

**THE IMPACTS OF DIFFERENT FIRE FREQUENCIES ON VEGETATION
CHARACTERISTICS IN THE HAMOYE STATE FOREST, KAVANGO
REGION, NAMIBIA.**

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By

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Declaration

I, Rabanus Shoopala, hereby declare that this study is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education.

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Rabanus Shoopala

DEDICATION

I dedicate this thesis to my late brother, Timotheus Nyanyukweni Shoopala, who died in exile during the liberation struggle of Namibia. I extend this dedication to my best friend Anton Kuti Nekwaya, a rare true friend.

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Abstract

In Namibia, large areas burn each year with a distribution of burn relating to the rainfall gradient. As a result fires are widespread and frequent in the north, especially in the northeast. In these areas more than 2 million hectares of forested land burn each year. Fires, amongst other factors, have negative effects on biodiversity. These effects have not been fully assessed. Therefore, this study was conducted to investigate the effect of different fire frequencies on vegetation characteristics in the Hamoye State Forest (HSF). The study was carried out through a combination of analysis of Landsat satellite imagery and field sampling methods. Landsat satellite imagery was used to map and demarcate the forest into 3 different fire frequency zones (low, medium and high); with low being areas burnt less than five times, medium being areas burnt between 5 and 10 times, and high being areas burnt more than ten times since 1989. Field sampling was carried out to determine the effect of different fire frequencies on species diversity and richness, plant density, cover, height and tree basal area. A total of thirty randomly chosen 35 x 35m plots, ten in each fire frequency zone, were sampled. The results indicate that fire frequencies differed among the zones of the state forest, with high frequencies found in areas far from the State Forest buildings, while medium and low fire frequencies were found in areas within the proximity of the Forestry buildings. These differences were due to fire suppression by forestry personnel in areas within the proximity of forestry buildings. There were no significant differences in tree basal area, tree density, and stump density among the three fire frequency zones. However, frequent fires reduced tree and sapling height. Forb and shrub densities increased with increasing fire frequency. Most forbs are annual that quickly colonized unoccupied niches after fire burning, while most shrubs resprouted after intense fires resulting in high shrub density. The woody and grass cover all decreased with increasing fire frequency. High fire frequency reduced woody cover. Low grass cover in the higher fire frequency was due

to presence of high sapling density which increased space competition against grass. Frequent fires increased plant species richness as a result of new species taking up new niches created by fires. Frequent fires maintain species diversity by opening up niches for new species. The DCA ordination results show variations of plants species along a fire gradient on the second axis indicating that though the confounding affects of other factors needs to be considered, different fire frequencies have a significant effect on several attributes of the structure of vegetation communities in the Hamoye State Forest.

Keywords: Fire, Hamoye State Forest, Kalahari sands, Namibia, Plant diversity, Vegetation composition, Vegetation structure.

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CHAPTER ONE

1. GENERAL INTRODUCTION

1.1. INTRODUCTION

THE ROLE OF FIRE IN THE MAINTENANCE AND FUNCTIONING OF TROPICAL SAVANNAS IS PROBABLY THE OLDEST ISSUE IN SAVANNA ECOLOGY, BUT CERTAIN ASPECTS REMAIN CONTENTIOUS (SCHOLES & WALKER, 1993). ONE POINT OF VIEW, NOTING THE UBIQUITOUS OCCURRENCE OF FIRES IN SAVANNAS AND THE TENDENCY FOR WOODY PLANT DENSITY IN SAVANNAS TO INCREASE WHEN FIRES ARE EXCLUDED, CONCLUDES THAT SAVANNAS ARE FIRE SUB-CLIMAXES TO WOODLAND OR FOREST (SCHOLES & WALKER, 1993; BOND & VAN WILGEN, 1996). HOWEVER, SCHOLES & WALKER (1993), FROST & ROBERTSON, (1987) FURTHER STRESS THAT AFRICA HAS A LONG HISTORY OF FIRE, WITH THE NUMEROUS PLANT ADAPTATIONS TO SURVIVING FIRES. THEY INDICATED THAT FIRE ACTS AS A SAVANNA MODIFIER.

The intensity, timing and frequency of fire are three important factors in determining how vegetation responds to impacts of fire (Mapaure, 2001). Fire intensity is a measure of how fiercely a fire burns and variation in intensity is therefore important in determining the severity of a fire in terms of vegetation recovery (Bond, 1997). Fire

intensity is a function of fuel type, fuel load, moisture content, and atmospheric conditions at the time of burning. Consequently, fire intensity is linked to both the seasonality and frequency of burning (Bond & van Wilgen, 1996).

The frequency of fires is determined by the availability of fuel, suitable climate, and an ignition event (Bond & van Wilgen, 1996). Fire frequency determines the length of time that a plant has to recover before the next fire occurs. The slower the rate of recovery, the more likely it is that the structure and composition of the vegetation will be altered (Frost & Robertson, 1987). Frequent fires reduce woody plant densities in moist savannas, primarily by killing or suppressing individuals in the smaller size classes (Frost & Robertson, 1987). Protection from fire therefore increases the recruitment of woody plants thereby leading to increased density of woody plants, particularly of fire sensitive species (Gambiza, 2001).

Dominant woody plants in arid savannas appear to be more fire-sensitive than most of the plants occurring in moist savannas, despite generally lower fire intensities (Frost & Robertson, 1987). Fires in arid areas are, however, infrequent since fuel loads are generally low (Gambiza, 2001). Some plant populations mainly regenerate from seed after fire (Frost & Robertson, 1987; Scholes & Walker, 1993; Bond, 1997; Gambiza, 2001). This implies that arid savanna communities are highly susceptible to changes in species composition depending on post-fire environmental conditions (Frost & Robertson, 1987).

In contrast to woody plant communities, herbaceous communities are less affected by fire (Scholes & Walker, 1993). Distinct transformations in species composition occur at the extremes of fire frequency (i.e. annual burning and no burning). Variation in annual rainfall, however, confounds the response of herbaceous plants to fire (Frost & Robertson, 1987; Gambiza, 2001). Protection from fire results in increase in mesic, shade loving grasses such as *Panicum maximum*, *Andropogon tectorum*, *Crasspedorachis africanus* and forest species (Frost & Robertson, 1987). However, Frost & Robertson (1987) argued that some of these species may be responding to changes in tree density and associated microclimate than directly to the absence of fire since it is known that removal of woody plants influences herbaceous composition and production (Gambiza, 2001).

ACCORDING TO TRIGG & LE ROUX (2001), NRSC (2001, 2002, AND 2003), LARGE AREAS OF VEGETATION COMMUNITIES BURN EACH YEAR IN NAMIBIA. BURNED AREAS FOLLOW A RAINFALL DISTRIBUTION GRADIENT. THIS MEANS THAT FIRES ARE MOSTLY WIDESPREAD AND FREQUENT IN THE NORTH DUE TO AMOUNT OF FUEL LOAD IN THE REGION. FIRES ARE NORMALLY PRESENT ESPECIALLY IN THE NORTHEAST AT VARYING FREQUENCIES. ALTHOUGH IT IS PRESUMED THAT KAVANGO, CAPRIVI AND OTJOZONDJUPA REGIONS ARE SEVERELY AFFECTED BY WILDFIRES ON AN ANNUAL BASIS, THEIR EFFECTS ON THE STRUCTURE AND COMPOSITION OF THESE SAVANNA ECOSYSTEMS ARE

STILL NOT WELL DOCUMENTED IN NAMIBIA (NRSC, 2002). THIS LACK OF INFORMATION ON FIRE EFFECTS ON FOREST BIODIVERSITY IS A SERIOUS CONCERN THAT MIGHT HAMPER THE IMPLEMENTATION OF FIRE MANAGEMENT PROGRAMMES. THEREFORE THIS THESIS EXAMINES THE EFFECT OF DIFFERENT FIRE FREQUENCIES IN THE HAMOYE STATE FOREST.

1.2. Problem Statement

SOME WILDFIRES CLEARLY ENDANGER LIVES AND PROPERTIES, AND REPEATED BURNING CAN ALSO DAMAGE VEGETATION AND, MORE GENERALLY, HABITATS FOR PLANTS AND ANIMALS, THEREBY POTENTIALLY THREATENING SOME ELEMENTS OF BIODIVERSITY (FROST *ET AL.*, 1986). FREQUENT LATE DRY SEASON FIRES TRANSFORM SOUTHERN AFRICAN WOODY SAVANNAS INTO OPEN GRASSY SAVANNAS WITH ONLY ISOLATED FIRE-TOLERANT CANOPY TREES AND SCATTERED UNDER-STOREY TREES AND SHRUBS (FROST & ROBERTSON, 1987). IN CONTRAST, COMPLETE PROTECTION FROM WILDFIRE, AND TO A LESSER EXTENT, EARLY DRY SEASON BURNING, FAVOURS BOTH THE RECRUITMENT AND GROWTH OF WOODY PLANTS.

WILDFIRE FREQUENCIES HAVE INCREASED SIGNIFICANTLY IN THE LAST FEW CENTURIES OF HUMAN OCCUPATION, ESPECIALLY THE LAST FIFTY

YEARS DUE TO INCREASES IN HUMAN POPULATION. THIS INCREASE OF WILDFIRES IS FEARED TO HAVE SERIOUS NEGATIVE IMPACTS ON THE VEGETATION AND FOREST VEGETATION STRUCTURE, ESPECIALLY IN NAMIBIA'S MOIST NORTHEAST REGION WITH HIGH PLANT AND ANIMAL BIODIVERSITY (GRN, 2000). GIVEN THE FACT THAT THE NORTHEAST REGION'S VEGETATION HAS ALREADY BEEN UNDER COMMERCIAL EXPLOITATION DUE TO ITS RICHNESS IN TIMBER RESOURCES SINCE MID 1900S (ERKKILÄ AND SIISKONEN, 1992), THERE IS A NEED TO INVESTIGATE THE EFFECTS OF WILDFIRES ON VEGETATION COMPOSITION AND STRUCTURE. THIS STUDY THEREFORE AIMED AT ASSESSING THE IMPACTS OF DIFFERENT LEVELS OF FIRE FREQUENCIES ON WOODY COMPOSITION AND STRUCTURE IN A PROTECTED FOREST IN NORTH EASTERN NAMIBIA (FIGURE 1).

THE RESULTS OF THIS STUDY WOULD ASSIST THE DIRECTORATE OF FORESTRY IN DRAFTING A PLAN FOR FIRE MANAGEMENT OF THE HAMOYE STATE FOREST (HSF). THE RESULTING FIRE MAPS WILL BE A MAJOR TOOL IN ZONING AREAS OF PRIORITY IN FIRE MANAGEMENT.

1.3. Aims & Objectives

THE AIM OF THIS STUDY WAS TO ASSESS THE EFFECT OF FIRE FREQUENCY ON VEGETATION STRUCTURE AND COMPOSITION BETWEEN 1989 AND 2003.

TO ACHIEVE THIS, THE OBJECTIVES OF THIS STUDY WERE FORMULATED AS FOLLOWS:

- (A) TO MAP AREAS OF DIFFERENT FIRE FREQUENCIES WITHIN HSF.
- (B) TO DETERMINE AND COMPARE SPECIES COMPOSITION AND RICHNESS AMONG FIRE FREQUENCY ZONE HSF.
- (C) TO DETERMINE AND COMPARE SPECIES DIVERSITY AMONG FIRE FREQUENCY ZONES IN THE HSF.
- (D) TO DETERMINE AND COMPARE THE VEGETATION STRUCTURE (HEIGHT, BASAL AREA, DENSITY AND COVER) AMONG FIRE FREQUENCY ZONES IN THE HSF.

1.4. Key questions

- (A) DOES FIRE FREQUENCY DIFFER IN THE VARIOUS PARTS OF THE FOREST, IF SO HOW DOES IT DIFFER?
- (B) HOW DO DIFFERENT FIRE FREQUENCIES AFFECT THE SPECIES COMPOSITION AND RICHNESS OF THE STATE FOREST?
- (C) HOW DO DIFFERENT FIRE FREQUENCIES AFFECT THE SPECIES DIVERSITY OF THE STATE FOREST VEGETATION?

(D) HOW DO DIFFERENT FIRE FREQUENCIES AFFECT THE VEGETATION
STRUCTURE OF THE STATE FOREST?

1.5. Research hypotheses

- (A) THE ZONES OF THE STATE FOREST THAT ARE LOCATED FAR FROM
FORESTRY INFRASTRUCTURES HAVE HIGH FIRE FREQUENCY
COMPARED TO THE ZONES NEAR FORESTRY INFRASTRUCTURES AS
ZONES THAT ARE NEAR THE FORESTRY INFRASTRUCTURES RECEIVE
PROTECTION FROM FORESTRY PERSONNEL.
- (B) THERE IS A DIFFERENCE IN THE SPECIES COMPOSITION AMONG PARTS
OF THE STATE FOREST DUE TO VARIABILITY IN FIRE FREQUENCY AS
REPORTED BY CARRY AND MORRISON (1995).
- (C) THERE IS A DIFFERENCE IN THE SPECIES DIVERSITY AMONG ZONES OF
THE HSF, WITH HIGH SPECIES DIVERSITY FOUND IN MEDIUM FIRE
FREQUENCY ZONES, AND LOW SPECIES DIVERSITY IN HIGH AND LOW
FREQUENCY ZONES AS PREDICTED BY THE INTERMEDIATE
DISTURBANCE HYPOTHESIS (COLLINS *ET AL.*, 1995; SCHWILK *ET AL.*,
1997).

(D) THERE IS A DIFFERENCE IN THE VEGETATION STRUCTURE AMONG DIFFERENT PARTS OF THE STATE FOREST WITH A HIGH DOMINANCE OF LARGER TREES IN HIGH FREQUENCY ZONES IN COMPARISON TO SMALLER ONES IN MEDIUM AND LOW FIRE FREQUENCIES ZONES

(NRSC, 2002).

CHAPTER TWO

2.1. LITERATURE REVIEW

FIRE HAS BEEN A MAJOR FACTOR IN INFLUENCING TERRESTRIAL VEGETATION SINCE AT LEAST THE MESOZOIC TIMES (GAMBIZA, 2001). ITS FREQUENCY INCREASED SIGNIFICANTLY DURING THE MID – TERTIARY BECAUSE OF INCREASED DOMINANCE OF HIGHLY FLAMMABLE GRAMINOID SPECIES (GAMBIZA, 2001). IN THE PRESENT CONTEXT, MOST FIRES ARE STARTED BY PEOPLE, BOTH TO MODIFY THEIR ENVIRONMENT, FOR A VARIETY OF REASONS RELATED TO LAND-USE, AND TO FACILITATE HARVESTING OF NATURAL RESOURCES. HOWEVER, LIGHTNING IS AN IMPORTANT SOURCE OF IGNITION AT THE BEGINNING OF THE RAINY SEASONS (VAN WILGEN *ET AL.*, 1990).

IT HAS BEEN ESTIMATED THAT ANNUALLY, NON-PRESCRIBED WILDFIRES BURN ACROSS UP TO 500 MILLION HECTARES OF VEGETATION, OPEN FORESTS, TROPICAL AND SUB-TROPICAL SAVANNAS (ROWEN & MOORE, 1999). ANNUAL NON-PRESCRIBED WILDFIRES ARE ALSO ESTIMATED TO BURN ABOUT 10-15 MILLION HECTARES OF BOREAL AND TEMPERATE FOREST AND 20-40 MILLION HECTARES OF TROPICAL FORESTS GLOBALLY (GOLDAMMER *ET AL.*, 2002).

FURTHERMORE, WILDFIRE HAS BEEN VIEWED BY MANY AS AN ENVIRONMENTAL REVULSION AND IT IS RECOGNIZED AS AN IMPORTANT CONTRIBUTOR TO GLOBAL CLIMATE CHANGE BECAUSE OF ITS POTENTIAL TO MODIFY ATMOSPHERIC COMPOSITION (SCHOLES *ET AL.*, 1996). IT IS THEREFORE NOT SURPRISING THAT BIOMASS BURNING IS ESTIMATED TO BE CONTRIBUTING ABOUT 38% OF THE TROPOSPHERE OZONE, 32% OF THE GLOBAL CARBON MONOXIDE AS WELL AS 10% OF THE GLOBAL METHANE (SCHOLES & WALKER, 1993). DURING FIRE BURNING, CARBON AND ELEMENTS BOUND TO ASH, SUCH AS NITROGEN, PHOSPHORUS AND SULPHUR, ARE PARTIALLY OR COMPLETELY RELEASED TO THE ATMOSPHERE. DUE TO THIS, CARBON CONTENT HAS POTENTIAL TO SHOW SIGNIFICANT REDUCTIONS IN THE SOIL FOLLOWING ALTERATIONS IN THE FIRE REGIME (SCHOLES & WALKER, 1993).

PRESENTLY, FIRE IS ONE OF THE LARGEST ANTHROPOGENIC INFLUENCES ON TERRESTRIAL ECOSYSTEMS AFTER URBAN AND AGRICULTURAL ACTIVITIES (GAMBIZA, 2001). THE IMPORTANCE OF FIRE IN INFLUENCING VEGETATION STRUCTURE AND FUNCTIONING IS EVIDENT IN SAVANNAS (FROST *ET AL.*, 1986). IN SAVANNAS, A LONG DRY SEASON AND AVAILABILITY OF DRY AND HIGHLY COMBUSTIBLE GRASS BIOMASS PROMOTE INTENSE FIRES (GAMBIZA, 2001).

SCHOLES & WALKER (1993) DEFINED FIRE REGIME AS A TERM TO DESCRIBE FIRE TYPE AND ITS INTENSITY, ITS SEASONAL OCCURRENCE AND FREQUENCIES. FIRE REGIMES VARY GREATLY ACROSS THE RANGE OF SAVANNA TYPES. FURTHERMORE, SCHOLES & WALKER (1993) STATED THAT NATURAL FIRE FREQUENCIES IN MOIST SAVANNAS OCCUR IN THE DRY SEASON OR EARLY WET SEASON AT AN INTERVAL OF 1-3 YEARS OR MORE. IN CONTRAST, FIRES CAN OCCUR ALMOST AT ANY TIME IN MORE ARID SAVANNAS. THE FIRE FREQUENCIES IN THESE REGIONS RANGE FROM FIVE TO 50 YEARS IN ARID SAVANNAS BECAUSE OF LOW FUEL LOADS (GAMBIZA, 2001).

FIRES OCCURRING IN THE EARLY DRY SEASON TEND TO BE COOL, PATCHY AND LESS DAMAGING WHILE THOSE WHICH OCCUR IN THE LATE DRY SEASON ARE USUALLY HOT, EXTENSIVE AND MORE DAMAGING TO VEGETATION (MAPAURE, 2001). WHERE FIRE FREQUENCY IS HIGH, PLANT COMMUNITIES GRADUALLY BECOME DOMINATED BY FIRE TOLERANT SPECIES (MAPAURE, 2001). MOST SAVANNA FIRES ARE SURFACE FIRES THAT BURN THROUGH THE HERBACEOUS LAYER, THEREFORE FLAME HEIGHTS OF THESE SURFACE FIRES ARE GENERALLY LOW. THEY RANGE FROM 1.2 M TO 5.0 M FOR FIRES BURNING WITH THE WIND (HEAD FIRES) AND 0.5 M TO 1.5 M FOR FIRES BURNING AGAINST THE WIND (BACK FIRES) (FROST & ROBERTSON, 1987). DUE TO THIS NATURE OF FIRES, HIGH

VEGETATION MATERIALS ARE LESS AFFECTED, ALTHOUGH THE REFLECTED FIRES HEAT CAN REDUCE THE BIOMASS CONTENT OF THE WOODY MATERIAL ABOVE THIS. THE REFLECTED HEAT IS ALSO INFLUENCED BY THE INTENSITY OF FIRE (GAMBIZA, 2001).

FIRE INTENSITY IS A FUNCTION OF FACTORS SUCH AS THE MAGNITUDE OF THE PHYSICAL FORCE, THE MORPHOLOGICAL AND PHYSICAL CHARACTERISTICS OF THE FUEL THAT INFLUENCES THROUGH FEEDBACK TO FIRE AND THE ABOVEGROUND BIOMASS (SHEUYANGE, 2002).

INTENSITY ALSO DEPENDS ON MOISTURE CONTENT OF THE FUEL AND THE WEATHER CONDITIONS AT THE TIME OF THE BURN. SINCE GRASS IS THE MAJOR FUEL FOR SAVANNA FIRES, FIRE INTENSITIES VARY GREATLY IN BOTH TIME AND SPACE AND AMONG VEGETATION TYPES (TROLLOPE 1980). PLANT COMMUNITIES WITH A HIGH GRASS BIOMASS SUCH AS VALLEY BOTTOMS AND FLOODPLAINS EXPERIENCE MORE INTENSE FIRES THAN WOODLANDS WHERE THERE IS GENERALLY A LOWER GRASS BIOMASS (GAMBIZA, 2001).

THE DIRECT INFLUENCE OF FIRE CENTERS ON THE FIRE, AND ON THE REDUCTION OF THE ORGANIC MATTER AND RELEASE OF THE ELEMENTS. FIRES ARE GENERALLY HOTTEST AT, OR JUST ABOVE, THE SOIL SURFACE (GAMBIZA, 2001). BACK FIRES ARE GENERAL HOTTER THAN HEAD FIRES

AT THE SOIL SURFACE THOUGH THERE IS AN EXCEPTION WHEN THIS IS NOT THE CASE (TROLLOPE, 1978). IN SAVANNA GRASSLANDS, SOME HEAD

FIRES ARE ALMOST ALWAYS HOTTER THAN BACK FIRES.

TEMPERATURES FOR SURFACE FIRES ARE GENERALLY MUCH LOWER THAN THOSE CLOSER TO THE GROUND AND DECREASE SHARPLY WITH INCREASING HEIGHT (FROST & ROBERTSON, 1987). SOIL HAS A LOW THERMAL CONDUCTIVITY, THEREFORE TEMPERATURES RECORDED AT 2 CM BELOW THE SURFACE BARELY EXCEED 35° C, WHILE AT 5 CM DEPTH THERE IS ALMOST NO RISE IN TEMPERATURE (FROST & ROBERTSON, 1987). THESE FLUCTUATIONS IN SOIL TEMPERATURES DUE TO FIRES MAY AFFECT FUNCTIONING OF THE SOIL BIOTA AND THE EXTENT OF DAMAGE TO SOIL SEED BANKS AND BELOW GROUND PLANT BIOMASS (GAMBIZA, 2001).

FIRES ALSO CAUSE AN INCREASE IN SOIL MOISTURE IN THE ACTIVE LAYER FOR A FEW YEARS AFTER THE REMOVAL OF THE VEGETATION. THIS ALLOWS MORE SOLAR RADIATION TO REACH THE GROUND AND INCREASE THE ALBEDO OF THE GROUND LAYER. ALBEDO IS DEFINED AS THE RATIO OF THE AMOUNT OF ELECTROMAGNETIC ENERGY REFLECTED BY A SURFACE TO THE AMOUNT OF ENERGY INCIDENT UPON IT (MODIS, 2003).

Many studies and literature have shown that reduction of the fire frequency or intensity in savannas results in an increase in the number of woody plants and their structure (Sheuyange, 2002; Frost and Robertson, 1987; Hoffmann, 1996; Dublin *et al.*, 1990), canopy volume (Scholes & Walker, 1993), and composition (Mapaure, 2001). Frequent fires reduce woody plant densities, primarily by killing or suppressing individuals in small size classes (Gambiza, 2001).

Mapaure (2001) showed a gradual conversion of woodland to woodland thickets, a resulting in small scale variations in species composition of the vegetation of the miombo woodland in Sengwa Wildlife Research Area, Zimbabwe. In the Fynbos shrublands of the Cape Province of South Africa, frequent fire alters the species composition by eliminating the large shrubs (Schwilk *et al.*, 1997). These large shrubs that get eliminated are mostly members of the Proteaceae that do not have time to reach maturity between fires (Schwilk *et al.*, 1997). Likewise very long intervals between fires may eliminate the largest shrubs because many of these proteoid species rely upon canopy-stored seed banks; the shrubs may senesce before fire allows their serotinous cones to open (Schwilk *at el.*, 1997). Other workers have also reported that seed germination can be stimulated directly by smoke (Bond & van Wilgen, 1996). Smoke stimulation was first reported for *Audouinia* (Bruniaceae), a rare shrub species in the Cape fynbos and it has since been reported in many other fynbos species (Bond & van Wilgen, 1996).

According to Frost & Robertson (1987), events occurring in the interval between fires also influence the eventual outcome. Events of drought, above-average rainfall and herbivory affect fuel loads, and thereby fire intensity, as well as the condition of individual plants and their degree of recovery. Because of this, effects of fire regime on species composition therefore cannot be seen in isolation from the influence of these other factors. This complicates the interpretation of the results of most of the experiments on fire in savannas. This sentiment was supported by Yeaton's (1988) findings on tree mortality at Nysvley Nature Reserve, South Africa. According to Yeaton (1988), porcupines, fires and windstorms interact over along time to cause tree mortality.

Despite a growing awareness of the importance of fire in many plant communities, few studies have investigated the role of fire frequency in creating patterns of species diversity. Although the intermediate disturbance hypothesis is a widely accepted explanation for patterns of species diversity at the alpha level, its support has come mainly from studies of marine intertidal organisms (Schwilk *et al*, 1997). The intermediate disturbance hypothesis 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 disturbance frequencies (Schwilk *et al*, 1997). One of the studies tested this hypothesis was Hobbs *et al*. (1984) who counted the number of species in a chronosequence of Scottish heath in the first year after fire. Hobbs *et al*. (1984) also estimated species persisting in the seed bank at different stand ages. Their

results showed that stands burnt at intermediate intervals (6-15) had the highest diversity, but there were no stands burnt at intervals shorter than 6 years, so the predictions of the hypothesis were only half tested (Bond & van Wilgen, 1996).

Bond & van Wilgen, (1996) found that burning frequency had no significant effect on richness at the wet and dry ends of the gradient but annual burning significantly increased richness at intermediate moisture levels. Schwilk *et al.* (1997) found an opposite of what the intermediate disturbance hypothesis predicted. They found diversities at most spatial scales were lowest at sites that had experienced an intermediate fire frequency. Bond & van Wilgen (1996) highlighted that support for the intermediate disturbance hypothesis from fire studies is less than unanimous. Furthermore, Bond & van Wilgen (1996) stated that part of the problem is that diversity patterns after a single burn have been confounded with patterns created by repeated burning, and to separate the two, diversity should be censused at the same stage in post-fire succession.

THE USE OF FIRE AS A MANAGEMENT TOOL IS DEEPLY EMBEDDED IN THE CULTURE AND TRADITIONS OF MANY SOCIETIES IN THE WORLD. IT IS THEREFORE NOT SURPRISING, THAT THE MAJORITY OF WILDFIRES AROUND THE GLOBE ARE CAUSED BY HUMANS, WITH LIGHTNING MERELY ACCOUNTING FOR A LITTLE PROPORTION (GOLDAMMER *ET AL.*, 2002).). FIRE IS WIDELY USED BY FARMERS TO REMOVE UNWANTED

BIOMASS FROM LAND BEING OPENED UP FOR CULTIVATION, OR TO FERTILIZE NUTRIENT-DEFICIENT SOILS BY RELEASING NUTRIENTS SEQUESTERED IN PLANT BIOMASS. PASTORALISTS SET FIRES IN THE LATE DRY SEASON, BOTH TO INDUCE A FLUSH OF PROTEIN-RICH GRASS ON WHICH THEIR LIVESTOCK CAN GRAZE AND TO CONTROL BUSH ENCROACHMENT (SHEUYANGE, 2002).

WHILE WILDLIFE AGENCIES USE FIRES TO MANAGE VEGETATION STRUCTURE AND REDUCE FUEL LOADS, HUNTERS USED TO APPLY FIRE TO DRIVE ANIMALS OR TO ATTRACT THEM LATER TO THE RE-GROWTH ON THE BURNED AREAS, SOME STILL DO (NRSC, 2002). PEOPLE ALSO USE FIRE TO CREATE FIREBREAKS AROUND THEIR HOMESTEADS OR TO IMPROVE VISIBILITY AND ENHANCE SECURITY AGAINST PREDATORS OR OTHER DANGEROUS ANIMALS, ESPECIALLY ALONG PATHS BETWEEN VILLAGES (NRSC, 2002). HOWEVER, SOME WILDFIRES UNDOUBTEDLY START THROUGH CARELESSNESS OR INADEQUATE CONTROL WHILE PEOPLE ARE COOKING, SMOKING OUT BEEHIVES, MAKING CHARCOAL, OR TRYING TO KEEP WARM WHILE WAITING AT THE ROADSIDE FOR TRANSPORT. OTHERS ARE STARTED BY INDIVIDUALS PLAYING WITH FIRE RECREATIONALLY OR USING FIRE WITH MALICIOUS INTENT (GOLDAMMER *ET AL.*, 2002).

ACCORDING TO MAPAURE & CAMPBELL (2002) SUCH NON-PRESCRIBED WILDFIRES ARE A MAJOR MANAGEMENT PROBLEM IN AFRICAN SAVANNAS, PARTICULARLY IN PROTECTED AREAS WHERE THEIR OCCURRENCE IS OFTEN VIEWED NEGATIVELY. CONSEQUENTLY, EACH YEAR FOREST DEPARTMENTS ALLOCATE HUGE FINANCIAL AND HUMAN RESOURCES INTO FIRE MANAGEMENT. MANY CONSERVATION AREAS IN SUB-SAHARAN AFRICA THEREFORE USE FIRE AS AN ACTIVE MANAGEMENT TOOL, WHICH OFTEN FOLLOWS STRICT MANAGEMENT PROGRAMMES BASED ON PRE-DETERMINED GOALS (MAPAURE & CAMPBELL, 2002).

THERE HAVE BEEN EFFORTS TO TRY AND TURN THE TIDE OF WILDFIRES IN MANY PARTS OF THE WORLD. IN AFRICA, USING CAPRIVI AND KAVANGO REGIONS IN NAMIBIA AS EXAMPLES, LOCAL PEOPLE ARE IN CHARGE OF FIRE MANAGEMENT PROJECTS (JURVÉLIUS & KAWANA, 1998).

THIS IS PROOF THAT COMMUNITY FIRE MANAGEMENT WORKS.

ACCORDING TO JURVÉLIUS & KAWANA (1998), COMMUNITY FIRE MANAGEMENT IS ONE OF THE FEW OPTIONS IN AFRICA TODAY, WITH THE GROWING POPULATION IN THE RURAL AREAS WHERE GOVERNMENTS' EFFORTS ARE LESS EFFECTIVE AS THERE IS NO MONEY OR RESOURCES TO SUSTAIN FIRE MANAGEMENT PROGRAMMES.

TRIGG & LE ROUX (2001), TRIGG (2000), GOLDAMMER (1998) AND NRSC (2001, 2002, 2003) REPORTED THAT MORE THAN 3 MILLION HECTARES OF NAMIBIAN FORESTED LAND BURN EACH YEAR. THERE IS ALSO A PERCEPTION THAT EXCESSIVE, INDISCRIMINATE BURNING IS HAVING NEGATIVE EFFECTS ON SOME ECOSYSTEMS IN NAMIBIA, WHILST IN OTHER AREAS, FIRE FREQUENCIES ARE MORE IN EQUILIBRIUM WITH REQUIREMENTS FOR LONG-TERM STABILITY OF EXISTING VEGETATION COMMUNITIES (GOLDAMMER, 1999).

THE GOVERNMENT OF NAMIBIA IS UNDERTAKING VARIOUS STRATEGIES TO REDUCE FIRES, INCLUDING THE ESTABLISHMENT AND MANAGEMENT OF FIREBREAKS, INFORMATION DISTRIBUTION, PUBLIC AWARENESS, WORKSHOPS, AND THE INVOLVEMENT OF WOOD CARVERS (MET & NFFP, 2001). THE PRACTICES HAVE BEEN EVALUATED SOCIO-ECONOMICALLY AND TECHNICALLY (KAMMINGA, 1999, 2001; TROLLOPE & TROLLOPE, 1999). KAMMINGA (1999; 2001) REPORTED THAT PUTTING EMPHASIS ON FIRE SUPPRESSION THAN FIRE PREVENTION BY THE PREVIOUS GOVERNMENT HAS PERPETUATED THE IDEA THAT THE GOVERNMENT WAS IN CHARGE, AND THIS RESULTED IN LOW LEVEL OF RESPONSIBILITY BY COMMUNITIES AT THAT TIME.

THOUGH NAMIBIA DOES NOT HAVE A STAND-ALONE FIRE POLICY IN PLACE YET, THE NAMIBIA FORESTRY STRATEGIC PLAN (MID 1990S) RECOGNIZES THE NEED FOR DIFFERENT REGIONS IN NAMIBIA TO ADOPT DIFFERENT FIRE MANAGEMENT POLICIES AS NECESSARY. TO DATE, PROGRESS HAS BEEN MADE TOWARDS DEVELOPING A NATIONAL FIRE POLICY AS THE DIRECTORATE OF FORESTRY, TOGETHER WITH ALL STAKEHOLDERS FORMULATED A DRAFT NATIONAL FIRE POLICY IN 2003. THE DIRECTORATE OF FORESTRY HAS ALSO DRAFTED MANAGEMENT PLANS FOR VARIOUS FORESTED AREAS AND THESE PLANS INCLUDE FIRE MANAGEMENT, WHICH IS CONSIDERED TO BE AN IMPORTANT ASPECT, ESPECIALLY IN THE KAVANGO AND CAPRIVI REGIONS (LAAMANEN & OTSUB, 2003).

DESPITE THE ABOVE FOREST FIRE GUIDELINES IN PLACE, THE IMPACT OF FIRE ON THE BIODIVERSITY AND FUNCTIONING OF THE NAMIBIAN VEGETATION TYPES HAS BEEN GIVEN LITTLE ATTENTION. TRIGG (2000), TRIGG & FLASSE (2000), AND TRIGG & LE ROUX (2001) GAVE A NATIONAL ACCOUNT OF NAMIBIA'S FIRE SITUATION SINCE THE INCEPTION OF THE FIRE MANAGEMENT PROJECT IN THE CAPRIVI REGION, WITH MORE THAN 3 MILLION HECTARES ESTIMATED TO HAVE BURNED IN 1997 NATIONALLY. DU PLESSIS (1997) DID THE REFINEMENTS TO THE BURNING STRATEGIES IN THE ETOSHA NATIONAL PARK. ERKILLÄ & SIISKONEN

(1992) MAPPED CHANGES IN FOREST COVER IN NORTH-CENTRAL NAMIBIA (1943-1996), BUT WITH EMPHASIS ON EFFECT OF POPULATION EXPANSION ON VEGETATION. IN THEIR STUDY, ERKILLÄ & SIISKONEN (1992) REPORTED AN ANNUAL CHANGE IN FOREST COVER OF -0.2% DURING THE PERIOD 1981 – 1992, AND -1.5 % DURING 1992 – 1996.

IN THEIR STUDY, THE NATIONAL REMOTE SENSING CENTRE (NRSC) MAPPED THE EFFECT OF FIRE ON WOODY VEGETATION COVER IN KAVANGO AND CAPRIVI REGION USING LANDSAT TM AND ETM+ SCENES BETWEEN 1990 AND 2000 (NRSC, 2002). THE MANDATE FOR THE NRSC STUDY WAS TO PREPARE A REFERENCE GIS DATABASE ON WOODY BIOMASS IN 1990 AND 2000, BASED UPON LANDSAT TM SATELLITE IMAGERY OF THE KAVANGO AND CAPRIVI REGIONS. THE NRSC (2002) STUDY HAS SHOWN THAT THERE ARE FIRE HOTSPOTS (HIGH FIRE FREQUENCY AREAS) IN KAVANGO AND CAPRIVI REGIONS. SHEUYANGE (2002) REPORTED VEGETATION RESPONSES TO FIRE RETURN INTERVALS (NUMBER OF YEARS SINCE LAST FIRE) AT A LANDSCAPE LEVEL IN OHANGWENA REGION. ALL AFOREMENTIONED STUDIES ABOVE (TRIGG & LE ROUX, 2001; TRIGG, 2000; TRIGG & FLASSE, 2000; ERKILLÄ & SIISKONEN, 1992; NRSC, 2002 AND SHEUYANGE 2002) DID NOT QUANTITATIVELY INVESTIGATE THE IMPACT OF FIRE ON VEGETATION STRUCTURE AND COMPOSITION DUE TO FIRE FREQUENCIES.

THE UN CONVENTION ON BIOLOGICAL DIVERSITY CALLS FOR SUSTAINABLE DEVELOPMENT THAT ENCOMPASSES PROTECTION OF BIOLOGICAL DIVERSITY AND ECOSYSTEMS. AS A WAY OF HEEDING THIS CALL, IN ITS TEN-YEAR STRATEGIC PLAN OF ACTION FOR SUSTAINABLE DEVELOPMENT (STRATEGIC AIM 4.3) NAMIBIA CALLS FOR FOCUSED STUDIES ON THE BIODIVERSITY IMPACTS OF FREQUENT UNCONTROLLED FIRES ON DIFFERENT VEGETATION TYPES. THIS STUDY CONTRIBUTES TO THIS EFFORT BY INVESTIGATING THE INFLUENCE OF FIRE FREQUENCY ON VEGETATION STRUCTURE AND COMPOSITION, IN A PROTECTED FOREST RESERVE IN THE NORTHEAST (NE) NAMIBIA, THE HAMOYE STATE FOREST (HSF) SINCE 1989.

CHAPTER THREE

MATERIALS AND METHODS

3.1. STUDY AREA

3.1.1. Location and background

THE STUDY WAS CONDUCTED IN KAVANGO REGION, WHICH IS ONE OF THE THIRTEEN POLITICAL REGIONS OF NAMIBIA AND LIES BETWEEN 18.00°E AND 22.00°E AND 17.09° AND 18. 01° S (FIGURE 1). NAMIBIA IS LOCATED IN THE SOUTHWESTERN PART OF THE AFRICAN CONTINENT, ALONG THE ATLANTIC OCEAN ON THE WEST, AND IS A MEMBER OF THE SOUTHERN AFRICA DEVELOPMENT COMMUNITY (SADC).

THE COUNTRY HAS A POPULATION OF APPROXIMATELY 1.8 MILLION (CENTRAL STATISTICS OF NAMIBIA 2001, NHIES 2003/2004) AND A LAND AREA SIZE OF 824,268 KM² (REPRESENTING A DENSITY OF 2.2 PERSON PER 1 KM²). THIS IS HOWEVER DECEIVING, BEARING IN MIND THAT 16% OF THE COUNTRY IS UNINHABITABLE AS IT IS DESERT, AND 40% OF THE LAND ARE OWNED BY COMMERCIAL FARMERS. THIS INDICATES THAT HIGHER DENSITIES ARE EXPERIENCED AT LOCAL LEVELS, ESPECIALLY IN COMMUNAL AREAS.

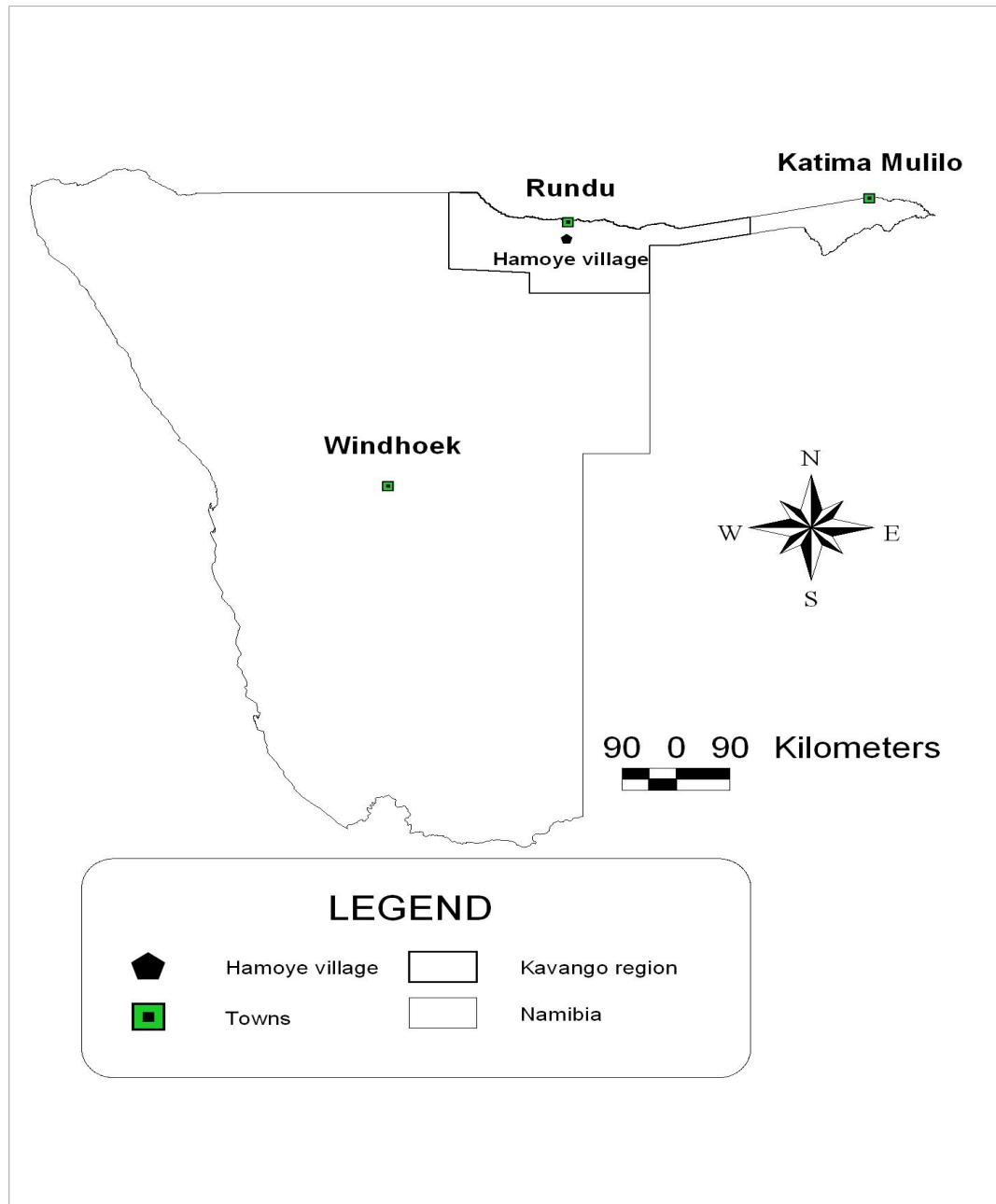


Figure 1. Map showing the geographical location of Hamoye in Kavango Region, Namibia.

3.2. Physical characteristics

3.2.1. Climate

The Kavango Region has an average annual rainfall of 550 mm, which increases slightly from southwest to northeast. The first rains fall in September or October and the late rains in May. Eighty percent of the rain falls between December and March, when the maximum rainfall in 24 hours can be 100-120 mm (Erkkilä and Siiskonen 1992).

The long term average temperature varies from 16°C in June – July to 26°C in October – January, with mean maximum and mean minimum temperatures of 35°C and 7°C, respectively. October is the hottest month, and July is the coldest. There is a slight possibility of a few night frosts in June (Erkkilä and Siiskonen, 1992). The summer season stretches from November to January while the autumn season is from February to April. Winter and spring seasons range from May to July and August to October, respectively.

3.2.2. Soils and Geology

The soils of the area fall under aeolian Kalahari sands (arenosols), which have a low water holding capacity and are sensitive to wind erosion (Erkkilä and Siiskonen 1992). According to Young (1998), landforms of savannas are characterized by undulating plains and ancient erosion surfaces that form patterns of valleys. This is also true for the Kavango area, due to the Kalahari sands that have been deposited over million years

through aeolian processes. In these soils, the silt and clay contents vary little. Alluvial and colluvial soils are found locally along the major watercourses and the Okavango River. Where there are no deep sands, underlying calcareous deposits are prominent (Erkkilä and Siiskonen 1992).

3.2.3. Drainage Systems

The perennial Okavango River is the dominant physical feature of this remarkably flat region that lies at an average altitude of 1 100 meters. The river rises from the well drained central plateau of Angola, and follows a south-easterly course to the Okavango swamps in Botswana. The river course flows through a broad flood valley that is annually inundated by the floods and provides good grazing during both wet and dry seasons.

A narrow strip of fertile soil, about more than 3 km wide stretches along the banks of the Okavango. Numerous islands are encountered in the eastern parts of the river, particularly between Mukwe and Bagani settlements. Some of these islands form habitation to Mbukushu and Mbarakwengo people.

The vast hinterland of the river course forms part of the northern Kalahari region, and is traversed by numerous watercourses. These watercourses are all draining in a northerly direction to the Okavango River (Figure 2). The most significant ones are the Dikwaya, Mpungu, and Namungundo running through the Kwangali tribal area, the watercourse

Löwen that enters the Okavango River in Mbunzu territory, the well-known Matako watercourse that originates in the Otjiwarongo district and runs through the former Hereroland-West and the Gciriku area of Kavango region.

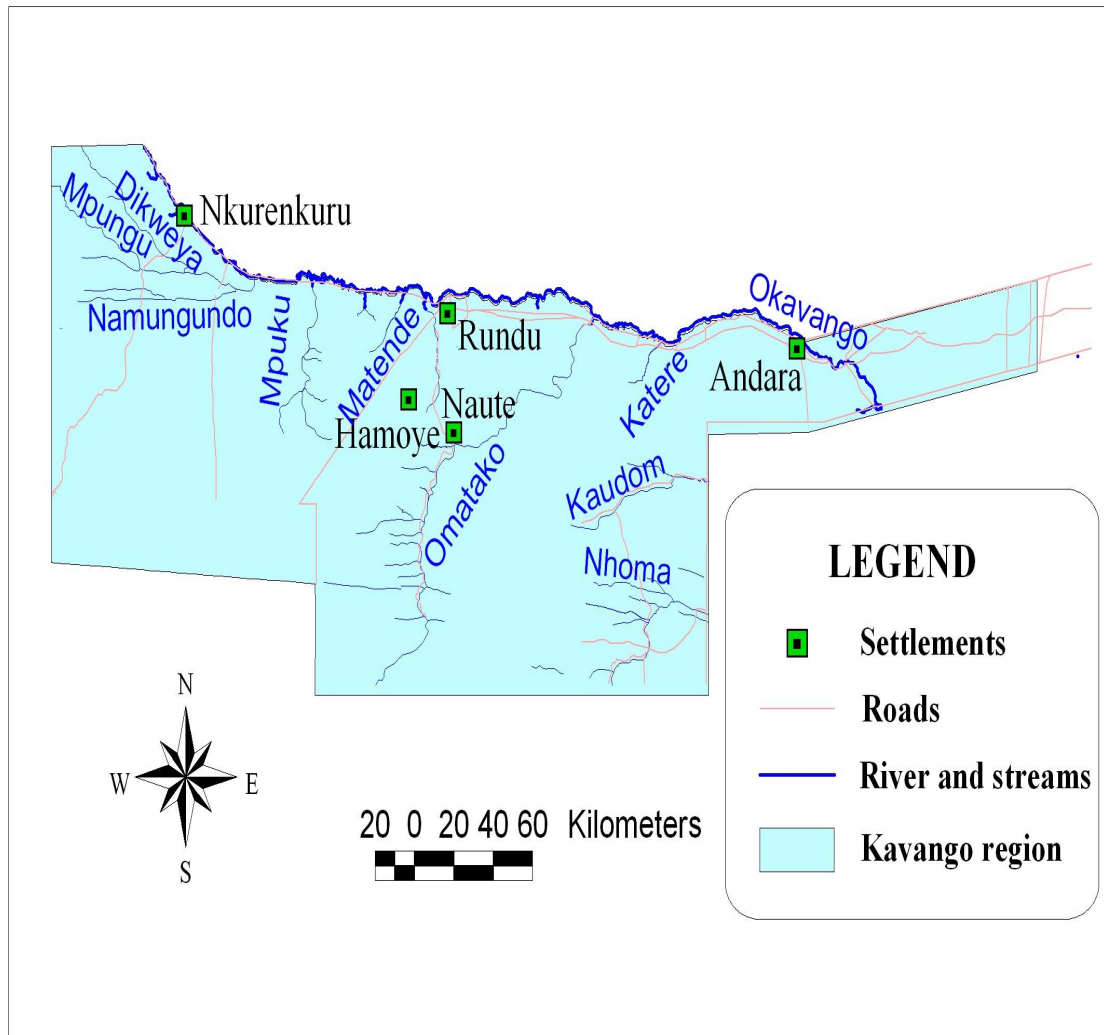


Figure 2. Map showing a detailed map of the Kavango Region, Namibia.

Although these watercourses only flow on the surface after rains, they have a high underground water level and water may be obtained by digging holes in the riverbeds (Malan, 2004). Isolated patches of fertile soils are also found near some of the watercourses, and this together with the availability of water, accounts for the settlement of subsistence farmers along these watercourses.

3.3. Human population and settlements

The Kavango region has a population of 201 093 of which 105 168 (52.3%) are women and 95 925 (47.7%) are men (Central Statistics of Namibia 2001). The five Kavango ethnic groups (Kwangali, Mbunza, Shambyu, Gciriku, and Mbukushu) reside in villages situated mainly along the Okavango River in Namibia. Several villages of Kavango people are found also on the lower courses of some of the *omiramba*, the dry river beds that join the Okavango river valley (Malan, 2004). Four different dialects are spoken in the Region. Both the Kwangali and the Mbunza, speak Rukwangali since the old Mbunza dialect has now become virtually extinct. The eastern part of the Region, two closely related languages, Rushambyu and Rugciriku, are spoken. However, currently Rumenyo language, the combination of Rushambyu and Rugciriku is used in schools under the Shambyu and Gciliku jurisdictions. To the extreme east, Thimbukushu is the spoken language. The Thimbukushu language differs markedly from the other languages (Malan, 2004).

3.4. Natural environment

The Kavango people are settled along the river where they practice subsistence agriculture on the narrow strip of fertile soil. They graze their cattle on the flood-plains (Malan, 2004). Lately, many people have been moving in- land in search of good agricultural and grazing land. Horticulture is the primary livelihood activity, practiced mostly by women. However, activities such as clearing of lands, ploughing, harvesting and threshing of crops are exclusively practiced by men. The most important crops are pearl millet, sorghum, and maize. Ground nuts, beans, pumpkins, gourds and tobacco are cultivated on a smaller scale (Mendelson & El Obeid, 2004).

The success of crops is largely dependent on rain, and failures sometimes occur. The people practice a subsistence economy by only producing enough food for one year. The crops that they cultivate depend on rain and people trust God and their ancestors to send enough rain in order for them to produce enough food for another year. No traditional method has been developed to use the abundant waters of the Okavango River (Mendelson & El Obeid, 2004). However, various irrigation schemes were developed by the former South African Administration of the territory as well as by a number of missionary stations. Today the region boasts water pipeline network supplied by government. Good harvesting results are achieved with intensive irrigation farming (Mendelson & El Obeid, 2004).

Animal husbandry is playing an increasing role in the economic lives of the Kavango people. In recent years most villagers are practicing cattle and small stocks farming. Cattle are not only kept for their milk, meat, and hides, but are used in draught power and have very high social value as a status symbol. Furthermore, animal sacrifices to the ancestral spirits feature strongly in the performances of various rituals (Malan, 2004).

Another important economic activity is fishing, which provides a substantial source of protein to the people. The species mostly caught are tiger, barbell and bream fish. Weirs are built in the river, while fishing baskets and lines and hooks are also used. Fish are sometimes shot with bow and arrow, or even speared where the water is shallow. Canoes are made by hollowing out tree trunks and frequently used on the river (Malan, 2004).

Because of a diversity of plant species, the area was reported to have abundant wildlife (Malan, 2004). Hunting traditionally constituted an important part of the economic activities of the people living in the region. The Mbukushu people traditionally were the hunting people who practiced agriculture to a minor extent (Malan, 2004). Most of the game was hunted by traps of various kinds. Huge pitfalls are also dug in the paths of the animals. These pitfalls are covered with thin branches, leaves and grass which easily collapse under weight. Small game and birds are snared with a trip (Malan, 2004). Porcupines, antbears, and badgers are killed in their burrows with smoke. A huge fire is made in the mouth of the hole while all other entrances to the burrow are blocked. The

dead animal is then dug out (Malan, 2004). Although fire is still used as a hunting tool by some local people, at present there is little game left in the region.

Additional sources of income include sale of thatching grass and carving for women and men, respectively. Residents also generate income from selling fuel wood, planks and poles. Production of planks for sale threaten some of the tree species, especially *Pterocarpus angolensis* and *Guibuortia coleosperma* (Mendelson & El Obeid, 2005). A significant income is also generated from fish sales and shebeen operations. Women also generate income from the sale of various vegetables at the rundu open market and other places in the Region.

3.5. Flora and Fauna

The study area is one of the areas with the best timber resources in Namibia (Erkkilä and Siiskonen, 1992). Due to its timber resources, the area was proclaimed a state forest in 1991. The potential of the Kavango Region in forestry was recognized as early as 1948, when the first survey of the forests of the Kavango region was carried out. The results were satisfactory in terms of available useful timber, seedlings and shoots (Erkkilä and Siiskonen, 1992). The vegetation of this area falls under the savanna vegetation based on the classification of Giess (1971). The most common tree species include *Baikiaea plurijuga*, *Pterocarpus angolensis* and *Terminalia sericea*.

The study area, HSF (Figure 3) is located about 30 km south of Rundu town along the gravel road to Ncaute settlement. It covers approximately 10 km². The study area is not inhabited by humans, although there are community settlements about 4 km away. From discussions with the local forestry officers stationed at Hamoye Forestry Research Office (HFRO), and working in the field together with a local informant, important insights into fire history pre- and post-independence were gained. Although it is documented that the HSF was declared a state forest just after independence in 1990, the actual protection from fire only came about in 1996 when the construction of fire breaks was introduced.

According to local informant, who resettled in the nearby village (Hamoye village) in 1988, the state forest only got physically demarcated from the rest of the communal forest in 1996, after the establishment of the former brigade project, which established a 30-m wide fire-break surrounding the State Forest, this fire-break is referred to as perimeter fire-break in this report). Six years later, 2001, an east to west 10-m wide outline was also established to divide the state forest in two equal halves, with each half about 10 x 5 km², hence referred to as 5 km outline in this report.

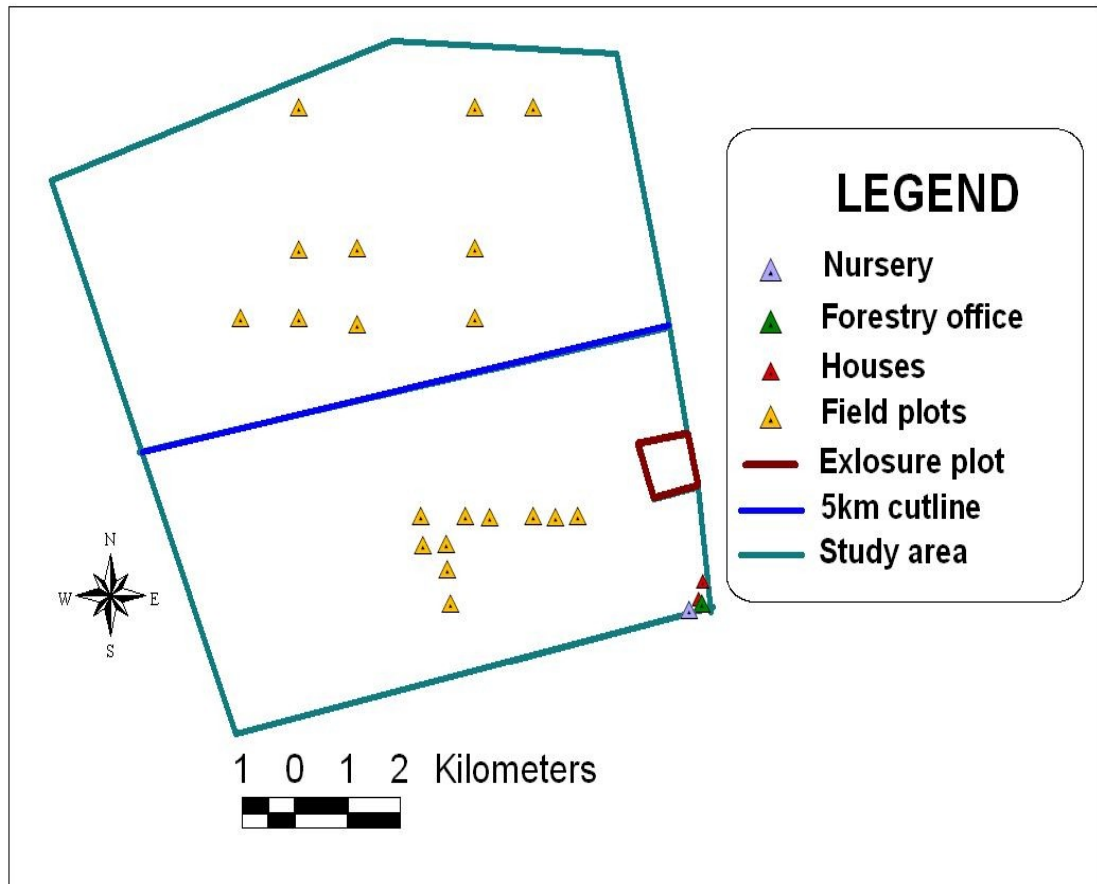


Figure 3. Map showing the actual study area (Hamoye State Forest) in the Kavango Region, Namibia.

The main purpose for the state forest demarcation into two parts was to prevent the whole state forest from burning in the event of fire. Prior to the demarcation of community forest from the communal land, a 1 km x 1 km research plot was established in 1995. The research plot was established to carry out long-term studies on the influence of fire exclusion on vegetation. The cut line surrounding the research plot is well maintained, hence the minimal burning.

3.6. Determination of fire frequency

3.6.1 Image data source

For fire frequency mapping, resampled free downloads from the internet were used. The main datasets for fire frequency mapping were obtained from the National Remote Sensing Center (NRSC), and Satellite Applications Centre (SAC)'s website (www.sac.co.za). The datasets contained the required relevant data on: quicklooks, images, roads and tracks, villages, settlements, population, land-cover, rainfall, and geomorphology. The oldest image was from May 1989 and the most recent was from December 2003) (Appendix 1).

3.6.2. Viewing, selecting and downloading images

The images used for mapping fire frequencies were those of May to December or later (January, February, etc), depending on the rainfall in the area for each year. Visual examination allowed the selection of best images. Best images were those that were 100% cloud-free. Only best images were selected to avoid cloud shadows during mapping. At least one image per month was saved, as the fire scars have the tendency to fade after a few months (NRSC, 2001).

3.6.3. Geo-correcting the images

The images, saved as JPEGs (for use in ER-mapper or ERDAS) or BMPs (for use in IDRISI mapping program) were georeferenced using ERDAS program. The images

were geocorrected using the NRSC's archive and from other sources, including the data collected by Lux-Development project ended in 2002.

3.6.4. On-screen digitizing of fire scars

The ArcView program was used to digitize the fire-affected areas and the final maps were also produced using this software. The calculation of areas was done in ARCVIEW program. It was found that visual interpretation is easier and more reliable, especially when an image of a previous month is toggled on and off on Arcview program project window. Areas that do not appear in the previous image, and look like fire scars, are certainly fire scars. Areas that keep appearing in previous images might be shaded mountain areas, or water. It was possible to digitize the scenes image by image. This resulted in a detailed time series of fire scars on a monthly basis from May 1989 to December 2003.

A few active fires can be seen in the center of right side of the upper image (plate 1a). In a colour composite, they appear as dark red with a light fringe (this fringe is the fire front). A few lighter red areas can be seen. Those are areas that burned previously in the same year. The bluish areas are likely to be older fire scars from the previous burning season as their pattern corresponds with the pattern of the visible fire scars. A much larger area affected by fire is seen on the second image (plate 1b). The straight line in the image is the main road from Grootfontein to Rundu.

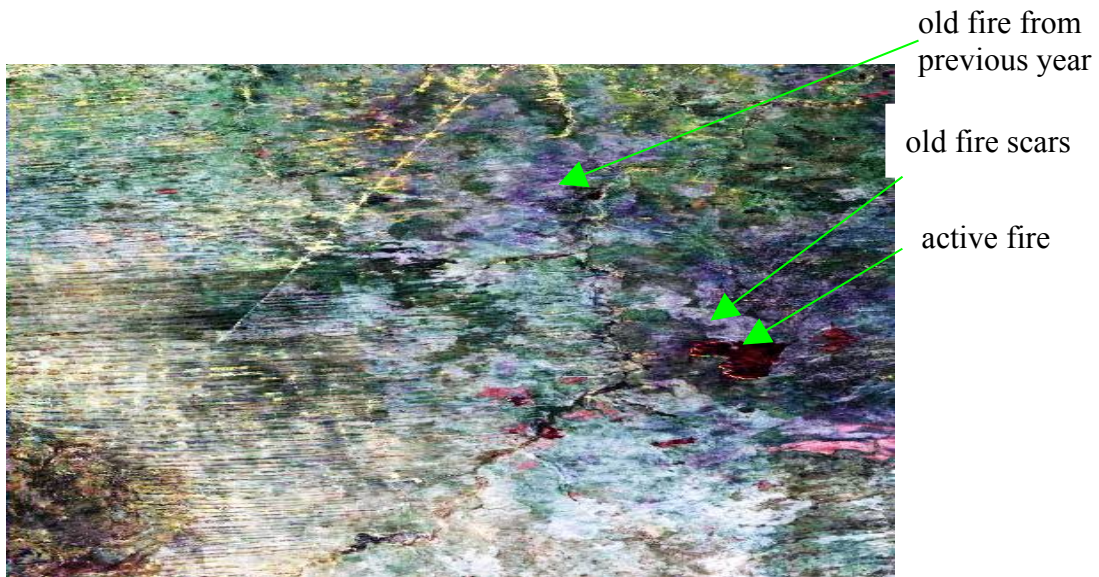


Plate 1a. Quicklook of a Landsat 5 TM scene of an area between Rundu and Tsumkwe for 17 August 2001

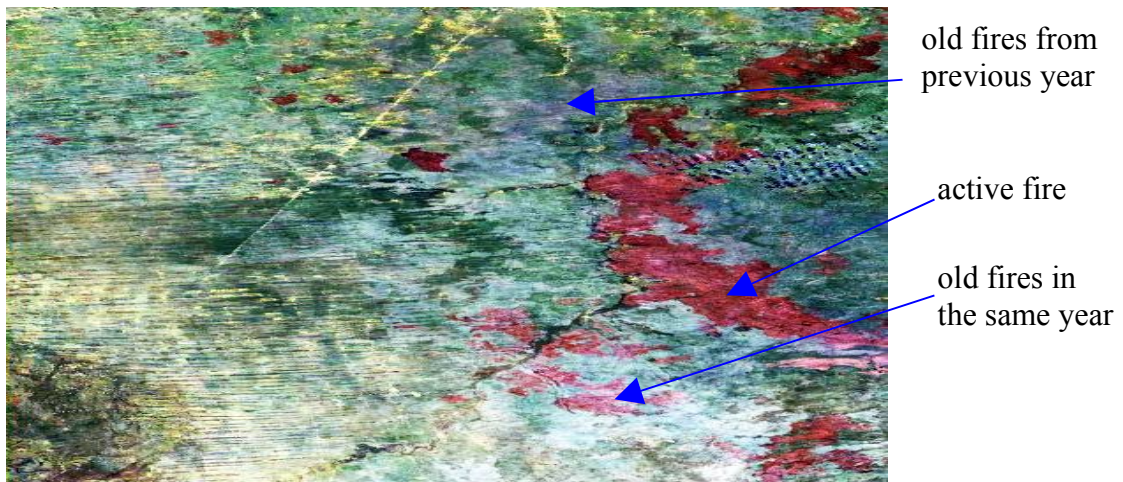


Plate 1b. Quicklook of a Landsat 5 TM scene of an area between Rundu and Tsumkwe for 2 September 2001.

3.6.5. Determination of fire frequency zones

The fire maps produced through on-screen digitizing were processed further in GIS to define areas with different degrees of fire frequency over the past 15 years. This resulted in the state forest being stratified into three different fire frequency zones, namely: low,

medium and high. Low fire frequency zone were areas that were burnt less than five times since 1989, medium frequency were areas that were burnt between five and 10 times, and high frequency were areas burnt more than ten times since 1989.

3.7. Determination of vegetation characteristics

3.7.1. Vegetation composition and structure

The sampling method is similar to the one used by Gambiza (2001). Ten plots of equal size were laid out in each of the three fire frequency zones to determine vegetation composition. The minimum plot size was derived using species area curve as described by Barbour *et al.*, (1987). Plots were 35 m x 35 m each and were randomly laid in each zone by dividing each zone into grids of cells numbered 1 to 30 and choosing 10 grid cells at random. The geographical location of these cells were recorded and entered into the GPS equipment, which was later used to locate these cells in the field (Appendix 2).

A tree was defined as an individual taller than 3 m and a stem circumference at breast height greater than 6 cm (Gambiza, 2001). Each tree was identified to species level and all individual diameters were measured using a diameter tape (diameter at breast height (DBH)) (Gambiza, 2001). For multi-stemmed trees, the DBH of each stem was recorded separately and was used in the determination of stem density, whereas the total of a multi-stem tree diameter was used to calculate the basal area. The heights of individual trees were estimated to the nearest meter or half a meter with the aid of ranging rod.

For a multi-stemmed tree, the highest point of the stems was taken as the overall tree height. Individual tree status was recorded either as live or dead. A stump was defined as the part of a tree stem left protruding from the ground after the tree has fallen or has been cut. Only stumps that were shorter than 1.3 meters and DBH greater than 6 cm were enumerated. All individual stumps were recorded and identified to species level. Trees were recorded to determine the density of trees in the State Forest. Stumps and dead trees were recorded to determine density of trees destroyed in the state forest.

To record sapling density and structure, a subplot measuring 5 m x 5 m was demarcated in the north-eastern corner of each 35 m x 35 m plot (see figure 4). All saplings in each 5 m x 5 m subplot were counted, their species recorded and their heights were measured using a tape. Saplings included all woody individuals that were one to two rainy seasons old to individuals up to 3m tall (Gambiza, 2001). The total number of stems was used to calculate sapling stem densities, expressed per ha and separately per species.

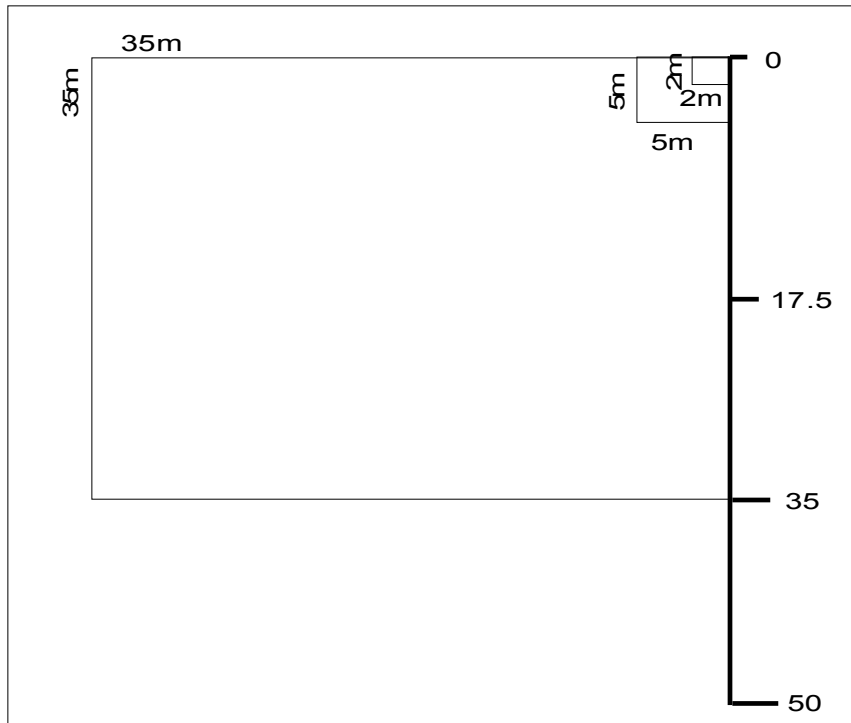


Figure 4. Field plot set up: 35 m x 35 m plot: all individual tree diameter and height, tree stem and tree species were recorded. In a 5 m x 5 m subplot, all saplings numbers, their heights and species were recorded. Grass cover and composition were also recorded. In a 2 m x 2 m subplot, all individual forbs were recorded and their species recorded. In a 50 m line transect, woody cover assessment was carried out.

3.7.2. Determination of woody canopy cover

The line-intercept method as explained by Zar (1997) was used. In each of the 30 plots, a 50-meter line transect was laid out north to south on the eastern side of each 35 m x 35 m plot (Figure 4). A canopy intercept measurement was made of all woody plants intercepted by a vertical plane running through the tape. Each woody species

intercepting the transect line was identified to species level, and its corresponding intercept length was recorded in meters.

3.7.3. Herbaceous cover assessment

The overall percentage grass cover in a single 5 m x 5 m subplot located in a north-eastern corner of the 35 m x 35 m plot was visually estimated and all individual grasses within the subplot were identified to species level, and the percentage cover of individual species was visually estimated. The grass species were recorded to determine species composition and richness. Key grass species were those that had high grass cover in all three fire frequency zones. Individual forbs from a single 2 m x 2 m subplot within a 5 m x 5 m subplot were counted and identified to species level to determine their abundance and composition.

3.8. Data manipulation and analysis

3.8.1 Analysis of the fire frequencies

The extent of burnt area during each year in each zone (for the period 1989 to 2003) was calculated using the Xtools extensions in the ArcView program. The data were not normally distributed. Hence, the Kruskal Wallis test was used to test for the mean area burnt among fire frequency zones between 1989 and 2003. The differences in mean burnt area between the fire frequency zones were tested using Kruskal Wallis test, while

the Mann Whitney test was used to reveal the burnt differences among the fire frequency zones.

3.8.2. Tree basal area frequency distribution

Basal area (BA) was calculated using the formula $BA=C^2/ (4\pi)$, where C is a basal circumference of a tree, $\pi = 3.1416$. BA was expressed in cm^2 . The resultant basal area values were then divided into 6 classes as follows: class 1: $< 200 \text{ cm}^2$, class 2: $200\text{-}399 \text{ cm}^2$, class 3: $400\text{-}599 \text{ cm}^2$, class 4: $600\text{-}799 \text{ cm}^2$, class 5: $800\text{-}999 \text{ cm}^2$, and class 6: $> 999 \text{ cm}^2$. A Chi – square (χ^2) test was used to analyse the differences in basal area distribution of trees among fire frequency zones.

3.8.3. Height frequency distribution

Tree height data were divided in six classes, as follows: class: $< 2.9 \text{ m}$, class 2: $3\text{-}5.9 \text{ m}$, class 3: $6\text{-}8.9 \text{ m}$, class 4: $9\text{-}11.9 \text{ m}$, class 5: $12\text{-}14.9 \text{ m}$, and class 6: $>15 \text{ m}$. The percentages of trees in the different height class were used to draw the tree height class distribution chart, while the Chi – square test was used to analyze the differences in tree height distribution, using actual counts in each class.

3.8.4. Woody canopy cover and grass cover

The percent canopy cover of each plant species was calculated by totalling the canopy intercept measurements for all individuals of that species along the transect line. The total canopy intercept distance was converted to a percentage by dividing that value by the total length of the line. Total canopy cover measured from the transect line was

calculated by adding the cover percentages of all the species. The Kruskal Wallis test was used to test for differences in the overall canopy cover among fire frequency zones. The Mann Whitney test was used to reveal the differences in overall canopy site cover among the fire frequency zones. The Kruskal Wallis test was used to test for differences in grass cover, while the Mann Whitney test was used to reveal the differences among the fire frequency zones. The Kruskal Wallis test was again used to test the plot grass percentage cover for each key grass species (*T. superba*, *Cypogon spp.*, and *D. Seriata*) among fire frequency zones.

3.8.5. Tree, stump, sapling, and forb densities

The stem, live tree and stump densities were calculated by dividing the total abundance of plants by plot size in hectares. The live tree, stem, stump, forb and sapling density data were all normally distributed. The t-test was used to test the difference in stem and live tree density in each zone, while the one-way analysis of variance was used to test for differences in the dead tree, stump, sapling and forb densities among fire frequency zones.

3.8.6. SPECIES DIVERSITY AND RICHNESS

The species diversity in each of the 30 plots was calculated using the Shannon's

diversity index

The proportion of species i relative to the total

number of species (p_i) was calculated, and then multiplied by the natural logarithm of this proportion ($\ln p_i$). The resulting product was summed across species, and multiplied

by -1. The data were normally distributed, and the one-way analysis of variance was used to test for differences in plants (grasses were excluded as grass percentage rather than individual grass count was recorded) species diversity among the fire zones. Species richness of all plants was obtained by counting the number of species per plot. The data were tested for normality and were found to be normally distributed. The one-way analysis of variance was used to test for differences in tree species richness among the fire zones.

3.8.7. Species composition

Hierarchical Cluster Analysis (HCA) using average linkage method was performed on a matrix of 30 plots by 60 species, using species presence /absence data. This was done to produce a classification identifying similarities amongst plots based on species composition (Mapaure, 2001).

3.8.8. VARIATIONS IN COMMUNITY COMPOSITION

Detrended Correspondence Analysis (DCA), an indirect gradient analysis, was performed on the diversity data matrix of 30 plots and 60 species to reveal variations in the community composition. The diversity matrix data were first converted from Excel to FORTRAN format. The CANOCO version 4.5 for Windows package was used to analyse variation between plant communities.

CHAPTER FOUR

RESULTS

4.1. Fire frequencies

The annual fire scar maps (Figure 5) revealed that the high frequency zone burnt 11 times in 15 years, the medium fire frequency zone burnt 8 times in 15 years, while the low fire frequency burnt 4 times in 15 years.

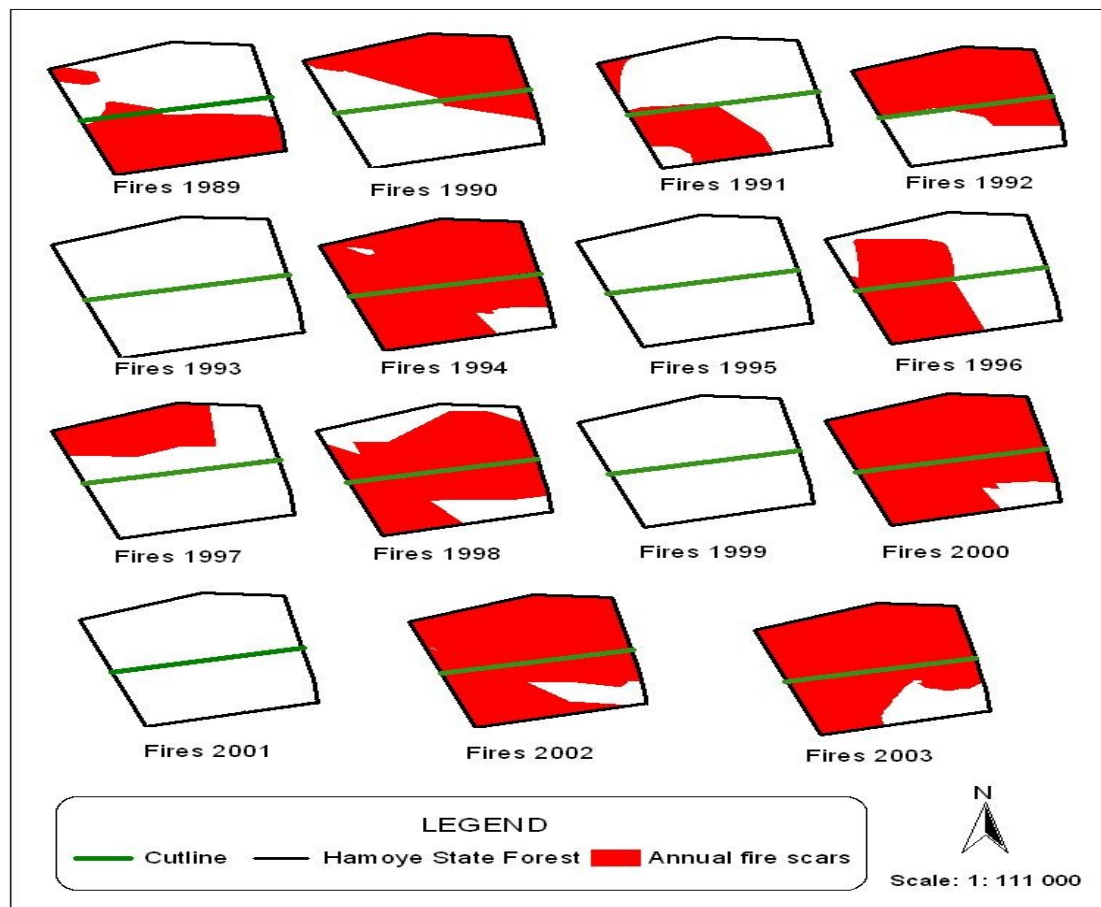


Figure 5. Annual fire scars from 1989 to 2003 in the Hamoye State Forest, mapped from Landsat 5 & 7 images.

The southeastern corner had fewer annual fire scars, while most annual scars were distributed on the northern and western sides of the forest. Figure 6 shows how fire frequencies were distributed in the Hamoye State Forest between 1989 and 2003.

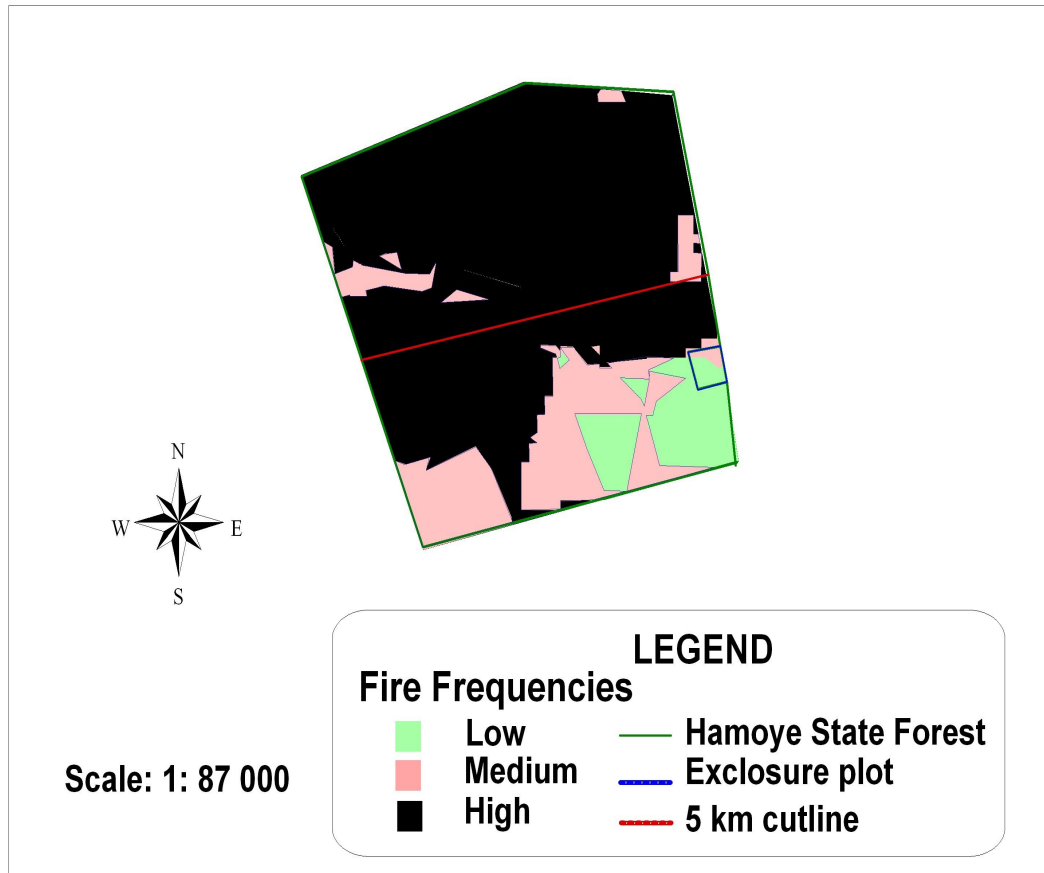


Figure 6. A map of Hamoye State Forest showing the zones of different fire frequencies between 1989 and 2003.

On average, an area of 11467.28 hectares of the Hamoye State Forest was affected by fire during 1989 to 2003. This breaks down into 8442.14 hectares affected by high fire

frequency, 2019.94 hectares affected by medium fire frequency and 925.06 hectares affected by low fire frequency.

Spatially, high fire frequency zone covered most parts of northern half of the State Forest, although there are few small patches of medium fire frequencies. High fire frequencies were also distributed in the southern half of the State Forest, forming a linear shape just south of the cutline that divides the State Forest into 2 equal parts. The medium fire frequencies were distributed around the southwestern corner and south-central areas of the state forest. There were also few small patches of medium frequencies in the northern half of the state forest.

The low fire frequencies were distributed around the southeastern corner and south, and in the area forming a triangle in the central south of the state forest. The south eastern corner had fewer annual scars. Most annual scars were distributed on the northern and western side of the forest.

4.2. Comparisons of burnt areas

The extent of burnt areas in the high fire frequency zone ranged from 0% in 1993, 1999 and 2001, to 73% in 2000. The burnt area in the medium fire frequency zone ranged from 0% in 1993, 1995, 1999 and 2001 to 18% in 1994. The low fire frequency zone area burnt ranged from 0% in 1990, 1992, 1993-7, 1999-2001, and 2003 to just 8% in 1989.

Figure 7 below, illustrates the fluctuations of areas affected by fire over time in the different fire frequency zones between 1989 and 2003.

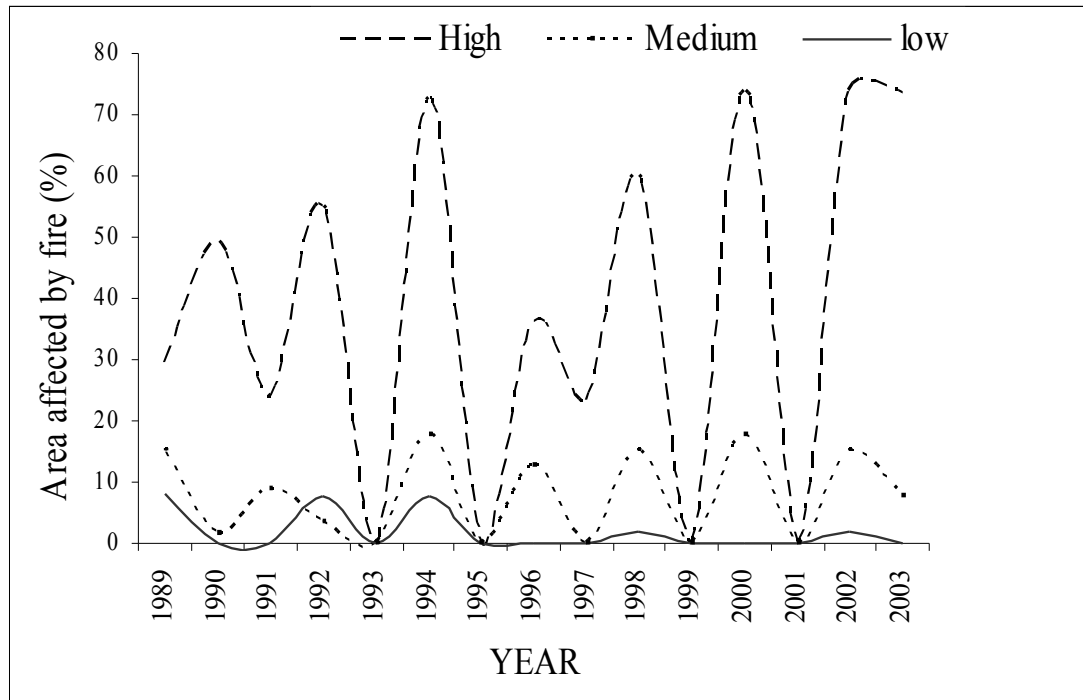


Figure 7. Time series of areas affected by fire between 1989 and 2003 in the three fire frequency zones of the Hamoye State Forest, Kavango Region.

The data were not normally distributed. There were significant differences in mean area burnt in 15-year period ($H = 16.887$, $df = 2$, $p < 0.001$) among fire frequency zones. Mean area burnt was significantly higher in the high fire frequency zone than the medium ($Z = -2.651$, $P < 0.01$) and low ($Z = -3.501$, $P < 0.001$) fire frequency zones. Medium fire frequency zone had significantly higher mean area burnt than low fire frequency zone ($Z = -2.771$, $P < 0.01$).

4.3. Vegetation structure

4.3.1. Sample sizes

A total 7316 plants (live and dead combined) were assessed in all three fire frequency zones combined, consisting of 517 trees, 13 stumps, 3116 saplings and 211 forbs in the high fire frequency zone, 251 trees, 15 stumps, 735 saplings, and 100 forbs in the medium fire frequency zones and 288 trees, 13 stumps, 1999 saplings and 58 forbs in the low fire frequency zones.

4.3.2. Tree basal area

Guibourtia coleosperma had the highest mean basal area of 1280 and 1188 m²/ha in the high and low fire frequency zone, respectively (Table 1). Although *Burkea africana* was the most common species in all fire frequency zones, it had a low mean basal area.

Table 1. Basal area for selected traditional timber tree species per fire frequency zone.

P = p-value from the overall test. * = p<0.05, ** = p<0.01.

Species	Basal area in each frequency zone (m ² /ha)			
	High	Medium	Low	P
<i>Burkea africana</i>	298 ± 31.2	260 ± 22.2	380 ± 56.9	*
<i>Baikiaea plurijuga</i>	0	422 ± 157.2	476 ± 108.2	**
<i>Guibourtia coleosperma</i>	1280 ± 261.2	376 ± 167.9	1188 ± 614.9	**
<i>Pterocarpus angolensis</i>	478 ± 124.9	423 ± 70.4	331 ± 47.1	*
<i>Terminalia sericea</i>	355 ± 108.0	151 ± 30.8	113 ± 18.3	*

Other species with low traditional timber value whose differences in basal areas among the three fire frequency zones were significant all at p< 0.05 included: *Combretum collinum*, *Combretum zeyheri*, *Combretum psidioides*, *Dialium engleranum*, *Diplorhynchus condylocarpon*, *Ochna pulchra*, *Schinziophyton rautanenii*, *Strychnos*

cocculoides and *Strychnos pungens*. Other species such as *Swartzia madagascariensis*, *Commiphora sp.* and *Rhus tenuinervis* had a very low frequency of occurrence and only appeared in one of the three fire frequency zones. For this reason their differences in basal area among fire frequency zones were not tested.

Individual tree basal areas ranged from 0.21 to 1.65 m²/ha in the high fire frequency zone; from 0.49 to 0.89 m²/ha in the medium fire frequency zone and from 0.31 to 1.69 m²/ha in the low fire frequency zone. The mean of total basal area data were normally distributed ($Z = 0.653$, $P > 0.05$). There were no significant differences in mean basal area among the fire frequency zones ($F = 2.944$, $p > 0.05$) (Figure 8).

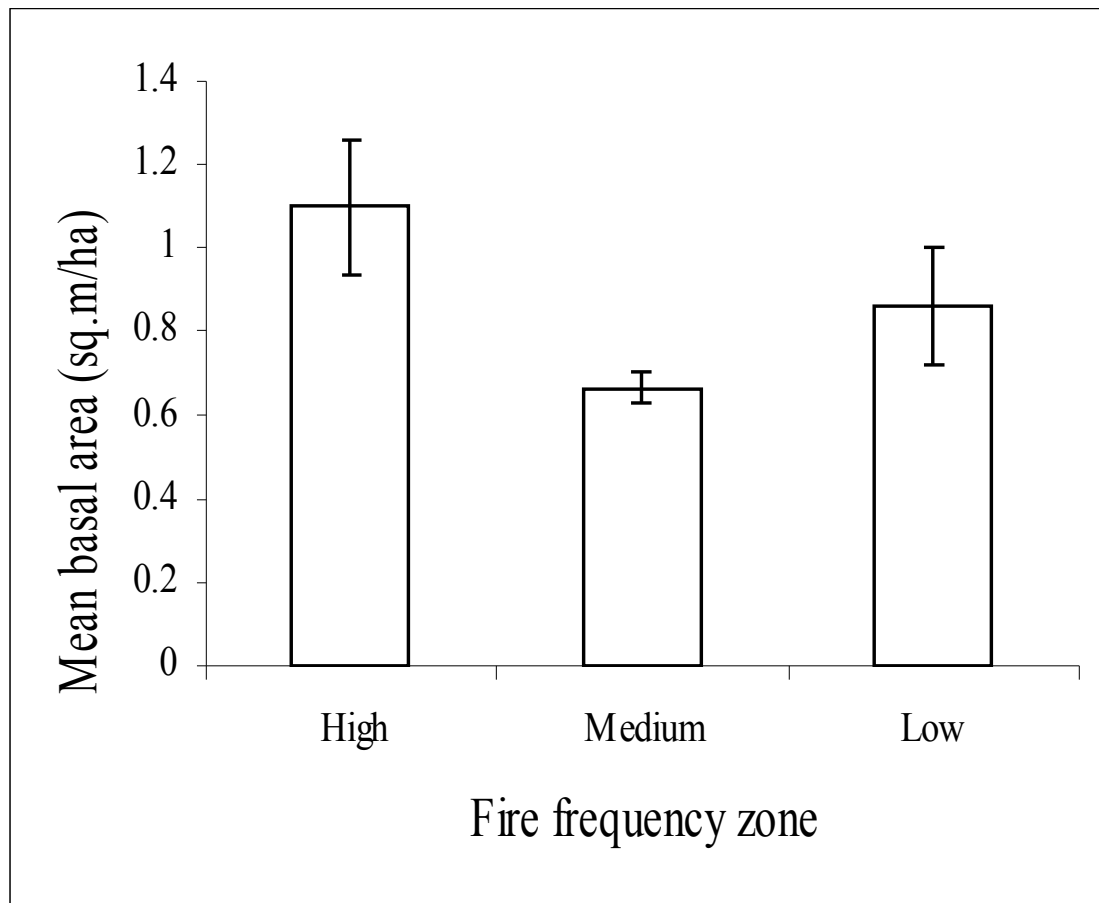


Figure 8. Variations in total basal area (mean \pm SE) of trees in high, medium and low fire frequency zones of the Hamoye State Forest, in Kavango Region, northeastern Namibia.

Basal area distribution patterns indicated higher proportions of smaller-sized (< 200 cm²) individual trees than medium-sized (200-399 cm², 400-599 cm² and 600-799 cm²) and large-sized trees (800-999 cm² and >900 cm²). The basal area distribution in the high fire frequency zone portrays an inverse-J shape pattern, with sharp declines from small-sized to large-sized trees at all fire frequency zones. The proportion of medium and large sized trees in all fire frequency zones was below twenty percent (Figure 9). Both the medium and low fire frequency zones display distribution patterns showing

high portions of small-sized, but with degreasing proportion in larger-sized individuals. There were no significant differences in basal area distribution patterns amongst the fire frequency zones ($\chi^2 = 30$, $df = 10$, $p > 0.05$).

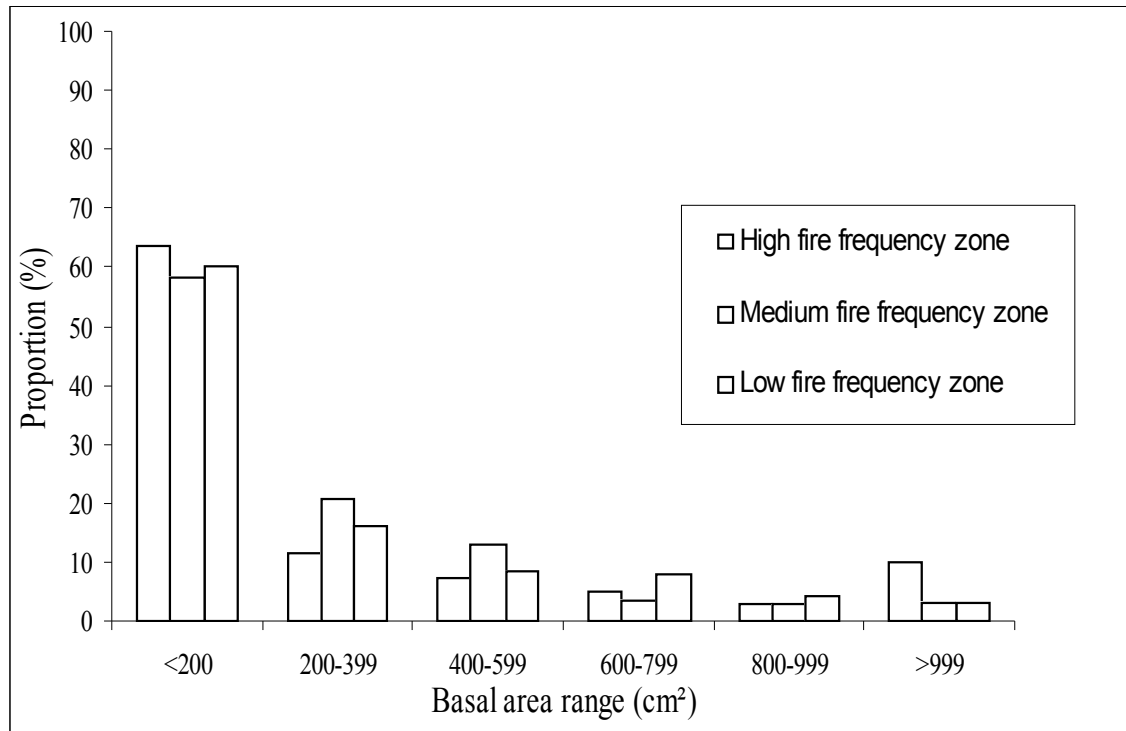


Figure 9. Comparison of the basal area distribution of trees in the three fire frequency zones of the Hamoye State Forest, in Kavango region, northeastern Namibia.

4.3.3. Tree height class distribution patterns

The heights of trees ranged from 1.3 m to more than 15 m in all the three fire frequency zones. The tree height class distribution patterns for the three fire frequency zones are described as follows: left-skew patterns for the high and low fire frequency zone and right-skew pattern for the medium fire frequency zone. Tree height class distribution patterns indicated lower proportions of trees <2 m in all three fire frequency zones. All

three fire frequency zones had many medium-sized trees (3 to 12.9 m height range). Only the medium fire frequency zone had a high proportion of taller trees (>15 m). There were hardly any tall trees (>15) in the high and low fire frequency zones (Figure 10).

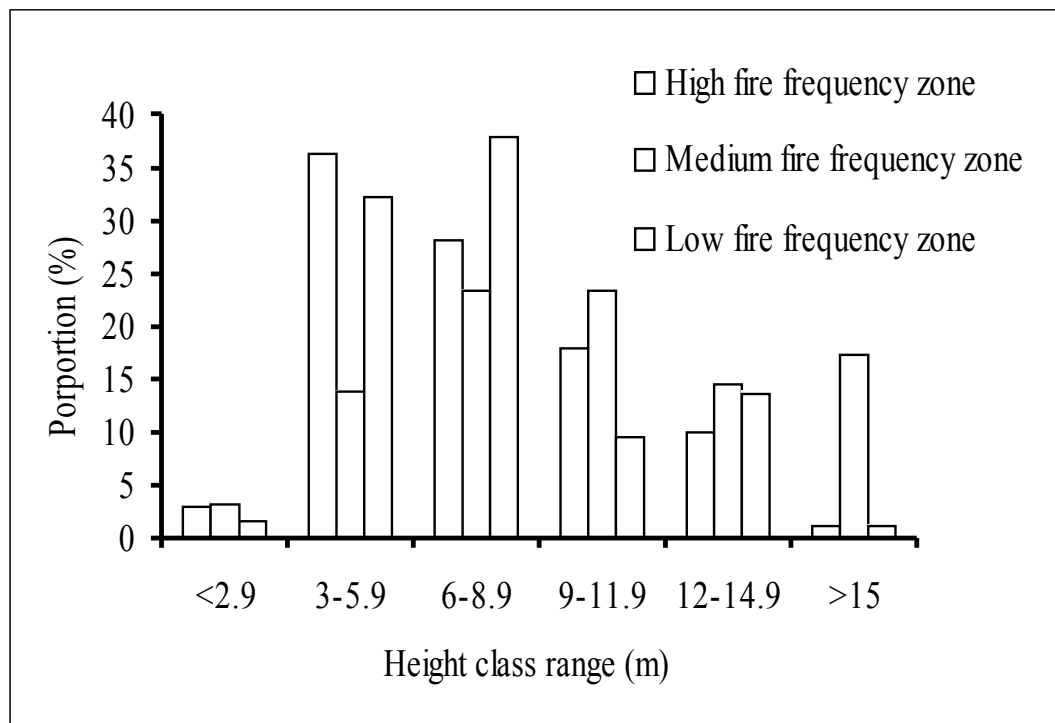


Figure 10. Comparison of height class distribution patterns of trees in the three fire frequency zones of the Hamoye State Forest, in Kavango region, northeastern Namibia.

Statistical comparisons revealed significant differences in tree height class distribution patterns among the three fire frequency zones ($\chi^2 = 135.7$, $df = 10$, $p < 0.001$). These differences can mainly be attributed to more than expected individual trees in the high fire frequency zone for class 3-5.9 m, in the low fire frequency zone for classes 6-8.9 m; 9-11.9 and >15 m. The differences were also due to less than expected individual trees in the medium fire frequency zone for classes 3-3.9 m; 9-11.9 and >15 m.

4.3.4. Sapling height class distribution patterns

Sapling height class distribution patterns indicated that most saplings were < 25cm high, in all fire frequency zones. The distribution for the high fire frequency zone portrays an inverse-J pattern with a much higher number of saplings for the middle sized height classes (26-50, 51-100 cm, 101-150 and 151 - 200cm) than the medium and low fire frequency zones (Figure 11). The medium fire frequency distribution did not have saplings in the middle class distributions (51-100 cm) and high class distributions (>200). The low fire frequency distribution did not have saplings in the middle class distributions (51-100 and 101-150 cm) and high class distributions (151-200 cm).

Statistical comparisons revealed significant differences in sapling height class distribution patterns among the three fire frequency zones ($\chi^2 = 408.54$, $df = 10$, $p < 0.001$). There were less than expected saplings in the high fire frequency zone for the classes <25 cm, in the medium fire frequency zone in the classes 51-100 cm and 101-150 cm, and less than expected saplings in the low fire frequency zone for the classes 51-100 cm and 101-150cm.

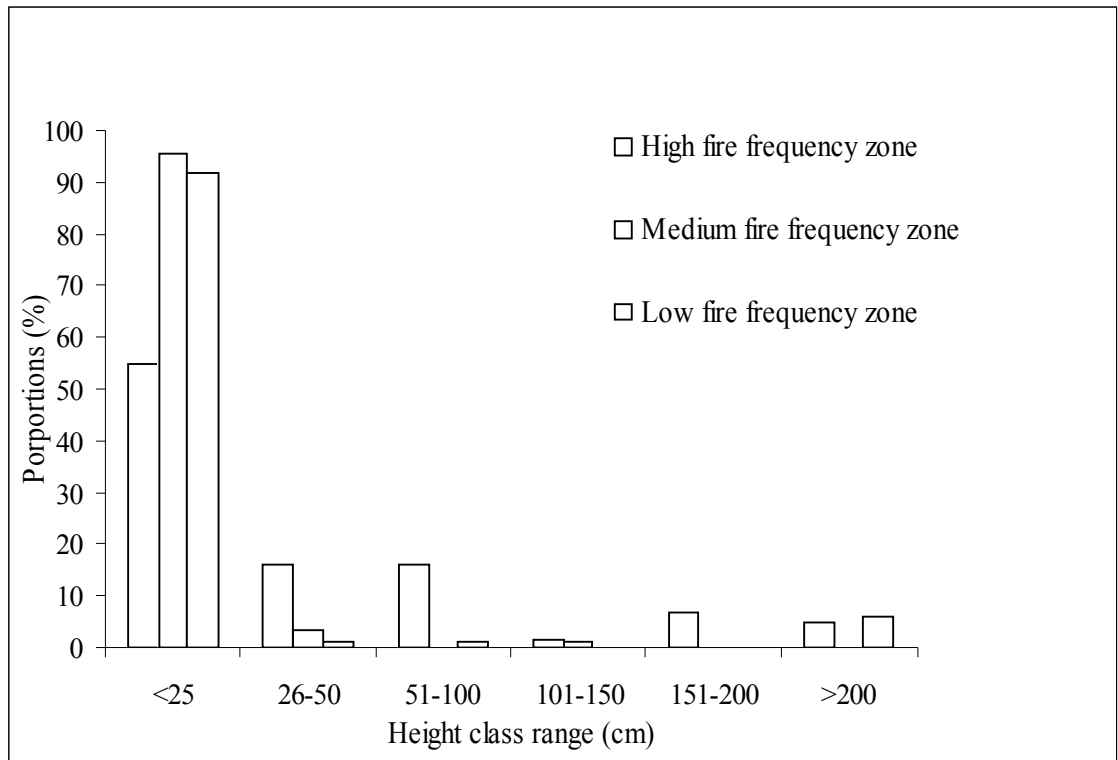


Figure 11. Sapling height class distribution patterns in the high, medium and low fire frequency zones in the Hamoye State Forest, in Kavango region, northeastern Namibia.

4.3.5. Plant densities

4.3.5.1. Density of forbs

The density of individual forbs ranged from 0 to 20/m² in the high fire frequency zone, from 0 to 11/m² in the medium fire frequency zone and from 0.25 to 8.7/m² in the low fire frequency zone. The data were not normally distributed, consequently, statistical comparisons using Kruskal Wallis test revealed significant differences in forb density among fire frequency zones ($H = 43$, $df = 2$, $p < 0.05$). Forb density was significantly higher in the high fire frequency zone than in the low fire frequency zone ($Z = -2.241$, $p < 0.05$). However, the differences in forb density were not significant between high and

medium fire frequency zones ($Z = -1.224$, $p > 0.05$), and between medium and low fire frequency zones ($Z = -1.062$, $p > 0.05$) (Figure 12).

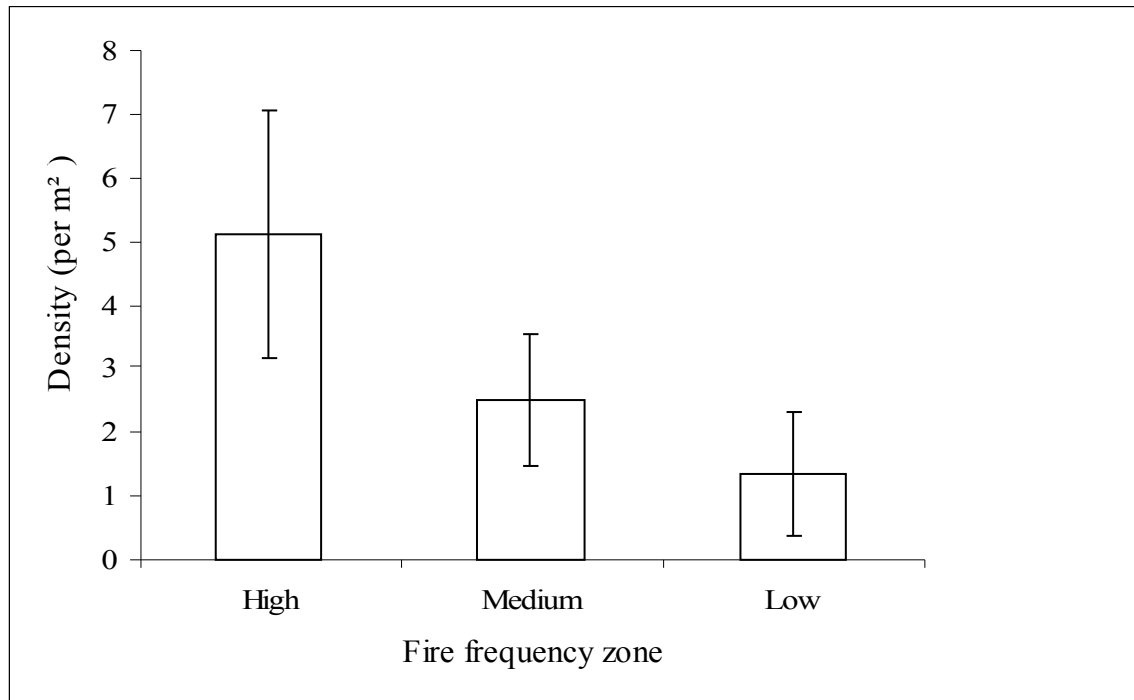


Figure 12. Differences in the densities (mean \pm SE) of individual forbs at three fire frequency zones in Hamoye State Forest, in Kavango region, northeastern Namibia.

4.3.5. Density of trees

4.3.5.1. Live trees

The density of individual live trees (Figure 12) ranged from 98 to 490/ha in the high fire frequency zone; from 49 to 278/ha in the medium fire frequency zone and from 57 to 351/ha in the low fire frequency zone.

Stem and live tree densities were normally distributed. The statistical comparisons of stem and live tree densities indicated no significant differences among zones (Figure 13). Stem densities did not differ significantly from individual tree densities in the high

fire frequency zone ($t = 1.860$, $df = 9$, $p > 0.05$), in the medium fire frequency zone ($t = 2.298$, $df = 9$, $p > 0.05$), and in the low fire frequency zone ($t = 1.627$, $df = 9$, $p > 0.05$).

There were no significant differences in stem densities amongst the three fire frequency zones ($F = 1.603$, $df = 2$, $p > 0.05$). Similarly, there were no significant differences in individual tree densities amongst the three fire frequency zones ($F = 2.085$, $df = 2$, $p > 0.05$).

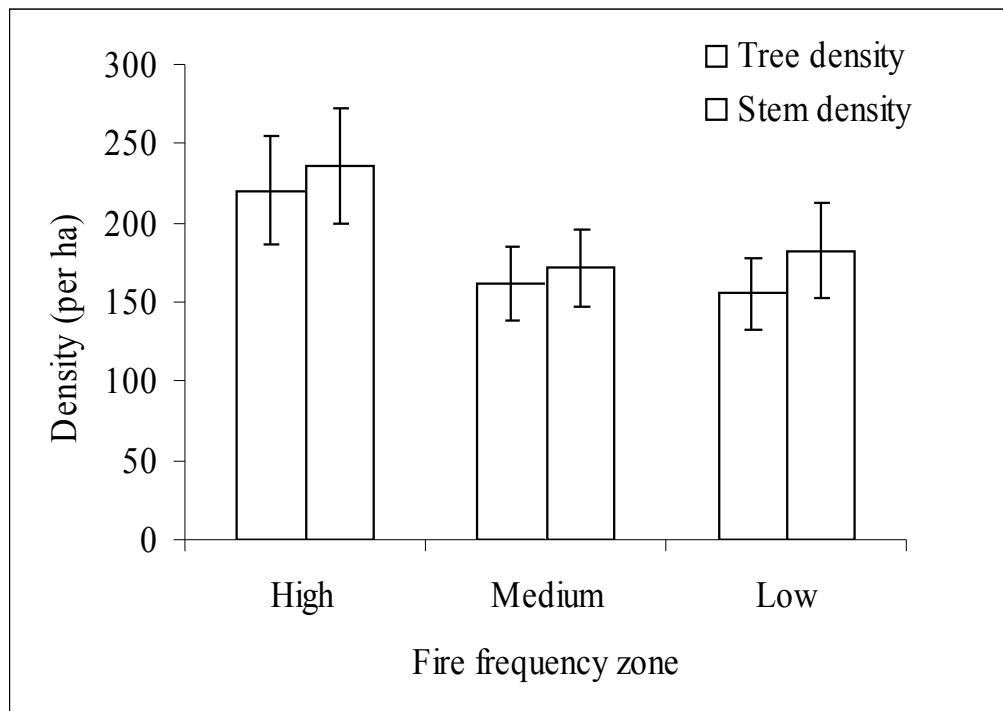


Figure 13. Differences in the densities (mean \pm SE) of individual live trees and stems at three fire frequency zones in Hamoye State Forest, in Kavango region, northeastern Namibia.

4.3.5.2. Dead trees

The density of dead trees ranged from 0 to 49/ha in the high fire frequency zone, from 16 to 41/ha in the medium fire frequency zone and from 8 to 57/ha in the low fire frequency zone (Figure 14).

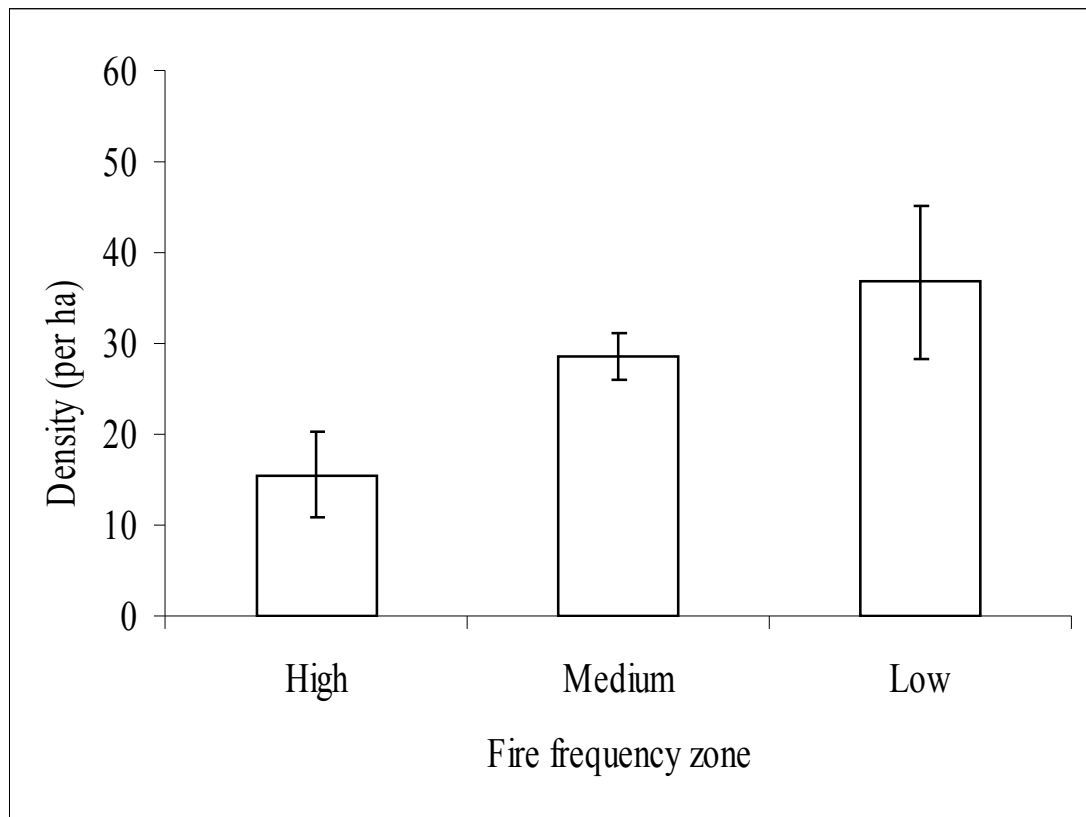


Figure 14. Differences in the dead tree densities (mean \pm SE) in three fire frequency zones in Hamoye State Forest, in Kavango Region, northeastern Namibia.

The dead tree density data were normally distributed. There were significant differences in the dead tree densities among the three fire frequency zones ($F = 3.530$, $df = 2$, $p < 0.05$). Dead tree densities were significantly lower in the high fire frequency zone than in the low fire frequency zone ($p < 0.05$). Tree densities did not differ significantly

between the medium and low fire frequency zones ($p > 0.05$). Similarly, dead tree densities did not differ significantly between high and medium fire frequency zones ($p > 0.05$).

4.3.5.3. Density of stumps

The density of stumps ranged from 0 to 51/ha in the high fire frequency zone, from 5 to 41/ha in the medium fire frequency zone and from 8 to 57/ha in the low fire frequency zone (Figure 15). There were no significant differences in stump densities among the three fire frequency zones ($F = 1.344, p > 0.05$).

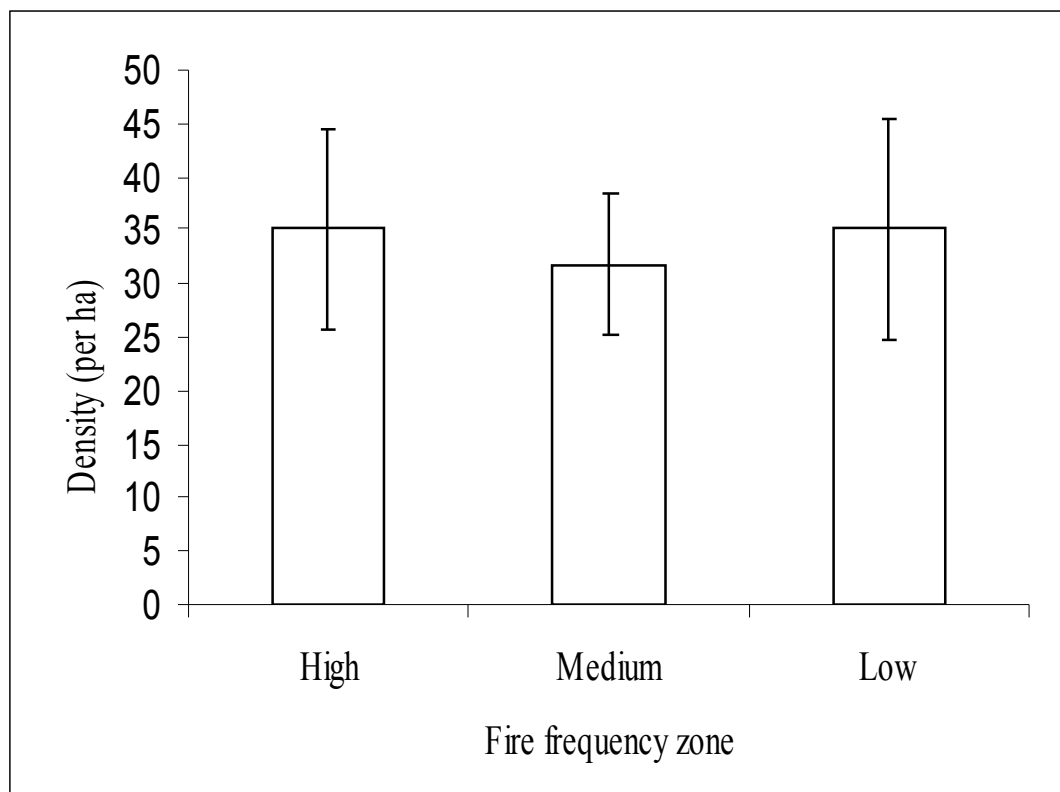


Figure 15. Differences in the densities of stumps (mean \pm SE) in three fire frequency zones in Hamoye State Forest, in Kavango Region, northeastern Namibia.

4.3.5.4. Density of saplings

Densities of saplings (Figure 16) ranged from 16 000 to 348 000/ha in the high fire frequency; from 6 400 to 66 000/ha in the medium fire frequency zone and from 6 400 to 410 000/ha in the low fire frequency zone. The data were not normally distributed, subsequently the Kruskal Wallis test found significant differences in the sapling densities amongst the fire frequency zones ($H = 8.791$, $df = 2$, $p < 0.05$). Sapling densities were significantly higher in the high fire frequency zone than in the medium ($Z = -3.028$, $p < 0.01$). However, there were no significant differences in sapling densities between the medium and low fire frequency zones ($Z = -0.038$, $df = 1$, $p > 0.05$).

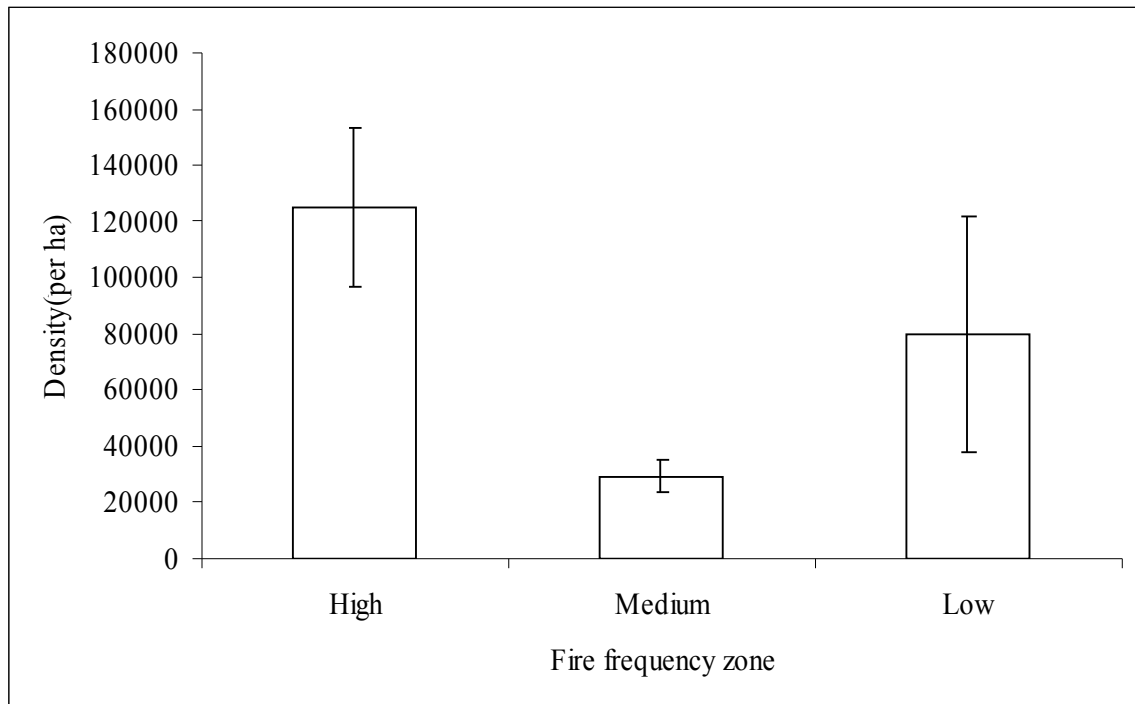


Figure 16. Differences in the densities (mean \pm SE) of individual saplings at high, medium and low fire frequency zones in Hamoye State Forest, in Kavango Region, northeastern Namibia.

4.3.6. Plant cover

4.3.6.1. Woody cover

The woody canopy cover ranged from 10 to 84 % in the high fire frequency zone, from 25 to 133 % in the medium fire frequency zone and from 31 to 117 % in the low fire frequency zone. There were significant differences in mean woody canopy cover (Figure 17) among the three fire frequency zones ($H = 7.311$, $df = 2$, $p < 0.05$). The mean woody canopy cover was both higher in the low fire frequency zone ($Z = -2.419$, $df = 1$, $p < 0.05$) and medium fire frequency zone ($Z = -2.419$, $df = 1$, $p < 0.05$) than in the high fire frequency. There were however no significant differences in mean woody canopy cover between the medium and low fire frequency zones ($Z = -0.038$, $df = 1$, $p > 0.05$).

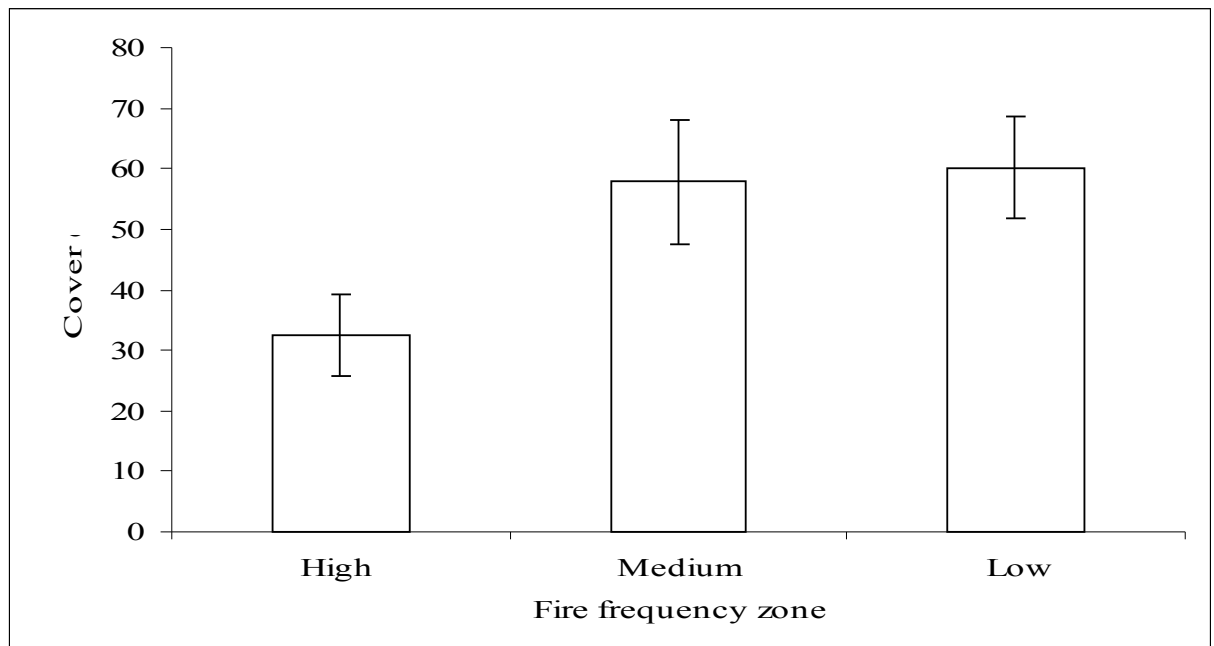


Figure 17. Woody percentage cover (mean \pm SE) in high, medium and low fire frequency zones in the Hamoye State Forest, in Kavango region, northeastern Namibia.

There were no significant differences in mean woody canopy cover between the medium and low fire frequency zones ($Z = -2.192$, $p > 0.05$).

4.3.6.2. Grass cover

The grass cover ranged from 18 to 75 % in the high fire frequency zone, from 40 to 90 % in the medium fire frequency zone and from 35 to 100 % in the low fire frequency zone. There were significant differences in the mean grass cover among the three fire frequency zones ($H = 7.237$, $p < 0.05$) (Figure 18). The mean grass cover was higher in the low fire frequency zone than in the high fire frequency zone ($Z = -2.777$, $p < 0.01$).

There were however no significant differences in the mean grass cover between the high and medium fire frequency zone ($Z = -1.405$, $p > 0.05$).

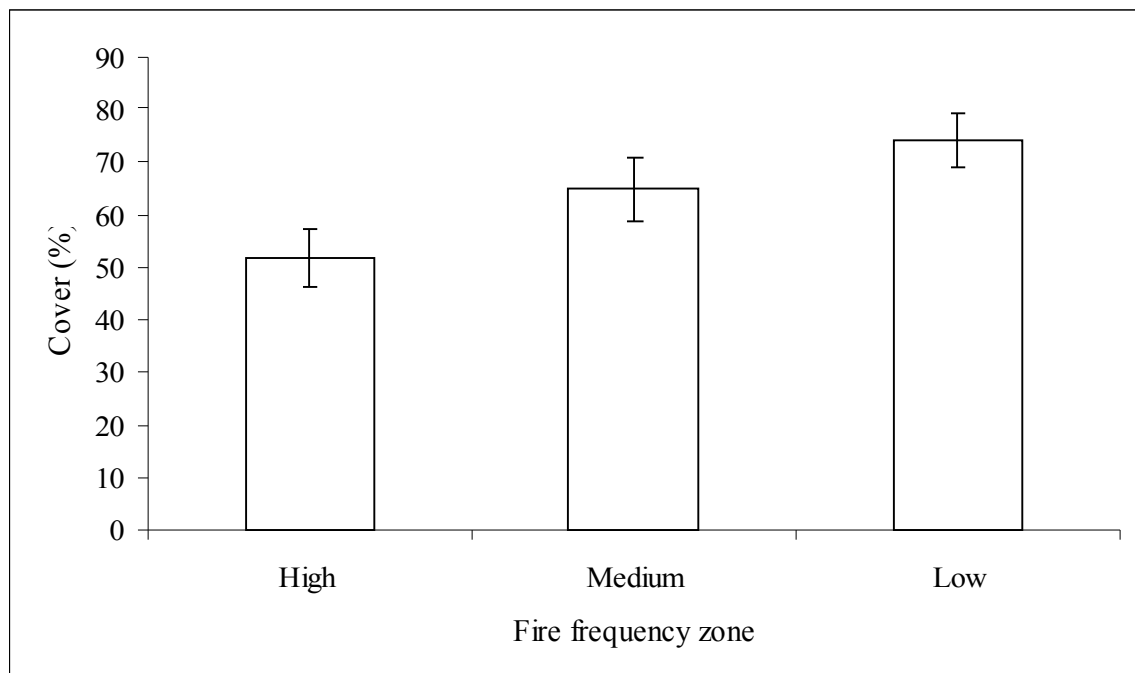


Figure 18. Differences in grass percentage cover (mean \pm SE) among fire frequency zones in the Hamoye State Forest, Kavango Region, in northeastern Namibia.

Figure 19 presents mean percentage cover for three key grass species, namely: *Tristachya superba*, *Cymbopogon sp.* and *Digitaria seriata* in the three fire frequency zones.

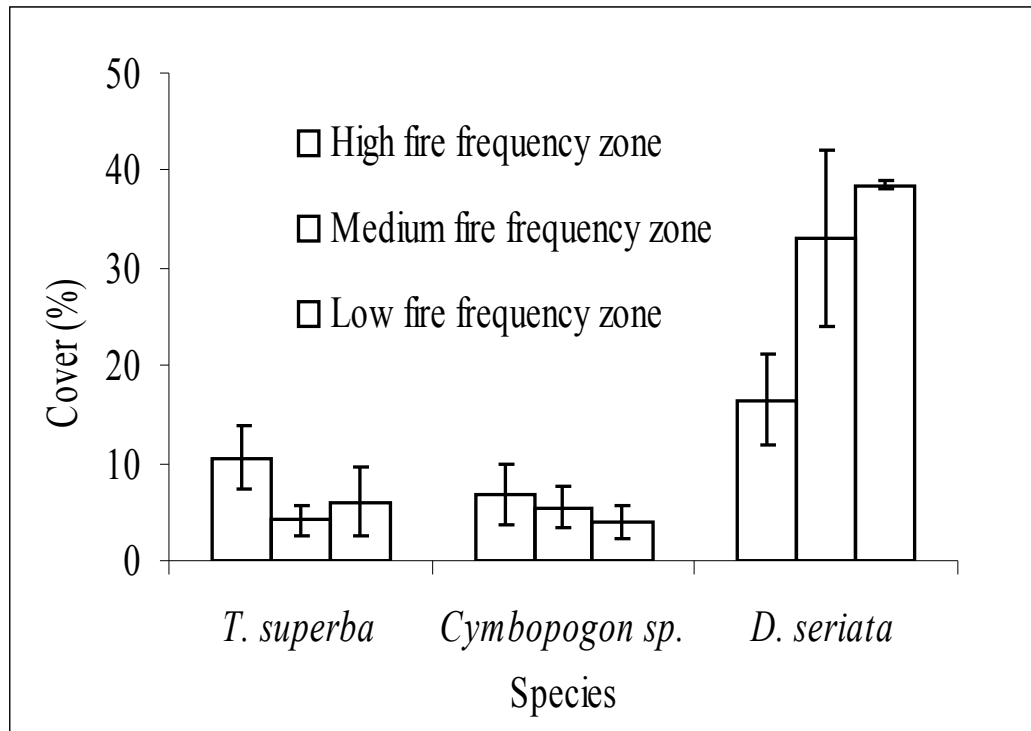


Figure 19. Differences in grass percentage cover (mean \pm SE) among fire frequency zones in the Hamoye State Forest, Kavango Region, in northeastern Namibia.

There were no significant differences in mean grass cover for the pioneer and sub-climax species *Tristachya superba* ($H = 2.370$, $df = 2$, $P > 0.05$) and *Cymbopogon sp.* ($H = 0.290$, $df = 2$, $P > 0.05$) among fire frequency zones. However, there were significant differences in mean grass cover for the climax species *Digitaria seriata* among fire frequency zones. The mean grass cover for *Digitaria seriata* was higher in the low fire

frequency zone than in the high fire frequency ($Z = -2.521$, $p < 0.01$), however it did not differ significantly between high and medium fire frequency zones ($Z = -.759$, $p > 0.05$).

4.3.7. Species diversity and richness

A total of 60 plant species were recorded during the inventories, which included 34 woody species and 26 herbaceous (grasses, sedges and forbs). *Burkea africana* had the highest proportional abundance of all plants species encountered. Two key commercial timber species, namely *Guibortia coleosperma* and *Pterocarpus angolensis* all had low proportional abundance.

The diversity of plants (grasses excluded) species ranged from 0.82 to 2.06 in the high fire frequency zone, from 0.97 to 2.20 in the medium fire frequency zone and from 0.18 to 2.67 in the low fire frequency zone (Figure 20). Statistical comparisons indicated significant differences in mean plant species diversity ($H = 6.204$, $df = 2$, $p < 0.05$). *Post hoc* analyses revealed significantly lower plants species diversity in the high fire frequency zone ($Z = -2.268$, $p < 0.05$) and in the low fire frequency zone ($Z = -1.361$, $p < 0.05$) than the medium fire frequency zone. There were however, no significant differences in mean plant species diversity between the high fire frequency zone and the low fire frequency zone.

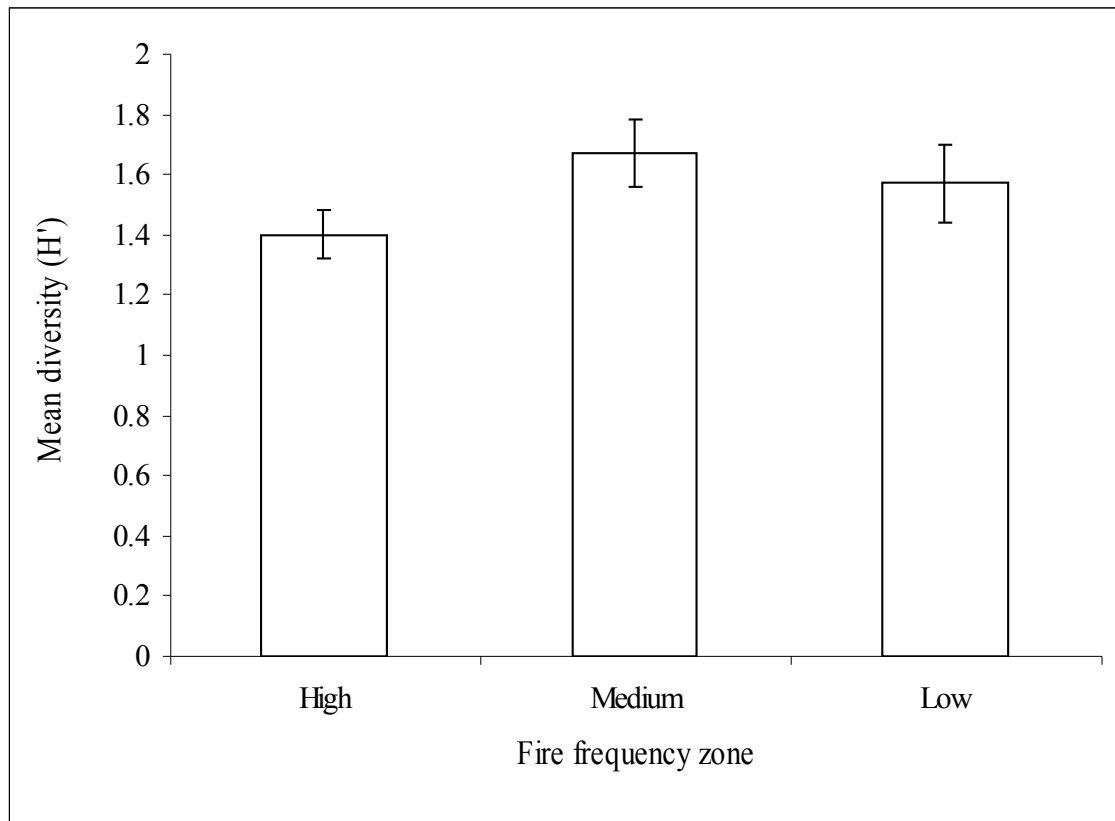


Figure 20. Differences in plant species diversity (mean \pm SE) among three fire frequency zones in the Hamoye State Forest, Kavango Region, in the northeastern Namibia.

The woody species richness ranged from 6 to 15 per plot in the high fire frequency zone, from 7 to 13 per plot in the medium fire frequency zone and from 6 to 14 per plot in the low fire frequency zone. The species richness for the non-woody plants ranged from 3 to 12 per plot in the high fire frequency zone and from 2 to 8 per plot in both the medium and low fire frequency zones. The differences in species richness for both woody and non-woody plants (Table 2) among the fire frequency zones were not significant.

Table 2. Mean species richness of plants in the three fire frequency zones. p = p-value, n.s. = not significant.

Fire frequency zone	Total number of species of vegetation life forms	
	Woody species	Herbaceous species
High	10 ± 0.8	7.5 ± 0.79
Medium	9.9 ± 0.62	5.1 ± 0.59
Low	10 ± 0.9	4.6 ± 0.62
P	n.s.	n.s.

However, there were significant differences in overall plant species richness (Figure 21) among the three fire frequency zones ($F = 3.434$, $df = 9$, $p < 0.05$). Plant species richness was higher in the higher fire frequency zone than in the low fire frequency zone ($p < 0.05$). There were however, no significant differences in plant species richness between high and medium fire frequency zones.

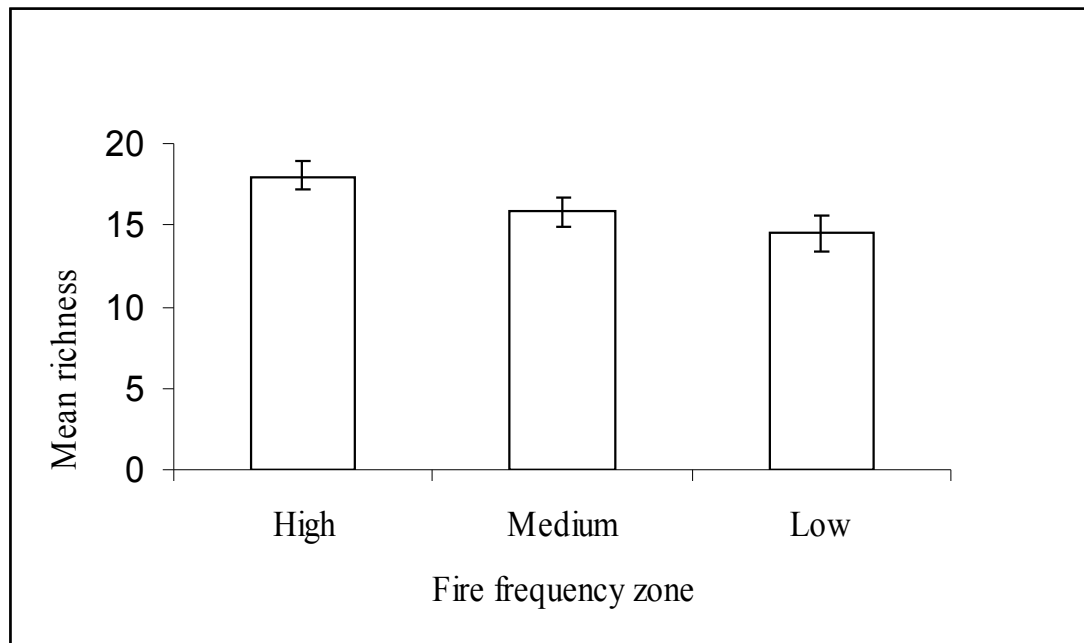


Figure 21. Differences in plant species richness (mean \pm SE) among three fire frequency zones in the Hamoye State Forest, in the Kavango Region, in the northeastern Namibia.

4.3.8. Species composition

The Hierarchical Cluster Analysis (HCA) separated the vegetation into four main floristic associations mainly representing *Burkea africana*, *Burkea africana- Baikiaea plurijuga*, *Burkea africana-Pterocarpus angolensis* and *Burkea africana-Dialium engleranum* woodlands (Figure 22).

Cluster 1: *Burkea africana- Baikiaea plurijuga* woodland. This woodland occurred in a semi-compacted sandy soil and consisted mainly of *Burkea africana* trees with diameter and height averaging 16 cm and 8 m respectively, while *Baikiaea plurijuga* consists of trees mainly of small sized individuals trees (<10 cm dbh) with a height ranging from 6

to 10 m. Other common trees included *Ochna pulchra*, *Terminalia sericea*, *Guibourtia coleosperma*, *Strychnos cocculoides*, *Strychnos pungens* and *Combretum psidioides*. The grass layer was moderately developed and mainly dominated by *Digitaria seriata*. The shrub layer was dominated by *Strychnos pungens* at <50 cm height, and *Diospyros chamaethamnus* at >50 cm height. Other shrubs include *Bauhinia petersiana*, *Psydrax livida*, *Lannea zastrowiana* and *Diplorhynchus condylocarpon*. *Hermannia tomentosa* was the only forb species encountered and occurred mainly in the medium fire frequency zone. A total of 16 woody and 12 herbaceous species were recorded in the four sample plots all belonging to the medium fire frequency zone community.

Cluster 2: *Burkea africana*-*Pterocarpus angolensis* closed woodland. This woodland comprised mainly plots from low fire frequency zone and it was found in a sandy soil on an undulating terrain. *Burkea africana* trees dominated this woodland, and had diameter and height averaging 17 cm and 7 m respectively. *Pterocarpus angolensis*, another dominating species, had trees with diameter and height averaged 20 cm and 8 m respectively. Other notable trees included *Dialium engleranum*, *Ochna pulchra*, *Terminalia sericea*, *Guibourtia coleosperma*, *Diplorhynchus condylocarpon*, *Combretum psidioides*, *Combretum zeyheri*, *Schinziophyton rautanenii* and *Baikiaea plurijuga*. The shrub layer was dominated by *Diospyros chamaethamnus* and *Ochna pulchra* at a <51 cm height and by *Bauhinia petersiana* and *Burkea africana* at >51 cm height. Other shrubs included *Lannea zastrowiana*, *Dialium engleranum*, *Combretum zeyheri*, *Combretum psidioides*, *Terminalia sericea*, *Strychnos pungens* and *Baikiaea*

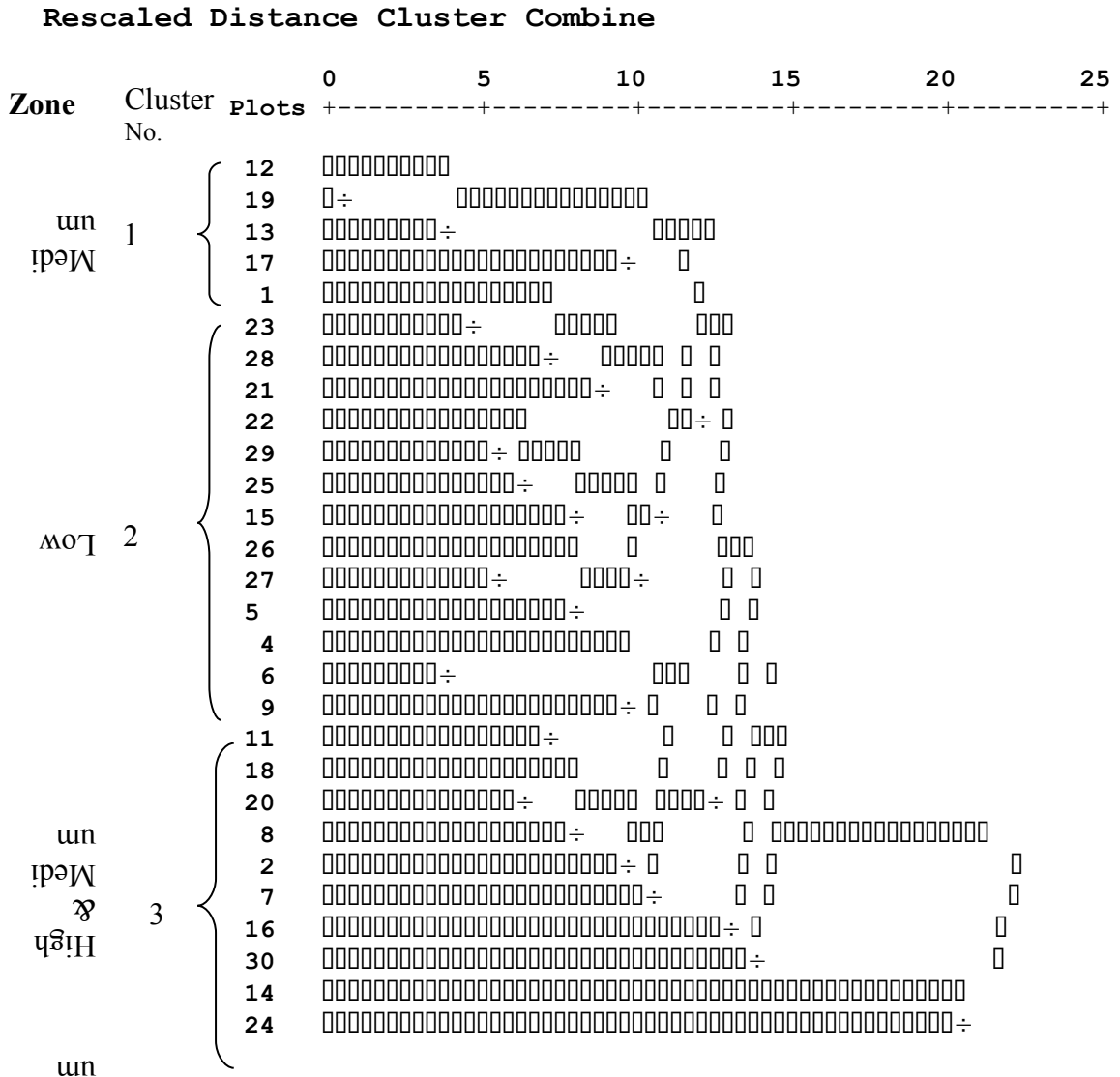
plurijuga. The grass layer was well developed with high grass cover mainly of moribund material due to long fire intervals in the zone. Common grasses included *Digitaria seriata*, *Digitaria eriantha*, and *Schmidtia pappophoroides*. Forbs included *Oxygonum delagoense*, *Ancylanthos rubiginosus*, *Vigna sp.* and *Phyllanthus omahekensis*. The woodland had many high trees and most shrubs were shorter than two meters. A total of 24 woody and 18 herbaceous species were recorded in the four sample plots all belonging to this low fire frequency zone community.

Cluster 3: *Burkea africana* woodland. This woodland consisted of plots mainly found on a level terrain with deep sandy soils in the high fire frequency zone. *Burkea africana* trees had diameter and height averaging 17 cm and 6.7 m respectively. *Pterocarpus angolensis* and *Dialium engleranum*, the two other common trees were not as common as *Burkea africana*, but were present in all 30 plots except in two. *Pterocarpus angolensis* and *Dialium engleranum* trees had diameter averaging 21 and 15 cm respectively. *Dialium engleranum* had shorter trees averaging 5 m high, while *Pterocarpus angolensis* had taller trees averaging 9 m high. Other notable trees included *Commiphora sp.*, *Ochna pulchra*, *Strychnos pungens*, *Strychnos cocculoides*, *Combretum psidioides*, *Terminalia sericea*, *Combretum collinum* and *Guibourtia coleosperma*. Common shrubs included *Diospyros chamaethamnus*, *Bauhinia petersiana*, *Lannea zastrowiana*, *Burkea africana*, *Ochna pulchra* and *Diplorhynchus condylocarpon*. The grass layer was fairly developed, with cover averaging 50% per plot. Dominant grasses included *Tristachya superba*, *Cymbopogon sp.* and *Digitaria*

seriata. Forbs included *Lophiocarpus tenuissimus*, *Euphorbia neopolyonemoides*, *Vernonia poskeana*, *Phyllanthus omahekensis*, *Camptorrhiza strumosa*, *Oxygonum delagoense*, *Bulbostylis sp.* and *Vigna sp.*

Cluster 4: *Burkea africana-Dialium engleranum* mixed woodland. This mixed woodland occurred both in the medium and low fire frequency zones. *Burkea africana* trees had diameter and height averaging 19 cm and 8 m respectively. The second dominant species *Dialium engleranum* is mainly occurring in the two plots (24 & 30) for the low fire frequency zone, and had trees of diameter and height averaging 15 cm and 7 m respectively. Other notable trees included *Baikiaea plurijuga*, *Terminalia sericea*, *Schinziophyton rautanenii*, and *Guibourtia coleosperma*. The soil types differed, with sandy and compacted soil found in the medium fire frequency zone plots (14 & 16) while the two low fire frequency zone plots (24 & 30) had mainly sandy soil on undulating terrain.

The grass layer was moderately developed and similar to (cluster 3) above in cover. Dominant grasses included *Digitaria seriata* and *Digitaria eriantha*. The shrub layer was dominated by *Grewia avellana* and *Dialium engleranum* at < 200 cm height. Other notable shrubs included *Psydrax livida*, *Terminalia sericea*, *Lannea zastrowiana*, and *Bauhinia petersiana*. Forbs included *Phyllanthus omahekensis*, *Oxygonum delagoense*, *Lophiocarpus tenuissimus* and *Ancylanthos rubiginosus*.



22. Hierarchical cluster analysis (HCA) dendrogram showing a classification of plots into four clusters in Hamoye State Forest, Kavango Region, based on species diversity data. Plots 1 to 10 belong to high fire frequency zone, plots 11 to 20 to medium fire frequency zone, and plots 21 to 30 are low fire frequency zone

4.3.9. Variations in community composition



Variations in plant communities were significant among sites, with the first axis accounted for the highest variations in plant community (37.8%) while the second axis accounted for second highest variations plant community (21.7%). The third and fourth axis accounted for 13% and 10% of the variations in plant community respectively.

There were mainly four groupings (groups I, II, III and IV) (Figure 23). Group I comprised plots from the high fire frequency zone (plots 1-10) however, two plots (11 & 20) belonged to medium fire frequency zone. The main all timber species in this group were *Burkea africana*, *Pterocapus angolensis*, *Baikiaea plurijuga*, while the grass species were *Digitaria seriata* and *Tristachya superba*. Group II, all plots but 1 (plot 24) in this group are medium fire frequency zone. This grouping contained all timber species (*Burkea africana*, *Pterocapus angolensis*, *Baikiaea plurijuga* and *Guibourtia coleosperma*) except *Terminalia sericea*. *Schinziophyton rautanenii* species was also present in this group. Key grass species (*Digitaria seriata*, *Cymbopogon sp.* and *Tristachya superba*) were all present. Group III comprises plots from low fire frequency (plots 21-23, 26-29), however, one plot (plot 18) belonged to medium fire frequency zone). *Burkea africana*, *Pterocapus angolensis*, *Baikiaea plurijuga* contained in this group. There was also a notable presence of *Commiphora* species. The grass species were mainly *Digitaria seriata* and *Digitaria eriantha* species.

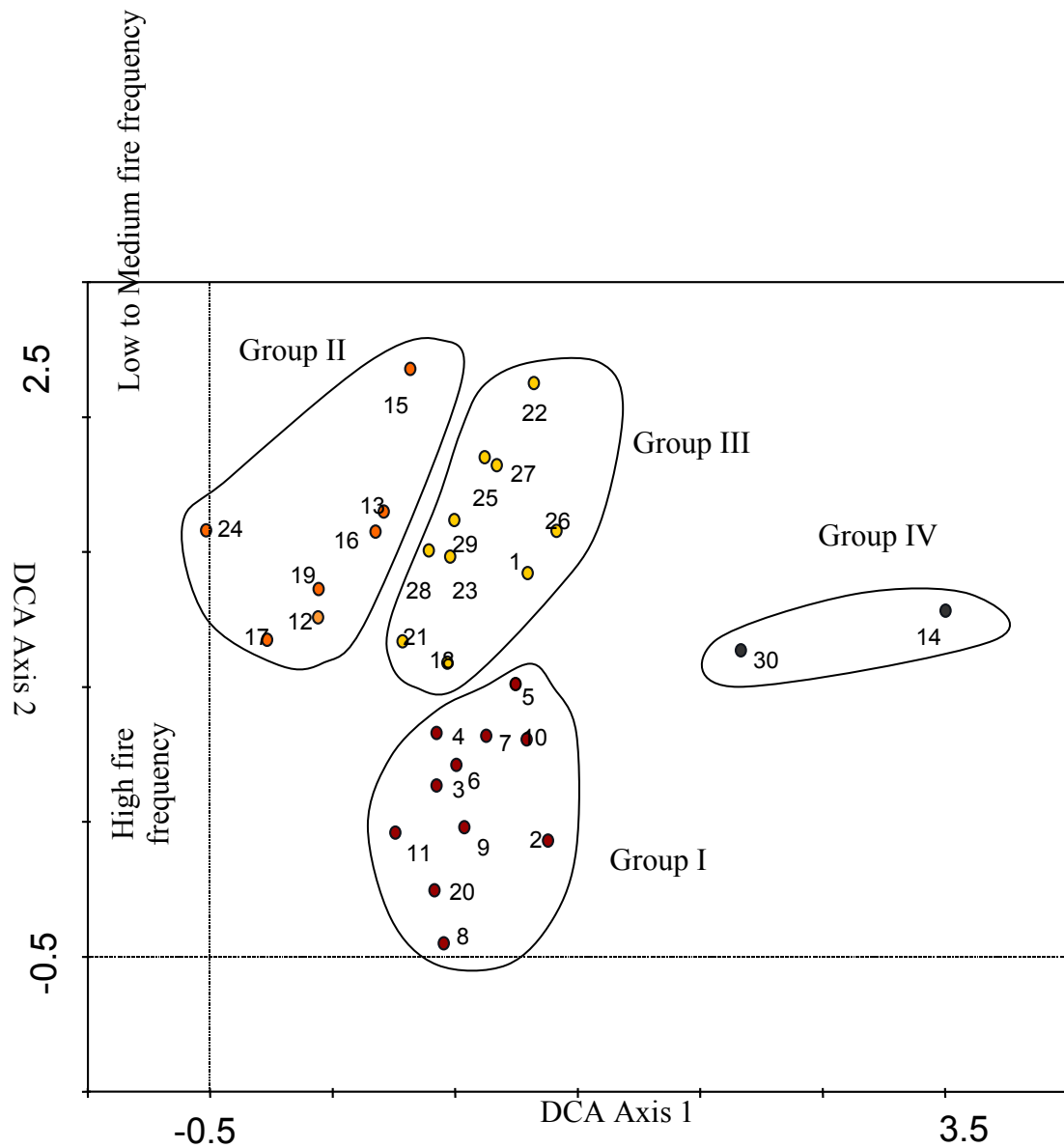


Figure 23. DCA ordination diagram showing the separation of vegetation plots into four main floristic groups relating to fire frequency.

Group IV contained only two plots (14 and 30), from medium and low fire frequency respectively and mainly contained *Burkea Africana* and *Schinziophyton rautanenii* as

tree species and *Psyrax livida* shrub species. *Digitaria seriata*, cilata grass species were also present.

CHAPTER FIVE

DISCUSSION

5.1. Extent of areas burnt and fire management

In the absence of early burning strategies, Forestry personnel at Hamoye State Forest depend on a non pro-active strategy of suppressing fires. However, due to inadequate funds and trained personnel to fight fires, fire has always managed to burn the larger parts of the forest. The local Forestry office has a total of 22 personnel. This comprises 3 Forest Rangers, 2 Forest Guards, 13 General workers and 4 watchmen. Out of the 22 staff, only 2 Forest rangers and 1 Forest Guard received training in fire management and suppression (Elago, S., pers. comm, 2007). This lack of trained personnel in fire suppression and management is evident by the regular annual incident of fires in the State Forest. Statistical comparisons have shown that there were significant differences in burnt areas over a 15-period among fire frequency zones of the State Forest, with high fire frequency zone having high burnt areas than the medium and low fire frequency zone. However, burnt areas in the medium fire frequency zone were higher than those in the low fire frequency zone.

Satellite images show that most wildfires in the northern and southern part of the state forest often started in the communal land. This could be attributed to burning unwanted biomass from the land cleared for cultivation by farmers. Some of these fires started as a result of pastoralists setting fires in the late dry season, both to induce a flush of protein-

rich grass on which their livestock can graze (NRSC, 2002). Fires in the southwest corner was the results of fires spreading from the northern part of the State Forest and fires spreading from the communal lands south of the State Forest.

Fires that started in the communal land take time to reach the State Forest. This gave forest personnel enough time to prepared for its suppression. However, these fires often occurred in dry season where factors such as high fuel load, wind speed and air temperature favoured intense fires that were difficult to fight (Trollope & Potgieter, 1993). Fires that entered the State Forest from the northern side often burnt the whole northern half and jumped the 5 km cutline. Fires that jumped the 5 km cutline were perceived as very dangerous as they could spread to the southeast corner where most of the Forest Department infrastructures and experimental plots are located (see Figure 3). These fires often get suppressed by forestry personnel and the surrounding community before they reached the south eastern corner. Significant differences in fire frequencies between areas south and north of the 5 km cutline may be attributed to suppression of fires in the southern eastern sections.

Although there is a perimeter fire-break, the satellite data show that fires from the communal land easily spread into the State Forest. Wildfire accompanied by strong wind can easily jump and enter the state forest as the perimeter fire-break was not regularly maintained and perhaps not wide enough. The 5 km cutline was also not wide enough and not regularly maintained as fire easily spread from the northern part down the

southern half of the State Forest. Perhaps a 40-m wide cutline would be a better option, as NRSC (2002) reported that wildfire even jumped the main road between Grootfontein and Rundu, suggesting that firebreaks have to be even wider to be effective. In Etosha National Park, the effectiveness of the fire breaks largely depends on wind speed, fuel load and fuel type (Hipondoka, M., pers. Comm., 2007). Complete exclusion of fires from the State Forest also has disadvantage to plant species that are promoted by fire (e.g. *Pterocarpus angolensis* is stimulated by fire to germinate). Fires were also reported to have induced flowering of several serotinous species in the Cape Fynbos flora (Bond and van Wilgen, 1996).

Reasons for moderate frequency in the southwest corner were due to the area's strategic location and period of fire burn. Often when these fires burnt, they occur around July and August months. Often Fires enter the state forest from the southern side via a small grassy waterstream located about 2 km away, east of this corner. The wind speed and heavy grass fuel-load in this waterstream often speed up fire and divert its direction; hence this corner is always left unburned.

The problem of fire spreading from the communal land into the protected area is not unique to the Hamoye State Forest alone. Several studies reported problem of fires originating from communal lands into protected areas as a result of clearing land for cultivation or simply by feeling no sense of ownership of the protected area (Edwin,

2002; Mapaire, 2001), logging and smoking out beehives (Goldammer *et al.*, 2002; NRSC, 2002).

Information from satellite images revealed that some fires started from within the high fire frequency zone of the State Forest. The source of ignition within the Hamoye State Forest is the result of illegal timber poaching. Personal observations and discussions with staff at the Hamoye Forestry Station (Elago, S., Elago, S.E., Hamusira, M.L., pers. comm., 2006) revealed that illegal commercial timber poachers of *Pterocarpus angolensis* within the State Forest cause fires. Often their cooking fires escape their temporal camps and spread through the whole zone. These illegal harvesters also set fire with intent to destroy footprint evidence when pursued by forest officials. This finding is supported by several studies that reported sources of ignition within protected areas ranging from poaching (Mapaire, 2001) to lightning (Du Plessis, 1999; Bond and van Wilgen, 1996).

In contrast to fires that started from the communal land, fires that started from within the pose a threat to Forest personnel. The size of the State Forest (10 km²), means fires that start in the high fire frequency zone have short distance before they reach the southeastern area. These fires gives Forestry Personnel little time to organise themselves for their suppression. These fires are therefore sometimes not effectively controlled by forestry staff and burnt most area of the State Forest.

5.2. Vegetation structure

Typically, the vegetation structure associated with the fire frequencies. High frequency resulted in many big trees able to survive frequent fires and fewer saplings which were more than 1 m in height, as they were burnt back by fires. Mature trees were often highly resistant to burning but fire kills young plants in woodland savannas (Bond and van Wilgen, 1996). While saplings in the high fire frequency zone were mainly less than 1 m in height, medium and low fire frequency zone had more saplings measuring more than a meter in height. This implies that reduction of the fire frequency in savannas results in an increase in the density of woody plants and their height, while high fire frequency trapped woody plants in a fire-prone woody class (Bond & van Wilgen, 1996; Frost and Robertson 1987; Gambiza, 2001).

Mean total basal area of trees did not differ significantly among the three fire frequency zones. Similarly, basal area frequency distributions did not show any significant differences among the three sites. There were many small sized (basal area < 200 cm²) trees at both fire frequency zones but few larger trees in all fire frequency zones. This finding does not support the results of other researchers (Cochrane & Schulze, 1999; Peterson & Reich, 2001; Shackleton & Scholes, 2000; Scholes & Walker, 1993) who reported basal area that decreases with increasing fire frequency. The deviation from the expected results may be attributed to the season and intensity of fire in the State Forest. Satellite images have shown that most fires occur around July and August, a period considered to be an early dry season (NRSC, 2002). Fires in the early dry season of

more arid African savannas are less intense, hence less damaging in comparison to the more damaging late dry season with driest grass and hottest conditions (Frost & Robertson, 1987).

The general trend in the three fire frequency zones was high number of small trees relative to big ones. Vegetation ecologists have used size distribution as characteristics of healthy and stable vegetation population as this means emergence of enough mature trees to replace those that have been killed by fire especially in the bigger sized classes (Saha & Hiremath, 2003). Given that the State Forest experienced uniform fire treatment before the 1996 (perimeter firebreak), high number of small sized trees could be remnants of saplings that survived due to the introduction of fire-breaks in 1996. It appeared that bigger trees were more prone to fire damage. Mendelson & el Obeid (2005) reported that most trees in the bigger sized die as a result of successive burns over a number of years.

There were significant differences in tree height class distributions between fire frequency zones, with high and medium fire frequency zones having more trees of medium height (3 to 9 m) than the low fire frequency zone. Less fire in the medium fire frequency means less tree thinning resulting in more inter-tree competition with a consequence of stunted growth among individual trees. As expected, high fire frequency zones had few short trees and more medium and higher trees as fire suppress short trees than the more resilient medium and higher individual trees. Both medium and low fire

frequency zones were expected to have a distribution that is evenly spread across the height classes, a sign of healthy state in the of the Kalahari woodland, as low fire frequency promotes canopy height (Shackleton & Scholes, 2000).

The three fire frequency zones had few short trees. High and low fire frequency even had fewer tall trees. About 60% of all trees recorded in each zone fall in the medium height classes range (3-5.9 m and 7 m). As expected high fire frequency zone had fewer short trees but individuals of medium height were widespread. The absence of short trees and more trees in the middle height class range is a common effect of frequent fires on the vegetation. Impacts of fire have been reported to be more severe in plants lower than 3 m in height, while the architecture of large trees is unaffected by fire (Bond 1997).

It appears that there was either less or no recruitment of shorter cohorts into larger trees, judging from the absence of larger trees in the high fire frequency zone. A similar trend was been reported by other researchers who worked in similar environment in the sub-continent (Bond, 1997; Shackleton & Scholes, 2000; Frost & Robertson, 1987). The whole distribution pattern in the high fire frequency resembles what Bond and van Wilgen (1996) referred as type II pattern in their interval-depend hypothesis of fire induced mortality. According to Bond and van Wilgen (1996)'s interval-depend hypothesis, some plants become increasingly resistant to fire as they grow larger but are vulnerable over a larger range of sizes especially if the barks have been weakened by

previous fires. Although the medium and low fire frequency zones had many trees of the middle height class range, both had few short trees. This implies that most young trees have been recruited to bigger larger ones due to fire free periods since the introduction of the 5 km cut-line in 2001.

The results revealed that there were significant differences in the sapling height class distributions amongst all fire frequency zones, and that the high fire frequency zone had fewer shorter but more medium and high saplings than the two fire frequency zones. Many saplings in the shorter height class range are characteristics of less frequent fire that promotes woody plants in the medium and fire frequency zones. However, many shorter saplings compared to fewer taller saplings in the high fire frequency zone is a characteristic of what Bond & van Wilgen (1996) referred to as “Gullivers” in a vegetation community.

“Gullivers” are fire-suppressed stunted multi-stemmed shrubs (Mapaure, 2001) that struggle to emerge from the herbaceous zone as juveniles, but grow taller during long fire intervals to become established plants with high fire resilience (Bond & van Wilgen, 1996). These “Gullivers” may persist for years surviving repeated burning by sprouting from root systems (Bond & van Wilgen, 1996). This finding is supported by several researchers (Frost & Robertson, 1987; Hoffmann, 1996; Mapaure, 2001; Scholes & Walker, 1993; Shauyange, 2002; van Wilgen *et al.*, 1990) who reported reduction in

sapling heights with shorter fire intervals. These taller saplings are possibly remnants of taller shrubs that were burnt back to lower height classes.

Forb density differed significantly among the three fire frequency zones. As expected, high fire frequency zone had significantly higher forb densities in comparison to medium and low fire frequency zones. The medium and low fire frequency zones forb densities did not differ significantly. The high forb density in the high fire frequency zone therefore confirmed the general observation that high fire frequency increases the forb density. This result is consistent with the findings of several studies (Gambiza, 2001; Scholes & Walker, 1993; Lonsdale *et al.*, 1998) who reported increasing forb density in area burnt at higher frequency. According to Lonsdale *et al.*, (1998), many forb species are pioneer plants that quickly colonise disturbed (i.e. burnt) areas.

Statistical analyses found no significant differences between stem and live tree densities in each fire frequency zone. Differences in stem density among fire frequency zones were not significant. Moreover, there were no significant differences in live tree density among fire frequency zones. It was expected that stems will have higher density than trees especially in the high fire frequency zone as high fire frequency affect the architecture of young trees vegetations through sprouting (Bond, 1997). Savanna trees often form fire-resistant multi-stemmed juvenile trees, but lose the capacity to sprout when they are large, single-stemmed trees (Bond & van Wilgen, 1996). Several studies (Strang, 1974; Trollope, 1982) reported little effect of fire frequency on tree density.

However, other studies (Schackleton & Scholes, 2000) reported decreasing tree density with regular burning in shorter tree height classes (< 4.5 m), while tree density in taller height category (>4.5 m) was approximately 40 times greater in the exclusion plots than the fire treatments. With these contradicting findings, Schackleton & Scholes (2000) concluded that perhaps density of tree stems is an inadequate index of fire impact, and 15 years is too short a time to contrast fire. It could be that the State Forest experienced uniform fire before the introduction of the perimeter fire break in 1996. For this reason, it might therefore be that even if the vegetation is responsive to fires, the impacts might be not long enough to elicit significant differences in tree and stem densities among fire frequency zones.

The density of dead trees in the high fire frequency zone was significantly lower than those in the low fire frequency zone. However, the differences were not significant between the high and medium fire frequency zones. The density of dead trees was expected to be high in the high fire frequency zone due to high trees mortality resulting from frequent burnings. However, the results show that density of dead trees in the high fire frequency zone was low. This implies that large percentage of trees killed by fire had been destroyed entirely by repeated burnings.

Frequent fires lead to mortality of trees, especially the young ones that have low resilience to burning. Frequent fire also killed large trees as some species become more prone to fire damage in the largest size classes (Cochrane & Schulze, 1999; Yeaton,

1988). Fire-free periods in the medium and low fire frequency zones may explain this dead trees density. It takes repeated burnings and strong windstorms for trees to fall (Mendelson & el Obeid, 2005).

This study however, did not find significant differences in stump density among the three fire frequency zones. Stumps are known to persist in burnt environments for many years (Stearns & Likens, 2002) and this could have led to lack of significance among fire frequency zones.

Sapling densities were significantly higher in the high fire frequency zone than in the medium and low fire frequency zone. It was expected that low and medium fire frequency zones will have high sapling density in comparison to high fire frequency zone. High density of shrubs in the high fire frequency zone is a typical characteristic of short fire intervals. Frequent fires trap shrubs in herbaceous layers maintain them in the multi-stemmed form (Bond & van Wilgen, 1996). However, following intense fires these shrubs coppiced resulting in high shrub density. Alternative explanations to high density of saplings in the high fire frequency could be the high proportional abundance of the presence of *Diospyros chamaethmnus*, a dwarf shrub that forms extensive and dense colonies which accounted for almost 40% of the total saplings densities in the fire frequency zone.

Woody cover differed significantly among the three fire frequency zones, with the low fire frequency zone having the highest cover exceeding 100%. This was due to many canopy overlaps recorded. These findings are consistent with the results of many researchers who reported the increased woody cover with long fire intervals (Cochrane & Schulze, 1999; Frost & Robertson, 1987; Bond & van Wilgen, 1996; Gambiza, 2001; NRSC, 2002) and decreased woody cover at short fire intervals (Mapaure, 2001; Scholes & Walker, 1993). Reduction in the fire frequency or intensity of fires in the low fire frequency zone resulted in a densely spaced woody environment, hence the high woody cover in the low fire frequency zone. Grass cover shows virtually the reverse trend of woody cover. The high fire frequency zone recorded low grass cover and the low fire frequency zones recorded high grass cover. It was expected that reduction in woody cover would increase the grass biomass. Although the species composition was the same in the two fire frequency zones, low fire frequency zone had high moribund grass materials. If moribund grass material were to be excluded, grass cover would be closer to expectations. This implies that high grass cover was a result of grass fuel load accumulations due to long fire return intervals (Gambiza, 2001).

For the species analysed per fire frequency zone, *Burkea africana* had the highest proportions of tress in high and medium fire frequency zones. However in low fire frequency zone, *Baikiaea plurijuga* had the highest proportions of trees. *Guibourtia coleosperma* had the lowest portion in the medium zone. The difference in the three species could not be tested statically as they were not common.

5.3. Species diversity, richness and composition

Statistical tests revealed that that species diversity did not differ significantly among fire frequency zones, however, species richness differed significantly among fire frequency zones. High fire frequency zone had significantly higher species richness than the medium and low fire frequency zones. Several studies (Beeby 1993; Collins 1992; Schwilk *et al.* 1997) used the concept of intermediate disturbance hypothesis to explain the species diversity. According to this hypothesis, species diversity and its measures such as richness and evenness will rise and fall as disturbances rate increases, with the highest diversity occurring at intermediate level of disturbances and lowest diversity occurring at low and high level of disturbances.

However, in the South African mountain fynbos, Schwilk *et al.*, (1997) found the opposite of what the theory predicted, with least burned areas with significantly lower species richness at the lowest spatial scale, but the highest species richness at larger scale. Some studies have shown that this hypothesis may not hold true in communities where fire is the disturbance (Collins, 1992; Schwilk *et al.*, 1997). Furthermore, Schwilk *et al.* (1997) explained that temporal changes in species richness following fire can complicate investigation into the effect of frequency on species diversity. Collins (1992), therefore highlighted that diversity should be compared among sites at the same stage in post fire succession.

The Hierarchical Cluster Analysis (HCA), showed similarity and dissimilarity between plots among the three fire frequency zones. The classification of vegetation mainly represented two major vegetation types, open woodland dominated by *Burkea africana* and *Baikiaea plurijuga* in the fire frequency zones, and four closed woodland of *Burkea africana*-*Pterocarpus angolensis*, *Burkea africana*, and a mixed *Pterocarpus angolensis*-*Dialium engleranum*-*Burkea africana*.

The DCA diagram shows a grouping of plots from high fire frequency to low fire frequency along the second axis of ordination (Figure 23). The variations along the second axis are largely associated with fire frequency. The separation between the two extreme plots (plot 8 & 15) along this ordination axis is about 2.5 SD units. A 100% species turnover would occur at a minimum distance of 4 SD units (Mapaure, 2001), therefore this implies that species turn over along the second axis would be 63%. The separation between the two extreme plots along the first ordination axis is about 3.2 SD and therefore, a species turn over along the first axis would therefore be 80%. Although fire frequency represents the gradient of main species change, the species turnover is not abrupt but very gradual there is no gap between groups in the second ordination axis. The first axis accounted for most variations in plant community with the highest eigen value (37.8%). It is hypothesized that non-investigated factors such as soil moisture and topography may have influenced the variations of plants community along the first axis.

CHAPTER SIX

6.1. CONCLUSIONS

The results of this study provide strong evidence that fire frequency differed in the various parts of the forest with burnt areas varying with zones of the State Forest. Some areas of the State Forest burnt 11 times in 15 years, other areas burnt 8 times in 15 years, while others burnt 4 times in 15 years. Areas that are closer to forestry buildings had low fire frequencies as they get suppression priority by forestry personnel.

Fires influenced the species composition with different fire frequencies resulting in distinct clustering of floristic associations. Although *Burkea africana* in all clusters, its proportional abundance differed, with more *Burkea africana* trees in the high fire frequency zone.

Species richness was affected by fire frequency with high species richness in the high fire frequency zone, while medium fire frequency increased plant species diversity. Frequent burning promotes species richness with new species colonies after fire burning to exploit new niches opened up by fire burning.

Fire frequency affected the vegetation structure, particularly the tree and sapling height through fire top-kill. Forbs and sapling density increased with fire, and this was attributed to annual forbs that colonise burned area quickly after fire. The high sapling

density was attributed to resprouting of burnt shrub stems. Woody cover decreased with fire due to reduction in number of small trees. The low grass cover in the high fire frequency zone was attributed to competition between grasses and shrubs. There were no differences in tree basal area, stem, and live tree density and stump density. Different fire frequencies therefore had a marked effect on several attributes of the structure of vegetation communities in the Hamoye State Forest.

CHAPTER SEVEN

5.1. RECOMMENDATIONS

Although fire did not cause a difference in tree and stem density, it reduced woody cover in the high fire frequency zone. Frequent fires enhanced species richness through the creation of new niches, this situation is undesirable as the main purpose of the State Forest is management of forest resources of national importance and preservation of ecosystems and other component of biological diversity (Forest Act, 2001). The creation of new niches means original species within these localised areas are being replaced by intruder species. This replacement of original species has a negative end-effect as it means if the uncontrolled fires continue burning, it will eventually result in the extinction of species at local scale.

The mainly problem of the uncontrolled fires in the Hamoye State Forest is rooted in the absence of management plans for Forestry officials to carry out management activities in the State Forest in a systematic way. Given this problem, the following management options are therefore being suggested:

- 1) The management plan for the State Forest should be put in place and this should make provisions for prescribed burning of peripheral areas during early fire season (in May/June) and according to fire early burning strategy manual of the

Kavango region to prevent fire spreading from the communal land into the State Forest.

- 2) The fire management plan should also be put in place with provisions of measures such as regular maintenance of the existing 5 km cut-line and the perimeter fire-breaks, as well as monitoring systems such as annual fire scars mapping.
- 3) The study plots should be permanently marked and made a long term study to monitor the vegetation study. However, other factors that might also influence the vegetation but were not investigated should be included in the monitoring to provide a holistic approach to the study.
- 4) Enforcement patrols should be conducted on a regular basis, and these patrols should be conducted not just along the perimeter fire-break but also inside the State Forest to curb illegal harvest by timber poachers in the State Forest.
- 5) The Directorate of Forestry, through the National Remote Sensing Centre should introduce a grid system as being used by other protected areas in the neighbouring countries such as Zimbabwe and South Africa to record fire incidences. The size of burnt area, cause of fire, location of fire and its effect on vegetation must be recorded. Staff at Hamoye Forestry office should receive

training to implement the said system because the reason why system is not in place is due to lack of capacity of the Hamoye Forestry staff.

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APPENDICES

Appendix 1:

Table 3, list of the images used for digitizing fire scars for this project with year, path, row and date of capture.

Year	Path	Row	Date	Year	Path	Row	Date	Year	Path	Row	Date
1989	177	73	15-Aug	1994	177	73	3-Jun	1999	177	73	20-Aug
1989	177	73	19-Nov	1994	177	73	6-Aug	1999	177	73	21-Sep
1989	177	73	14-Jun	1994	177	73	7-Sep	1999	177	73	4-Aug
1989	177	73	14-Oct	1994	177	73	9-Oct	1999	177	73	5-Sep
1989	177	73	16-Jul	1995	177	73	24-Jul	2000	177	73	10-Nov
1989	177	73	18-Sep	1995	177	73	26-Sep	2000	177	73	18-May
1990	177	73	11-Aug	1995	177	73	6-Jun	2000	177	73	21-Jul
1990	177	73	15-Nov	1995	177	73	8-Jul	2000	177	73	23-Sep
1990	177	73	24-Jun	1995	177	73	12-Oct	2001	177	73	10-Aug
1990	177	73	24-Oct	1995	177	73	22-Jun	2001	177	73	16-Nov
1990	177	73	26-Jul	1996	177	73	10-Jul	2001	177	73	24-Jun
1990	177	73	28-Sep	1996	177	73	11-Aug	2001	177	73	22-Oct
1991	177	73	11-Jun	1996	177	73	26-Jul	2001	177	73	166-Jul
1991	177	73	17-Oct	1996	177	73	27-Aug	2001	177	73	18-Sep
1991	177	73	1-Oct	1996	177	73	8-Jun	2002	177	73	12-Jun
1992	177	73	13-Jun	1997	177	73	11-Jun	2002	177	73	18-Oct
1992	177	73	17-Sep	1997	177	73	17-Oct	2002	177	73	11-Oct
1993	177	73	18-Jul	1997	177	73	27-Jun	2002	177	73	19-Jun
1993	177	73	19-Aug	1997	177	73	29-Jul	2002	177	73	14-Sep
1993	177	73	20-Sep	1998	177	73	17-Aug	2003	177	73	11-Jul
1993	177	73	22-Oct	1998	177	73	20-Oct	2003	177	73	13-Aug
1994	177	73	21-Jul	1998	177	73	21-Nov	2003	177	73	21-Sep
1994	177	73	22-Aug	1998	177	73	30-Jun	2003	177	73	22-Oct
1994	177	73	25-Oct	1998	177	73	4-Oct				

Appendix 2

Table 4. A list coordinates locations of plots in the three fire frequency zones.

High fire frequency zone plots

Plot number	Coordinates	
1	S 18° 11'19.9''	E 19° 41' 20.1''
2	S 18° 11'23.6''	E 19° 40' 00.1''
3	S 18° 11'20.3''	E 19° 39' 20.0''
4	S 18° 11'20.0''	E 19° 38' 40.3''
5	S 18° 10'40.1''	E 19° 41' 20.0''
6	S 18° 10'40.0''	E 19° 40' 00.1''
7	S 18° 10'41.1''	E 19° 39' 20.0''
8	S 18° 09'20.0''	E 19° 39' 20.0''
9	S 18° 09'20.0''	E 19° 41' 20.0''
10	S 18° 09'20.0''	E 19° 42' 00.0''
Medium fire frequency zone plots		
Plot number		
11	S 18° 13'00.0''	E 19° 41' 30.0''
12	S 18° 13'20.0''	E 19° 41' 00.0''
13	S 18° 11'13.0''	E 19° 42' 00.0''
14	S 18° 13'13.4''	E 19° 42' 14.8''
15	S 18° 13'13.0''	E 19° 42' 30.0''
16	S 18° 13'14.9''	E 19° 41' 00.0''
17	S 18° 13'14.9''	E 19° 40' 45.0''
18	S 18° 12'59.9''	E 19° 41' 15.1''
19	S 18° 11'19.9''	E 19° 41' 20.1''
20	S 18° 14'05.4''	E 19° 40' 49.9''
Low fire frequency zone plots		
Plot number		
21	S 18° 12'30.0''	E 19° 43' 30.0''
22	S 18° 13'01.4''	E 19° 43' 30.0''
23	S 18° 13'00.0''	E 19° 42' 28.9''
24	S 18° 13'00.0''	E 19° 42' 00.0''
25	S 18° 12'35.0''	E 19° 43' 40.0''
26	S 18° 12'39.8''	E 19° 43' 19.9''
27	S 18° 12'40.1''	E 19° 43' 24.9''
28	S 18° 12'40.1''	E 19° 43' 39.9''
29	S 18° 12'45.9''	E 19° 43' 19.9''
30	S 18° 12'45.0''	E 19° 43' 35.0''

Appendix 3

Table 5. List of all vegetation species that were found in the HSF

Plant species encountered in the survey
Scientific name
<i>Ancylanthos rubiginosus</i>
<i>Aristida meridionalis</i>
<i>Aristida stipitata</i>
<i>Baikiaea plurijuga</i>

<i>Baphia massaiensis</i>
<i>Bauhinia petersiana</i>
<i>Brachystemma</i> sp.
<i>Burkea africana</i>
<i>Combretum collinum</i>
<i>Combretum psidioides</i>
<i>Combretum zeyheri</i>
<i>Commiphora</i> sp.
<i>Dialium engleranum</i>
<i>Dichapetalum rhodesicum</i>
<i>Dichapetalum rhodesicum</i>
<i>Dicoma tomentosa</i>
<i>Digitaria cilialis</i>
<i>Digitaria eriantha</i>
<i>Diospyros chamaethamnus</i>
<i>Dipcadi</i> sp.
<i>Diplorhynchus condylocarpon</i>
<i>Eragrostis nindensis</i>
<i>Euphorbia neopolycnemoides</i>
<i>Gardenia branchthamnus</i>
<i>Grewia avellana</i>
<i>Grewia retinervis</i>
<i>Guibortia coleosperma</i>
<i>Hemizygia petrensis</i>
<i>Hermannia tomentosa</i>
<i>Hyperthelia dissoluta</i>
<i>Hypoestes forskalii</i>
<i>Lannea zastrowiana</i>
<i>Lantana rugosa</i>
<i>Melinis repens</i>
<i>Ochna pulchra</i>
<i>Oxygonum delagoense</i>
<i>Ozoroa paniculosa</i>
<i>Panicum maximum</i>
<i>Phyllanthus pentandrus</i>
<i>Pleiotaxis antunesii</i>
<i>Pogonatria fleckii</i>
<i>Psyrax livida</i>
<i>Pterocapus angolensis</i>
<i>Rhus tenuinervis</i>
<i>Schinziophyton rautanenii</i>
<i>Schmidtia pappophoroides</i>
<i>Securidata longepedunculata</i>
<i>Stipagrostis uniplumis</i>
<i>Strychnos cocculoides</i>

<i>Strychnos pungens</i>
<i>Swartzia madagascariensis</i>
<i>Terminalia sericea</i>
<i>Tristachya superba</i>
<i>Ximenia americana</i>
<i>Ximenia caffra</i>
<i>Ancylanthos rubiginosus</i>