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De Ronde C.

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PRESCRIBED BURNING INSIDE *PINUS PINASTER* STANDS: CONSIDERING SURFACE FIRE FUEL BEDS, COMPARISONS WITH OTHER *PINUS* SPECIES AND THE RELATIVE RESISTANCE TO FIRE DAMAGE

C. de Ronde
Silva Forest Services CC
6573 Sedgefield, South Africa
e-mail: nderonde@brd.dorea.co.za

Abstract

Research results of P. pinaster prescribed burning experiments in the Cape Regions of South Africa have proved that this management technique can be applied successfully, without harm to the tree stands and their habitat. The species have an excellent resistance to fire damage, and light intensity fires have in some cases been recorded to provide some short-term benefits to tree growth as a result of the ash-bed effect. However, it has also been observed that prescribed burning results are significantly dependent on the understorey vegetation and fuel-bed status of these stands, particularly in the contrasting fuels found in the species' vegetation and fuel base. Guidelines to the application of fire within these fuels are provided in this paper, with similar fuel appraisal techniques recommended for Mediterranean countries and elsewhere.

Keywords: *Pinus pinaster*, prescribed burning, surface fuel, *Pinus* spp., fire effects, fire ecology.

INTRODUCTION

Industrial plantations in Southern Africa are covering more than two million hectares, comprising mostly *Acacia*, *Eucalyptus* and *Pinus* spp. Today new even-aged plantations are also being established at a large scale in countries such as Mozambique, and even in Angola, but the main area under exotic trees is still found in South Africa, where more than 1.5 million hectare of even-aged plantations have been established.

Pinus pinaster was one of the pioneer species to be planted in South Africa on a commercial scale, particularly in the Cape Forest Regions, which today cover the most southern portions of the Western Cape and Eastern Cape provinces. The species never exceeded a planted area of more than 50 000 ha, and after 1990, this area was further reduced as a result of the species' relatively slow growth rate and its habit to invade the natural fynbos vegetation of the Western Cape. However, this decrease in the use of the species for commercial forestry is today in some quarters debated, and its role in the forestry industry in South Africa might even be re-considered in the future.

During the 1978 to date period, various prescribed burning experiments were conducted in *Pinus* stands in South Africa, Swaziland and Zimbabwe, but burning experiments in *P. pinaster* stands were only executed during the 1978 to 1988 period (*e.g.* de Ronde, 1980, 1982, 1983, 1988, 1990a and 1990b). Burning experiments with other species, such as *P. elliottii*, *P. greggii*, *P. patula* and *P. taeda* have continued in the summer rainfall regions of Southern Africa, though at a smaller scale, because of lack of funding. The results, however, of most of the research work conducted after 1988, have never been published, even though some of this information may be of interest to the international forestry and fire ecology community, particularly in Mediterranean countries.

METHODS

Surface fire fuel beds

I have not only considered the fynbos fuel base of the winter and constant rainfall areas of South Africa where *P. pinaster* is growing mostly at present, but also montane grassland and savanna vegetation types in the summer rainfall area, which dominate most of the Southern African forestry regions. This approach was followed because e.g. montane grassland is the natural fuel base where most *Pinus* spp. other than

P. pinaster have been established, and because *P. pinaster* might be growing in similar fuel bases as grasslands elsewhere in the world. The dynamic grassland fuel base of both montane grassland and savanna was also included in this study, because early planting experiments have shown that *P. pinaster* can be grown successfully in some of these regions. The fuel bed of mature *P. pinaster* stands - with closed crown canopies - has also been included as a significant fuel base for the purpose of this study. At this stage of *P. pinaster* tree development the tree stands' fuel bed is dominated by a dead layer of needle-type leaves on the forest floor, with most of the original natural vegetation at this trees' growth stage being completely absent or suppressed. The following main fuel/vegetation fuel bases have been identified for the purpose of this study:

- Fynbos vegetation
- Montane grassland and savanna*
- Mature *P. pinaster* forest floor

Within each of these fuel/vegetation bases, some significant differences have been identified with regard to fuel distribution, loading, density and structure, which will be discussed in this paper, where this could significantly influence fire behaviour and fire effects. Most of these “within-fuel class” variations are normally linked to the age of the trees and/or base vegetation, but some are also related to season (*e.g.* grassland in the summer rainfall regions, after curing during autumn and winter vs. before curing, during spring and summer). Other contributing factors in fuel-related bases, which have been identified as having a significant effect of fire on tree health and growth, are (a) tree volume growth rates, (b) some climatic factors (particularly rainfall) and (c) tree species' growth characteristics (*e.g.* crown form, yearly biomass addition in the form of leaf fall and decomposition dynamics). Examples of fire behaviour and fire effects recorded will be provided for the main fuel and vegetation classes identified.

Fire effects: Comparisons with other *Pinus* species

Under this heading I will use the results from various studies conducted to investigate the effect of prescribed burning under trees, as well as the effect of slash burning after clear felling, on tree health and growth. The results of most of these studies were published earlier (de Ronde, 1983; 1988; 1990a; 1992 and de Ronde and Zwolinski, 2000). The recorded results of later *P. elliottii, P.taeda* and *P. patula* burning experiments - with particular reference to the effect of fire on tree health and growth will also be provided.

The preliminary results of a prescribed burning experiment, conducted in the NE Cape Region of the Eastern Cape province, a tree stand comprising eight different *Pinus* species, three years after tree establishment in a montane grassland base (de Ronde and du Plessis, 2002) will also be provided. This experiment was demarcated as a two-way ANOVA statistical design, with species as treatments and sites as replications.

Relative resistance to fire damage: *P. pinaster* vs. other *Pinus* spp.

Here earlier published results (de Ronde, 1982) as well as some later observations of fire effects on trees (de Ronde, unpublished) will be discussed. This information was recorded in some prescribed burning experiments as well as during certain post-wildfire observations in South Africa. The latter studies were conducted in the form of fire damage assessments at various times after these uncontrolled fires occurred. Results will be summarized for *P. elliottii, P. patula, P. pinaster, P. taeda* and *P. radiata*, with regard to:

- Occurrence of cambium damage
- Average flame height/crown scorch height ratio recorded
- Survival rate after complete crown scorch
- Resprouting occurrence

The effect of fire on plantation ecosystem properties, other than trees

Under this heading a comparison will be made between the outcome of certain prescribed burning experiments inside *Pinus* stands (including *P. pinaster*), slash burning experiments after tree felling and

* = Not considering the indigenous tree components normally found in savanna fuels, because these are normally removed before exotic tree stands are established.

wildfire effects, with regard to:

- Chemical soil properties
- Physical soil properties
- Fungal activities and decomposition processes
- Secondary damage recorded
- Regeneration of forest floor vegetation (including weeds)

These observations were recorded over two decades, after the assessment of certain wildfires for tree survival and exploitation priority determination purposes, during the period 1984 1994 (de Ronde *et al.*, 1986; de Ronde 1988; de Ronde 1992 and other in-house reports) as well as during some wildfire investigations for legal purposes (de Ronde, various confidential reports, 1994 - 2005).

RESULTS

Surface fire fuel beds

Fynbos:

This Mediterranean-type of evergreen sclerophyllous heathland and shrubland vegetation, forms the main vegetation base for trees planted for commercial forestation in the winter and constant rainfall regions, within which the forestry districts of the Western Cape and Eastern Cape provinces of South Africa are found. *Pinus* spp. established here in the form of even-aged stands, are mainly *P. elliottii*, *P. pinaster* and *P. radiata*. This (smallest of the world) floral Kingdom is fire-prone, and is normally exposed to fire on a 12 to 25-year rotation, depending on the rainfall experienced in the area. Despite the structural uniformity, fynbos is renowned for its floristic diversity. The biome contains some 7300 species, of which about 80% are endemic (Bond *et al.*, 2004). Dead fuel material within this biome normally develops with age, and only starts dominating available fuel beyond its required fire rotation, normally when older than 20 years of age.

With regard to *Pinus* plantations established in natural fynbos, five major fuel classes have been identified, which range from a dominant pine needle layer under mature trees, to old fynbos dominated stands, with poor tree growth as a result of poor soil qualities and nutrient deficiencies, which adversely affect commercial tree growth with subsequently maintained open tree crown canopies (de Ronde, 1980 and 1988). According to de Ronde (1980), in three of these fuel classes, fynbos can still be regarded as the dominating fuel. For the purpose of this study I have identified three out of five of these classes as being dominated by fynbos to some large degree:

- **A**: Class V (1): In young *Pinus* stands before significant tree biomass additions (normally until approximately 6 8 years tree stand age);
- **B**: Class V (2): Mature *Pinus* stands where the tree crown canopy never closed, and the main available fuel type consist of old fynbos with a high percentage dead fuel material; and
- **C**: Class IV: *Pinus* tree stands of different ages, with only a partly-closed tree crown canopy, with a mixture of Pine needles and remaining (partly suppressed) fynbos vegetation.

Montane grassland and savanna:

The dynamic* montane grasslands and savanna are normally found at the higher altitudes in Southern Africa, where high rainfall mainly occurs during the summer. The extent of these grasslands is strongly determined by climatic variables, with fire and grazing exerting considerable influence over the boundaries of the grassland biome (Cowling and Hilton-Taylor, 1997). With only a grassland base, these fuels are normally prescribed-burned before tree plantation establishment. However, in the following two age classes of *Pinus* trees this fuel is still prominent:

- **D**: *Pinus* stands until approximately five years of age, when grass fuel is prominent; and
- **E**: *Pinus* stands approximately 6 - 8 years of age, when the fuel consists of a mixture of old (all cured, suppressed) grassland as well as needle fall from the trees.

Pinus spp. established for commercial afforestation within these biomes, are dominantly *P. elliottii*, *P. taeda* and *P. patula*, and less often *P. caribeae, P. greggii, P. khasia* and *P. leyophylla.*

* = Where the grass fuel is completely cured at the end of the wet summer season, mainly as a result of frost but also as a result of moisture stress.

Mature P. pinaster forest floor:

This type of fuel can also be found in mature stands of spp. other than *P. pinaster*, provided crown canopies are closed, and the understorey vegetation has mainly been suppressed, providing a prominent, continuous and dense, needle mat as the main available fuel base (**F**).

Based on the results obtained from ten prescribed burning experiments inside *P. pinaster* stands and more than 60 similar experiments in stands of species other than *P. pinaster,* conducted over a period of 25 years (de Ronde, various published and unpublished results), fire behaviour under prescribed burning conditions and their suitability for fire application in the fuel types discussed (**A - F**) can be summarised as follows:

Table 1. Summary of fire behaviour recorded and comments about prescribed burning suitability, in the A- F fuel types identified.

Fuel Type	Flame height	Fireline Intensity	Fire rate of spread	Flare up occurrence	Prescribed burning suitability
A	Very high, irregular	Mostly high, because of irregular drying rate	Relatively slow	Very common	Not suitable, in most stands, trees mortality can be expected
B	Extremely high, irregular	Very high when dry, otherwise too moist to burn	Relatively slow	Very common	Not suitable, common tree mortality can be expected
C	Very high, but more even than A or B-fuels	Very high under most conditions, even soon after good rain	Slow with backing fires, but relatively fast with head fires	Very common	Mostly not suitable. If burning is required, high crown scorch and some mortality can be expected
D	Fairly high and irregular	Low, related to A, B and C	Fast, related to A, B and C	Low profile, but common	Not recommended. Some mortality can be expected
E	Fairly high and irregular	Mostly high	Slower than D	Irregular, none with backing fires	Caution required. Only backing fires recommended
F	Low and even	Fairly high	Slow	None or rare	Highly recommended

From Table 1 it is clear that fuel type **F** is by far the most desirable fuel base to have when prescribed burning is to be applied inside *P. pinaster* stands, as well as in stands with other *Pinus* spp. In fuel types **D** and **E** prescribed burning can be applied, but caution is required, while a certain degree of tree mortality is possible. In the case of the latter two fuel types, only the backing fire prescribed burning technique is recommended.

Prescribed burning effects on tree health and growth

When slash burning was applied after clear felling of trees:

In a field experiment, conducted on the Tsitsikamma plateau in the Eastern Cape province on P-deficient soils, the following slash treatments were applied after clear felling a *P. pinaster* stand:

- **I**: No stacking of slash and no burning
- **II**: Stacking of slash in rows without burning
- **III**: Broadcast burning of slash, without stacking
- **IV**: Stacking of slash in heaps

The stand was then re-established with *P. elliottii*. Tree height, measured up to five years stand age, showed a highly significant response to the burning treatment (1% level), but the significance of this tree height gain disappeared when the trees were getting older. This confirms a clear “ash-bed” effect (Walker *et al.*, 1984; de Ronde, 1990a).

When prescribed burning is applied inside tree stands:

No other beneficial prescribed burning effects on tree growth have been recorded in the region, when burning inside tree stands, provided no serious crown scorch was experienced, in which case up to two years' tree height growth increment can be lost (de Ronde, 1983*).

In the NE Cape, an experiment demarcated in montane grassland, demonstrated that a significantly number of 3-year old *Pinus* trees could survive prescribed burning. The best survival rate was recorded in four out of the eight *Pinus* spp. (regarded as being commercially viable in the area). They were *P. elliottii* (average 92.5%, range from 76.3 to 97.4%), *P. greggii* var. *greggii* (average 84.1%, range 61.8 to 99.0%), *P. patula* (average 56.7%, range 11.4 to 97.3%) and *P. greggii* var. *austral*. (average 54.2%, range 48.7% to 79.0%). The higher mortality rates were only recorded in the plots where strip head fire instead of the backing fire technique was applied. From these results the following conclusions can be made:

- Three-year old *P. elliottii*, growing in a montane grassland fuel base, can be successfully prescribed-burned (*e.g.* if the species has to act as a firebreak), with a negligible mortality rate.
- *P. greggii* var. *greggii* can also be prescribed burned at early age, but then a mortality rate of up to 38% can be experienced. However, when only using the backing fire technique, tree mortality can be reduced to less than 10%
- *P. patula* can be prescribed-burned successfully at such early age, provided only the backing firing technique is used, in which case a mortality rate of approximately 2.6% can be expected. If a head fire is used, mortality will increase to more than 80%, because the species is very susceptible to high crown scorch and subsequent common mortality.
- *P. greggii* var. *austral.* is not suitable for prescribed burning at early stand age, as the tree mortality rate will be unacceptably high.

Relative resistance of *Pinus* spp. to fire damage

The relative resistance of trees to fire damage and and/or mortality, has been recorded in South Africa over 25 years, in prescribed burning experiments as well as during past-wildfire assessments. If we compare the relative resistance of *P. pinaster* with that of other commercial *Pinus* spp. grown in Southern Africa, the following results can be summarised:

Table 2. Summary of the relative resistance and other tree surviving features, of *P. pinaster* vs. other commercial *Pinus* spp., against fire damage and tree mortality.

Pinus spp.	Cambium damage	Flame ht./crown scorch ht. ratio	Survival rate after complete crown scorch	Resprouting ability
P. elliottii	Highly resistant. Only recorded after very high intensity wild fires	1 : 6	Excellent. Surviving 100% with ease	Excellent, during all seasons
P.patula	Susceptible to cambium damage after all wild fires, but has not been recorded after prescribed burning in grassland	1 : 5	Variable, depending on fire intensity and residence time experienced	Ranging from none at all to excellent, depending mostly on stress variables and season
P. pinaster	Highly resistant. cambium damage seldom recorded after wild fires	1 : 7	Survives high crown scorch with ease, but 100% scorch less often	Relatively little at times, but mostly variable
P. radiata	Very susceptible to cambium damage, even when exposed to light intensity prescribed burns	1 : 4.5	Normally does not survive 100% crown scorch at all	Poor if any
P. taeda	Resistant to cambium damage, but less than *P. pinaster*	1 : 6	Variable, as for *P. patula*	Variable, but many times good, even after high intensity wild fires

* = This was recorded over a range of *P. elliottii* and *P. pinaster* prescribed burning experiments throughout the Western and Eastern Cape regions.

It is clear that *P. elliottii* can be regarded as the most suitable commercial *Pinus* spp. in Southern Africa for the application of prescribed burning inside stands, even at early age. However, it has been experienced that *P. pinaster* is also very suitable for prescribed burning application, provided it has a closed crown canopy when growing in a fynbos fuel base. The same applies to *P. taeda. P. patula* can also be prescribed-burned successfully, but only the backing burning technique should be used at early age, to restrict crown scorch. *P. radiata* is mostly unsuitable for prescribed burning application, except when mature, with a closed crown canopy and with a thick bark layer, when a light intensity fire may succeed without tree damage. However, in such cases it is also recommended to physically remove fuel from tree bases, to avoid cambium damage.

The effect of fire on plantation ecosystem properties other than trees

As the trees only comprise one component of the plantation ecosystem, only forming a link in some complicated processes and cycles, which maintains the system, it is important that we also consider fire effects on these other components, budgets and processes. The following table provides a summary of the outcome of various studies over more than two decades:

Table 3. Summary of fire effects (other than on trees) recorded in *Pinus* plantation ecosystems of Southern Africa, during the 1978 to 2004 period, which had a significant beneficial effect on tree health and growth.

Fire effects	Recorded after prescribed burning inside stands	Recorded after slash burning after clear felling of stands	Recorded after serious wild fires
On chemical soil properties	Negligible, apart from a slight beneficial ash-bed effect in some cases	Significant increase in particularly P-budgets as a result of the ash-bed effect	Significant decreases have been recorded in nutrient budgets
On physical soil properties	None recorded	Some water repellency recorded, where heaps of slash were burned with a long residence time**	Serious water repellency and top soil discoloration has been recorded
On fungal activities and decomposition	Increase in fungal activities* and improved decomposition	As a result of exploitation disturbing forest floor material, could not be recorded	As a result of total consumption of forest floors, could not be determined during short-term studies
On secondary damage occurrence	None	*Rhizina undulata* has been recorded on some site, sometimes***	Serious outbreaks of *Rhizina* have been recorded, killing all surviving trees
On the regeneration of weeds	Slight increases, in particularly in *Acacia* weeds. Effectively decreased *Gleichenia* fern infestation	Serious weed regeneration has been recorded, particularly with *Acacia* and *Setaria* spp.	Very serious weed regeneration problems have been recorded, of various spp.

* = Including an abundance of mushrooms, such as *Lactarius deliciosus* and *Boletus edulis.*

** = Restricted to the sites where the stacks were burned.

***= By delaying re-establishment a few months, this did not have a detrimental affect on tree growth and seedling survival.

DISCUSSION AND CONCLUSION

From the “Southern Africa” experience it is clear that *P. pinaster* can be prescribed-burned inside stands without harm to the trees or its ecosystem, provided certain precautions are considered. Its

relative resistance against fire also compares favourably with that of other *Pinus* spp. commercially grown in Southern Africa. Where fuel accumulation after *P. pinaster* clear felling presents re-establishment problems, broadcast burning of slash is recommended, and has been recorded to create a significant (and short-term beneficial) ash-bed effect.

During the past three years, the Southern African forestry industry has been hit by some very serious plantation wild fires, and during 2003/04 some 50 000 ha of trees burned down during extreme weather conditions. It is also clear that global warming is also contributing to the fire problem, and as a result forest managers had a serious look at certain emergency measures, such as prescribed burning inside tree stands. As a result, there has been a significant increase in the use of prescribed burning in Southern Africa, inside natural ecosystems (such as in fynbos, montane grassland and savanna) as well as inside *Pinus* stands as a management tool, particularly to strengthen firebreak system in forestry regions. During the 2004/05 season, it is estimated that some 10 000 ha of commercial plantations were prescribed-burned successfully, and this figure will probably more than double during 2005/06, as more foresters are being trained in the use of the technique, and the success rate is excellent.

How many more natural and forestry land has to burn down in the Mediterranean, before this vital option is being applied at a large scale, to reduce the spiral of wild fires Southern Europe? Increased use of prescribed fire in natural and in forestry ecosystems is strongly recommended as a matter of urgency, and maybe this paper can contribute to favour such decision-making.

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