CHAPTER 4

4 Fire frequency and vegetation of Tablelands and Gorge

Landscapes have a language of their own, expressing the soul of the things, lofty or humble, which constitute them, from the mighty peaks to the smallest of the tiny flowers hidden in the meadow's grass

-- Alexandria David-Neel

4.1 Introduction

Disturbance regimes are a determinant of vegetation structure and composition (White and Pickett, 1985; Pickett and White, 1985; Graetz, 1990b; Peet, 1992). Through time, vegetation communities change in composition and structure, particularly in response to the timing, frequency and amplitude of disturbance events (Kruger, 1984; Gilbertson et al., 1985; NSW NPWS, 1995; Bowles et al., 1996). Over a short-term, disturbance events can change the composition and structure of the vegetation community. Fire is one disturbance agent that has had a long and lasting impact on the composition and structure of many Australian vegetation communities (e.g. Fox and Fox, 1986; McFarland, 1988; Fensham, 1990; Buckney and Morrison, 1992; Cary and Morrison, 1995; Morrison et al., 1995a). Inappropriate fire regimes can lead to the loss of native species, communities and ecosystems (Gill and Bradstock, 1995; Williams and Gill, 1995; Keith, 1996), and have been identified as an on-going threat to the persistence of Australian biological diversity (Saunders et al., 1998). For these reasons, changes in composition and structure are key variables of interest in fire ecology.

Vegetation studies based on long-term fire records (> 10 years) are not common. In Australia, correlative studies of the interaction between fire regimes and vegetation communities have relied on existing fire records (Cary and Morrison, 1995; Morrison et al., 1995a) or derived fire history from satellite data (Russell-Smith et al., 1997). Otherwise, studies of fires in natural ecosystems have relied on experimental burns, comparing plots known to have been burnt at different times in the past, or using the opportunity of unexpected burns to survey post-fire recovery. The most common approach has been utilising experimental burns. Generally plots have been located and surveyed before the burn, the burn is undertaken and observations made for varying periods afterwards (e.g. Purdie, 1977a; 1977b; Fox, 1988). These studies provide important information, but consider the impact of a limited numbers of fires, not a sequence of fires over longer periods. Similarly, opportunistic ecological studies have been undertaken following (often large) unplanned wildfires. These studies provide valuable information on what can be significant fires in the history of the landscape, but again, consider the impact of only one fire (e.g. Turner et al., 1994; Inbar et al., 1998). Few long-term studies covering a number of fires have been undertaken.

Of the components of the fire regime (frequency, intensity, season and type) and biotic interactions, intensity has been quite well studied (e.g. Bradstock and Myerscough, 1988; Bond et al., 1990; Moreno and Oechel, 1991; Bradstock and Auld, 1995; Ducey et al., 1996; Setterfield, 1997; Morrison and Renwick, 2000). This includes recognition of the fire intensity requirements of some species for regeneration (Chapter 5). Fire season has been less well studied, although recent investigations are showing that repeated burning at times critical to seed development can influence regeneration (Morgan, 1996; Whelan and York, 1998;

McLoughlin, 1998; Brown and Whelan, 1999). Fire frequency has been more widely studied, but in the context of TSLF and post-fire vegetation recovery (e.g. Purdie and Slatyer, 1976; Russell and Parsons, 1978; Bell and Koch, 1980; Chesterfield et al., 1990; Lunt, 1994). There is increasing evidence that fire frequency may have a significant effect on vegetation composition and structure. Studies in the Sydney region have found fire frequency may account for 60% of floristic variation in dry sclerophyll forest (Morrison et al., 1995a) attributable to time since fire and inter-fire interval. Fire frequency models have suggested that high fire frequency can lead to a reduction in ecosystem complexity with diminished diversity and structure (Noble and Slatyer, 1981; Catling, 1991). Similarly, combinations of inter-fire intervals and the interactions of the variables of fire frequency, NOF and TSLF, are less widely studied, but have been shown to have significant influence on floristic composition (Cary and Morrison, 1995; Morrison et al., 1995a) with repeated short inter-fire intervals (1-3 years) causing radically different community composition (Cary and Morrison, 1995).

This study aimed to determine whether the components of fire frequency (NOF, SIFI and TSLF) affected the composition and structure of woody trees and shrubs in northern NSW. The null hypothesis that fire frequency has no effect on vegetation composition and structure was tested by:

(1) Investigating whether aspects of fire frequency (e.g. NOF, SIFI and TSLF) have affected woody composition or structure in the Tablelands and Gorge regions of GFRNP;

(2) Investigating whether fire frequency has affected ground cover;

(3) Identifying ranges or domains of fire frequency that optimise floristic abundance and habitat complexity.

The results are discussed in light of potential future fire management goals.

4.2 Method

The study region is described in Chapter 2. Due to the sharp physiographic and geological contrasts between the Tablelands and Gorge area, the study focused initially on these two areas independently. In each area, the aim was to select a range of sites that varied in fire frequency categories, but were otherwise similar. In this way, the variation in vegetation between sites would largely reflect differences in the fire frequency categories, rather than physical environmental factors.

4.2.1 Fire frequency data stratification

The fire frequency stratification was undertaken with data on NOF, SIFI and TSLF (the fire history data derived in Chapter 3). These data were grouped into categories of low, moderate and high and the selection of study sites was undertaken within these categories.

The Tablelands survey was restricted to an area of approximately 5 x 5 km incorporating the area of highest NOF in the whole study region. In this area, the NOF ranged from zero to eight mapped fires over 25 years. The NOF was divided into categories of 'low' (no recorded fires), 'moderate' (2-4 fires in 25 years) and 'high' (≥ 6 fires in 25 years). All of the defined categories for NOF, SIFI and TSLF are relative to those recorded in the GFRNP fire history, these terms are not relative to other areas.

The SIFI varied from 1-26 years. Re-occurring fires on the time-scale of 1-2 years have been found to be linked to species decline (e.g. Bradstock et al., 1997), so 1-2 years was chosen for the 'short' category in SIFI. All the areas of high NOF had a lowest SIFI of one year. A 10-year fire interval has been suggested as an appropriate time period for post-fire regeneration of *Allocasuarina* plants (Ross Bradstock, pers. comm., in Reid et al., 1996). A period of 10-25 years was selected as the 'long' category in SIFI. However, in the areas of high NOF, there were no areas with a SIFI greater than 10 years. Areas with no recorded fires were categorised as having a very long (> 25 years) SIFI.

A large fire that occurred in October 1994 in the Tablelands survey area dominated the TSLF category. The classes were therefore divided into 'very long' (> 25 years) and 'short' (3-4 years). No area was found to have a TSLF between 4-25 years so this category was not used. The 'very long' were those areas where no fires were detected. The possible combinations, and final surveyed combinations of NOF, SIFI and TSLF for the Tablelands are shown in Table 4.1. As this study was a non-manipulative natural experiment, not all of the categories occurred in the survey area.

Table 4.1. The combinations of number of fires, shortest inter-fire interval and time since last fire for fire categories in the Tablelands vegetation. The combinations are given in the final row in bold. The number in parentheses for number of fires is the number of mapped fires, for shortest inter-fire interval is the number of years between each fire, and time since last fire is the number of years since the last mapped fire. Crosses indicate categories that did not occur.

Number of fires (NOF)	Low (0)	Moderate (2-4)		High (≥ 6)	
Shortest inter-fire interval (SIFI)	Very Long (> 25)	Short (1-2)	Long (10-25)	Short (1-2)	✗
Time since last fire (TSLF)	Very Long (> 25)	Short (3-4)		Short (3-4)	
Final categories	**Low-Long-Long**	**Moderate-Short-Short**	**Moderate-Long-Short**	✗	**High-Short-Short**

Similarly, fire categories in the Gorge were based on the NOF, SIFI and TSLF data derived in Chapter 3. In the Gorge there were no significant patches of high or low NOF, with the majority of areas having a moderate NOF of between two and four fires over 25 years. The NOF categories were 'low' (no recorded fires) and 'moderate' (2-4 fires in the study period). The SIFI was divided into 'short', 'long' and 'very long' categories. The 'short' category was between one and three years as the shortest interval recorded between fires in the 25-year history. Compared to the Tablelands, this was one year longer in order to have enough areas available to survey. The 'long' category was 10-25 years, as in the Tablelands. The 'very long' category was greater than 25 years, and included areas where no fire had been detected. Time since last fire was divided into the categories of 'short' (≤ 5 years), 'long' (10-25 years) and 'very long' (> 25 years), where again, 'very long' included those areas where no fire had been detected. There were five final fire categories in the Gorge (Table 4.2). The Tablelands and Gorge fire categories are compared in Table 4.3.

Fire categories are referred to using the fire category names given in Table 4.3, based on the sequence of NOF, SIFI and TSLF. For example, a site with a 'moderate-short-long' fire history (abbreviated to MSL) has a 'moderate' NOF (M), 'short' SIFI (S) and 'long' TSLF (L). Similarly, the 'high-short-short' or HSS fire category has a 'high' NOF (H), 'short' SIFI (S) and 'short' TSLF (S). For simplicity, the sites where no fires were detected (low-very long-very long) were referred to as Low-Long-Long (LLL). The fire categories and acronyms will be used throughout this and subsequent chapters so are summarised in Appendix 1.1.

Table 4.2. The combinations for fire frequency categories used in the Gorge. The number in brackets for the number of fires is the number of mapped fires, for the shortest inter-fire interval is the number of years between each fire and for the time since last fire is the number of years since the last mapped fire. The final categories are given in bold.

Number of fires (NOF)	Moderate (2-4)				Low (0)
Shortest inter-fire interval (SIFI)	Short (1-3)		Long (10-25)		Very long (> 25)
Time since last fire (TSLF)	Short (≤ 5)		Long (10-25)		Very long (> 25)
Final categories	**Moderate-Short-Short (MSS)**	**Moderate-Short-Long (MSL)**	**Moderate-Long-Short (MLS)**	**Moderate-Long-Long (MLL)**	**Low-Long-Long (LLL)**

Table 4.3. Comparison of fire categories between the Tablelands and Gorge. ✗ indicates combinations that do not occur.

	Tablelands	Gorge
Fire categories	Low-Long-Long	Low-Long-Long
	✗	Moderate-Long-Long
	Moderate-Long-Short	Moderate-Long-Short
	✗	Moderate-Short-Long
	Moderate-Short-Short	Moderate-Short-Short
	High-Short-Short	✗
Categories	Tablelands	Gorge
Number of fires	Low (0)	Low (0)
	Moderate (2-4)	Moderate (2-4)
	High (≥ 6)	
Shortest inter-fire interval	Short (1-2)	Short (1-3)
	Long (10-25)	Long (10-25)
	Very long (> 25)	Very long (> 25)
Time since last fire	Short (3-4)	Short (≤ 5)
	✗	Long (10-25)
	Very long (> 25)	Very long (> 25)

4.2.2 Environmental data stratification

Changes in topography, parent material, drainage and soil affect the structure and species composition of vegetation (Specht, 1970). Site selection aimed to identify and constrain environmental variation within the survey areas. Digital data were compiled for the physiography, elevation, geology (parent material), mean annual rainfall, mean annual temperature and incoming solar radiation.

The physiographic regions were derived from data on slope and elevation and divided into three categories (1) the Tablelands (high elevation, low slope), (2) the Gorge (low and high elevation, with high slope) and (3) the valley floor (low elevation, low slope). The Tablelands component of the study was constrained to category 1 and the Gorge component to category 2. The elevation data were supplied by NSW NPWS and consisted of a DEM with 25 m grid cells. The slope data were derived from the DEM.

The geology data were compiled from the Dorrigo-Coffs Harbour (SH 56-10 & 11) and Grafton (SH 56-6) sheets from the 1:250 000 Australian geological map series (Geological Survey of NSW, 1969a; 1969b). The data were obtained from NSW NPWS who had converted the hardcopy maps to digital data. The main geological types in the study region included metasediment, granite and basalt. The two dominant rock types occurred in combination with the physiographic regions, with granite occurring predominantly on the Tablelands and metasediment mainly on the slopes in the Gorge. The stratification, therefore, separated these two geology types within the constraints of the physiographic regions of the Tablelands and Gorge.

Digital data on the mean annual rainfall had been derived from weather station data interpolated with a DEM and was available from NSW NPWS. The data were classified into low (628-800 mm), moderate (801-1000 mm), high (1001-1200 mm) and very high (> 1200 mm) rainfall categories. Digital data for mean annual temperature were obtained from NSW NPWS. The data were classified into low (< 12°C), moderate (12-15°C) and high (> 15°C) temperature categories.

Digital data for incoming solar radiation derived from the DEM were obtained from NSW NPWS. The data measured the amount of solar radiation received at any point on the ground, adjusted for mountainous terrain (Nunez, 1980). The method combined factors such as slope and aspect with adjustments for shadowing from neighbouring features. The units for solar radiation are mega joules per square meter per day ($MJm^{-2}day^{-1}$). A high value represents an exposed area and a lower value a less exposed area, generally a south or southeast facing slope. The data were classified into categories of low (13500-15250), moderate (15251-20500) and high (> 20500). The data will be referred to as the topographic index.

4.2.3 Site selection

The fire categories and environmental data were combined in a GIS. For each fire category, five sites in discontinuous polygons and of similar physical environment were randomly selected in each of the Tablelands and Gorge areas. Due to the large number of combinations of physical variables (environmental strata) a hierarchy within the variables was developed.

Where possible, sites within the required fire categories were selected and constrained within one environmental stratum. If it was not possible to select five discontinuous sites, the environmental variable at the bottom of the hierarchy (level 5) was relaxed and the remaining sites selected, keeping the remaining environmental variables constant. The hierarchy of environmental variables is shown in Table 4.4, with level one the highest priority. For example, in the Tablelands study area, having selected the required fire category, suitable sites were sought on granite substrate, with high rainfall, moderate temperature and moderate incoming solar radiation. If five or more sites could not be found, sites were selected with all of the above features but with low or high incoming solar radiation. The final range of states is given in Table 4.5. The aim was to have five replicate sites in each fire category. In one fire category on the Tablelands and one in the Gorge, it was difficult to locate the required number of replicates even within the hierarchical framework. This was due to a lack of suitable areas that satisfied the required conditions without pseudo-replicating (Hurlbert, 1984; Heffner et al., 1996). Therefore, in the Tablelands the moderate-long-short (MLS) fire category had only four sites, and in the Gorge the moderate-short-long (MSL) category had only three sites.

Table 4.4. Hierarchy of environmental variables

Level	*Environmental variable*
1	Physiography
2	Geology
3	Rainfall
4	Temperature
5	Solar radiation

Table 4.5. Stratification states selected for the Tablelands and Gorge. The range in parentheses is the final range used.

Environmental variable	Gorge states	Tablelands states
Physiography	Gorge, slope steep (> 20°)	Tablelands, slope flat (< 15°)
Geology	Metasediment	Granite
Annual rainfall (mm/annum)	Moderate to high (801-1200)	High (1001-1200)
Average annual temperature (°C)	Moderate to high (12-18)	Moderate (12-15)
Incoming solar radiation ($MJm^{-2}day^{-1}$)	Low to high (≥ 13500)	Moderate to high (> 15250)

Within each survey area, sites were randomly located and where possible, at least 50 m away from the polygon boundary. Random placement in the site selection was required in order to maintain the requirement for randomness of replication in the statistical analysis (Fry, 1993). The random function in the ARC/INFO GRID GIS software was used to specify the upper and lower limit of the polygon and a point within this location was randomly generated. This became the proposed site location. In the field, a Global Positioning System (GPS) was used to get as close as possible to the proposed site. In the Gorge there were many difficulties accessing the proposed sites. If access was not possible, the location was made as close as possible to the proposed site, but still within the selected polygon. Once the location was established, the centroid of the site was placed using a random northeast walk to remove any unconscious bias in the site selection. A random number table was used to generate two values between 1 and 10. The first number was the number of paces taken north and the second number was the number of paces east, at which the steel post making the centroid of the site was placed. This method has been used in other site selection processes for soil sampling (D. O'Connell, pers. comm.). As this study was focused on woody trees and shrubs in a predominantly open-forest habitat, the size of the site was set at a suitable size for this type of vegetation (0.1 hectare (ha)) (Gilbertson et al., 1985).

4.2.4 Site sampling

At each site the centre was marked with a 1.8 m steel stake. A GPS was used to record the location of the centre stake. Four 22.6 m tapes were run out along the four compass bearings and an outside string used to mark a 0.1 hectare area (Figure 4.1). A description was made of the environmental characteristics and observed fire patterns. This included a written description of how to locate the site from known physical features. Although each site was well marked with a steel stake, flagging tape and a GPS reading, a location description was also made in case these features went missing. A map of the location of the sites is shown in Figure 4.2. The Tablelands sites are the 19 sites clustered in the east, and the remaining 24 sites are scattered through the Gorge.

The physiography of the site was recorded using the categories of plateau, middle, lower or upper slope, flats or valley bottom. The altitude of the site was taken from the 1:25 000 topographic map sheet based on the GPS location. The other features recorded were slope (using a clinometer), aspect (to the nearest 5°), topography and surface soil texture. A photographic record was made of each site along either the east-west or north-south tapes through the centre stake.

Evidence of disturbance, clearing, logging, grazing, erosion, feral animals, mining or fire was recorded. For fire, the amount of charcoal in the soil and the amount of blackened fallen timber were recorded in categories of high, moderate or low. Scorch height was measured as a surrogate for fire intensity as used for mapping fire severity (Kitchin et al., 1998). Scorch height was recorded as the highest level at which a prominent burn mark could be observed.

Height and total percentage foliage cover, assuming a non-opaque crown, of the overstorey, mid-storey and substratum was recorded for each site.

Figure 4.1. Centre of the site (steel marking post) with four tapes running along the compass axes setting out site layout, in an HSS Tablelands site.

4.2.5 Sampling methods

The overall aim was to measure composition and structure. Species composition was measured as each unique tree and shrub species in the quadrat. Density, the total number of individuals of each species found in the site, was recorded as a measure of species abundance. Plant structure was measured as the height and diameter of each species and overall community structure measured as the average for each height class.

Plant frequency and density are common measures of plant abundance, and cover is a measure of plant cover within the area. Frequency, measured in a nested-quadrat arrangement, has been used for vegetation studies and in Gorge systems on the Northern Tablelands (Gross and Pisanu, 1996; Clarke et al., 1997). The nested-quadrat approach has been found to be a better predictor of density than the standard frequency method (Morrison et al., 1995b). Plant cover, was defined as the area of the site occupied by the above ground parts of a plant (Gilbertson et al., 1985). Only those species rooted in the site were counted.

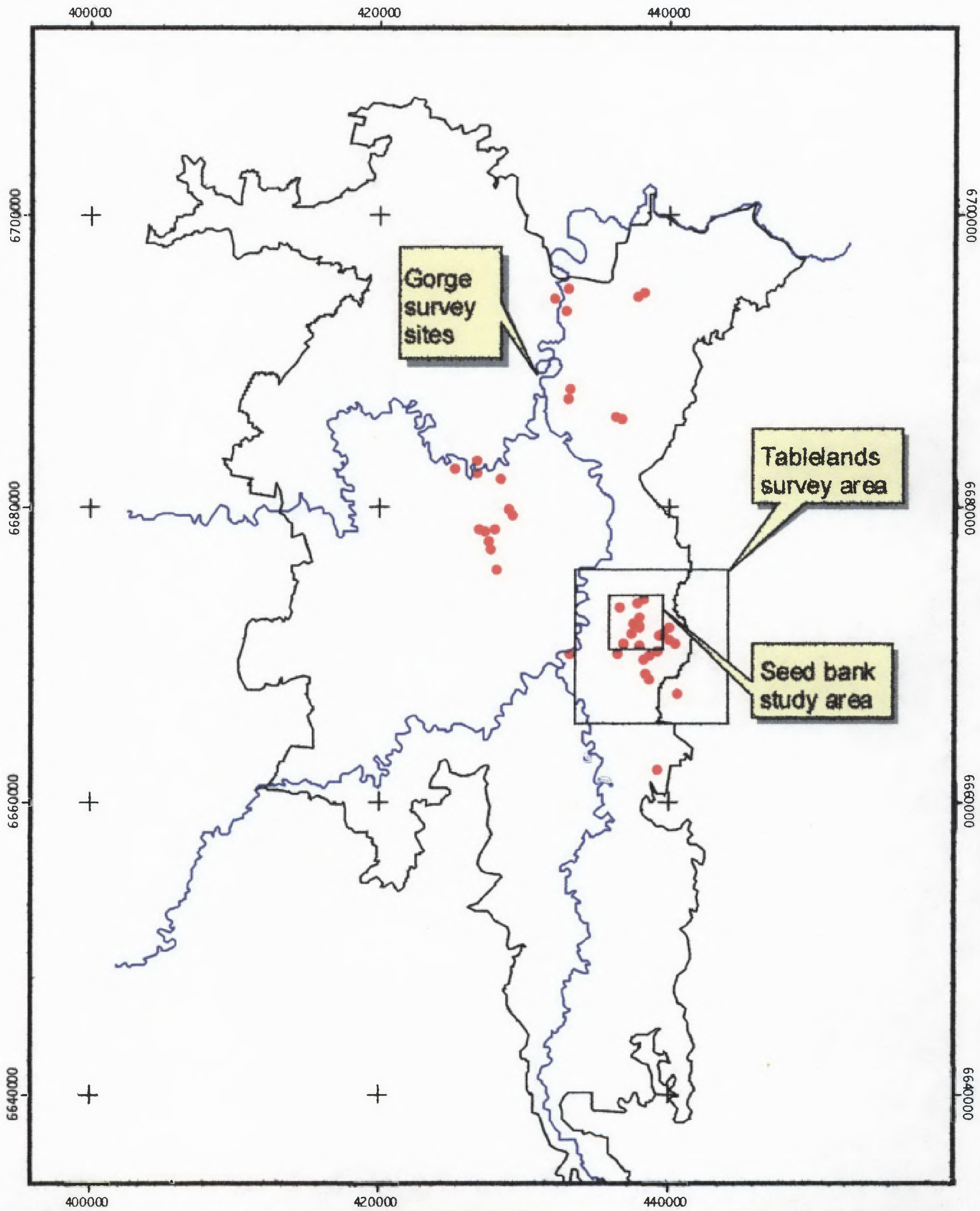

Figure 4.2. Location of vegetation survey sites for the Tablelands (large box), Gorge (other) and the soil seed bank study (small box).

Hydrology
Study region
Vegetation survey sites

0 8 16 24 Km

A 0.1 hectare quadrat was used to measure the density of all woody shrub and tree species. Density was measured in preference to the two other common measures of abundance, frequency and plant cover. Plant structure was measured using height and diameter at breast height over bark (DBH) of each plant of 2 m or more high. For all species less than 2 m, only height was recorded. For the smallest reproducing individual on the site, the diameter at the base was measured. The aim was to measure the smallest size at which a species could reproduce after burning. Any flowering or fruiting structures on the plant was recorded. Regenerative structures such as basal swellings, sprouts from dead adults or epicormic growth were noted for evidence of post-fire regenerative methods. Plant cover of the site was measured through a visual estimate of the amount of area covered by the canopy of the plant over the site.

Dominant herbaceous cover was recorded in ten 1 m^2 plots randomly located in the site. In each site the percentage cover of all species was recorded as well as rock and leaf litter cover. Unidentified species were collected and identified in the laboratory.

4.2.6 Data analysis

The data were analysed separately for the Tablelands, the Gorge and then combined over the study region. For all woody tree and shrub species the mean density and standard error of the mean (SE) was calculated. The classification of adult tree or shrub followed that of McDonald et al. (1990) where 'tree' was defined as a woody plant more than 2 m tall with a single stem and branching well above the base. A 'shrub' was defined as a woody plant that was multistemmed at the base (or within 200 mm of the ground) or, if single-stemmed, less than 2 m tall. These classifications were applied to the adult tree or shrub and juvenile plants of the adult were subdivided by size for plant structural analysis into low (≤ 2m), medium (2-10 m) and tall (> 10m) classes.

In both physiographic regions, two types of analysis were undertaken. Where species were found in five or more sites (designated "common species"), a univariate multiple regression on plant density with the fire and environmental variables was undertaken. This was used to assess direct correlations between fire frequency and the common species. Where species occurred in two sites or more a multivariate analysis was undertaken to assess overall patterns and investigate relationships between many species sampled and all of the environmental variables.

Univariate analysis

Multiple regressions were used to analyse the density, mean height and mean diameter of the most common species with the fire (NOF, SIFI and TSLF) and environmental variables. The environmental variables were elevation, slope, aspect, rainfall and the topographic index. The more common species were those that occurred in five sites or more in either physiographic region. For all species, except for *Hibbertia obtusifolia* and *Breynia oblongifolia* in the Gorge, the data were natural-log transformed prior to the analysis due to skewed data distribution.

The regression technique used was a forward step-wise multiple regression. This method has been used in other studies on habitat use (Haering and Fox, 1997). Forward stepwise multiple-regression individually adds the independent variables, at each step of the regression, until the 'best' regression model is obtained. Multiple regressions were used to determine relationships between variables, and to isolate the smallest set of predictor variables that contributed to explaining the measured variance.

For most regression methods at least ten times as many observations are required as there are variables, otherwise the estimates of the regression can be unstable and unlikely to be repeated if one were to re-do the study (StatSoft, 1995). Unfortunately this limitation could not be overcome in this study. The number of sites (42) was limited by the time and resources available to collect data in a study region with severe access limitations. Regression analysis was used to identify species response, but the limitation of few sites and many variables was borne in mind when interpreting the results.

On the Tablelands, the species tested were *Acacia falciformis, A. irrorata, A. melanoxylon, Allocasuarina littoralis, Bursaria spinosa, Eucalyptus caliginosa, E. campanulata, E. nobilis, E. saligna, Hibbertia obtusifolia, Leucopogon lanceolatus, Leptospermum polygalifolium, Lomatia silaifolia, Persoonia oleoides, Pimelea linifolia, Polyscias sambuccafolia, Olearia oppositifolia* and *Ozothamnus diosmifolius*. In the Gorge, the species tested were *Acacia melanoxylon, Angophora subvelutina, Allocasuarina torulosa, Breynia oblongifolia, Exocarpos cupressiformis, Eucalyptus biturbinata, E. crebra, E. eugenoides, E. microcorys, E. tereticornis, Hibbertia obtusifolia, Jacksonia scoparia, Lotus australis, Lespedeza juncea* and *Maytenus silvestris.*

Overall species richness and abundance were calculated for each fire category and assessed using analysis of variance (ANOVA). The abundance data were log-transformed to stabilise the variance.

Multivariate analysis

Species composition, using density as the variable for each species, in relation to all the fire and environmental variables, was studied using multivariate ordination techniques. Univariate methods such as generalised linear modelling can be used to study individual species and their responses to many environmental variables (Austin et al., 1984). However, separate regression equations for each individual species fail to identify groups of species that respond in a similar manner or patterns evident in the whole community. Ter Braak (1986) noted that when the number of species is large, separate regression analyses can be impractical and separate analyses cannot be easily combined to provide an overview of how community composition varies with many environmental variables. Multivariate ordination also provided statistical techniques for the study of variables in data that contain intercorrelations (Ter Braak, 1986). As this study aimed to look at species composition and many environmental variables, multivariate approaches were appropriate.

Ordination is a multivariate technique that orders vegetation or samples along axes that represent the main gradients in the data. Ordination is divided into two methods: constrained (direct gradient analysis) and unconstrained (indirect gradient analysis). In unconstrained ordination, the axes are computed iteratively and are interpreted *a posteriori* using other, usually environmental data. In constrained ordination, an additional multiple regression step is added to the interpretation process so the ordination is constrained to linear combinations of environmental variables (Økland, 1996). In this study, unconstrained ordination (detrended correspondence analysis (DCA)) was initially used to identify the appropriate constrained ordination technique (canonic correspondence analysis (CCA) or detrended canonic correspondence analysis (DCCA)) for the data structure. The constrained ordination technique was then used to relate the fire and environmental variables to the plant density data.

Within the range of constrained ordination approaches there are choices of techniques based on whether the species' response curves in the data are linear or unimodal (Gaussian). Linear response models (e.g. CCA) are recommended where the abundance of species increase or decrease with the value of each of the environmental variables. Unimodal response models (e.g. DCCA) are recommended for species that occur across a limited range of environmental variables (Ter Braak, 1995). Only a few of the species recorded in this study occurred over the full range of fire frequency categories, suggesting a unimodal model was more appropriate. Ter Braak and Smilauer (1988) recommended that if the data gradients are long (> 4 standard deviations [SD] along the axes), unimodal techniques are appropriate, and if the gradients are short (< 3 SD) linear techniques are recommended. As recommended, in this study a DCCA was used when the data gradients were longer than four standard deviations.

The second ordination axes can become correlated with the canonic axes with long gradients, causing an arching effect in the data. The potential arch effect can occur in strongly binomially distributed data (Ter Braak, 1995).

The environmental data tested in the analysis were rainfall and the topographic index (CTI) derived from the DEM as described in the stratification section; slope and aspect measured at the sites and elevation recorded from 1:25 000 topographic maps.

Interpretation of the correlations between the vegetation and environmental data was made from the species-environment correlations, the eigenvalues and the species biplot. The vegetation-environment correlations are a measure of the strength of the relationship between vegetation and environmental variables for a particular axis (Ter Braak and Smilauer, 1988). The eigenvalues measure the variation in the plant data as explained by the axes (Ter Braak, 1995). The biplot is an approximation of the relative abundance of species and environmental variables from which one can infer fire and environmental effects using the direction of species change with each variable, for groups of plants in the vegetation community.

The interpretation of the ordination axes was assessed from canonical coefficients and intraset correlations. Canonical coefficients are the partial regression coefficients from the multiple regressions of the site scores on the environmental variables. They define the ordination axes as linear combinations of the environmental variables. Intraset correlations are the correlation coefficients between the environmental variables and the ordination axes (Ter Braak, 1986). The sign and relative magnitude of the canonical coefficients and intraset correlations describe the relative importance of each environmental variable for predicting community composition and species abundance. However, the canonical coefficients have been found to be unstable when the environmental variables are strongly correlated (Ter Braak, 1986). As the fire variables were correlated, the intraset correlations and biplot were predominantly used for interpretation.

The analysis was undertaken for the Tablelands and Gorge data sets separately and then the density data for the two data sets combined. The data were log-transformed prior to the analysis due to left-skewed data distributions. The options of inter-species distance and biplot scaling (Ter Braak and Smilauer, 1988) were selected. The statistical significance of each of the fire and environmental variables and their ranked importance for determining species abundance was undertaken using forward selection. Forward selection is the CANOCO-equivalent variable selection routine usually performed with multiple regression (e.g. Montgomery and Peck, 1982). It was used to determine the statistical significance of individual environmental variables. The forward selection process is a sequence where each variable that adds most to the explained variance of the species data is selected and tested (Ter Braak and Smilauer, 1988). The LambdaA variable indicated the additional variance each variable explained at the time it was included in the process. The variables were considered significant (at the 5% level) if the P-value was less than or equal to 0.05. Monte-Carlo permutation tests were used to assess the significance of each of the variables separately. The Monte-Carlo permutation is a mathematical test of statistical significance obtained by repeatedly shuffling (permutating) the samples (Ter Braak and Smilauer, 1988). The P-value was used to determine the significance of the variable in explaining the variance, based on the test statistic (F-value).

Constrained ordination techniques become less constrained as the number of environmental variables increase. If the number of environmental variables is 1 less than the number of samples, then the analysis becomes unconstrained (Ter Braak and Smilauer, 1988). Superfluous environmental variables were removed from the analysis as this also avoided the possibility of trending in the data or the 'arch' effect (Ter Braak, 1995). To maintain the smallest number of significant variables temperature was removed from the analysis in the Gorge due to the high correlation of temperature and elevation. Due to observations in the field and confirmation in the exploratory data analysis that the LLL sites had experienced recent (< 25 years) fire, the sites in the LLL category in the Gorge and site 2 in the Tablelands, were removed from the analysis.

Plant structure

The impact of the fire variables on plant height and diameter in the Tablelands was tested using multiple regressions. The mean height per site was calculated and a multiple regression analysis undertaken of mean height of each of the 18 common species. The forward-selection approach was used and significant variables identified for each species.

The broad vegetation community structural differences between fire categories were tested using analysis of variance (ANOVA). The mean height of all the shrubs and trees surveyed in three height classes for each of the fire categories, were tested for significant differences using one-way ANOVA. The height classes were: low (≤ 2m), medium (2-10 m) and tall (> 10m). All of the classes were tested prior to analysis for normality using the Shapiro-Wilks test. All classes except for the trees greater than 10 m required a log transformation to normalise the distribution.

Ground cover

The dominant herbaceous cover over the ten random 1 m^2 subplots for non-woody plant species, including grasses, herbs and sedges, was analysed using canonic correspondence analysis for both Tablelands and Gorge data sets. The intraset correlation coefficients were used to assess the significance of each of the canonical axes. The forward-selection option in CANOCO was used to assess the strength of the fire variables in explaining the overall data variance. The site and species biplot was used to identify patterns in relation to each of the fire frequency categories.

4.3 Results

4.3.1 Tablelands woody tree and shrub composition

The Tablelands vegetation survey sampled 19 sites in four fire categories. This included five sites in the 'low-very long-very long' (LLL), 'moderate-short-short' (MSS) and 'high-short-short' (HSS) fire categories and four sites in the 'moderate-long-short' (MSL) fire category. In total 74 woody shrub and tree species were sampled on the Tablelands (5 only to genus).

The number of Tablelands woody tree and shrub species decreased with increasing fire occurrence. Of the species sampled, 55% had a propensity for only one fire category and of these, the majority (56%) occurred in the LLL sites. These sites were the most diverse in species composition, including *Cryptocarya rigida*, *Notelea longifolia*, *Melicope elleryana* and *Pittosporum revolutum*, species often associated with wet sclerophyll forests. In the MLS category, 27% of the species sampled were unique to that category, and 5% and 12% in the MSS and HSS categories respectively. The species unique only to the HSS category were all eucalypts. The species that occurred only in one fire category are listed in Table 4.6.

Table 4.6. Mean densities (± SE) of species surveyed in the Tablelands occurring in only one fire category with the mean and standard error of the mean (± SE) for each species in each fire category. Species are sorted by decreasing mean density within the fire category. LLL = Low number of fires, long shortest inter-fire interval and long time since last fire, MLS = moderate number of fires, long shortest inter-fire interval and short time since last fire, MSS = moderate number of fires, short shortest inter-fire interval and short time since last fire and HSS = high number of fires, short shortest inter-fire interval and short time since last fire.

	LLL		**MLS**		**MSS**		**HSS**	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Gonocarpus oreophilus	263.00	0.00						
Cryptocarya rigida	177.00	0.00						
Exocarpos strictus	91.00	0.00						
Rhodamnia rubescens	89.00	0.00						
Acacia filicifolia	51.00	29.73						
Eucalyptus cameronii	49.50	27.51						
Eupomatia laurina	45.00	0.00						
Notelea longifolia	35.00	0.00						
Eucalyptus laevopinea	27.00	0.00						
Santalum obtusifolium	25.00	19.10						
Eucalyptus obliqua	20.50	11.70						
Angophora subvelutina	19.00	0.00						
Bursaria longisepala	14.00	0.00						
Hakea micranthus	12.00	0.00						
Melicope elleryana	11.00	0.00						

Pimelea curviflora	9.00	0.00						
Pimelea ligustrina	8.00	0.00						
Eucalyptus williamsiana	6.00	0.00						
Breynia oblongifolia	5.00	0.00						
Hibbertia aspera s.l.	5.00	0.00						
Physalis sp.	5.00	0.00						
Senecio amygdalifolius	3.00	0.00						
Pittosporum revolutum	2.00	0.00						
Podolobium ilicifolium			290.00	0.00				
Platysace lanceolata			123.00	0.00				
Notelea sp. A			29.00	0.00				
Acacia stricta			9.00	0.00				
Acacia ulicifolia			7.50	1.06				
Exocarpos cupressiformis			5.00	0.00				
Senecio quadridentatus			3.00	0.00				
Solanum sp.			2.50	0.35				
Callistemon sp.			2.00	0.00				
Monotoca scoparia			2.00	0.00				
Hovea lanceolata			1.00	0.00				
Callistemon salignus					21.00	0.00		
Acacia implexa					2.00	0.00		
Eucalyptus melliodora							10.00	2.21
Eucalyptus bridgesiana							8.67	0.00
Eucalyptus sp. *(stringy bark)*							8.00	0.00
Eucalyptus sp. *(gum)*							4.33	0.00
Eucalyptus amplifolia							3.00	4.01

Seven of the species occurred in all fire categories. These (*Leptospermum polygalifolium, Leucopogon lanceolatus, Allocasuarina littoralis, Eucalyptus caliginosa, E. nobilis, E. campanulata* and *Persoonia oleoides*) were generally common and abundant throughout the Tablelands. Most of these species tended to have higher mean density in a certain fire category (Table 4.7). For example, *Leptospermum polygalifolium* and *Leucopogon lanceolatus* had highest mean density in the LLL and MSL sites decreasing to very few stems in the sites of higher NOF. *Eucalyptus campanulata* and *Persoonia oleoides* preferred the mid-range fire categories. The remaining species surveyed occurred in two or three fire categories (Table 4.8).

Table 4.7. Species surveyed in the Tablelands occurring in all fire categories with the mean and standard error of the mean (± SE) for each species in each fire category. Species are sorted by decreasing mean density within the LLL fire category. See Table 4.6 for fire category definitions.

	LLL		MLS		MSS		HSS	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Leptospermum polygalifolium	454.50	275.43	167.00	0.00	2.00	0.00	3.00	0.00
Leucopogon lanceolatus	155.00	71.33	33.75	11.98	30.80	12.33	5.00	1.18
Allocasuarina littoralis	104.50	23.08	183.00	105.20	31.50	21.43	326.00	0.00
Eucalyptus caliginosa	44.67	9.21	31.00	21.75	78.40	10.28	25.80	6.80
Eucalyptus nobilis	38.00	4.43	9.00	5.66	9.67	5.18	14.67	2.88
Eucalyptus campanulata	5.33	2.29	896.00	148.89	169.00	52.80	5.00	0.00
Persoonia oleoides	4.33	0.52	11.00	1.73	31.80	6.81	1.00	0.00

Table 4.8. Species surveyed in the Tablelands vegetation survey and occurring in 2 or 3 fire categories, with mean (± SE) for each fire category. See Table 4.6 for fire category definitions.

	LLL		MLS		MSS		HSS	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Jacksonia scoparia	26.50	16.13			1.25	0.22	7.00	0.00
Eucalyptus microcorys	19.67	6.94	28.67	19.64			10.00	0.00
Acacia irrorata	12.50	3.40	159.50	112.08	65.67	38.29		
Acacia melanoxylon	10.33	6.85	36.50	25.10	25.00	17.06		
Eucalyptus saligna	10.25	3.60			4.00	0.77	3.50	1.58
Pimelea linifolia	8.80	1.16			97.00	0.00	34.50	18.70
Lomatia silaifolia	5.00	1.26	29.00	5.63	25.00	0.00		
Eucalyptus brunnea	4.00	0.00	67.00	0.00	7.00	0.00		
Bursaria spinosa	2.00	0.00			19.00	7.60	2.00	0.63
Hibbertia obtusifolia			20.00	0.00	43.00	28.73	35.50	45.96
Ozothamnus diosmifolius			55.00	115.42	6.00	4.24	2.00	0.00
Indigofera australis	163.00	0.00	10.50	6.72				
Polyscias sambuccifolia	37.67	13.66	16.00	7.26				
Acacia falciformis	29.00	3.79	1087.00	568.97				
Banksia integrifolia	22.50	2.21			2.00	0.00		
Goodia lotifolia	18.33	9.55	253.00	0.00				
Lespedeza juncea	15.00	0.00					10.00	0.00
Phyllanthus gunnii	10.50	4.11			4.00	0.00		
Solanum stelligerum	7.00	0.00			4.50	0.95		
Maytenus silvestris	4.00	0.00	43.00	28.28				
Olearia oppositifolia	3.00	1.26	7.00	2.83				
Pultenaea microphylla	2.00	0.00			6.00	0.00		
Eucalyptus dorrigoensis	1.00	0.00	2.00	0.00				
Eucalyptus retinens			147.33	78.71	29.00	0.00		
Melichrus urceolatus			1.50	0.35	7.00	3.13		
Eucalyptus dalrympleana					15.00	0.00	23.00	7.03

Of the 18 most common Tablelands species analysed with multiple regressions, 10 were significantly related ($P < 0.05$) to the fire or environmental variables, and seven of these included at least one of the fire variables in the final regression model (Table 4.9). Species where other variables were significant include *Acacia faciformis* (elevation and temperature), *A. irrorata* (slope), *Bursaria spinosa* (slope, compound topographic index), *Lomatia silaifolia* (elevation), *Leucopogon lanceolatus* and *Persoonia oleoides* (rainfall). Species that were not related to the measured variables were *Acacia melanoxylon, Allocasuarina littoralis, Eucalyptus caliginosa, E. nobilis, Leptospermum polygalifolium* and *Ozothamnus diosmifolius*. Species that were significantly related to at least one of the fire variables were *Pimelea linifolia* (NOF), *Polyscias sambuccafolia, Olearia oppositifolia, Hibbertia obtusifolia* (SIFI), *E. campanulata* and *E. saligna* (TSLF). The density of the majority of species analysed were decreasing with increasing NOF and decreasing SIFI (*Acacia faciformis, A. irrorata, A. melanoxylon, Eucalyptus campanulata, E. saligna, Leucopogon lanceolatus,* *Leptospermum polygalifolium, Lomatia silaifolia, Olearia oppositifolia* and *Polyscias sambuccafolia*). *Allocasuarina littoralis* and *Persoonia oleoides* were decreasing in density with increasing NOF but increasing SIFI. Six species were increasing in density with increasing NOF, with *Bursaria spinosa, Eucalyptus caliginosa, Hibbertia obtusifolia, Ozothamnus diosmifolius* and *Pimelea linifolia* decreasing with increasing SIFI and *E. nobilis* increasing with increasing interval.

The overall species richness for each of the fire categories increased with decreasing NOF and increasing length of the SIFI (Figure 4.3). There was a significant difference ($F_{3,15} = 9.16$, $P < 0.001$) between the fire frequency categories and woody species richness when tested using ANOVA. This was primarily due to the high species richness in the LLL sites reflected in the differences between the HSS and LLL and the MSS and LLL categories.

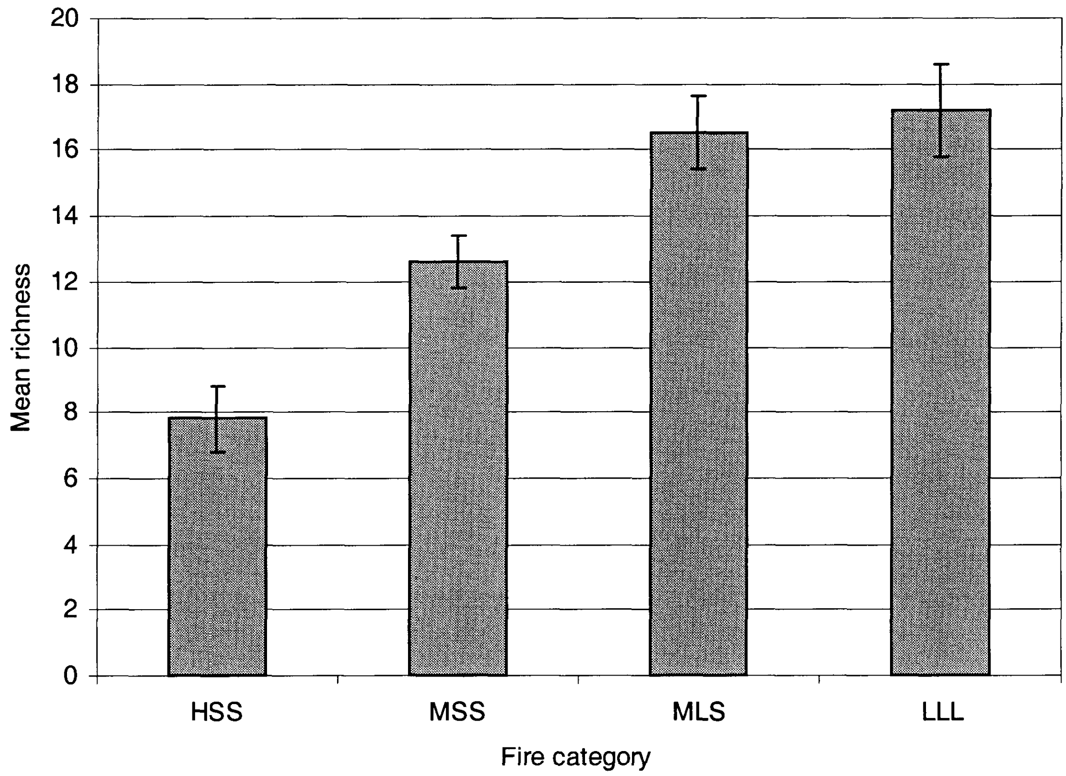

Figure 4.3. Mean woody species richness by fire category (mean ± SE). The fire categories are: HSS = high number of fires, short shortest inter-fire interval, short time since last fire; MSS = moderate number of fires, short shortest inter-fire interval, short time since last fire; MLS = moderate number of fires, long shortest inter-fire interval, short time since last fire; LLL = low number of fires, long shortest inter-fire interval, long time since last fire. These category definitions are used for all subsequent plots.

Table 4.9. Multiple regression results for the common species of the Tablelands. Significant species (P-value < 0.05) in bold. Species are: *Acacia falciformis* (Acfa), *A. irrorata* (Acir), *A. melanoxylon* (Acml), *Allocasuarina littoralis* (Alit), *Bursaria spinosa* (Busp), *Eucalyptus caliginosa* (Euca), *E. campanulata* (Eucam), *E. nobilis* (Eunob), *E. saligna* (Eusa), *Hibbertia obtusifolia* (Hiob), *Leucopogon lanceolatus* (Lela), *Leptospermum polygalifolium* (Lepto), *Lomatia silaifolia* (Losi), *Ozothamnus diosmifolius* (Ozdi), *Olearia oppositifolia* (Olop), *Persoonia oleoides* (Peol), *Pimelea linifolia* (Pili) and *Polyscias sambuccafolia* (Posm).

Species	**Acfa**	**Acir**	**Acml**	**Alit**	**Busp**	**Euca**	**Eucam**	**Eunob**	**Eusa**	**Hiob**	**Lela**	**Lepto**	**Losi**	**Ozdi**	**Olop**	**Peol**	**Piln**	**Posm**
No. of sites species sampled.	5	9	8	10	6	17	10	8	9	7	15	5	6	6	5	12	7	6
P-value																		
Number of fires						0.137											**0.028**	
Shortest inter-fire interval					0.302	0.730	0.070			**0.029**					**0.034**	0.201		**0.002**
Time since last fire		0.103					**0.012**		**0.005**			0.088		0.379	0.089			
Elevation	**0.001**	0.209					**0.011**	0.132	0.326				**0.002**	0.302	0.091	0.704	**0.033**	**0.042**
Slope	0.106	**0.001**	0.290	**0.028**	**0.047**	0.163	**0.013**					0.250		0.123	0.052	0.133		0.180
Aspect					0.333		0.054	0.125	0.086				0.119	0.187		0.272		
Mean annual rainfall			0.222		0.139	0.078				0.274	**0.009**					**0.018**	0.237	
Topographic index	**0.004**	0.130		0.182	**0.039**	0.113			0.143				0.058		0.243	0.191		
Regression results																		
Degrees of freedom	3,15	4,14	2,16	2,16	5,13	5,13	5,13	2,16	4,14	2,16	1,17	2,16	3,15	4,14	5,13	6,12	3,15	3,15
F-value	15.347	5.743	2.093	3.042	3.204	2.540	16.808	2.360	3.058	2.850	8.658	2.499	8.629	2.944	2.779	3.859	4.286	6.208
P-value	**0.000**	**0.006**	0.156	0.076	**0.042**	0.082	**0.000**	0.126	**0.050**	0.088	**0.009**	0.114	**0.001**	0.059	0.064	**0.022**	**0.023**	**0.006**
R^2	0.868	0.788	0.207	0.276	0.552	0.494	0.815	0.228	0.466	0.262	0.337	0.238	0.633	0.457	0.517	0.659	0.462	0.554

Multivariate analysis

The multivariate ordination provided further evidence that species composition was reflecting the fire categories with some influence attributed to the environmental variation between sites. The unconstrained ordination (detrended correspondence analysis) had a gradient length of 3.43 therefore, a canonical correspondence analysis was selected as the appropriate constrained ordination for these data. The analysis of the Tablelands species density with fire and environmental variables had a combined eigenvalue of the first two axes of 0.812 (Table 4.10).

Table 4.10. Eigenvalues and the species-environment correlation coefficients for the Tablelands canonic correspondence analysis.

	Axis 1	Axis 2
Eigenvalue	0.468	0.344
Species-environment correlation coefficients	0.964	0.984

The intraset correlation coefficients identified NOF of primary influence along axis 1, explaining the majority of the variance. Time since last fire was the principal correlate in axis 2 (Table 4.11). The forward selection of variables demonstrated that NOF, SIFI and TSLF were explaining 0.92 of the total explained variance (1.57). This was 59% of the variance attributed to the fire variables (NOF, SIFI and TSLF) compared to 41% of the variance explained by the other environmental variables. Only the fire variables were significant ($P < 0.05$) in relation to species density (Table 4.12).

Table 4.11. Intraset correlations of the environmental variables from the Tablelands. Principal correlates indicated with **.

	Axis 1	**Axis 2**
Number of fires	0.7192 **	-0.5903
Shortest inter-fire interval	-0.5952	0.7074
Time since last fire	-0.0780	0.9729 **
Elevation	-0.6724	-0.4739
Slope	-0.5006	-0.3169
Aspect	-0.1760	0.2120
Rainfall	-0.6666	0.0542
Topographic index	0.7042	0.0441

Table 4.12. Forward selection results of all variables in the Tablelands canonic correspondence analysis. Significant variables (P < 0.05) indicated with **, sorted by descending values of LambdaA.

Variable name	LambdaA	F-ratio	P-value
Number of fires	0.38	2.91	0.005 **
Time since last fire	0.25	2.08	0.005 **
Shortest inter-fire interval	0.18	1.50	0.035 **
Rainfall	0.14	1.25	0.220
Elevation	0.11	1.02	0.435
Slope	0.10	0.92	0.570
Aspect	0.09	0.81	0.675
Topographic index	0.09	0.78	0.605

For clarity, the site and species biplots have been presented and will be discussed separately for each of the ordination results. The site ordination (Figure 4.4) separated groups based primarily on the fire categories in one direction and except for aspect, in an orthogonal direction to the other environmental variables. The first canonic axis separated the sites primarily on NOF (demonstrated by the upper-left to lower-right trend) and the second canonic axis separated the sites primarily on environmental factors (demonstrated by the lower-left to upper-right trend). The environmental variables, particularly elevation and slope, were orthogonal to the fire variables, extending from the upper right to the lower left of the ordination. Fire and environmental variables thus had differing impacts on species density. The HSS sites were all clustered together in the higher region of the NOF axes. This was also characterised by high exposure in relation to the topographic index. The sites of moderate NOF, clustered in the lower half of the plot, were differentiated by longer fire intervals with the MLS sites occurring in the region of higher slope and elevation. The MSS sites were delineated by higher topographic index and lower rainfall. The LLL sites clustered to the axes of low frequencies and long SIFI.

The species biplot (Figure 4.5) reflected the site separation seen in Figure 4.3, and the propensity of the species for certain fire categories. Species were distributed primarily along the envelope of the NOF axis. A small number of species occurred to the lower-left of the biplot, reflecting the greater influence of the environmental variables for these species. There was a gradation of species groupings from those tolerant of high NOF and short SIFI on the right of the biplot, through to the species more suited to lower NOF and longer SIFI. Those to the left were characterised by higher rainfall, slope and elevation and those to the right by higher topographic index. The high frequency and short SIFI were characterised primarily by *Eucalyptus* tree species. *Pimelea linifolia* and *Hibbertia obtusifolia* occurred throughout the study region, but had highest abundance in these sites and thus were characterised by this region of the ordination. In the centre of the biplot of number of species occurred that were representative of the mid-range fire categories. Species such as *Acacia irrorata* and *A.*

melanoxylon occurred in these sites rather than the higher NOF sites. The species characterising the longer SIFI and lower NOF included a number of woody mid-stratum shrub species such as *Banksia integrifolia, Leptospermum polygalifolium, Polyscias sambuccifolia* and *Indigofera australis*. The species common to the LLL sites were those that declined with increasing NOF and shorter SIFI in the centre upper left of the biplot through to those species intolerant of high NOF and short SIFI in the very upper left. Species such as *Santalum obtusifolium, Goodia lotifolia* and *Eucalyptus laevopinea* were only found in the Tablelands, in the LLL sites and found in the ordination axis of long SIFI and long TSLF.

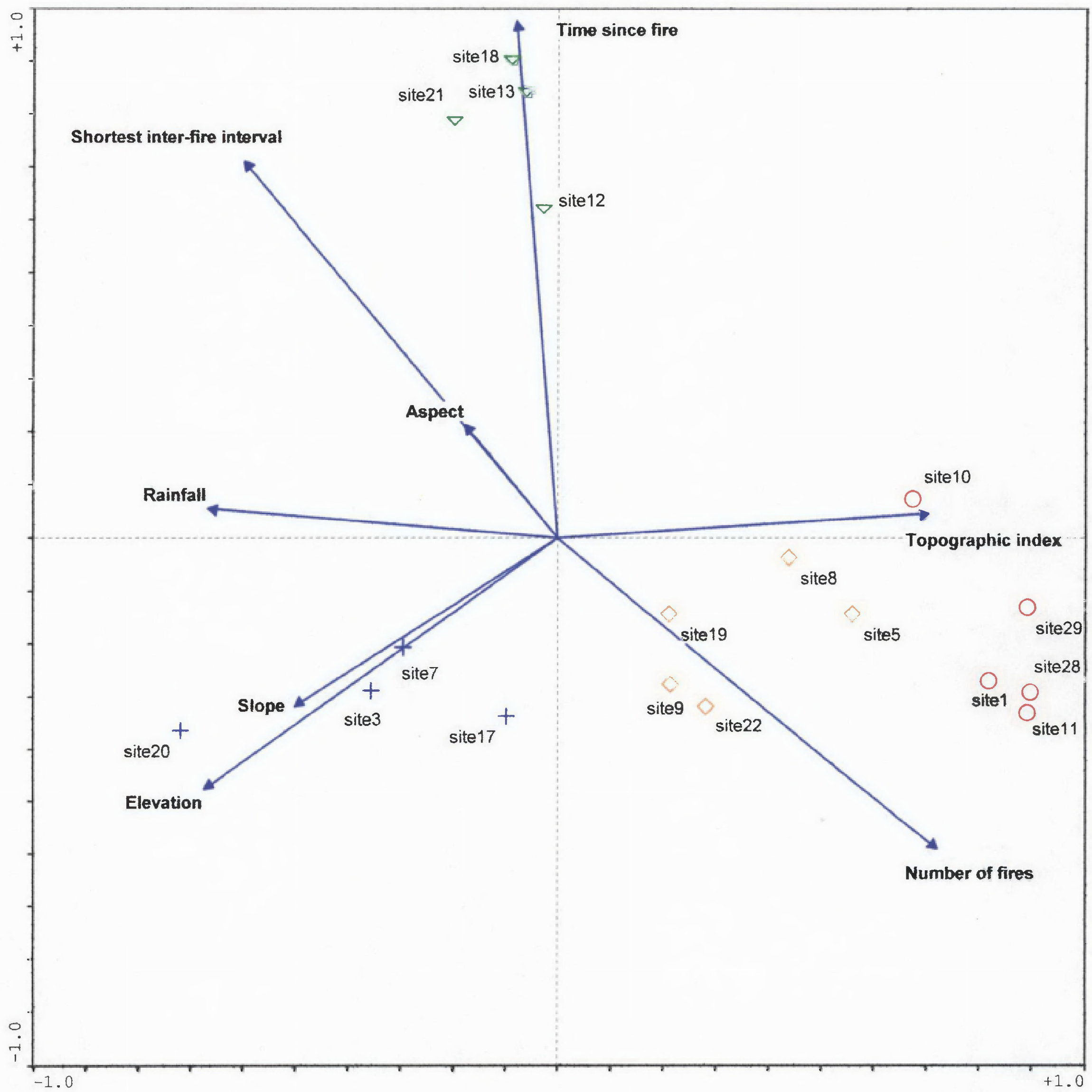

Figure 4.4. Sites by ordination biplot for the Tablelands canonic correspondence analysis. Sites represented with a circle = HSS, diamond = MSS, cross = MLS and triangle = LLL.

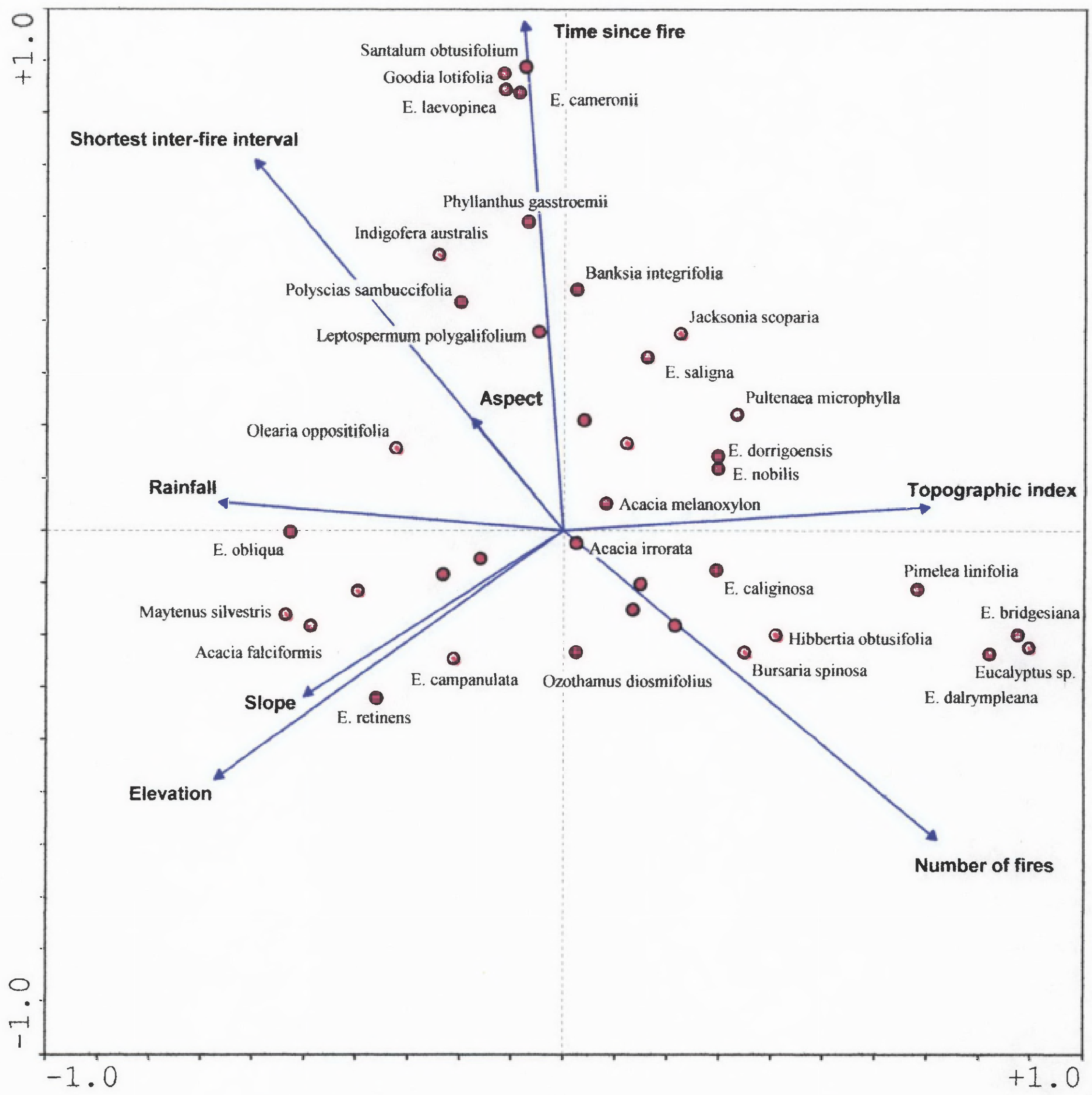

Figure 4.5. Location of species in relation to the first two axes of the Tablelands canonic correspondence analysis (species biplot). Where possible, species names have been added.

4.3.2 Tablelands woody tree and shrub plant structure

The plant structure of the Tablelands woody trees and shrubs was different between fire categories. The multiple regressions of mean height for the 18 most frequent Tablelands species split the species into those that were increasing or decreasing in height in response to the fire variables with some interaction with the environmental variables (Table 4.13). Average height was a significant function of NOF for *Eucalyptus caliginosa,* of SIFI for *Acacia falciformis* and *Olearia oppositifolia* and of TSLF for *A. irrorata, A. melanoxylon, E. saligna* and *O. oppositifolia.*

The majority of species decreased in height in relation to increasing NOF and decreasing SIFI. These species (*Acacia falciformis, A. irrorata, A. melanoxylon, Allocasuarina littoralis, E.*

campanulata, E. saligna, Leucopogon lanceolatus, Leptospermum polygalifolium, Lomatia silaifolia, Olearia oppositifolia, Persoonia oleoides and *Polyscias sambuccifolia)* showed a decrease in height with increasing NOF and decreasing SIFI that is characterised in Figure 4.6A. *Bursaria spinosa, E. caliginosa, Hibbertia obtusifolia, Ozothamnus diosmifolius* and *Pimelea linifolia* increased in height with increasing NOF and decreased with increasing SIFI (Figure 4.6B). *Eucalyptus nobilis* was the only species to have increased in height with increasing NOF and SIFI.

Similarly, the mean stem diameter of species could be summarised in two distinct trends. Average diameter was significantly correlated with NOF for *E. caliginosa*, with the SIFI for *A. falciformis* and with TSLF for *A. melanoxylon, E. saligna* and *Polyscias sambuccifolia* (Table 4.14). The majority of species had a similar trend in diameter, as was found with height. *Acacia falciformis, A. irrorata, A. melanoxylon, Allocasuarina littoralis, E. campanulata, E. saligna, Leucopogon lanceolatus, Leptospermum polygalifolium, Lomatia silaifolia, Olearia oppositifolia, Persoonia oleoides* and *Polyscias sambuccifolia* decreased in diameter with increasing NOF and decreasing SIFI (Figure 4.6A). In contrast, *Bursaria spinosa, E. caliginosa, E. nobilis, Hibbertia obtusifolia, Ozothamnus diosmifolius* and *Pimelea linifolia* increased in diameter with increasing NOF and decreased in diameter with increasing SIFI (Figure 4.6B).

Table 4.13. Multiple regression results of the mean height of the most frequent Tablelands species with fire and environmental variables. Significant variables (P < 0.05) indicated with **.

Abbreviations used are Acfa=*Acacia falciformis*, Acir=*Acacia irrorata*, Acml=*Acacia melanoxylon*, Alit=*Allocasuarina littoralis*, Busp=*Bursaria spinosa*, Euca=*Eucalyptus caliginosa*, Eucam=*E. campanulata*, Eunob=*E. nobilis*, Eusa=*E. saligna*, Hiob=*Hibbertia obtusifolia*, Lela=*Leucopogon lanceolatus*, Lepto=*Leptospermum polygalifolium*, Losi=*Lomatia silaifolia*, Ozdi=*Ozothamnus diosmifolius*, Olop=*Olearia oppositifolia*, Peol=*Persoonia oleoides*, Piln=*Pimelea linifolia* and Posm=*Polyscias sambuccifolia*.

Species	**Acfa**	**Acir**	**Acml**	**Alit**	**Busp**	**Euca**	**Eucam**	**Eunob**	**Eusa**
Variables									
P-value									
Number of fires						0.014**			
Shortest inter-fire interval	0.035**		0.303		0.062				
Time since last fire		0.001**	0.043**			0.225			0.003**
Elevation	0.018**								0.085
Slope	0.059	0.038**	0.132	0.001**		0.082	0.142		
Aspect				0.198				0.027**	0.015**
Rainfall						0.108		0.044**	
Topographic index	0.149			0.020**					0.045**
Regression results									
Degrees of freedom	4,14	2,16	3,15	3,15	1,17	4,14	1,17	2,16	4,14
F-value	5.755	28.525	3.746	6.458	3.977	3.912	2.377	4.545	4.255
P-value	0.006**	0.001**	0.034**	0.005**	0.062	0.025**	0.142	0.027**	0.018**
R^2	0.789	0.884	0.428	0.564	0.190	0.528	0.123	0.362	0.549

Species	**Hiob**	**Lela**	**Lepto**	**Losi**	**Ozdi**	**Olop**	**Peol**	**Piln**	**Posm**
Variables									
P-value									
Total	0.012**	0.120	0.555	0.315	0.258	0.091	0.003**	0.461	0.679
Number of fires								0.101	
Shortest inter-fire interval						0.006**			0.748
Time since last fire					0.287	0.048	0.267	0.286	0.269
Elevation	0.116	0.171	0.013**	0.105				0.397	0.004**
Slope		0.023**			0.209	0.021**	0.121		0.108
Aspect				0.180	0.308		0.322		
Rainfall			0.041**	0.372		0.069	0.003**		
Topographic index	0.011**			0.208			0.108		0.140
Regression results									
Degrees of freedom	2,16	2,16	2,16	4,14	3,15	4,14	5,13	3,15	5,13
F-value	4.771	3.189	4.186	4.042	1.595	5.362	4.177	2.189	9.564
P-value	0.024**	0.068	0.035**	0.022**	0.232	0.008**	0.017**	0.132	0.001**
R^2	0.374	0.285	0.344	0.536	0.242	0.605	0.616	0.304	0.786

Table 4.14. Significant species from the multiple regressions of mean stem diameter (or base diameter for plants under 2 m) of the most frequent Tablelands species with fire and environmental variables. Significant variables ($P < 0.05$) indicated with **, species name abbreviations in Table 4.13.

Species	**Acfa**	**Acir**	**Acml**	**Alit**	**Busp**	**Euca**	**Eucam**	**Eunob**	**Eusa**
P-value									
Number of fires						0.005**			
Shortest inter-fire interval	0.002**								
Time since last fire		0.000**	0.009**						0.001**
Elevation	0.064				0.072				0.085
Slope	0.093	0.027**		0.002**		0.018**	0.076	0.291	
Aspect			0.177		0.166			0.019**	0.010**
Rainfall			0.300				0.263	0.022**	
Topographic index				0.113	0.013**	0.224	0.073		0.048**
Regression results									
Degrees of freedom	3,15	2,16	3,15	2,16	3,15	3,15	3,15	3,15	4,14
F-value	5.448	70.342	4.921	7.162	3.832	5.439	2.323	3.807	4.926
P-value	0.010**	0.001**	0.142	0.006**	0.321	0.010**	0.116	0.033**	0.011**
R^2	0.722	0.898	0.496	0.472	0.434	0.521	0.317	0.432	0.585

Species	**Hiob**	**Lela**	**Lepto**	**Losi**	**Ozdi**	**Olop**	**Peol**	**Piln**	**Posm**
P-value									
Number of fires	0.079						0.205	0.018**	
Shortest inter-fire interval		0.327				0.071	0.116		
Time since last fire			0.053		0.161	0.191		0.133	0.001**
Elevation	0.428								0.040**
Slope	0.168	0.058			0.196				
Aspect	0.123						0.266		
Rainfall				0.055			0.023**		0.204
Topographic index	0.039**			0.066		0.095			
Regression results									
Degrees of freedom	5,13	2,16	1,17	2,16	2,16	3,15	4,14	2,16	3,15
F-value	2.941	3.910	4.322	6.412	1.882	1.664	2.913	3.441	8.759
P-value	0.054	0.041**	0.053	0.009**	0.184	0.217	0.060	0.057	0.001**
R^2	0.531	0.328	0.203	0.445	0.190	0.250	0.454	0.301	0.637

A

B

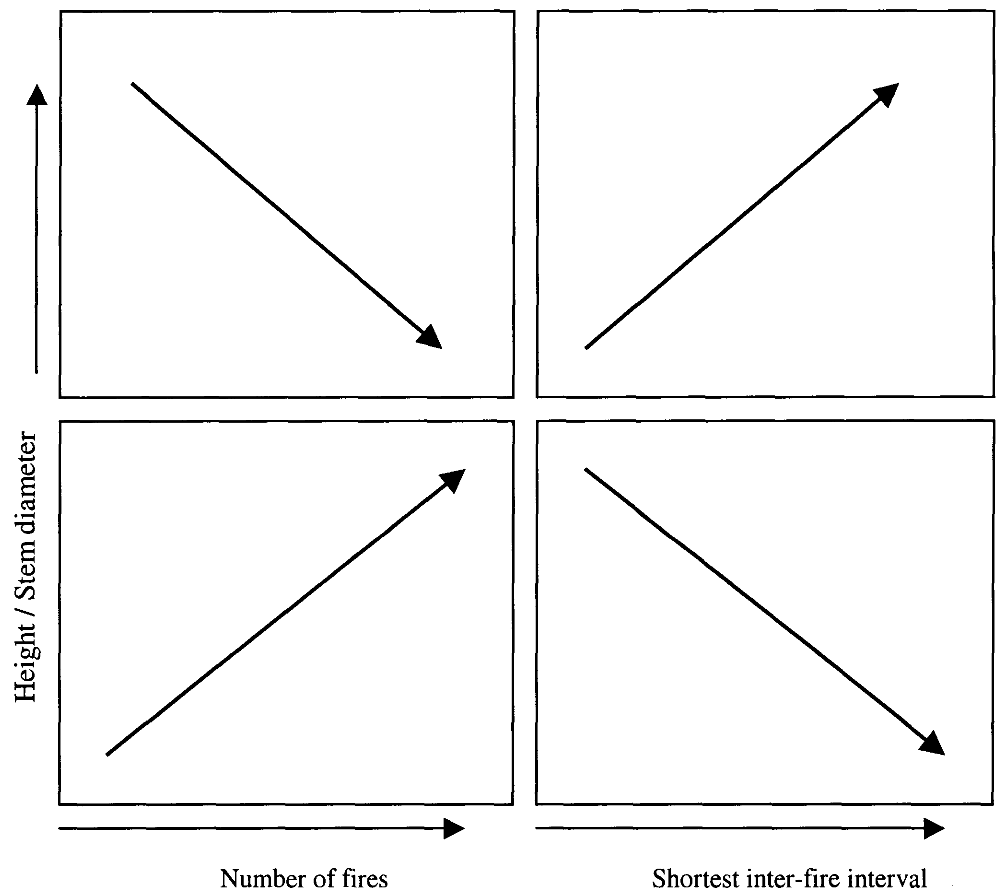

Figure 4.6. Trends in species responses characterised by decreasing NOF and increasing SIFI (A) as opposed to increasing NOF and decreasing SIFI (B).

The vegetation community structural differences between the shrubs and trees were evident when analysed over all fire categories within height classes. The structure of Tablelands woody species varied significantly with frequency of fire. A significant difference was found between fire categories and the mean number of trees and shrubs in height and diameter classes (≤ 2 m, > 2-10 m and > 10 m). The plot of the mean number of shrubs and trees in each class against the fire categories (Figures 4.7) showed statistically significant differences (Table 4.15) in all height classes. There was a peak in abundance in the 'long' SIFI category (MLS) and lowest numbers of small trees or shrubs in the sites of high NOF and short SIFI (HSS). Tall shrubs declined rapidly in density with increasing fire occurrence. The large increase in trees and shrubs (especially in the two smaller size classes Figure 4.7 B & C) in the MLS category was primarily due to the very high numbers of *Acacia falciformis* found in sites 7 and 20 and *Eucalyptus campanulata* in sites 3, 7 and 20. These sites were all in the MLS category and these species were regenerating profusely following the October 1994 fire.

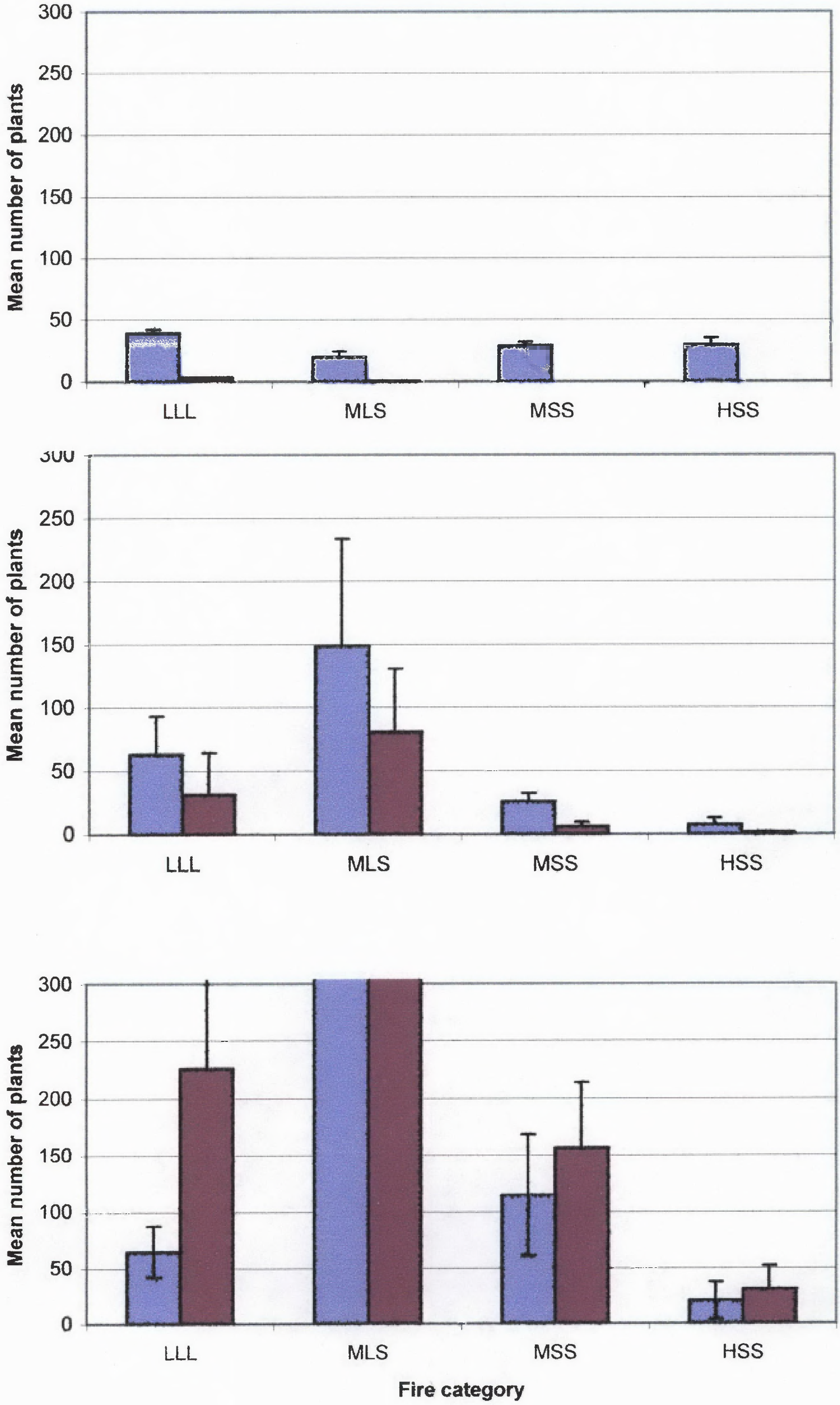

Figure 4.7. Mean number of trees (blue) and shrubs (red) in the height category of greater than 10 meters (A), > 2-10 meters (B) and less than or equal to 2 meters (C). The MLS fire category of graph C has been truncated for ease of comparison, the maximum in trees = 867 and maximum in shrubs = 726.

Table 4.15. ANOVA results for structure classes of Tablelands woody trees and shrubs (all classes degrees of freedom = 3,15). Significant height categories (P < 0.05) indicated with **.

Growth form and height category	F-value	P-value
Shrubs less than 2 m	5.418	0.009**
Shrubs greater than 2 to 10 m	6.487	0.005**
Shrubs greater than 10 m	5.117	0.012**
Trees less than 2 m	6.819	0.004**
Tree greater than 2 to 10 m	6.955	0.004**
Trees greater than 10 m	3.742	0.050**

Total woody plant abundance differed significantly in relation to the fire categories ($F_{3,15}$ = 13.41, P< 0.001). The number of woody stems per site increased sharply in the MLS fire category (Figure 4.8). The structural and compositional differences observed between the sites within the fire categories are shown pictorially in Figures 4.9 to 4.12.

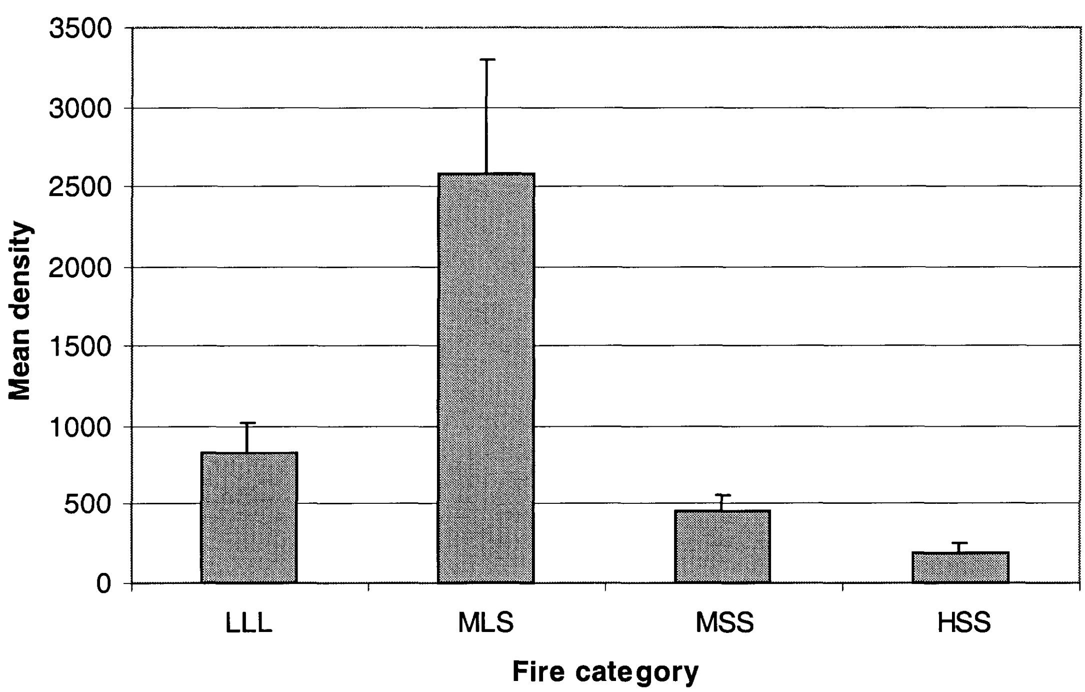

Figure 4.8. Mean stem density by fire category (± SE).

Figure 4.9. Site 010 from the high-short-short (HSS) fire category. The typical composition and structure is open forest and a grassy understorey.

Figure 4.10. Site 022 from the medium-short-short (MSS) fire category. The typical structure and composition is open forest with a grass understorey and some emergent shrubs.

Figure 4.11. Site 007 from the medium-long-short (MLS) fire category. The typical composition and structure is open forest and a shrub understorey.

Figure 4.12. Site 013 from the low-long-long (LLL) fire category. The typical composition and structure is forest and a multi-layered understorey.

4.3.3 Tablelands ground cover

The Tablelands survey sampled 150 ground cover species (16 to genus level, 4 to family level including 3 unknown daisies (Asteraceae spp.), 1 unknown grass (Poaceae sp.) and 3 unknown orchids). The ground cover survey included 38 juvenile woody species that were excluded from further analyses as these have already been analysed in Sections 4.3.1 and 4.3.2. The mean and SE for each species within each fire category is shown in Appendix 4.1 (woody plants excluded). All of the grasses occurred in the HSS fire category.

Multivariate analysis

The gradients in the Tablelands ground cover were long (4.22), therefore the data were analysed using a detrended canonic correspondence analysis. The overall variance of the data was 2.961 with all of the variables explaining 53% of this variance. The first and second eigenvalues of the first two axes explained a significant proportion of the data (63.8%). The first axis was primarily a function of the SIFI and the second axis was primarily topographic index (Table 4.16). The fire variables (NOF, SIFI and TSLF) explained 46% of the explained variance. Forward selection of each of the fire variables showed only SIFI was significant in relation to the cover of the ground species (Table 4.17).

Table 4.16. Intraset correlation coefficients for the Tablelands ground cover data. Principal correlates indicated **.

Variable name	Axis 1	Axis 2
Number of fires	-0.7197	-0.0737
Shortest inter-fire interval	0.7843 **	0.0070
Time since last fire	0.6441	-0.3124
Elevation	0.4180	0.2431
Slope	0.2701	0.1204
Aspect	0.3746	-0.1379
Rainfall	0.6252	0.2794
Topographic index	-0.5765	-0.3636 **

Table 4.17. Forward selection of the Tablelands ground cover data. Significant variables ($P < 0.05$) indicated **, sorted by decreasing LambdaA.

Variable name	LambdaA	F-value	P-value
Shortest inter-fire interval	0.32	1.91	0.010**
Elevation	0.22	1.39	0.105
Time since last fire	0.19	1.18	0.180
Topographic index	0.18	1.15	0.280
Rainfall	0.14	0.89	0.590
Slope	0.15	0.94	0.460
Number of fires	0.14	0.88	0.580
Aspect	0.09	0.49	0.905

The dominant feature of the ground cover ordination was the occurrence of all variables aligned with the horizontal axis (Figure 4.13). Sites associated with longer SIFI grouped to the right of the biplot and were characterised by long SIFI and high rainfall, slope and aspect. The HSS and MSS sites were grouped in the left and centre of the ordination and were associated with high NOF and higher topographic index and temperature. The MLS fire category was orthogonal to this trend with the sites separated along axis 2.

The ground cover species biplot (Figure 4.14) had the majority of species clustered in the centre of the plot associated with the mid-range of most variables. Those species associated with lower NOF and longer SIFI such as *Hydrocotyle pedicellosa*, *Cissus antarctica* and *Urtica incisa* were primarily found in the LLL sites. Species such as *Blechnum cartilagineum*, *Centella asiatica* and *Eustrephus latifolius* were predominantly associated with longer SIFI and higher rainfall, elevation and slope. MLS sites were widely distributed in the upper right of the plot and were mainly differentiated from LLL sites by higher rainfall, elevation and slope values. The common and abundant ground cover species such as the grasses *Entolasia stricta* and *Poa sieberiana* and the forbs *Geranium solanderi*, *Pratia purpurascens* and *Desmodium varians* were related to moderate fire ranges and the mid-range of the environmental variables.