Past approaches and future challenges to the management of fire and invasive alien plants in the new Garden Route National Park

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The recently established Garden Route National Park (GRNP) along the Cape south coast of South Africa occurs in a landscape where indigenous forests, fire-prone fynbos shrublands and fire-sensitive plantations of alien invasive trees are interspersed. We used the area as a case study in the challenges facing conservation managers in the achievement of biodiversity goals in a fire-prone environment. We explored the context within which fire management was practised during the past century by interviewing former catchment managers and reviewing forestry and catchment management policies. Mountain fynbos adjacent to plantations was subjected to burning regimes aimed at the protection of commercial timber resources rather than the preservation of fynbos biodiversity. Prescribed burning of fynbos adjacent to the plantations was typically done in multiple belt systems at rotations of about 4–8 years during spring, summer and autumn, to avoid the winter berg wind season. Such short-rotation and low-intensity fires favour resprouting graminoids over slow-maturing reseeders, and likely account for the compositional impoverishment observed in fynbos near plantations. Current and future challenges faced by the GRNP include (1) balancing conflicting fire management requirements for plantation safety against fynbos conservation; (2) the continual invasion of fynbos by fire-propagated alien pines sourced from plantations; (3) inadequate resources to redress the 'invasion debt' caused by the socio-economic legacy and past management neglect; and (4) fragmentation of land use between conservation and forestry threatening the sustainability of the region at large. We provide recommendations for management actions and research priorities to address these challenges.

Introduction

Fire has been a key process and evolutionary force shaping plant traits and vegetation communities across the globe for much of its history.[1,2] It has been the most ubiquitous terrestrial disturbance, surpassed more recently only by human transformation of the landscape.[3] Anthropogenic changes in land use have in turn resulted in modifications in the way fire occurs in space and time,[1] along with changes in our perceptions of fire and demands placed on land management agencies to protect lives and property.[4,5,6]

In the exceptionally diverse[7] and threatened[8] Mediterranean-climate (summer drought, winter rain) biotas of the world,[9] fire is the most important ecological disturbance factor and predates humans in these ecosystems.[2,10] Mediterranean floras have evolved specialised post-fire persistence traits, which are sensitive to the specifics of fire regimes, such as seed banking in the soil or canopy, resprouting, and fire-stimulated flowering and germination.[9,11] Fire is instrumental in maintaining diversity in the fynbos of the Cape Floral Kingdom (CFK) of South Africa,[12] and may be considered the most important fynbos management practice, being both a key ecological factor and a practical tool for resource manipulation.

The fire ecology of fynbos has been well researched since the early 1970s and by the 1990s fairly detailed fire management prescriptions were available.[13,14,15] However, much emphasis was on the western, strictly winter-rainfall part of the CFK[12,16] and the inland arid mountains,[17,18,19] whereas the eastern coastal part of the CFK has been neglected. The climate of the eastern coastal part is less seasonal (rainfall is bimodal[20,21]) and species' phenology,[22] and possibly plant growth and maturation rates, differ accordingly, which has implications for the management of fire regimes.

Fuel-reduction burning in fynbos (as in south-eastern Australia[23]) largely developed from the early 1900s in response to the need to protect commercial timber resources. Early fire legislation has hence been embedded in forestry acts.[24,25] Fire management practices aimed at hazard reduction are often in conflict with ecological objectives.[6,23] Simple management compromises intended to reconcile conflicting objectives may ultimately not achieve either hazard reduction or biodiversity conservation.[23] Therefore, management agencies have to set very clear and realistic

objectives to determine the most appropriate management practices for each particular area.[24,26] In the fynbos, as elsewhere, invasion by fire-adapted plants can complicate fire management. Invasion of fynbos ecosystems by invasive trees and shrubs, and notably by pines, is one of the largest threats to conservation.[15] These invasive pines originate from commercial plantations that have been established throughout the CFK, and they often exacerbate the potential negative effects of both altered fire regimes and invasive species.[1,10,15]

Improved understanding of fire ecology is becoming increasingly important as climates change, protected area networks expand, pressure from alien invasive biota increases, the wildland–urban interface enlarges, and demands to manage fuel loads of natural habitat for asset protection grow.[4,15,27,28] Where new protected areas are established, systems are likely to be poorly researched and management prescriptions may have to be made in the absence of a clear understanding of ecosystem processes and responses. Recent additions to protected areas are often not in pristine condition and are affected by historic management that has implications for management into the future.

The recent establishment of the Garden Route National Park (GRNP; ~130 000 ha[29]) along the Cape south coast of South Africa involved the amalgamation of certain parcels of land. These land parcels have in the past been variously managed for water conservation, biodiversity conservation, plantation forestry using alien invasive species, and the harvesting of natural resources, mainly timber from indigenous forests.[30] We used the fynbos areas of the GRNP as a case study for exploring the challenges facing conservation managers in the achievement of biodiversity goals in a fire-prone environment. Our analysis was underpinned by a number of issues. Firstly, the GRNP is located within the south-eastern coastal part of the CFK where fynbos fire ecology is inadequately understood. Secondly, it is a new park, and a reconstruction and critical review of past fire management approaches is needed. Thirdly, the institutional history and landscape context of the park pose particular difficulties that need to be addressed by the fire management policy, including high levels of invasion by alien trees, and significant pressure from the adjacent plantation industry to reduce wildfire hazard. Being a new park, there is still opportunity to influence the management policy and practice in the interest of biodiversity conservation.

In this paper we present the environmental and institutional context within which historical catchment management practices in the region of the GRNP evolved, and we consider how the adoption of a new mandate, with conservation as its central goal, will require changes to research priorities, management actions and land-use practices.

The Garden Route mountain catchments

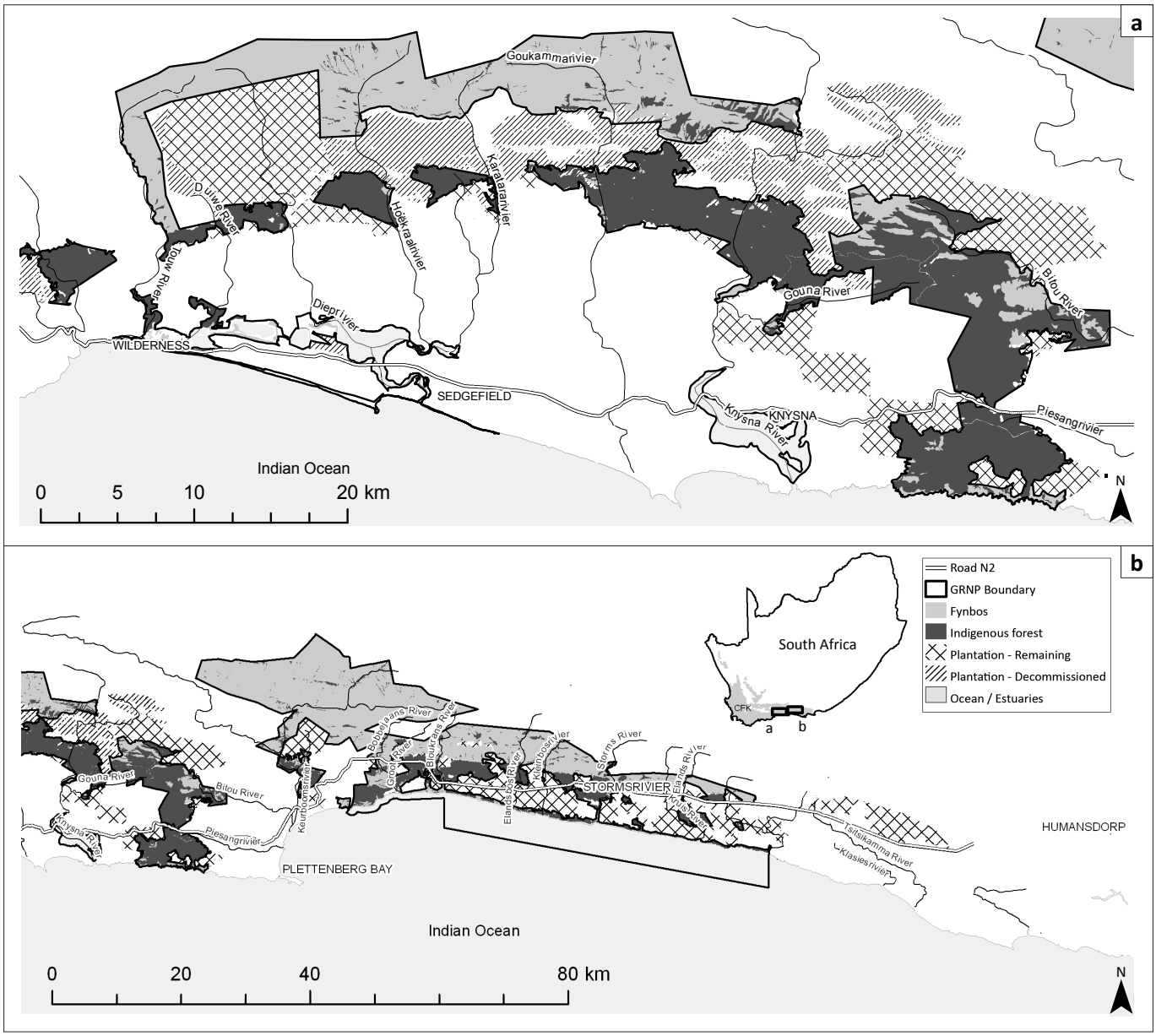
Biophysical environment

The study area is broadly defined as the southern slopes of the Outeniqua Mountains east of the Touw River, and the southern slopes of the Tsitsikamma Mountains (22.59°E – 24.26°E; hereafter collectively referred to as the Garden Route coastal mountains, GRCMs), with emphasis on those areas recently proclaimed as part of the GRNP[29] (Figure 1). The GRCMs form part of the Cape Fold Belt Mountains[31] and run in an east–west direction, parallel to the coast.[32] The highest peaks in the eastern Outeniqua and Tsitsikamma Mountains are 1469 m and 1675 m, respectively. Deeply incised remnants of an early Cenozoic peneplain form the coastal foreland south of these mountains.[32] The Table Mountain Group rocks of the Cape Supergroup are the main mountain-forming substrata.[31] Acidic (pH 3.3 – pH 5.5) lithosol soils, which are moderately deep, dark-coloured loamy sands, generally poor in bases, phosphorus and nitrogen, predominate.[33,34]

Owing to maritime influence, the climate of the GRCMs is relatively temperate. In contrast to the strictly Mediterranean climate in the western part of the CFK, rain falls throughout the year.[21,22] Rainfall peaks in spring and autumn, winter months are the driest, and the proportion of summer rain increases eastwards.[35] Annual rainfall increases eastwards, the mean for the Outeniqua and Tsitsikamma Mountains being 820 mm and 1078 mm, respectively.[34,36] Rain is mostly cyclonic and orographic with occasional thunderstorms.[34] Lightning occurs throughout the year and at a density of < 2 flashes/km^2/year.[32] Temperatures are mild with mean minima and maxima ranging from 7 °C and 19 °C in June to 15 °C and 26 °C in January.[34,36] South-easterly winds prevail in summer and north to north-westerly winds (hot dry berg winds) prevail in autumn and winter, whilst south-westerly winds occur throughout the year.[34,36] Berg wind conditions in particular increase the fire potential[19] and are associated with a higher incidence of fire, as well as an increase in the severity and size of fires.[21]

The coastal slopes of the eastern Outeniquas contribute run-off to various rivers, some of which support estuarine systems of national and international importance[37] (Figure 1). The coastal slopes of the Tsitsikammas are drained by short rivers flowing through deep gorges incised through the coastal plain.[36] In 1986, the water draining from the state-managed GRCMs was estimated to be 1046 million cubic metres per annum, then valued at R178 billion.[30] Sustained yields of water from these catchments are vital to agriculture and coastal towns in the area,[38] a dependency that has been highlighted by recent severe droughts.[39]

The vegetation of the area comprises fire-prone and fire-dependent fynbos shrublands, interspersed with lesser areas of fire-free and fire-resistant Afrotemperate forest. The fynbos mostly occurs between the mountain crests and the belt of indigenous forest on the coastal platform at the foot slopes of the mountains[32] (Figure 1). South Outeniqua Sandstone Fynbos and Tsitsikamma Sandstone Fynbos occur to the west and east of the Keurbooms River, respectively.[33] Both these vegetation types are tall, medium-dense proteoid shrublands, with medium-tall, dense ericoid-leaved shrub understoreys and a prominent restioid component. Ericaceous fynbos dominates at high altitudes, grassy fynbos at lower altitudes, and forest in fire refugia.[32,33]



CFK, Cape Floral Kingdom.

FIGURE 1: Map of the study area showing the distribution of fynbos, indigenous forest and decommissioning plantations (to be clearfelled and rehabilitated) within the boundaries of the Garden Route National Park (GRNP). The shown distribution of remaining plantations, on state land and managed by Mountain to Ocean Forestry, follows the recommendations for the partial reversal of the plantation decommissioning strategy. The map is split into (a) the Outeniqua region and (b) the Tsitsikamma region.

Plantations of alien pine trees (*Pinus pinaster* Aiton and *Pinus radiata* D.Don) have fragmented and replaced large tracts of fynbos, mostly along the lower and mid-mountain slopes (Figure 1). The plantations of Bergplaas, Karatara and Buffelsnek in the Outeniquas, and Kromrivier in the Tsitsikammas, reach deeper into the upper catchments. The extant fynbos of the GRCMs thus typically abuts the commercial plantations to the south. Depending on the topography and altitudinal reach of the plantations, the fynbos forms a belt of 2 km – 6 km wide, and is generally narrower along the Outeniquas than along the Tsitsikammas (Figure 1). Considerable tracts of unprofitable plantations in the Outeniqua Mountains are in the process of being phased out, scheduled for rehabilitation to fynbos and incorporation into the GRNP during the next decade.[40,41] The landscape setting of the GRNP is thus a mosaic of fynbos and forest amongst remaining and decommissioned plantations, most of which were formerly owned and managed by the state (the extent of these land groupings is indicated in Table 1 and Figure 1). The mix of fynbos and fire-prone pine plantations in the landscape has led to two major management problems: (1) the need to protect the plantations from fire, which kills the adult trees; and (2) invasions by fire-adapted pines, where fire drives the rapid spread and proliferation of these species[42] (Figure 2).

Institutional context

Since the early 1900s, water and soil conservation have been central to the management (and acquisition in places) by the South African state of fynbos mountain catchments, including the approach to fire management in these

TABLE 1: Extent of Fynbos and Forest Biomes within the Garden Route National Park and the extent of former state-owned plantations, now managed by Mountain to Ocean Forestry.

Vegetation type	Area (ha)		
	Outeniqua	Tsitsikamma	Total
Fynbos vegetation	17 000	53 000	70 000
Proportion of fynbos vegetation where no active management was done between 1988 and 2006 ('no-man's land')	14 000	21 000	35 000
Indigenous forest	26 000	17 000	43 000
Plantations – remaining	22 000	25 000	47 000
Plantations – decommissioned	17 000	0	17 000

Figures are shown for the Outeniqua (east of the Touw River) and Tsitsikamma Mountains (33.8°S 22.6°E to 34.0°S 24.3°E) and rounded to the nearest thousand hectares.

areas.[15,24,30] However, plantation-based timber production has from early on been recognised as a major land use and catchment management consideration in the GRCMs,[30] perhaps more so than in other fynbos catchments. The first state plantations in the area were established in 1883 near the town of Knysna.[24,43] The state has since then, until the early 1990s, actively encouraged and subsidised the industry as a strategic move to provide for the country's demand for timber and to alleviate pressure on the limited and over-exploited indigenous forests.[43,44] Considerable expansion occurred in response to timber shortages experienced during the First and Second World Wars. Afforestation was further promoted as a means to relieve poverty amongst unemployed White people (1918 – 1938) and Italian prisoners of the Second World War.[24,43,44] 'Off-site planting' resulted from the application of poverty relief labour, whereby some of the areas planted were unsuitable for commercial plantation forestry.[44] The former Cape Province (including the present Western and Eastern Cape Provinces) was the only province where state plantations covered more area (three times more) than private plantations.[45] The state was thus the main player in the forestry industry in the Cape Province and largely focused on growing pines.[46]

The generally held notion at the turn of the 19th century was that forests increase rainfall.[24] Afforestation was accordingly seen as a beneficial land use in mountain catchments which otherwise had limited economic potential.[24] However, droughts, public complaints about reductions in stream flow, and alleged desertification of South Africa during the first half of the 20th century prompted the Department of Forestry to undertake hydrological research in mountain catchments.[24,47] This research exposed the high water consumption of plantation trees,[48] which led to the introduction in 1972 of an afforestation permit system to regulate new afforestation according to impacts on catchment run-off.[43,49] Although it was by then recognised that afforestation competes with the conservation of water supplies and floral diversity, plantation forestry in the GRCMs was justified because 'surplus water [is] presently still flowing into the sea from the humid coastal mountain ranges'[30].

For most of the 20th century, the state-owned mountain catchments of the Outeniquas and Tsitsikammas were managed by the national Department of Forestry (DoF) in its various forms[38,45] – either an independent department, or a branch of the national departments of Environment Affairs or Water Affairs[25,50] (for simplicity, we henceforth refer to DoF). The state managed a combination of fynbos, indigenous forests and exotic timber plantations on state land. During the mid-1970s, DoF adopted a formal policy of 'multiple use', which included timber production (from both indigenous forests and plantations), fire management and alien invasive plant control in the catchments, soil and water conservation and recreation.[24,25,30,51] The same labour force that planted and tended pine trees also cleared alien invasive plants and conducted prescribed fires. The managers of these forestry estates were compelled to consider all aspects of this 'multiple use'. However, governmental restructuring of DoF during the mid-1980s, separated plantation forestry (a commercial undertaking, earmarked for privatisation), catchment fynbos and indigenous forest management (conservation undertakings), and research.[25,49,52,53] The restructuring divided the land into (1) plantations, which were transferred to the South African Forestry Company Limited (SAFCOL); (2) fynbos areas that had not been afforested and were to be devolved to provincial nature conservation agencies; (3) indigenous forests, which remained under the jurisdiction of DoF; and (4) research areas, which went to the Council for Scientific and Industrial Research.[49,54]

Following restructuring, large tracts of mountain fynbos within the former Cape Province were transferred to Cape Nature Conservation (which later split into CapeNature in the Western Cape Province and Eastern Cape Parks and Tourism Agency in the Eastern Cape Province), accompanied by reductions in state funding of conservation management functions. However, DoF retained responsibility for large

Source: Photograph taken by Tineke Kraaij

FIGURE 2: A landscape mosaic characteristic of the Tsitsikamma region, with dairy pastures in the foreground, a pine plantation in the middle ground, and mountain fynbos invaded by pine trees in the background. The lucrative dairy industry and coastal towns in the region are dependent on water emanating from the pine covered catchments.

areas of the state-owned catchments in the GRCMs to the north of plantations for the purposes of fire protection.[53,55] Prior to the restructuring, DoF largely achieved the fundamental principles of catchment management, that is, nature conservation[51] and sustainable water delivery, by applying appropriate fire and alien plant control regimes. With the commercialisation of state-owned timber plantations and the establishment of SAFCOL (owned by the Department of Public Enterprises) in 1993, the focus shifted to explicitly growing trees for profit.[44,54] Nationally, privatisation of SAFCOL was largely finalised by 2002, although a buyer could not be found for the Western and Southern Cape plantations (including the study area), packaged as Mountain to Ocean (MTO) Forestry.[56] MTO Forestry was only sold to Cape Timber Resources in 2004, based on a 70-year land-lease agreement with DoF.[54,56] However, SAFCOL retained a 25% share on behalf of the government in all privatised plantations.[41] The costly burden of catchment management (and in particular fire and alien plant management), which yields no financial return on investment, was not the primary mandate of the plantation companies. Likewise DoF, the landowner, has neglected to assume or delegate management responsibility for those areas originally retained for the purposes of fire protection of the plantations.[55] In the process, large tracts of unafforested fynbos in the GRMCs were left without a custodian and became known as the 'no-man's land'.[53] Management of the GRMCs languished for almost 20 years.[44] Only recently has the management of this 'no-man's land' been assigned to South African National Parks (SANParks) with the incorporation of the formerly DoF-managed forests and fynbos into the new Garden Route National Park.[29,41]

In 2000, the South African government decided to phase out plantation forestry in much of the Western Cape Province, including the Outeniqua region, as these plantations were economically and environmentally unsustainable.[40,41,54] Approximately 45 000 hectares of plantations (most of which were in the Outeniqua region) were to be felled over a 20-year period and converted to other land uses.[41,54,56,57] However, this decision was partly reversed in 2006,[77] with approximately half the area recommissioned for plantation forestry (Table 1; Stehle T 2010, personal communication, November 25) on account of changing markets and the national demand for timber exceeding the growth of plantations.[41] The decision was based on the presumption that productivity of the plantations in the Outeniqua region could be substantially increased by appropriate silviculture, site-specific soil preparation and continuous fertilisation.[58]

History of catchment and fire management

The general approach to fire management in fynbos mountain catchments during the 20th century is presented elsewhere.[15,30] Here we specifically focus on the approach to catchment and fire management in the GRCMs during the past century, as informed by our review of historical policy and management documentation and interviews with past and current land managers (Table 2).

Prescribed burning of mountain fynbos became fully accepted as a management practice during the 1970s to promote water, soil and biodiversity conservation.[30] The general approach to fire management was based on, and continually influenced by, sound ecological principles emerging from a productive fynbos research programme at the time.[14,15] However, and in contrast to policies elsewhere in the fynbos, nature conservation was the primary objective only in parts of state catchments zoned as nature reserves. Fire protection of plantations was the primary objective in vast areas of fynbos in the GRCMs to the north of the plantations (Table 2), where high-hazard, berg wind-driven fires characteristically originated.

For the conservation of fynbos, moderate to high-intensity fires at 10–20 year intervals are optimal.[15] Conversely, for plantation protection purposes, it is desirable to burn adjacent fynbos vegetation under cool, safe conditions as soon as there is sufficient fuel available to sustain a fire, usually at vegetation ages of 3–8 years, depending on site characteristics. Various systems have been proposed and/or pursued in the GRCMs in an attempt to reconcile this fundamental conflict of interest.[23] The most common approach has been the so-called double- (or triple-) belt system (Table 2). Accordingly, fynbos to the north of the plantations was divided into two to three parallel belts, each burnt at a fixed rotation, for example every eight years but four years apart. The vegetation age in one of the belts would consequently always be four years or less, thereby reducing the likelihood of fires spreading from catchment fynbos to the plantations. In some cases, plantation managers aimed to burn the fynbos adjacent to the plantations as soon as it could burn.

It is clear that fire management in the GRCMs has, since the establishment of the plantations until the early 1990s, been primarily aimed at the protection of commercial timber resources (Table 2). Although it is unlikely that catchment managers managed to execute prescribed burning every time and everywhere as planned, it seems reasonable to assume that large parts of the GRCMs' fynbos have at times been burnt at shorter fire return intervals, and lower intensities, than those deemed ecologically desirable for fynbos conservation. Both frequent and low intensity fires in fynbos and other Mediterranean-climate shrublands favour resprouters over slow-maturing reseeders.[59,60] This preference may account for the dominance of graminoid sprouters and the paucity of slow-maturing reseeding shrubs of the Proteaceae family in parts of the GRCMs, particularly in areas near plantations (Kraaij T, personal observation). With regard to fire season, prescribed burning has mostly been carried out during spring, summer and early autumn (October to April) in order to avoid the winter berg wind season (May to September) associated with conditions of high fire danger and an increased risk of uncontrollable fires (Table 2).

The conflict of interest in terms of fire management (fire return periods in particular) in the GRCMs has been brought into sharp focus by the separation of plantation

TABLE 2: Chronological account of the approach to fire management in the fynbos of the Garden Route coastal mountains (GRCMs), based on interviews with former catchment managers and a review of catchment management policies of the national Department of Forestry (DoF).

Period	General approach	Measures proposed and/or implemented to protect plantations	Fire return periods	Fire season and intensity
1920s	Deemed desirable that catchments be acquired and protected by the State. Contemplated a policy of fire exclusion from Cape mountains (for water preservation), except in the vicinity of afforested areas where burning was to be carried out to reduce fire risk to plantations.	Mountain vegetation adjacent to plantations (often on private land) to be burnt as widely (100 m – 200 m or more) and frequently as possible and grazing permits to be issued freely. Vegetation in exterior fire breaks (50 m – 100 m wide) to be slashed such that it could be burnt at a very young age. Gum (*Eucalyptus* spp.) belts (producing little litter) to be planted on ridges as fire breaks. Communal land adjacent to plantations to be ploughed and planted with kikuyu (*Pennisetum clandestinum*) grass to make it fireproof.	Mountain fynbos adjacent to plantations: as frequently as possible.	Forestry approach: summer is safest for prescribed burning. Agriculture approach: winter is best to promote grazing.
1930s to mid-1940s	Exclusion of all fires from catchment fynbos except for prescribed burning of mountain belts to protect plantations. Safety of plantations took precedence over fynbos conservation.	A series of fire breaks along northern boundary of plantations and in places along the mountain crest. Mountain belts (each 300 m – 500 m wide, often on private land) to be burnt (not ploughed) in double-belt or triple-belt systems where and whenever possible. Limited burning of fynbos deeper into catchments, but reported that belt burning often spread upslope to the first crest. Grazing permits issued freely.	Fire breaks and mountain belts: whenever possible.	Mountain belts: spring and early summer. Burn during warmest, driest time of day to obtain clean burn. Fire danger (berg wind) season to be avoided: winter (May–August).
Mid-1940s to late 1950s	Fire no longer had to be excluded from fynbos. Adopted the principle of prescribed burning of more than just fire belts on a rotational basis to create a mosaic of veld ages within catchment.	State-managed catchments north of plantations throughout GRCMs to be burnt as soon as they could burn. Double-belt or triple-belt fire breaks along the northern boundary of plantations and along mountain crest, and the area in-between divided into one or two (east–west) parallel belts (each about 1 km – 2 km wide). North–south cut-offs subdivided these mountain belts into blocks, with the aim to create a mosaic of veld ages. In some areas short rotation burning of belts along the northern slopes was additionally prescribed (e.g. at Witelsbos). Private land adjacent to plantations to be burnt as often as possible.	Mountain belts: 5–6 years, but no less than 3 years. Fynbos not immediately adjacent to plantations: 10 years.	Spring and early summer (September–December).
1960 to late 1970s	Prescribed burning of mountain belts and, where necessary, blocks.	Double mountain belt along southern slopes up to the crest (belts each 300 m – 500 m wide). Fynbos close to plantations on private and state land to be 'tamed' by burning at 7–10 year rotation. Fire breaks on northern boundaries of plantations were to be ploughed or hoed rather than burnt. Reported that ~500 km of fire breaks or fire belts were burnt annually in the catchments of the Southern Cape. All lightning fires and unplanned anthropogenic fires were to be extinguished, whether or not these threatened plantations. Insurance of private plantations against fire damage became the norm.[41]	Mountain belts: 5–6 years (3 years apart). Other fynbos: 7–10 years.	Prescribed burning season: (end) October–March. Fire danger season: April–September. Agriculture recommended winter burning to promote grazing value of vegetation.
Early 1980s	Fire protection of plantations considered the primary objective in GRCMs. Fynbos conservation the primary objective only in designated nature reserves (i.e. Millwood Nature Reserve in the Outeniquas). Block burning was common practice (mountains regarded as 'tamed').	Well-maintained double-belt or triple-belt systems (belts each 100 m – 1000 m wide). In places, an additional single- or double-belt system north of crest on private land. Significant areas burnt in block burns. State plantations were not insured against fire damage.	Mountain belts: 6–8 years (2–4 years apart). Block burning: 8–15 years. Increasing motivation for block burn rotations of ≥ 12 years. 12 year rotation triple-belt system (4 years apart) proposed to reconcile fire protection and fynbos conservation objectives.	Block burning: summer, and not from June or July to September or November as this was regarded as detrimental to reseeding plants. Fire break burning: September–November after good rains. Prescribed burning to be done under warm dry conditions but not with dropping air pressure.
Mid-1980s to mid-1990s	Plantation and conservation functions split within DoF, the former subsequently operated on a Trading Account. Plantation management was instructed to cut down on fire protection expenses (i.e. external fire breaks or fire belts), as this was deemed the responsibility of another division within DoF. Nationally, catchments were transferred to provincial conservation authorities, but GRCMs largely remained with DoF (except for Formosa and Millwood Nature Reserves).	Plantation management wanted prescribed burning of mountain belts (double-belt system with belts each 200 m wide) to continue as before, but neglect commenced in what became the 'no-man's land' and implementation fell behind. A single belt or fire break of 200 m wide was maintained along the northern boundary of some plantations. Block burning ceased during the early 1990s. All lightning fires were to be extinguished. State plantations were not insured against fire damage.	Mountain belts: 8 years (4 years apart).	Belt burning: October or November to March. Block burning: January–April. Fire danger season: April–October. Extreme danger: June–August.

'Mountain belts' (normally > 100 m wide) refer to the fynbos north of the plantations and south of the main mountain crests where fire management was generally geared towards protection of the plantations, and where fuel was regularly reduced by prescribed burning in order to reduce the risk and severity of fires. 'Fire breaks' refer to narrower strips (normally < 100 m wide) that were burnt, hoed or brush cut (i.e. virtually devoid of fuel) along the boundaries of the plantations to prevent the spread of fire into the plantations, or to serve as access points and safety zones during fire fighting. The fire protection measures proposed or applied sometimes varied in different areas, accounting for ostensibly conflicting measures listed here. Burning frequency, season and intensity indicated are those deemed appropriate for prescribed burning operations.

Table 2 continues on the next page →

TABLE 2 (Continues...): Chronological account of the approach to fire management in the fynbos of the Garden Route coastal mountains (GRCMs), based on interviews with former catchment managers and a review of catchment management policies of the national Department of Forestry (DoF).

Period	General approach	Measures proposed and/or implemented to protect plantations	Fire return periods	Fire season and intensity
Mid-1990s to early 2000s	Complete separation of catchment and plantation management with the establishment of SAFCOL. Block burning in catchments largely ceased as funding declined. Conservation agencies adopted natural fire zone management in some fynbos areas, whilst neglect prevailed in the 'no-man's land'. Alien invasive plant clearing regarded to be a 'Working for Water' function.	Mountain belt system replaced with ~50 m wide fire breaks (tracer belt and brushcut) along northern boundary of plantations. Plantation management (what became SAFCOL) wanted the fynbos north of the plantations to be burnt at 8–10 year rotations as before, but with institutional separation, catchment management no longer had an interest in this expensive undertaking without direct benefits. To cut down on expenses, SAFCOL largely reduced or stopped block and belt burning, as well as post-harvesting burning within plantations to suppress weedy growth of coral fern (*Gleichenia polypodioides*). SAFCOL plantations were insured against fire damage.	Mountain fynbos serving to protect plantations: 8–10 years.	Prescribed burning: October–November and February–March.
Early 2000s to present	SAFCOL plantations sold to Mountain to Ocean Forestry (MTO; DoF remained the landowner), and management of a large portion of GRCMs fynbos transferred to SANParks. Conflict of interest between requirements of plantation industry for short rotation burning of fynbos adjacent to plantations, and ecological objectives (longer fire rotations and allowing natural fires) of protected areas. Limited resources available to SANParks to rectify fire and invader plant management after 20 years' neglect.	MTO intended to reinstate fire break and block burning, with 10 m – 30 m wide fire breaks (slashed, hoed or burnt) along northern boundaries of plantations, whilst larger mountain belts would revert back to fynbos conservation management. MTO and SANParks agreed on jointly implementing prescribed burning in high fire danger zones (divided into double-belt) within Tsitsikammas. History of catchment neglect (particularly the extent of invader plants) makes implementation of prescribed burning under conditions of acceptable fire danger largely unachievable in these zones. The approach to fire management in remote parts of SANParks-managed catchment is that of adaptive interference,[13] with lightning regarded as the main source of ignition and interventions limited to where or when necessary. MTO plantations are not insured against fire damage, only public liability coverage. MTO sued the land owner (DoF) and neighbouring catchment management agencies (SANParks and Eastern Cape Parks Board) for plantation losses suffered during the large 2005 fire in the Tsitsikamma Mountains.	High fire danger zones in Tsitsikammas: 8 years (4 years apart); not yet established for Outeniquas. Remote catchment fynbos: 10–25 years. Fynbos within plantations: 12–15 years.	Prescribed burning by plantation managers: October–November and February–March (i.e. no berg winds and less erratic weather conditions). Prescribed burning by protected area managers: November–April, but may be broadened[22] pending local research.

'Mountain belts' (normally > 100 m wide) refer to the fynbos north of the plantations and south of the main mountain crests where fire management was generally geared towards protection of the plantations, and where fuel was regularly reduced by prescribed burning in order to reduce the risk and severity of fires. 'Fire breaks' refer to narrower strips (normally < 100 m wide) that were burnt, hoed or brush cut (i.e. virtually devoid of fuel) along the boundaries of the plantations to prevent the spread of fire into the plantations, or to serve as access points and safety zones during fire fighting. The fire protection measures proposed or applied sometimes varied in different areas, accounting for ostensibly conflicting measures listed here. Burning frequency, season and intensity indicated are those deemed appropriate for prescribed burning operations.

and catchment management functions within DoF, and later the privatisation of plantations and handover of catchment management to conservation agencies. Catchment management has further been complicated, ecologically and economically, by the extensive infestations of invasive alien plant species (particularly *Pinus* spp.) almost exclusively sourced from adjacent plantations, with hardly any invasive alien plant control carried out in the 'no-man's land' in almost two decades[61] (Figure 2).

Management challenges

Fire management

Sound ecological management of fires in the study area is constrained by various factors. Repeated institutional disruptions, that is, transfers of DoF between different state departments and changing land management agencies, resulted in poor record preservation and data continuity. The history of fires in the study area has therefore been inadequately documented. Fynbos fire ecology in the south-eastern CFK is poorly understood in terms of appropriate fire season and return interval.[15,22] Moreover, fundamental conflict exists between fire intervals required for the reduction of fire hazard to commercial timber plantations, and those deemed necessary for the conservation of fynbos diversity.[6,23]

Negative feedback mechanisms between fire, alien invasive trees and water resources threaten the achievement of the goals of sustained yields of water[48] from the GRCMs, which are important catchment areas.[53] Fire behaviour and ease of access for the purposes of prescribed burns or fire fighting are negatively affected by the invasion of fynbos by alien shrubs and trees. The invaders increase fuel loads and consequently fire intensity, particularly under extreme conditions.[62] Extreme fire intensities increase the risk to infrastructure and assets (such as plantations) and fire fighters, and detrimentally affect post-fire recovery of fynbos, soil and water conservation.[63,64,65] Alien pines are spread and proliferated by fire,[42] which in turn exacerbates their detrimental impacts. Areas in close proximity to plantations, where fire safety measures in the GRCMs ought to be focused, are often the worst invaded, thereby rendering prescribed burning and fire fighting operations impossible. Pines had invaded 54% of the catchment of the Keurbooms River in 1999 to some degree, causing an estimated 22% reduction in river flow.[66] It was further estimated that in the absence of

management intervention, the invasions could potentially occupy 77% of the catchment by 2025, with a projected flow reduction of 95%.[66]

Historical legacy

Past neglect of fire and alien plant management in large parts of the GRCMs has left current conservation agencies financially incapable of correcting the situation given normal operational funding, and thus unable to fulfil their primary mandate of conserving biodiversity. Previous joint government ownership and management of plantations and surrounding catchment fynbos fostered the expectation that contemporary fynbos managers should provide protection from fire to adjacent commercial plantations – at a considerable cost to the former. This political and institutional legacy yielded a plantation industry which is commercially and environmentally unsustainable[44,56] in the absence of subsidisation in the form of fire safety management and alien plant control on adjacent land. Even with government subsidisation (prior to the 1990s), and without taking on the costly burden of catchment management (during the period of neglect of the 'no-man's land'), SAFCOL plantations in the Western Cape Province operated at a financial loss.[44] This financial situation is why a buyer could initially not be found at the time of privatisation[56] and why the decision was taken to phase out plantation forestry in the area.[40,41,44,54]

Sustainable management at landscape scale

Sustainable management of the current conservation-plantation matrix will not be achievable in the study area if the continual invasion of the surrounding landscape by self-sown timber species is not controlled.[53] The current environmental and social certification system (the Forestry Stewardship Council, FSC), adhered to by the plantation industry[67] inadequately appraises environmental accountability (i.e. spread of invasive trees and their impact on water resources) beyond the borders of the plantation management unit. Indeed, in 2004, environmental NGOs requested that a moratorium be placed on further certification of plantations worldwide, which led to a review of standards for FSC certification of plantations.[41,68] The development of new standards and the implementation of trial audits have not resolved this issue, which remains contentious amongst FSC stakeholder groups. Whether plantation forestry can be undertaken sustainably in South Africa and whether it should be certified remains an open question.[67] Biological control, which may be seen as the only viable option for the control of vast infestations of invasive pines in remote catchments, continues to be opposed by the plantation industry.[42,69,70] Legislation pertaining to the control of alien invasive plants is not enforced, whilst a discrepancy between the capacities to enforce legislation pertaining to fire risk management versus invasive plant control[70] intensifies the conflict between the conservation and plantation sectors. This conflict is evident from substantial legal claims instituted against conservation authorities for fire damage to plantations in recent years (Table 2). Finally, the sustainability of both sectors is additionally compromised by government's decision to partially reverse the plantation decommissioning programme.[58] The outcome will be a more fragmented landscape where neither plantations nor protected areas can be suitably consolidated or coherently managed in terms of fire, invasive plants or general operations[44] (Stehle T 2010, personal communication, November 25).

Way forward

Research priorities

The challenges associated with managing the new national park are substantial, and knowledge and solutions are not always available, which indicates the need for further research. Firstly, understanding of the historical fire regime in the area and how it has changed during the past century[71] has to be improved through the creation and analysis of a database of historical fire records.[72] Ongoing accurate mapping of future fires is furthermore necessary to serve as a basis for the design of natural experiments and fire management decisions.[28] Secondly, the ecological requirements of eastern coastal CFK fynbos in terms of fire season and minimum fire return intervals need to be determined. To this end, post-fire recruitment success and youth periods of slow-maturing reseeding species (e.g. the Proteaceae[16,18]) should be studied. Similarly, the youth periods of invasive pine species need to be established under local conditions. In combination, these should inform fire management guidelines aimed at facilitating fynbos conservation and invasive pine control. It should furthermore inform thresholds[73] within which fire managers can attempt to resolve the conflicting demands of fire hazard reduction and biodiversity conservation. Thirdly, a legal review should be conducted to consider the practicalities of implementing fire legislation in the face of conflicting land management objectives (fire risk vs. biodiversity conservation). The respective responsibilities applicable to the conservation and commercial forestry sectors in terms of fire and invader plant legislation need to be clarified. This clarification should facilitate cross-cutting compliance and cooperation without the need for costly legal action. Lastly, resource economics research should further explore alternative funding for alien plant clearing initiatives in watersheds. Approaches based on payment for ecosystem services[38] should be expanded, targeting major water users, such as agricultural industries, municipalities and the tourism industry. Cost–benefit analyses need to compare the environmental and socio-economic advantages of invasive plant clearing versus desalinisation of sea water as different means to secure water supply to water-stressed coastal towns[39] (Preston G 2010, personal communication, October 01).

Management interventions to be considered

Fire management

Land owners and managers in the area need to realise that fynbos and plantations cannot be fire-proofed.[71] It has been shown for fire-prone shrublands and forests across the globe that large fires are not dependent on a build-up of fuel, and therefore frequent burning to reduce fuel loads will

not necessarily reduce the risk of runaway wildfires.[27,74,75,76] The combination of fire danger restrictions and financial constraints furthermore makes large-scale prescribed burning of catchment vegetation unattainable.[27] The most effective strategy for facilitating fire safety where necessary is to focus effort on (limited) strategic locations. A legal review should furthermore clarify the respective responsibilities of the conservation and forestry sectors under current fire legislation. Official agreements between neighbouring land managing agencies should clearly stipulate fire management protocols, and should be formalised within regional Fire Protection Agencies.

Invasive plant control

The timber industry should recognise its legal responsibility to control the spread of invasive alien trees from their plantations in terms of the *Conservation of Agricultural Resources Act*.[42] The South African government proposed the introduction of a seed pollution levy on the forestry sector in 2005 under the *National Environmental Management Act: Biodiversity Act*, which has been vehemently opposed by the industry on account of its potential economic impact and because it is perceived as discriminatory.[77] Plantation forestry in the Cape has in the past externalised its environmental costs, and continues to do so by not taking sufficient responsibility for invasive plant clearing beyond plantation borders and by leaving the task to the neighbouring conservation agencies.[44] As the intention of government is now clearly to separate the functions of commercial forestry and conservation, the former has an obligation to the latter to offset these previously externalised costs, as government has been cautioned to 'not end up subsidising a single business'[44]. Nonetheless, a 'polluter pays' policy remains to be implemented, possibly through the imposition of a levy on timber products.[42] Likewise, the FSC and other certification bodies should consider adopting stricter criteria for the mitigation of the negative effects of invasive trees beyond the borders of forestry estates.[42,67] The best approach to management of invasive alien plants would be to integrate various control methods.[35] Options include (1) manual clearing; (2) manipulation of disturbance regimes, i.e. fire; (3) future planting of less invasive species and/or sterile varieties; and (4) allowing the release of host-specific, seed-attacking biological control organisms for invasive *Pinus* species.[42] Biological control for pines has been considered,[78] but, in a highly conservative move, has been abandoned for fears that it could potentially be detrimental to the forest industry.[69]

Landscape rationalisation

The invasive pine problem in the GRCMs is an example of 'invasion debt'[79] where the current pattern of invasion primarily reflects the historical socio-economic and political legacy. Neglect of the 'no-man's land' during the past 20 years has further aggravated the invasive plant problem. Government appropriately stated in its White Paper on sustainable forest development in South Africa[52] that 'the costs and benefits of this [the plantation] industry in terms of water resources and the environment in general need to be properly evaluated' and furthermore that 'Government believes that a responsible attitude in forestry would have plantation forests removed from areas where demonstrable environmental damage has been done'. These statements imply three distinct undertakings by the state: (1) application of sound economic and environmental standards to the commercial forestry industry (DoF is ultimately responsible for overseeing and regulating the industry[25,52]); (2) appropriate allocation of resources for the rehabilitation of decommissioned plantations and neighbouring areas damaged by invader plants historically sourced from plantations[38]; and (3) a review of the decision to reverse the plantation decommissioning strategy.[44,58] A balanced analysis of the full public costs and benefits of the plantations, and their economic and ecological impacts and future risks, have to be considered at landscape scale.[54,80] Land use fragmentation needs rationalisation in the interests of both the plantation and conservation sectors. This was the original intention of DoF with their plantation decommissioning strategy. In this strategy, DoF emphasised the link between plantation withdrawal and the transfer of other conservation land to SANParks, and required that these processes be well coordinated.[57]

Conclusion

Owing to successive institutional disruptions in the study area, the collation of fire management related policies, practices and data has been challenging. Our account constitutes a first qualitative regional history of fire management in the CFK published in the primary literature. Such published accounts will become invaluable where there is a reliance on tacit knowledge, and particularly where institutional memory is rapidly fading. Fire management in the fynbos catchments of the new GRNP presents considerable challenges that cannot be overcome without addressing the invasive alien plant problem in the area. In the short and medium term, substantial resources will be required to correct the situation left by decades of management neglect. Longer-term sustainability of the region necessitates rationalisation of the currently highly fragmented land use with their conflicting requirements.

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References

1. DellaSala DA, Williams JE, Williams CD, Franklin JE. Beyond smoke and mirrors: A synthesis of fire policy and science. Conserv Biol. 2004;18(4):976–986. doi:10.1111/j.1523-1739.2004.00529.x
2. Bond WJ, Woodward FI, Midgley GF. The global distribution of ecosystems in a world without fire. New Phytol. 2005;165:525–538. doi:10.1111/j.1469-8137.2004.01252.x, PMid:15720663
3. Bond WJ, Van Wilgen BW. Fire and plants. Population and Community Biology Series 14. London: Chapman and Hall; 1996.
4. Cortner H, Gardner P, Taylor J. Fire hazards at the urban-wildland interface: What the public expects. Environ Manage. 1990;14:57–62. doi:10.1007/BF02394019
5. Sturtevant BR, Miranda BR, Yang J, He HS, Gustafson EJ, Scheller RM. Studying fire mitigation strategies in multi-ownership landscapes: Balancing the management of fire-dependent ecosystems and fire risk. Ecosystems. 2009;12:445–461. doi:10.1007/s10021-009-9234-8
6. Driscoll DA, Lindenmayer DB, Bennett AF, et al. Resolving conflicts in fire management using decision theory: Asset-protection versus biodiversity conservation. Conserv Letters. 2010;3:215–223. doi:10.1111/j.1755-263X.2010.00115.x
7. Cowling RM, Rundel PW, Lamont BB, Arroyo MK, Arianoutsou M. Plant diversity in Mediterranean-climate regions. Trends Ecol Evol. 1996;11:362–366. doi:10.1016/0169-5347(96)10044-8
8. Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca GAB, Kent J. Biodiversity hotspots for conservation priorities. Nature. 2000;403:853–858. doi:10.1038/35002501, PMid:10706275
9. Naveh Z. The evolutionary significance of fire in the Mediterranean region. Vegetatio. 1975;29:199–208. doi:10.1007/BF02390011
10. Syphard AD, Radeloff VC, Hawbaker TJ, Stewart SI. Conservation threats due to human-caused increases in fire frequency in Mediterranean-climate ecosystems. Conserv Biol. 2009;23(3):758–769. doi:10.1111/j.1523-1739.2009.01223.x
11. Cowling RM. Fire and its role in coexistence and speciation in Gondwanan shrublands. S Afr J Sci. 1987;83:106–112.
12. Kruger FJ, Bigalke RC. Fire in fynbos. In: Booysen PV, Tainton NM, editors. Ecological effects of fire in South African ecosystems. Ecological Studies 48. Berlin: Springer-Verlag, 1984; p. 67–114.
13. Seydack AHW. Fire management options in fynbos mountain catchment areas. S Afr For J. 1992;161:53–58.
14. Van Wilgen BW, Bond WJ, Richardson DM. Ecosystem management. In: Cowling RM, editor. The ecology of fynbos: Nutrients, fire and diversity. Cape Town: Oxford University Press, 1992; p. 345–371.
15. Van Wilgen BW. The evolution of fire and invasive alien plant management practices in fynbos. S Afr J Sci. 2009;105:1–8.
16. Van Wilgen BW, Viviers M. The effect of season of fire on serotinous Proteaceae in the Western Cape and the implications for fynbos management. S Afr For J. 1985;133:47–53.
17. Bond WJ, Vlok J, Viviers M. Variation in seedling recruitment of Cape Proteaceae after fire. J Ecol. 1984;72:209–221. doi:10.2307/2260014
18. Midgley JJ. Season of burn of serotinous fynbos Proteaceae: A critical review and further data. S Afr J Bot. 1989;55:165–170.
19. Seydack AHW, Bekker SJ, Marshall AH. Shrubland fire regime scenarios in the Swartberg Mountain Range, South Africa: Implications for fire management. Int J Wildl Fire. 2007;16:81–95. doi:10.1071/WF06015
20. Van Wilgen BW. Fire climates in the southern and western Cape Province and their potential use in fire control management. S Afr J Sci. 1984;80:358–362.
21. Southey D. Wildfires in the Cape Floristic Region: Exploring vegetation and weather as drivers of fire frequency. MSc dissertation, Cape Town, University of Cape Town, 2009.
22. Heelemann S, Proches S, Rebelo AG, Van Wilgen BW, Porembski S, Cowling RM. Fire season effects on the recruitment of non-sprouting serotinous Proteaceae in the eastern (bimodal rainfall) fynbos biome, South Africa. Austr Ecol. 2008;33(2):119–127. doi:10.1111/j.1442-9993.2007.01797.x
23. Morrison DA, Buckney RT, Bewick BJ. Conservation conflicts over burning bush in south-eastern Australia. Biol Conserv. 1996;76:167–175 doi:10.1016/0006-3207(95)00098-4
24. Uys HJE. [National forest policy in South Africa]. MSc dissertation, Stellenbosch, University of Stellenbosch, 1979. Afrikaans.
25. Van der Zel DW. Forest policy. In: Owen DL, editor. South African Forestry Handbook. Pretoria: Southern African Institute of Forestry, 2000; p. 11–15.
26. Fernandes PM, Botelho S. A review of prescribed burning effectiveness in fire hazard reduction. Int J Wildl Fire. 2003;12:117–128. doi:10.1071/WF02042
27. Keeley JE, Fotheringham CJ, Morais M. Reexamining fire suppression impacts on brushland fire regimes. Science. 1999;284(5421):1829–1832. doi:10.1126/science.284.5421.1829, PMid:10364554
28. Driscoll DA, Lindenmayer DB, Bennett AF, et al. Fire management for biodiversity conservation: Key research questions and our capacity to answer them. Biol Conserv. 2010;143:1928–1939. doi:10.1016/j.biocon.2010.05.026
29. Department of Environmental Affairs and Tourism. Government Gazette No 31981. Notice No 248. Pretoria: Department of Environmental Affairs and Tourism, 2009; p. 2–7.
30. Seydack AHW, Southwood AJ, Bekker SJ, De Lange C, Swart JAJ, Voges K. Regional policy memorandum for the management of mountain catchment areas in the Southern Cape and Tsitsikamma forest regions. Knysna: Department of Environment Affairs, Forestry Branch; 1986.
31. Toerien DK. The geology of the Oudtshoorn area. Explanation to sheet 3322. 1:250 000 geological series. Pretoria: Chief Director of Surveys and Mapping, Government Printer; 1979.
32. Geldenhuys CJ. Bergwind fires and the location pattern of forest patches in the southern Cape landscape, South Africa. J Biogeogr. 1994;21:49–62. doi:10.2307/2845603
33. Rebelo AG, Boucher C, Helme N, Mucina L, Rutherford MC. Fynbos biome. In: Mucina L, Rutherford MC, editors. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. Pretoria: South African National Biodiversity Institute, 2006; p. 158–159.
34. Bond WJ. Vegetation gradients in the southern Cape Mountains. MSc dissertation, Cape Town, University of Cape Town, 1981.
35. Tyson PD, Preston-Whyte RA. The weather and climate of southern Africa. Cape Town: Oxford University Press; 2000.
36. Southwood AJ. Policy memorandum: Tsitsikamma Mountain Catchment Area. Knysna: Department of Environment Affairs, Forestry Branch; 1984.
37. Turpie JK, Adams JB, Joubert A, et al. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA. 2002;28(2):191–206.
38. Hutchinson S. Addressing water resources and alien plant invasions in the Tsitsikamma: Landowner perceptions towards a payment for ecosystem services scheme. Honours dissertation, Grahamstown, Rhodes University, 2010.
39. Bisseker C. Heal hills or run dry. Financial Mail 2010 Jan 22;46–47.
40. Venter I. Forest restructuring: Seeing the wood for the trees. Engineering News [serial online]. c2001 [cited 2010 Oct 15]. Available from: http://www.engineeringnews.co.za/article/forest-restructuring-seeing-the-wood-for-the-trees-2001-11-23
41. Louw WJA. General history of the South African forest industry: 2003 to 2006. S Afr For J. 2006;208(1):79–88.
42. Richardson DM. Forestry trees as invasive aliens. Conserv Biol. 1998;12(1):18–26. doi:10.1046/j.1523-1739.1998.96392.x
43. Van der Zel DW, Brink AJ. [The history of forestry in South Africa. Part II: Plantation forestry]. S Afr For J. 1980;115:17–27. Afrikaans.
44. Venter JH. Handover report Cape Conversion Process. Unpublished report compiled by Cape Conversion Process Manager for the Department of Public Enterprises, South Africa; 2005.
45. Van der Zel DW. Forestry statistics for southern Africa. In: Van der Sijde HA, editor. South African forestry handbook. Pretoria: Southern African Institute of Forestry, 1994; p. 2–3.
46. Le Maitre DC. Pines in cultivation: A global view. In: Richardson DM, editor. Ecology and biogeography of *Pinus*. Cambridge: Cambridge University Press, 1998; p. 407–431.
47. Van der Zel DW. Catchment research at Zachariashoek. Forestry in South Africa. 1974;15:23–30.
48. Van Wyk DB. Some effects of afforestation on streamflow in the Western Cape Province, South Africa. Water SA. 1987;13(1):31–36.
49. Louw WJA. General history of the South African forest industry: 1975 to 1990. S Afr For J. 2004;200:77–86.
50. Owen DL, Van der Zel DW. Trees, forests and plantations in southern Africa. In: Owen DL, editor. South African forestry handbook. Pretoria: Southern African Institute of Forestry, 2000; p. 3–8.
51. Ackerman DP. The conservation role of forestry in South Africa. Koedoe. 1977;supplement:203–209.
52. Department of Water Affairs and Forestry (DWAF). Sustainable forest development in South Africa. The policy of the government of national unity. White Paper. Pretoria: DWAF; 1996.
53. Cowling R, Van Wilgen B, Kraaij T, Britton J. How no-man's land is now everyone's problem. The renowned Cape flora is everywhere in retreat as runaway pine invasions transform the Outeniqua and Tsitsikamma Mountains. Veld & Flora 2009;95(3):147–149.
54. Department of Water Affairs and Forestry. Key issue paper for a policy on transfers of state owned industrial plantations [document on the Internet]. c2004 [cited 2010 Dec 23]. Available from: http://www2.dwaf.gov.za/dwaf/cmsdocs/Elsa/Docs/Transfers/KIP%20Policy%20on%20Transfers%202004.pdf
55. Geldenhuys C. Assessment of state forest management by provincial authorities: Eastern Cape. Report commissioned by Department of Water Affairs and Forestry, South Africa; 2000.
56. Louw WJA. General history of the South African forest industry: 1991 to 2002. S Afr For J. 2004;201:65–76.
57. Department of Water Affairs and Forestry. Forestry change programme: Business process analysis report. Forestry transfers process. Version 5.0 [document on the Internet]. c2005 [cited 2010 Dec 23]. Available from: http://www2.dwaf.gov.za/dwaf/cmsdocs/Elsa/Docs/Transfers/Business%20Process%20Analysis%20Report%20Transfers%202005.pdf

58. VECON. Cape Conversion Process: Review of the original recommendations and decisions taken about phasing out plantation forestry on state land in the Southern and Western Cape and recommendations on a decision to reverse the withdrawal strategy. Report produced by VECON for DWAF, South Africa; 2005.
59. Haidinger TL, Keeley JE. Role of high fire frequency in destruction of mixed chaparral. Madroño. 1993;40:141–147.
60. Vlok JHJ, Yeaton RI. The effect of short fire cycles on the cover and density of understorey sprouting species in South African mountain fynbos. Divers Distrib. 2000;6:233–242. doi:10.1046/j.1472-4642.2000.00087.x
61. Moeller J. Spatial analysis of pine tree invasion in the Tsitsikamma region, South Africa: A pilot study. Honours dissertation, Grahamstown, Rhodes University, 2010.
62. Van Wilgen BW, Richardson DM. The effect of alien scrub invasion on vegetation structure and fire behaviour in South African fynbos shrublands. J Appl Ecol. 1985;22:955–966. doi:10.2307/2403243
63. Richardson DM, Van Wilgen BW. The effects of fire in felled *Hakea sericea* and natural fynbos and implications for weed control in mountain catchments. S Afr For J. 1986;139:4–14.
64. Breytenbach GJ. Alien control: Can we afford to slash and burn *Hakea* in fynbos ecosystems? S Afr For J. 1989;151:6–16.
65. Scott DF. The hydrological effects of fire in South African mountain catchments. J Hydrol. 1993;150:409–432. doi:10.1016/0022-1694(93)90119-T
66. Le Maitre DC, Van Wilgen BW, Gelderblom CM, Bailey C, Chapman RA, Nel JA. Invasive alien trees and water resources in South Africa: Case studies of the costs and benefits of management. For Ecol Manage. 2002;160:143–159.
67. Scotcher JSB. Guest editorial. Forest certification in South Africa – the next phase. Southern Forests: A Journal of Forest Science. 2010;72(1):1–4.
68. Forestry SA. 3rd Annual report for the year ended 31st December 2004 [document on the Internet]. c2004 [cited 2010 Dec 23]. Available from: http://www.forestry.co.za/website_about_fsa_annual_reports/
69. Lennox CL, Hoffmann JH, Coutinho TA, Roques A. A threat of exacerbating the spread of pitch canker precludes further consideration of a cone weevil, *Pissodes validirostris*, for biological control of invasive pines in South Africa. Biol Control. 2009;50:179–184. doi:10.1016/j.biocontrol.2009.03.012
70. Van Wilgen BW, Van der Heyden F, Zimmermann HG, Magadlela D, Willems T. Big returns from small organisms: Developing a strategy for the biological control of invasive alien plants in South Africa. S Afr J Sci. 2000;96:148–152.
71. Agee JK. The fallacy of passive management. Managing for fire safe forest reserves. Conservation in practice [document on the Internet]. c2002 [cited 2010 Oct 13]. Available from: http://www.conbio.org/cip/redesign/article31FPM.cfm
72. Morgan P, Hardy CC, Swetnam TW, Rollins MG, Long DG. Mapping fire regimes across time and space: Understanding coarse and fine-scale fire patterns. Int J Wildl Fire. 2001;10:329–342. doi:10.1071/WF01032
73. Van Wilgen BW, Govender N, Forsyth GG, Kraaij T. The adaptive management of fire regimes for the conservation of biodiversity: Examples from South African National Parks. Koedoe. 2011;53(2), Art. #982, 9 pages. doi:10.4102/koedoe.v53i2.982
74. Bessie WC, Johnson EA. The relative importance of fuels and weather on fire behavior in subalpine forests. Ecology. 1995;76(3):747–762. doi:10.2307/1939341
75. Moritz MA. Spatiotemporal analysis of controls on shrubland fire regimes: Age dependency and fire hazard. Ecology. 2003;84(2):351–361. doi:10.1890/0012-9658(2003)084[0351:SAOCOS]2.0.CO;2
76. Van Wilgen BW, Forsyth GG, De Klerk H, Das S, Khuluse S, Schmitz P. Fire management in Mediterranean-climate shrublands: A case study from the Cape fynbos, South Africa. J Appl Ecol. 2010;47(3):631–638. doi:10.1111/j.1365-2664.2010.01800.x
77. Forestry SA. 4th Annual report for the year ended 31st December 2005 [document on the Internet]. c2005 [cited 2010 Dec 23]. Available from: http://www.forestry.co.za/website_about_fsa_annual_reports/
78. Moran VC, Hoffmann JH, Donnelly D, Zimmermann HG, Van Wilgen BW. Biological control of alien invasive pine trees (*Pinus* species) in South Africa. In: Spencer NR, editor. Proceedings of the 5th International Symposium on Biological Control of Weeds; 1999 Jul 04–14; Bozeman, MT, USA. Bozeman: Montana State University; 2000. p. 941–953.
79. Essl F, Dullinger S, Rabitsch W, et al. Socioeconomic legacy yields an invasion debt. Proc Natl Acad Sci USA. 2010. doi: 10.1073/pnas.1011728108, PMCid:2901442
80. De Wit MP, Crookes DJ, Van Wilgen BW. Conflicts of interest in environmental management: Estimating the costs and benefits of a tree invasion. Biol Invasions. 2001;3:167–178. doi:10.1023/A:1014563702261