7 DISCUSSION

7.1 SIMILARITIES AND DIFFERENCES IN THE WOODY VEGETATION BETWEEN THE PRETORIUSKOP EBP REPLICATES

The four EBP replicates in the Pretoriuskop region are located in two distinct vegetation types, namely the open and the closed *Terminalia sericea \ Combretum* woodlands of Pretoriuskop (Figure 3-3 p. 18). The Numbi and Shabeni replicates are located in the open *Terminalia sericea \ Combretum* woodlands in the north-eastern part of the Pretoriuskop region (Figure 3-3). The Kambeni and Fayi replicates are located in the closed *Terminalia sericea \ Combretum* woodlands in the south-western part of the Pretoriuskop region (Figure 3-3). The location of the replicates has an influence on the structure and composition of the woody vegetation on the replicates. The Kambeni replicate is located near a transition between the open and the closed *Terminalia sericea \ Combretum* woodlands in the central part of the Pretoriuskop region, and some of the characteristics of the open *Terminalia sericea \ Combretum* woodlands are manifest on the Kambeni replicate.

In 1954 and in 1996 the number of species, species richness, species diversity, and species evenness of the woody vegetation was higher on the Numbi and Shabeni replicates occurring in the open *Terminalia sericea \ Combretum* woodlands than on the Kambeni and Fayi replicates occurring in the closed *Terminalia sericea \ Combretum* woodlands. The species composition of many of the plots on the Numbi and Shabeni replicates was more similar than the species composition on the plots of the Kambeni and Fayi replicates. In 1954, the species composition on some of the Kambeni plots was similar to the species composition of some Numbi and Shabeni replicate plots. However, in 1996 the species composition on most of the Kambeni plots was similar to the species composition of the Fayi plots. This may suggest that the transition between the open and closed *Terminalia sericea \ Combretum* woodlands migrated slightly northwards between 1954 and 1996, because the Kambeni replicate plots are dominated by closed *Terminalia sericea \ Combretum* woodland vegetation characteristics in 1996. It was found that plots that were adjacent to one another were more likely to have similar species compositions than plots that were further apart. Furthermore, the species composition of many plots in 1954 was found to be an important determinant of the species composition of the plots in 1996 regardless of treatment. It was found that there were plots that were similar to one another in species composition in 1996 that had been similar to one another in species composition in 1954, and this was regardless of the fire treatment applied to the plots between 1954 and 1996.

Generally, the density, height, number of tree equivalents, number of structural groups, structural richness, structural diversity, and structural evenness of the woody vegetation on the Pretoriuskop replicates were similar in 1954 and 1996. In 1954, it was found that the establishment of the plots in two distinct phases had an impact on the baseline structure of the woody vegetation. The structural composition of most plots that were established and surveyed in 1954 was more similar to one another than with plots that were established and surveyed between 1956 and 1958. However, there was no clear pattern regarding location of the replicates and the structural composition of the vegetation on the replicates.

The main differences in the woody vegetation between the Pretoriuskop replicates were slightly different species abundances and compositions in the open and closed *Terminalia sericea \ Combretum* woodlands. All other woody vegetation characteristics were similar between the replicates in 1954 and 1996, even though there were large changes in the density of the woody vegetation between 1954 and 1996.

7.2 THE EFFECT OF FIRE FREQUENCY ON THE WOODY VEGETATION OF THE PRETORIUSKOP SOURVELD

Change in the density of the woody vegetation as the inter-fire period increases in the Pretoriuskop region is approximately J shaped (Figure 7-1). There is an initial decrease in the woody plant density as the inter-fire period increases from 1 year to 3 years, thereafter the density of the woody vegetation increases as the inter-fire period increases beyond 3 years. Change in the number of tree equivalents as the inter-fire period increases is however, not J shaped, and is approximately logarithmic (Figure 7-1). This indicates that the initial decrease in the density of the woody vegetation is caused by a decrease in the density of very short individuals.

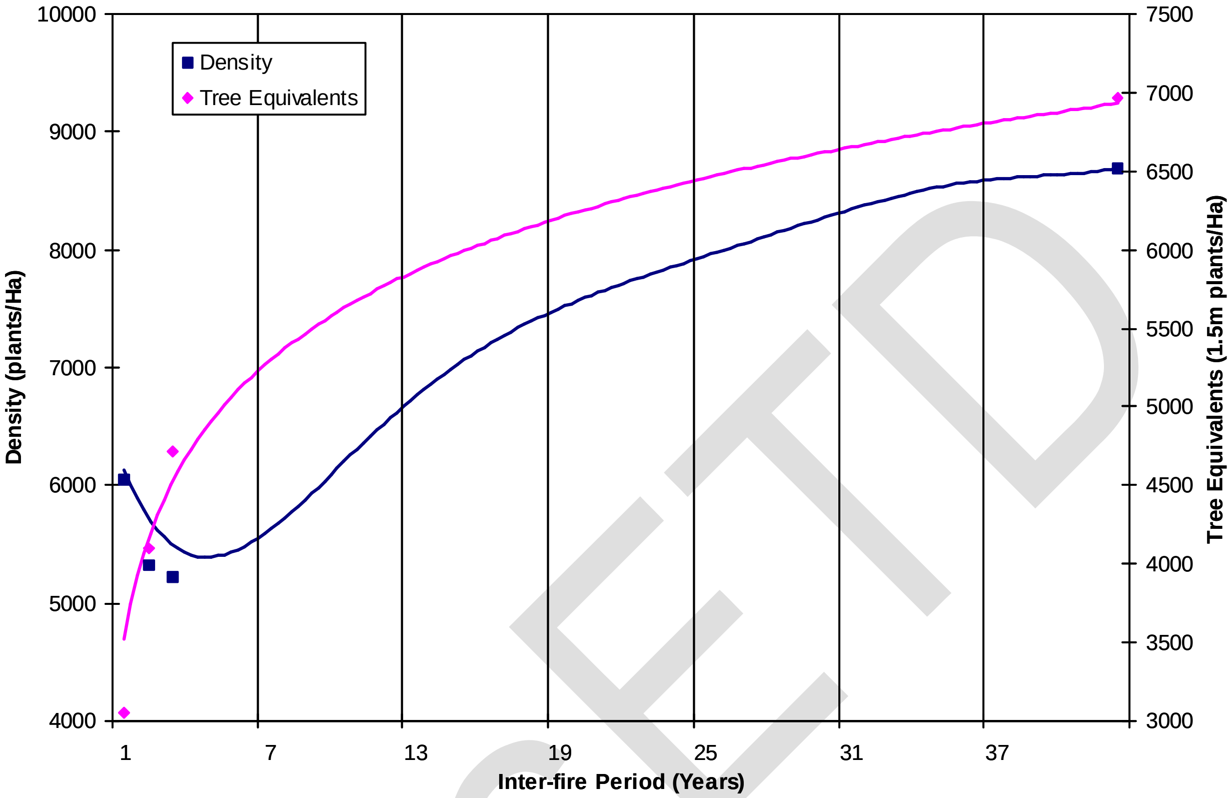

Figure 7-1: Model of the change in the density (plants/Ha) and the number of tree equivalents (tree equivalents/Ha) of the woody vegetation in the Pretoriuskop region as the period between fires increases.

Figure 7-2 shows that the density of individuals 0-1m tall (understorey individuals) decreases as the inter-fire period increases from 1 year to 3 years, and the density of individuals 1-3m tall (overstorey individuals) increases as the inter-fire period increases from 1 year to 3 years. The decrease in the density of the understorey woody vegetation is proportionately greater than the increase in density of the overstorey woody vegetation. This indicates that as the inter-fire period increases from 1 year to 3 years a large proportion of the understorey plants disappear. Many of the understorey individuals at an inter-fire period of 1 year and 3 years are stunted fire tolerant individuals that sprout in response to fire damage. These individuals most often have a resilience response to fire events because they experience 100% mortality of their above ground parts (topkill), and they then sprout from meristematic tissues below ground that have not been damaged by fire.

The dominant understorey species that are common between 1 and 3 years inter-fire periods are *Catunaregam spinosa*, *Dichrostachys cinerea*, *Maytenus senegalensis*, *Pavetta schumanniana*, *Senna petersiana*, *Strychnos madagascariensis*, *Terminalia sericea*, and *Turraea nilotica* (Figure 7-4 and Figure 7-5). The understorey species that dominate when the vegetation is burnt annually but not triennially are *Albizia versicolor*, *Annona senegalensis*, *Euclea natalensis*, and *Lonchocarpus capassa* (Figure 7-4). The understorey species that dominate when the vegetation is burnt triennially but not annually are *Acacia gerrardii*, *Combretum hereroense*, *Diospyros lycioides*, and *Hippobromus pauciflorus* (Figure 7-5). After the initial decrease in the density of the woody understorey community, the density begins to increase between inter-fire periods of 3 to 5 years. This is seen in Figure 7-3 where a resurvey of the control plots in 1959 after 5 years of fire exclusion showed that the density of the woody understorey community had increased since the baseline survey in 1954. Some species no longer dominate the understorey community when fire has been excluded from the vegetation for over 40 years, for example *Acacia gerrardii*, *Albizia versicolor*, *Combretum hereroense*, *Hippobromus pauciflorus*, *Lonchocarpus capassa*, *Pavetta schumanniana*, *Senna petersiana*, and *Turraea nilotica* (Figure 7-4, Figure 7-5 and Figure 7-6). While these species are certainly fire tolerant, they may not be shade tolerant and therefore do not thrive well as seedlings or saplings, when in the absence of fire the overstorey becomes more wooded. Furthermore, these species may not survive well when the grass and herbaceous layer is not periodically removed by fire and becomes overgrown and moribund.

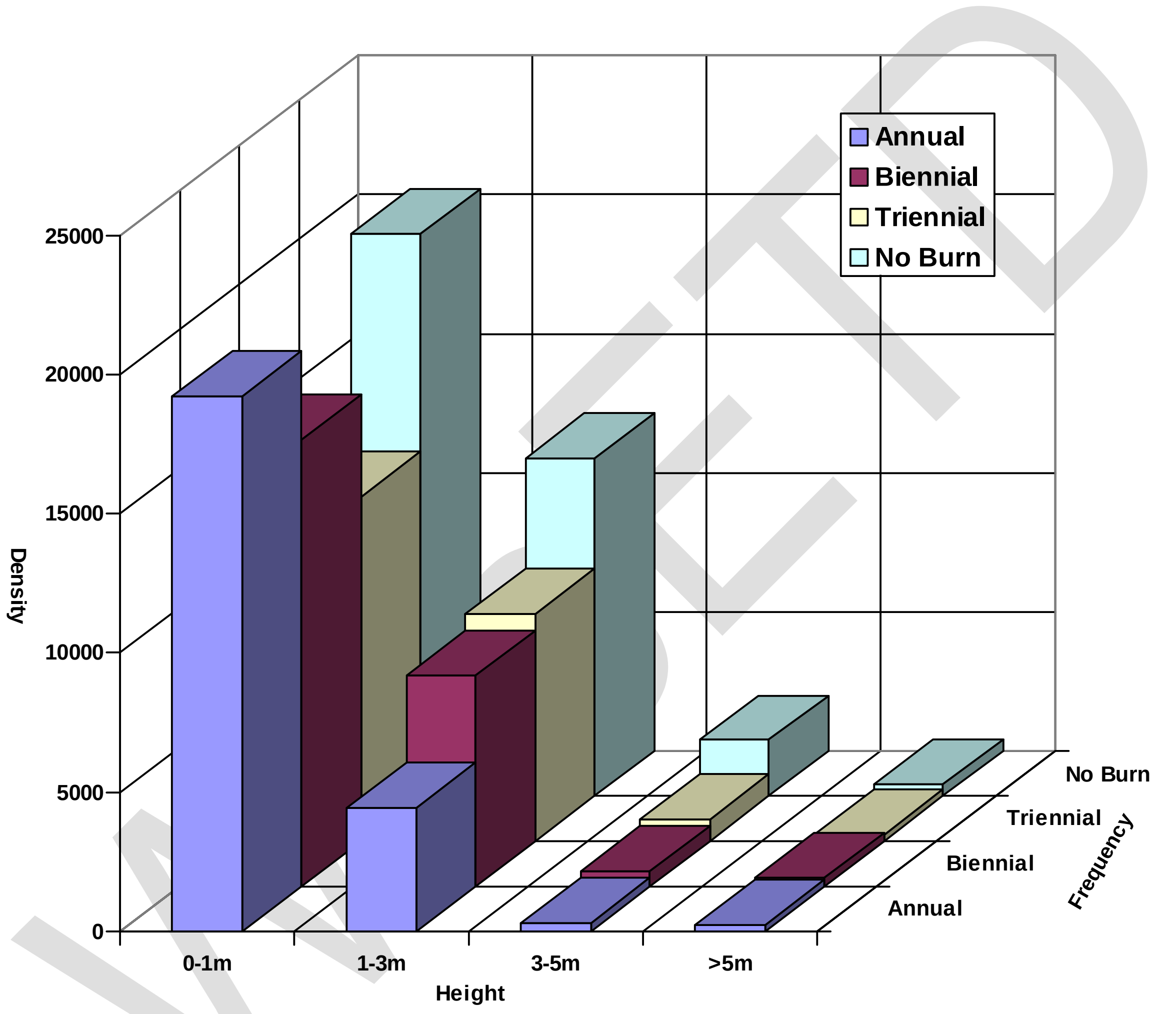

Figure 7-2: The density (plants/Ha) of the woody vegetation at different height classes of vegetation burnt at different fire frequencies.

Figure 7-2 shows that the density of the understorey and overstorey communities increases significantly as the inter-fire period approaches over 40 years. The understorey community of vegetation where fire has been excluded comprises fire sensitive, fire intolerant, and fire tolerant species. Some understorey species that dominate when fire has been excluded are also dominant in vegetation that has been burnt with high or medium frequencies, namely *Catunaregam spinosa*, *Dichrostachys cinerea*, *Diospyros lycioides*, *Maytenus senegalensis*, *Strychnos madagascariensis*, and *Terminalia sericea* (Figure 7-4, Figure 7-5 and Figure 7-6). Some understorey species only dominate when fire has been excluded, such as *Canthium* species, *Dalbergia melanoxylon*, *Diospyros whyteana*, *Ochna natalitia*, *Olea europaea*, *Parinari curatellifolia*, *Putterlickia pyracantha*, and *Zanthoxylum capense* (Figure 7-4, Figure 7-5 and Figure 7-6). Some of these species are fire sensitive or fire intolerant, and furthermore these species are almost certainly shade tolerant and survive well when the grass and herbaceous layer become overgrown and moribund.

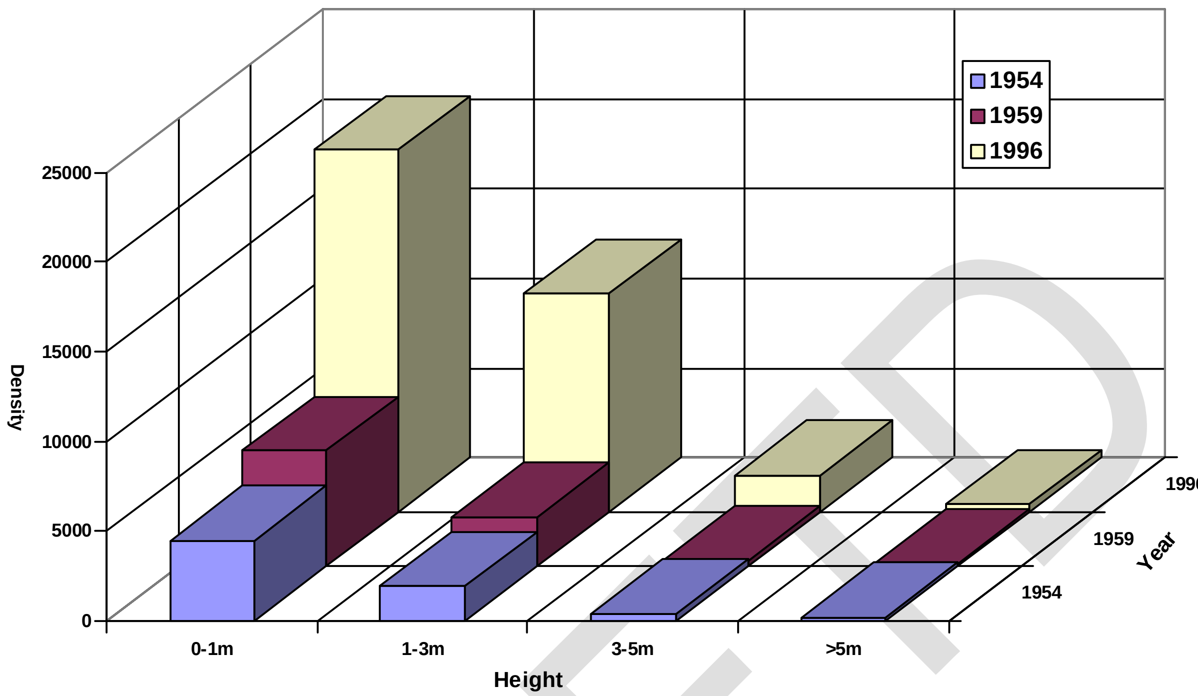

Figure 7-3: The density (plants/Ha) of the woody vegetation at different heights on the control plots at three different years (1954, 1959, and 1996).

As the period between fires increases in the Pretoriuskop region the number of species, species diversity, and species evenness increases. Factors such as the initial species composition of a site and proximity to other sites were found to exercise a great influence on the species composition of a site. However, some generalisations can be made regarding the effects of fire frequency on the species composition of the woody vegetation of the Pretoriuskop region. Species tolerant of high frequency fires are *Albizia versicolor*, *Catunaregam spinosa*, *Lonchocarpus capassa*, *Pavetta schumanniana*, *Senna petersiana*, *Strychnos madagascariensis*, and *Turraea nilotica* (Figure 7-7). *Catunaregam spinosa*, *Senna petersiana*, *Strychnos madagascariensis*, and *Turraea nilotica* are found in areas burnt less frequently. However, they are most abundant in areas burnt frequently where they occur in densities that exceed 600, 200, 240, and 190 plants/Ha respectively. Most individuals of these species are 0-1m tall in areas that are burnt frequently. Species tolerant of medium frequency fires are *Acacia gerrardii*, *Combretum hereroense*, *Diospyros lycioides*, *Hippobromus pauciflorus*, *Maytenus senegalensis*, and *Terminalia sericea* (Figure 7-7). *Terminalia sericea* occurs most abundantly in areas that are burnt less frequently with densities that exceed 320 plants/Ha.

Fire sensitive and fire intolerant species are *Acacia swazica*, *Bauhinia galpinii*, *Combretum mossambicense*, *Commiphora neglecta*, *Croton gratissimus*, *Dalbergia melanoxylon*, *Diospyros lycioides*, *Diospyros whyteana*, *Euclea natalensis*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Ochna natalitia*, *Olea europaea*, *Psydrax locuples*, *Putterlickia pyracantha*, *Tarenna supra-axillaris*, and *Zanthoxylum capense* (Figure 7-7). Species like *Catunaregam spinosa*, *Dichrostachys cinerea*, *Senna petersiana*, and *Terminalia sericea* decrease in density as the inter-fire period increases beyond medium frequency fires.

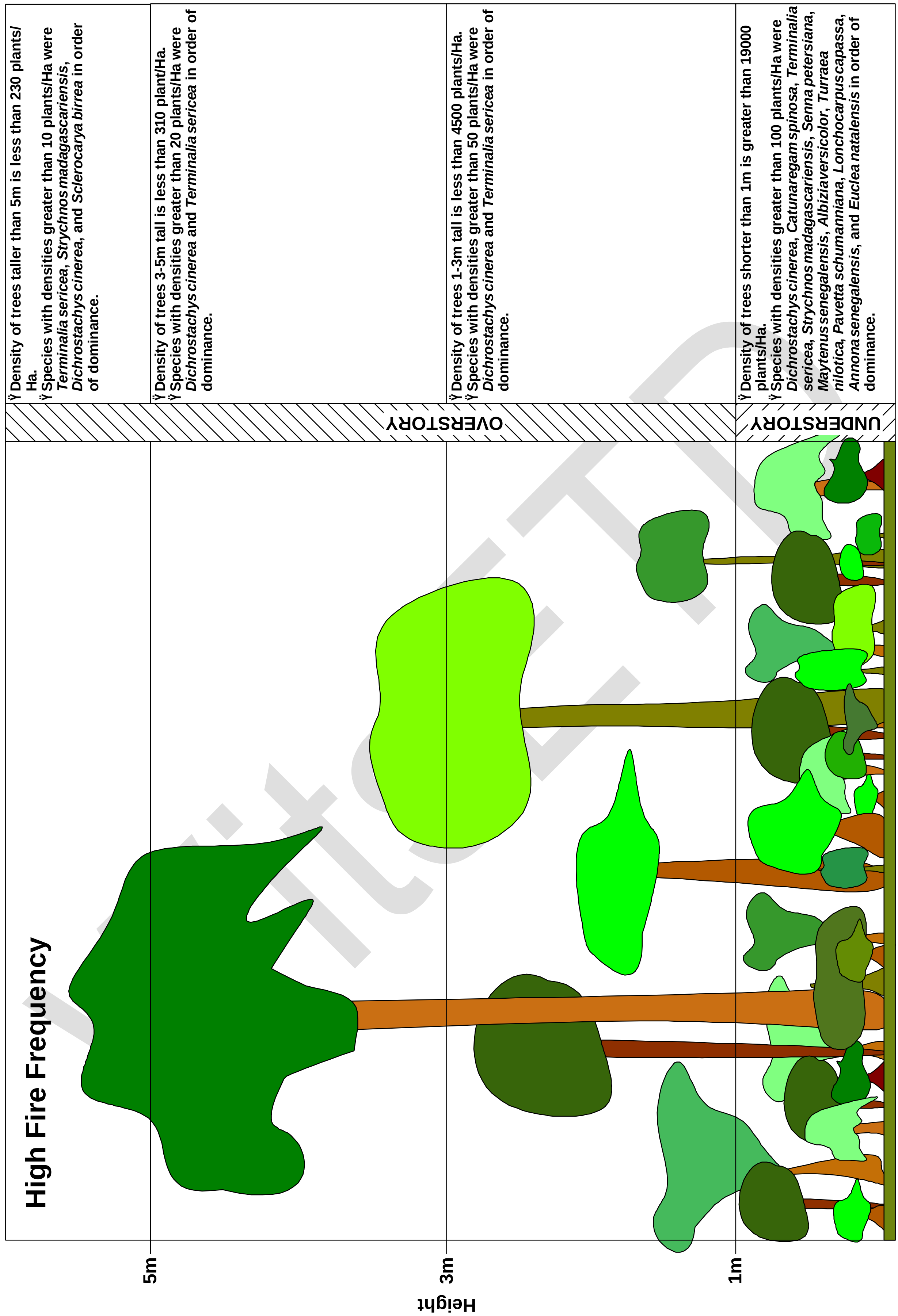

Figure 7-4: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being subjected to high frequency (Annual) fires.

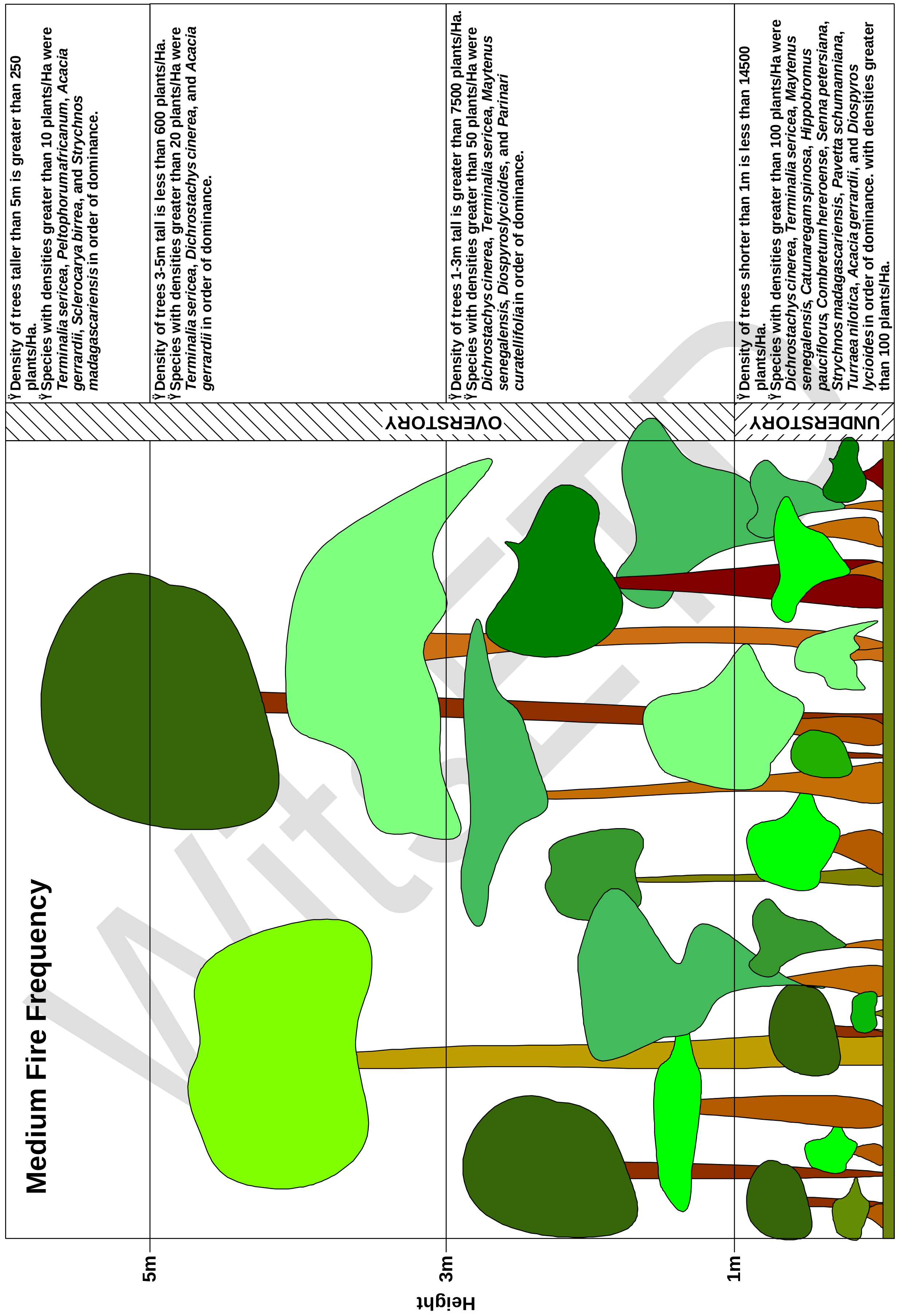

Figure 7-5: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being subjected to medium frequency (Biennial and Triennial) fires.

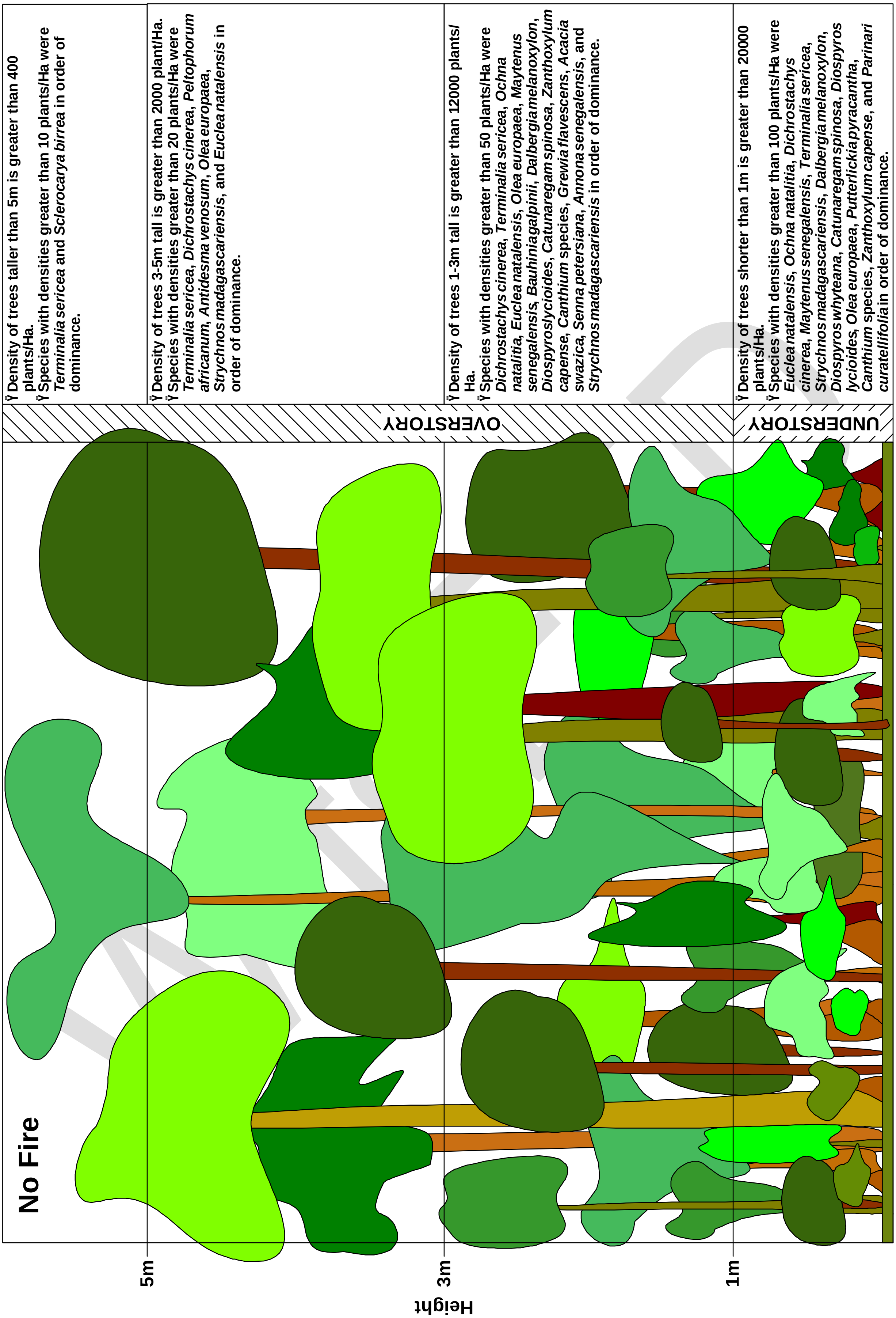

Figure 7-6: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being protected from fire for 42 years.

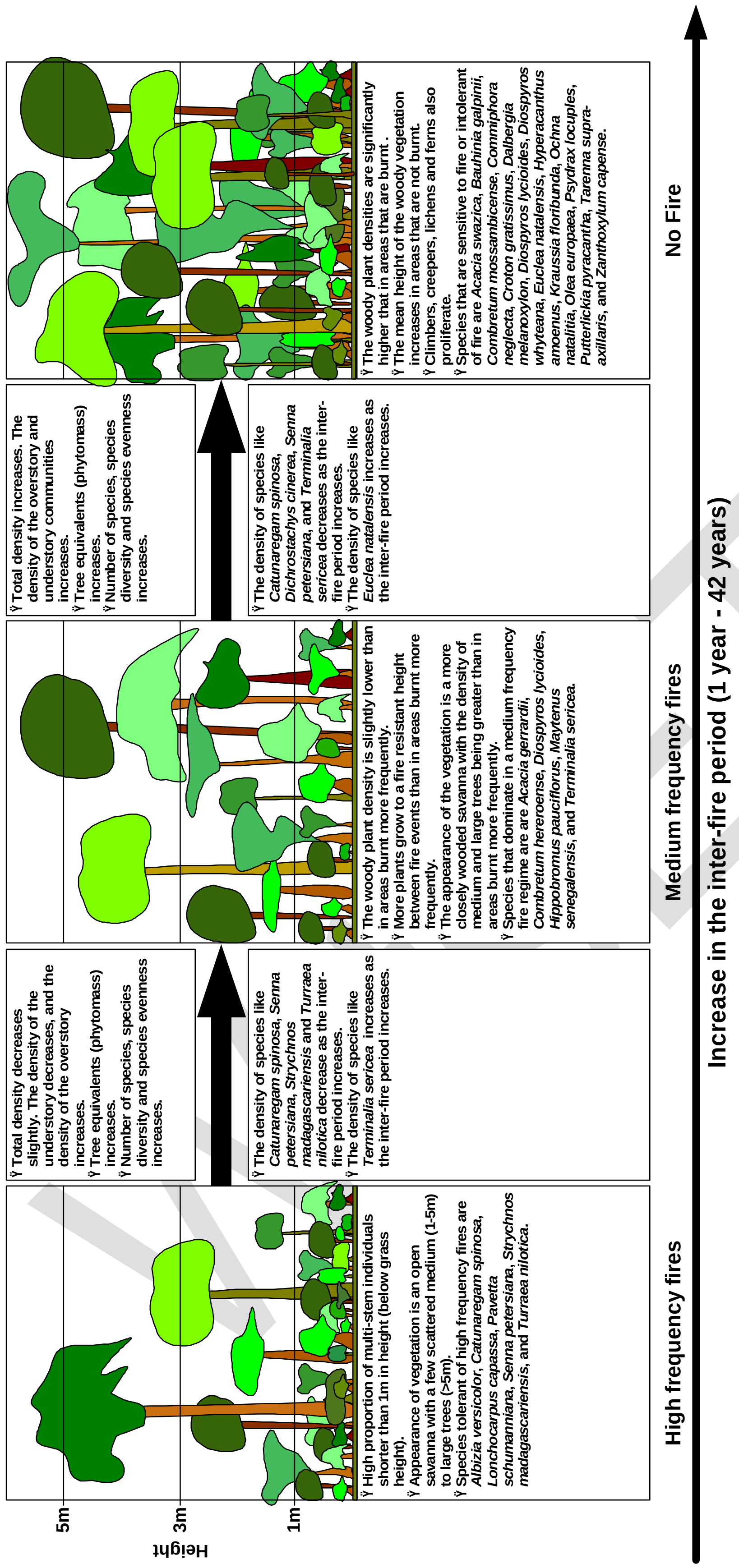

Figure 7-7: Conceptual model showing the changes in the woody vegetation of the Pretoriuskop region as the fire frequency decreases from high frequency fires to fire exclusion.

Some fire sensitive species do occur in areas that have been burnt but they are most abundant in areas that have not been burnt. Furthermore, when these species are found in areas that are burnt they are most often found on termitaria or rocky ground, which act as fire refuges. *Euclea natalensis* is most abundant in areas where fire has been excluded, where its densities exceed 500 plants/Ha. Areas where fire is naturally excluded like rocky outcrops and large termitaria are fire refuges for fire sensitive species and fire intolerant species within the Pretoriuskop landscape. However, the occurrence of fire sensitive and fire intolerant species in areas where fire has been excluded is dependant on the proximity of other fire refuges where these species survive and reproduce. For this reason, fire can be excluded from an area that has no local fire refugia, and many of the above fire sensitive and fire intolerant species will not appear for many years if at all.

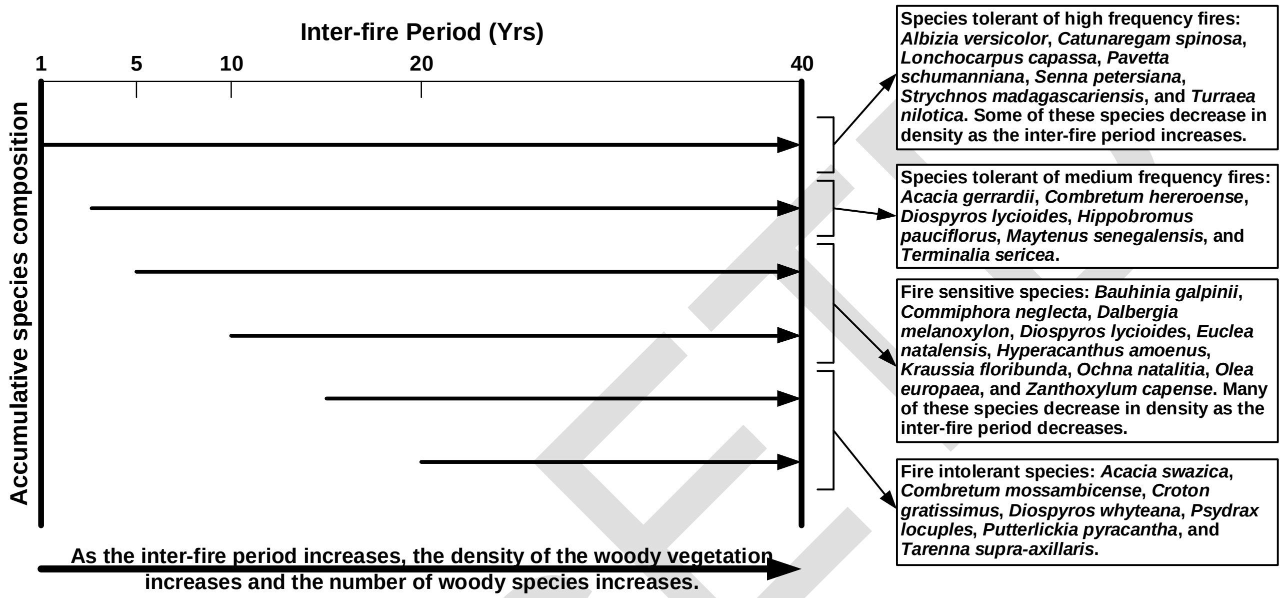

Figure 7-8: The typical accumulative floristic succession of the woody vegetation in the Pretoriuskop region as the inter-fire period increases.

The exclusion of fire in the Pretoriuskop region does not result in typical relay floristic succession in the woody vegetation where fire tolerant species are replaced by fire sensitive species, which in turn are replaced by fire intolerant species. Floristic succession in the Pretoriuskop region when fire is excluded is accumulative (Figure 7-8).

Table 7-1: The average density of woody vegetation (plants/Ha) on the Control EBPs (fire excluded) in the Pretoriuskop region 1954, 1959, 1969, and 1996. The densities of the woody vegetation in 1954, 1959, and 1996 were from belt transect surveys of the Pretoriuskop EBPs. The density of the woody vegetation in 1969 was from a quadrate middle-point survey of the Pretoriuskop EBPs (Van Wyk 1971).

Treatment	1954	1959	1969	1996
Con0	1722	2397	3506	8696

As the inter-fire period increases from high frequency fires to medium frequency fires, species that are tolerant of high frequency fires coexist with species that are tolerant of medium frequency fires. As the inter-fire period increases from medium frequency fires to low frequency fires, species that are tolerant of high and medium frequency fires coexist with species that are fire sensitive and are tolerant of low frequency fires. Finally, as the inter-fire period increases beyond 40 years fire tolerant, fire sensitive, and fire intolerant species coexist. The net result of the accumulative floristic succession in the woody vegetation is that the density of the woody vegetation increases (Table 7-1). Furthermore, the number of woody species increases when fire is excluded from the woody vegetation in the Pretoriuskop region.

Generally, as the inter-fire period increases the number of structural groups, structural diversity, and structural evenness increases. Factors such as the initial structural composition and vegetation type (i.e. open or closed *Terminalia sericea \ Combretum* woodlands) did not have a great influence on the structural composition of the woody vegetation of a site. Occasionally the structural composition of the woody vegetation was found to be similar at adjacent sites. However, post fire age was found to be an important factor that affects the structural composition of the woody vegetation in the Pretoriuskop region.

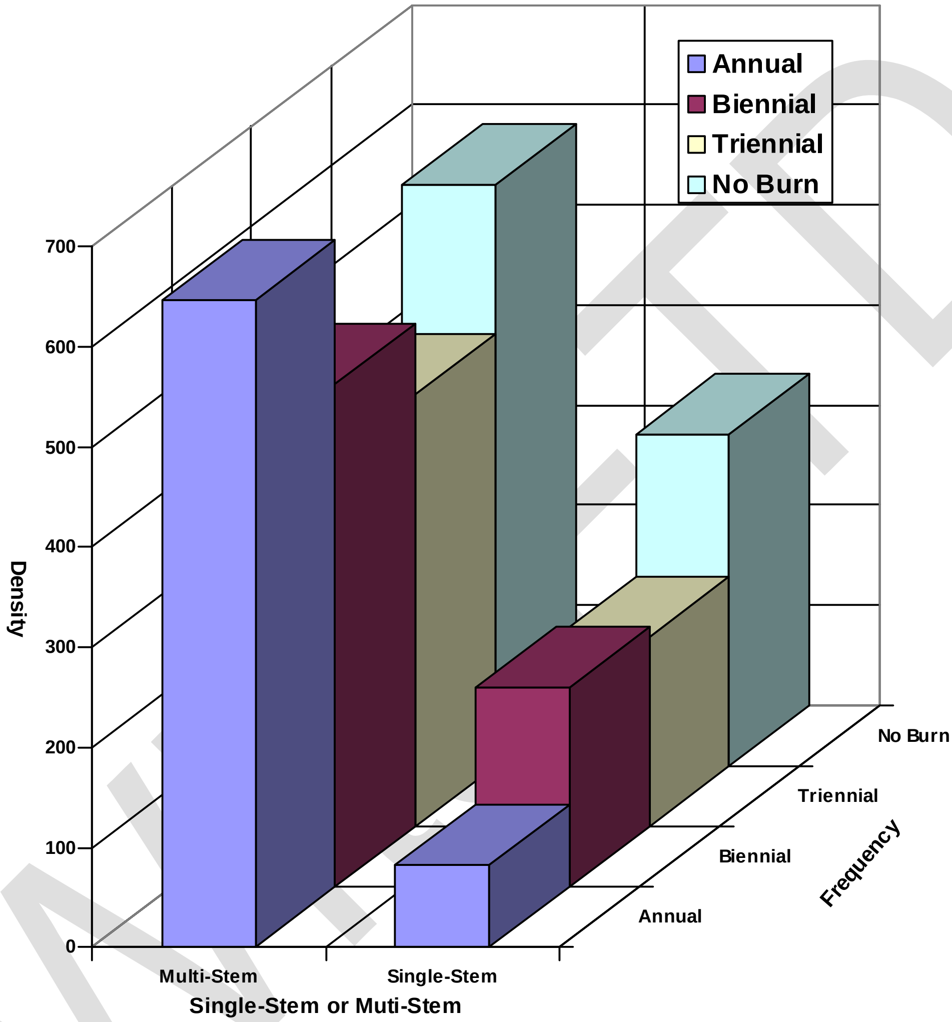

Figure 7-9: The density (plants/Ha) of single-stem and multi-stem woody plants in vegetation burnt at different fire frequencies.

It was found that as the period since the last fire event increases the single-stem to multi-stem index increases. Figure 7-9, Figure 7-10, and Figure 7-11 show that as the inter-fire period increases from 1 year to 3 years, the density of multi-stem plants decreases, and the density of single-stem plants increases. The density of multi-stem plants and single-stem plants increases as the inter-fire period increases beyond 3 years (Figure 7-9, Figure 7-10, Figure 7-11 and Figure 7-12). However, the single-stem to multi-stem index increases as the inter-fire period increases beyond 3 years, which indicates that the ratio of single-stem to multi-stem individuals decreases as the inter-fire period increases.

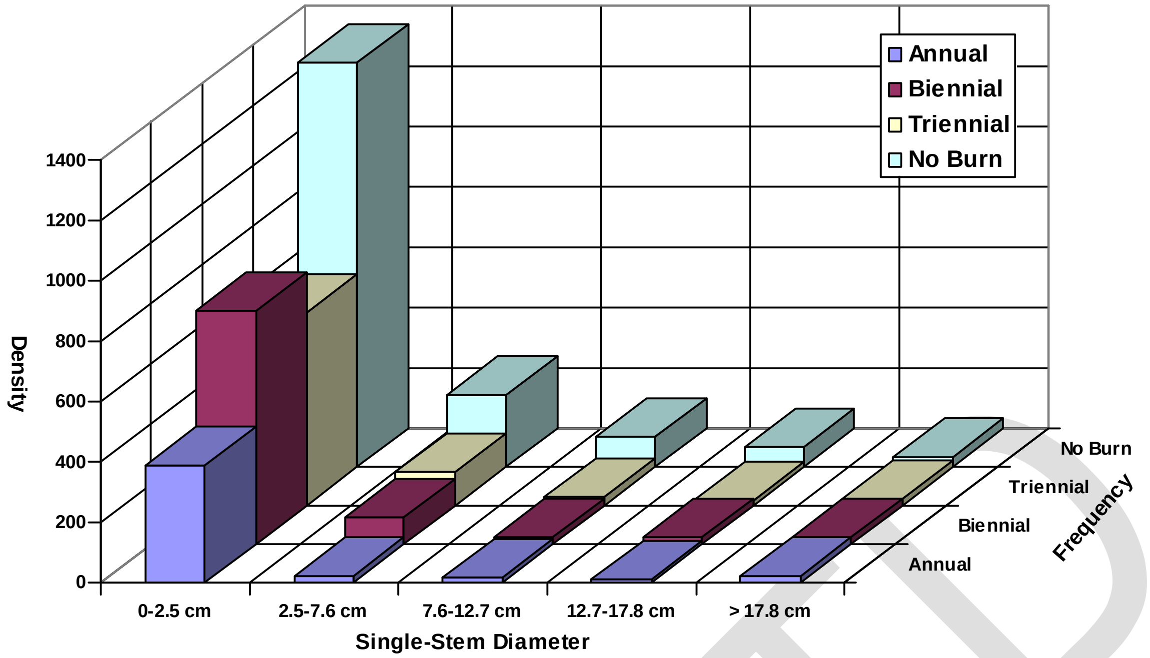

Figure 7-10: The density (plants/Ha) of different diameter classes of single-stem woody plants in vegetation burnt at different fire frequencies.

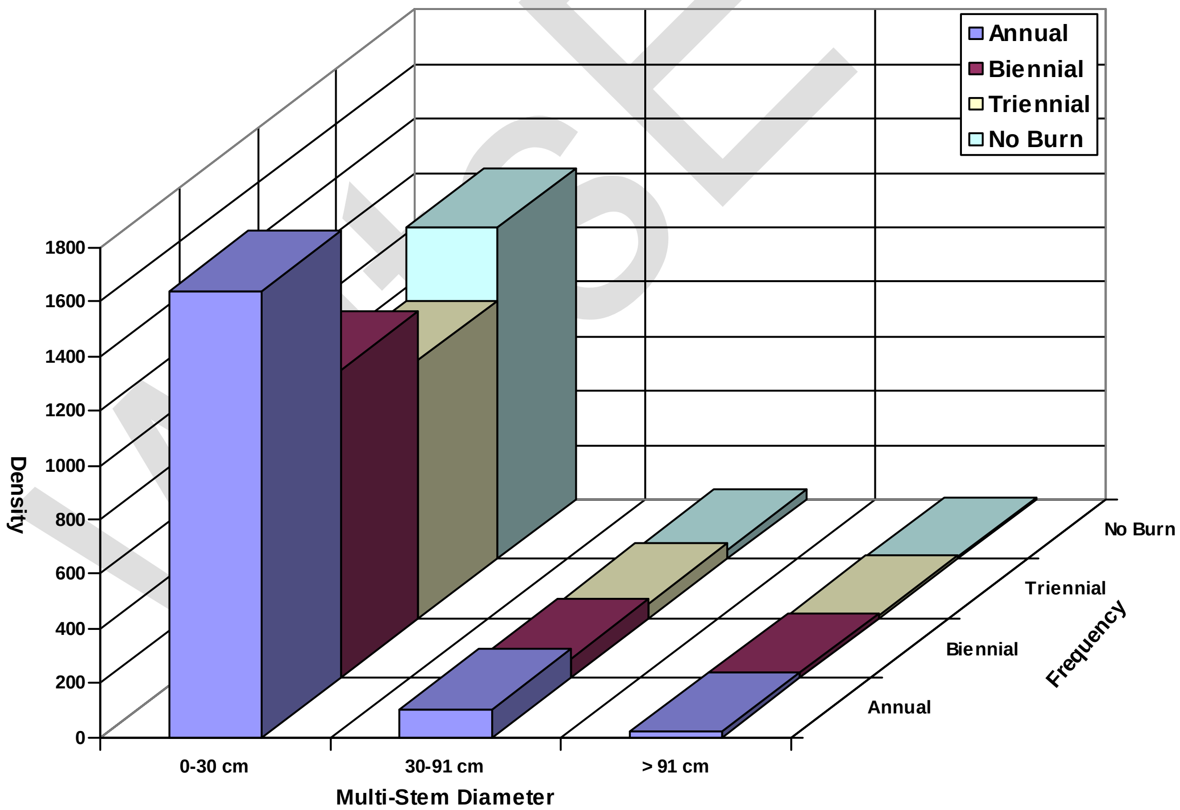

Figure 7-11: The density (plants/Ha) of different diameter classes of multi-stem woody plants in vegetation burnt at different fire frequencies.

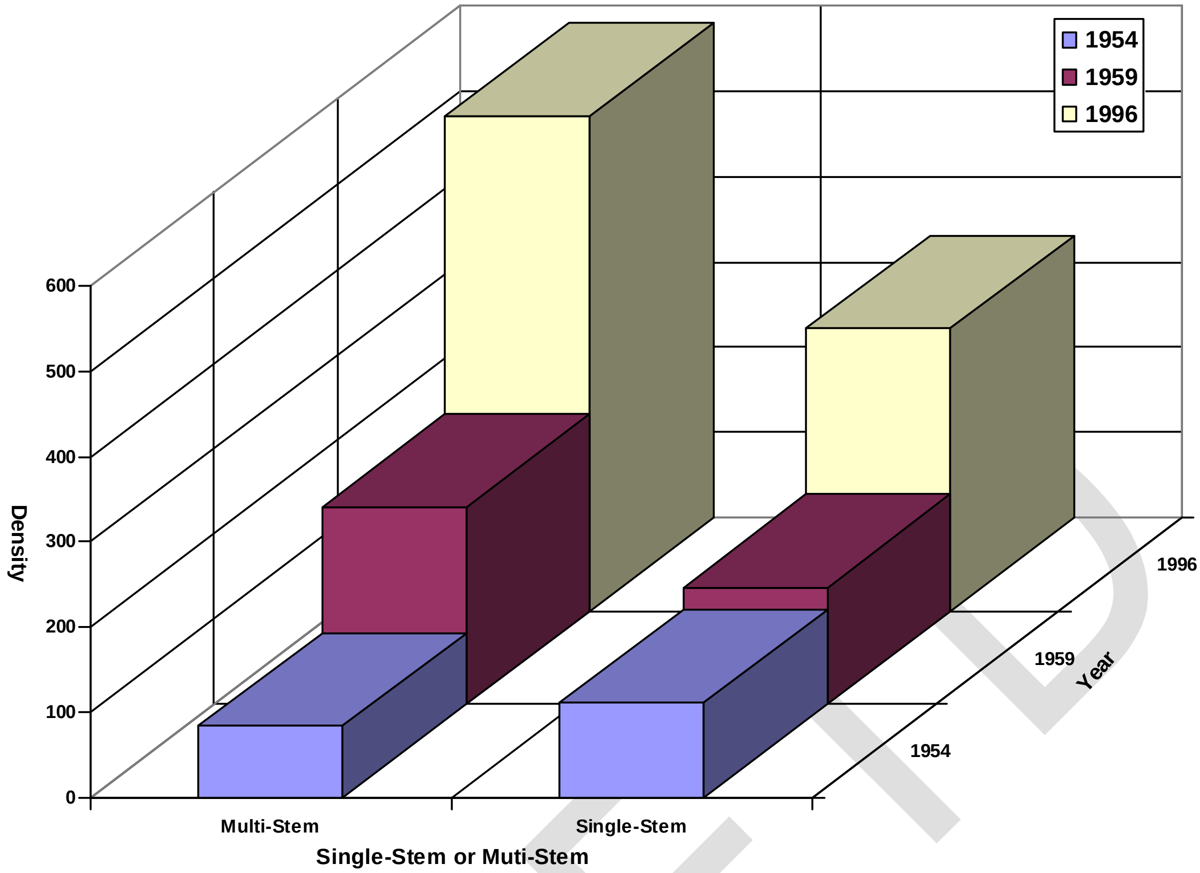

Figure 7-12: The density (plants/Ha) of single-stem and multi-stem woody plants on the control plots at three different years (1954, 1959, and 1996).

The increase in the density of single-stem plants in the 0-2.5 cm and 2.5-7.6 cm classes accounts for most of the increase in single-stem plants as the inter-fire period increases from 1 year to beyond 3 years (Figure 7-10). The decrease in density of multi-stem plants in the 0-30 cm class accounts for most of the decrease in multi-stem plants as the inter-fire period increases from 1 year to 3 years (Figure 7-11). The increase in density of multi-stem plants in the 0-30 cm class also accounts for most of the increase in multi-stem plants as the inter-fire period increases beyond 3 years (Figure 7-11). In contrast, the density of multi-stem plants in the 30-91 cm class decreases as the inter-fire period increases form 1 year to beyond 3 years.

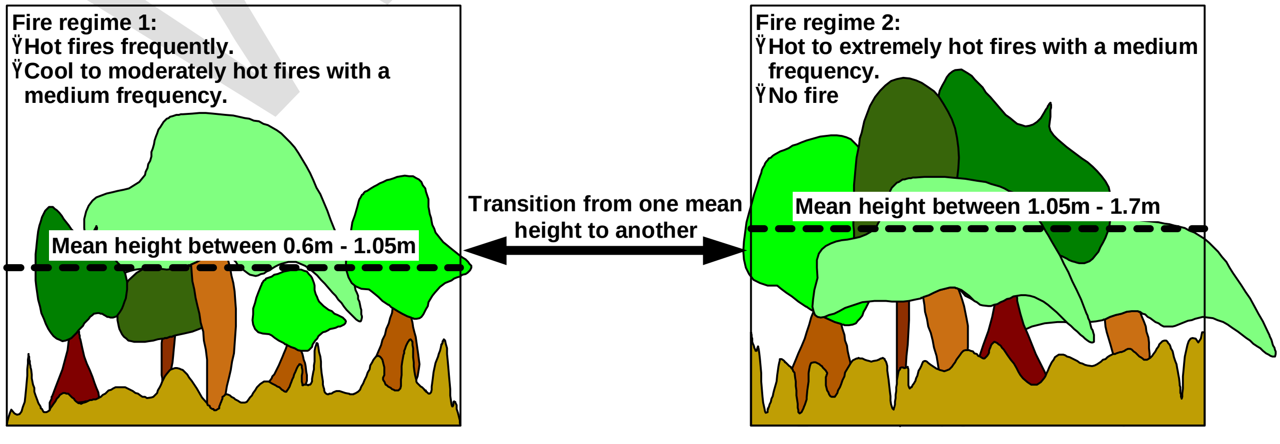

Figure 7-13: Model showing the combined effect of fire frequency and fire intensity on the height structure of the woody vegetation on the Pretoriuskop EBPs.

In Pretoriuskop, the mean height of the woody vegetation increases as the inter-fire period increases. It was found that vegetation burnt with hot fires frequently or cool to moderately hot fires with a medium frequency (fire regime 1) had a shorter mean plant height than vegetation burnt with hot to extremely hot fires with a medium frequency or where fire had been excluded (fire regime 2) (Figure 7-13 and Figure 7-14). The density of woody plants 0-1m tall is greater when the vegetation is exposed to fire regime 1 than when the vegetation is exposed to fire regime 2. Conversely, the density of woody plants 1-3 m tall is greater when the vegetation is exposed to fire regime 2 than when the vegetation is exposed to fire regime 1. This is why the average difference between the woody plant density and number of tree equivalents in the vegetation burnt with fire regime 1 was almost double the average difference in vegetation burnt with fire regime 2.

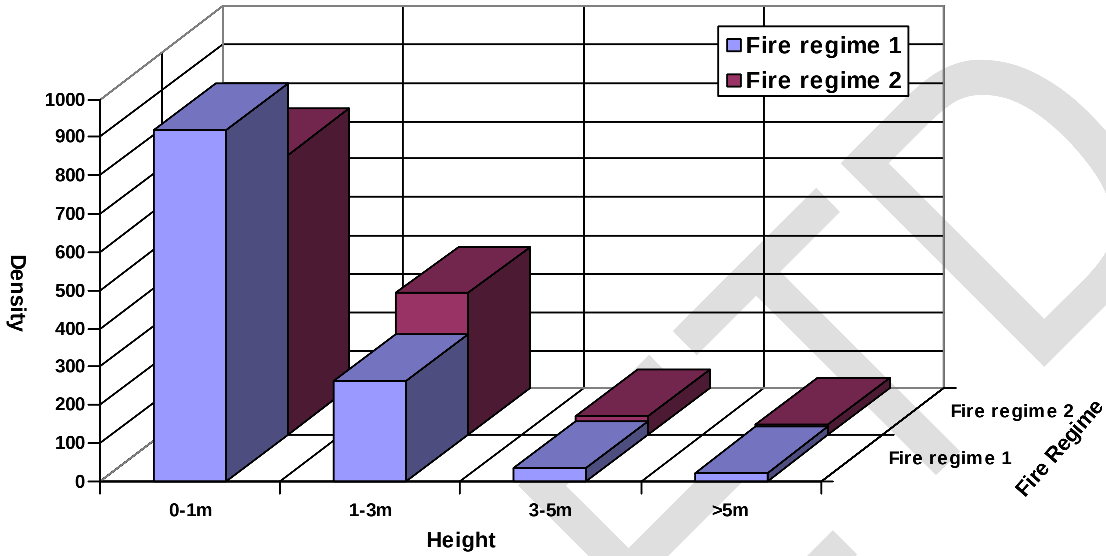

Figure 7-14: The density (plants/Ha) of the woody vegetation at different height classes burnt under two fire regimes, Fire regime 1 denotes hot fires burnt frequently or cool to moderately hot fires burnt with a medium frequency. Fire regime 2 denotes where fire has been excluded, or hot to extremely hot fires burnt with a medium frequency.

The findings from the Morale fire experiment in Botswana are different to those in Pretoriuskop. The Morale Fire experiment was established in 1958 at the Pasture Research Station at Morale in Botswana (Sweet 1982). The Morale is in an arid savanna, which is dominated by *Acacia nigrescens* and *Combretum apiculatum*. The annual average rainfall at Morale is approximately 450mm occurring predominantly between October and March.

Table 7-2: Results from analyses performed on the density (plants/Ha) of the woody vegetation in 1981 on the Morale Fire experimental plots burnt at different frequencies between 1958 and 1981 (Sweet 1982).

	Annual	Biennial	Triennial	Quadrennial	Pentennial	No burn	Density	N
Annual	1.000						1210	1
Biennial		1.000					1240	1
Triennial	0.001	0.001	1.000				1870	1
Quadrennial	0.001	0.001		1.000			1960	1
Pentennial	0.001	0.001	0.001	0.001	1.000		2180	1
No burn			0.001	0.001	0.001	1.000	1280	1

Note: The methods of analyses used by Sweet (1982) were not specified.

The Morale fire experiment comprised six plots of 1.2 Ha each to which six fire treatments were applied. The treatments were no burn and five burn treatments at different return periods during the dry season, namely annual, biennial, triennial, quadrennial, and pentennial. The mean annual grass (fuel) production (dry mass) at Morale is between 1676 and 1740 Kg/Ha/year, and the cumulative fuel load on the plots burnt pentennially was estimated at approximately 5876 Kg/Ha/year (Sweet 1982). In 1981, a survey of the woody vegetation on each of the plots was conducted which provided a 23 year period over which the effects of the treatments were assessed (Table 7-2) (Sweet 1982).

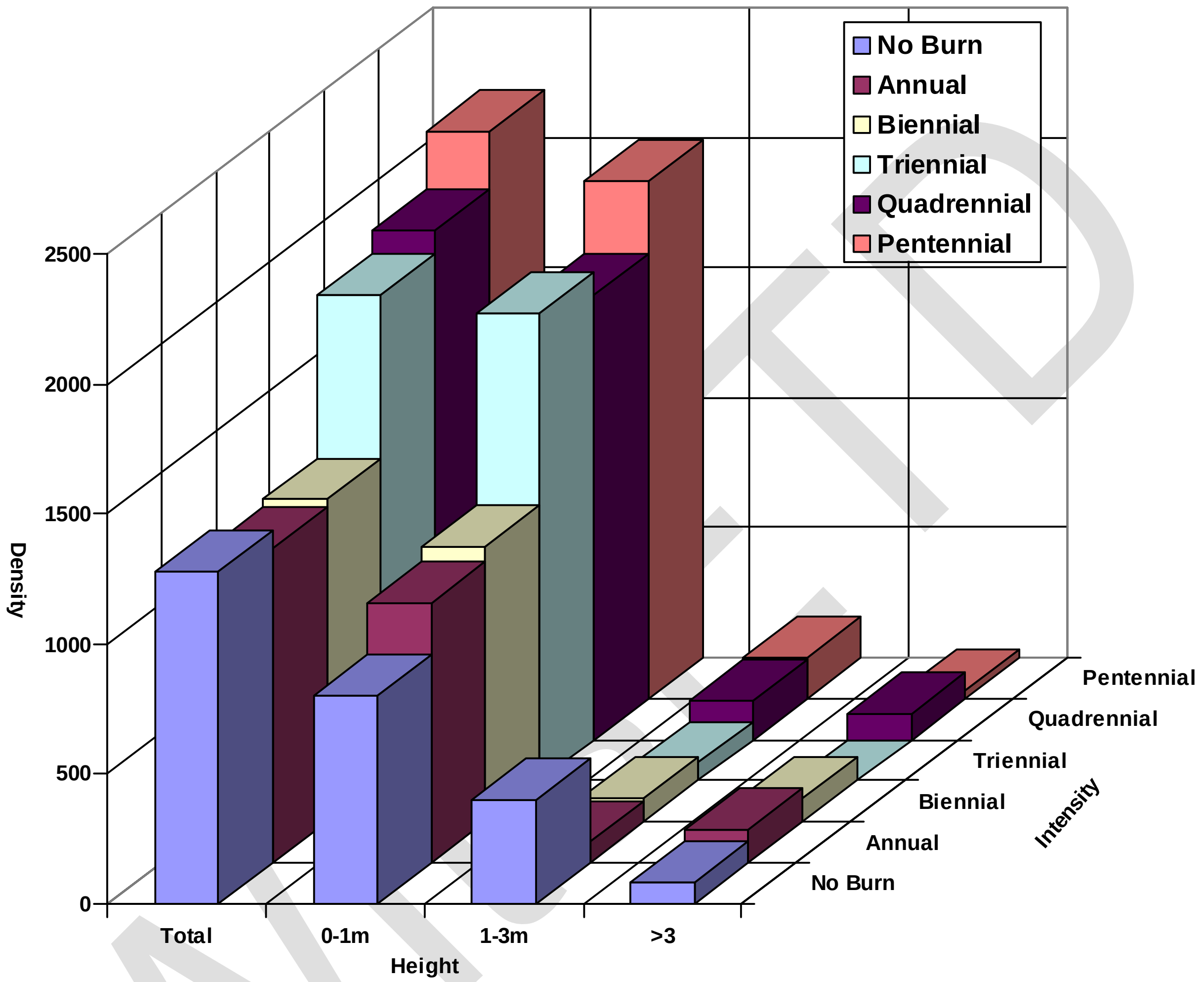

Figure 7-15: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Morale Fire experimental plots in 1981 (Sweet 1982).

At Morale, Sweet (1982) found that as the inter-fire period increased from 1 year to 5 years the density of the woody vegetation increased significantly, without any initial decrease as was found in Pretoriuskop (Table 7-2). Furthermore, at Morale as the inter-fire period increased beyond 5 years and approached 20 years, the density of the woody vegetation decreased significantly (Table 7-2). However, at Pretoriuskop the density of the woody vegetation increased significantly as the inter-fire period increased beyond 3 years (Figure 7-2 and Figure 7-3). Sweet (1982) concluded that the growth of woody plant seedlings and coppicing individuals shorter than 1m tall was suppressed by frequent fire, which resulted in the density of the woody vegetation being low when burnt annually and biennially (Figure 7-15). Sweet (1982) also concluded that the exclusion of fire resulted in the escape of individuals less than 1m tall from the grass layer being restricted, which explained why the density of the woody vegetation was low when fire was excluded (Figure 7-15). The findings at Morale are in contrast with the findings in Pretoriuskop where the exclusion of fire results in an increase in the density of the woody vegetation. In Pretoriuskop, the exclusion of fire results in seedlings and coppicing individuals escaping the grass layer and savanna woodlands are the result.

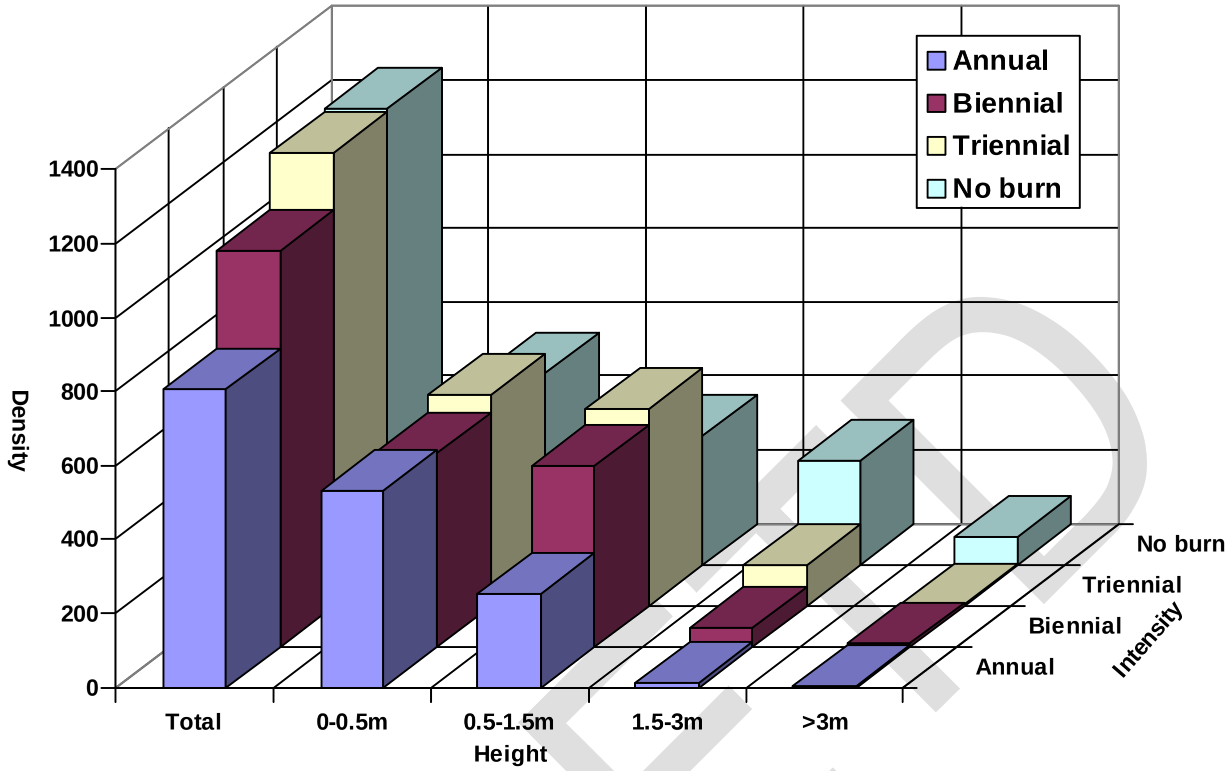

Figure 7-16: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Satara EBPs in 1971 (Gertenbach and Potgieter 1975).

The findings in Pretoriuskop are also different from the findings on the EBPs in the Satara region of the KNP. The Satara region is more arid than Pretoriuskop and experiences on average 548 mm of rainfall annually (Gertenbach 1983). In 1975, it was found that as the inter-fire period increased from 1 year to 3 years the density of the woody vegetation increased without an initial decrease (Figure 7-16). However, as the inter-fire period increased beyond 3 years the density of the woody vegetation did not increase. Figure 7-16 shows that the density of woody individuals 0-1.5m tall decreases as the inter-fire period increases beyond 3 years, and the density of woody individuals > 1.5m tall increases as the inter-fire period increases beyond 3 years. During 1980, two treatments were added to the EBPs in the Satara region, namely the October 4-year and 6-year treatments (Annual report 1980). In 2000, two separate studies on the Satara EBPs found that as the inter-fire period increased from 1 year to 4 year the density of the woody vegetation increased without any initial decrease (Gertenbach and Potgieter 1975, Enslin *et al.* 2000, Shackleton and Scholes 2000). The density of the woody vegetation then decreased as the inter-fire period increased beyond 4 years (Gertenbach and Potgieter 1975, Enslin *et al.* 2000, Shackleton and Scholes 2000). The findings on the Satara EBPs in 1975 and 2000 are similar to those at the Morale fire experiment where the exclusion of fire results in a decrease in the density of the woody vegetation.

The difference in vegetation response to the exclusion of fire in Morale and Satara as opposed to Pretoriuskop is believed to be because Morale and Satara are semi-arid savannas and Pretoriuskop is a mesic savanna. This point is reinforced by findings in the mesic savannas of the northern Accra Plains in Ghana (Carson and Abbiw, 1990). The northern Accra Plains experience on average 1170 mm of rainfall annually. It was found that the exclusion of fire over a 29-year period resulted in forest vegetation displacing the savanna vegetation.

It appears that the exclusion of fire in moist savannas that receive more than 600 mm of rain annually results in the woody vegetation becoming denser to various degrees ranging from savanna woodlands to forests. The exclusion of fire in arid to semi-arid savannas that receive less than 600 mm of rain annually does not result in the woody vegetation becoming denser. However, the biomass of the woody vegetation does increase when fire is suppressed in arid and semi-arid savannas.

7.3 THE EFFECT OF FIRE TIMING ON THE WOODY VEGETATION OF THE PRETORIUSKOP SOURVELD

The density of the woody vegetation in the Pretoriuskop region is lower when burnt by the hot to extremely hot fires in August and October than when burnt by the very cool to moderately hot fires in February and December. There are a number of reasons why the density of the woody vegetation is higher in vegetation that is burnt in December and February as opposed to August and October.

Generally, topkill of the woody vegetation in the KNP is higher when burnt by more intense fires than less intense fires (Trollope and Tainton 1986, Trollope 1999b). The intensity of fires in August and October is higher than in December and February, and therefore topkill of trees and shrubs is higher in August and October than in December and February. In many savanna woody species topkill does not equate to mortality however, other factors such as seasonal non-structural carbohydrate (starch) phenology combined with topkill, as discussed below, may well equate with mortality.

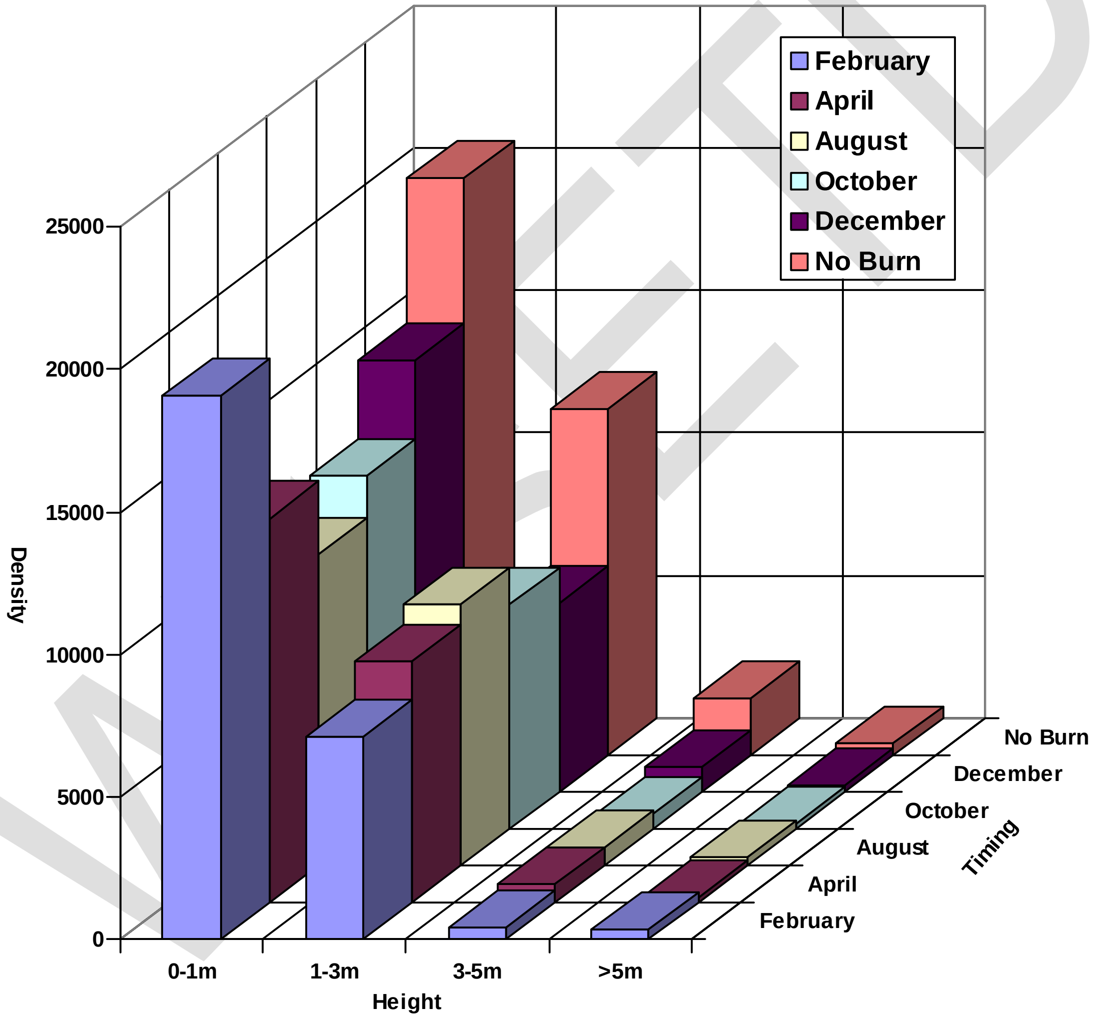

Figure 7-17: The density (plants/Ha) of the woody vegetation burnt at different times of the year at different height classes. Note: The August Annual treatment data was excluded.

However, short bushes (0-1m tall) are most prone to significant topkill regardless of the intensity of a fire (Trollope and Tainton 1986). So why is the density of the understorey vegetation so much higher in areas burnt in December and February than in areas burnt in August and October (Figure 7-17)? Buffalo grass (*Panicum maximum*) that grows under the large trees in the Pretoriuskop region is green in the summer months between December and February. The green *Panicum maximum* prevents fire from burning under the large trees and effectively protects seedlings, juvenile trees, and shrubs from fire. The areas under large trees effectively become fire refuges and nurseries of seedlings, juvenile trees, and shrubs. The growth of the juvenile trees and shrubs is suppressed by the *Panicum maximum* growing under the trees and the juvenile trees and shrubs remain stunted under the large trees because of the shading effect the overstorey trees. The result is a high density of seedlings and stunted juveniles between 0-1m high (understorey trees) in vegetation burnt during the summer months of December and February as opposed to the winter months of August and October (Figure 7-17). The dominant understorey species that are common in vegetation burnt in summer and in winter in Pretoriuskop are *Catunaregam spinosa*, *Dichrostachys cinerea*, *Maytenus senegalensis*, *Pavetta schumanniana*, *Senna petersiana*, *Strychnos madagascariensis*, *Terminalia sericea*, and *Turraea nilotica*. The understorey species that dominate when the vegetation is burnt in summer are *Canthium* species, *Dalbergia melanoxylon*, *Diospyros whyteana*, *Olea europaea*, *Parinari curatellifolia*, *Putterlickia pyracantha*, and *Zanthoxylum capense*. The understorey species that dominate when the vegetation is burnt in winter are *Lonchocarpus capassa* and *Parinari curatellifolia*. Although, the density of understorey woody vegetation is highest in vegetation burnt in the summer months, the density of the overstorey woody vegetation (1m – 3m) is higher in vegetation burnt during the winter months (Figure 7-17). This is why the average height of the woody vegetation is higher in vegetation burnt in August and October, than in vegetation burnt in February and April, and why the number of tree equivalents (phytomass) is lower in vegetation burnt in December and February in comparison with August and October.

Finally, the levels of non-structural carbohydrate reserves of the woody plants have a direct effect on the heat resistance and the sprouting capacity of woody plants in response to fire damage (West 1965, Hoffmann *et al.* 2000). The levels of non-structural carbohydrate reserves of plants are lowest toward the end of the dry season and the beginning of the new growth season between August and October when they have been depleted (West 1965). While the levels of non-structural carbohydrate reserves are highest in the middle of the growing season between December and February (West 1965). Between August and October, woody plants in Pretoriuskop are most susceptible to fatal damage by fire because they are most susceptible to heat damage and less able to sprout from undamaged meristematic tissues. While between December and February the woody plants in Pretoriuskop are least susceptible to fatal damage by fire as they have excess non-structural carbohydrate reserves, which enable them to sprout from undamaged meristematic tissues.

Ignoring areas in which fire has been excluded, Figure 7-18 shows that the density of the understorey woody vegetation tends to be higher when burnt by very cool, to cool fires than when burnt by hot to extremely hot fires. Furthermore, the density of overstorey vegetation (1-3m) tends to be highest in areas burnt by extremely hot fires and lowest in areas burnt by very cool fires (Figure 7-18). However, it is difficult to separate the intensity effects from the timing effects of fire because the hot to extremely hot fires occur in August and October, while the very cool, to cool fires occur in December and February (Table 3-7 p. 22).

In Pretoriuskop, the number of species and species diversity of the woody vegetation is higher in vegetation that is burnt in December and February in comparison with vegetation burnt in August and October. In 1963, Ramsay and Innes reviewed six fire experiments in West Africa and concluded, “late dry-season (fierce) burns are particularly destructive to trees and shrubs of all except the most fire-resistant species” (Ramsay and Innes 1963). In Pretoriuskop, some species may not be adapted to surviving the late dry season fires in August and October because they are very intense and furthermore the starch stores of the plants are depleted, which may explain why the number of species and species diversity is lower in areas burnt in August and October.

The species composition of the woody vegetation in areas burnt in December and February is more similar than with areas that have been burnt in August and October. Furthermore, the species composition of the woody vegetation in areas where fire has been excluded is more similar to the species composition of woody vegetation burnt in December and February than in areas that have been burnt in August and October. The species associated with woody vegetation burnt in December and February and where fire has been excluded are *Euclea natalensis*, *Antidesma venosum*, *Diospyros lycioides*, *Phyllanthus reticulatus*, *Grewia flavescens*, *Grewia monticola*, *Ochna natalitia*, *Peltophorum africanum*, *Rhus pyroides*, *Diospyros mespiliformis*, *Rhus transvaalensis*, *Securinega virosa*, *Putterlickia pyracantha*, *Rhus pentheri*, *Commiphora neglecta*, *Heteropyxis natalensis*, and *Olea europaea*.

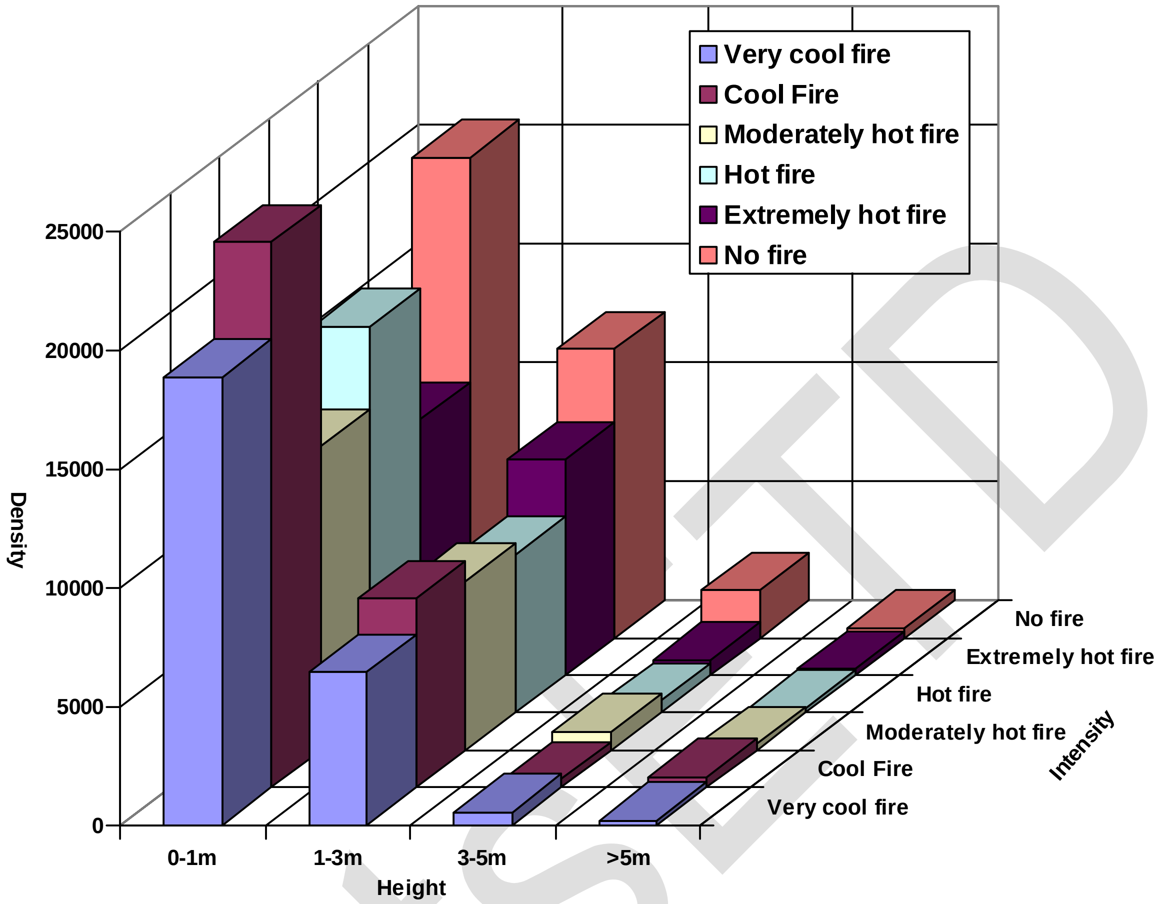

Figure 7-18: The density (plants/Ha) of the woody vegetation burnt with different fire intensities. The fire intensity classes used are those defined in "The intensity of fires on the Pretoriuskop EBP treatments" p. 19.

Structurally, the mean height of woody vegetation is shorter in areas burnt in February and December than in areas burnt in August and December and where fire has been excluded. The woody vegetation has more multi-stem individuals relative to single-stem individuals in vegetation burnt in August and October than in vegetation burnt in December and February or where fire has been excluded. Furthermore, the structural composition of areas burnt in December and February and where fire has been excluded is more similar than with areas burnt in August and October. Generally, the structure of the woody vegetation in areas burnt in August and October is dominated by multi-stem individuals with basal diameters ranging from almost zero to greater than 3 m that are 0-1m tall or 3-5m tall. The structure of the woody vegetation in areas not burnt or areas burnt in December, February, and April is dominated by both single-stem and multi-stem individuals of all heights and basal diameters.

The woody vegetation in Pretoriuskop responds differently to fires occurring in December and February than to fires occurring in August and October. However, the woody vegetation of Pretoriuskop has a mixed response to fires occurring in April. The woody vegetation response to fires in April is sometimes similar to the response to fires in December and February. For example, the mean height of the woody vegetation and number of single-stem individuals relative to multi-stem individuals of the woody vegetation in areas burnt in April is similar to areas burnt in December and February. The structure of the woody vegetation in areas burnt in April is generally similar to the structure of the woody vegetation burnt in December and February. The woody vegetation response to fires in April is sometimes similar to the response to fires in August and October. For example, the tree equivalents, number of species, and species diversity of woody vegetation burnt in April is similar to areas burnt in August and October. The structure of the woody vegetation in areas burnt in April is occasionally similar to the structure of woody vegetation burnt in August, especially regarding the high densities of multi-stem individuals 1-3m tall. The woody vegetation response to fires in April is sometimes at some point between the response of the woody vegetation to December and February fires and to August and October fires. For example, the density of woody vegetation burnt in April is between that of areas burnt in December and February and areas burnt in August and October.

There are a number of reasons for this. Fires in April are more intense than fires in December and February but less intense than fires in August and October, and topkill of woody vegetation in April is expected to be higher than in February and December (Table 3-7 p. 22). Furthermore, the density of the understorey woody vegetation is lower in April than in December and February (Figure 7-17), this is because the vegetation burnt in April does not recover fully before the dry season, and the woody vegetation 0-1m tall is often browsed heavily during the winter months. However, the levels of stored non-structural carbohydrates in woody plants are not depleted in April because it is the end of the growing season. This results in a lower probability of topkill related mortality in April than in August and October. These factors contribute to the mixed response of the woody vegetation in Pretoriuskop to fires in April.

The findings of the Olokemeji Fire experiment in Nigeria are similar to those in Pretoriuskop. The Olokemeji Fire experiment was established near Ibadan in south-western Nigeria in 1923 is located in a mesic savanna with a mean annual rainfall of about 1320 mm (West 1965, Fuwape 1991). The experiment comprised three treatment plots each 42.6 X 39.6 m in size. Three fire treatments were applied to the plots, namely a control in which fire was excluded and annual fires in the early dry season (December) and the late dry season (March) (Fuwape 1991). These treatments are similar to the control treatment, the April treatment (early dry season), and the August (late dry season) treatment in the EBP experiment.

Table 7-3: Data from five vegetation surveys on the Olokemeji Fire experiment plots showing the density of woody plant (plants/Ha) on plots that were burnt annually at different times of the year (Fuwape 1991).

Year	**March burn (Late dry season)**	**December burn (Early dry season)**	**No burn Control**
1929	2181	2259	2259
1935	445	1304	2330
1957	581	966	2567
1976	788	1399	2703
1988	640	1429	3302

In the Olokemeji Fire experiment, the density of the woody vegetation was highest on the fire-protected plot at each of the surveys between 1929 and 1988 (Table 7-3). The density of the woody vegetation increased steadily between 1929 and 1988 on the fire-protected plot at a rate of between 7 and 50 plants/Ha/year. The density of the woody vegetation on the late dry season treatment decreased dramatically between 1929 and 1935 at a rate of 289 plants/Ha/year. The density of the woody vegetation then fluctuated between 445 and 788 plants/Ha between 1935 and 1988 (Table 7-3). The density of the woody vegetation on the early dry season treatment also decreased between 1929 and 1935 at a rate of 159 plants/Ha/year. The density of the woody vegetation then fluctuated between 966 and 1429 plants/Ha between 1935 and 1988 (Table 7-3). These results are similar to the findings on the Pretoriuskop EBPs where the density of the woody vegetation was lower on the late dry season treatments in August than the early dry season treatments in April. Furthermore, the fire-protected plots on the Pretoriuskop EBPs also had the highest woody plant density.

The findings of the Kainji Fire experiment in Nigeria are similar to those of the Olokemeji Fire experiment in Nigeria and the EBPs in Pretoriuskop. The Kainji Fire experiment was established in 1971 in the Kainji Park in a landscape dominated by *Terminalia macroptera*, and it is located in a mesic savanna with an average annual rainfall of about 1070 mm (Fuwape 1991). The experiment comprised three treatment plots each 50 X 20 m in size. Three fire treatments similar to the Olokemeji Fire experiment were applied to the experimental plots, namely annual burns in the early dry season (December) and late dry season (March), and a control from which fire was excluded (Fuwape 1991). These treatments are similar to the April (early dry season), August (late dry season), and no burn treatments in the EBP experiment.

Table 7-4: Data from two vegetation surveys on the Kainji Fire experiment plots showing the density of woody plant (plants/Ha) on plots that were burnt annually at different times of the year (Fuwape 1991).

Year	March burn (Late dry season)	December burn (Early dry season)	No burn Control
1973	130	200	120
1976	110	210	170

In the Kainji Fire experiments the density of the woody vegetation decreased on the late dry season treatment, it increased slightly on the early dry season treatment, and it increased markedly on the fire-protected treatment (Table 7-4). Although the period over which the treatments were applied to the vegetation is much shorter than for the Olokemeji Fire experiment and the Pretoriuskop EBPs the trends are certainly similar.

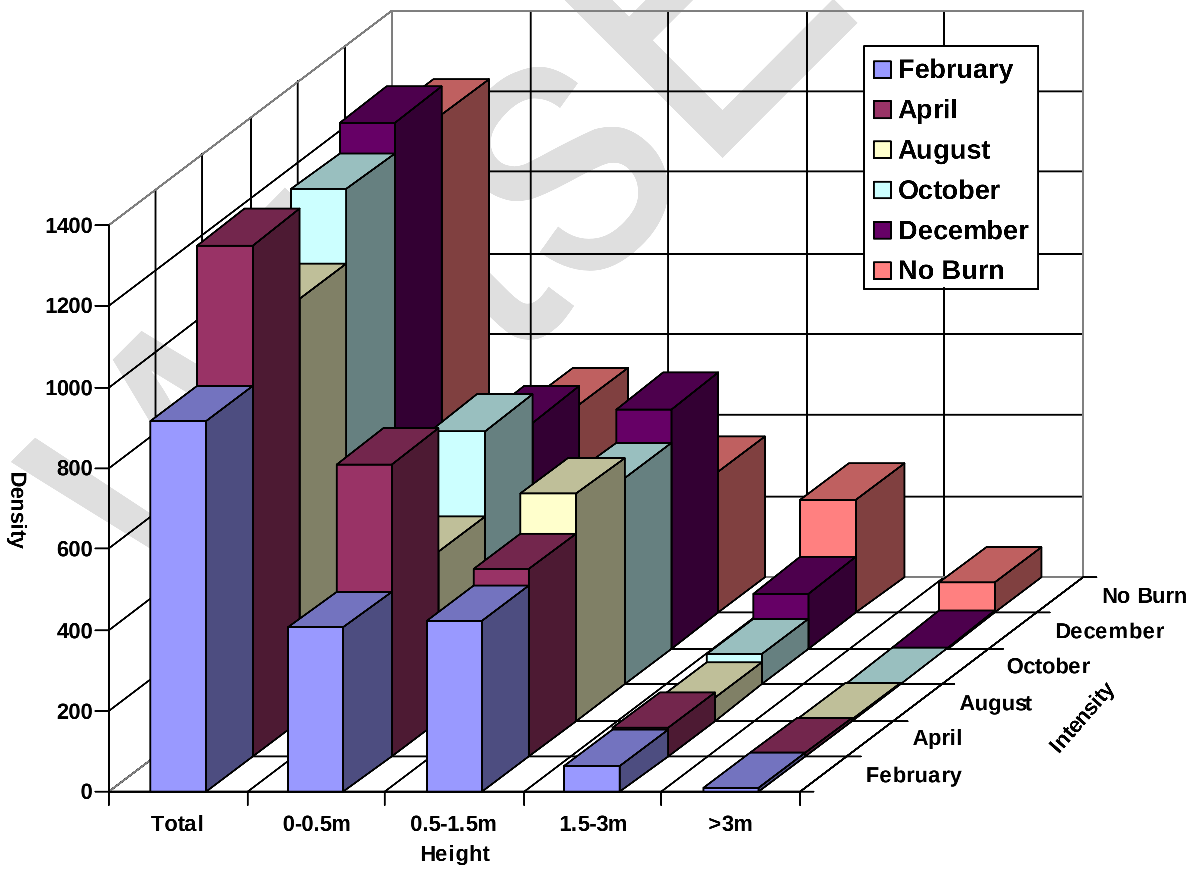

Figure 7-19: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Satara EBPs in 1971 (Gertenbach and Potgieter 1975). Note: The August Annual treatment data was excluded

The findings regarding the effects of early dry season fires and late dry season fires on the density of the woody vegetation in the Satara EBPs of the KNP are similar to those of the Olokemeji and Kainji fire experiments and the Pretoriuskop EBPs. The density of woody vegetation in areas burnt in the early dry season (April) is higher than in areas burnt in the late dry season (August) (Figure 7-19) (Enslin *et al.* 2000). However, regarding differences in the density of the woody vegetation burnt at other times of the year the patterns are very different. In Pretoriuskop, the density of the woody vegetation was highest when burnt in December and February however, in Satara the density of the woody vegetation was highest when burnt in April, October, and December (Figure 7-19). Furthermore in Pretoriuskop the density of the woody vegetation was lowest when burnt in August and October fires however, in Satara the density of the woody vegetation was lowest when burnt in February and April (Figure 7-19).

Many studies compare the effects of early dry season fires on woody vegetation in comparison with late dry season fires. These results have then been compared between different vegetation types with the aim to establish pattern especially regarding the use of fire to maintain or decrease the density of woody vegetation. However, the results from the Pretoriuskop and Satara EBPs in the KNP suggest that from an ecosystem perspective the timing of fires may affect the woody vegetation differently in different areas even when the affects at certain times appear similar.

7.4 CHANGES IN THE WOODY VEGETATION OF THE PRETORIUSKOP REGION BETWEEN 1954 AND 1996

The density of the woody vegetation (plants/Ha) in Pretoriuskop increased slightly (14.55%) between 1954 and 1969 (Table 7-5). However, the density of the woody vegetation in Pretoriuskop increased significantly (160.79%) between 1969 and 1996 (Table 7-5). The rate of increase in the woody plant density between 1954 and 1969 was 14.9 plants/Ha/year, and the rate of increase between 1969 and 1996 was 136.8 plants/Ha/year. Furthermore, the number of tree equivalents per hectare (phytomass) increased significantly between 1954 and 1996 from 1571.7 in 1954 to 4285.9 in 1996. This increase in the number of tree equivalents (phytomass) of the woody vegetation between 1954 and 1996 was a result of the increase in the woody plant density and not an increase in the height structure of the woody vegetation between 1954 and 1996.

Table 7-5: The average density of woody vegetation (plants/Ha) on the twelve Pretoriuskop EBP treatments in 1954, 1969, and 1996. The densities of the woody vegetation in 1954, and 1996 were calculated from the belt transect surveys of the Pretoriuskop EBPs. The densities of the woody vegetation in 1969 were calculated from the quadrate middle-point survey of the Pretoriuskop EBPs in 1969 (Van Wyk 1971).

Treatment	1954	1969	1996	% change from 1954 to 1969	% change from 1969 to 1996	% change from 1954 to 1996
Apr2	2255.25	2064.14	5250.75	-8.47	154.38	132.82
Apr3	1859.75	2022.11	6155.50	8.73	204.41	230.99
Aug1	2326.00	2306.98	6054.00	-0.82	162.42	160.28
Aug2	2433.50	2417.89	5316.75	-0.64	119.89	118.48
Aug3	2023.50	2005.77	5217.25	-0.88	160.11	157.83
Con0	1721.50	3506.00	8696.00	103.66	148.03	405.14
Dec2	1663.25	1984.75	6520.75	19.33	228.54	292.05
Dec3	2295.50	1897.19	4912.75	-17.35	158.95	114.02
Feb2	2406.75	2903.57	7937.50	20.64	173.37	229.8
Feb3	2540.75	2459.92	5593.00	-3.18	127.37	120.13
Oct2	2290.75	2175.05	5496.50	-5.05	152.71	139.94
Oct3	1317.00	2089.83	5001.25	58.68	139.31	279.75
Average	2094.46	2319.43	6012.67	14.55	160.79	198.44

A factor contributing to the dramatic increase in the density of the woody vegetation of Pretoriuskop between 1954 and 1996, especially between 1969 and 1996, is believed to be the increase in the concentration of atmospheric CO_2 that has occurred between the 1950s and the turn of the millennium (Figure 7-20). In 1958 the concentration of atmospheric CO_2 was approximately 314.78 parts per million by volume (ppmv), and in 2003 the concentration of atmospheric CO_2 was approximately 375.57 ppmv (Appendix 8 Table 16-1 p.271) (Keeling and Whorf 2004). Using the Sheffield Dynamic Global Vegetation Model, Bond *et al.* (2003) predict that the increase in the concentration of atmospheric CO_2 from pre-industrial levels (approximately 180 ppmv) to their current levels (approximately 370 ppmv) will cause mesic savannas to become woodier. It appears that this has occurred in the mesic savannas of the Pretoriuskop region over the past half a century. What is interesting is that the density of the woody vegetation on the Pretoriuskop EBPs did not increase that much between 1954 and 1969 (Table 7-5 and Figure 7-20). However, it did increase dramatically between 1969 and 1996 (Table 7-5 and Figure 7-20). The increase in the density of the woody vegetation between 1969 and 1996 in comparison with 1954 and 1969 is disproportionately greater than the period between 1969 and 1996 (28 years) in comparison with 1954 and 1969 (15 years). Furthermore, the density of the woody vegetation on some of the treatments in 1969 was almost the same or lower than in 1954 (i.e. August Annual, Biennial, and Triennial treatments, the Biennial April and October treatments, and Triennial February and December treatments) (Table 7-5). While, the density of the woody vegetation increased on all treatments between 1969 and 1996 (Table 7-5). The reason for the disproportionate increase in the woody vegetation between 1969 and 1996 in comparison with 1954 and 1969 is believed to be that the KNP experienced a number of drought years between 1960 and 1970 (Gertenbach 1980a, Van Wilgen et al. 2000). Between 1961 and 1971, the mean annual rainfall in KNP was 457.5mm, while between 1971 and 1981 the mean annual rainfall was 638.7mm (Van Wilgen *et al.* 2000). Furthermore, the concentration of atmospheric CO_2 increased approximately 2.9% between 1954 and 1969 (Figure 7-20) (Keeling and Whorf 2004). However, the concentration of atmospheric CO_2 increased approximately 16.0% between 1969 and 1996 (Figure 7-20) (Keeling and Whorf 2004). The greater increase in the concentration of atmospheric CO_2 between 1969 and 1996 as opposed to between 1954 and 1969 is also believed to be the reason why the density of the woody vegetation increased more between 1969 and 1996 than between 1954 and 1969.

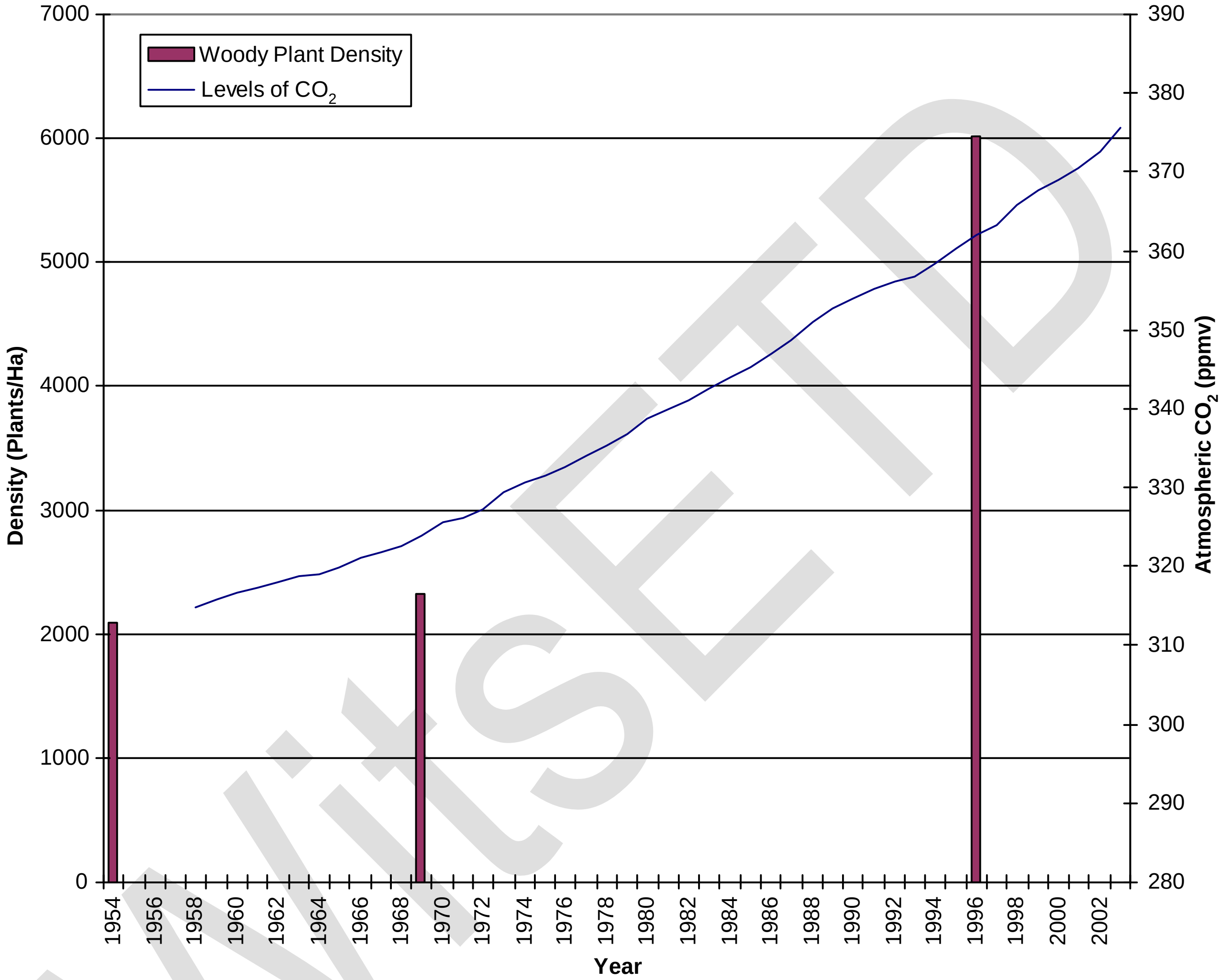

Figure 7-20: The mean density of woody vegetation (plants/Ha) on the Pretoriuskop EBPs in 1954, 1969, and 1996, and the atmospheric CO_2 concentration (ppmv) between 1958 and 2003 taken as the average annual atmospheric CO_2 concentration at 10 Scripps Institution of Oceanography (SIO) air sampling sites (Keeling and Whorf 2004). The annual average atmospheric CO_2 concentration for each SIO site is presented in Appendix 8 Table 16-1 (p.271).

Generally, the number of species and species diversity increased from 1954 to 1996, while the species evenness decreased between 1954 and 1996. Some species were dominant in 1954 and in 1996 regardless of the changes in the density of the woody vegetation that occurred, namely *Dichrostachys cinerea*, *Diospyros lycioides*, *Maytenus senegalensis*, *Pavetta schumanniana*, *Sclerocarya birrea*, *Senna petersiana*, *Strychnos madagascariensis*, *Terminalia sericea*, and *Turraea nilotica*. In 1954, *Acacia gerrardii*, *Annona senegalensis*, *Combretum molle*, *Lonchocarpus capassa*, *Mundulea sericea*, and *Parinari curatellifolia* were found to be dominant but were not dominant in 1996. In 1996, *Catunaregam spinosa*, *Euclea natalensis*, *Ochna natalitia*, and *Dalbergia melanoxylon* were found to be dominant but were not dominant in 1954. The height structure of the woody vegetation between 1954 and 1996 was similar. However, the number of single-stem individuals relative to multi-stem individuals decreased between 1954 and 1996. Generally, the structural richness, structural diversity, and the structural evenness of the woody vegetation decreased between 1954 and 1996.

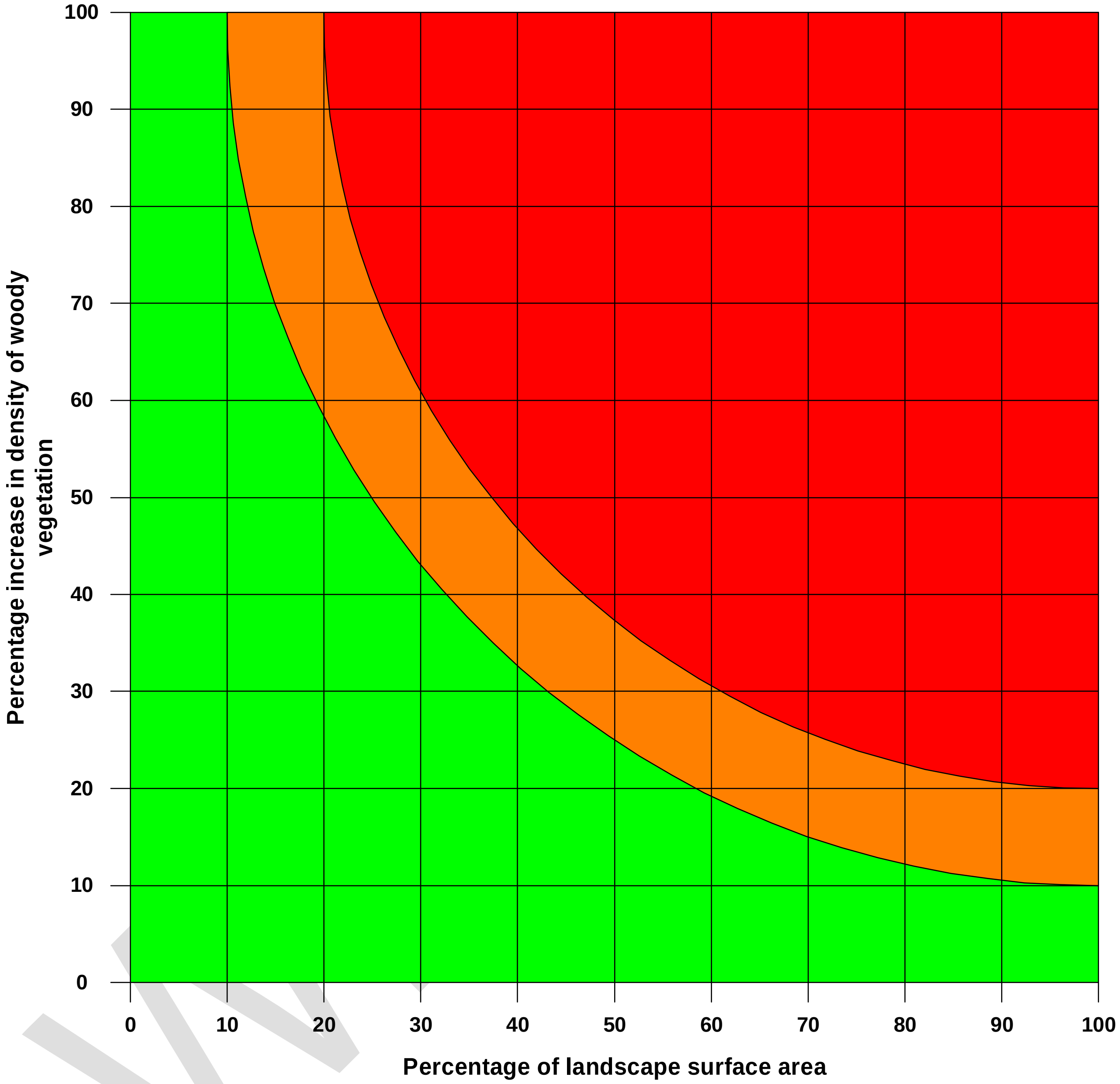

Figure 7-21: Graph showing the upper limits of the Thresholds of Potential Concern for the density (plants/Ha) of the woody vegetation within a landscape in the KNP (Provided by N Zambatis KNP Scientific Services). The colours green, orange, and red indicate the level of concern that expressed regarding the magnitude of change, namely green is ok, orange is caution, and red is potential concern.

KNP management have incorporated Thresholds for Potential Concern (TPC) into their biodiversity monitoring system. TPCs are used to identify limits in biodiversity indicators, which when exceeded signal a potential concern for the management in the KNP. Figure 7-21 models the non-linear upper limits of the TPCs related to the density of the woody vegetation. This TPC defines the upper limit of acceptable change in woody vegetation density depending on the spatial extent of that change. Looking at the green area in Figure 7-21, in any landscape in the KNP an increase in woody plant density of up to 100% is acceptable if the area in which that amount of change occurred covered less that 10% of the area of that landscape. Furthermore, for an entire landscape an increase of only 20% in the density of woody plants would be accepted before there would be cause for concern.

The point from which change in the density of the woody vegetation is measured is the earliest recorded data regarding the density of the woody vegetation in an area. In the Pretoriuskop landscape, the surveys on the EBPs in 1954 and 1996 provide data at two points in time 42 years apart. This data gives a window into the changes that have occurred in the woody vegetation over the past half a century. In Pretoriuskop, the density of the woody vegetation increased by almost 200% between 1954 and 1996. In terms of the suggested TPCs regarding the density of the woody vegetation at the landscape level, this increase in woody plant density by almost 200% would appear to raise a flag. However, the increase in woody plant density since the mid 1950s is driven by factors that are outside of the control of KNP management.

Herein lays the heart of the issue. Should the KNP management respond to this TPC red flag by making every attempt to stem the densification of the Pretoriuskop woody vegetation or should the densification process be allowed to proceed unchecked because it is driven by factors, such as atmospheric CO_2 levels, which are outside of the control of the KNP management? These are important considerations, not the least because if KNP management decided to stem the densification process then they would most certainly have to review their current approach to prescribed burning in the Pretoriuskop region. Trollope (1983) has shown that the densification of savanna ecosystems can be successfully stemmed and even reversed with the judicious use of fire at the right time and frequency. The current patch mosaic burning approach to fire management is not believed to be structured nor rigorous enough to stem the densification of the woody vegetation in the Pretoriuskop region. Furthermore, it is expected that if current patch mosaic prescribed burning approach is not adjusted, the current application of fire could result in the densification of the woody vegetation in the Pretoriuskop region being accelerated as the atmospheric CO_2 levels increase globally.