Edwards, 1984). Rocks can be dislodged by various agents including mountain climbers and baboons (Brown *et al*., 1993). Wicht (1945) cites direct evidence of a fire that was started by a falling rock accidentally dislodged by a labourer constructing a mountain path at Jonkershoek. He also notes that natural falls of rock as well as those caused by baboons were observed to dislodge and roll rocks from precipices that resulted in fires. Andrag (1977) recorded that 23% of fires recorded between 1958 and 1974 in the Cederberg Mountains were caused by rolling rocks. Edwards (1984) argues that though fires ignited by rock falls do occur, they are limited to mountainous areas where there is adequate flammable plant material during dry weather conditions. Lightning strikes occur on mountain tops during summer thunderstorms, which result in fire ignitions during this period of vegetation stress. Lightning strike density has been recorded at less than 1 km^2 /year for the Western Cape Region, which is equivalent to less than one successful lightning induced fire for every five hundred lightning flashes per square kilometre every five years (Edwards, 1984).

1.10 Legislation governing veld fires

South African Fire Management is regulated by various sets of legislation. With relevance to the legislation that guides and binds the Kogelberg Nature Reserve, the following legislation is applicable:

- National Veld and Forest Act, 1998 (Act No. 101 of 1998)
- Forest Act, 1984 (Act No. 22 of 1984)
- Mountain Catchment Areas Act, 1970 (Act No 63 of 1970)
- Nature Conservation Ordinance, 1974 (Ordinance No.19 of 1974)
- Occupational Health and Safety Act, 1993 (Act No.85 of 1993)
- Compensation for Occupational Injuries and Disease Act, 1993 (Act No.130 of 1993)
- Criminal Procedure Act, 1977 (Act No.51 of 1977)
- Fire Brigade Services Act, 1987 (Act No.99 of 1987)
- Conservation of Agricultural Resources Act, (Act No.43 of 1983)
- Disaster Management Act, 2002 (Act No.57 of 2002)
- National Environmental management Act, 2003 (Act No.10 of 2003)
- National Environmental Management: Protected Areas Act, 2004 (31 of 2004)

For this chapter special attention and emphasis will be on the **National Veld and Forest Act, 1998 (Act No. 101 of 1998**). The purpose of this Act is to prevent and combat Veld, forest and mountain fires throughout the Republic. Under this Act, the following become applicable:

a) **Fire Protection Associations** - Chapter 2 of the Act provides for the establishment, registration, duties and functioning of Fire Protection Associations (FPA's) and the appointment and duties of a Fire Protection Association. CapeNature is compelled in terms of the section 4 of the act to join an FPA registered in the area in which the land is situated

b) **Firebreaks** - In terms of section 12 and 14 of the Act, every landowner must prepare and maintain firebreaks as determined in section 13. Failure to prepare a firebreak is an offence in terms section 25(3), unless exemption has been made by the Minister in terms of section 15.

c) **Fire Fighting Preparedness -** There is also a further duty on landowners to have equipment, protective clothing and trained personnel available in the eventuality that there may be a fire on their property (section 17). Failure to meet this requirement is an offence in terms of section 25(4).

d) **Actions to Fight Fires** - Every land owner must do everything in his power to stop the spread of fire from his land or that of adjoining land (section 18(1) (b). Failure to do so is an offence in terms of section 25(5).

e) **Agreements for Mutual Assistance** - Section 19 of the Act provides for agreements to be entered into to provide mutual assistance in fighting fires. These agreements may provide payment of compensation for the assistance rendered.

f) **Penalties** - Section 24 of the Act makes provision for the imposition of a fine and/or imprisonment for various offences committed in terms of section 25.

g) **Presumption of Negligence** - If a person institutes civil proceedings for loss suffered from veld fire which the defendant caused or started on or spread from land owned by the defendant, the defendant is presumed to have been negligent until the contrary is proved, unless the defendant is a member of an FPA in the area where the fire occurred (section 34).

h) **National Fire Danger Rating System**

The South African National Fire Danger Rating System has been derived from the United States National Fire Danger Rating System that is described by Deeming *et al.,* (1978) and is well documented. The system uses weather data to simulate trends in the moisture content of fuels that largely affect fire danger. In order to predict the expected rate of fire spread and intensity of free burning fires, the system uses

Rothermel's (1972) fire spread model. This model requires the physical and chemical make-up of the model and environmental conditions in which it is expected to burn. These are obtained from weather data and the simulated moisture content of fuels, and from the specific fuel model for the vegetation type concerned. The structure of the system is shown below:

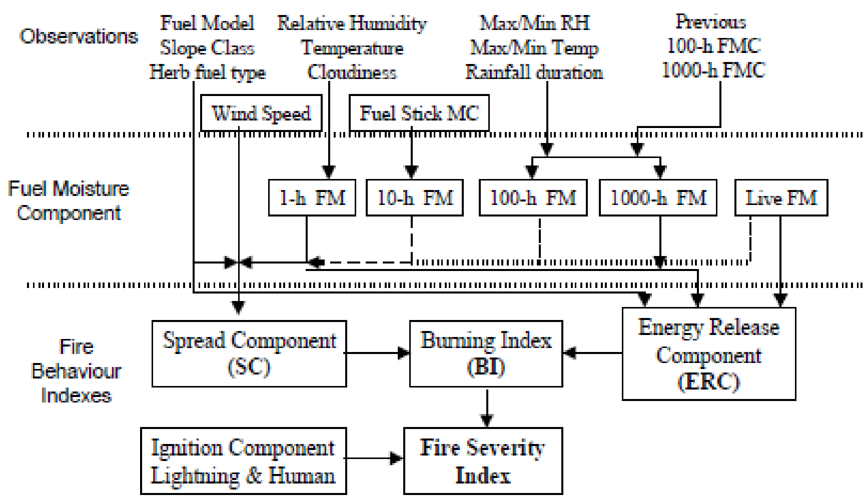

Figure 1.1: Components of the United States National Fire Danger Rating System (Willis et al., 2001). The components show the physical, chemical and environmental requirements to make the model work.

On 8 July 2005, the Director of Forestry Regulation published regulations in terms of the National Veld and Forest Fire Act, 1998 (Act No.101 of 1998). The regulations provide for the structure and formula, fire danger rating, fire regions and threshold values and provides for the delegation of the communication of the fire danger rating to the South African Weather Services. Burns are allowed during periods where indicative colour is blue and green. No open-air fires are allowed during orange and red periods. During yellow periods, only fires authorised by the Fire Protection Officer (where a fire Protection Association exists) or the Chief Fire Officer are allowed, unless those fires are in designated fireplaces.

The National Veld and Forest Act (section 10(2)) is quite clear that where a warning has been published the fire danger is high, no person may light, use or maintain a fire in the open air in the region where the fire danger is high. The Act does not make allowance for exceptions or exemptions.

In respect of burning fire breaks, section 12(4) provides that a landowner may not burn a fire break if a warning has been published because the fire danger is high in the region. An exemption is provided for in section 12(10) which provides for the possibility of a fire protection association making different rules for the burning of firebreaks if those rules are approved by the Minister.

1.11 Training

According to the Fire management Policy and Guidelines of CapeNature version 4 of November, 2006, the following objectives are applicable when it comes to training for fire control and suppression;

a) Establishment of training, skills knowledge, experience and physical fitness standards
b) Improvement of fire safety
c) Reduction of costs by increasing efficiency through training

1.12 Fire Management Operations

According to the policy and guidelines for CapeNature (version 4, 2006), Fire Management Operations in the Western Cape are based on preparedness.

Preparedness – this involves the completion of a risk analysis of the potential for fires on each reserve and for managers to plan for the eventuality of fires, predicting the type and possible location of fires. They need to have the following;

i) **Fire Management Plan** - a detailed inventory on the resources available and how they are to be deployed which includes fire protection measures such as firebreaks and prescribed burn schedules.
ii) **Pre-season audits** - this should be carried out yearly in consultation with the Business Unit Manager to identify all risks and ensure their suitability to contend fires.
iii) **Fire Danger Indices** – These are forecasts from which all management decisions can be made which include planning prescribed burns or placing of fire-fighting teams on stand-by.

1.13 Equipment required for conservation Fire Management

Based on information that has been drawn from the website of the Lowveld and Escarpment Fire Protection Association (www.lefpa.co.za), the following equipment is recommended for managing fires in Commercial Farming/Conservation areas of 4 000-10 000 ha;

- 4 x truck or tractor drawn fire fighting units with a minimum capacity of 5 000 litres of water
- 2 x bakkie fast reaction units with a minimum of 500 litres capacity of water
- 100 x Rake Hoes
- 40 Knapsack Pumps (minimum 15 litres capacity)
- 2 x Drip Torches
- 6 x Mobile Radios
- 4 Hand Held Radios
- 1 Cell phone
- 5 x First Aid Kits
- 100 x fire fighters
- 5 x crew leaders
- 1 x fire boss

1.14 Fires and climate change in the Western Cape

Van Wilgen *et al.*, (1992) argue that if fires become more frequent in the Western Cape, it will result in negative impacts on the biodiversity. For example, if fire is reduced from once in 15 years to once in 5 years, many plant species would become extirpated as they would not have enough time to mature and set seed between fires.

In a study by van Wilgen and Scott (2001) the number of days per year when the fire danger index exceeded fifty (fire behaviour described as dangerous and extreme caution required when controlled burning is carried out) for four days or more was found to be “more frequent in the last decade of the 20th century than in the preceding two and a half decades”. This suggested that this “may be indicative of changing climatic conditions". However, the data presented were not comprehensive enough to make definitive conclusions. The factors that would promote higher fire frequencies and intensities would include lower rainfall (reducing the moisture content of fuels), lower relative humidity, longer droughts, and higher wind speeds. Such changes are predicted by climate change scenarios (Midgley *et al*., 2005).

Wilson *et al.,* (2010) alludes to the fact that climate change is likely to lead to a substantial increase in fire frequency in the Fynbos Biome. The Kogelberg Nature Reserve being a unique conservation area needs to be studied to confirm any suspicion that its fire regime may have changed and whether the alteration is being driven by climate change.

1.15 Study site

Kogelberg Nature Reserve is often considered the heart of the Cape Floral Kingdom (CFK), because of the exceptional quality of its fynbos (Kogelberg Biosphere Reserve, 1991). It is one of the six Floral Kingdoms recognised throughout the world and whereas the other kingdoms encompass more than one continent, this kingdom is confined to one province at the southern tip of Africa (Jordaan, 1991). Oliver *et al.,* 1983, found that the floristic diversity of this area is also evident from the distribution patterns of a sample of 1 936 plant taxa from plant families and genera which are characteristic of the Cape flora such as Proteaceae, Ericaceae, Restionaceae and Bruniaceae. Kogelberg Nature Reserve is said to have the highest percentage occurrence of these taxa per quarter degree square (20 - 26%). It has twice the species density for these taxa in the northern parts of the Cape floral region (Cederberg) and more than three times the species density in the mountains of the southern and eastern parts of the region (Oliver *et al*., 1983; Jordaan 1991).

1.15.1 Location on map and identification of geographical co-ordinates

The Kogelberg Nature Reserve is situated between latitudes 34° 10' and 34° 21' S and longitudes 18° 49' and 19° 03' E as shown in Figure 1.1. The reserve lies within the southern stretch of the rugged Hottentots Holland mountain range, and has remained isolated and remarkably unspoilt (CapeNature Reserve descriptions, 2004). Its high mountain peaks, steep kloofs, valleys and several tributaries of the pristine Palmiet River create a sense of remote wilderness.

The reserve falls between the Steenbras catchment area and Kleinmond, which is 5 km to the south. It is bounded by coastal areas to the west and agricultural and forestry land to the east. The area of the reserve is 18 920 ha.

1.15.2 Description of boundaries

Boucher (1982) describes the Kogelberg Nature Reserve as stretching from the eastern shores of False Bay to the western edge of the Elgin Basin and includes the southern end of the precipitous Hottentots Holland range, bordering on the Steenbras Dam to the North and Betty's Bay to the South. The highest peak (the Kogelberg Peak-1 268 m) is clearly visible from Cape Town some 50 kilometres away to the north-west.

1.15.3 Neighbouring towns

The nearby towns to Kogelberg Nature Reserve are; Gordon's Bay, Betty's Bay, Fisherhaven, Hawston, Kleinmond, Pringle Bay, Rooi Els, Elgin and Grabouw.

1.15.4 History of Kogelberg Nature Reserve

The Kogelberg area has evidence of early Stone Age hunters, who probably lived off game, shellfish and edible plants. Khoi people inhabited the area from about 100 000 years ago until modern times, and their middens and burial sites can be found along the coast. Eighteenth century European explorers described the beauty of the area and the plentiful game, but early farmers found the area too rugged for agriculture. This meant that the Kogelberg was left practically untouched over the years, unlike many other areas of the Cape (Kogelberg Biosphere Reserve, 1991). According to Boucher (1978), William Paterson produced one of the earliest written accounts providing a glimpse of the area in 1777 as a wooded coastline with a number of streams, lakes and animals.

In 1810, the government of the Cape demarcated certain Crown Lands, which included the Kogelberg area. Access was extremely difficult until 1935 when a road was built. In 1937 the then Department of Forestry became responsible for the area and declared it a State Forest. During World War II, a military road was built around the coast and the peripheral coastal area slowly became more developed. Two portions namely Oudebosch and Dwarsrivier were purchased by the State with the aid of the Cape Tercentenary Fund to consolidate the reserve in 1961. Oudebosch was previously owned by the Hangklip Beach Estate Company and it had served as a market garden for vegetables. On being acquired by the State, it became a Protea Research Farm under Dr Marie Vogts of the former Department of Agricultural Technical Services. Kogelberg was transferred to CapeNature in 1987, and declared a nature reserve.

1.15.5 Proclamation Date and Number

The area was proclaimed a mountain catchment area in October 1981 in Government Gazette No. 7824. The reserve is currently demarcated as State Forest under the Forest Act, no. 122 of 1984. Legal responsibility for this total area was assigned to the Administrator of the Cape by State President's Proclamation No.97 of 1992, in Govt. Gazette no. 14246 of 21 August 1992.

1.15.6 Biosphere Reserve

Kogelberg Nature Reserve is now managed according to the internationally accepted principles of a biosphere reserve. This implies that the sensitive core area of 18 920 ha remains pristine and essentially wild, with a high level of biological diversity, and is buffered by a more resilient area. Beyond the reserve's borders, agriculture and commercial pine plantations form a transitional zone. The biosphere concept accommodates conservation and development, and ensures that sensitive areas and biological diversity are adequately protected.

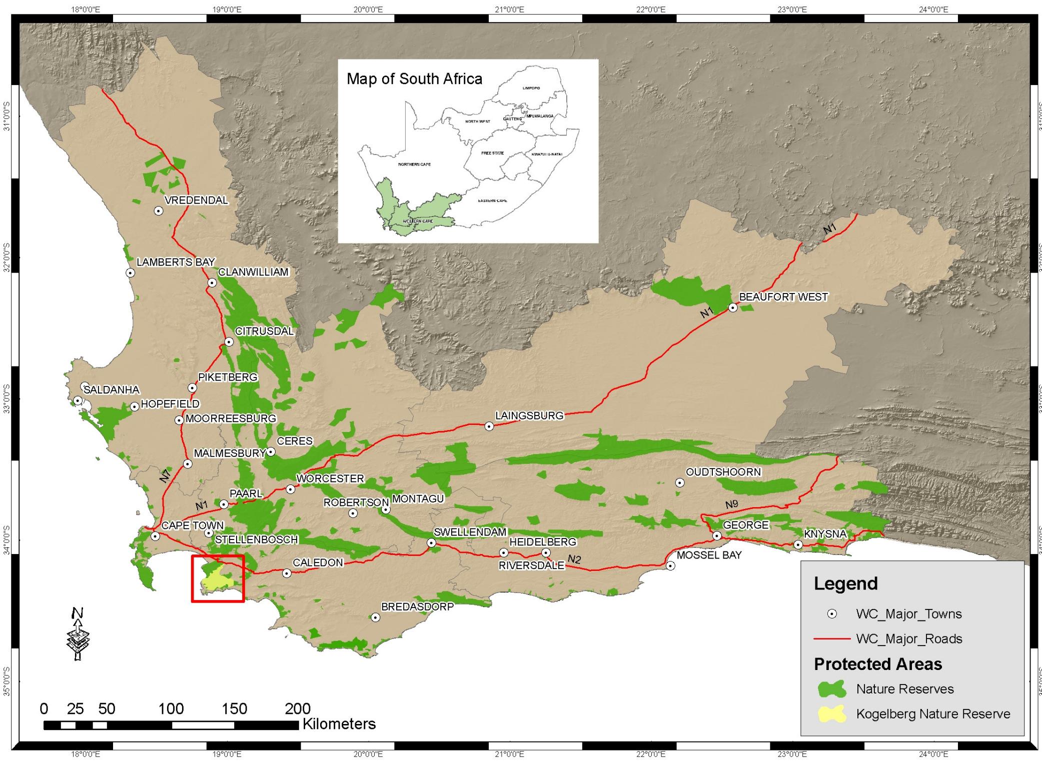

Figure 1.2: Map showing the location of the Kogelberg Biosphere Reserve generated from Arc view GIS. The map shows the Kogelberg Nature Reserve in yellow and the other surrounding nature reserves in green.

1.15.7 Vegetation

The long isolation of the Kogelberg area has helped to protect its floral wealth and keep it clear of alien vegetation, and today the reserve presents perhaps the finest example of mountain fynbos in the Western Cape. It has a species list of 1 654 plant species, of which about 150 are locally endemic (Boucher, 1982; Jordaan, 1991). Many spectacular members of the protea family occur in the reserve. These include the endangered marsh rose, *Orothamnus zeyheri*, once on the brink of extinction, and now known to occur on a few inaccessible peaks; and the highest concentration of mimetes species in the Cape, most notably the endangered *Mimetes hottentoticus* and *Mimetes capitulatus*.

Kogelberg has three patches of relic indigenous forest, Louwsbos, Platbos and Oudebos. These patches are similar to the Knysna forests, and include *Cladrastis lutea, Celtis africana* and *Rapanea melanophloeos* trees. The Palmiet River and its associated riparian vegetation are of the most pristine in the south-western Cape.

1.15.8 Climate

Boucher (1978) describes the climate of the Kogelberg as Mediterranean-type which according to Köppens classification can be classified as **Csb**, **Cfsa** and **Cfsb** or, according to Thornwaite's classification as **BB**'s. This classification is similar to the classification described by van Wilgen (1984).

Rainfall

Jackson and Tyson (1971) showed that the winter rainfall is associated with eastward moving cyclonic systems passing the south-western Cape with orographic rains occurring which may last for several days and the rainfall being heavier in the mountains. Boucher, 1978 explains that due to passing weather depressions; the wind backs to south-westerly and later to southerly when clearing showers occur. These conditions result in snow often associated with the passage of a cold front and fine weather following a depression that may last for over a week.

The variation in precipitation over different parts of the area is considerable, for example at Steenbras Dam, an annual average rainfall of 1050.7 mm was recorded at an altitude of 579m in contrast to a record of 874 mm recorded at a nearby weather station situated at an altitude of 338m (Weather Bureau, 1957). According to Boucher (1978), between 80 and 120 days per year have at least 0.25mm of rain, 80 days have more than 1,00mm of rain and 10 days have 10,00mm or more of rain per day.

Temperature

Tyson (1969) describes the temperature of the Kogelberg as equable due to the close proximity to the sea. This study suggested that the inland temperatures bordering the Elgin Basin are lower and frosts are common whilst the higher altitude of the Steenbras dam has intermediate conditions between the coastal plain and the Elgin Basin. Insolation is less on the south facing than on the north facing slopes and the moister condition of some of the southerly slopes is probably associated with the reduced insolation.

Data from the Weather Bureau of 1954 show that the average annual range between the mean daily maximum and minimum temperatures is 7.1^{o}C in comparison to 4.2^{o}C at Cape Point which is almost surrounded by the sea. The latter is regarded as the narrowest average range in South Africa. The average annual range between the maximum and minimum daily temperatures at Elgin is 28.1^{o}C, whereas at Steenbras Dam it is at 22.3^{o}C in contrast to 7.1^{o}C at Silversands. The lowest average daily maximum temperatures occur during July and the highest in January and February (Boucher, 1978).

Wind

Swart (1956) and Tyson (1969) describe the wind in the south-western Cape as associated with disturbances in the circum-polar westerly winds, taking the form of a succession of eastward moving cyclones or depressions and anti-cyclones.

Jackson and Tyson (1971) showed that summer circulation is characterized by south and south-east winds prevailing for about 60% of the time, with force and direction being modified to some extent by the alignment of the mountains. The southeasters are notoriously strong and gusty, often blowing with gale force for two or three days at a time. These winds blow during the dry season and are usually associated with typical fair weather clouds capping the mountains such as the well known "table-cloth" on Table Mountain.

Boucher (1978) observed that plants growing on the mountain peaks where they are exposed to the full force of the south-east and north-west winds are deformed by the strength of the winds. This study suggested that the vegetation along the coast shows characteristic deformation, particularly from the constant direction of the south-east wind. The strong persistent southeasters blow during the fire season and are instrumental in the formation of dunes, particularly in the constantly burnt areas.

Relative Humidity

Boucher (1978) describes the average monthly relative humidity of the Kogelberg as being higher in the morning (averaging 77.4%) than in the evening (averaging 67.7%). The relative humidity remains fairly constant throughout the year.

1.15.9 Incidence of fire (both historically and currently)

Anthropogenic changes to the natural fire regime of the area probably pre-date the arrival of colonial settlers. People have influenced the incidence of fire in fynbos for at least the last 150 000 years (Deacon, 1986). Archaeological evidence suggests that hunter gatherers known as the Soaqua (Parkington, 1977) who populated the Fynbos Biome since 10000 BP, probably used fire stick farming to encourage natural fields of geophytes (Deacon, 1992), or to attract game to palatable fresh plant growth (Parkington, 1977). The practise of fire stick farming in the fynbos at least since the Late Pleistocene is thought to have resulted in a quantum increase in the incidence of fires over that of the natural fire regime. Around 2000 BP pastoral people, the Khoi Khoi herders, moved into the biome with sheep and cattle, and burnt the vegetation on a regular basis to provide pasture (Bands, 1977). Historical records show that these burns were carried out in late summer (*e.g.* Mossop, 1927). These herders may have pushed the San into more marginal habitats so that they permanently occupied the mountains and in turn changed the fire regime through regular patch burning (Sugden and Meadows, 1990).

Early European settlers in the Kogelberg Conservation Area burnt the mountain vegetation in late winter or early spring to provide summer grazing. These unseasonable fires would have been detrimental to the fynbos (Kruger and Bigalke, 1984).

1.15.10 Recent and current incidence of fire

The Policy Memorandum of CapeNature of 2006 recommends prescribed burning of compartments on a 12-14 year cycle. The burning season extends from 1 February to 15 April. Scheduled burns carried out under suitable fire hazard conditions, are subject to prior approval from the Regional Director. No burning during spring is permitted.

At present a form of Adaptive Interference Fire Management is applied where a stochastic fire regime, utilising natural ignitions, is supplemented with intentional burns if necessary. The aim is to emulate the natural fire regime as closely as possible so as to maintain fire patterns that allow the natural vegetation to persist in full diversity and vigour

1.15.11 Why preserve the Kogelberg?

Jordaan, 1991 claims that 70% of the fynbos plant species are endemic and are not found naturally anywhere else on earth. The Kogelberg is said to be the centre of endemicity where roughly a fifth of all fynbos species are known to occur. To illustrate the conviction that the Kogelberg forms the nucleus of the Cape Floral Kingdom a comparison with areas of well known conservation status as shown in Table 1.2 below.

Table 1.2: The conservation value of the Kogelberg Nature Reserve compared with other well known conservation sites and two countries - adapted from Jordaan (1991)

	Nature Reserves			Countries	
	Kogelberg	De Hoop	Kruger N P	British Isles	South Africa
Size (ha)	19 000	40 000	2 000 000	3 080 000	118 500 000
Plants	1 600 spp., 150 end	1 400 spp., 50 end	2 000 spp., <10 end	1 500 spp., 18 end	243 spp., 50 end
Mammals	70 spp., 0 end	57 spp., 0 end	137 spp., 0end	50 spp., 0 end	382 spp., 195 end
Reptiles	43 spp., 1 end	36 spp., 0 end	112 spp., 4 end	6 spp., 0 end	106 spp., 61 end
Amphibians	22 spp., 6 end	14 spp., 0 end	33 spp., 0 end	7 spp., 0 end	

*spp: Total number of species *end: Total number of endemic species

1.16 United States National Fire Danger Rating System (NFDRS)

The United States National Fire Danger Rating System provides a guide to wildfire control and suppression by its indicator values that measure the relative potential of initiating fires (Cohen and Deeming, 1985). The US NFDRS was first introduced and applied nationally in the US in 1972. The model has been tested in South Africa, Europe, Asia and Australia (Willis *et al.,* 2001). In addition, two other models are incorporated into the United States National Fire Danger Rating System. They are the fuel and moisture models that simulate fuel types and moisture content of the dead and live fuel respectively (van Wilgen *et al.*, 2003)

The USNFDRS model produces a range of indices that relate to different aspects of the fire danger problem, and this in turn would allow fire managers to adequately address these aspects (for example, the energy release component would track trends in fire severity and can be used for medium-term planning, while the burning index estimates the difficulty of fire control and can be used to decide on levels of initial attack).

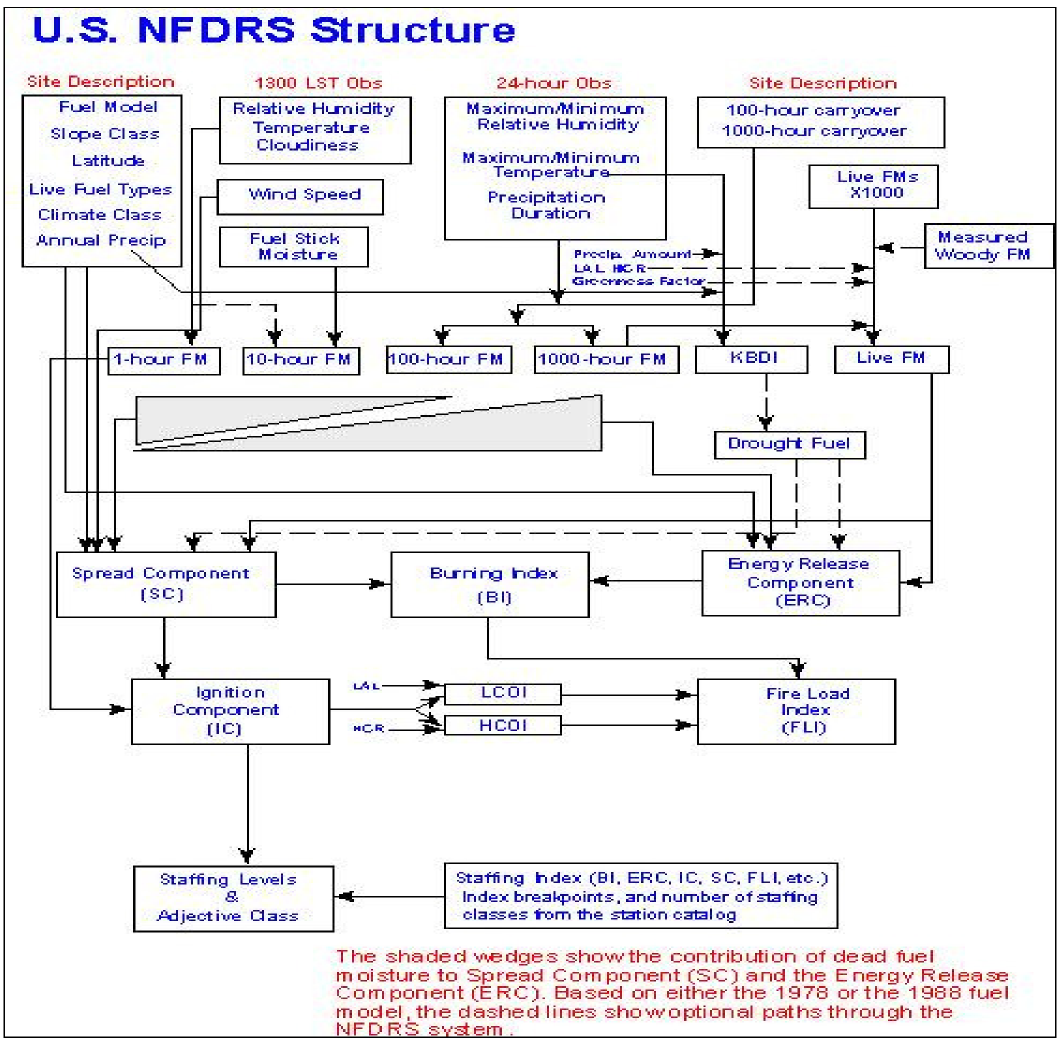

Figure 1.3: The United States National Fire Danger Rating System structure (NOAA-NWS, 2002)

1.17 Development of a National Fire Danger Rating for South Africa

During 1998, South Africa passed the National Veld and Forest Fire Act (Act 101 of 1998). The Act provides for the prevention of veld, forest and mountain fires through the deployment of a National Fire Danger Rating System (NFDRS). The Department of Water Affairs and Forestry (DWAF) contracted the CSIR to develop a NFDRS for South Africa. The NFDRS was developed by a team of experts, in consultation with the Veld and Forest Fire Committee of the Department of Water Affairs and Forestry and several key stakeholders (Willis *et al.*, 2003).

The team conducted an assessment of five candidate fire danger rating models: the Lowveld Model; the McArthur Forest Model; the McArthur Grassland Model; the United States National Fire Danger Rating System (US Model) and Keetch-Byram Drought Index. The criteria relating to "Performance" were ranked as far more important than those relating to "Ease of Adoption" or "Ease of Future Improvements". Given these weights, the US Model was the preferred choice (see table below), because the influence of fuel moisture content (especially of dead fuels) on fire behaviour is arguably the most significant contributor to fire danger in South Africa, and the US Model is the only model that is able to deal with fuel moisture content explicitly (van Wilgen *et al.*, 2003).

Table 1.3: Results of the comparison of the four fire danger rating models (van Wilgen *et al*., 2003)

Candidate Model	Positive Aspects	Negative Aspects	Recommendation
McArthur Forest Model	-Simple model. - Well documented basis in theory - User acceptance is likely to be high.	- Does not deal with green up and curing. -Has only one indicator value.	Do not adopt.
McArthur Grassland Model	- Ability to model green up and curing. - Well documented basis in theory.	- The model requires curing estimates. - Has only one indicator value.	Do not adopt
US Model	- Model is easy to understand on the essential processes that affect fire danger amongst users. - Caters for green up and curing. - Has more than one indicator value. - Well documented basis in theory.	- Complex model - Requires higher costs to develop competence but this may be necessary to develop the skills of fire managers - Resistance among user community to adopt	Adopt
Lowveld Model	- Readiness and willingness among user community to adopt. - Simple model and requires little cost in developing competence.	- The model's ability to cater for drying after rain is poor. -Does not cater for green up and curing. - No basis in theory and not well documented. - Only has one indicator value.	Do not adopt.
Keetch-Byram Drought Index	-Tracks extended periods of drought.	- Does not respond to daily weather variables.	Adopt to run in parallel with US Model

According to the report of van Wilgen *et al*., (2003), the team recommended that South Africa adopt the United States Fire Danger Rating System (US model) because of the following: The model deals explicitly with important processes that affect fire behaviour. These include;

- an ability to vary fuel loads by means of selecting fuel models,
- an ability to model green up and curing,
- an ability to model fuel moisture.

All of these features will make a significant contribution to the model's ability to support the development of a detailed understanding of processes that affect fire danger amongst users, and to an ability to support rational decisions relating to appropriate activities commensurate with the relevant fire danger rating on any given day.

It was recommended that the standard fuel models for California Chaparral and for Pine-Grass Savanna be used for representing fynbos, grassland and savannah areas in South Africa respectively, until such time as custom-built South African fuel models can be incorporated into the software.

1.18 Limitations of the study

The study was limited to:

1. **Site** - Kogelberg Nature Reserve because of its uniqueness and conservation value and that limited research into the fire regime and it potential drivers was done.
2. **Weather records** - only one weather station (Boontjieskraal) which was closest to the nature reserve and where there were records of rainfall, wind speed, relative humidity and temperature longer than twenty five years was used.
3. **Population data** - only the data from 1996-2006 was used due to non-availability of data prior to that due to differences in demarcations before 1994. The census used was from the following towns which are in the vicinity of the Kogelberg Nature Reserve; Grabouw, Kleinmond, Betty's Bay, Pringle Bay, Rooi Els, Bot River, Fisherhaven and Hawston.
4. **Fire data** – This study was limited only to the fire data from 1952-April, 2006 which was made available by CapeNature before the data were given to the CSIR for a project which had commercial value to the CSIR.

1.19 Statement of the problem

In the last 20 years there has been a marked increase in the number of people settling closer to nature reserves in the Western Cape. At the same time fire fighting resources and experienced fire fighters have dwindled as a result of changes in government spending priorities. Clear signs of climate change are evident in the temperature records of the Western Cape and rainfall trends though variable also suggest that there is a shift from the "normal" climate regime (Midgely *et al*., 2005). In addition recent advances have been made in the understanding of the effects of the frequency (van Wilgen, 1981) and seasonality of fires in fynbos (Bond *et. al*., 1984).

If species diversity and community structure and processes are to be maintained, the disturbance regime under which the species evolved should be emulated as closely as possible. The Kogelberg Nature Reserve being of exceptional conservation significance appears to have the highest levels of plant species richness and endemism in the Fynbos Biome**.** Endemics are vulnerable to changing fire regimes and therefore human impact or climate change could lead to extinctions (Cowling, 1983 and Bond, 1997). A comprehensive record of the fire history of an area provides the basis for informed future management and so far no record of the analysis of the fire regime of the Kogelberg Nature Reserve is available to indicate the possible drivers of the fire regime of the Kogelberg Nature Reserve. An analysis of the history of the fire regime will assist a proper approach to the problem and further research is required to assess the localised impact of the changes in climate, fire fighting resources and demography/populations on fire regime in conservation of the Kogelberg Nature Reserve. A historic account of the fire regime and its drivers would provide more opportunities for research into the effects of the past fire regime on various components of the ecosystem.

1.20 Aims of the study

Mediterranean-climate regions occupy less than 5% of the earth's surface, yet they contain about 20% of the world's flora (Cowling *et al.* 1997). These centres are also major centres of human population growth and thus anthropogenic impacts on natural ecosystems have been a matter of concern, particularly because of the potential for introducing new disturbances or altering the frequency and intensity of existing ones (Montenegro *et al*., 2004). A fire regime is a statistical characterization of recurring fire in an ecosystem and parameters that are often measured include fire interval, size, intensity and season (Moritz *et al*., 2004). Fire scientists need to understand what the fire regime for an area is and how it varies, if at all over time. If the fire regime has changed with time, managers need to understand how the regime is changing and what the consequences of changes will be (van Wilgen, 2005). With the correct fire records it is possible to quantify a fire regime of a certain area. Following the accurate compilation of fire data for the Kogelberg Nature Reserve and considering its heritage status as Biosphere Reserve, it is imperative that a scientific analysis of the fire regime be made to determine if the fire regime has changed and if so what has driven the change.

It is for this reason that a study was initiated to address the question of whether the fire regime of the Kogelberg Nature Reserve is changing, and if so to what degree these changes are driven by climate change, changes in human population density and the availability of resources to manage fires.

1.21 Research Hypothesis

Research by Wilson *et al*., (2010) has indicated that changes in climate are likely to lead to substantial increase in fire frequency in the Fynbos Biome. Fire patterns will almost certainly change in response to population, land use and climatic changes in Africa (Boko *et al*., 2007), and an understanding of the drivers of such changes will be needed to predict their consequences (Archibald *et al*., 2009).

Humans can affect fire regimes directly by altering the ignition regime indirectly by reducing the fuels and fragmenting the landscape, thus reducing the fuel continuity (Archibald *et al*., 2009).

According to Erasmus (2006), the challenges facing management of the Protected Areas of the Western Cape are increasing in complexity and magnitude due to vegetation structures and patterns that have been altered by past land-use practices and the invasion of alien plant species. In addition, urban and agricultural fringes are escalating as the population grows. The resources made available to managers have become scarce and expensive, while large wildfires regularly threaten thousands of hectares of pristine fynbos (Erasmus, 2006).

Data on fire regimes i.e. patterns in frequency, seasonality and intensity of fire are required for a thorough analysis of fire ecological problems so as to make possible the formulation of appropriate management systems. Of particular interest is evidence on the kind of natural fire regimes that are likely to occur in any given area. (Horne, 1981). In the last three years information about the fire regimes of different nature reserves in the Fynbos Biome has been published since CapeNature compiled a database of the fires that burnt in the Protected Areas of the Western Cape managed by CapeNature however no information has been generated for the Kogelberg Nature Reserve in spite of its historical heritage status.

This dissertation aims to determine whether the fire regime of the Kogelberg Nature Reserve is changing, and to what extent climate change, fire management and other social factors have affected the fire regime of Kogelberg Nature Reserve.

Chapter 2

Analysis of the fire regime of the Kogelberg Nature Reserve

2.1 Introduction

A fire regime can be defined as the combination of the elements of fire frequency, fire season and fire intensity prevalent at any given site (Gill, 1974). Variables in the fire regime include the intensity of burning, season in which the fire occurs, time between the fires (fire free interval), and the size of the area burned. The combination of these variables means that each fire that occurs is different.

The high diversity of plant species as well as the large number of functional types in fynbos ecosystems means that different species have varying optimum growth strategies and are adapted to different fire regimes (Debano, 1999). It is this relationship between plant functional type and varying fire regime that led to the evolution of the unique and biologically diverse flora (Cowling and Richardson, 1995; Bond, 1997 and Debano, 1999).

The last details about the fire regime of the Kogelberg Nature Reserve were published by Richardson *et al.*, (1994) prior to the large migration of people to the Western Cape and settling on the periphery of the Kogelberg Nature Reserve. Until recently, no fire records were up-dated on the fires that burn the Fynbos Biome of the Cape Floristic Region. This made it almost impossible to construct the historic (or pre-historic) fire regime in the biome since fire regimes at any given sites are never fixed, but occur at varying intervals, in varying seasons and at different intensities. Each fire is therefore unique and its effects will depend on both its own parameters and the nature of fires that preceded it (van Wilgen, 1987). The ecological role of fire in an ecosystem managed by burning must be understood in terms of its regime, i.e. the frequency, seasonality, intensity and size of the fires. Fire scientists need to understand what the fire regime for an area is and how it varies in space and time. If the fire regime has changed with time, managers need to understand how the regime is changing and what the consequences of changes will be (van Wilgen, 2005). The correct fire records have made it possible to quantify the fire regime of the Kogelberg Nature Reserve. According to van Wilgen and Scott (2001), fires in the Western Cape normally occur on average every 15 years or so, with actual intervals between fires ranging between four and 40 years. This means that fires occur on the same spot roughly every 15 years (the mean “return period”), and if the fires are evenly spread over time, it means that on average, about 7% of the region will burn every year. The prevailing warm, dry summers are conducive to fires, which are common between November and March each year; especially when hot, dry and windy conditions prevail for several days.

Fynbos communities accumulate enough fuel to readily sustain a fire that can easily spread under average summer conditions once they have reached a post-fire age of four years and may even burn when three years old under severe fire danger conditions (Kruger, 1977). At the other end of the scale most fires probably occur before 40 years. Fire frequency depends on (a) fuel being available, (b) sources of ignition and (c) suitable weather conditions that coincide with both (a) and (b).

This chapter seeks to:

1. Determine the fire frequency (number and size of fires over time) of the Kogelberg Nature Reserve,
2. Determine the fire return intervals (number of years between fires) of the Kogelberg Nature Reserve and
3. Determine the fire seasonality of the Kogelberg Nature Reserve

2.2 Methodology

2.2.1 Fire regime data analysis

Fire records of the study site were used to determine trends in the fire frequency (number of fires over time), fire return interval (number of years between fires), fire sources, seasonality and evidence that the presence of young vegetation limits the spread of fires.

The fire records were analysed for different periods to determine the trend in the fire regime of the Kogelberg Nature Reserve. Since the fire regime is built over a period of time and changes over time as well, it was important that the changes (if any) were analysed. The periods of analysis were as follows:

1952-1980 - this period was the longest period analysed since the accuracy of the records was less precise and also because the pressure of human settlement around the Kogelberg was of limited significance.

1981-2006 - during this period, the reserve had been declared a nature reserve area. More people were settling around the neighbouring towns and the fire risk was increasing and allegations of climate change were made. CapeNature was in charge of the water catchment areas of the Western Cape with limited resources for fire management.

2.2.2 Fire data records

Fire records analysed for this study were from the beginning of 1952 until April, 2006. Analysis of all the fire data (up to April, 2006) was carried out to address the question of whether the fire regime is changing and if so, to what degree these changes are driven by climate change, changes in human population density and the availability of resources to manage fires.

Using the NFDRS, the weather data from Boontjieskraal weather station from the period January 1973 to December 2005 was analysed using Fire Family Plus 3 software to derive burning indices. The burning indices period was broken into 3 periods of roughly equal lengths (1973-1985, 1986-1995 and 1996-2005) and the threshold values for the burning indices that delimit categories of fire danger (Categories extreme, high, moderate, low and insignificant) were established. A comparison of the categories per period was made to determine any changes in the fire danger indices above 50.

Information and data on all fires that occurred on the Kogelberg Nature Reserve from the beginning of 1952 to April, 2006 were extracted from fire reports, maps, aerial photographs, block files and Department of Water Affairs archives. The fire database stores both the fire report and the fire boundary. The records for the fires used in this study included the following: fire identity, years, months, dates started, dates extinguished, locality type, veld age and number of hectares burnt. For the fire return interval, Thresholds of Potential Concern were also used as described by van Wilgen (2001) to define the upper and lower levels along a continuum of change that indicates whether or not an acceptable degree of variation is being achieved.

Note: The reports were not always complete for the period 1952-1969, but usually provided data on locality, year, month, area burnt and occasionally the cause. Completeness and accuracy of the data recording improved from 1970-2006. Sketch maps of area burned, usually at the scale 1:50 000 were available with increasing completeness and accuracy over time.

2.2.3 Data analysis

The fire data were analysed to determine:

1. Fire frequency - number and size of fires over time
2. Fire return intervals - number of years between fires
3. Fire seasonality - months in which fires burnt

2.2.3.1 Objective one

Fire Frequency at Kogelberg Nature Reserve

The fire records were analysed for different management periods to identify differences in the fire regime of the Kogelberg Nature Reserve. Since the regime is built over a period of time and it changes over time as well, it was important that the changes, if any, were identified. The management periods were analysed for the periods 1952-1980 and 1981-2006.

2.2.3.2 Objective two

Fire return interval: number of years between fires in the Kogelberg Nature Reserve

Analysis of all the data (from 1952 up to April 2006) was carried out to identify changes in fire frequency over the period of the study. Intervals of 1952-1980 and

1952-2006 were allocated respectively to the data.

To calculate the fire interval for all the fires that occurred in the Kogelberg Nature Reserve, GIS Arc view 3.3 and Excel were used to join multiple fire dates into polygons for a particular area using the method described by De Klerk *et al*. (2005)

2.2.3.3 Objective three
Seasons of burn

Brown *et al*., (1991) describes the natural fire season for fynbos as November to April, with a peak between November and February. All the fires that burnt at the Kogelberg Nature Reserve in the two management periods of the study were analysed to determine in which months they burnt the total area that burnt during those months and if there were any shifts in the season of burn.

GraphPad Prism 5® (GraphPad Software, San Diego California USA), Arc view GIS 3.3 and Microsoft Excel were used to analyse the data. As the fire data were not normally distributed, the median was used as a more appropriate indication of the central tendency rather than the mean. Non parametric Mann–Whitney U tests (GraphPad Prism 5) were used for statistical analysis. The test was two-tailed and P-values ≤ 0.05 were considered significant.

2.3 Results

2.3.1 Objective one
Fire Frequency at Kogelberg Nature Reserve

During the entire study period a total number of 120 fires were recorded of which a total area of 104 067 hectares was burnt. Of the total area burnt, 42 fires were regarded as very small (0-100) hectares; the smallest being 0.28 ha. Only one fire was regarded as very large (14 905 ha). Of the total area burnt there were more fires in the smaller sizes category of 101-500 ha in which 43 fires burnt (Table 2.1).

Table 2.1: Fire distribution and area burnt at the Kogelberg Nature Reserve over the two periods of the study (1952 - 1980 and 1981 - 2006) (percentages in brackets)

Size Class (ha)	Fire management periods		
	1952-1980	1981-2006	All fires
0 -100	4(1)	38(1)	42(1)
101-500	8(8)	35(12)	43(11)
501-1000	6(17)	3(3)	9(7)
1001-2000	6(32)	7(12)	13(17)
2001-3000	2(17)	3(9)	5(11)
3001-5000	2(25)	1(5)	4(11)
5001-10 000	0	4(38)	4(28)
10 001-20 000	0	1(20)	1(14)
Total number of fires	28(100)	92(100)	120(100)
Mean area burnt (ha)	971	836	867
Median area burnt (ha)	669	161	216
Total area burnt (ha)	27 176	76 891	104 067
Mean area burnt (ha) per year	937	2 848	1 858

Proportionally of all the fires that burnt, the largest area burnt was between 5 001-10 000 ha. Although the period 1981-2006 was shorter than the period 1952-1980, the total number of fires, total area burnt and area burnt per hectare were much higher than that of the period 1952-1980. However, the mean area burnt as well as the median of the period 1952-1980 were higher than that of 1981-2006 (Figure 2.1). Based on the information shown in Figure 2.1, the total number of fires burnt increased from 28 fires to 92 fires in the period 1981-2006

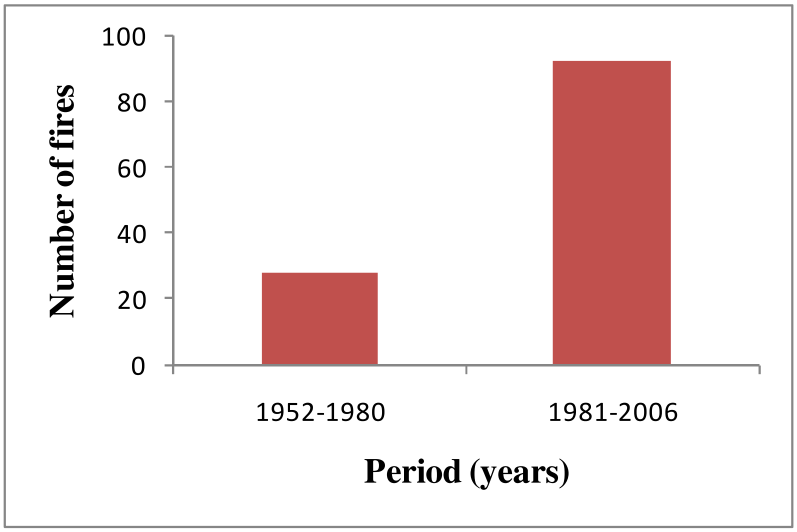

Figure 2.1: Number of fires during the 1952-1980 and 1981-2006 periods.

The median of the total area burnt (835ha for 92 fires) for the period 1981-2006 was significantly smaller (p=0.0013) compared to the median of the total area burnt (970 ha for only 28 fires) for the period 1952-1980 (Figure 2.2).

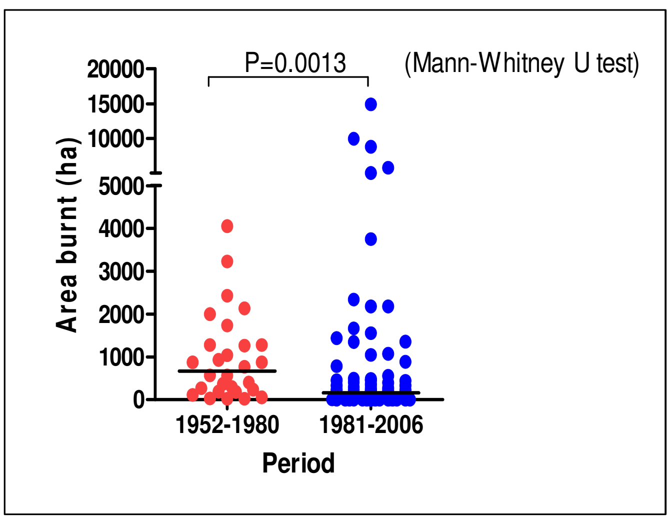

Figure 2.2: Statistical analysis for area burnt during the 1952-1980 and 1981-2006 periods. The black horizontal lines represent the median of area burnt and the dots represent each individual fire. Mann–Whitney U test was used for comparison of the medians of area burnt during the 1952-1980 periods and the 1981-2006 periods (GraphPad Prism 5). The y-axis has been segmented into two, first segment showing major ticks interval of 1 000 and the second segment showing major tick intervals of 5 000

In summary, the total area burnt increased during the period 1981-2006, however, the individual fire sizes were smaller compared to the period 1952-1980. The steady increase in the number of fires is an indication of an increase in sources of ignition. The fact that the fires were smaller in size could be an indication that either there was a quick response to extinguish them or there was less fuel to promote the spread of the fires due to the younger age of vegetation.

2.3.2 Objective two

Fire return interval: number of years between fires in the Kogelberg Nature Reserve

The fire returns intervals for the Kogelberg Nature Reserve from the beginning of 1952 until April, 2006 ranged from 0-54 years. Intervals were calculated as the time in days between fires divided by 365 and an integer taken. Therefore an interval of 0 indicates up to one year between fires.

The fire return interval graph (Figure 2.3) shows that the 50% cumulative probability of fire return with time was just more than 15 years for the entire study period. The recommended fire return interval to maintain biodiversity in fynbos is 15-20 years between fires at 50% probability (van Wilgen, 1982). Furthermore, data in Table 2.2 were interpolated using a graph in Figure 2.3. Table 2.2 shows a steady increase in the 50% probability of fire burning from 1952-2006 where a mean fire return interval of just above 15 years was achieved by 2006. Table 2.2 also shows the probability of 80% fires burning from the previous one, where there was an increase in the mean fire return interval from 8.11 years during the period 1952-1970 to 22.69 years during the period 1952-2006. At 30 % probability, an improvement to above 8 years in the last six years was noted as shown in Table 2.2. This improvement is desirable for a balanced biodiversity management point of view (van Wilgen and Scott, 2001).

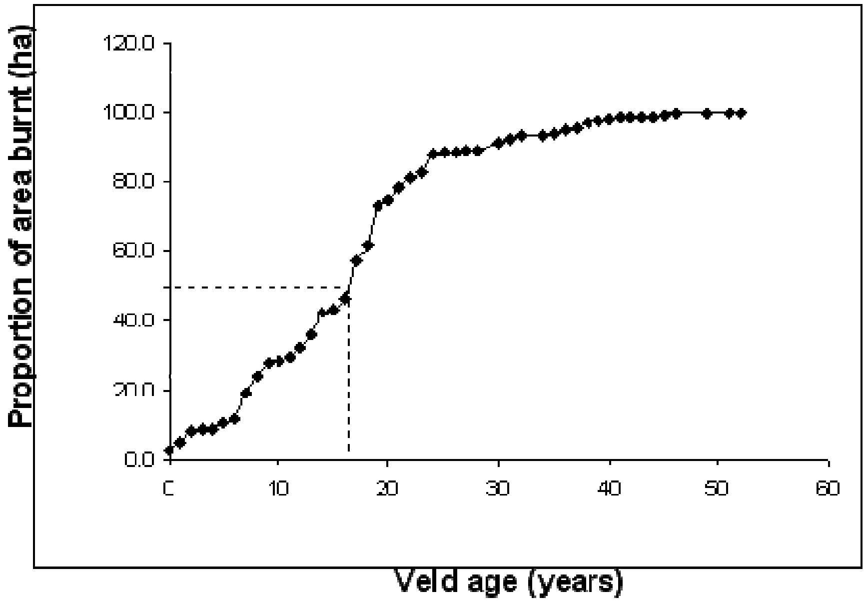

Figure 2.3: Fire return interval for the period 1952-2006. The dotted lines indicate 50% cumulative probability of ignition with time in the Kogelberg Nature Reserve. Probabilities were derived from the intervals between fires dissected into 713 polygons using Arc View GIS 3.3.

Table 2.2: Interpolated cumulative probability of fire return interval

Cumulative Probability entered	**1952-1970**	**1952-1980**	**1952-1990**	**1952-2000**	**1952-2006**
30	5.76	4.16	7.66	7.9	8.02
50	6.96	8.43	13.95	15.01	15.36
80	8.11	12.69	20.25	22.05	22.69

Figure 2.4 indicates that there was a significant increase in the fire return interval during the period 1952-2000 compared to the period 1952-1970 ($p<0.05$). There was also a significant increase in the fire return interval for the period 1952-2006 compared to the period 1952-1970 ($p<0.05$) and a significant increase in veld age during the periods 1952-2000 compared to periods 1952-1980 ($p<0.05$). A very significant increase in veld age was noted during the periods 1952-2006 compared to periods 1952-1980 ($p<0.005$). Overall, this means that the fire return interval at 50% cumulative probability increased over the study periods to desirable levels in fynbos fire management.

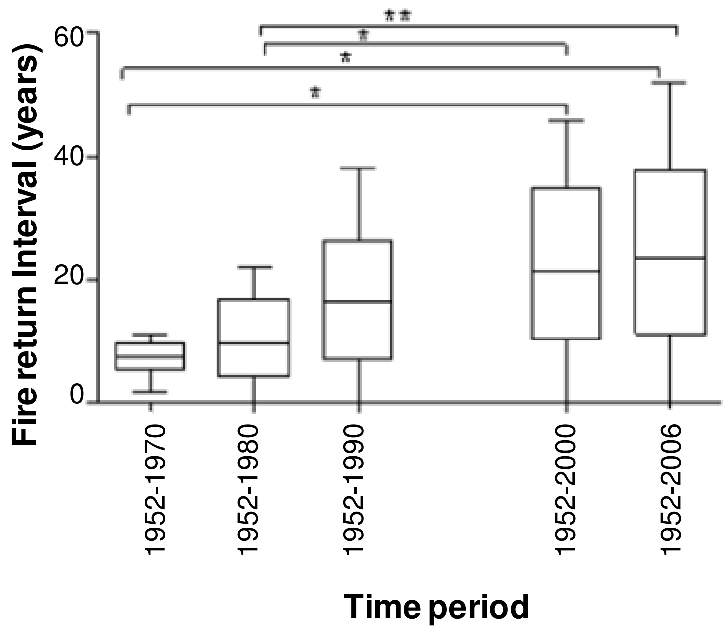

Figure 2.4: Statistical analysis of the 50% cumulative fire return interval for the study period 1952-2006. Box-and-Whisker plots represent the median (centre black line) of fire return interval for the periods 1952-1970, 1952-1980, 1952-1990, 1952-1995, 1952-200 and 1952-2006 of Kogelberg Nature Reserve. The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of fire return intervals. P-values ≤ 0.05 were considered significant. (*p<0.05 and **p<0.005).

2.3.4 Objective three

Seasons of burn

The information in Table 2.3 indicates that during the period 1981-2006 there was a more than 3-fold increase in the number of fires that burnt in summer compared to the number of fires that burnt in summer during the period 1952-1980. A slight increase in the autumn fires during the period 1981-2006 was noted compared to period 1952-1980. During the period 1981-2006 the winter fires decreased sharply by more than twenty times compared to that of the period 1952-1980 whilst the spring fires decreased by more than half during the period 1981-2006 compared to the period 1952-1980 (Table 2.3). The rise in the number of summer fires could be attributed to an increase in sources of ignition, more suitable weather conditions for fires to start and availability of fuel. Conversely, the sharp decrease in spring and winter fires could be due to the measures taken to conserve the area as from 1980 (van Wilgen *et al.*, 1994). The increase in autumn fires could be due to prescribed burning which was introduced to the Kogelberg Nature Reserve after being managed as a nature reserve. The smaller fire sizes could be due to less fuel to spread the fires or the extra care taken to prevent the fires from spreading to the homesteads that have been built in the neighbouring towns.

The total area burnt during the fire season, particularly between the months of February to April during the period 1981-2006, was remarkably higher compared to the area burnt during the period 1952-1980 (Figure 2.5).

Table 2.3: Total area burnt and season of burn at the Kogelberg Nature Reserve for the periods 1952-1980 and 1981-2006.

	Total area burnt (ha)			Total area burnt per season (ha)	
Month	**1952-1980**	**1981-2006**		**1952-1980**	**1981-2006**
Dec	2 104	5 629	Summer	7 186	21 001
Jan	1 163	1 244			
Feb	3 918	14 127			
Mar	0	22 294	Autumn	32 506	47 727
Apr	25	23 248			
May	3 225	2 184			
Jun	0	1 764	Winter	5 570	230
Jul	3 435	490			
Aug	2 135	48			
Sep	6 440	2 491	Spring	10 984	5 858
Oct	3 671	59			
Nov	872	3 307			
Unknown	182	0	Unknown	182	

The seasons were defined as follows;

Summer: December, January and February.

Autumn: March, April and May.

Winter: June, July and August.

Spring: September, October and November.

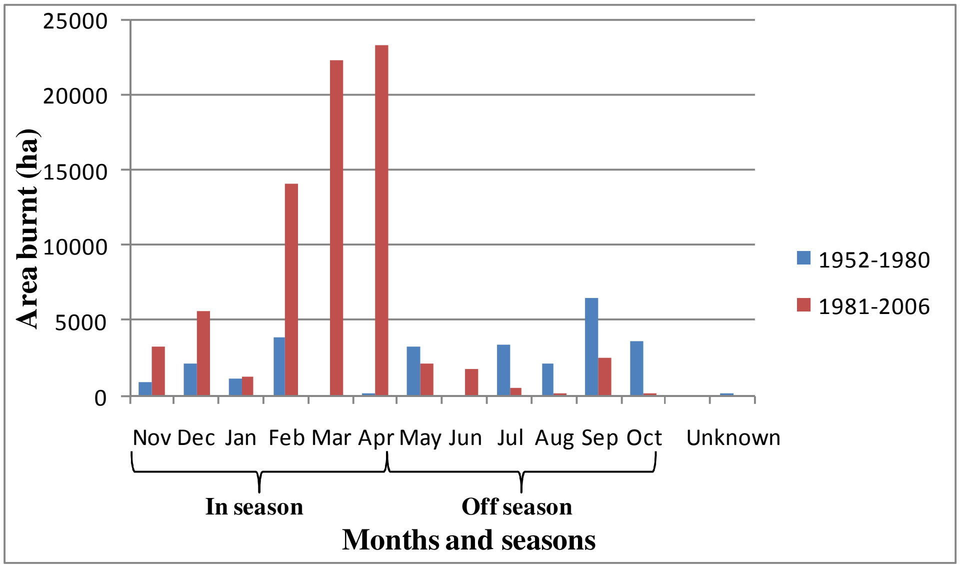

Figure 2.5: Total area burnt per month and per fire season. The graph illustrates the total area burnt per month during fire season (November to April) and out of fire season (May to October) in the Kogelberg Nature Reserve during the two management periods 1952-1980 (blue bars) and 1981-2006 (red bars).

Statistical analysis of the fires of the Kogelberg Nature Reserve with regards to the fire season of fynbos, indicated that the total area burnt off-season (May to October) has decreased significantly during the period 1981-2006 compared to the period 1952-1980 (p=0.0496, Figure 2.6). On analysis, there was no significant difference in the total area burnt in-season between both management periods (data not shown). However, there was a significant increase in the fire frequency during the management period 1981-2006 compared to the period 1952-1980 (p=0.0062, Figure 2.7). This suggests that although the fire frequency increased significantly in-season during the period 1981-2006 compared to the period 1952-1980, the increase in the total area burnt between the two management periods was insignificant.

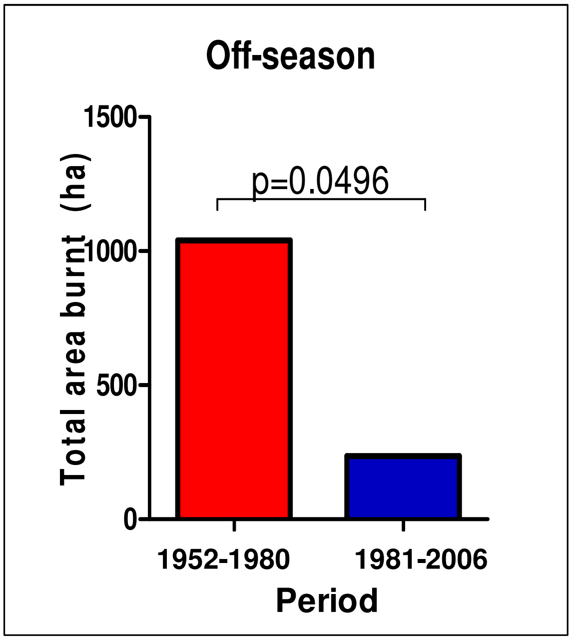

Figure 2.6: Statistical analysis of total area burnt off-season. Total area burnt during the off- season at the Kogelberg Nature Reserve was compared between the two management periods 1952-1980 (red bar) and 1981-2006 (blue bar). The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of fire return intervals.

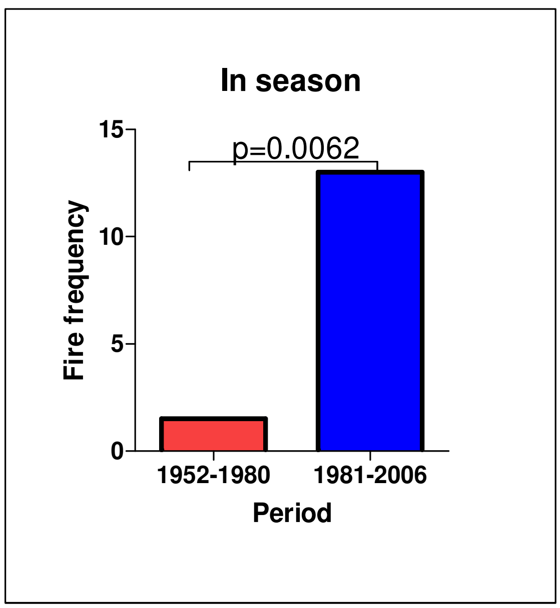

Figure 2.7: Statistical analysis of fire frequency in-season. Fire frequency at the Kogelberg Nature Reserve was compared between the management periods 1952-1980 (red bar) and 1981-2006 (blue bar) using the Mann-Whitney U test (GraphPad Prism 5). P values ≤ 0.05 were considered significant.

Table 2.4 shows the fire frequency per month and season in the Kogelberg Nature Reserve during the management periods 1952-1980 and 1981-2006. For all the seasons in the period 1981-2006 there was an increase in the number of fires burnt due to an increase in the fire frequency as analysed in objective one (Section 2.4). The increase in the frequency of the autumn fires could be ascribed to the prescribed burning that was introduced in 1980 (van Wilgen, 1994) and the sharp increase of the summer fires could only be ascribed to unplanned fires because no prescribed burning was allowed during the summer period and these unplanned fires could be due to increased sources of ignition.

Table 2.4: Seasonal and monthly number of fires burnt in the Kogelberg Nature Reserve for the periods 1952-1980 and 1981-2006.

Frequency of fires per month			**Frequency of fires per season**		
Month	**1952-1980**	**1981-2006**	Seasons	**1952-1980**	**1981-2006**
Dec	2	11	Summer	10	38
Jan	2	8			
Feb	6	19			
Mar	0	16	Autumn	2	37
Apr	1	15			
May	1	6			
Jun	0	3	Winter	5	6
Jul	3	2			
Aug	2	1			
Sep	5	3	Spring	10	11
Oct	4	2			
Nov	1	6			
Unknown	1	0	Unknown	1	0

2.4 Discussion

Moll *et al.,* (1980) postulated that the lack of tree vegetation in the fynbos may be due to an increase in fire frequency since the advent of pastoralists about 2000 BC. Fire return interval is the measure of the number of years between fires. Studies on the life histories of plants support the hypothesis that fynbos is adapted to fire intervals of between 10 and 30 years (van Wilgen, 1984). Juvenile periods in fynbos plants do not usually exceed eight years and when they do, they usually occur in plant species that can escape fires in some way or another (Kruger and Bigalke, 1984). Where large fires occur leaving vast areas of young veld, this can reduce food availability and pose a problem of dispersal if distances that animals need to cross become too large (De Klerk *et al.*, 2005).

All estimates of the fire return interval experienced at Kogelberg Nature Reserve during the period 1952 –April 2006 indicate a tendency for fires to burn every 7-15 years. This is lower than the desired interval of 15-20 years as described by van Wilgen (1982). In dealing with the variability of the fire return intervals, the long term assessment of the fire return interval derived from the curve of probability can be used to indicate either an increase in the mean, median or maximum return period (van Wilgen and Forsyth, 1992).

When using the three thresholds of potential concern in this case as used in van Wilgen (2001) and as shown in Table 2.4, the maximum threshold of potential concern is 22.7 years which indicates that less than 20% of the plant species escape fires longer than 30 years which is good for obligate seeding plants species which if left without fire for longer than 30 years, senesce and die. At least 20% of the vegetation survives fire intervals longer than 20 years, which is good for the breeding of the Cape sugarbirds that are pollinators of the dominant *Protea* shrubs. The second threshold of potential concern, where 50% of the fires burnt should be between 10 and 20 years that is the optimum return period that will allow most species to mature and reproduce in a fire prone environment, Kogelberg Nature Reserve has a mean of around 15 years, which implies a healthy fire regime.

The third threshold of potential concern looks into the minimum fire return period that should not be less than 5-6 years failing which many plant species would not have sufficient time to mature and set seed between fires and eventually be lost from the community. The results from the Kogelberg Nature Reserve fires show that the minimum fire return intervals were an average of just over eight years. This is a positive indication good fire management in the Kogelberg Nature Reserve.

The natural fire season is identified as November-April with a peak between November and February (Brown *et al.,* 1991). The results of this study indicate that during the first half of the study (1952-1981) more fires had burnt during the off-season period. That changed significantly in the latter half as a result of prescribed burning and also could be a result of changes in the climate of the area coupled with lots of sources of ignition from people moving to the neighbouring areas. Although it has been suggested that the veld can occasionally be burnt in autumn (late April – May), i.e. after the peak fire season, in order to reduce fire risk to infrastructure and human life, the policy at Western Cape Nature Conservation Board is to manage fire for ecological reasons, and therefore policy at Western Cape Nature Conservation Board is to avoid low intensity or out of season fires (Erasmus, 2003). In addition, there are enough accidental fires (caused by arson, etc.) taking place in the cooler months (outside the fire season) to cater for the variation in fire season which some managers argue is important (de Klerk *et al*., 2005).

With reference to targets of 10:50:40 (spring: summer: autumn) proportions for fire season as suggested by van Wilgen and Scot (2001), the fires at the Kogelberg Nature Reserve were almost 25:30:30 for the period 1952-2006 which does not meet the desired objective of these targets.. There were more fires in summer and early autumn, however spring fire occurrences are still too high. Seasonal proportions of fires should be 5-15% in spring, in summer 50-60% and in autumn they should be 30-80% (Bond *et al*., 1984). What this means is that there is very poor regeneration of *Protea* shrubs at the Kogelberg Nature Reserve. The spring proportion is almost all right whereas the summer proportion is lower than the ideal. The problem with the proportion of fires in autumn is that it is too high and it could have an impact on the fynbos birds that nest in the period August to October. Management of the Kogelberg Nature Reserve must minimise the fires in autumn to allow the nesting of the birds.

2.5 Conclusions

Van Wilgen *et al*., (2010) summed up the fire frequency, season and sizes of fires in the climatic zones of the Western Cape by saying that the mean fire return intervals ranged from 10 to 13 years in most parts of the province. Whereas fires occurred in every month of the year, the majority occurred from November to March. Southey (2009) concluded that the influence of people on the fire regime results in shorter fire intervals and accidental ignitions resulted in intervals shorter than the natural fire intervals.

The increase in the number of fires at the Kogelberg Nature Reserve in the period 1981-2006 compared to the period 1952-1980 could be as a result of a combination of an increase in sources of ignition and, change in the climate of the area which may result in the conditions for starting fires becoming more prevalent. It could also be due to more sources of ignition resulting from more people settling in the neighbourhood of the nature reserve and dwindling resources of fire fighting resources that came as result of changes in government spending in relation to fire management in the protected areas of the Western Cape.

The improved fire return intervals could be ascribed to the introduction of prescribed burning which resulted in the correct and desired median. Fires that occur in autumn are not necessarily good for nesting birds that are affected by more fires during the nesting period. This may affect nesting birds, yet the summer fires were below the recommended threshold by van Wilgen and Scott (2001). van Wilgen and Scott 2001 support that the majority of fires (80-90%) should occur in summer and autumn. The spring fires were acceptable. This may have been achieved as a result of changes in climate and sources of ignition.

Chapter 3

The impact of climate change on the fire regime of the Kogelberg Nature Reserve

3.1 Introduction

Midgley (2006) explains that in the past climate change probably influenced the process of speciation (the evolution of species) which created the plant species rich Fynbos and Succulent Karoo Biomes. It is suggested that as climate cooled during glacial periods, Fynbos expanded northwards and Succulent Karoo plants took refuge in the Knersvlakte and Richtersveld (both centres of endemism today). As the climate warmed during the interglacial periods, the Fynbos retreated into the cooler mountainous areas and the Succulent Karoo expanded into its current distribution (www.sanbi.org/climrep/6.htm).

During 2003/2004 the Western Cape suffered a serious drought, leading to the declaration of a "State of Emergency" by the then Premier of the Western Cape (van Wilgen, 2000). The Premier, in collaboration with other provincial Ministers and heads of departments, decided that the Department of Environmental Affairs and Development Planning must undertake a response study on climate change in the Western Cape to understand climate change and its effects on the Western Cape as well as develop a response mechanism. Dr Guy Midgley, Chief Specialist Scientist for South African National Botanical Institute Climate Change Group, led this study, which confirmed that the Western Cape is being impacted by climate change. In his report he said "Climate change is nothing new; it's all happened before but neither in the same way nor to the same degree. He claimed that rapid climate change has occurred in the past, but the critical point is that global mean temperature has oscillated for many hundreds of thousands of years between a frigid glacial level of below 10°C and the balmy interglacial levels of 14-15°C during inter-glacials. Human-induced climate change will cause this level to be exceeded sometime in the next 50 years. Further increases into new temperature territory will continue for several decades beyond if we do not curb greenhouse gas emissions. The cool earth to which most of our natural species and existing farming practices has evolved will become warm enough to be outside the evolutionary experience of many species and unable to sustain current farming practices.

Clear signs of climate change are evident in the temperature records of the Western Cape, and rainfall trends, though more variable, also suggest that there is a shift in the "normal" climate regime (Midgley *et al*., 2005). In a study by Van Wilgen and Scott (2001) the number of days per year when the fire danger index exceeded 50 (fire behaviour described as dangerous and extreme caution required when controlled burning is carried out) for four days or more was found to be "more frequent in the last decade of the 20^{th} century than in the preceding two and a half decades". This suggested that this "may be indicative of changing climatic conditions". However, the data presented were not comprehensive enough to make definitive conclusions. The factors that would promote higher fire frequencies and intensities would include lower rainfall (reducing the moisture content of fuels), lower relative humidity, longer droughts, and higher wind speeds. Such changes are predicted by climate change scenarios (Midgley *et al*., 2005). Fire is a dominant ecological factor in Mediterranean ecosystems and changes in the fire regime can have important consequences for the stability of landscapes (Pausas, 2001).

3.1.1 Possible effects of climate change on fynbos management

Van Wilgen and Scott (2001) concluded that the number of days per year when the fire danger index exceeded 50 for 4 days or more were found to be more frequent in the last decade of the 20^{th} century than the preceding two and a half decades and suggested that this may be indicative of changing climatic conditions. However the data presented were not comprehensive enough to support such conclusions. Since fire regimes at any given sites are never fixed, they occur at varying intervals, in varying seasons and at different intensities and each fire is therefore unique and its effects will depend on both its own parameters and the nature of fires that preceded. Based on the possible impacts of the changes in climate change as alluded by research and the significant status of the Kogelberg Nature Reserve on biodiversity conservation, it is important to understand the possible impacts of climate change in the shift of the fire regime as noted during the analysis of the fire history of the reserve.

3.1.2 Statement of the problem

As climate becomes hotter and drier, fires may become more frequent and extensive and if fynbos burns before plants are old enough to seed, local extinctions could result (www.sanbi.org/climrep/6.htm). So far the history of fires in the Kogelberg Nature Reserve shows an increase in the frequency and sizes of larger fires in the last twenty years. Research on fynbos fires points to climate change as the possible driver of the shift in the fire regime. It is for this reason that a study was initiated to assess the extent of the possible impact of changes in climate on the fire regime of the Kogelberg Nature Reserve.

3.1.3 Aims of the study

Following the results of the fire regime analysis of the Kogelberg Nature Reserve (Chapter 2), it appears that the regime has shifted from the "norm" because of the increased fire frequency that could be ascribed to changes in climate. An analysis of the extent of these alleged changes will help in understanding what needs to be done to ensure that the changes do not adversely affect the levels of plant species richness and endemism of the fynbos biome of the Kogelberg Nature Reserve.

Therefore a study aimed to assess the extent of the impact of climate change was initiated to investigate the following objectives:

a) If number of days per year when fire danger index exceeded 50 for 4 days or more was found to be more frequent in the last decade of the 20th Century than the preceding two and three decades.
b) If larger fires were caused by an increase in fire danger indicators in Kogelberg Nature Reserve.
c) The effects of climate change on the shift in the fire frequency of the Kogelberg Nature Reserve.

3.2 Methodology

3.2.1 Weather records

Weather records from Boontjieskraal weather station, which had all four weather factors (rainfall, wind speed, relative humidity and temperature) that make up the fire danger indicator, were used to analyse for climate change. The USA NFDRS was used to calculate the burning indices.

Burning Index – According to Bridgett and Forsyth (2004), the Burning Index is a number related to the contribution of fire behaviour to the effort of containing a fire. It is expressed as a numeric value closely related to the flame length in feet multiplied by 10. The scale is open-ended which allows the range of numbers to adequately define fire problems, even in time of low to moderate fire danger. It is directly related to effort required to suppress a fire. The Burning Index is the basis for rating fire danger. It is designed to reflect the difficulty in controlling a fire, and therefore provides the basis for increasing preparedness.

The daily weather variables (rainfall, wind speed, relative humidity and temperature) influence the live and dead fuel moisture content of each individual fuel model differently. Fine fuel moisture contents (1-hour and 10-hour) have a proportionately large influence on the Spread Component. The moisture content of coarse fuels (100-hour and 1000-hour) has a larger influence on the Energy Release Component. Together the Spread Component and Energy Release Component determine the Burning Index while the Spread Component and the 1-hour fuel moisture content of the fuel model in question (Van Wilgen *et al*., 2004), determine the Ignition Component.

Boontjieskraal Station is situated in the same fire climate zone as Kogelberg Nature Reserve. The weather data starts on 1st January 1973 and ends on December 31st 2005, spanning a period of 33 years. Where gaps occurred in the weather data record, additional data were obtained from Elgin weather station that is in the proximity of the Kogelberg Nature Reserve.

3.2.2 Data analysis input required to analyse for climate change

To test for climatic change, weather data (temperature, wind speed, relative humidity and rainfall) from the meteorological station in the vicinity of the reserve were analysed to calculate daily weather fire danger indicators using Fire Family Plus. The Fire Family Plus software does not have an option for a fynbos fuel model, so the Californian medium chaparral fuel model option was used as recommended by van Wilgen and Scott (2001) and van Wilgen *et al*., (2003). The USA NFRDS was used to formulate burning indices from the weather data. As discussed in chapter 1, it has been recommended that the US Model be used to underpin a National Fire Danger Rating System in South Africa (van Wilgen *et al.*, 2003). The daily weather record consisting of daily minimum and maximum temperature, minimum and maximum relative humidity, rainfall and wind speed was used. The NFDRS requires observations at a standard time each day (van Wilgen, 1984). The data had been collected at 14h00 which is typical for when the fires are at their hottest.

3.2.3 Daily weather data

The most significant weather data required to calculate fire danger indicators are dry bulb temperature, relative humidity, wind speed, and amount of precipitation. The data used by the model should be reflective of conditions experienced or anticipated to occur within the fire danger rating area. The weather data were collected from a Stephenson's screen.

(i) Dry Bulb Temperature

In the weather station, the temperature of the air was measured in the shade, 1.2 m above the ground

(ii) Relative Humidity

The ratio of the actual amount of water vapour in the air expressed as a percentage of the amount necessary to saturate the air at that temperature and pressure.

(iii) Wind Speed

Wind speed measured at 5.75 m above the ground. In the United States, the value used at 14h00 is an average of the previous 12 logged 5-minute values.

(iv) Precipitation amount

This is the total amount of precipitation that occurred within the preceding 24-hour period measured in mm.

3.2.4 Fynbos fuel model

Fynbos fuels are complex, comprising mixtures of restioid and ericoid elements forming a continuous fuel bed below a stratum of broad-leaved sclerophyllous proteoid shrubs (van Wilgen *et al* 1992).

In a study to adapt the USFDRS to fynbos in South Africa, Van Wilgen, (1984) describes fynbos as floristically an extremely diverse vegetation type and this complicates the selection of representative species. Fynbos in South Africa is usually considered to consist of three major components, namely:

a) Restioids

b) Ericoids and

c) Proteoids strata.

Fynbos fires are regarded as canopy fires with fire intensities ranging between >500 and <20 000 kW/m (van Wilgen and Scholes 1997). Because of the longer intervals between fires, fuel loads are much higher than those associated with grasslands or savanna. Typical fuels range from 1000 to 3000 g/m2 at 15 years post fire with maximum fuel loads of >7000 g/m2 in 40 year post-fire stands (van Wilgen and Scholes 1997).

Van Wilgen *et al*., (2003) recommended that in order to estimate fire danger over large areas such as the Western Cape, one fuel model representative of the vegetation generally should be used and that this model should not be designed to predict fire behaviour to any degree of accuracy but to rather produce relative indices of fire danger. They recommended that the standard fuel models for California Chaparral be used for representing fynbos, and grassland and savanna, areas in South Africa respectively, until such time as custom-built South African fuel models can be incorporated into the software. In this study, it is assumed that the variation in fynbos structure is not significant in the characteristics that affect fire danger indicators.

The NFDRS produces four indices for fire danger measurement, namely:

(i) Burning Index

The Burning Index is a number related to the contribution of fire behaviour to the effort of containing a fire. The Burning Index is derived from a combination of the

Spread and Energy Release Components, and relates to the difficulty of containing a wild fire. It is expressed as a numeric value closely related to the flame length in feet multiplied by 10.

(ii) Energy Release Component

The Energy Release Component is a number related to the available energy (British Thermal Units or BTU) per unit area (square foot) within the flaming front at the head of a fire. Daily variations in the Energy Release Component are due to changes in moisture content of the various fuels present, both live and dead. The Energy Release Component is a cumulative or "build-up" type of index i.e. it will indicate increasing drought effects by rising during prolonged dry periods. Wind speed does not affect the Energy Release Component.

(iii) Spread Component

The Spread Component is a rating of the forward rate of spread of a head fire. The Spread Component is numerically equal to the theoretical ideal rate of spread expressed in feet-per-minute. Wind speed, slope and fine fuel moisture are key inputs to the calculation of the Spread Component, thus accounting for a high variability from day to day. It is expressed on an open-ended scale. This component enables the fire manager to understand the behaviour of the fire should one take place. It does not allow the manager insight into fire management in the long term. It will however, enable the fire manager to have insight into the degree of difficulty that might arise in containing a fire.

(iv) Ignition Component

The Ignition Component is a rating of the probability that a firebrand will cause a fire requiring suppressive action. Since it is expressed as a probability, it ranges from 0-100. An Ignition Component of 100 means that every firebrand will cause an actionable fire if it contacts a receptive fuel. This indicator value enhances the fire manager's knowledge of the probability of a fire starting due to negligence or natural causes. This will enhance his or her preparedness and ensure adequate staff and equipment is available.

3.2.5 Data analysis

(i) Fire Family Plus 3

To analyse the weather data, Fire Family Plus 3 was used. In addition to the daily weather inputs, the model that calculates indicator values for fire danger also requires station parameters. These parameters are entered once only at the time when the calculation of the fire danger indices are initiated. The station parameters comprise information describing the attributes of the weather station as well as the inputs necessary to govern the types of calculations that are used for that particular station. The software requires:

a) Station ID – Weather station identity was inserted in six digits
b) Station Name - Boontjieskraal
c) Fuel model - In adapting the fire danger rating system (Deeming *et al.*, 1978) to South African conditions, it was proposed that a model similar to the chaparral model would be the closest approximation to fynbos.
d) Station type – manual and automatic.
e) Use 1988 Model – Yes
f) Slope class - The slope class chosen for this analysis was 26 – 40 %
g) Climate Class – Sub-humid climate class
h) Green Up Day of year – N/A
i) Earliest Freeze date – N/A
j) Start Freeze date – N/A
k) Start Keetch-Byram Drought Index – N/A
l) Start Fuel Moisture 1000 – N/A
m) Average Annual Precipitation- 500 millimetres
n) Fuel Moisture1=Fuel moisture -10
o) Deciduous shrubs- N/A
p) Aspect-N/A
q) Slope position-N/A
r) Elevation- 128 metres
s) Latitudes 34° 10' and 34° 21' S and longitudes 18° 49' and 19° 03' E

N/A- denotes not applicable in this case. Conversion of the weather data from Windows Excel to Fire Family Plus 3- summary was done using the method recommended van Wilgen *et al*., (2003).

(ii) Other analysis methods

GraphPad Prism 5 and Windows Excel were used to analyse the data as previously described in Chapter 2 (Section 2.2.2). Spearman Rank test (GraphPad Prism 5) was a non-parametric test used to test correlations.

3.3 Results

3.3.1 Objective one

3.3.1.1 Number of days per year when the fire danger index exceeded 50

One of the indicators of climate change highlighted by previous research was that the number of days per year when fire danger index exceeded 50 for 4 consecutive days or more was found to be more frequent in the last decade of the 20th Century than the preceding two and three decades. To assess whether this was true or not in the case of Kogelberg Nature Reserve, weather data from Boontjieskraal weather station was used to calculate burning indices and later fire danger indices. Only data where the Fire Danger Indicators exceeded 50 for 4 consecutive days or more were considered. The periods of comparison were 1973-1988 and 1989-2005. The number of days when fire danger index exceeded 50 for 4 consecutive days or more over two periods from 1973-1988 and 1989-2005 which was the duration of the weather data at Boontjieskraal weather station are shown in Figure 3.1.

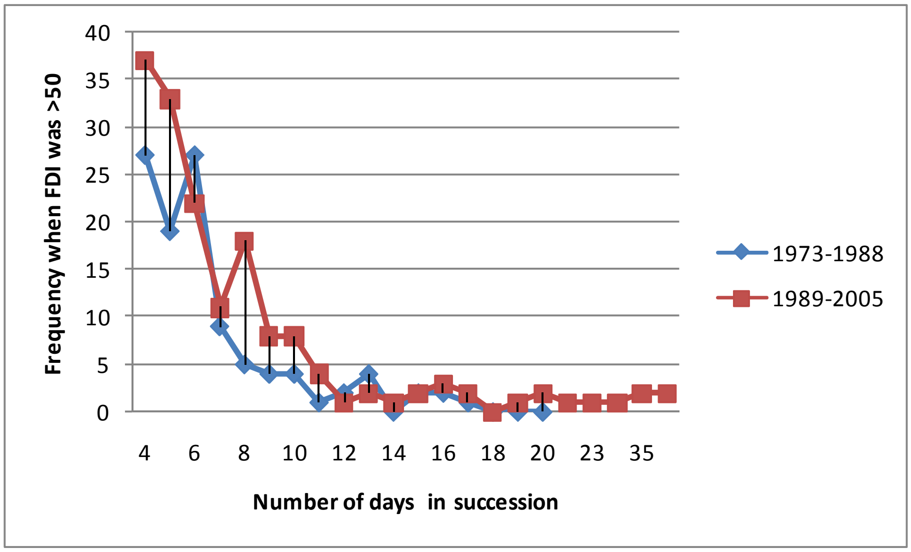

Figure 3.1: Number of days per year and fire frequency when the fire danger index exceeded 50 for four consecutive days or more during the periods 1973-1988 and 1989-2005

Based on the information in Figure 3.1, the incidence where the burning index was 50 or more for 4 consecutive days, increased from 28 to 37 for the period 1989-2005. Similarly, there was an increase from 19 to 33 in the frequency where the burning index was 50 or more, for 6 consecutive days in the same period of the study. However, there was a slight decrease in the 6 days category that was noted from 27 to 22 in the same period of the weather data. From 7 days to 10 days, the frequency of FDI exceeding 50 remained slightly higher in the 1989-2005 period compared to the 1973-1988 period. There were no clear differences in frequency between the two periods when the burning index was 50 or more for 12 to 20 days in succession. For the period 1989-2005, exceptional long periods where the fire danger index exceeded 50 was 20 days and up to 42 days in succession were recorded in the period 1989-2005 which was unheard of during the period 1973-1988. Based on the results shown in Figure 3.1, it is clear that there was change in the climate of the Boontjieskraal weather station that may have an effect on the spread of the veld fires at Kogelberg Nature Reserve.

3.3.2 Objective two

3.3.2.1 Effect of fire danger indicators on fire sizes in the Kogelberg Nature Reserve

Of the 97 fires on record that burnt between January 1973 and December 2005 at the Kogelberg Nature Reserve, 63 fires had a full record of when they were started and extinguished. Only 15 fires were larger than 1 000 hectares of which four of those had no record of when the fires were started and extinguished. Table 3.1 shows all the fires larger than 1 000 hectares that burnt at the Kogelberg Nature Reserve whose dates of ignition were known.

Table 3.1: Fires larger than 1 000 ha whose Fire Danger Index was measured between the years 1973 and 2003 at the Kogelberg Nature Reserve.

Year	Area burnt (ha)	Cause	Fire Danger Index Range	No of days that the fire burnt
1973	1079	Unknown	35-35	2
1982	2176	Unknown	40	Unknown
1988	1405	Accidental	50	1
1988	4854	Natural Lightning	41-38	2
1991	10258	Natural Lightning	109-105	5
1995	8791	Natural Lightning	32-104	5
1997	6186	Accidental	66-68	5
1998	1046	Accidental	51-50	3
1999	12239	Unknown	40-35	5
2001	1352	Arson	121-98	4
2003	1439	Unknown	90-85	2

The information in Table 3.1 shows that there were larger fires on record in the last fifteen years of the study period recorded at the Boontjieskraal weather station, regardless of the source of ignition. However, during the first 18 years larger fires occurred when the fire danger indicators were lower and moderate regardless of the source of ignition. Prescribed burns were excluded in this analysis because only unplanned fires would be a threat to the Kogelberg Nature Reserve.

The association between the Fire Danger Index and total area burnt was determined. There was no significant correlation between Fire Danger Index and total area burnt for both the 1973-1988 and 1989-2005 periods (1973-1988: P=0.83, r=0.06; 1989-2005: P=0.66, r=0.07; Figure 3.2). Interestingly, it was observed that Fire Danger Index was significantly higher during the 1989-2005 period compared to the 1973-1988 period (p=0.044; Figure 3.3). However, no significant differences were observed between total area burnt per fire between the periods 1989-2005 and 1973-1988 (data not shown).

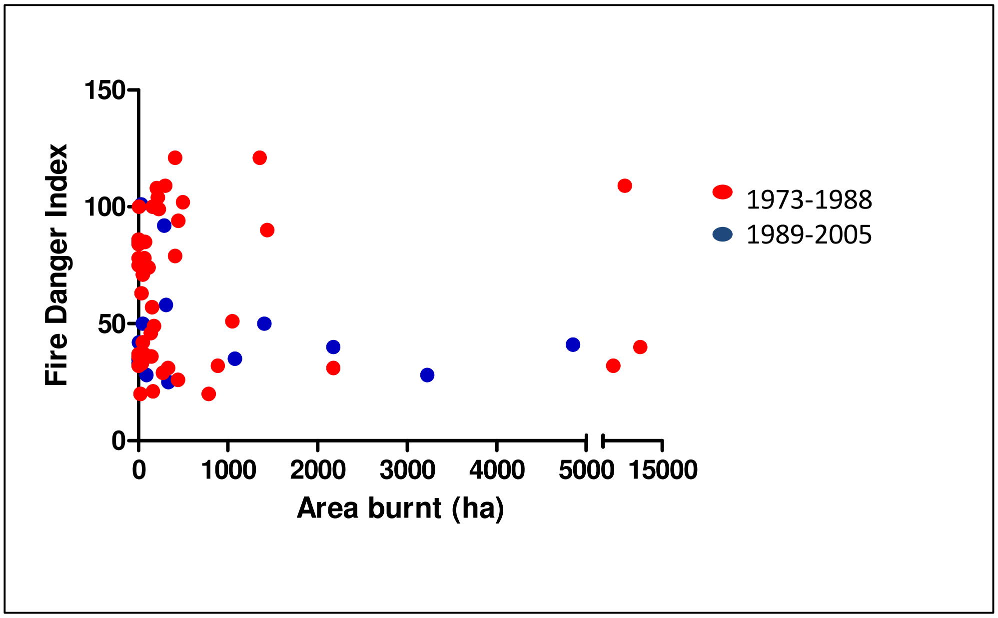

Figure 3.2: Association between Fire Danger Index and total area burnt during 1973-1988 and 1989-2005 periods. Spearman Rank test (GraphPad Prism 5) was used to test association between Fire Danger Index and area burnt for the 1973-1988 (blue dots) period and the 1989-2005 (red dots), P-values ≤ 0.05 were considered significant. The x-axis has been segmented into two, first segment showing major ticks interval of 1 000 and the second segment showing major tick interval of 15 000.

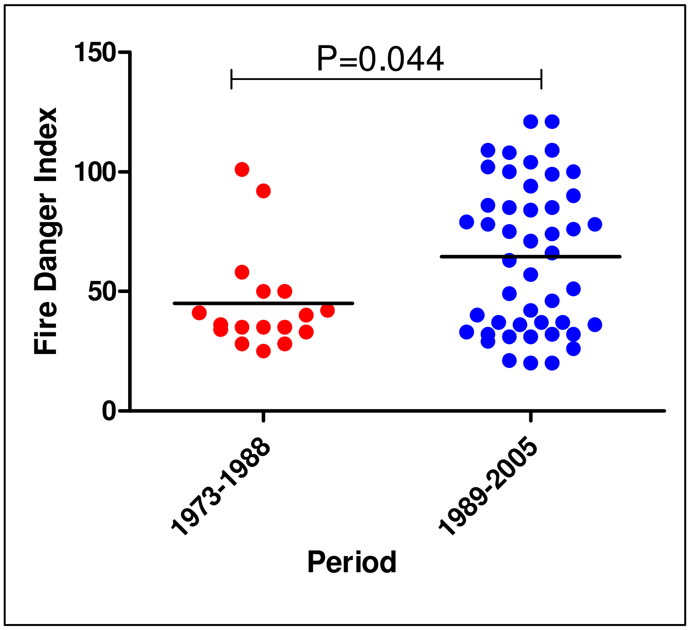

Figure 3.3: Comparison of Fire Danger Index of individual fires during the period 1973-1988 versus the period 1989-2005. Fire Danger Indices were compared between the two management periods 1973-1988 (red dots) and 1989-2005 (blue dots). Horizontal lines represent medians. The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of Fire Danger Index. P-values ≤ 0.05 were considered significant.

3.3 3 Objective three

3.3.3.1 The effects of Fire Danger Index on the fire frequency and fire size in the Kogelberg Nature Reserve

Fires were divided into five categories of Fire Danger Index based on the Burning Index (BI) thresholds values. BI threshold of >95 was categorized as extremely high Fire Danger Index, BI of 71-94 was categorized as high Fire Danger Index, whilst the BI threshold of 42-70 was categorized as moderate and finally BI threshold of 20-41 was categorized as low Fire Danger Index. Table 3.2 shows the Fire Danger Index over two periods (1973-1988 and 1989-2005). Based on the information in Table 3.2 the fires that started when the Fire Danger Index was extremely high increased from one in the period 1973-1988 to 10 in the period 1989-2005. Similarly, the total area burnt under extremely high Fire Danger Index conditions also increased from less than 32 ha in the period 1973-1988 to just under 14 000 ha in the period 1989-2005 (Table 3.2).

When the Fire Danger Index was high the number of fires increased from one in the period 1973-1988 of the study to 13 fires in the period 1989-2005. Similarly, the total area burnt under high conditions of Fire Danger Index also increased from 287 ha in the period 1973-1988 to 2 622 ha in the period 1989-2005 (Table 3.2). When the Fire Danger Index was either moderate or low, there was an increase in both the number of fires and area burnt in the period 1989-2005 compared to the period 1973-1988 (Table 3.2).

Table 3.2: Comparison of the categories of Fire Danger Rating between the periods 1973-1988 and 1989-2005

1973-1988	**Fire Danger Rating**	**BI Thresholds**	**No of fires**	**Total area**
	Extremely high	>95	1	32
	High	71-94	1	287
	Moderate	42-70	3	319
	Low	20-41	12	11884
1989-2005	Extremely high	>95	10	13619
	High	71-94	13	2622
	Moderate	42-70	7	7777
	Low	20-41	17	26381

3.4 Discussion

In a study of 12 weather stations situated on experimental farms of the Western Cape, it was found that the temperature in a 34-year period had increased by more than 1°C on average. This represents more than 0.74°C of the global average over a 100 years projection (Midgley, 2008).

Forsyth and van Wilgen (2008) found that for the Table Mountain National Park, fires take place under a wide range of weather conditions including low fire danger indices. Table Mountain National Park was found to experience relatively mild fire weather conditions when compared to fynbos areas further inland. This was due to its proximity to the sea that exercises a moderating effect on the weather (Forsyth and van Wilgen, 2009).

In this study, the results indicate in the last 18 years of the study period (1989-2005), the Fire Danger Index increased significantly and so did the fire sizes and frequency. This change correlates to changing climate in the Kogelberg Nature Reserve.

3.5 Conclusions

The increased burning indices improve conditions for successful ignition. The combination of fuel, favourable weather conditions and the increased sources of ignition make the change in climate a possible driver for the reduced fire return interval that is a threat to biodiversity conservation.

Whilst there are clear signs of climate change and an increase in the fire frequency at Kogelberg Nature Reserve, there is a need for measures to be taken to mitigate the threats related to climate change. These include applying best conservation practices like creating awareness about the Fire Danger Index and also having the resources available to combat possible fires that are a threat to the biodiversity of the Kogelberg Nature Reserve. With the evidence of high incidence of fires in the Kogelberg Nature Reserve, the fire regime has changed significantly and the change in climate may have played a role. However, other factors such as population change may contribute to greater burning frequency.

Chapter 4

Analysis of the impact of sources of ignition, fire control/ suppression resources and population change on the fire regime of the Kogelberg Nature Reserve

4.1 Introduction

The variety of physical causes of fire ignition in fynbos vegetation include falling boulders, earthquake activity and spontaneous combustion, although there is little evidence for significant spontaneous combustion taking place in vegetation (Edwards, 1984). Lightning is the main natural source of ignition for vegetation in the Western Cape but sparks from rolling quartzite rocks also cause veld fires (van Wilgen 1981). Bond and van Wilgen (1996) suggested that human action is the main cause of contemporary veld fires. Kruger and Bigalke (1984) found that seven of 16 wildfires are as a result of human activities in the Western Cape. As population levels increase, the relative importance of humans as a source of ignition will continue to rise.

4.1.1 Human population of the Kogelberg Biosphere Reserve

The population in the region varies considerably because many of the landowners are not permanent residents, but occupy their properties during weekends and holiday seasons. There is also a large contingent of informal settlers in the region of which the numbers vary considerably from time to time. The Kogelberg Nature Reserve is uninhabited apart from the resident Reserve Manager.

4.1.2 Communities living within the Kogelberg Biosphere Reserve

The major towns within the Kogelberg Biosphere Reserve are Kleinmond and Grabouw.

a) Grabouw has almost 30 000 permanent residents (SA Stats, 2007) and the town mainly serves the apple industry. In the rural areas, the majority of landowners are apple farmers and most of the workers are involved in the apple industry.

b) Kleinmond, although being a very popular holiday destination, has many permanent residents and a well-developed infrastructure. Within the town is a small informal settlement, in contrast to most of the Western Cape, has almost no unemployed residents.

The towns of Betty's Bay namely, Pringle Bay and Rooi Els form a strip of development between the mountains and the sea. These towns are mainly holiday destinations with some permanent residents. The developed areas are included in the transition zone of the Kogelberg Biosphere Reserve, while the natural and near-natural areas in between, for example the smallholdings, are included in the buffer zone. Although this whole coastal area has about 5 000 permanent residents, it escalates to around 50 000 during the peak summer holiday season and that is when most fires occur (Kogelberg Biosphere Reserve, 1992). Gordon's Bay lies on the periphery of the Kogelberg Biosphere Reserve. The town is also a very popular holiday destination.

The small towns on the eastern periphery of the Biosphere Reserve are Bot River, Fisherhaven and Hawston. Bot River mainly serves the farming community. Fisherhaven and Hawston border onto the Bot River Vlei and are mainly holiday towns with some permanent residents. Distributed throughout the region are some small settlements mainly for SAFCOL workers involved with the commercial pine plantations.

4.1.3 Statement of the problem

The challenge facing conservation managers is increasing in complexity and magnitude. Vegetation structures and patterns have been altered by land use practices and the invasion of alien plant species. In addition, urban and agricultural fringes are escalating as the population grows. The resources made available to managers have become scarce and expensive whilst large wildfires regularly threaten thousands of hectares of pristine fynbos (Erasmus, 2006). The Kogelberg Nature Reserve being of exceptional conservation significance is situated in an area surrounded by small towns that have seen lots of migration in the last fifteen years and as the small towns grow, so do informal settlements that may result in increased fire frequencies as noted in the fire regime analysis. The nature reserve is managed by the Western Cape Nature Conservation Board trading as CapeNature, a parastatal that depends mainly on government for financial support. CapeNature is faced with the challenges of dwindling fire fighting and control resources due to pressure in government spending patterns. It is for this reason that a study was initiated to review the extent of the impact of changes in ignition sources, fire control and fighting resources and changes in population growth as well, and to determine how these affect the shifts in the fire regime of the Kogelberg Nature Reserve.

4.1.4 Aims of the study

In Chapter 2 it was shown that the fire regime has changed significantly in the period 1981-2006 and this change correlated with the change in climate. In this Chapter, the impact of the changes in sources of ignition, fire control, declining resources and increased population on the fire regime was investigated.

This study aimed to investigate the following:

a) Changes in the sources of ignition in the Kogelberg Nature Reserve over time.
b) Changes in the resources available to control and fight fires at the Kogelberg Nature Reserve over time.
c) Changes in the demography of the residents of the towns near Kogelberg Nature Reserve from 1996 to 2006.

4.2 Methodology

4.2.1 Sources of ignition

All the fires on the records of Kogelberg Nature Reserve in the last 54 years were classified into the sources of ignition to determine the origin, number of fires linked to that origin and the area covered by that particular fire. The fire periods were broken down into two management periods, namely 1952-1980 and 1981- April 2006 (as previously described in Chapter 1 (Section 1.16).

4.2.2 Fire control and suppression resources

The Kogelberg water catchment was transferred to CapeNature in 1987 and declared a nature reserve. To be able to assess and analyse the impact of fire control and suppression resources at the Kogelberg Nature Reserve, information on these was made available by the Reserve Manager. A comparison of the resources available in the periods 1988-1994, 1995-2000 and 2001-2006 was made to ascertain whether there have been changes that adversely affected the control and suppression of fires in this nature reserve.

4.2.3 Population changes

To analyse the possible changes in human population change, statistics on population growth for the towns surrounding the nature reserve were used. The data available for the period 1996 -2006 were obtained from Statistics South Africa. Unfortunately there are no data available prior to 1996.

Kleinmond is the major town within the biosphere reserve with a large resident population of 30 000 within an area of 4 km^2, but the other villages, namely Rooi Els, Pringle Bay and Betty's Bay, have small resident populations and are mainly used as holiday retreats. Within Betty's Bay, extensive areas of natural vegetation still occur on commonage land and many owners retain natural vegetation on their plots and control alien vegetation. Census statistics of the listed towns and villages were obtained from Stats SA.

4.2.4 Data analysis

GraphPad Prism 5 was used to compare medians (non-parametric Mann–Whitney U tests) and correlations (non-parametric Spearman Rank and Linear regression tests) as previously described in Chapter 2 (Section 2.2.2).

4.3 Results

4.3.1 Objective one

Impact of sources of ignition

Table 4.1 shows the different sources of ignition of all the fires that burnt at the Kogelberg Nature Reserve for the study period from 1952 to April 2006. Sources of ignition identified at the Kogelberg Nature Reserve were either arson, lightning, controlled burning, accidental, or unknown (Table 4.1).

Table 4.1: Sources of ignition at the Kogelberg Nature Reserve for the study period of 1952 to April 2006.

Cause of fire	1952-1980	1981-2006	All fires
Arson			
No of fires	1	9	10
% Frequency	5	9	
% of area burnt	21	79	100
Unknown			
No of fires	12	21	33
% Frequency	42	22	
% of area burnt	32	68	100
Lightning			
No of fires	2	2	4
% Frequency	7	7	
% of area burnt	50	50	100
Controlled burning			
No of fires	10	13	23
% Frequency	36	36	
% of area burnt	43	57	100
Accidental			
No of fires	3	31	34
% Frequency	11	34	
% of area burnt	7	93	100

Arson

As per Table 4.1, there were 10 fires on record that were regarded as arson related and they burnt a total area of 2 940ha during both study periods (1952-1980 and 1981-2006). These fires constituted 2.8% of all the fires that burnt at the Kogelberg Nature

Reserve between 1952 and April, 2006 period. For summer, autumn and spring, three fires per season burnt and only one fire that was arson related burnt in winter during the study period. There was no significance difference in the total area burnt due to arson in the period 1952-1980 compared to the period 1981-2006. This was most probably due to a small sample size with only one fire due to arson in the period 1952-1980 (Figure 4.1).

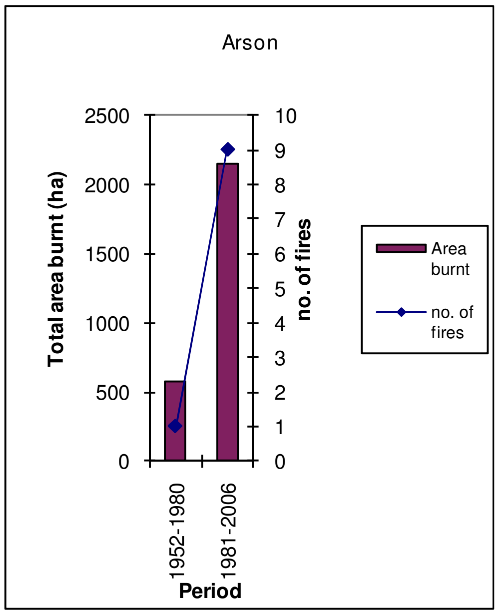

Figure 4.1: Total area burnt and the number of fires due to arson at the Kogelberg Nature Reserve for the periods 1952-1980 and 1981-2006. Red bars represent total area burnt and the blue line represents number of fires. There was no significant difference between the medians. The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of area burnt per fire. P-values $\leq$ 0.05 were considered significant.

Fires of Unknown origin

Thirty-three of the fires that burnt at Kogelberg Nature Reserve in the period 1952-April, 2006 were said to be of unknown origin and these fires burnt a total area of 37 062ha which made up 36% of the total area burnt. Only one fire that burnt in 1976 had no month or date allocated to it and it burnt an area of 182ha. These fires were evenly distributed throughout the fire seasons. Twenty-one fires burnt during the period 1981-2006 as shown in Table 4.1 compared to the 12 that burnt during the period 1952-1980. The largest fire in the reserve was also of unknown origin.

The total area burnt due to unknown origin was significantly higher the period 1981-2006 compared to area burnt in the period 1952-1980 (p=0.0175; Figure 4.2). The total area burnt was higher in the period 1981-2006 due to the high number of fires. However, the fire sizes were smaller compared to those of the period 1952-1980.

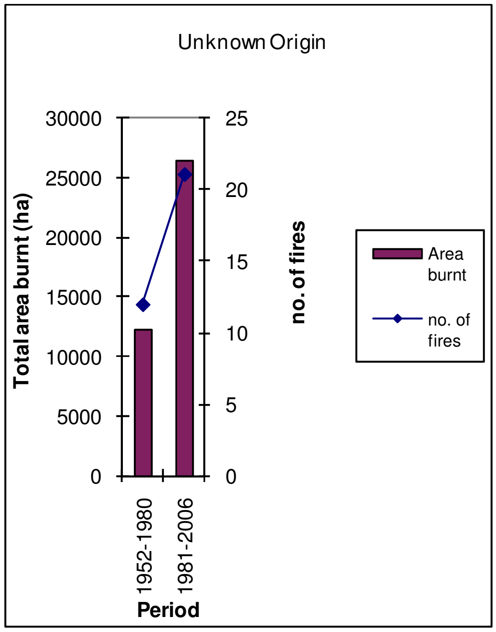

Figure 4.2: Total areas burnt and the number of fires classified as unknown origin at the Kogelberg Nature Reserve for the periods 1952-1980 and 1981-2006. Red bars represent total area burnt and the blue line represents number of fires. The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of area burnt per fire. P-values $\leq$ 0.05 were considered significant.

The great concern is that in spite of the available training in fire investigations and the risk associated with litigation if the fire spread to neighbouring houses, CapeNature does not investigate the sources of these fires to reduce the number of unknown fires.

Accidental fires

This category constituted the largest number of fires recorded during the study but had the lowest area burnt during the 54 years of study. In this category fires of the following origin were classified as accidental; fireworks, braaivleis run away fires, control burns burning out of control, bosslapers making fire, mechanical (train, heavy vehicles), people working in the area (smoking, control burn flare ups), power-lines and vehicle accidents. These fires burnt throughout the seasons and were more prevalent in the period 2001-2006 and made up most of the smaller fires.

From Table 4.1, the fires of accidental origin increased from three in 1952-1980 to 31 in 1981-2006. This means more sources of unplanned fires prevailed in the later period which could be ascribed to an increased population that was not sensitized about the possibility of a veld fire and what consequences it has for conservation. The combination of increased number of fires and increased area burnt does not help the plight of Kogelberg Nature Reserve management that lacks the resources to combat the fire problem. Statistical analysis using the Mann-Whitney U test indicated that there was no significant difference in the total area burnt as a result of accidental fires because there were only three fires during the period 1952-1980 (Figure 4.3).

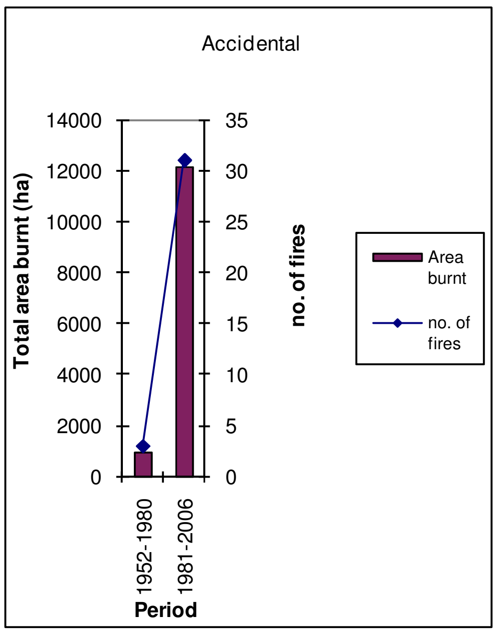

Figure 4.3: Total areas burnt and the number of fires caused by accidental origin at the Kogelberg Nature Reserve for the periods 1952-1980 and 1981-2006. Red bars represent total area burnt and the blue line represents number of fires. There was no significant difference between the medians. The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of area burnt per fire. P-values ≤ 0.05 were considered significant.

Controlled burns

There were 33 fires from prescribed burning during the study period which made up the third largest area burnt (17 972ha) and burnt from February to October. Figure 4.4 shows that there was a sharp increase in the number of fires caused by the prescribed burning which was conducted by the management of the reserve during the period 1981-2006 which is part of the management strategy of Kogelberg Nature Reserve.

Results in Figure 4.4 indicate a drastic drop in the area burnt in the period 1981-2006 for control burns at the Kogelberg Nature Reserve compared to the period 1952-1980.This was due to the fact that CapeNature had not enough resources to carry out the prescribed burns and also because in the last seven to ten years of the study period, there were many unplanned fires that resulted in younger vegetation.

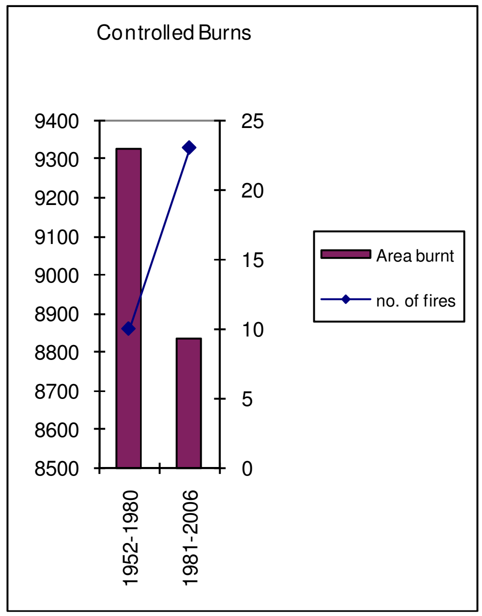

Figure 4.4: Total area burnt and the number of fires caused by controlled burning at the Kogelberg Nature Reserve for the periods 1952-1980 and 1981-2006. Red bars represent total area burnt and the blue line represents number of fires. There was no significant difference between the medians. The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of area burnt per fire. P-values ≤ 0.05 were considered significant.

Lightning

This category contributed about 30% of all the area burnt during the analysis period. Seven of the 10 fires recorded ranged from 1 074ha to 9 929ha and are classified as large fires. The reason for the larger area burnt could be attributed to the fire management plan of 1994. This was a form of Adaptive Interference Fire Management that was applied, which meant a stochastic fire regime utilising natural ignitions and supplemented with intentional burns if necessary (van Wilgen *et al.*, 1992). Lightning is the most common cause of periodic veld fires, aided by southeasterly winds that predominate in the summer in the Cape Floristic Region (Edwards, 1984).

An increase in the number of fires and total area burnt caused by lightning during the period 1981-2006 was noted (Figure 4.5). An increase in the total area burnt, could either mean that these fires were left to burn out on their own or were assisted by staff as part of the management strategy introduced in 1994.

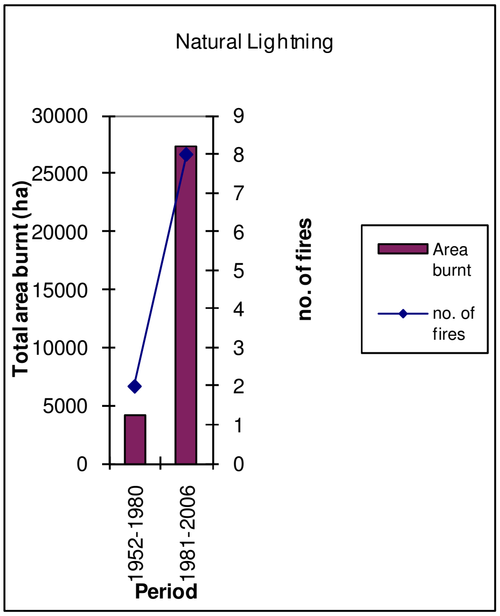

Figure 4.5: Total area burnt and the number of fires caused by natural lightning at the Kogelberg Nature Reserve for the periods 1952-1980 and 1981-2006. Red bars represent total area burnt and the blue line represents number of fires. There was no significant difference between the medians. The Mann-Whitney U-test (GraphPad Prism 5) was used to compare medians of area burnt per fire. P-values ≤ 0.05 were considered significant.

4.3.2 Objective Two

Resources required and available to control and suppress fires in the Kogelberg Nature Reserve

To examine the resources required to control and extinguish veld fires at the Kogelberg Nature Reserve, a similar survey as that conducted in a study by Erasmus (2006) was undertaken. Erasmus (2006) determined the resources required to practice fire management in the Protected Areas of the Western Cape to lobby for funds for fire management. Tables similar to those of Erasmus (2006) were used to create the information in Tables 4.2- 4.5. Data in Tables 4.2, 4.3, 4.4 and 4.5 shows what Kogelberg Nature Reserve should have had and what they actually had to control fires from the time the Kogelberg was proclaimed a nature reserve until April 2006. The fact that Erasmus (2006) has carried out a survey to explain the resources required to carry out fire management in fynbos shows how much they know yet from the beginning they have failed to comply and this lack of resources is driving the fire regime of the Kogelberg Nature Reserve.

Table 4.2: Person days required to carry out Fire Management requirements for the Kogelberg Nature Reserve.

Activity	Norm	Number of person days required
Fire breaks	50 units per ha or 2 km@ 200m) for fire breaks, 1 unit per 200m^2 (tracers, hoed breaks and brush cut) breaks	200
Controlled breaks	160 units per 1000 ha burn for ecological burns for biodiversity and 50 units per 10 ha burn	288
Wild Fire Suppression	Information based on availability for a specific fire	1315
Total personnel required to work full time on Fire Management	Total of person days divided by 230, this being the total number of work days in a year minus weekends, public holidays and annual leave	8

Table 4.3: Estimated costs for keeping a Fire Management team at the Kogelberg Nature Reserve to carry out Fire Management requirements at the nature reserve

Cost	Norm /annum (R)	Total (R)	Justification based on what the current market costs
Wages	42 000	336 000	Based on the starting salary for a General Assistant/labourer
Training	1 000	8 000	Refresher course on basic fire fighting
Protective clothing	2 000	16 000	Overalls, gloves, boots
Equipment	5 000	40 000	Drip torches, fire beaters, rake hoes, knapsack pumps, etc
Administrative costs	3 500	28 000	Communication
Operational costs	15 000	120 000	Transport, rations/refreshments, fuel etc.
Totals	68 500	548 000	

Table 4.4: Resources available to control and fight fires at Kogelberg Nature Reserve for the period 1988 - April 2006.

Operation	1988-1994	1995-2000	2001-2006
No of personnel available to prepare fire breaks	Non compliant	Non compliant	Non compliant, (only in 2009 did the reserve receive additional funding to meet legal obligation)
No of personnel available to prepare control burns	20	20	10
No of personnel available to fight wild fires	20	20	Team of 12 fire fighters contracted each year for the fire season, (Dec – March) and able to draw on WoF resources, (Team of 22) as and when required
Budget available to control and fight fires	No budget, i.e. over expenditure motivated to Province for additional funding	No budget, i.e. over expenditure motivated to Province for additional funding.	R180 000 per annum

Table 4.5: Number of people trained and equipment available for control and fighting fires at the Kogelberg Nature Reserve for the period 1988-April, 2006.

Operation	1988-1994	1995-2000	2001-2006
No of personnel trained to fight wild fires	1 Manager (20 informally trained)	1 Manager (20 informally trained)	2 Managers (12 informally trained)
Equipment available to fight wild fires	1x 500 litre bakkie fire unit	1x 500 litre bakkie fire unit	2x 500 litre bakkie fire units

4.3.3 Objective three

Changes in the population of the residents of the towns near Kogelberg Nature Reserve from 1996 to 2006

Information about the human demography of the towns and settlements around the Kogelberg Nature Reserve was obtained from Statistics South Africa and the Development Bank of South Africa. Since no information was available for the periods before the demarcation of the new boundaries after the new South Africa (1994), analysis for population increase/decrease had to be limited to the period between 1996 and 2005 (dates of census).

Table 4.6 indicates the statistics of the human demography in towns situated/bordering the Kogelberg Biosphere Reserve as shown by the Development Bank of South Africa. The total number of people who permanently resided in the vicinity of the Kogelberg Biosphere Reserve increased over the 10-year period (Table 4.6). Population size in Betty's Bay, for example, increased by 206%, Fisherhaven increased more than 8 times, Pringle Bay by almost 4-fold, Hawston by almost 3-fold, Rooi Els and Grabouw by almost 2-fold. Only Gordon's Bay of the nine towns saw the population decrease steadily over the 10 year period by 22% (684 residents) (Table 4.6). The overall increase represents an increase of 2-fold compared to original population and this is much higher than that of the entire Western Cape which increased from 3.5 million to 5.1 million which represents a 1.3-fold increase.

Table 4.6: Population size of permanent residents over the period 1996 to 2006 in towns near Kogelberg (data extracted from the Development Bank of South Africa, 2007).

Main town	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Gordon's Bay	3 079	3 010	2 943	2 877	2 813	2 750	2 675	2 602	2 531	2 462	2 395
Betty's Bay	215	241	270	303	340	381	425	474	529	590	659
Fisherhaven	175	216	267	330	408	507	625	770	949	1 169	1 440
Hawston	3 960	4 405	4 901	5 452	6 065	6 748	7 473	8 276	9 166	10 151	11 242
Kleinmond	3 435	3 889	4 403	4 985	5 644	6 392	7 205	8 122	9 156	10 321	11 634
Pringle Bay	290	332	380	435	498	571	651	742	846	965	1 100
Rooi Els	49	52	56	60	64	69	74	79	84	90	96
Grabouw	15 998	16 987	18 037	19 152	20 336	21 591	22 817	24 113	25 483	26 930	28 460
Elgin Forest	4	4	4	4	4	6	6	6	6	6	6
Totals	27 205	29136	31 261	33 598	36 172	39 015	41 951	45 184	48 750	52684	57 032

The increase in population size over time was further confirmed by statistical analysis, where it was found that there was a significant increase in the population size over time (Linear regression test, $P<0.0001$ and Spearman test, $P<0.0001$; Figure 4.6).

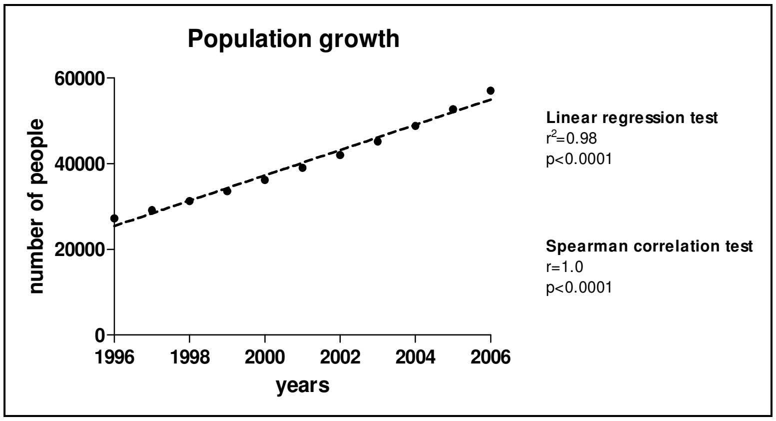

Figure 4.6: Changes in the population size over time in towns surrounding the Kogelberg Biosphere Reserve. The changes in the total number of people in towns surrounding the Kogelberg Biosphere Reserve were plotted for the period 1996-2006. Spearman Rank and linear regression tests (GraphPad Prism 5) were used to test association between number of people and years.

There was a significant increase in the number of fires over time (Linear regression test, P=0.025 and Spearman test, P=0.046; Figure 4.7). Figure 4.8 also shows an increase in the fire frequency. Whilst there are no data available for the population of the towns around the Kogelberg Nature Reserve prior to 1996, based on the increase of the number of ignitions analysed in objective two of this study more fires of human origin are evident compared to the previous years when the migration to the Western Cape was restricted during the apartheid era.

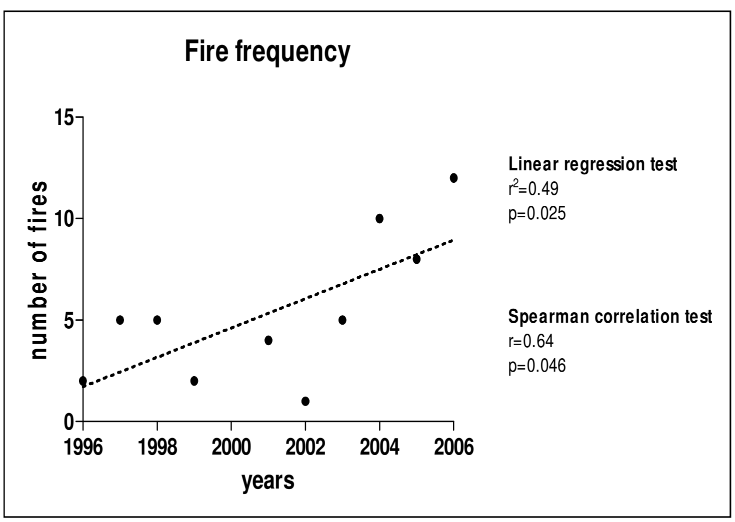

Figure 4.7: Fire frequency over time in the Kogelberg Biosphere Reserve. The numbers of fires in the Kogelberg Biosphere Reserve were plotted for the period 1996-2006. Spearman Rank and linear regression tests (GraphPad Prism 5) were used to test association between number of fires and years.

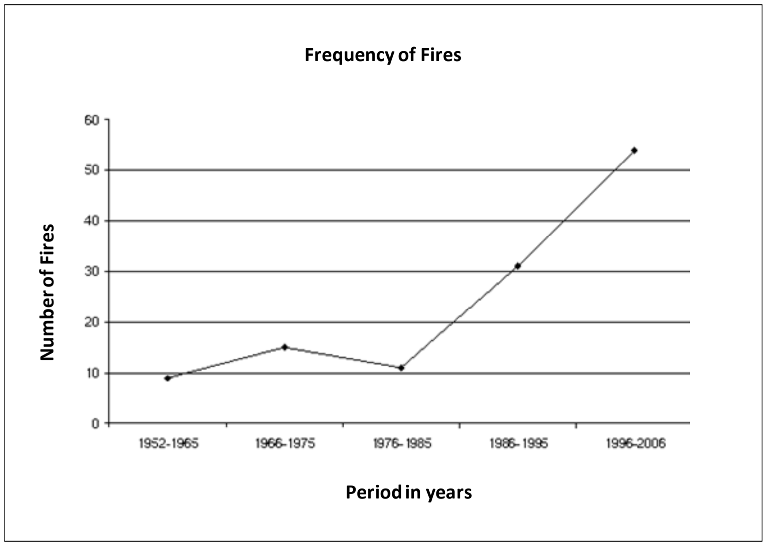

Figure 4.8: Frequency of fires from 1952 to 2006 at the Kogelberg Nature Reserve. The numbers of fires after ±10 years (i.e. 1952-1965, 1966-1975, 1976-1985, 1986-1995 and 1996-2006) in the period 1952-2006 were plotted.

Another interesting part of the results is that whilst the number of people and ignitions increased in the last ten years of the study period, the area burnt decreased, although this was not significant (Figure 4.9).

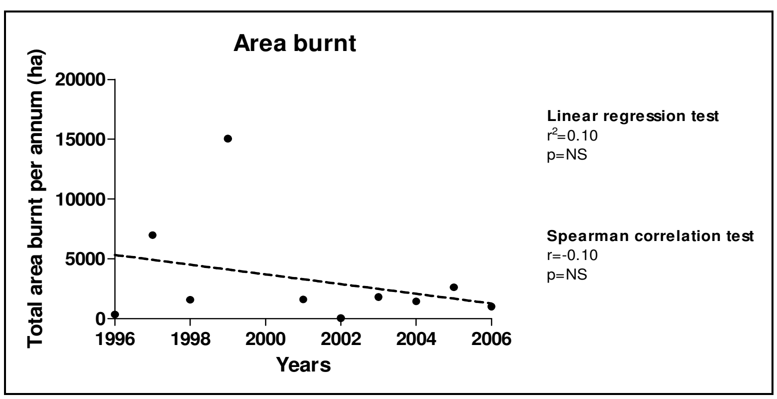

Figure 4.9: Total area burnt per annum from 1996-2006 in the Kogelberg Biosphere Reserve. Spearman Rank and linear regression tests (GraphPad Prism 5) were used to test relationship between total areas burnt per annum with time. NS=not significant

4.4 Discussion

From the analysis of the sources of ignition and population growth, it is evident that in the last ten years of the study, there were more people coming to live in the towns surrounding the nature reserve and coupled with that were more fires started besides the natural lighting and control burns. Whilst there is no control of lightning there were only two fires caused by control burns during the last ten years of the study period and they covered a very small area. This observation is exacerbated by the outcome of the analysis of the resources of control and fire fighting which are not sufficient to meet the increased fires in the area. Forsyth and van Wilgen (2008) cited that >80% of fires in the Table Mountain national Park were a result of wild fires.

The results of the analysis of the resources for controlling fires also revealed that whilst the physical resources were not sufficient to control fires and suppress them, there was also a shortage of skills development and manpower that is critical in controlling and fighting fires. This dates back from the time DWAF offered voluntary retrenchment packages to staff members during the late 1990s and many of the remaining experienced veld fire managers accepted these packages and left the organisation. Many of the fires from the nature reserve or towards the reserve were due to lack of capacity and leadership at the suppression operations as noted by Kruger *et al.*, (2000). The lack of experienced capacity to respond to fires led CapeNature to depend on contractors from 2002. The problem with the use of contractors is that they are seasonal and only used to help control fires during the fire season and paid a daily tariff. Fire breaks are not completed which is a contravention of the law and the policy of Fire Management at CapeNature states that personnel involved in fire suppression should be trained and qualified, physically fit and motivated to protect the property of CapeNature. This means that CapeNature is not practising effective Fire Management, they only react to fires if and when they start and that is not good for the conservation of such an endemic global asset.

4.5 Conclusions

The trend of urbanisation of wild land areas results in a collision of the conservation areas with humans. The cycle starts with some people who move into these natural areas motivated by being in harmony with nature i.e. running away from the busy city life to a quieter lifestyle free from the hassles of the rat race, either permanently or on weekends or holidays. This move creates job opportunities for the group that cannot afford to purchase land hence they build informal settlements in close proximity to the nature reserve. Usually, the people who move to these informal areas come from places where the vegetation is different from fynbos, mainly grasslands that are burnt annually. Once there is combination of informal settlements and the development that goes on in a wild-land urban interface, a high-risk mix of development and fire prone vegetation exists and then wild fires can spread from the vegetation to the structures or from the structures to the vegetation. With more people moving to the land bordering the natural vegetation coupled with improved conditions for wild fires facilitated by changes in weather conditions, these results in a higher risk of ignitions of wild fires. The impact of increased fire ignition sources coupled with increased population growth and limited resources for fire control and suppression may have the following impact:

1. More frequent unplanned fires that will result in a fire regime change. This could result in a reduced fire return interval which has an ecological effect on the conservation of fynbos and the availability of water in the Western Cape. More proteas will be adversely affected whereas ericas will thrive.
2. The lives and properties of the residents of the neighbouring towns are at risk that has resulted in litigation.
3. Without resources and finances to implement a fire control programme, it is impossible to carry out the recommendations of the National Veld and Forest Act, 1998 (Act No.101 of 1998).
4. The lives of Fire fighters and emergency services personnel are put at risk, as they have to fight fires on difficult terrain to protect lives and property.

5. Keeping structures and personnel safe takes precedence over the main objective of fynbos conservation fire when it comes to prioritising resources and that leaves the fynbos to burn further.

With all the threats listed above, the conservation of the pristine fynbos at the Kogelberg Nature Reserve is threatened unless drastic measures are taken to mitigate the risk through political lobbying for sufficient resources to control and suppress fires as they start and also through investigations of all the arson related fires and successful prosecutions take place to discourage the perpetrators of arson. Fire awareness programmes should be run more frequently especially during the fire season to alert the new settlers of the risks about starting a fire in a fynbos area.

It is worth noting that the section on resources for control and suppression is limited to 1988 -2006 only due to available data. However, a conclusion can be drawn that the lack of resources to control fires has had an effect on the control of fires. This has resulted in fires being not easier to control in the Kogelberg Nature Reserve.

Chapter 5

Relating the impact of changes in climate, population density and fire frequency (number of fires and area burnt) of the Kogelberg Nature Reserve

5.1 Introduction

The Kogelberg Nature Reserve, a world heritage site situated close to Cape Town has an exceptional diversity of natural environments characterized by a range of marine and coastal environments, rare black water lakelets, marshes, estuaries, rivers and coastal mountains bordering on a narrow coastal plain. The natural features make it a desirable destination for eco-tourists and provide unparalleled opportunities for environmental education. In the interest of local communities, landowners and the general public Kogelberg Nature Reserve should be maintained in a predominately natural condition and the resources should be used sustainably (Jordaan, 1991).

The Kogelberg Nature Reserve is said to be the centre for nature reserves in the Fynbos Biome on the basis of its phytogeographical significance and plant species richness (Rebelo and Siegfried, 1990). This is supported by results of a study where in a single 14 400 ha core reserve counted in the Kogelberg State Forest and adjacent coastal area, an estimated 17% of the Cape flora could be protected (Rebelo and Siegfried, 1990).

5.2 Statement of the problem

Gill *et al.*, (2002) states that beyond the management of fires as isolated events is the understanding of management of fire regimes which will require a far better understanding of whether and how fire regimes can be influenced. Parr and Anderson, 2006 says that the understanding can only be gained if long term fire records are adequately analysed and interpreted and such an understanding is often absent and fire managers can only respond to 'visible mosaic'.

Results of the analysis of the fire regime of the Kogelberg Nature Reserve in the period 1981-2006 show that there has been an increase in the number of fires and the total area burnt even though the sizes of individual fires had reduced in size compared to the period 1952-1980. On the analysis of the resources for fire fighting in the Kogelberg Nature Reserve, it is evident that there were not enough measures for preventative action in case of wild fires.

There was also an indication that the number of ignitions had increased for unplanned fires. This could be an indication that the conditions for fires to start were more conducive during that period due to changes in climate, sources of ignition and reduced fire fighting resources. However, there is no evidence to prove that these are the drivers of the fire regime of the Kogelberg Nature Reserve as there was not scientific method used to prove this. This chapter seeks to ascertain whether there was a correlation and association of these factors to the fire regime of the Kogelberg Nature Reserve. To tie the relationship between the alleged drivers (Climate change, Population Change and the number of fires and fire sizes) of the fire regime of the Kogelberg Nature Reserve, a statistical model was derived.

5.3 Aim of the chapter

The aim of the chapter is to quantify and describe patterns in the fire regime of the Kogelberg Nature Reserve and correlate it with the potential driving factors over the period 1996-2005.

5.4 Methodology

As noted in chapter 4, resources to control fires are not enough to meet the needs of fire prevention and control at the Kogelberg Nature Reserve. To determine whether there is a causal link between the changes in the fire regime, changes in climate as measured in burning indices and population change, a multivariate model of pulling together the relationship of humans and climate on number of fires and area burnt was developed using Partial Least Squares (PLS) and Principal Component Analysis (PCA). This was done using the program XL STAT 2011.

5.4.1 Statistical procedures used with XLSTAT (2011)

Two statistical analyses were used to describe the data of table 5.1 namely Principal Component Analysis and multiple regression (PLS).

Principal component analysis (PCA)

PCA (Principal Component Analysis) is a statistical package that looks at all the variables at once. It is a dimension reducing technique which help to identify patterns in data and expressing the data in such a way as to highlight their similarities and differences. PCA is applied to data with no groups among the observations and no partitioning into x and y variables.

Suppose the data has N number samples on which measured p variables were measured. If you could simultaneously envision all variables, then there would be little need for a technique like PCA. However, with more than three dimensions, we usually need a little help. What PCA does is that it takes the cloud of data points, and rotates it such that the maximum variability is visible. PCA makes linear combinations of all variables. PCA1 (first principal component) is the linear combination with the maximum variance. We are essentially searching for a dimension along which the observations are maximally spread out. The second principal component is the linear combination with maximum variance in a direction orthogonal (and therefore uncorrelated) to the previous principal component of the same dataset (Rencher, 2002). Data for this procedure should be standardised. There are a few methods available to use but for this study correlation matrix was used to standardise the data.

5.4.2 Multiple regression (= Partial Least Square model with one dependent variable)

The general purpose of multiple regression (the term was first used by Pearson, 1908) is to learn more about the relationship between several independent or predictor variables and a dependent or criterion variable. The PLS was used to predict the y (dependent variable, Area burnt) from independent variables (population, fire danger index and number of fires).

5.5 Data used

To determine changes in the fire regime of the Kogelberg Nature Reserve fire data from 1952-2006 were used. To analyse for climate change, using burning indices from the Boontjieskraal weather station the only data available were from 1973- 2005. Census data from 1996-2006 were used to calculate population density change. However because the periods of the available data for the different calculations was not the same, to tie up the relationship of fire (numbers and total area burnt) with population density and climate change, only date where all the variables were available was used to determine if climate change and population density were the drivers of either fire numbers and total area burn. The data used were limited to 1996 - 2005 when population data were available. The 2006 data was not used because the fire data were available up to end of April.

5.6 Results

Table 5.1: Data used for the multivariate analysis during the period 1996-2005.

Year	Total area burnt	Number of fires	Average burning index	Population	Average days per fire
1996	72	1	85	27 205	1
1997	7 385	4	44	29 136	2
1998	1 081	2	57	31 261	2
1999	12 383	2	38	34 598	5
2000	0	0	0	36 172	0
2001	1 619	4	86	39 015	2
2002	48	1	42	42 951	1
2003	1 619	5	53	45 184	2
2004	1 892	11	79	49 750	1
2005	2 626	8	69	53 684	1

Total area burnt - As explained in the methodology, only data for a ten year period was used to establish a causal link between fire frequency, population density and climate change. The results of Table 5.1 show that the largest area burnt was more than 10 000ha (12 383ha) in 1999 and the smallest being 48 ha that burnt in the year 2002. It is worth noting that there was no fire in the year 2000.

Number of fires – With the exception of the 2000, the number of fires ranged from 1 to 11.

Average burning index -.the range of burning indices was 42 to 85. Six of the years where fires burnt had an average burning index of more than 50 which is classified in chapter three as having a strong possibility for a fire to start.

Population density – there was no change in the population as per the original data shown in chapter four.

Average duration of fires per year – the average days burning per fire per year ranged from 1 to 5.

5.7 Principal Component Analysis (PCA)

The Principal Component Analysis (PCA bi-plot) was used to describe the relationship between variables. Associations between the factors (year) and variables were shown in the PCA bi-plot as a visual representation of the Principle Component Analysis.

Table 5.2: Pearson's correlation matrix (Pearson product moment correlation) from the Principal Component Analysis method.

Variables	Total area burnt	Number of fires	Burning index for each fire	Population	Number of days
Total area burnt	**1**	0.031	-0.177	-0.228	**0.886**
Number of fires	0.031	**1**	0.513	**0.721**	-0.193
Burning index for each fire	-0.177	0.513	**1**	0.178	-0.370
Population	-0.228	**0.721**	0.178	**1**	-0.278
Number of days	**0.886**	-0.193	-0.370	-0.278	**1**

Values in bold are different from 0 with a significant level alpha = 0.05. The yellow line (population and the correlation with other variables changed). The only significant correlation are between number of days and area burnt and population density with number of fires.

Table 5.3: Principal Component analysis (PC1) indicating % variations in the multivariate data.

	F1	F2	F3	F4	F5
Eigen value	2.420	1.513	0.832	0.169	0.066
Variability (%)	**48**	**30**	17	3	1
Cumulative %	**48**	**79**	95	990	100

As described in the methodology, PCA is a technique looking for patterns. The variance in the data accounted by the PCA is 79% as shown in Table 5.3 (yellow colour) above.

PCA1 (first principal component) is the linear combination with the maximum variance. The aim is to search for a dimension along which the observations are maximally spread out. The second principal component is the linear combination with maximum variance in a direction orthogonal (and therefore uncorrelated) to the previous principal component of the same dataset. In the Principal Component

Analysis (PC1) shown in Table 5.3, the first Principal Component (PC1=F1) declares 48% of the variation in the data. The second PCA is 30% (=PC2=F2). The result accepts the 2 PCAs because a shift to PC3=F3 is but 14%.

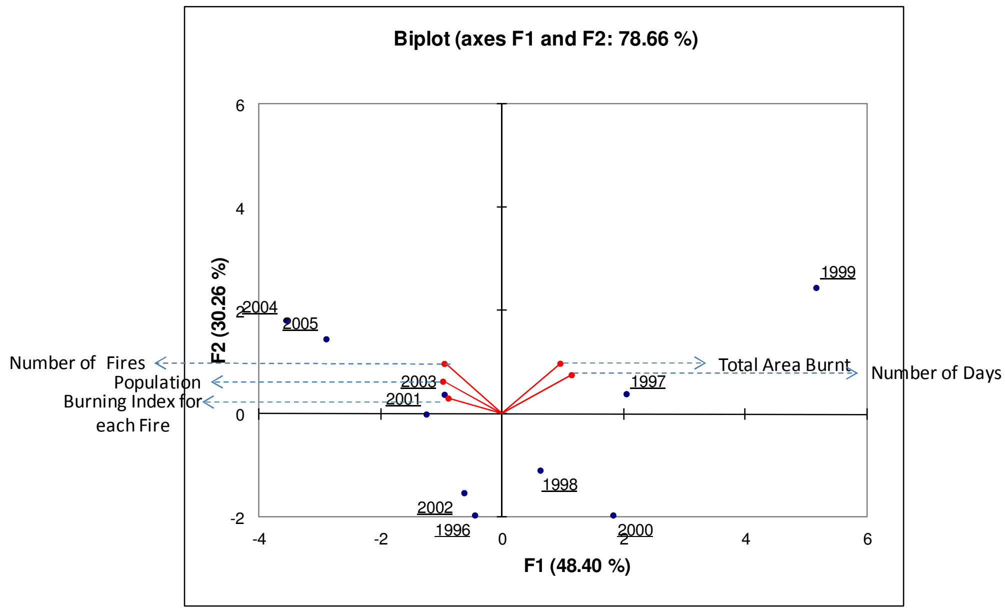

Figure 5.1: Principal Component Analysis bi-plot showing the relationship between variables and correlations.

In Figure 5.2 the total area burnt is highly correlated with the number of days (they lie close together in quadrant 2). This shows that there were more days on which a fire burnt and resulted in a larger total area burnt. It is also noted that year 2001, 2003, 2004 and 2005 are associated with an increase in the number of burning fires, an increase burning index per fire and an increase in Population.

5.8 Partial Least Squares Analysis (Multiple regression).

Table 5.4: Correlation matrix using the Partial Least Squares Analysis method (multiple regression in this case).

Variables	Number of fires	Burning index for each fire	Population	Number of days	Total area burnt
Number of fires	**1.000**	0.367	0.746	-0.209	**-0.075**
Burning index for each fire	0.367	**1.000**	0.160	-0.547	**-0.557**
Population	0.746	0.160	**1.000**	-0.279	**-0.262**
Number of days	-0.209	-0.547	-0.279	**1.000**	**0.916**
Total area burnt	**-0.075**	**-0.557**	**-0.262**	**0.916**	**1.000**

The blue coloured lines in Table 5.4 indicate the correlations between area burnt (=y) with all 4 factors (=x), which are predictors. The outcome of the analysis shows a good correlation between area burnt and number of days on which the fires were burning (r=Pearson product correlation coefficient r=0.916 at 5% or p=0.05).

Table 5.5: Model parameters

Variable	Total area burnt
Intercept	1961
Number of fires	369
Burning index for each fire	-34
Population	-0.098
Number of days	2821

The following equation could be used to predict the area burnt from the number of fires, population size and number of days as derived from Table 5.5:

Total area burnt = 1 961 + 369 (number of fires) – 34 (burning index for each fire) – 0.098 (population) + 2821 (number of days)

The R-square = 0.894 is significant at 5% (p=0.05) and gives an indication of how good the model fits this specific data

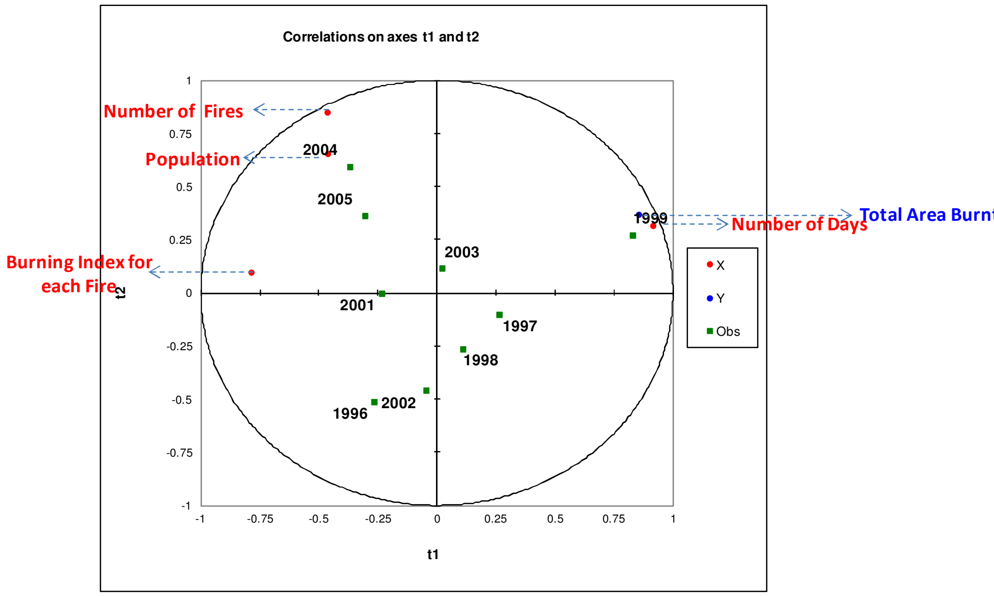

Figure 5.2: Partial Least Square bi-plot. The total area burnt (coloured blue) is the predicted variable and the number of fires, population (=population size) and burning index of each fire (coloured red) are the predictors. In Figure 5.2 the area burnt and the number of days of burning (duration of fire) nearly coincide.

An illustration of the fire frequency in the Kogelberg Nature Reserve is shown in Figures 5.3, 5.4 and 5.5 whilst an illustration of the FDI range (1973-2005) is shown in Figure 5.6. These figures summarize the extent of the fires on the Kogelberg Nature Reserve which could be ascribed to the effects of increased sources of ignition that came about as a result of increased population density, lack of resources to control fires and increased conditions for fires to start.

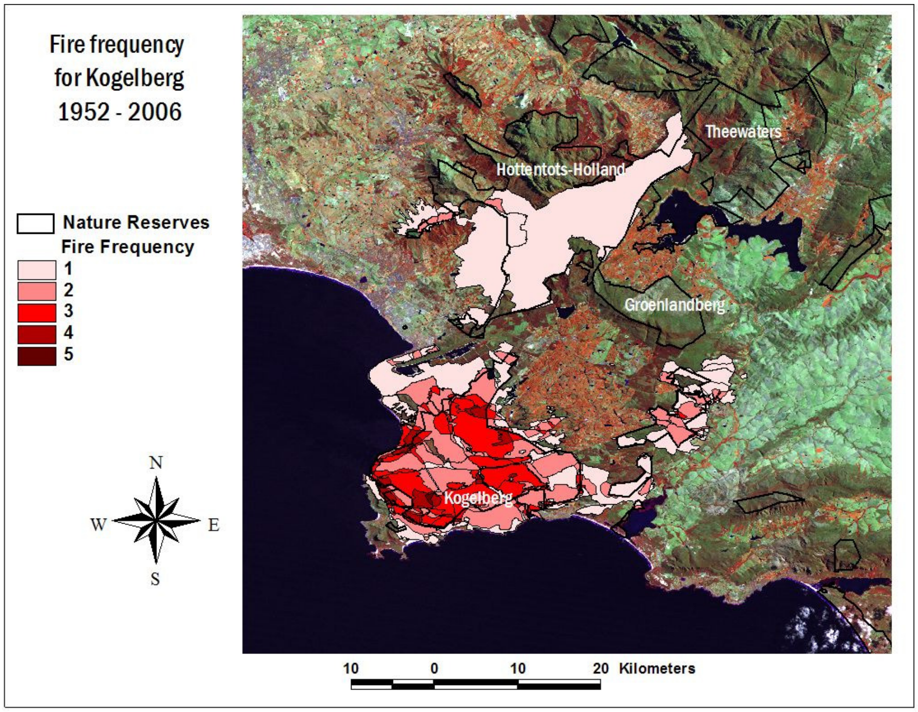

Figure 5.3: Fire frequency for the Kogelberg Nature Reserve from 1952-2006 using GIS 3.1

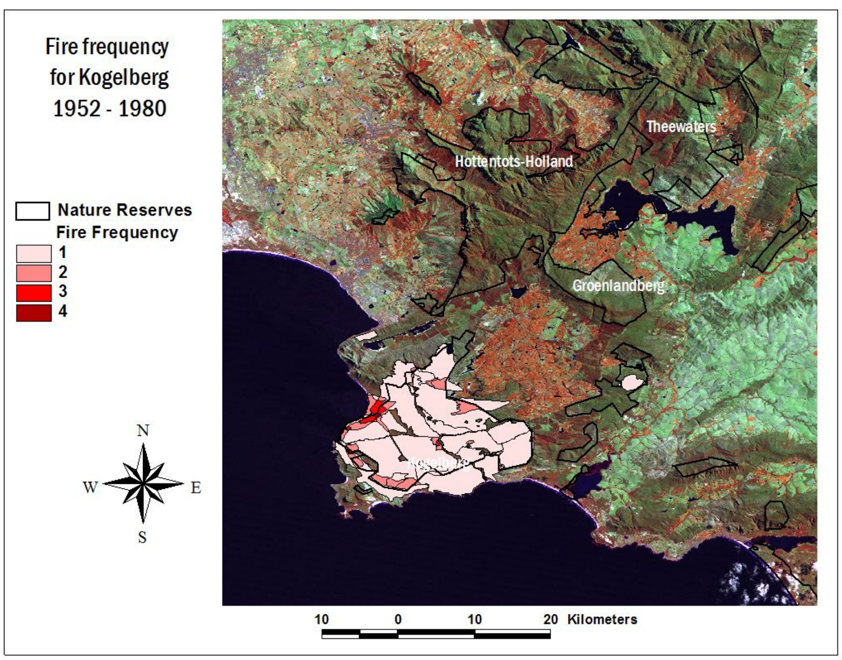

Figure 5.4: Fire frequency of the Kogelberg Nature Reserve for the first period of the study period (1952-1980) using GIS 3.1.

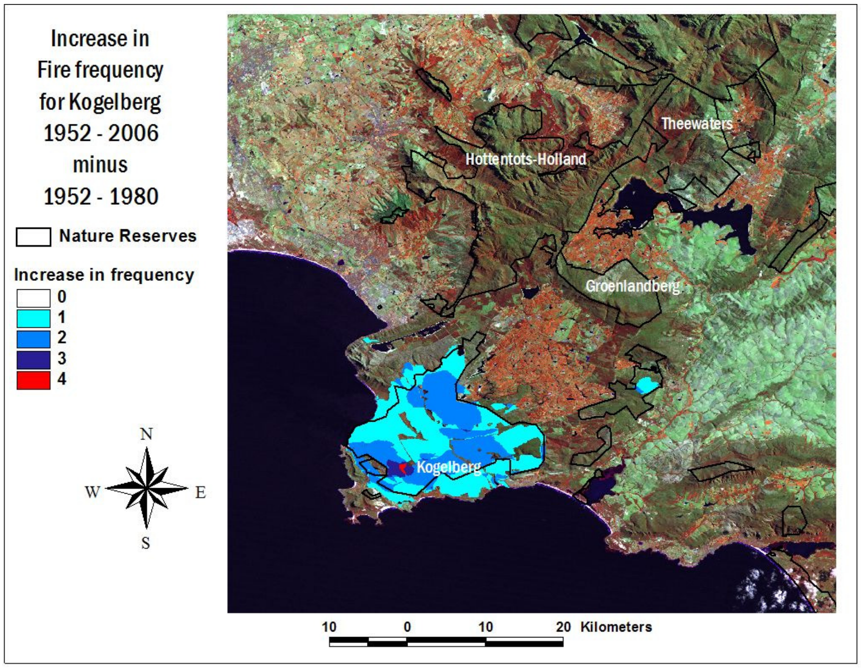

Figure 5.5: The difference in the fire frequency of the Kogelberg Nature Reserve for the two study periods using GIS 3.1

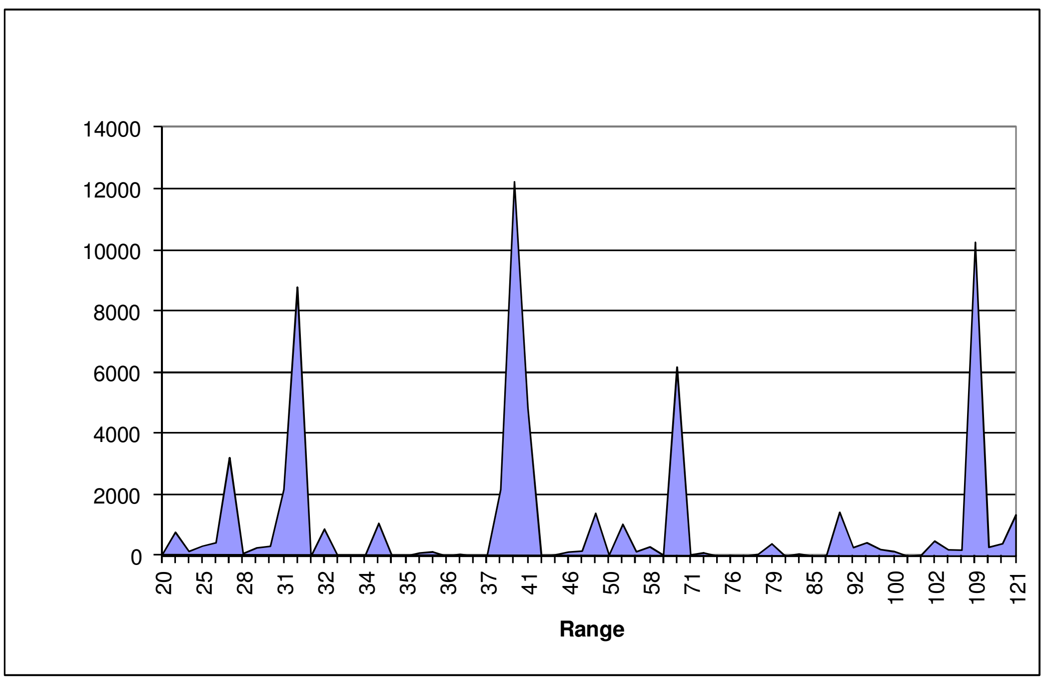

Figure 5.6: Fire burning indices and the total area burnt for all the fires during the period 1996-2005 in the Kogelberg Nature Reserve. This is an indication that fires occurred in all ranges of the weather pattern and affected all ranges of total area burnt.

5.9 Discussions and conclusions

Managers charged with conserving biodiversity in fire dependent ecosystems need to assess whether fire regimes remain within acceptable limits (Forsyth and van Wilgen, 2008). In fire prone ecosystems, individual fire events contribute to the fire regime over time and managers usually seek to promote a particular regime by burning a selected proportion of the land in any given season and at the appropriate return interval (van Wilgen *et al.*, 2010). In keeping with sound fynbos conservation practices, managers should keep the majority of fires (80-90%) in summer or autumn to avoid negative impact (van Wilgen and Scott, 2001). In the Kogelberg Nature Reserve, the season of burn has not been affected as most of the fires burnt during the summer and autumn in the last twenty years of the study period. This has happened in spite of the fact that there were less prescribed burned fires due to lack of resources to do the prescribed burns.

Having noted that the fire numbers and sizes have increased significantly from the analysis, the big question was what really drives the fire regime of the Kogelberg Nature Reserve. During the last ten years of the study there was no prescribed burning taking place due to lack of resources, however, the frequency of unplanned fires from various sources increased. Whilst the fire sizes were relatively smaller, the nucleus of wild fire increased which is a cause of concern since that has reduced the return interval. From the analysis of both the burning indices and population densities of the people that that have settled in the towns neighbouring the Kogelberg Nature Reserve, a significant increase in both is noted.

In tying the population density and climate change to the area burnt and number of fires, the results show that there was a significant correlation between the number of days on which the fires burnt and the total area burnt and population density with the number of fires as shown in Table 5.3. This result corresponds with the hypothesis that an increase in the population of the people living in the vicinity of the Kogelberg Nature Reserve will increase the number of fires in the reserve. An increase in the number of days on which fires were burning resulted in a significant increase in the total area burnt.

From the multivariate analysis presented in this chapter, the relationship between the increase in sources of ignition (number of fires) and population density in 2001, 2003, 2004 and 2005 as shown in Figure 5.2 is highly significant. This is proof that in the beginning of the 21^{st} century, the conditions for starting fires increased coupled with an increase in population density which is associated with increased sources of ignition.

The results of this thesis show that the Kogelberg Nature Reserve has been negatively impacted by increased conditions of ignitions associated with climate change, increased unplanned fires associated with increased population growth and lack of capacity and resources to prevent and control the veld fires.

Chapter 6 Conclusions

The study was conducted to evaluate various factors that might be responsible for observed increase in the fire frequency of the Kogelberg Nature Reserve over the past decades. Analyses show that the increased frequency of fire correlates to increases in high fire hazard weather conditions, population increase and a lack of equipment and skills in CapeNature to combat fires.

Mlisa *et al* (2009) ruled out changes in fire fuels and landscape fragmentation as possible drivers of the fire regime in the Kogelberg Nature Reserve. This study shows that the neighbouring towns have grown in population density significantly in the last ten years. It is possible that population change over the years may be one of the possible drivers of the fire regime in the Kogelberg Nature Reserve. There is a strong association between fire numbers and fire sizes with population changes. Population density is identified as one of the drivers of the fire frequency of the Kogelberg Nature Reserve.

The fire data from 1952 -2006 show that with the exception of prescribed burns which were last done before the year 2000, all the wild fires come from the neighbouring farms and towns. There is also a marked increase in the number of fires caused by arson which is a cause of great concern.

Fires that burn more frequently and out of phase with the natural regime represent a major threat to the reserve. The Fire Management plan of the Kogelberg Nature Reserve involves a prescribed burning programme using a stochastic rotation approach to maintain the vegetation mosaic in order to promote plant and animal diversity.

The results of the analysis of the resources for controlling fires also revealed that whilst the physical resources were not sufficient to control fires and suppress them, there was also a shortage of skills development and manpower that is critical in controlling and fighting fires. Many of the fires from the nature reserve or towards the reserve were due to lack of capacity and leadership at the suppression operations as noted by Kruger *et al.,* (2000). The lack of experienced capacity to respond to fires led CapeNature to depend on contractors from the year 2002. The problem with the use of contractors is that they are seasonal and only used to help control fires during the fire season does not attract the experienced fire fighters. Fire breaks are not completed which is a contravention of the law and the policy of Fire Management. CapeNature Fire Management Policy of 2006 states that personnel involved in fire suppression should be trained and qualified, physically fit and motivated to protect the property of CapeNature.

The knowledge gained from this study can be summarised as follows:

1. **Fire frequency** - There are more frequent unplanned fires in the Kogelberg Nature Reserve in the last twenty years of the study period resulting in a fire regime change and a reduced fire return interval that has a negative ecological effect on the conservation of fynbos.
2. **Climate change** - The climate of the area has changed significantly in the last twenty years thereby increasing the potential for starting wild fires that are a threat to fynbos conservation. However, fires start in all ranges of the weather data therefore requiring that control measures must be in place to control the fires.
3. **The population density** – The population density of the neighbouring towns surrounding the Kogelberg Nature Reserve has more than doubled in the last twenty years of the study period that also increases the ignition sources which has an impact on the fire return interval of the fynbos.
4. **Fire Fighting Resources** – For the last twenty years of the study, there were limited resources to practise effective fire control in the Kogelberg Nature Reserve hence the conservation of the pristine fynbos plants is compromised. This implies that if there is a fire that starts from the outskirts of the reserve, the fire brigade would rather protect the lives and properties of the residents of the neighbouring towns than to help protect fynbos from fires. If a fire was to start from the reserve and spread to

neighbouring properties, CapeNature would face litigation because it lacks the resources to prepare fire breaks as required by law.

5. **Multivariate analysis** has indicated that there is a significant correlation between the number of days and area burnt with population and number of fires. In the same analysis, from 2001-2005 there was a correlation of the years with the number of fires and population. The years 1997 and 1999 were associated with large fires that ravaged the Kogelberg Nature Reserve and more days when fires were burning.

Total area burnt model below can be used to predict the area burnt in future if the same variables are used for different observations:

Total area burnt = 1 961 + 369 (number of fires) – 34 (burning index for each fire) – 0.098 (population) + 2821 (number of days)

The conclusions of this thesis have significant implications for fire management and Conservation Science with regards to the fire management of the Kogelberg Nature Reserve. They highlight the current status and the history of fire management of the reserve which support the logic that a comprehensive record of the fire history of an area provides the basis for informed future management. This thesis identified areas that have been subject to ecologically appropriate and inappropriate fire frequencies. Climate change is a natural occurrence which no manager can control; however creating awareness to the potential sources of ignition when the chances of starting a wild fire is great can go a long way towards reducing unplanned fires. In the last five years of the study, arson related fires became common and because there are no investigations that lead to prosecution of the perpetrators no action was taken against the guilty parties. CapeNature should appoint private investigators to get to the bottom of these dangerous acts because they may result in adverse effect on the fire return interval of the fynbos. The South African government should enforce the National Veld and Forest Act, 1998 (Act No.101 of 1998) and make provision for resources to prevent fires to important conservation sites such as Kogelberg Nature Reserve so that they do not lose their international reserve status which is also good for tourism and the economy of the region.

As highlighted in chapter 4, Kogelberg Nature Reserve is poorly resourced to prepare preventative measures for fire control let alone suppressing fires that enter the reserve from neighbouring properties. The members of the Kogelberg Biosphere Reserve must form an active Fire Protection Association to enforce the compliance to wild fire protection that will include creating awareness about wild fires to the schools and communities.

In conclusion, it can be stated that this study has achieved its aim of determining the effects of changes in climate, population density and other social factors on the fire regime of the Kogelberg Nature Reserve. Since the multivariate analysis was only for ten years due to the limitation in the data available for all the variables, it would help to have an analysis of data that spans more than twenty years. This would be more relevant to an ideal fire return interval of the Kogelberg Nature Reserve that should be between 15-20 years. For future studies it would help to study the fire intensity of the fires in the Kogelberg Nature Reserve because fire intensity is also an important measure of fire regimes. Finally it would help to investigate all the fires of unknown origin that burn at the Kogelberg Nature Reserve to be able to point out to the real reason for all the fires that are unplanned.

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