

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Successional management of large areas of natural vegetation depends on knowledge of the composition of the vegetation, the extent to which it is being used, and the changes that take place in response to differential use by herbivores and by fire (Walker, 1976). Recently, more attention has been given to the Kalahari sand forests of north western Matabeleland, which have so often been ignored. One of the major management problems in the Kalahari sands woodlands is knowing whether regeneration is adequate, given exploitation rates and effects of previous logging. Knowledge of disturbance regimes is critical in understanding current and future composition of forests (Gutierrez, Armesto and Aravena, 2004).

Numerous factors affect structure and composition of dry woodland. These factors could be divided into biotic and abiotic. Abiotic factors include edaphic components such as nitrogen and phosphorus concentrations (Stromgraad, 1992; Chidumayo, 1994), and disturbances such as natural fire (Kikula, 1986, Chidumayo, 1988a). Biotic factors can be divided into natural occurring forces such as damage by herbivores and anthropogenic factors including commercial charcoal production (Monela, O'king Ati and Kiwele, 1993), and collection of fuelwood (Abbot and Homewood, 1999). Dynamic changes in dry savanna woodland systems are often interpreted to be the result of disturbances, such as overgrazing, over browsing (Lubke and Thatcher, 1983; Pellew, 1983; Coughenour and Ellis, 1993), fire (Bell, 1982; Trollope, 1980,

Bond and Van Wilgen, 1996) and human utilisation (Blackmore, Mentis and Scholes, 1990; Shackleton, Griffin, Banks, Mavrandonis and Shackleton, 1994 (as cited by Gotosa, 2002). Fire intensity influences regeneration of timber species by reducing seedling establishment and recruitment of saplings to canopy (Gambiza, 2001).

Changes in population structure might indicate management impact before the loss of a valuable timber species occurs. It may also alert managers to situations of declining recruitment (Walker, Stone, Henderson and Venede, 1986). Size class distributions (Weiner and Caswell, 1977; Knowles and Grant, 1983) or stage class distributions (Silvertown, 1987) are better indicators of reproductive output from a woodland or forest.

Due to effect of fire and herbivory on seedling establishment, resprouting from stem bases and roots are the major regenerative strategy in *Baikiaea plurijuga*, commonly called Zambezi Teak (Gambiza, 2001). Regeneration of *B. plurijuga* is poor (Pierce, 1986). Furthermore, its growth rate is low. This has led to speculations of future loss of some forests due to lack of regeneration and recruitment. It has been hypothesized that current extraction rates of exploitable stock would be exhausted at the turn of the century (Mushove, 1991). Increasing demand for timber and timber products has led to speculation that there is insufficient time for wood regeneration (Scholes and Parsons, 1997).

While few studies have been carried out in Kalahari sand forests to document ecological impacts of timber extraction, logging has been proved to have extensive impacts on: floristic structure and composition, edaphic properties, and fauna. It is not

clear if this trend is discernible with *B. plurijuga*. The vegetation dynamics in Kalahari sands are determined by, logging, fire, herbivory and interactions among plants (Gambiza, 2001). Regeneration rate of *B. plurijuga* is slow, and disturbance through felling, overgrazing and fire could lead to invasion by miombo species (Bradley and Dewees, 1993).

1.2 Logging in the woodlands

Logging consists of periodic physical removal of portions of the dominant tree canopy. This may benefit trees and shrubs that remain (Calvert, 1986a). In Zimbabwe, the exploitation of commercial timber is carried out through private concessions, and is regulated by the Forestry Commission under the Forest Act. There has been concern over the decline of some indigenous timber species and their capacity to regenerate after a disturbance. Increased demand for high quality timber has resulted in extensive logging of important indigenous timber species. This has led to gene impoverishment (Gondo, Nobanda and Mapaure, unpublished paper). Extraction of wood for commercial sale and fuel is proceeding at an accelerated rate (Scholes and Parsons, 1997). Indigenous timber trees that are harvested from woodlands are mainly Zambezi teak and mukwa. These tree species mainly occur in the Kalahari sands. Logging has increased due to increased demand for timber for manufacturing. This is creating pressure on these indigenous timber species.

1.3 Justification

With increased harvesting pressure on indigenous timber species due to increased demand for timber and timber products in the Kalahari sands, it has become imperative to study these tree species. Furthermore, the extent of logging needs to be

documented in light of increasing impacts of logging. Data on extent of logging could help in decision-making pertaining to logging cycles. Many studies have concentrated mainly on fire, yet logging is also a major form of disturbance in the indigenous timber woodlands. Effects of prolonged logging are not fully understood. Data from the present study will help in monitoring and assessment of impacts of logging on regeneration of *B. plurijug* and species composition of the Gwayi Forest. For effective management of Zambezi teak woodlands, there is need to monitor whether the rate of timber extraction is sustainable. Such knowledge will help understand the dynamics of species in the Gwayi Forest. This study seeks to assess regeneration, extent of logging and changes in species composition in light of disturbances such as logging.

1.4 Objectives

This study aimed at developing baseline data on regenerative capacity of *B plurijuga* under different logging regimes. The specific objectives were:

- ◆ to examine the size class structure of *Baikiaea plurijuga* in unlogged and logged areas;
- ◆ to compare the extent of logging in two logged areas, one logged in 1995 and another in 1999;
- ◆ to examine regeneration patterns in areas logged at different periods;
- ◆ to examine patterns of change in diversity and richness accompanying regeneration;
- ◆ to describe species composition patterns, and their relationship with soil pH, Nitrogen, Phosphorus and Potassium.

1.5 Research questions

- ◆ How do size class structure, diversity and richness compare in an unlogged area and areas logged at different times (1995 and 1999)?
- ◆ How do extents of logging and pattern of regeneration compare in areas logged at different times (1995 and 1999)?
- ◆ What is the relationship between species distribution and pH, Nitrogen, Phosphorus and Potassium in areas logged at different times (1999 and 1995)?

1.6 Alternative hypotheses were:

H₁: The size class structure of *B. plurijuga* is different in an unlogged area, area logged in 1999 and area logged in 1995

H₂: Regeneration patterns and diversity are different in unlogged area, area logged in 1999 and area logged in 1995

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Baikiaea plurijuga is a deciduous tree that belongs to the family leguminosae (Theilade, Sekeli, Hald and Graudal, 2001). It can grow to a maximum height of 20 metres and has a smooth bark, which becomes fissured and cracked later on. Leaves are alternate, compound with four to five pairs of leaflets (Theilade, *et al.*, 2001). Its flowers are large and arranged in axial racemes up to 30 cm long. The bark is dark brown and has dark brown buds. *B. plurijuga* starts flowering in December extending into March with the peak in the middle of the rain season (Childes and Walker, 1987).

2.2 Zambezi Teak woodlands: definition, distribution and characteristics

Zambezi Teak woodlands are in fact dry savanna woodlands rather than true forests. The vegetation in these woodlands are limited by available soil moisture within rooting depth, seasonality of water availability, low nutrients and fire (Timberlake, Nobanda and Mapaure, 1993).

The present distribution of Kalahari sands is azonal, and they are found from about 13°S to 20° S, at least 6° of the latitude (Huckabay, 1984). Kalahari sands cover 1 988 400 hectares world wide (Hogberg, 1986). Zambezi teak woodlands are found on Kalahari sands. In Africa, they are found in Northern Transvaal, Zimbabwe, Botswana, Northern Namibia, Southeastern Angola, Southern Zambia, Malawi and Mozambique (Hogberg, 1986). In Zimbabwe, they are found in the southwest part of the country (Childes and Walker, 1987).

Zambezi teak woodlands occur in sandstone formation in association with *P. Angolensis*, *Guibourtia coleosperma*, *Terminalia* and *Combretum* species. Zambezi teak grows slowly, but is adapted to infertile, deep sands of Kalahari formation (Bradley and Dewees, 1993). The 'big three', in terms of utilisation in Zimbabwe, are *B. plurijuga*, *P. angolensis* and *Afzelia quanzensis* (Pearce, 1993).

2.3 History of Logging

Exploitation of *Baikaea plurijuga* started in the indigenous forests of northwestern Matabeleland in 1907. The officer appointed to oversee logging operations in north western Matabeleland found that the forests were being overexploited. A forest policy was then established in the 1920s by the Rhodesia Native Timber Concession, which harvested teak for railway sleepers (Chenje, Sola and Paleczny, 1998). In subsequent years, different companies were awarded tenders to extract timber from the forest. The Forestry Commission granted concessions to companies to perform logging in Gwayi forest. Between 1996 and 1999, contracts were awarded to the Zimbabwe Building Services. The contracts were renewable every year. A company called Hyde Timbers and the local community did logging in 1995. In another area, logging was last done in 1999 and there has been no logging in another area. (Mashingaidze, pers. comm)

2.4 Ecological effects of logging

Logging of timber species alters forest ecology by opening up the canopy. Bare patches created favour the growth of grass and thicket, limiting regeneration through competition for soil moisture (Bradley and Dewees, 1993). Logging also exposes the forest floor, thus changing the microclimate of the forest (Calvert, 1986a). For

instance, the soil moisture regime is altered by removal of a number of large dominants, which benefits trees and shrubs that remain. Development of seedlings and suckers around tree stumps is well pronounced in the opened up areas than in unlogged forests. This could be due to suppression of undergrowth by forest cover (Chigwerewe, 1996). Felling of huge trees opens up forest canopy, allowing high levels of radiation to reach the soil, thus triggering germination of seeds, and promoting improved growth rate (Chigwerewe, 1996). Logging determines the pathway of succession. Differences in gap characteristics between logged and unlogged forests lead to corresponding differences in microclimate, flora, fauna, frequencies of large herbivore incursions and plant succession (Kasanene, 1987). There are four major factors responsible for slow post-logging tree regeneration (Kasanene, 1987, Struhsaker, Lwanga and Kasanene, 1996). These factors are (i) timber harvesting intensity, (ii) establishment and persistence of an aggressive shrub or herb layer, (iii) increased elephant use of logged areas compared with lightly logged and unlogged areas, and (iv) high seed predator rodent densities in the large gaps of logged areas. Some gaps that are created by logging become infested with pioneering herbs, vines and shrubs instead of promoting the growth of established saplings and seedlings (Chapman and Chapman, 1997).

Logging affects species richness. Number of stems of saplings is reduced in the gaps than in undisturbed sites (Babaasa, *et al.*, 2004). Gaps created by logging do not affect sapling community composition, species richness or relative species abundance (Uhl, *et al.*, 1988), and gaps are dominated by shade-tolerant tree species that are present before gap formation. Gap sizes have an impact on local abundance and species richness of tree regeneration (Babaasa, *et al.*, 2004). Logging of trees leads to

vigorous herbaceous growth (Dye and Spear, 1982; Calvert, 1986a). Successful regeneration in forests, under both natural and silvicultural variables, depends on nature of disturbance (Figueroa-Rangel and Olvera-Vargas, 2000).

The vegetation of any given area is dynamic due to intrinsic factors such as differential longevity of species and environmental factors (Gotosa, 2002). Disturbance on vegetation can be natural as in the case of drought, floods and fire, or human induced such as large scale clearing for cultivation or selective harvesting of plant species like timber logging. Vegetation composition is often influenced by herbivores through their selective consumption of seedlings and damage to mature plants (Huntly, 1991). Herbivores also assist with seed dispersal for some plant species (Wolf and Debussche, 1999).

Lands that have been degraded by previous land use practices such as agriculture and logging are generally difficult to re-vegetate with desirable species because degraded soils and competition from undesirable species arrest successional process (Lieth & Lohman, 1993).

2.5 Logging and fire

Forests in the unlogged areas have the most fire resiliency and present lower fire risk compared to logged areas (<http://www.ems.org/wildfires>). This could be due to limited fuel load since in the logged areas there would be dry stumps that promote fire establishment. Logging removes the relatively large diameter wood that can be converted into wood products. This leaves behind small material, which increases the rate of spread of fires (<http://www.ems.org/wildfires>).

2.6 Canopy gaps

Logging results in the formation of gaps that lead to rapid tree recruitment and redevelopment of the canopy (Brokaw, 1985a; Denslow, 1987). A forest gap is created when an open space occurs within the forest and results from the death of a canopy tree or a broken branch (Timberlake, Muller and Mapaure, unpublished). Gaps play an important role in plant succession, and hence forest regeneration. It induces significant changes in the gap microclimate compared to forest understory (Denslow, 1987). Consequently, germination, establishment, growth, and reproduction of many gap plants are increased (Babaasa, Ellu, Kasangaki, Bifariho and McNellage, 2004). Canopy gaps associated with selective logging or other major disturbances of tropical forests increase light reaching the forest floor, and may benefit the growth of the established saplings and seedlings (Cannon, *et al.*, 1994; Chazdon, 1998). In some cases, such gaps become infested with aggressive pioneering herbs, vines and shrubs (Osmaston, 1959; Howlett and Davidson, 1996; Ashton *et al.*, 1997; Chapman and Chapman, 1997) that appear to repress tree regeneration and halt succession towards a mature forest community (Sarmiento, 1997; Chapman and Chapman, 1997). At times, pioneer species are still absent from these sites decades after disturbance (Pinard *et al.*, 1996; Chapman and Chapman, 1997). Successful regeneration in forests depends on a disturbance in the canopy that eventually involves gap creation (Figueroa-Rangel and Olivera-Vargas, 2000).

2.7 Intermediate Disturbance Hypothesis (IDH)

IDH states that diversity will be highest at sites that have had an intermediate frequency of disturbance, and will be lower at sites that have experienced very high or

very low levels of disturbance (Schwilk, Keely and Bond, 1997). This hypothesis is attributed to Connell (1978) and Huston (1979 as quoted by Schwilk, *et al.*, 1997). Basically, intermediate levels of disturbance maximise species diversity because completely dominant species exclude poor competitors at low disturbance but too much disturbance leads to local extinctions(<http://www.findarticles.com/p/articles/mi>). Essential elements of IDH are that there should be repeated local disturbance, creating bare patches. Furthermore, disturbance must be frequent enough so that competitive exclusion does not occur over the whole area. Lastly, the frequency of disturbance has to be seen in the context of generation time (Wilson, 1994).

2.8 Regeneration of *B. plurijuga*

Natural regeneration in forestry means the renewal of the tree canopy by self-sown seed or vegetative regrowth (Pearce, 1993). Regeneration is the key process that influences population dynamics (Begon, Townsend and Harper, 1996). The majority of Southern Africa's commercial timber species, their slow growth and the need for long term management, do not make large scale planting of indigenous trees for wood products an attractive or economic proposition (Pearce, 1993). In Zimbabwe, the social forestry fraternity is now learning to build upon local strategies of woodland management based on natural regeneration (Makuku, 1990).

Teak forests if not grossly abused could be managed by natural regeneration to replace themselves (DeMeo, 1984). This entails application of the classical selection system, which entails the creation and maintenance of uneven-aged stands. There are many factors limiting natural regeneration, and these include erratic seed years, loss of seed eaten by rodents, and competition for available moisture (Chisumpa, 1984).

Regeneration is said to be mainly from seeds, which develops a root that grows up to 0.7-1.0 m during the first rains to about 1.5 m after three seasons (Calvert, 1986a). This is not consistent with Gambiza's observations who observed that regeneration of *B. plurijuga* was mainly by stem regeneration. An underground wood 'rhizome' develops from which new stems arise each season (Calvert, 1986a). Regeneration can also be by means of coppices, which vigorously grow from stools of any age or size (Mululuma, 1984). *B. plurijuga* has a lengthy establishment phase during which the tap-root develops very extensively, within six months reaching 2 m in length whilst the stem attains and may remain for several years no taller than 15 cm. The annual diameter increment for *B. plurijuga* in Zimbabwe is about 2.5 mm (Calvert, 1986a).

CHAPTER THREE

STUDY AREA

3.1 Location

The study was conducted at Gwayi State Forest (Figure 3.1). The forest is located three kilometres from Lupane Growth Point along the Bulawayo-Victoria Falls road, northwestern Zimbabwe. It extends from 18° 45' S to 19° 30' S and from 27° 40' E to 28° 11' E (Gambiza, 2001).

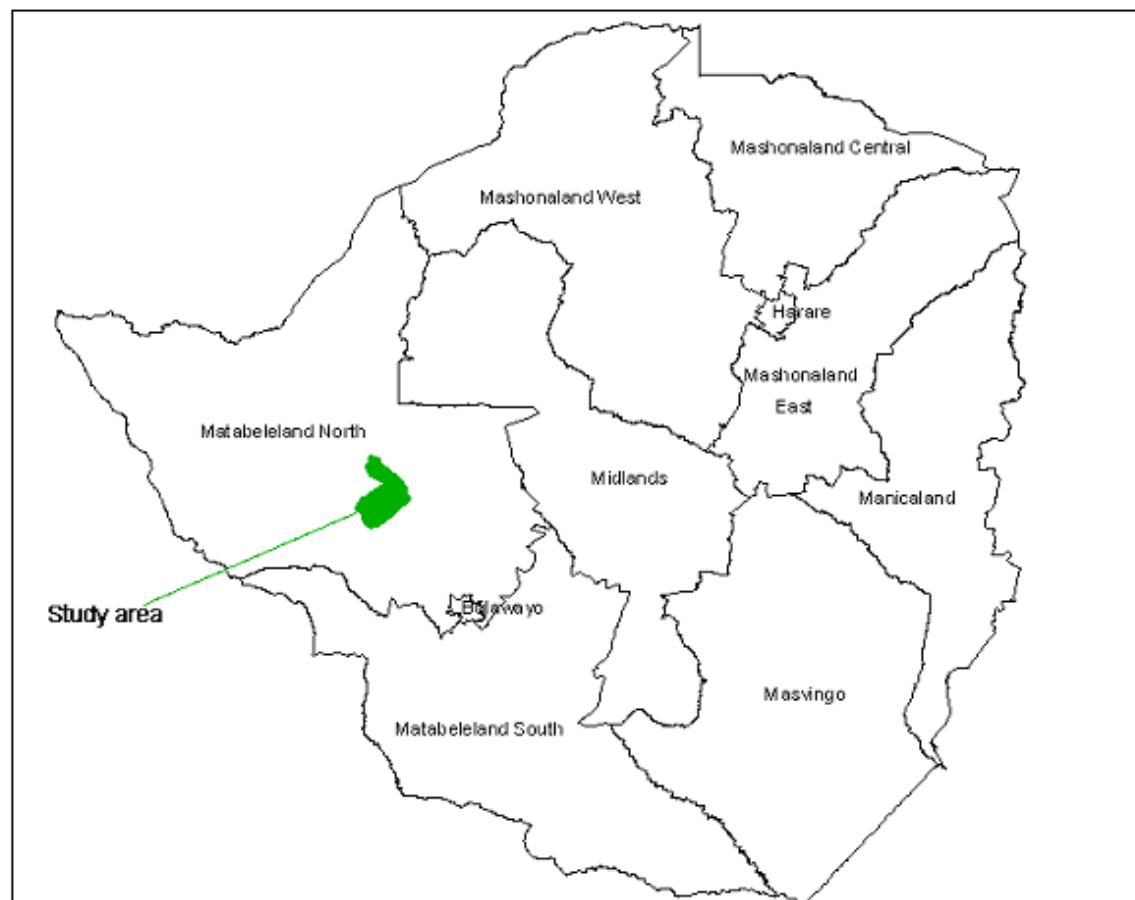


Figure 3.1: Location of study area in Zimbabwe

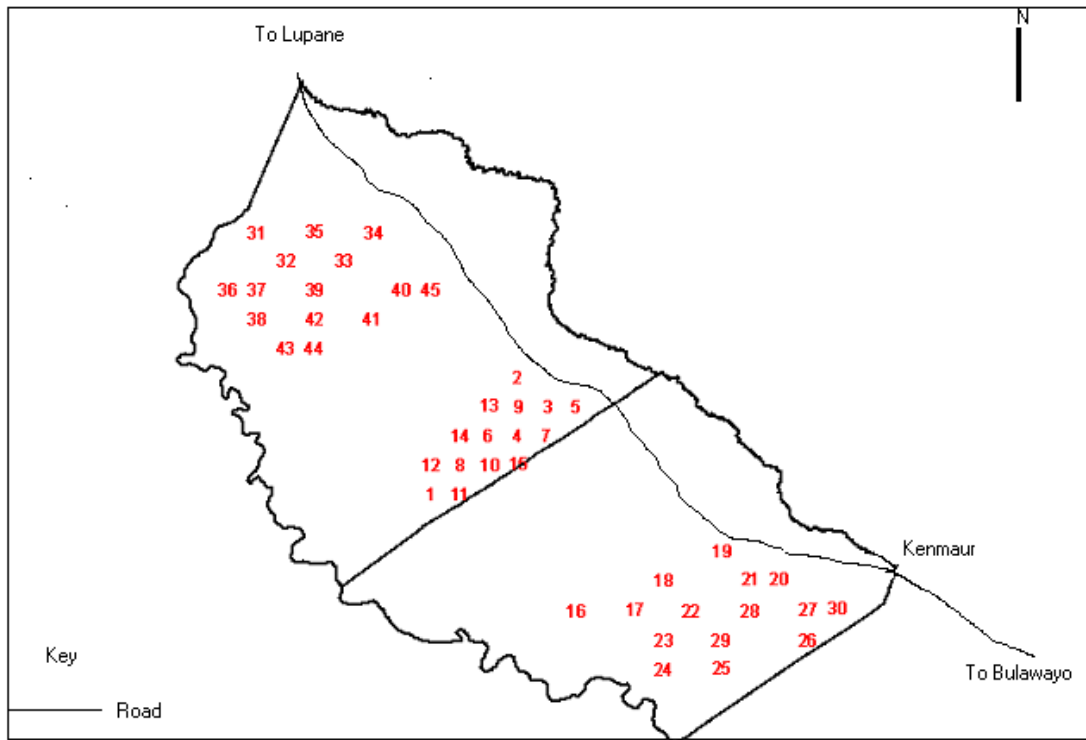


Figure 3.2: Map showing location of sampling points in the study area

3.2 Geology and soils

The area is underlain by cretaceous sedimentary rocks beneath which are karoo basalts and sedimentary deposits (The Forest Survey Final Report, 2001). The soils at the site are deep Kalahari sands that belong to the regosol group in the amorphic soil order (Nyamapfene, 1991 as cited by Gambiza, 2001). The forest soils are derived from four main geological formations on parent material (Judge, 1986). The sands are unconsolidated, red/orange, pink or buff coloured, structureless with a high proportion of fine dust (Mushove, Gondo and Gumbie, 1993).

3.3 Climate

There are three distinct seasons in Gwayi Forest namely: dry winter which stretches from April to August, hot season which spans October to November and wet season from mid-November to March (The Forest Survey Final Report, 2001). Rainfall ranges from 400mm to 800mm per year (The Forest Survey Final Report, 2001) and is short and erratic with frequent prolonged droughts (Nemarundwe and Mbedzi, 1999). Mean monthly temperature ranges from 15°C (June to September) and 25°C (October to December) (The Forest Survey Report, 2001).

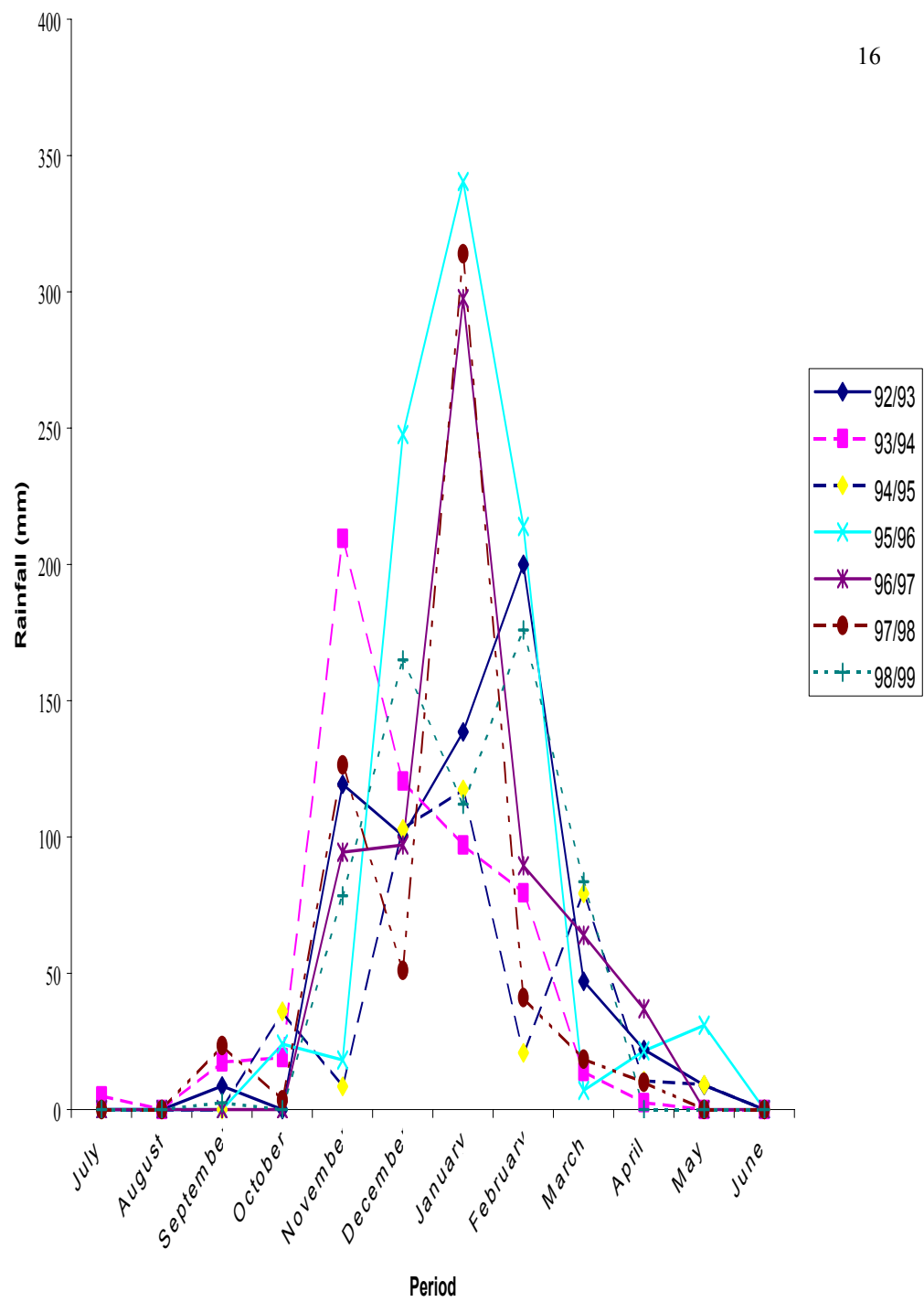


Figure 3.3: Rainfall pattern in the study area between 1992 and 1999

3.4 Vegetation

Zambezi Teak woodlands dominate the site. Vegetation is dominated by *Baikiaea plurijuga* commonly associated with *Guibourtia coleosperma*, *Burkea africana*, *Erythrophleum africanum*, *Pterocarpus angolensis*, *Combretum collinum*, *Croton gratissimus*, and *Schinziophyton rautanenii* (The Forest Survey Final Report, 2001). Other common canopy species are *Combretum zeyheri*, *Commiphora marlothii*, *Ochna pulchra*, *Baphia massaiensis*, *Terminalia sericea* and *Bauhinia petersiana* (Gambiza, 2001). *Dichapetulum rhodesiana* is also common including *Panicum maximum* and *Heteropogon melanocarpus*. Other common grasses are *Pogonarthria fleckii*, *Aristida stipitata*, *A. pilgeri*, *Triraphis schlechteri*, *Tristachya rehmanii*, *Eragrostis species* and *Digitaria pentzii* (Gambiza, 2001).

3.5 Settlements

Settlements were established in Gwayi Forest in the 1930s (Forest Final Survey Report, 2001). About 882 of the settled families do not have permits and are settled illegally. The Forestry Commission employs the shared management programme where the settlers are co-managers of the forest. The families farm, collect forest products and graze their livestock (The Forestry Survey Final Report, 2001).

3.6 Conservation status

Gwayi Forest was demarcated as state land in 1936 under the Land Apportionment Act of 1930 (The Forest Survey Final Report, 2001). Before that people lived in the forests and performed various activities. The Forestry Commission allowed them to remain in the forest as they assisted with putting out fires (The Forest Survey Final Report, 2001). The people were issued with permits to remain in the forest. Some

settlers moved in from elsewhere. There are four main legal instruments that relate to wood resources in Zimbabwe. These are the Natural Resources Act of 1941, revised in 1975 and 1981. This Act created the Natural Resources Board to control use of natural resources. The second piece of legislation is the Forestry Act of 1949, which created the Forestry Commission and charged it with control of forest utilisation. The third piece of legislation is the Communal Lands Acts of 1982, which gives Rural District Councils the rights to control harvesting of resources in their jurisdiction. The last piece of legislation the Communal Lands Forest Produce Act of 1987 which controls the harvesting of listed plant species in communal areas (Gondo, 1993)

CHAPTER FOUR

METHODS

4.1 Experimental design, area selection and location of sampling points

A vegetation map of the study area was used to delineate the area into three study sites based on period when forest was last logged. The three sites were: unlogged area (control), area logged in 1995 (10 years earlier prior to the study) and area logged in 1999 (four years earlier prior to the study). This delineation was based on Forestry Commission's logging records. The study was based on a completely randomised design, with three treatment levels, namely unlogged, logged four years earlier (1999), and logged 10 years earlier prior to the study (1995). Sampling points were selected in each sampling site by super-imposing a grid system on an aerial photograph. The sampling points were located on the grid intercepts. Fifteen sampling points were randomly selected from each of the three sampling sites. A reconnaissance, followed by ground truthing was conducted at the beginning of March 2005. This had the purpose of ascertaining area boundaries, and confirming presence or absence of the tree species of interest.

Sampling commenced immediately after ground truthing in late March 2005. Selection criteria of sampling points were that the sampling point should have been dominated by *B. plurijuga*, with at least 15 to 20 plants along a 50 m long stretch, 25m on either side of the point. The sampling point should not have been burned since logging, hence charred and burnt logs were searched for as a means of verification. Sampling points, which did not meet these criteria, were discarded. The distances of sampling points from the Victoria Falls-Bulawayo road were estimated on the aerial photograph using strings to trace distances and map scales to estimate distances. They

were then located in the field by estimating distance from the main road to the sampling point with the assistance of a Global Positioning System instrument.

4.2 Demarcation of plots

At each sampling point, a 50-m string was laid so that half of the string was on either side of the sampling point. Fifteen to twenty individuals of *B. plurijuga* were then counted on either side of the stretched string (Walker, 1976). On getting this number of trees, counting stopped as such a point would qualify to be assessed. Assessment was carried out within the plot. Plots were, therefore, parallel to the 50m stretches, and formed the main plot. This produced plots of fixed length but variable width. Simultaneously, three sub-plots (measuring 5m x 5m) were randomly placed within the main sampling plot for the assessments of saplings. Three smaller subplots (measuring 1m x 1m) were randomly placed in each sapling subplot for the assessment of seedlings.

4.3 Measurement and assessment of woodland structure

4.3.1 Plot counts

For each plot, *B. plurijuga* individuals were assessed for basal diameter and height, whilst other tree species were merely identified and counted. In this study, trees were defined as plants with a basal diameter of 0.060 m or more, and a height of 3 m or more. Saplings were defined as woody plants with a basal diameter of between 0.01 m and 0.059 m, but less than 3 m in height. Individuals less than 1 m in height were regarded as seedlings. In order to be included in the assessment, at least half the rooted stem of the plant had to lie within the plot in the case of multiple-stemmed shrubs, and live foliage lying within the plot was measured (Guy, 1981). Unless

multi-stemmed trees were distinctly joined at the base, the stems were measured separately. Multi-stemmed individuals with an average stem diameter of 0.06 m or more were regarded as trees, and each stem was recorded separately (Guy, 1981). Seedling heights were measured using a ruler, whilst those for other plant species were only identified and counted. Species that could not be identified were given identity letters, enumerated, their specimens collected and pressed, and taken to the National Herbarium for later identification.

4.3.2 Measurement of basal diameter and height

A tape measure was used to measure stem circumference of *B. plurijuga* 0.3 m above the base of the stem. The data was used to calculate the basal area using, $ba = (C)^2/4\pi$ where *C* stands for basal circumference and *ba* stands for basal area. For multi-stemmed trees, the basal circumference of each stem was measured separately and total basal area calculated. The heights of *B. plurijuga* were estimated by use of ranging rods. The data was entered in a field data sheet, which recorded logging state, *B. plurijuga* tree height, circumference, basal area and other tree species

4.3.3 Assessment of saplings and seedlings

The number of saplings was counted in three sub-plots each measuring 5m x 5m located at random within each tree-sampling plot. The height of each sapling was estimated using a ranging rod. Basal circumference was measured with a tape measure. The assessment of seedlings was done on three sub-plots measuring 1m x 1m located at random within each sapling-sampling plot. The height of each seedling was measured with a ruler from the base of the stem to the apical end. Data were recorded on field data sheets.

4.3.4 Assessment of stumps

Stumps of *B. plurijuga* were identified and counted in each plot. Each stump's status (with or without coppices) was recorded. Basal circumference was measured using a tape measure. Stumps represented clear evidence of logging.

4.4 Measurement of explanatory variables

4.4.1 Soil sampling

Soil samples were collected from three random points in the main plot. At each point, plant litter was removed prior to collection of the soil sub-sample. Soil samples were collected using a soil augur. Sub-samples were collected from a depth of 0.60 m. Soils from each plot were bulked to form a composite sample, and bagged for later determination of pH, nitrogen, phosphorus and potassium at the Soil Science and Engineering laboratory, University of Zimbabwe.

4.5 Data analyses

Hierarchical Cluster Analysis (HCA) (MINITAB, 2000) using average linkage method was performed on a matrix of 45 plots by 48 species to generate clusters of sample plots based on species presence/absence data. Cluster analysis develops meaningful aggregations, or groups, of entities based on a large number of independent variables (McGarigal, Cushman and Stafford, 2000). Its objective is to classify a sample of entities into a smaller number of usually mutually exclusive groups based on the multivariate similarities among entities (McGarigal, *et al.*, 2000). Average linkage is at times called unweighted pair-group average and it designates distance values between groups to be the average dissimilarity between clusters. When two clusters agglomerate, their dissimilarity is equal to the mean of the

distances between each entity in one cluster with each entity in the other cluster. The entities or clusters that have the lowest mean distance value detect fusion. This algorithm maximises the correlation between input dissimilarities and output dissimilarities implied by the resulting dendrogram (McGarigal, *et al.*, 2000).

Detrended Correspondence Analysis (DCA) (ter Braak, 1986, 1995, Gauch, 1982) was performed on species presence/absence data to elucidate relationships amongst the various plant associations and underlying environmental gradients (Mapaure, 2001). DCA is a reciprocal averaging technique, whose objective is to remove the arch effect and to compress the axis (McGarigal, *et al.*, 2000). 'Detrending' to eliminate the arch effect is accomplished by dividing the first axis into a number of equal segments, and within each segment, adjusting the ordination scores to a mean of zero. DCA has the advantage of being able to handle large, complex data sets, and uncovering extremely long ecological gradients, and has no arch effect. This technique performs well when data have non-linear and unimodal distribution (McGarigal, *et al.*, 2000). Its most important limitation is its sensitivity to outliers and discontinuities in the data, and its poor performance with skewed variable distributions (Palmer, 1993).

Canonical Correspondence Analysis (CCA) (ter Braak, 1987, 1988) contained in the programme package CANOCO version 4.0 (ter Braak, 1998) was used to explore species-environment relationships on the same species data set subjected to DCA. In this analysis, four explanatory variables were used. CCA is a hybrid of ordination and multiple regression (McGarigal, *et al.*, 2000). It arranges species along environmental variables and constructs those linear combinations of environmental variables, along

which the distributions of species are maximally separated (ter Braak, 1987). In this technique, ordination axes are constrained to linear combinations of environmental variables. The technique is used for detecting species–environment relationship, and for investigating specific questions about the response of species to environmental variables (ter Braak, 1987). In the CCA ‘triplot’, the distribution of species and sample points jointly represent the dominant ecological relationships as they are explained by explanatory variables (McGarigal, *et al.*, 2000). The explanatory variables from the second matrix are plotted in the CCA triplots as arrows emanating from the grand mean of all explanatory variables (ter Braak, 1986). The arrows in the ordination space indicate the direction of maximum change in each structuring variable with its length being equal to the rate of change of the weighted averages. CCA provides a measure of species distributions change along that explanatory variable, and the length indicates the importance of an environmental variable (McGarigal, *et al.*, 2000). The location of species points relative to the arrows indicates the characteristics of the ecological optima of each species (variable (McGarigal, *et al.*, 2000). The significance of the relationship between floristic and environmental variables was tested with the Monte Carlo permutation test, which contained within programme package CANOCO. This is a test of significance obtained by repeatedly shuffling (permuting) the sample (ter Braak and Smilauer, 1988).

Statistical significance of differences in the size class distribution patterns of the species among three areas was carried out using Chi-squared test. Size class structure of *B. plurijuga* was explored through the analysis of size class data. This gives an indication of recruitment at any one particular stage in the population’s history.

Data for species counts was used to calculate the Shannon-Weiner's Diversity index (H') (Ludwig and Reynolds, 1988) for each plot. These indices were then tested for normality using Kolmogorov-Smirnov test and were found to be normal. The indices were subjected to One-way ANOVA found in programme package MINITAB (MINITAB, 2000) to elucidate differences in diversity for each plot with logging status as a factor. There were areas that had never been logged, areas that were logged four years earlier, and areas that were logged ten years earlier. Treatments were: never logged (1), logged in 1995 (2) logged in 1999 (3). The Shannon-Weiner's Diversity index was used because it is simple to use. It is calculated by: $H' = -\sum (p_i) (\ln p_i)$, where H' is the index of species diversity, p_i = proportional abundance of species i , and \ln = natural logarithm (Krebs, 1972). This index incorporates both species richness and evenness into a single value (Ludwig and Reynolds, 1988). It is a measure of 'uncertainty' in predicting to what species one individual chosen at random from a collection will belong (Ludwig and Reynolds, 1988). This 'uncertainty' increases as the number of species increases, and as the distribution of individuals among species becomes even (Ludwig and Reynolds, 1988). Diversity indices can be used to evaluate the intensity of resources used by human populations, and can also help to determine a minimum area necessary for a native population based on data on resources used (Begossi, 1996). The Shannon-Weiner's Diversity index is regarded as having a moderate sensitivity to sample size (Maguran, 1988).

Data for explanatory variables, namely pH, N, P and K were tested for normality using the Kolmogorov-Smirnov test, and were found to be normally distributed. There

was no need for transformation of the data. Data were subjected to One-way ANOVA with each environmental variable as factors and logging period as treatments.

Data for tree density and stump density were tested for normality using the Kolmogorov- Smirnov test and was found to be not normal. Log-transformation using $\text{Log}_{10}(x + 1)$ was tried prior to testing the data for normality again using the above test. The data still could not pass the normality test. Due to failure of transformation, a non-parametric procedure was then employed. The significance of the two variables was then tested using Kruskal-Wallis test.



CHAPTER FIVE

RESULTS

5.1 Species composition and population structure of *B. plurijuga* in the sampling areas

A total of 824 woody species in the unlogged area, 549 in the area logged in 1995 and 603 in the area logged in 1999 were recorded (Appendix 23). Two hundred and forty three individuals of *B. plurijuga* were encountered in the unlogged area, 239 in the area logged in 1999 and 244 in the area logged in 1995 (Appendix 6). Size class distribution followed almost the same overall pattern in the unlogged area, area logged in 1995 and area logged in 1999 (Figure 5.1, Figure 5.2, Figure 5.3 and Figure 5.4). The graphs show roughly an inverse 'J size class distribution' with the greatest proportion of individuals in the lower diameter size class. The only difference was the greater proportion (and absolute densities) of individuals (size class <0.100 m) in the area logged in 1995 than in the unlogged area and in the area logged in 1999 (Figure 5.4). No *B. plurijuga* trees were recorded in the 0.501-0.600 m and 0.601-0.700 m classes in the unlogged area, area logged in 1995 and area logged in 1999 (Figure 5.1, Figure 5.2 and Figure 5.3). In the unlogged area there was a small proportion of trees in the 0.701-0.800m diameter size class but they were none in the area logged in 1999 and in the area logged in 1995 (Figure 5.1, Figure 5.2 and Figure 5.3). Results indicate that the highest proportion of trees in the 0.301-0.400 m diameter class was in the unlogged area (Figure 5.4). Basal diameter size classes were significantly different in the unlogged area, area logged in 1999 and area logged in 1995 ($X^2 = 20.721$, $df = 10$, $p < 0.05$) (Appendix 16).

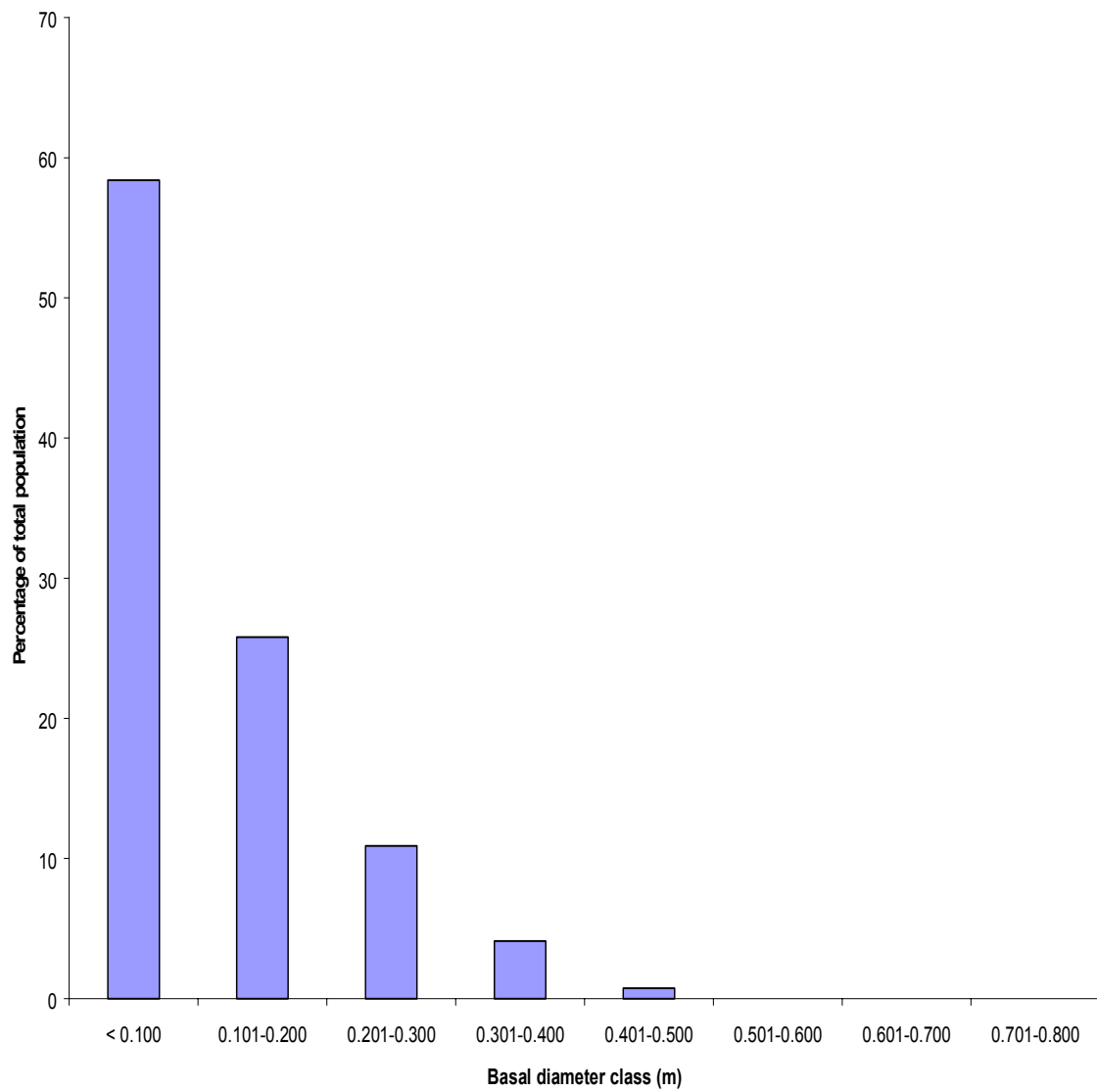


Figure 5.1: Basal diameter classes of *B. plurijuga* in an area logged in 1995 in Gwayi Forest

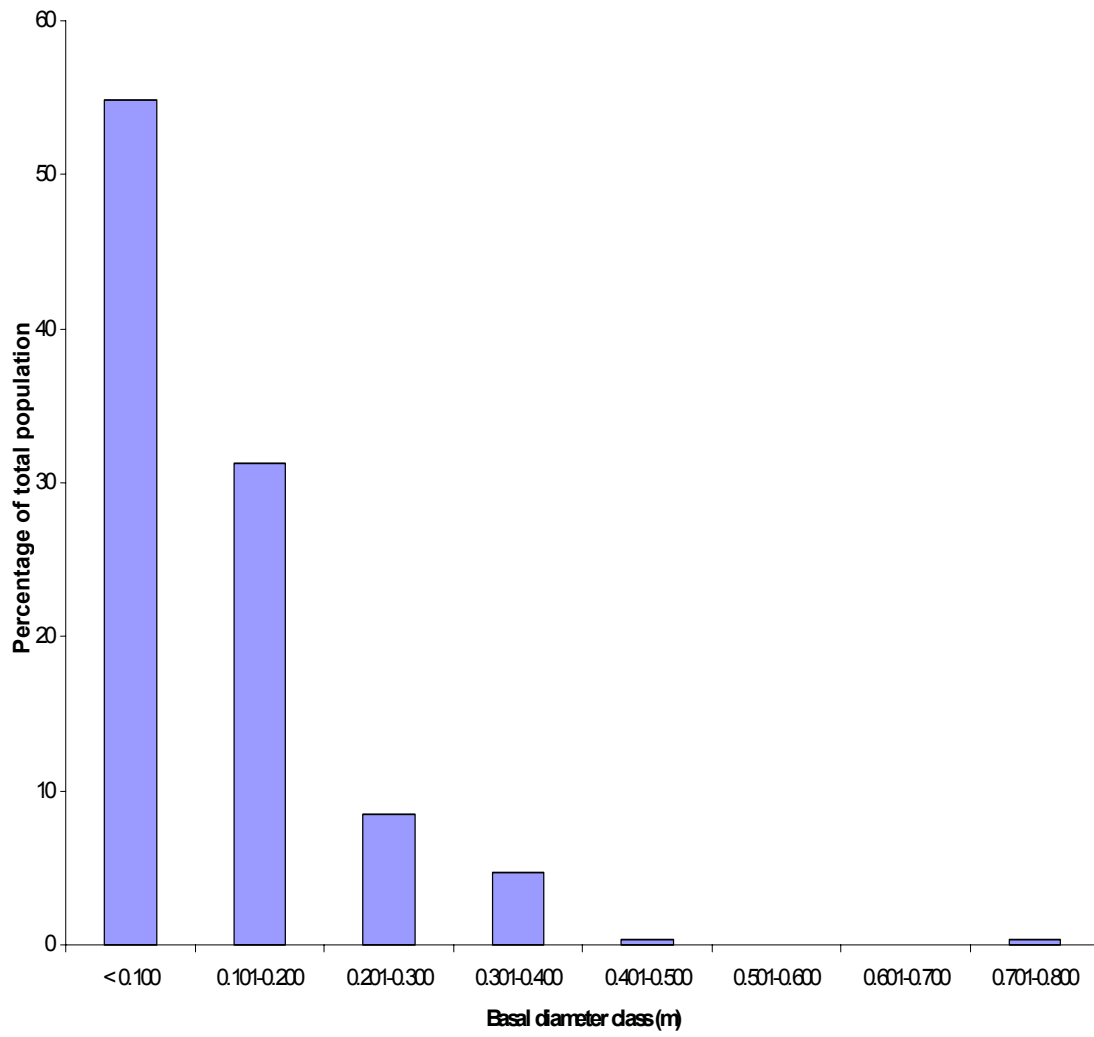


Figure 5.2: Basal diameter classes of *B. plurijuga* in an unlogged area in Gwayi Forest

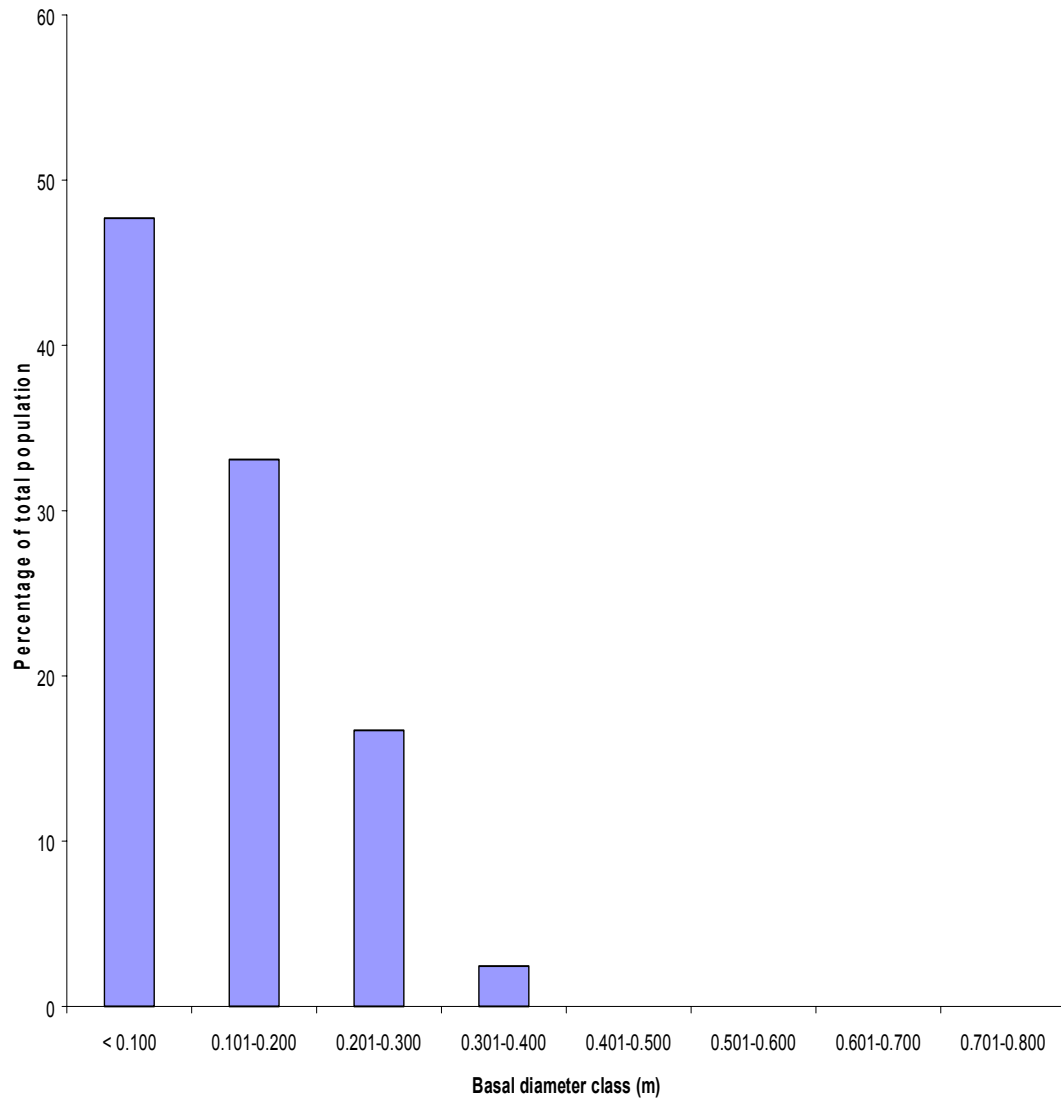
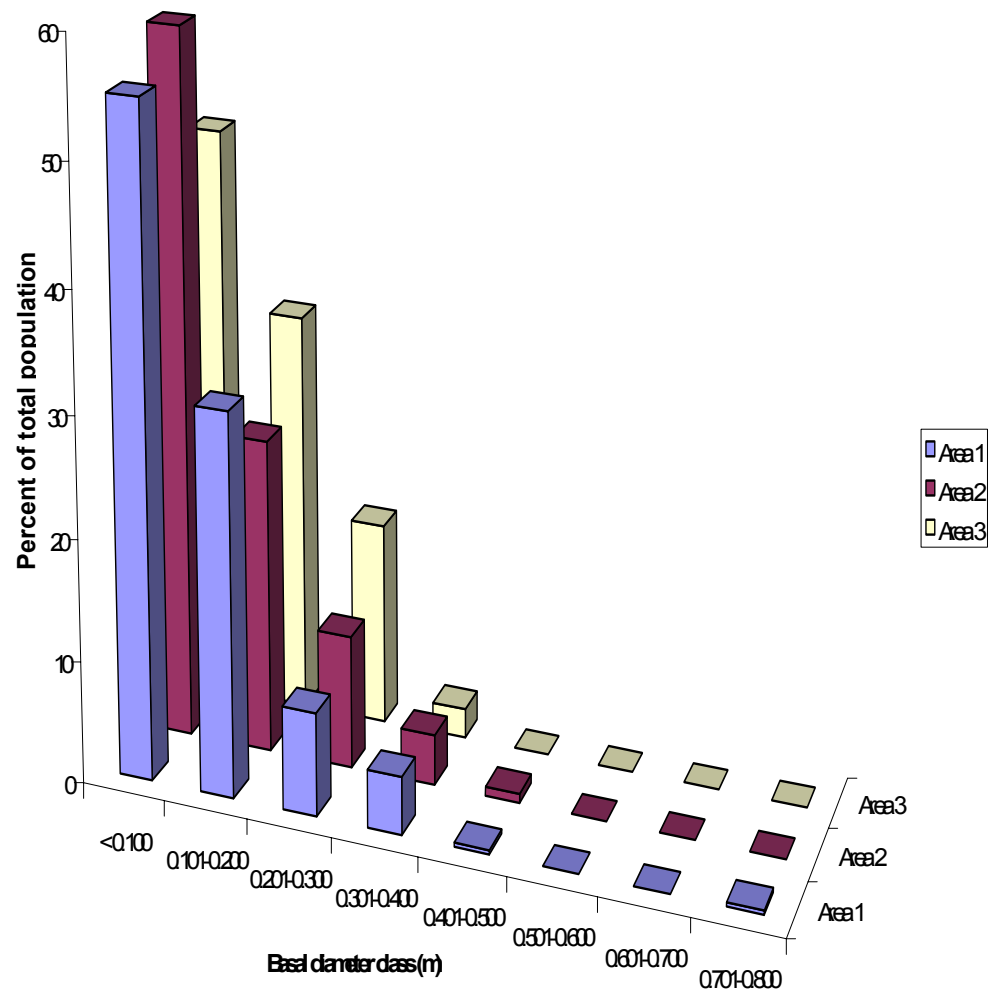


Figure 5.3: Basal diameter size classes in an area logged in 1999 in Gwayi Forest



(Area 1 represents unlogged area, Area 2 represents area logged in 1995 and Area 3 represents area logged in 1999)

Figure 5.4: Basal diameter classes in the unlogged area, area logged in 1995 and area logged in 1999 in Gwayi Forest

5.2 Species richness and species diversity

Data for calculating richness and diversity is in Appendix 23. Highest richness of 11 was found in Plots 4 and 5 found in an unlogged area and Plot 30 found in an area logged in 1995 (Appendix 13). The least richness was found in Plot 29 found in an area logged in 1995 and Plot 45 found in area logged in 1999. Highest mean richness was in the unlogged area and in the area logged in 1999 (Figure 5.6). Highest diversity was found in Plot 6 found in an unlogged area whilst lowest diversity was found in Plot 29 located in an area logged in 1995 and plot 45 located in area logged in 1999 (Appendix 13). Mean diversity was highest in the unlogged area and lowest in the area logged in 1995 (Figure 5.5). Results show that richness was highest in the area logged in 1995 and lowest in the area logged in 1999 (Appendix 23). There was no significant difference in species diversity, species richness, basal area, seedling regeneration and sapling regeneration ($F=1.37$, $P>0.05$; $F=0.023$, $p>0.05$; $F=2.38$, $p>0.05$; $F = 0.47$, $p > 0.05$; $F=0.84$, $p>0.05$) (Appendices 5, 9, 10, 21 and 22) respectively among the three sampling areas.

Table 5.1: Species richness and diversity in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

Area	Richness	Diversity (H')
Unlogged	29	2.39
Logged in 1999	28	2.26
Logged in 1995	33	1.90

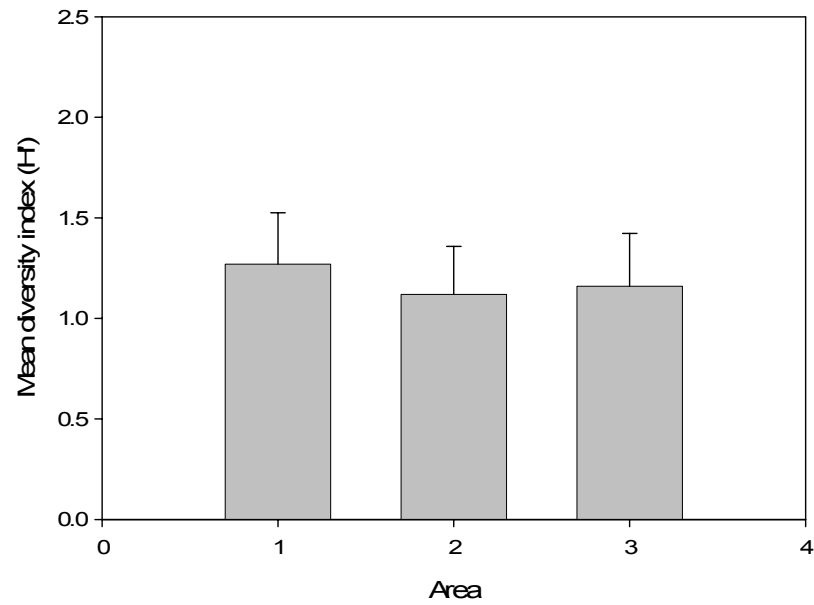


Figure 5.5: Differences in mean diversity in an unlogged area, area logged in 1999 and an area logged in 1999

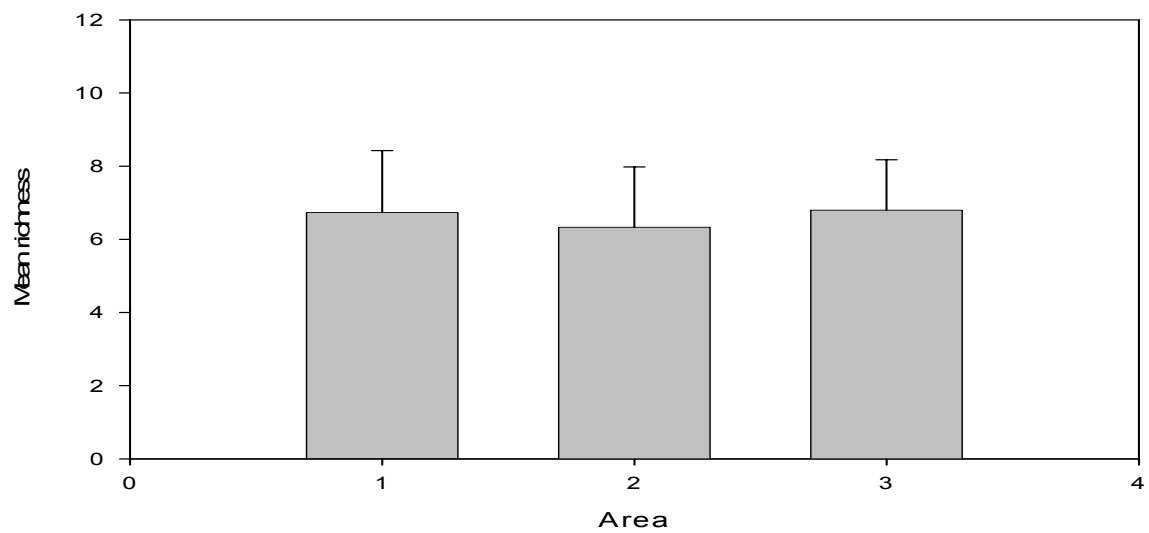


Figure 5.6: Differences in mean species richness in an unlogged area, areas logged in 1995 and 1999 (Area 1 represents the unlogged area, Area 2 logged in 1995 and Area 3 logged in 1999)

5.3 B. plurijuga densities, basal area, extent of logging and regeneration

Tree density was highest in the unlogged area. Density was similar in areas logged in 1999 and 1995 (Appendix 13). Results indicate that the tree and stump densities of *B. plurijuga* trees between the unlogged area, area logged in 1995 and area logged in 1999 were not significantly different ($H = 43.27, p > 0.05$; $H = 0.19, p > 0.05$) (Table 5.4, Appendix 7 and 8) respectively. Total basal area was highest in the unlogged area and lowest in the area logged in 1999 (Table 5.3). Mean basal area was highest in the unlogged area and lowest in the area logged in 1999 (Figure 5.7). Stump density was higher in the area logged in 1999 than in the area logged in 1995 (Table 5.2). Mean stump density was higher in the area logged in 1999 than in the area logged in 1995. Results indicate that more stumps were coppicing in the area logged in 1999 than in the area logged in 1995 (Table 5.5, Appendix 12). The density of seedlings was highest in the area logged in 1999 and lowest in the area logged in 1995 (Table 5.5). Mean number of seedlings was highest in the area logged in 1995 and lowest in the area logged in 1999 (Figure 5.9). The density of saplings was highest in the area logged in 1999 and lowest in the unlogged area (Table 5.5). The mean number of saplings was highest in the area logged in 1995 than in the area logged in 1999 (Figure 5.10). The highest number of seedlings, saplings and trees were recorded in the area logged in 1995 and the lowest was recorded in the area logged in 1999 (Figure 5.11). Approximately the same percentage of seedlings (<0.01m) that were recruited into the saplings basal diameter class (0.01-0.599 m) in the unlogged area was the same as the percentage number of saplings that were recruited into the tree basal diameter class (> 0.06m). In the area logged in 1995, fewer seedlings recruited into the saplings diameter class. More seedlings recruited into the saplings diameter

class in the area logged in 1999. In the unlogged area, more saplings were recruited into the tree basal diameter class. In the area logged in 1995, fewer saplings were recruited into the tree basal diameter class. In the area logged in 1999, more individuals were recruited into the tree basal diameter class.

Table 5.2: Density of *B. plurijuga* and extent of logging in an unlogged area, area logged in 1999 and area logged in 1995

Area	Tree density/ha	Stump density/ha
Unlogged	0.033	0
Logged in 1999	0.004	0.021
Logged in 1995	0.004	0.020

Table 5.3: Total basal areas in square metres for *B. plurijuga* in unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

Area	Total basal area in square metres
Unlogged area	6.729
Area logged in 1999	4.5144
Area logged in 1995	5.4631

Table 5.4: Summary of the Kruskal-Wallis test results of tree and stem densities in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

Areas	Variable	H-value	p-value	df
1, 2 and 3	Tree density	43.27	0.460	43 (adj)
	Tree density	38.48	0.668	43
2 and 3	Stump density	0.19	0.663	1

(Area 1 represents unlogged, Area 2 represents logged in 1995 and Area 3 represents logged in 1999)

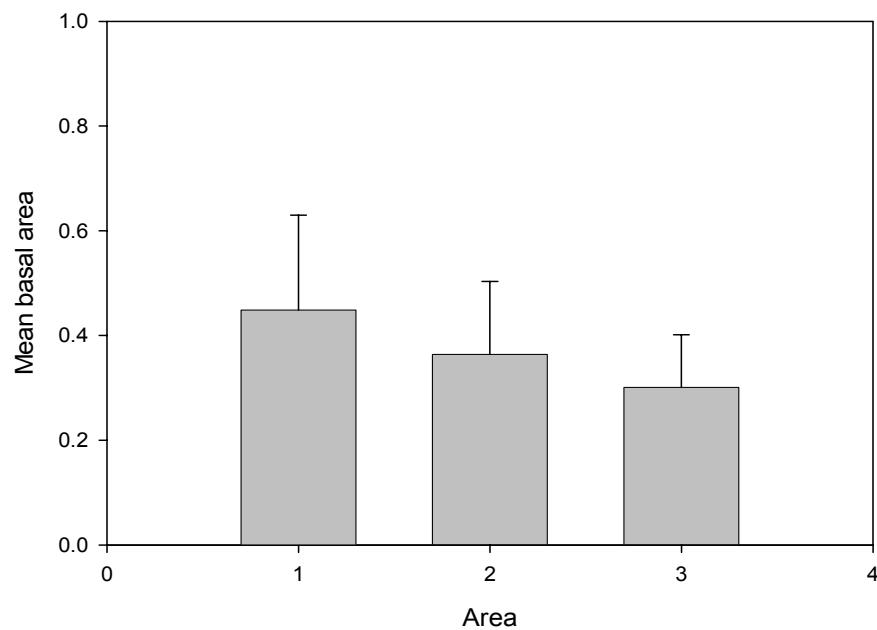


Figure 5.7: Differences in mean basal area in an unlogged area, Area logged in 1999 and Area logged in 1995 in Gwayi Forest (Area 1 represents an unlogged area, Area 2 represents the area logged in 1995 and Area 3 represents area logged in 1999)

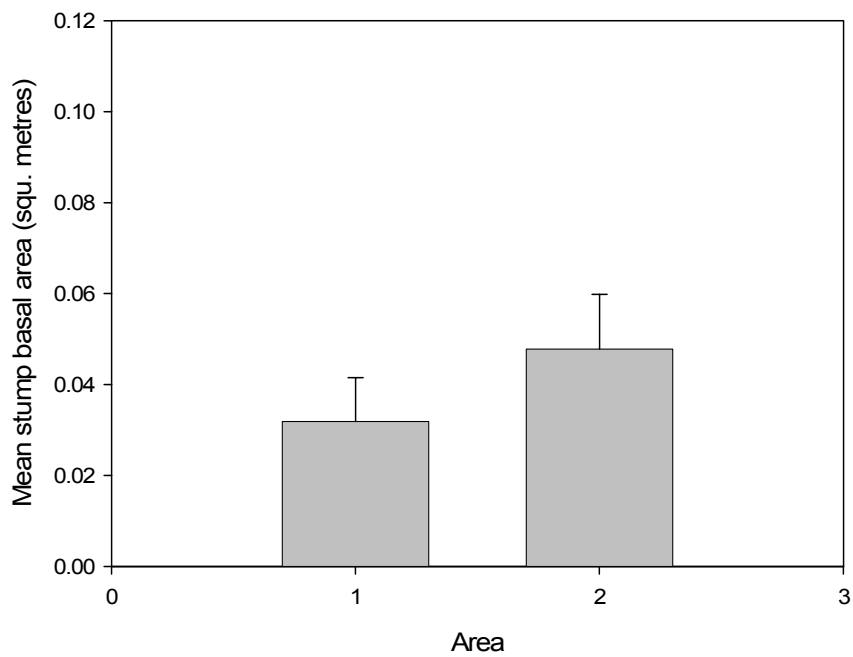


Figure 5.8: Differences in mean stump densities in an area logged in 1999 and an area logged in 1995 (Area 1 represents area logged in 1995 and Area 2 logged in 1999)

Table 5.5: Regeneration of *B. plurijuga* in an unlogged area, area logged in 1999 and area logged in 1995

Area	% Stumps coppicing	Seedlings/ha	Saplings/ha
Unlogged	0	0.042	0.045
Logged in 1999	57.4	0.0610	0.061
Logged in 1995	22	0.0414	0.047

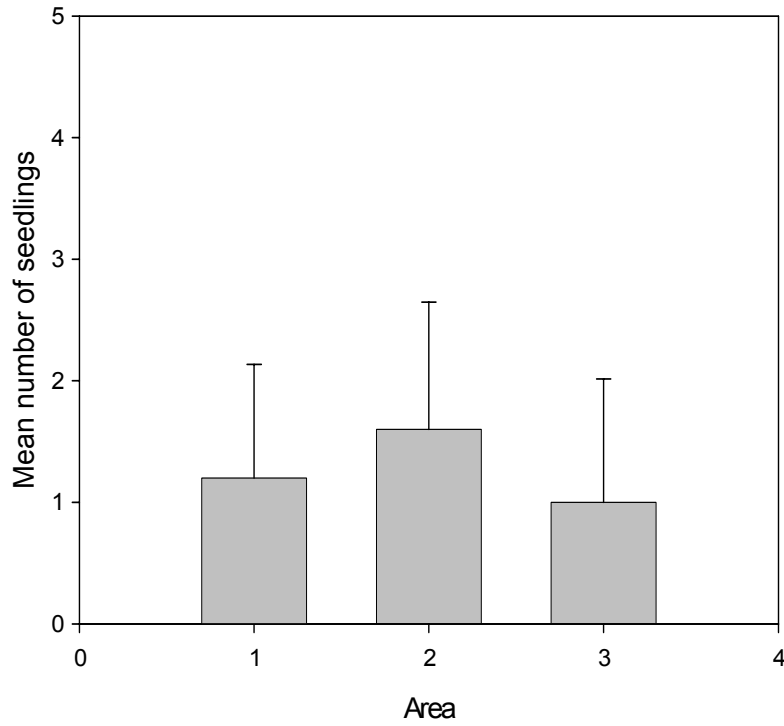


Figure 5.9: Mean number of seedlings in an unlogged area, area logged in 1999 and an area logged in 1995 (Area 1 represents the unlogged area, Area 2 logged in 1995 and Area 3 logged in 1999)

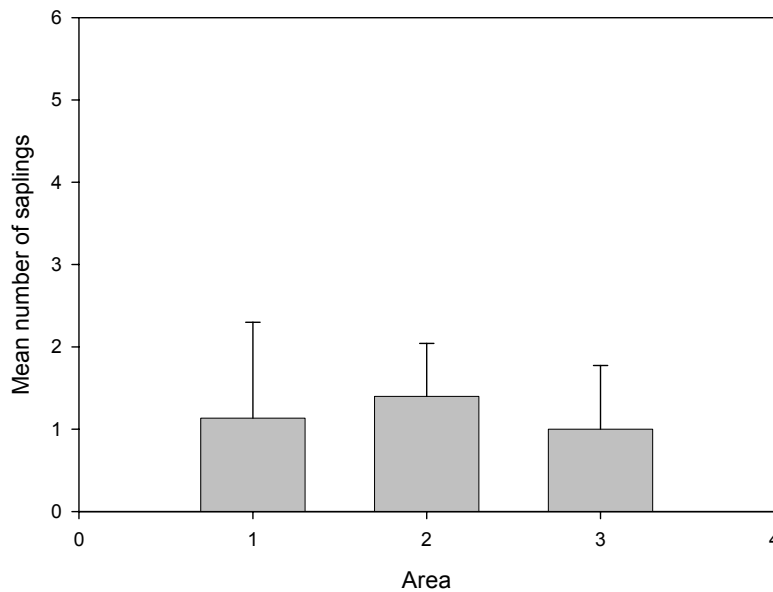


Figure 5.10: Differences in mean number of saplings in the logged area, area logged in 1999 and area logged in 1995 in Gwayi Forest (Area 1 represents an unlogged area, Area 2 logged in 1995 and Area 3 logged in 1999)

5.4 Vegetation classification

Presence/absence data used in this analysis is in Appendix 24. Based on species presence/absence data, seven floristic associations can be identified on the dendrogram (Figure 5.11). The species presence/absence matrix used in the multivariate analysis is presented in Appendix 24. Three plots from the unlogged area were grouped into one cluster with more than 65% similarity. These plots were dominated by *B. plurijuga*. The other common tree species were: *Terminalia sericea* and *Pterocarpus angolensis*. The plots were found in an area that is characterised by deep, brown well-drained sandy soils. Cluster 2 had seven plots, all from the unlogged area. The dominant tree in these plots was *B. plurijuga*. Other common trees species were *Croton gratissimus* and *Commiphora mollis*. The plots were found in an area with sandy, deep, brown and well- drained soils. The third cluster comprised five plots, two coming from an area logged in 1995 and three from an unlogged area. The

common tree species was *Croton gratissimus*. Cluster 4 had two plots, both from an area logged in 1995. Dominant tree species is *B. plurijuga*. Other common tree species are *Commiphora mollis*, Acacia species, *Combretum apiculatum* and *Combretum collinum*. The soils were deep, brown and sandy. Cluster 5 had eight plots, two from an area logged in 1999 and six from an area logged in 1995. *B. plurijuga* dominates these plots. *Commiphora mollis* was the common tree species in these plots. Cluster 6 had fifteen plots, two from the unlogged area, and thirteen from an area logged in 1999. The plots had brown, deep and well-drained soils. The dominant tree was *B. plurijuga*. Other common trees were: *Strychnos pungens*, *Diplorynchus condylocarpon*, *Combretum collinum*, *Terminalia sericea* and *Combretum molle*. Cluster 7 comprised five plots, all from the area logged in 1995. These plots were found in a gentle sloping area, with deep and well-drained soils. *B. plurijuga* was the dominant tree. Other common trees were *Grewia vertinevis*, *Commiphora mollis* and *Combretum molle*.

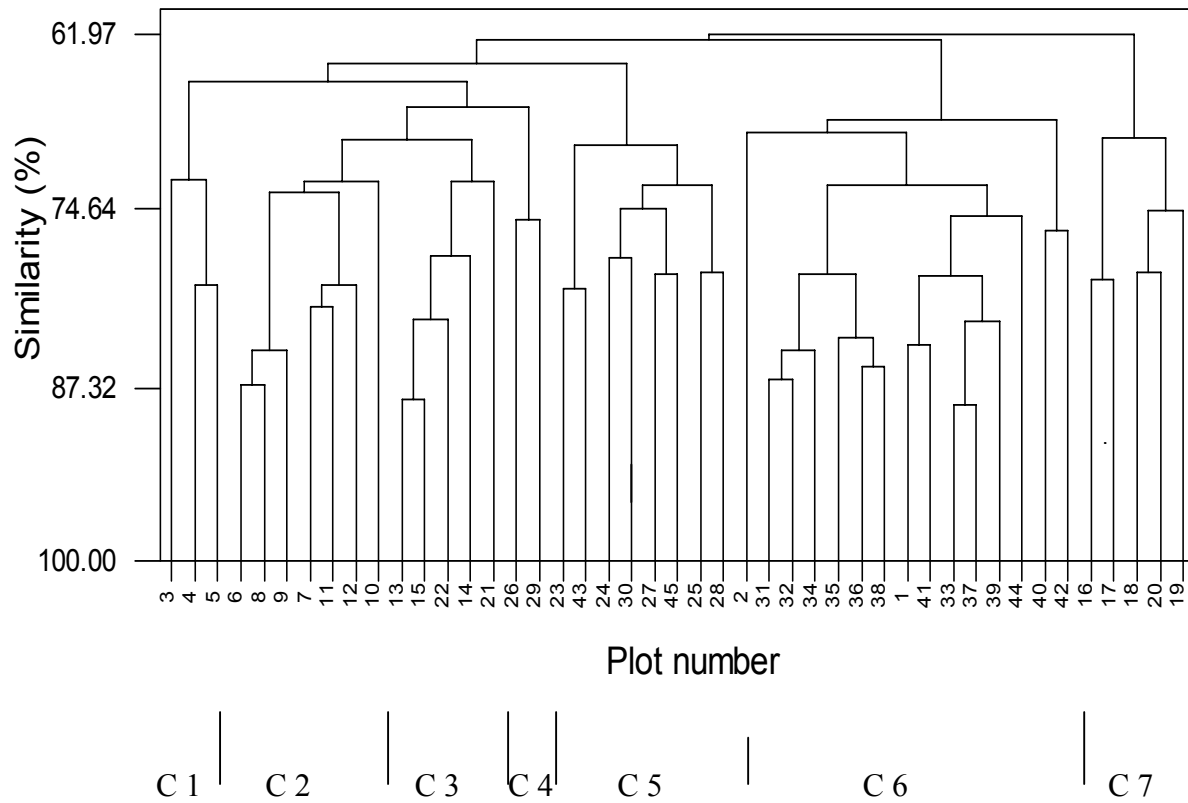


Figure 5.11: Hierarchical Cluster Analysis dendrogram showing classification of vegetation plots based on species presence/ absence data (C represents cluster, for example, C 3 represents cluster 3)

5.5 Species–environmental relationships

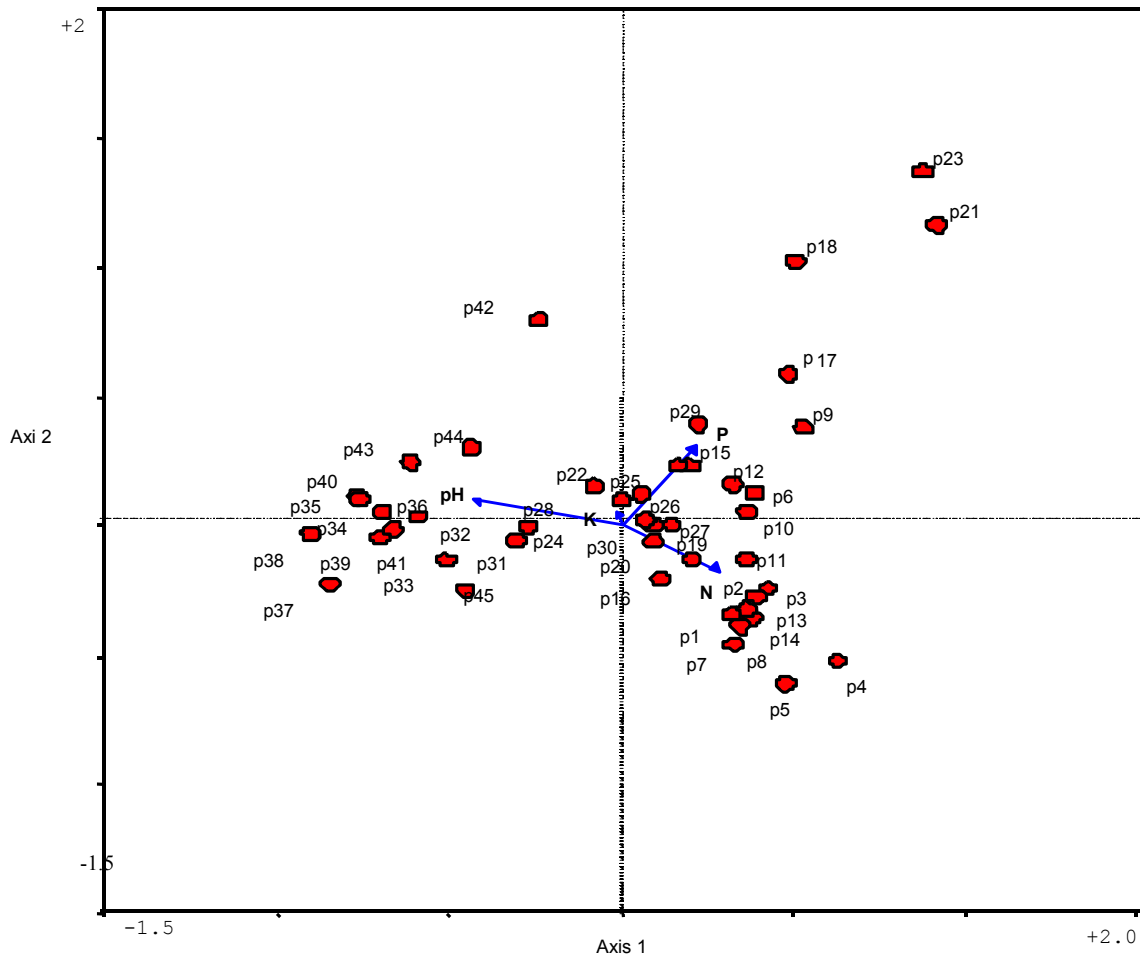
Presence/absence data for this analysis is in Appendix 24. Results of Canonical Correspondence Analysis (CCA) applied to four environmental variables and forty five plots indicates that that axis 1 accounted for 23.2% of observed variation, whereas Axes 2, 3 and 4 account for 12.8%, 10% and 6.7%, respectively (Table 5.6 and Appendix 18). The forty-five plots were separated by visual inspection into three groups. Group 1 (18, 21 and 23) are found in an area logged in 1995 and common

species are *Combretum molle* and *Combretum zeyheri*. The dominant species in all the forty-five plots was *B. plurijuga*. Group 2 (44, 43, 40, 35, 34, 36, 32, 24, 41, 28, 45, 39, 37, 38, 42 and 31) were found in an area logged in 1999. Common species were: *Terminalia sericea*, *Strychnos pungens*, *Diplorhynchus condylocarpon*, *Combretum collinum* and *Combretum molle* (Figure 5.13). Group 3 (26, 33, 27, 19, 16, 20, 30, 25, 22, 29 and 17) were found in an area logged in 1995 and (11, 3, 7, 5, 4, 6, 10, 1, 2, 15, 13, 8, 12, 14 and 9) were found in an unlogged area. Common species were: *Commiphora mollis*, *Acacia* species, *Terminalia sericea* and *Combretum collinum*. The analysis showed that nitrogen was positively correlated with axis 1 ($r = 0.54$) and phosphorus positively correlated with axis 2 ($r = 0.16$). pH was negatively correlated with axis 1 ($r = -0.80$) and potassium was positively correlated with axis 2 ($r = 0.02$) (Appendix 18). pH was negatively correlated with phosphorus ($r = -0.10$) and nitrogen ($r = -0.49$) (Appendix 18). Phosphorus was positively correlated with Potassium ($r = -0.09$) and negatively correlated nitrogen ($r = -0.01$) (Appendix 18). Nitrogen was negatively correlated with Potassium ($r = -0.24$). Out of the 4 environmental variables involved in the analysis, Phosphorus ($F = 1.72$, $p < 0.05$) and pH ($F = 2.50$, $p < 0.05$) contributed significantly to the total variance of floristic data (Appendix 18). Arrows in Figure 5.13 show the environmental gradients, their relative importance and intercorrelation of environmental variables.

5.6 Indirect gradient analysis

In the DCA ordination including all forty-five plots, species composition corresponded best to the first axis than the second DCA axis. The total variation in species data explained along the first DCA ordination was 34% while 24.8 % was explained along the second (Appendix 19 and Table 5.6). Plots were separated into

three main recognisable groupings according to species composition. Detrended Correspondence Analysis showed clustering of plots that have never been logged, those that were logged in 1995 and those that had been logged in 1999. The first axis seems to be associated with phosphorus variation. The eigen values for the first two axes of the Detrended Correspondence Analysis were 0.34 and 0.248, respectively, and explained 15.5 % of species variance. Group 1 represents *B. plurijuga*, *Combretum collinum* and *Terminalia sericea*. Group 2 represents *B. plurijuga*, *Commiphora mollis*, *Terminalia sericea*, *Strychnos spinosa* and *Diplorrhynchus condylocarpon*. Group 3 represents *B. plurijuga*, *Commiphora mollis*, *Terminalia sericea*, *Combretum collinum*, *Grewia monticola* and *Grewia retinervis*.



(Axi 2 represents Axis 2)

Figure 5.12: CCA ordination plot showing influence of edaphic factors on the distribution of sample plots in Gwayi Forest

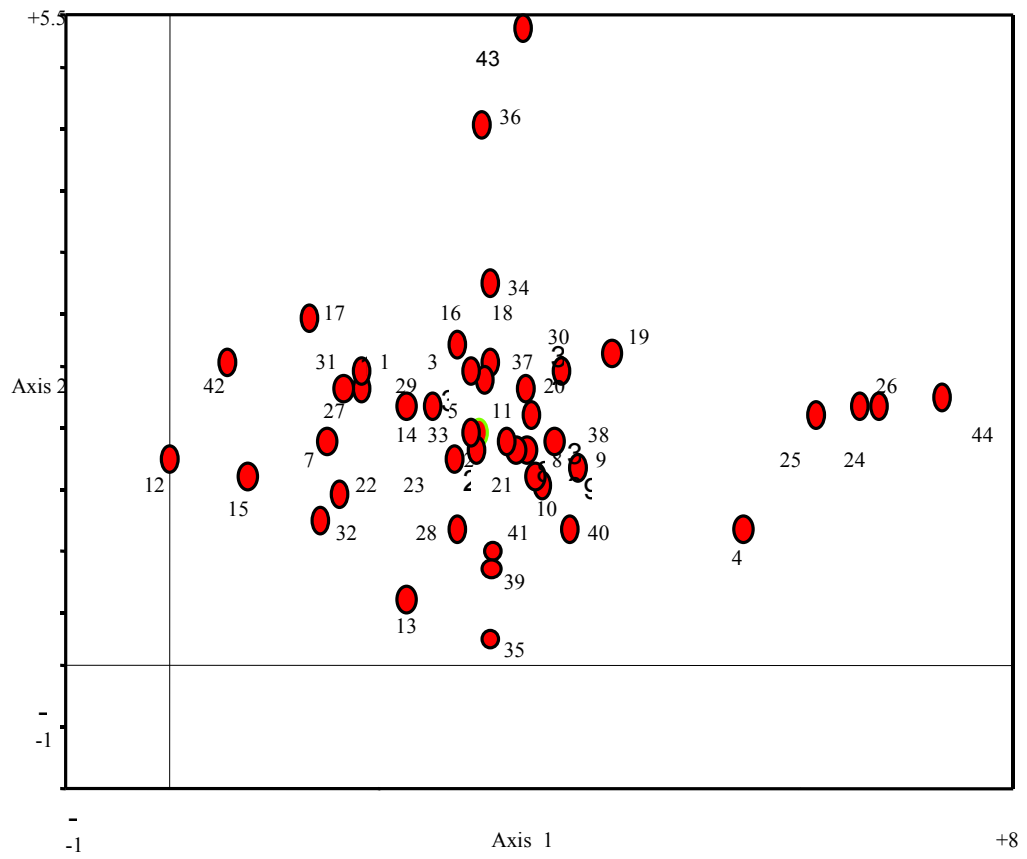


Figure 5.13: Position of forty five plots on the first two axes of DCA analysis

Table 5.6: Eigenvalues and percentage contribution of each component in the DCA and CCA analysis ordination of plots in Gwayi Forest

Dimension	Eigenvalue	Percentage contribution (%)	Cumulative percentage
(%) CCA			
1	0.232	23.2	44
2	0.128	12.8	68.4
3	0.100	10	87.3
4	0.067	6.7	100
DCA			
1	0.34	34	
2	0.248	24.8	
3	0.174	17.4	
4	0.132	13.2	

5.8 Influence of edaphic factors on vegetation distribution

Results show that mean Nitrogen (ppm) was highest in the unlogged area, and lowest in the area logged in 1999 (Figure 5.15). Differences in Nitrogen (ppm) were significant between the unlogged area, area logged in 1999 and area logged in 1995 ($F = 3.07$, $p < 0.05$, Appendix 4). Mean pH was highest in the area logged in 1999 and lowest in the area unlogged area (Figure 5.18). Differences in pH were significantly different in the unlogged area, area logged in 1999 and area logged in 1995 ($F = 9.20$, $p < 0.05$) (Appendix 1). Mean Phosphorus (ppm) was highest in the area logged in 1995 and lowest in the area logged in 1999 (Figure 5.17). Differences in soil Phosphorus (ppm) were not significant in the unlogged area, area logged in 1999 and area logged in 1995 ($F = 0.47$, $p > 0.05$, Appendix 2). Mean Potassium (me %) was highest in the area logged in 1995 and lowest in the unlogged area (Figure 5.16). Soil

Potassium (me%) of the unlogged area, area logged in 1999 and area logged in 1995 was not significantly different ($F = 0.85$, $p > 0.05$, Appendix 3).

Table 5.7 Summary of the significance of the effects of area variables on species composition in Gwayi Forest

Variable	F-ratio	p-value
Nitrogen (N)	3.07	0.006
Potassium (K)	0.85	0.556
Phosphorus (P)	0.47	0.850
pH	9.20	0.000

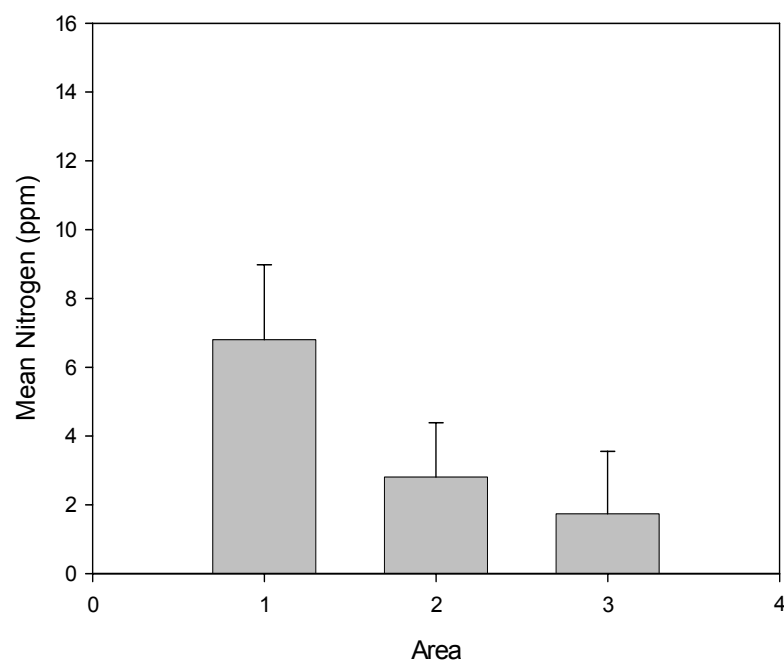


Figure 5.14: Differences in mean Nitrogen (ppm) in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

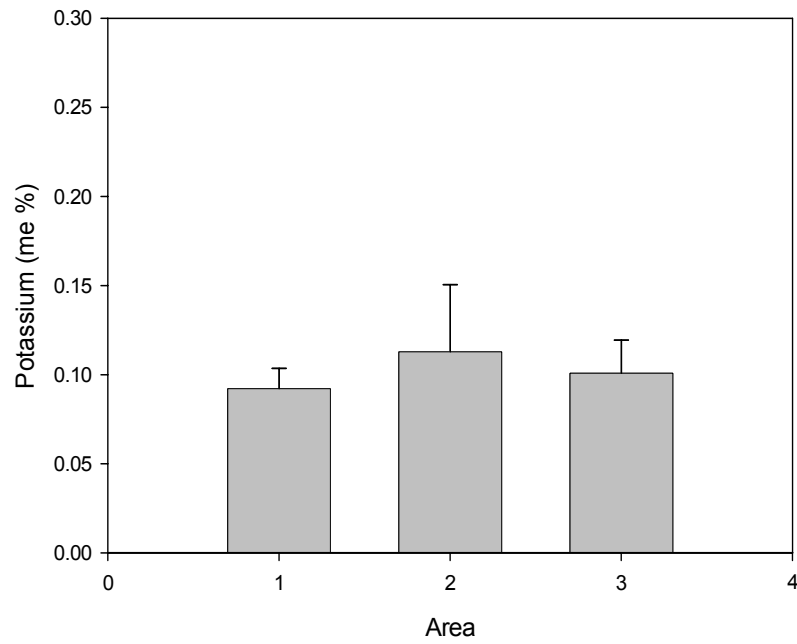


Figure 5.15: Differences in mean potassium (me%) in an unlogged area, area logged in 1999 and in an area logged in 1995 in Gwayi Forest

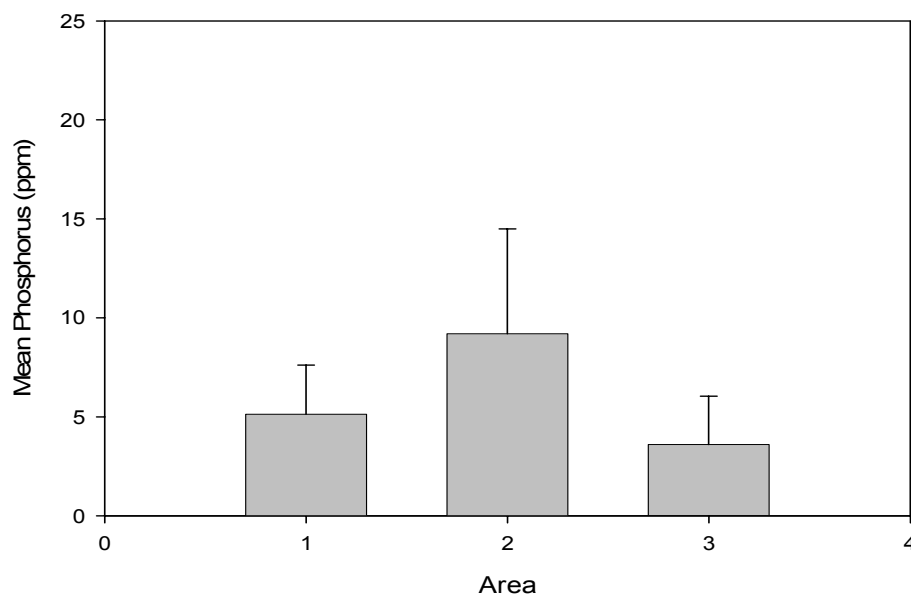


Figure 5.16: Differences in mean Phosphorus (ppm) content in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

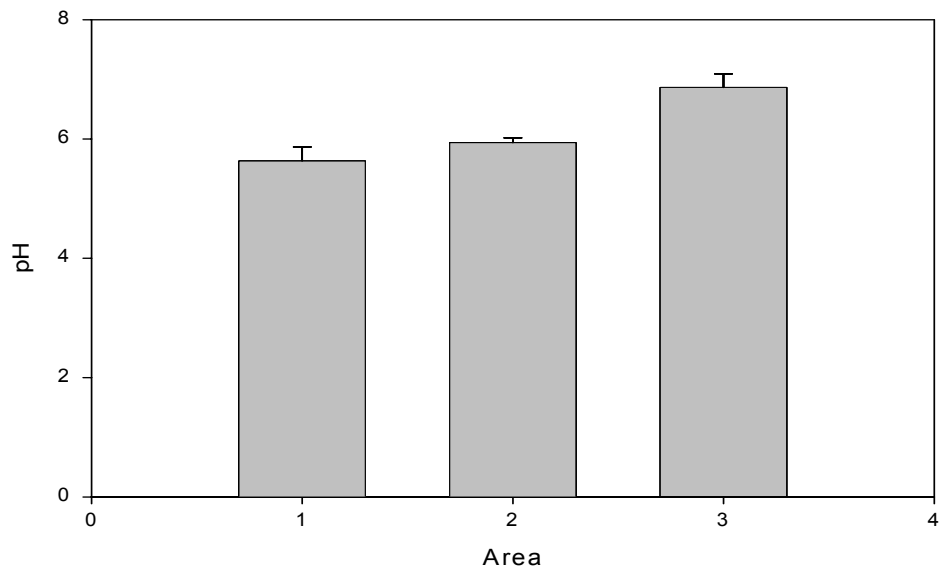


Figure 5.17: Differences in mean pH in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

CHAPTER SIX

DISCUSSION

6.1 Population structure

An 'inverse J' size class distributions in the unlogged area, area logged in 1995 and area logged in 1999 suggests that logging did not affect size class. This represents a stable distribution. This could indicate the existence of a cohort of immature trees that may have experienced a disturbance (Campbell, 1988). An irregular size class distribution on the other hand, would suggest the presence of episodic recruitment and irregular growth patterns (Botha, Witkowski and Shackleton, 2000). The 'inverse J' shapes also gives an idea of the recovery potential of each area. It is possible that the areas logged in 1999 and 1995 were recovering from logging as indicated by the prevalence of *B. plurijuga* in lower size classes. This type of distribution suggests continuous regeneration (Judge, 1986) and possible recruitment of seedlings in the study areas.

The absence of trees in the 0.501- 0.600 m and 0.601-0.700 m diameter size class in the unlogged area cannot be explained by these results since one would expect to record trees in all diameter classes. The higher prevalence of individuals in the 0.301-0.400 m basal diameter class in the unlogged area when compared to the logged areas suggest that this could be the basal diameter size class that is targeted for during logging, hence its prevalence could be attributed to absence of logging. The presence of trees in the 0.701 m -0.800 m diameter class further confirms the absence of logging or significant disturbance in the unlogged area.

Significant differences in basal diameter size classes suggests that recruitment of *B. plurijuga* individuals from a lower size class to another was taking place at different rates in the unlogged area, area logged in 1999 and area logged in 1995. Bormann and Likens (1979) concluded that clear felling of a forest is a drastic disturbance that leads to rapid successional changes. The high prevalence of *B. plurijuga* in the seedling and sapling basal diameter size classes could suggest adequate regeneration through propagules in all the three sites. Higher densities of seedlings and saplings compared to that of larger trees could have been due to higher initial seedling and sapling recruitment and frequent deaths, which decline with time (Swaine and Liberman, 1987).

6.2 Diversity and richness

Diversity was not significantly different among the unlogged area, area logged in 1999 and area logged in 1995. This falsifies the alternative hypothesis that diversity was significantly different in the study areas. Some of the plots showing high diversity values were found in the unlogged area. The unlogged area could have had highest diversity since no trees were removed through logging. Herbivory was also not intense. Probably the unlogged area had species that were shade-tolerant and were not suppressed by shade. The findings are not consistent with the conclusion that vegetation removal leads to rapid growth which leads to increased species diversity (Kobayashi, Hori and Nomoto, 1977). Were this conclusion true, then highest mean diversity could have been in the logged areas and not in the unlogged area.

Lowest species richness in the area logged in 1999 could mean that the vegetation change was not yet complete or there was a permanent loss of some species caused by

the disturbance (Gotosa, 2002). Highest mean richness in the unlogged area could suggest that the canopy tree species did not suppress other tree species or the woody species growing there were shade-tolerant. Species richness in forests was also observed to be low. Species richness is reported to decline with increasing stand disturbance (Sabogal, 1992). This observation is consistent with the results obtained in this research.

6.3 Density and basal area

B. plurijuga in the unlogged area could have inhibited the establishment of other species (Connell and Slatyer, 1977). Higher stump density in the area logged in 1999 could suggest slightly higher logging intensity compared to the area logged in 1995. Alternatively, it could have been due to logging by timber poachers since the area logged in 1999 is closer to Lupane Growth Point where demand for timber and timber products is high. Highest basal area recorded in the unlogged area further confirms that logging was a major disturbance, which reduced the basal area. Lowest basal area in the area logged in 1999 confirms that logging could have been more intense than in 1995.

6.4 Regeneration of *B. plurijuga*

Differences in stump regeneration with higher numbers of coppicing stumps in the area logged in 1999 than in the area logged in 1995 could suggest that some of the stumps that were logged in 1995 could have died as a result of cutting and inadequate moisture in the 1995/1996 rain season (Gambiza, 2001). Moisture is critical for regeneration. Any damage to a mature stem has been observed to inhibit future growth due to physiological stress (Tschaplinski and Blake, 1989; Baillie and Ashton,

1983). Furthermore, resprouting ability of trees is constrained by anatomy and physiology of the buds in stumps that are poorly cut (Paciorek, Condit, Hubbell and Foster, 2000). In 1995/1996 season, there was low rainfall. This could have resulted in the death of some stumps since regeneration is negatively correlated with shortage of moisture.

Differences in seedling and sapling abundance, with highest saplings and seedlings in the area logged in 1999 compared to other sites further confirm that adequate moisture is critical for regeneration. The results are consistent with findings that when a gap is created, suppressed seedlings are released and higher light levels are experienced in the gap (Ng, 1978; Oberbaur and Strain, 1985). Saplings and seedlings present on the site before gap creation may take advantage of the gap to grow towards the upper canopy of the forest (Ng, 1978; Oberbaur and Strain, 1985). De Steven (1991) showed that seedling survival and growth in early succession is selective due to influence of environmental factors and herbivore selection. Locally, the density of seedlings and saplings of *B. plurijuga* were observed to be high in the opened up areas than in unlogged areas (Chigwerewe, 1996). In the unlogged area, the establishment of seedlings could have been inhibited by the presence of large canopy trees, which limited the amount of light and nutrients reaching the soil. Furthermore, below average rainfall in 1994/1995 season could have resulted in the death of seedlings (Gambiza, 2001). Availability of moisture has been shown to affect seedling establishment (Walker, 1987).

6.5 Species associations

Plots separated according to the period of logging suggesting the importance of logging in forest structure. Cutting of wood has been observed to quickly bring irreversible changes in species composition, physiognomy and structure of vegetation leading to replacement of vegetation by dense, low thicket (Lieberman and Mingguang, 1992). The patterns observed could have been due to local variations in soil mineral content. Local variations in edaphic conditions involving features such as soil depth and soil reaction have been observed to strongly influence the distributions of many woodland species and result in the development of mosaics (Packham and Harding, 1982). The association between plots from the unlogged area, plots from an area logged in 1999 and in 1995 from hierarchical cluster analysis, DCA and CCA could suggest that there was recovery of vegetation from logging.

6.6 Effect of pH, Nitrogen, Phosphorus and Potassium on Species distribution

Significant differences in pH with the highest values in the area logged in 1999 cannot be explained by these results. With the removal of trees resulting in an increase in leaching, the soils could have become acidic. Low pH in the unlogged area could have been due to the abundance of organic matter leading to production of organic acids by microorganisms. The results are consistent with the conclusions by (Escudero, Garrido, Matias and Del Arco, 1988) that open woodlands cause strong spatial heterogeneity in environmental conditions due to shading and soil enrichment by tree crowns.

Significant differences in soil Nitrogen among the sampling areas with high values in the unlogged area could suggest that debris left after logging increased the amount of

organic matter which was later converted to ammonium compounds by micro organisms. Low nitrogen values in the area logged in 1999 suggest that logging reduced the amount of plant litter that fell into the ground. Consequently, the amount of organic material converted to ammonium compounds, and ultimately nitrogen, could have been reduced.

Highest mean potassium in the area logged in 1995 could be due to less leaching since vegetation recovery could have taken place. High potassium values were expected to be low in logged areas since leaching of highly soluble potassium could have been much more pronounced in the area logged in 1995 due to absence of canopy cover. Generally, the amount of soil potassium was significantly low since fertility is low in the Kalahari sands (Gambiza, 2001).

Phosphorus values were low according to the Bray method (Moukam and Nyakanou, 1997). This could have been due to intensity of land use in the area. In the unlogged area, grazing is a major form of land use, and this could affect phosphorus content. The highest phosphorus values in the area logged in 1995 could be due to the recovery of vegetation after logging. The lowest phosphorus values recorded in the area logged in 1999 could be a result of more intense logging. Low mean values of phosphorus could reflect high intensity of past land use (Moukam and Nyakanou, 1997). Zimbabwean soils are generally deficient in P, which explains why farmers are encouraged to supplement P to farm animals during the rainy season when much of it is leached away.

CONCLUSIONS

B plurijuga is exploited at basal diameter of between 0.3m and 0.4m for commercial use. At current rates of exploitation of *B plurijuga* in Gwayi forest, logging has no effect on size class distribution, species diversity, species richness, regeneration potential (through coppicing or seedlings) and stump density. This is explained by intensity of logging that is light and relatively selective. Differences in regeneration potential (coppicing and seedling) in areas logged in 1999 and 1995 could have been due to moisture availability and time since logging. Regeneration of *B. plurijuga* is mainly by basal sprouting and less through propagation by seedling.

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APPENDICES

Appendix 1: One-Way Analysis of Variance for variations in pH in Gwayi Forest

Source	DF	SS	MS	F	P
pH	17	24.711	1.454	9.20	0.000
Error	27	4.267	0.158		
Total	44	28.978			

APPENDIX 2: One-Way Analysis of Variance for variation of Phosphorus in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

Source	DF	SS	MS	F	P
P	7	2.440	0.349	0.47	0.850
Error	37	27.471	0.742		
Total	44	29.911			

Appendix 3: One-Way Analysis of Variance for variation of Potassium in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

Source	DF	SS	MS	F	P
K	7	4.135	0.591	0.85	0.556
Error	37	25.776	0.697		
Total	44	29.911			

Appendix 4: One-Way Analysis of Variance for Nitrogen variation in an unlogged area, area logged in 1999 and area logged in 1995 Gwayi Forest

Source	DF	SS	MS	F	P
N	11	15.128	1.375	3.07	0.006
Error	33	14.783	0.448		
Total	44	29.911			

Appendix 5: One-Way Analysis of Variance for diversity in an unlogged area, area logged in 1999 and area logged in 1995

Source	DF	SS	MS	F	P
Diversit	43	29.500	0.686	1.37	0.602
Error	1	0.500	0.500		

Total 44 30.000

Appendix 6: Total area sampled and number of *B. plurijuga* in unlogged area, area logged in 1995 and area logged in 1999 in Gwayi Forest

Area	Total area sampled	Total number of <i>B. plurijuga</i> trees
Unlogged	7644	243
Logged in 1999	9947.5	239
Logged in 1995	9915	244

Appendix 7: Kruskal-Wallis Test results for Area versus Tree Density in an unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

Tree Den	N	Median	Ave Rank	Z
0.518186	2	2.500	30.5	0.83
0.556803	1	3.000	38.0	1.15
0.633614	1	2.000	23.0	0.00
0.708346	1	2.000	23.0	0.00
0.709265	1	1.000	8.0	-1.15
0.754232	1	3.000	38.0	1.15
0.926309	1	1.000	8.0	-1.15
0.932112	1	1.000	8.0	-1.15
0.952266	1	2.000	23.0	0.00
0.984980	1	2.000	23.0	0.00
1.019496	1	3.000	38.0	1.15
1.025915	1	3.000	38.0	1.15
1.044186	1	3.000	38.0	1.15
1.085086	1	2.000	23.0	0.00
1.105005	1	3.000	38.0	1.15
1.110382	1	1.000	8.0	-1.15
1.133170	1	1.000	8.0	-1.15
1.154105	1	1.000	8.0	-1.15
1.165803	1	1.000	8.0	-1.15
1.195611	1	2.000	23.0	0.00
1.201209	1	1.000	8.0	-1.15
1.202353	1	2.000	23.0	0.00
1.221131	1	2.000	23.0	0.00
1.236533	1	1.000	8.0	-1.15
1.248825	1	2.000	23.0	0.00
1.248827	1	2.000	23.0	0.00
1.276066	1	3.000	38.0	1.15
1.344007	1	1.000	8.0	-1.15
1.369875	1	3.000	38.0	1.15
1.369995	1	3.000	38.0	1.15
1.369995	1	3.000	38.0	1.15
1.376622	1	2.000	23.0	0.00
1.395896	1	2.000	23.0	0.00
1.402567	1	1.000	8.0	-1.15
1.431954	1	3.000	38.0	1.15
1.441193	1	1.000	8.0	-1.15

1.444059	1	3.000	38.0	1.15
1.456586	1	2.000	23.0	0.00
1.506913	1	1.000	8.0	-1.15
1.519820	1	3.000	38.0	1.15
1.566603	1	2.000	23.0	0.00
1.593382	1	3.000	38.0	1.15
1.811675	1	1.000	8.0	-1.15
1.9736	1	1.000	8.0	-1.15
Overall	45		23.0	

H = 38.48 DF = 43 P = 0.668

H = 43.27 DF = 43 P = 0.460 (adjusted for ties)

Appendix 8: Kruskal-Wallis Test results for stump density versus logged area

Area	N	Median	Ave Rank	Z
Logged in 1995	15	0.005180	16.2	0.44
Logged in 1999	15	0.003900	14.8	-0.44
Overall	30	15.5		

H = 0.19 DF = 1 P = 0.663

Df= 20

Appendix 9: One-way Analysis of Variance for species Richness

Source	DF	SS	MS	F	P
Time	2	1.91	0.96	0.23	0.796
Error	42	174.67	4.16		
Total	44	176.58			

Appendix 10: One-way Analysis of Variance for comparing basal area in the unlogged area, area logged in 1999 and area logged in 1995

Source	DF	SS	MS	F	P
Time	2	0.1646	0.0823	2.38	0.105
Error	42	1.4544	0.0346		
Total	44	1.6190			

Appendix 11: Number of stumps per plot in an area logged in 1999 and area logged in 1995

Plot	Stumps/N	Stumps/C
16	5	1
17	0	0
18	1	2
19	2	1
20	4	1

21	4	0
22	2	0
23	1	1
24	2	1
25	3	0
26	3	1
27	1	1
28	3	1
29	3	0
30	5	1
31	1	0
32	2	1
33	1	3
34	1	1
35	2	1
36	1	3
37	1	1
38	1	2
39	2	1
40	2	2
41	2	5
42	1	1
43	2	1
44	1	2
45	0	3

Key

Stumps/N-Stumps not regenerating

Stumps/C-Stumps regenerating

Appendix 12: Chi-Square Test for comparing stump regeneration in the area logged in 1999 and in the area logged in 1995

	area		
	1995	1999	Total
Reg. Status 1	11 (19.59)	27 (18.41)	38
Reg. Status 2	39 (30.41)	20 (28.59)	59
Total	50	47	97

$$\text{Chi-Sq} = 3.765 + 4.005 + 2.425 + 2.580 = 12.775$$

$$\text{DF} = 1, \text{P-Value} = 0.000$$

Key

Reg. status- Regeneration status

(..)-E value

Site 1- Area logged in 1995

Site 2-Area logged in 1999

Appendix 13: Tree density, richness and diversity from sampling plots in Gwayi Forest

Plot number	Tree density	H	Richness
1	0.02	1.154105	7
2	0.03	1.165804	7
3	0.0209	1.506913	7
4	0.0273	1.811675	11
5	0.0197	1.9736	11
6	0.03478	1.402567	8
7	0.0545	0.709265	5
8	0.0588	0.932112	4
9	0.05313	1.344007	5
10	0.048	1.441194	9
11	0.035	1.20121	6
12	0.03214	1.236534	6
13	0.02833	1.110382	5
14	0.0475	0.926309	5
15	0.0459	1.13317	5
16	0.02957	1.376622	8
17	0.025	1.248827	7
18	0.0237	0.708347	4
19	0.02267	1.202354	6
20	0.0207	1.195612	6
21	0.03	0.984981	4
22	0.02727	1.395896	8
23	0.0323	1.248826	7
24	0.0133	1.456586	8
25	0.02326	1.221131	8
26	0.0283	1.085086	5
27	0.0536	0.633614	4
28	0.03448	0.952266	6
29	0.0298	0.518186	3
30	0.015075	1.566604	11
31	0.02454	1.105006	6
32	0.017	1.444059	7
33	0.029	1.369995	8
34	0.02677	1.593382	10
35	0.03	1.276066	8
36	0.0278	0.556804	8
37	0.027778	1.369875	8
38	0.019	1.044187	6
39	0.02459	1.431954	7
40	0.02133	1.519821	8
41	0.0411	1.369996	8
42	0.029	1.025916	5
43	0.01887	1.019497	5
44	0.01935	0.754232	5

45

0.022368 0.518186

3

APPENDIX 14: Measurements of environmental variables hypothesized to be influencing population structure and regeneration of *B. plurijuga* in Gwayi Forest

Plot	pH (0.01M CaCl_2)	Ppm P	Ppm N	Me% K
1	5.6	3	7	0.09
2	5.2	3	4	0.08
3	5.3	3	5	0.07
4	5.3	3	10	0.10
5	5.3	1	9	0.08
6	5.7	8	5	0.08
7	6.2	5	14	0.09
8	5.6	3	8	0.08
9	6.1	13	8	0.11
10	5.6	5	5	0.12
11	5.9	8	7	0.09
12	5.8	8	4	0.11
13	5.5	3	6	0.11
14	5.5	3	7	0.09
15	5.9	8	3	0.08
16	5.8	3	4	0.11
17	5.8	13	3	0.09
18	6.1	18	2	0.10
19	5.9	5	6	0.10
20	5.8	5	0	0.12
21	6.1	23	7	0.10
22	6.0	8	3	0.10
23	5.8	23	2	0.08
24	6.0	5	5	0.08
25	5.9	5	1	0.09
26	6.0	5	2	0.17
27	6.0	5	1	0.27
28	6.0	5	0	0.10
29	6.5	10	3	0.08
30	5.9	5	3	0.10
31	6.4	3	2	0.12
32	6.2	3	1	0.08
33	6.7	1	1	0.10
34	7.0	1	0	0.07
35	6.8	3	1	0.12
36	7.3	3	1	0.11
37	7.1	1	5	0.08
38	7.0	1	0	0.10
39	7.0	3	3	0.08
40	7.0	3	0	0.10
41	7.0	3	0	0.09
42	6.9	13	0	0.17
43	7.1	5	0	0.10
44	7.0	8	4	0.10
45	6.8	3	8	0.09

Appendix 15: *B. plurijuga* stem density, basal area and stump density calculated from sampling plots in Gwayi Forest

Plot number	Tree density/m ²	Basal area/m ²	Stump density/m ²
1	0.02	0.584	0
2	0.03	0.258	0
3	0.0209	0.513	0
4	0.0273	0.224	0
5	0.0197	0.072	0
6	0.03478	0.862	0
7	0.0545	0.523	0
8	0.0588	0.194	0
9	0.05313	0.84	0
10	0.048	0.327	0
11	0.035	0.515	0
12	0.03214	0.485	0
13	0.02833	0.425	0
14	0.0475	0.676	0
15	0.0459	0.231	0
16	0.02957	0.439	0.001739
17	0.025	0.46	0
18	0.0237	0.491	0.001481
19	0.02267	0.438	0.004
20	0.0207	0.738	0.00518
21	0.03	0.413	0.008
22	0.02727	0.495	0.03636
23	0.0323	0.112	0.0043
24	0.0133	0.568	0.0025
25	0.02326	0.266	0.00465
26	0.0283	0.2383	0.0053
27	0.0536	0.142	0.0071
28	0.03448	0.135	0.0069
29	0.0298	0.2194	0.00526
30	0.015075	0.3084	0.00603
31	0.02454	0.408	0.001444
32	0.017	0.275	0.003
33	0.029	0.258	0.007767
34	0.02677	0.467	0.00315
35	0.03	0.248	0.005
36	0.0278	0.319	0.00696
37	0.027778	0.3324	0.0037
38	0.019	0.286	0.00382
39	0.02459	0.173	0.0049
40	0.02133	0.618	0.005333
41	0.0411	0.237	0.019178
42	0.029	0.388	0.005455
43	0.01887	0.143	0.00377
44	0.01935	0.116	0.00387

45 0.022368 0.246 0.0039

Appendix 16: Chi square test for comparing basal size classes in unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest area

	1	2	3	Total
1	163	156	137	456
	159.14	143.07	153.79	
2	93	69	95	257
	89.69	80.63	86.67	
3	25	29	48	102
	35.60	32.00	34.40	
4	14	11	7	32
	11.17	10.04	10.79	
5	1	2	0	3
	1.05	0.94	1.01	
8	1	0	0	1
	0.35	0.31	0.34	
Total	297	267	287	851

$$\text{Chi-Sq} = 0.093 + 1.169 + 1.832 + 0.122 + 1.678 + 0.800 + 3.155 + 0.282 + 5.377 + 0.718 + 0.092 + 1.332 + 0.002 + 1.191 + 1.012 + 1.214 + 0.314 + 0.337 = 20.721$$

DF = 10

Appendix 17: Geographical positions of sampling plots in the unlogged area, area logged in 1999 and area logged in 1995 in Gwayi Forest

Plot number	UTM Position
1	586501, 7890520
2	589278, 7894532
3	590124, 7893097
4	589278, 7892532
5	591179, 7893097
6	588010, 7892532
7	590124, 7892532
8	587071, 7891183
9	589279, 7893097

10	588010, 7891183
11	587508, 7890520
12	586501, 7891183
13	588010, 7893097
14	587071, 7891532
15	589278, 7891183
16	591179, 7886202
17	593926, 7886202
18	594155, 78887267
19	596439, 7888963
20	598071, 7887267
21	597071, 7887267
22	595060, 7886962
23	594155, 7885840
24	594155, 7884836
25	596439, 7884836
26	599050, 7885840
27	599050, 7886962
28	597071, 7886962
29	596439, 7885840
30	600497, 7886962
31	580524, 7899321
32	581267, 7899356
33	583437, 7898356
34	584258, 7899321
35	582739, 7899321
36	580345, 7897321
37	580524, 7897321
38	580524, 7896438
39	582739, 7897321
40	585536, 7897321
41	584258, 7896438
42	582739, 7896321
43	581267, 7895594
44	582739, 789594
45	586501, 7897321

Appendix 18: CCA results for comparing species-environmental relations

SPEC AX1	1.0000								
SPEC AX2	-.0239	1.0000							
SPEC AX3	.0481	-.0620	1.0000						
SPEC AX4	.1179	-.1017	.0743	1.0000					
ENVI AX1	.8895	.0000	.0000	.0000	1.0000				
ENVI AX2	.0000	.7613	.0000	.0000	.0000	1.0000			
ENVI AX3	.0000	.0000	.7526	.0000	.0000	.0000	1.0000		
ENVI AX4	.0000	.0000	.0000	.6705	.0000	.0000	.0000	1.0000	
pH	-.7992	.2159	.2520	.0070	-.8985	.2837	.3349	.0105	
P	.4154	.6520	.1640	-.0199	.4670	.8565	.2180	-.0296	
N	.5416	-.3802	.4461	-.1132	.6088	-.4995	.5928	-.1688	
K	-.0209	.1117	.0186	.6628	-.0235	.1467	.0247	.9886	

	SPEC AX1 ENVI AX2	SPEC AX2 ENVI AX3	SPEC AX3 ENVI AX4	SPEC AX4	ENVI	AX1
Axes		1	2	3	4	Total inertia
Eigenvalues	:	.232	.128	.100	.067	3.798
Species-environment correlations	:		.890	.761	.753	.670
Cumulative percentage variance						
of species data	:	6.1	9.5	12.1	13.9	
of species-environment relation:		44.0	68.4	87.3	100.0	
Sum of all unconstrained eigenvalues						3.798
Sum of all canonical eigenvalues						.526

Appendix 19: Summary of DCA results

Axes		1	2	3	4	Total inertia
Eigenvalues	:	.340	.248	.174	.132	3.798
Lengths of gradient	:	7.331	5.418	5.884	5.963	
Cumulative percentage variance						
of species data	:	8.9	15.5	20.1	23.5	
Sum of all unconstrained eigenvalues						3.798

Appendix 20: Summary of Permutation test results

Variable	F-value	p
pH	2.50	0.0050
P	1.72	0.0250
N	1.33	0.1350
K	0.84	0.6100

Appendix 21: One-way ANOVA for comparing seedlings in the sampling plots

Source	DF	SS	MS	F	P
Plot	2	2.80	1.40	0.84	0.439
Error	42	70.00	1.67		
Total	44	72.80			

Appendix 22: One-way ANOVA for comparing saplings in the sampling plots

Source	DF	SS	MS	F	P
Plot	2	1.24	0.62	0.47	0.627
Error	42	55.33	1.32		
Total	44	56.58			

Appendix 23: Abundance of woody species in an Unlogged area, area logged in 1995 and area logged area logged in 1999

Species	Unlogged	Logged in 1995	Logged in 1999
<i>Diplorhynchus condylocarpon</i>	10	3	28
<i>Acacia species</i>	5	19	1
<i>Albizia antunesiana</i>	1	0	0
<i>Albizia tanganyicensis</i>	0	1	0
<i>Grewia species</i>	43	18	30
<i>Baikiaea plurijuga</i>	299	285	268
<i>Burkea Africana</i>	2	2	11
<i>Baphia massieensis</i>	0	0	0
<i>Bauhinia petersiana</i>	0	1	0
<i>Croton gratissimus</i>	41	26	0
<i>Commiphora mollis</i>	69	46	24
<i>Commiphora pyranthoides</i>	0	0	1
<i>Combretum apiculatum</i>	0	16	6
<i>Combretum collinum</i>	9	9	15
<i>Combretum hereroense</i>	0	1	0
<i>Combretum molle</i>	27	14	11
<i>Combretum zeyheri</i>	0	0	6
<i>Combretum species</i>	50	4	8
<i>Vangueria apiculata</i>	17	0	8
<i>Indigofera species</i>	4	0	0
<i>Guibourtia coleosperma</i>	0	3	11
<i>Grewia retinervis</i>	17	52	19
<i>Dichapetulum rhodesiana</i>	6	0	1
<i>Hymenodictyon species</i>	44	11	2
<i>Commiphora malorthii</i>	3	2	1
<i>Ochna pulchra</i>	0	4	19
<i>Pseudolachnostylis maprouneifolia</i>	5	3	5
<i>Pterocarpus angolensis</i>	9	5	5
<i>Vitex pyos</i>	35	0	0
<i>Schinziophyton rautanenii</i>	6	0	1
<i>Strychnos pungens</i>	2	1	44
<i>Strychnos spinosa</i>	0	3	2
<i>Vangueria infausta</i>	0	3	0
<i>Ximena Americana</i>	1	7	0
<i>Grewia flavescens</i>	2	0	0
<i>Rhus tenuinervis</i>	0	0	0
<i>Solanum species</i>	17	0	3
<i>Protorhus species</i>	1	0	0
<i>Grewia monticola</i>	5	1	0

<i>Strychnos madagascariensis</i>	0	0	0
<i>Ximenia caffra</i>	0	0	1
<i>Heteropogon melanocarpus</i>	0	4	0
<i>Azelia quanzensis</i>	0	0	0
<i>Commiphora longibracteata</i>	0	0	0
<i>Jasminum stenobolum</i>	0	1	0
<i>Xylopi odoratissima</i>	0	0	0
<i>Terminalia sericea</i>	47	4	40

Appendix 24: Presence/absence data used for CCA and DCA analysis

Plot/Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
<i>Diplorhynchus condylocarpon</i>	1	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
<i>Acacia species</i>	0	0	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1	1	0	0	0	1
<i>Albizia antunesiana</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Albizia tanganyicensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Grewia species</i>	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	1	0	1	0	1	0	1
<i>Baikiaea plurijuga</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
<i>Burkea africana</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Baphia massiensis</i>	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0
<i>Bauhinia petersiana</i>	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Croton gratissimus</i>	0	0	1	1	0	1	1	1	0	1	0	0	1	1	1	0	0	0	0	1	1	1	0	1	0	1	0	0
<i>Commiphora mollis</i>	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	1
<i>Commiphora pyranthoides</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Combretum apiculatum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
<i>Combretum collinum</i>	1	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
<i>Combretum hereroense</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
<i>Combretum molle</i>	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0
<i>Combretum zeyheri</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Combretum species</i>	1	1	0	0	1	0	0	1	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Vitex pyos</i>	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Vangueria apiculata</i>	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Dichapetulum rhodesiana</i>	0	0	0	1	1	0	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0
<i>Guibourtia coleosperma</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Grewia retinervis</i>	0	0	0	1	0	1	0	1	0	0	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1
<i>Combretum species</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Hymenodictyon species</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Commiphora marlothii</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ochna pulchra</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pseudolachnostylis maprouneifolia</i>	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
<i>Pterocarpus angolensis</i>	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Schziphyton rautanenii</i>	0	1	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Strychnos pungens</i>	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Strychnos spinosa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
<i>Terminalia sericea</i>	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0

<i>Vangueria infausta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0
<i>Ximения americana</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	
<i>Grewia flavescens</i>	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rhus tenuinervis</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Solanum species</i>	0	0	1	0	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Protorhus species</i>	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
<i>Grewia monticola</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Strychnos madagascariensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ximения caffra</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Heteropogon melanocarpus</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Indigofera species</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Azelia quanzensis</i>	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Commiphora longibracteata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Jasminum stenlobum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Xylopiя odoratissima</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Plot/species	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
<i>Diplorhynchus condylocarpon</i>	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0
<i>Acacia species</i>	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Albizia antunesiana</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Albizia tanganyicensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Grewia species</i>	1	0	1	1	1	1	0	0	1	0	1	1	1	0	1	1	1
<i>Baikiaea plurijuga</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Burkea africana</i>	0	1	0	0	1	0	0	0	1	0	1	0	1	0	0	1	1
<i>Baphia massiensis</i>	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0
<i>Bauhinia petersiana</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Croton gratissimus</i>	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Commiphora mollis</i>	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1
<i>Commiphora pyranthoides</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Combretum apiculatum</i>	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1
<i>Combretum collinum</i>	1	1	0	0	1	0	1	1	1	1	1	0	1	0	1	0	0
<i>Combretum hereroense</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Combretum molle</i>	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0
<i>Combretum zeyheri</i>	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0
<i>Combretum species</i>	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	1	0
<i>Vitex pyos</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Vangueria apiculata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Dichapetulum rhodesiana</i>	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
<i>Guibourtia coleosperma</i>	0	1	0	0	0	1	0	1	0	1	0	1	0	0	0	1	1
<i>Grewia retinervis</i>	1	1	1	1	0	1	1	1	0	1	1	1	0	1	0	0	1
<i>Combretum species</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Hymenodictyon species</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Commiphora marlothii</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ochna pulchra</i>	0	0	1	0	1	0	0	1	1	1	0	1	1	1	1	0	0
<i>Pseudolachnostylis maprouneifolia</i>	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	1

<i>Pterocarpus angolensis</i>	1	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0
<i>Schiziphyton rautanenii</i>	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Strychnos pungens</i>	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
<i>Strychnos spinosa</i>	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
<i>Terminalia sericea</i>	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
<i>Vangueria infausta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ximenia americana</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Grewia flavescens</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rhus tenuinervis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Solanum species</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
<i>Protorhus species</i>	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Grewia monticola</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Strychnos madagagascariensis</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ximenia caffra</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Heteropogon melanocarpus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Indigofera species</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Azelia quanzensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Commiphora longibracteata</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>Jasminum stenolobum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Xylopiya odoratissima</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0