# AN ASSESSMENT OF THE NATURAL REGENERATION OF VALUABLE WOODY SPECIES IN THE KAVANGO REGIONS OF NORTH EASTERN NAMIBIA

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# Table of Contents

TABLE OF CONTENTS .......... I

LIST OF FIGURES .......... III

LIST OF TABLES .......... V

DECLARATION .......... VI

USE AND RETENTION OF WORK .......... VII

DEDICATION .......... VIII

ABSTRACT .......... IX

1. INTRODUCTION .......... 1

1.1 BACKGROUND .......... 1
1.2 PROBLEM STATEMENT .......... 2
1.3 CONTEXTUAL FRAMEWORK .......... 3
1.4 AIM .......... 5
1.5 SPECIFIC OBJECTIVES .......... 6
1.6 KEY QUESTIONS AND HYPOTHESES .......... 6

2. LITERATURE REVIEW .......... 8

2.1 NATURAL REGENERATION .......... 8
*2.1.1 Asexual regeneration (Vegetative)* .......... 8
*2.1.2 Sexual regeneration (Germination)* .......... 10
2.1.3 TREE COMMUNITIES AND VEGETATION STRUCTURE .......... 11
2.2 FACTORS THAT INFLUENCE REGENERATION .......... 11
*2.2.1 Fire* .......... 12
*2.2.2 Distances to rivers, settlements and roads* .......... 14
2.3 VALUABLE WOODY SPECIES IN NAMIBIA .......... 18
*2.3.1 Economic valuation* .......... 19
*2.3.2 Social or cultural valuation* .......... 20
*2.3.3 Ecological valuation* .......... 20
*2.3.4 Baikiaea plurijuga* .......... 21
*2.3.5 Burkea africana* .......... 22
*2.3.6 Pterocarpus angolensis* .......... 23
*2.3.7 Schinziophyton rautanenii* .......... 24
*2.3.8 Strychnos cocculoides and Strychnos pungens* .......... 25

3. STUDY AREA .......... 26

*3.1 Location* .......... 27
*3.2 Geology and soils* .......... 27
*3.3 Climate and weather* .......... 28

*3.4 Vegetation description* ........ *29*
*3.5 Human dynamics* ........ *31*
*3.6 Land use* ........ *32*

**4. MATERIALS AND METHODS** ........ **33**

4.1 SAMPLING DESIGN ........ 33
4.2 PLOT DESIGN ........ 35
*4.2.1 Thirty meter (30 m) plot radius* ........ *36*
*4.2.2 Twenty meter (20 m) plot radius* ........ *36*
*4.2.3 Ten meter (10 m) plot radius* ........ *37*
*4.2.4 Five meter (5 m) plot radius* ........ *37*
4.3 DENSITY AND SIZE CLASSES OF SEEDLINGS. ........ 37
4.4 DIAMETER CLASS DISTRIBUTION AND REGENERATION STATUS OF VALUABLE WOODY SPECIES ........ 38
4.5 MODE OF REGENERATION FOR VALUABLE WOODY SPECIES ........ 41
4.5 FACTORS THAT INFLUENCE NATURAL REGENERATION OF VALUABLE WOODY SPECIES. ........ 42
*4.5.1 Fire* ........ *42*
*4.5.2 Vegetation cover* ........ *43*
*4.5.3 Distance to rivers, roads and settlements* ........ *45*
4.6 DATA ANALYSIS ........ 45
*4.6.1 Seedling density* ........ *45*
*4.6.2 Diameter class distribution of study species* ........ *46*
*4.6.3 Proportion of multi-stemmed individuals* ........ *47*
*4.6.4 Factors influencing regeneration density* ........ *47*

**5 RESULTS** ........ **48**

5.1 SEEDLING DENSITY ........ 48
*5.1.1 Density of seedlings in different areas* ........ *48*
*5.1.2 Regeneration occurrence assessment* ........ *51*
*5.1.3 Height classes of seedlings* ........ *52*
5.2 SIZE CLASS DISTRIBUTION OF VALUABLE WOODY SPECIES IN THE STUDY AREAS ........ 54
*5.2.1 Seedling to sapling ratio of the valuable woody species* ........ *59*
5.3 PROPORTION OF MULTI-STEMMED INDIVIDUALS AS AN INDICATION OF RESPROUTING ........ 60
*5.3.1 Proportion of multi-stemmed individuals* ........ *60*
5.4 FACTORS INFLUENCING REGENERATION ........ 61
*5.4.1 Seedling density and fire frequency* ........ *61*
*5.4.2 Seedling density and vegetation cover* ........ *63*
*5.4.3 Seedling density and distances to roads, settlements, the Kavango River and Omiramba.* *64*

**6. DISCUSSION** ........ **66**

6.1 *BAIKIAEA PLURIJUGA* ........ 66
*6.2 BURKEA AFRICANA* ........ 69
*6.3 PTEROCARPUS ANGOLENSIS* ........ 70
*6.4 SCHINZIOPHYTON RAUTANENII* ........ 72
*6.5 STRYCHNOS COCCULOIDES* AND *STRYCHNOS PUNGENS* ........ 73
6.6 NATURAL REGENERATION IN THE KAVANGO REGION ........ 75
6.7 FACTORS INFLUENCING REGENERATION ........ 78

**7. CONCLUSION** ........ **80**

**8. RECOMMENDATIONS** ........ **81**

**ACKNOWLEDGEMENTS** ............ **84**

**REFERENCES** ............ **86**

**APPENDICES** ............ **99**

APPENDIX A ............ 99
APPENDIX B ............ 100
APPENDIX C ............ 101
APPENDIX D ............ 102
APPENDIX E ............ 103
APPENDIX F ............ 105
APPENDIX G ............ 106
APPENDIX H ............ 107
APPENDIX I ............ 110
APPENDIX J ............ 111

## List of Figures

FIGURE 1: THE FIRE ZONES OF NAMIBIA BASED ON THE DIFFERENT FIRE REGIMES, DEVELOPED TO MAKE FIRE MANAGEMENT MORE APPROPRIATE TO DIFFERENT AREAS (TRIGG & LE ROUX, 2001). ............ 13
FIGURE 2: A CONCEPTUAL FRAMEWORK OF HOW THE GERMINATION SUCCESS OF *PTEROCARPUS ANGOLENSIS* RESPONDS TO FIRE TEMPERATURE (BANDA ET AL., 2006B). ............ 14
FIGURE 3: A MAP DEPICTING SETTLEMENTS OR VILLAGES IN THE KAVANGO AND THEIR PROXIMITY TO THE OKAVANGO RIVER WHICH FORMS THE BORDER BETWEEN NAMIBIA AND ANGOLA, AND ALSO TO OMIRAMBA IN THE AREA. THE RIVERS IN THE MAP LEGEND REFER TO THE PERENNIAL KAVANGO RIVER AND THE DRY RIVERS (OMIRAMBA) IN THE AREA. ............ 15
FIGURE 4: LOCATION OF THE STUDY SITES IN THE KAVANGO REGION IN NORTH EASTERN NAMIBIA, THE MAJOR TOWNS OF THE REGION AND THE ROADS (PRIMARY AND SECONDARY). ............ 27
FIGURE 5: MEAN ANNUAL TEMPERATURE FOR THE PERIOD 1980-2010 FOR THE OKAVANGO BASIN WHICH THE KAVANGO IS PART OF (WEINZIERL, WEHLBERG & LAMP, 2015) ............ 28
FIGURE 6: MEAN ANNUAL PRECIPITATION FOR THE PERIOD 1980-2010 FOR THE OKAVANGO BASIN WHICH THE KAVANGO REGION IS PART OF (WEINZIERL, WAHLBERG & LAMP, 2015) ............ 29
FIGURE 7: THE VEGETATION ZONES OF NAMIBIA AFTER (GIESS,1971) ............ 30
FIGURE 8: VEGETATION STRUCTURE IN THE SURVEYED STUDY SITES. THESE ARE SAMPLES OF WHAT SOME OF THE AREAS LOOK LIKE ESPECIALLY IN TERMS OF VEGETATION STRUCTURE. ............ 31
FIGURE 9: THE DISTRIBUTION OF PEOPLE IN THE KAVANGO REGION. MAP SOURCED FROM THE KAVANGO LAND USE PLANNING FRAMEWORK (MINISTRY OF LANDS AND RESETTLEMENT, 2010). ............ 32
FIGURE 10: THE LOCATION OF THE SAMPLE PLOTS IN THE DIFFERENT STUDY SITES. NOTE THE LOCATION OF THE SITES RANGING FROM FAR WEST AT KAHENGE AND EASTWARDS TO MASHARE ............ 34
FIGURE 11: AN ILLUSTRATION OF THE PLOT ARRANGEMENT AND DISTANCES BETWEEN SAMPLE PLOTS. THE DISTANCE BETWEEN THE PLOTS, IS ACTUALLY FROM THE PLOT CENTRE OF THE FIRST PLOT TO THE CENTRE OF THE NEXT PLOT, AND SO FORTH. ............ 35
FIGURE 12: SAMPLE PLOT DESIGN THAT WAS USED FOR THIS STUDY (BURKE ET AL., 1996) ............ 36
FIGURE 13: MEASURING SEEDLING HEIGHT USING A 5 M COLLAPSIBLE RULER (PHOTO: N. BAPTISTA, 2014) . 38
FIGURE 14: MEASURING DBH ON A *PTEROCARPUS ANGOLENSIS* TREE WITH A DIAMETER TAPE, NOTE FIRE DAMAGE TO THE TREE'S BARK. ............ 39
FIGURE 15: DBH MEASUREMENT GUIDELINES AS OUTLINED BY THE NFI GUIDELINES (BURKE ET AL., 1996) WHICH WERE USED FOR THIS STUDY. ............ 40

FIGURE 16: MEASURING VEGETATION COVER USING THE BITTERLICH GAUGE (PHOTO: R. SCHULZ, 2014) .... 44
FIGURE 17: A SCHEMATIC DIAGRAM OF THE LINE INTERCEPT METHOD THAT WAS USED TO ESTIMATE THE GRASS AND HERBACEOUS COVER WITHIN THE PLOTS. THE RED CLOUDS SYMBOLISE PLANTS WHOSE EXTENT ALONG THE LINE WOULD BE MEASURED AND THE BLUE ONES WOULD NOT BE MEASURED AS THEY DO NOT AT ANY POINT INTERCEPT ON THE LINE. ........ 45
FIGURE 18: MEAN DENSITY FOR *BAIKIAEA PLURIJUGA* IN THE DIFFERENT SITES OF THE KAVANGO REGION (ERROR BARS ARE 5% STANDARD ERROR). ........ 48
FIGURE 19: MEAN DENSITY OF *B. AFRICANA* IN THE DIFFERENT AREAS OF THE KAVANGO REGION (ERROR BARS ARE 5% STANDARD ERROR). ........ 49
FIGURE 20: MEAN DENSITIES OF *P. ANGOLENSIS* IN THE DIFFERENT AREAS OF THE KAVANGO REGION (ERROR BARS ARE 5% STANDARD ERROR). ........ 50
FIGURE 21: THE MEAN DENSITIES OF *S. RAUTANENII* IN THE DIFFERENT AREAS OF THE KAVANGO REGION (ERROR BARS ARE 5% STANDARD ERROR). ........ 50
FIGURE 22: THE MEAN DENSITIES OF S. *COCCULOIDES* (LEFT) AND *S. PUNGENS* (RIGHT) IN THE DIFFERENT AREAS OF THE KAVANGO REGION (ERROR BARS ARE 5% STANDARD ERROR). ........ 51
FIGURE 23: THE OCCURRENCE OF SEEDLINGS OF THE SELECTED WOODY SPECIES WITHIN THE DIFFERENT AREAS (LEGEND) AND THE AVERAGE OCCURRENCE ACROSS THE WHOLE REGION, ERROR BARS ARE STANDARD ERROR (95%). ........ 52
FIGURE 24: THE HEIGHT CLASS DISTRIBUTIONS USING AVERAGE DENSITY FOR THE SELECTED SPECIES IN THE DIFFERENT AREAS (BAIPLU=*B.PLURIJUGA*, BURAFR=*B. AFRICANA*, PTEANG= *P. ANGOLENSIS*, SCHRAU= *S. RAUTANENII*, STRCOC= *S. COCCULOIDES* AND STRPUN=*S. PUNGENS*). ........ 53
FIGURE 25: THE DIAMETER DISTRIBUTIONS FOR *B. PLURIJUGA* IN THE STUDY AREAS, WITH DIAMETER CLASSES ON THE X-AXIS AND DENSITY ON THE Y-AXIS. THE SCD SLOPE VALUES ARE ALSO INDICATED IN BRACKETS NEXT TO EACH SITE NAME IN THE LEGEND (ONLY FOUR AREAS OR SITES ARE GRAPHED, DUE TO THE ABSENCE OF THE SPECIES IN NCAUTE). ........ 55
FIGURE 26: THE DIAMETER DISTRIBUTIONS FOR *B. AFRICANA* IN THE STUDY AREAS, WITH DIAMETER CLASSES ON THE X-AXIS AND DENSITY ON THE Y-AXIS. THE SCD SLOPE VALUES ARE ALSO INDICATED IN BRACKETS NEXT TO EACH SITE NAME IN THE LEGEND. ........ 56
FIGURE 27: THE DIAMETER DISTRIBUTIONS FOR *P. ANGOLENSIS* IN THE STUDY AREAS, WITH DIAMETER CLASSES ON THE X-AXIS AND DENSITY ON THE Y-AXIS. THE SCD SLOPE VALUES ARE ALSO INDICATED IN BRACKETS NEXT TO EACH SITE NAME IN THE LEGEND. ........ 56
FIGURE 28: THE DIAMETER DISTRIBUTIONS FOR *S. RAUTANENII* IN THE STUDY AREAS, WITH DIAMETER CLASSES ON THE X-AXIS AND DENSITY ON THE Y-AXIS. THE SCD SLOPE VALUES ARE ALSO INDICATED IN BRACKETS NEXT TO EACH SITE NAME IN THE LEGEND. ........ 57
FIGURE 29: THE DIAMETER DISTRIBUTIONS FOR *S. COCCULOIDES* IN THE STUDY AREAS, WITH DIAMETER CLASSES ON THE X-AXIS AND DENSITY ON THE Y-AXIS. THE SCD SLOPE VALUES ARE ALSO INDICATED IN BRACKETS NEXT TO EACH SITE NAME IN THE LEGEND (NOTE THE FOUR AREAS GRAPHED, AS A RESULT OF THE SPECIES' ABSENCE IN MASHARE). ........ 58
FIGURE 30: THE DIAMETER DISTRIBUTIONS FOR *S. PUNGENS* IN THE STUDY AREAS, WITH DIAMETER CLASSES ON THE X-AXIS AND DENSITY ON THE Y-AXIS. THE SCD SLOPE VALUES ARE ALSO INDICATED IN BRACKETS NEXT TO EACH SITE NAME IN THE LEGEND (NOTE THE FOUR AREAS GRAPHED, AS A RESULT OF THE SPECIES' ABSENCE IN KAHENGE). ........ 58
FIGURE 31: THE PROPORTIONS OF TREES WITH MULTI-STEMS IN THE DIFFERENT SITES (LEFT) AND FOR THE REGION (RIGHT) FOR THE FOUR CANOPY SPECIES. (LEGEND: *BAIPLU = BAIKIAEA PLURIJUGA, BURAFR = BURKEA AFRICANA, PTEANG = PTEROCARPUS ANGOLENSIS AND SCHRAU = SCHINZIOPHYTON RAUTANENII)* ........ 61
FIGURE 32: SEEDLING DENSITIES OF THE VALUABLE SPECIES IN DIFFERENT FIRE FREQUENCY CATEGORIES.. 63

# List of Tables

TABLE 1: A SUMMARY AND COLLATION OF VEGETATION STUDIES COMPLETED IN NAMIBIA BETWEEN 1966 AND 2000, ADOPTED FROM BURKE AND STROHBACH (2000) AND OTHER VEGETATION STUDIES COMPLETED SINCE 1971 ........ 4
TABLE 2: A SUMMARY OF THE SELECTED SPECIES, INCLUDING THE NAMES, FAMILY AND COMMON USES, INFORMATION SOURCED FROM CURTIS AND MANNHEIMER (2009). ........ 18
TABLE 3: SUMMARY OF THE NUMBER OF INVENTORY AND REGENERATION PLOTS SAMPLED IN THE DIFFERENT SITES FOR THIS STUDY AND OTHER STUDIES, WHOSE DATA WERE USED FOR ANALYSIS AND INTERPRETATION. ........ 34
TABLE 4: THE EXPANSION FACTORS USED FOR THE DIFFERENT PLOT RADII AND DBH TO ATTAIN DENSITIES FOR THE TREES. ........ 40
TABLE 5: HEIGHT CLASS DISTRIBUTIONS FOR THE STUDY SPECIES, THE HCD DATA WERE DERIVED FROM THE HEIGHT CLASSES OF THE STUDY SPECIES. ........ 54
TABLE 6: THE SEEDLING TO SAPLING RATIOS OF THE OF THE SIX STUDY SPECIES WITHIN THE FIVE DIFFERENT AREAS. ........ 59
TABLE 7: MEAN VALUES FOR THE FIRE GAP IN YEARS AND THE FIRE FREQUENCY IN YEARS WITH STANDARD ERRORS GIVEN IN YEARS. ........ 62
TABLE 8: THE MEAN VALUES FOR DISTANCES TO VARIOUS FEATURES IN THE DIFFERENT AREAS WITH THEIR STANDARD ERRORS GIVEN IN BRACKETS. ........ 63
TABLE 9: RESULTS OF THE MULTI VARIATE LINEAR REGRESSION FOR HERBACEOUS COVER AND SEEDLING DENSITIES OF THE VALUABLE WOODY SPECIES IN THE KAVANGO REGION. ........ 64
TABLE 10: RESULTS OF THE MULTI VARIATE LINEAR REGRESSION FOR TREE COVER AND SEEDLING DENSITIES OF THE VALUABLE WOODY SPECIES IN THE KAVANGO REGION. ........ 64
TABLE 11: THE MEAN DISTANCE VALUES FOR THE DIFFERENT AREAS WITH THEIR STANDARD ERRORS GIVEN IN BRACKETS. ........ 65
TABLE 12: RESULTS OF THE MULTI VARIATE LINEAR REGRESSION FOR DISTANCE TO SETTLEMENTS AND SEEDLING DENSITIES OF THE VALUABLE WOODY SPECIES IN THE KAVANGO REGION ........ 65
TABLE 13: RESULTS OF THE MULTI VARIATE LINEAR REGRESSION FOR DISTANCE TO THE KAVANGO RIVER AND SEEDLING DENSITIES OF THE VALUABLE WOODY SPECIES IN THE KAVANGO REGION ........ 66

## Declaration

I Miya Whitney Kabajani hereby declare that the work contained in the thesis entitled: An assessment of the natural regeneration of valuable woody species in the Kavango regions of north eastern Namibia is my original work and that I have not previously in its entirety or in part submitted it at any university or other higher education institution for the award of a degree.

Signature:.......................... Date:........................

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I *Miya Whitney Kabajani* being a candidate for the degree of *Master of Natural Resources Management* accept the requirements of the Namibia University of Science and Technology relating to the retention and use of Master's theses deposited in the Library. In terms of these conditions, I agree that the original of my thesis deposited in the Library will be accessible for purposes of study and research, in accordance with the normal conditions established by the Librarian for the care, loan or reproduction of these.

Signature:............................. Date:......................

# Dedication

To my greatest cheerleader, *Agnes Namataa Puteho-Kamwi "Ima"*

For all the prayers, love and support

**AND IN MEMORY OF**

*Marlene Sheho Nzwala (1997-2014)*

A cheerful soul whose smile and laughter I will treasure all my life

*Maureen Mbombozana Khumalo-Kabajani "Kuku" (1911-2014)*

Who never received formal education but always encouraged me to study.

*Chrispin Kamwi Kabajani "Papa" (1956-2015)*

Who sparked my love for books and taught me to be proud and principled at all times.

## Abstract

The use of natural resources to meet the demands of society is a common practice that has gone on for centuries. In light of this the Kavango woodlands are considered to be threatened by many aspects including, timber harvesting, frequent fires and low recruitment rates of the woody species. It is with this in mind that this study was set out with the aim of assessing the density, abundance and influencing factors of the natural regeneration of valuable woody species.

Five different sites were surveyed in the Kavango regions, namely Hamoye state forest, Kahenge community forest, Katope community forest, Mashare communal area and Ncaute community forest. Forest inventories were carried out in these areas following the National Forestry Inventory sampling method which uses circular plots of 30 m radius. A total of 118 vegetation plots and 142 regeneration subplots were sampled. GIS data were also used to supplement the inventory data.

The study found that regeneration of the valuable woody species was different among the study species. *Burkea africana* had the most abundant densities of up to 790 seedlings per hectare and also had a stable seedling population with individuals in all height classes. *Schinziophyton rautanenii* was found to have the highest proportion of multistemmed individuals in the Kavango area with 100% proportion of multistems. The seedling to sapling ratios showed that species such as *Burkea africana* and *Strychnos pungens* had good recruitment trends to transition from seedlings to saplings, while *Strychnos cocculoides* had seedling to sapling ratios that showed low recruitment from seedlings to saplings.

The influencing factors were found to be in some cases non-significantly different following multi variate linear regressions with seedling densities of valuable woody species, but they were found to be significant for herb cover, tree cover, distances to the Kavango River and to settlements. This study found that current trends of regeneration densities and population size structures are in most cases a result of disturbances including fire.



**Keywords: Natural regeneration, Woodlands, Kavango, Fire frequency, Regeneration status, Size class distributions**

# 1. Introduction

## 1.1 Background

Natural resource use is a practise that has been employed by many communities for millennia. The communities in north eastern Namibia are therefore not an exception to this practise. The livelihood of communities in north eastern Namibia is centred mostly on using natural resources (Kamminga, 2001; Strohbach, 2013) as has been portrayed in the land use plan of the Kavango region (Ministry of Lands and Resettlement, 2010) and the national census report of 2011 (National Statistics Agency, 2012). These resources are important for the communities as they provide various resources ranging from fruits, building materials and fuel amongst others (Watts, 2010; Bille, Shikongo-Nambabi, & Cheikhyoussef, 2013). Woodland resources can be valued in many contexts, economically, socially and ecologically. Such valuations mean that the demand to use the resources is high, although this is dependent on the social dynamics and the geographic location of the area in which such resources occur (Benkenstein, Hengari and Mbongo, 2014).There is nonetheless some degree of selective utilisation of species. This means that some species are considered more valuable than others depending on the value placed on them by the local community. However, the use of these resources needs to be based on sound management plans (Benkenstein, Hengari and Bongo, 2014).

Considering that the woodlands of Namibia are concentrated in the north eastern part of the country forming the forest and woodland savannah vegetation zone (Giess, 1971, Barnes et al., 2010) it makes this study appropriate in the area. With woodland resources it is important to understand how much of these resources are in an area in terms of densities or biomass. This gives provision for forest managers and communities to know how much material they can use as they tend to view this as readily available material.

What is more important however, is creating an understanding of the forestry resource base. More specifically an understanding of the recruitment of the species in the woodlands of the country is vital. Recruitment is important as it ensures the continuity of a population through the introduction of new individuals into the system. This is a process that can occur naturally (Natural regeneration) or through the assistance of humans in nurseries or by altering the growth conditions (Assisted regeneration). This study however focused on the natural aspect of regeneration especially considering the absence of large scale forestry plantations in the country (Barnes, MacGregor, Nhuleipo, & Muteyauli, 2010). Natural regeneration is nevertheless influenced by several biotic and abiotic factors including fire, distance to settlements, vegetation cover, browsing and many other aspects and is a process that foresters need to understand for improved forest management (Hardwick, Healey, & Blakesley, 2000).

It is thought that most of the vegetation communities in the area are driven by the source and degree of disturbance (De Cauwer, 2013) which is in most cases in the form of threats to the vegetation. The woodlands of the Kavango regions are threatened by various aspects including the encroachment of alien invasive species (Strohbach, 2013). The strong dependence on the use of forest resources is one of the threats to the vegetation in the area, which is coupled with livestock grazing, clearing land for slash and burn agriculture and fire (Burke, 2002; Strohbach & Petersen, 2007). The current frequency of fires is believed to cause a reduction in recruitment (Proepper et al., 2015) of woody species. These threats give an idea of the influencing factors that impact on vegetation in the region and more importantly, they impact on natural regeneration.

A programme was developed to help involve communities in forest resource management through the Namibia-Finnish forestry programme (Seppanen, 2001). Through the programme, the National Forestry Inventory (NFI) was implemented as a component of the programme with the aim of collecting “adequate forest resource information which is being used for forestry strategic planning and operational management” (Seppanen, 2001). This approach provided some data on forest inventories in some of the northern regions of the country. There is however a noted limitation of data on forest cover and regeneration in Namibia (Benkenstein, Hengari, & Mbongo, 2014).There is an immense need for research to be carried out in order to provide more informed decisions in forest resource utilization and management. Vegetation studies are important to be able to understand what vegetation types we have, in what amounts and where they are. This information is crucial for natural resources management ( Burke & Strohbach, 2000).

## 1.2 Problem statement

The north eastern regions of Namibia are faced with increased pressure on woodland resources as populations continue to increase (National Statistics Agency, 2012). This demand has an influence on woodland structure, density and ultimately on natural regeneration. This constant increase in demand for natural resources is bound to over time alter the population structure and recruitment of the species that are harvested (Kennard, Gould, Putz, Fredericksen, & Morales, 2002). This is a common assumption that has not been fully investigated (Sullivan, 1999).

In line with the noted threats to the vegetation in the Kavango regions, it was deemed necessary to investigate a number of abiotic and biotic aspects that influence the environment in which seedlings regenerate. These environmental aspects include vegetation cover, distances to settlements, rivers and roads and fire return periods.

In the Kavango regions certain species are selectively utilised for their good quality wood or fruits. This highlights the need for regeneration studies focusing on those species. Kamminga (2001) noted that woodcarvers in the Zambezi region had expressed concern over the impact that uncontrolled fires were placing on the recruitment of their favoured woody species, namely *Combretum imberbe* and *Pterocarpus angolensis.* This shows that even the local people have begun to notice the possible influences even before being informed on scientific findings.

The selected valuable species for this study are *Baikiaea plurijuga*, *Burkea africana*, *Pterocarpus angolensis*, *Schinziophyton rautanenii* and two *Strychnos* species, namely *Strychnos cocculoides* and *Strychnos pungens*. These were chosen based mostly on their perceived economic uses at a local and national scale as will be discussed in each of the species' descriptions. This study therefore aimed at investigating different components of natural regeneration of the target species.

## 1.3 Contextual framework

The need for empirical research cannot be emphasized enough in all subjects. This extends to vegetation as well. It is therefore vital that vegetation studies are carried out at regional and national level in order to create an understanding of available resources. It is also important to understand how environmental conditions relate to the distribution and growth of these vegetation resources.

In a review publication, Burke and Strohbach (2000) list and describe vegetation studies that have been done in Namibia from as early as 1966 until 2000. Table 1 summarises some of the figures from the review. It can be seen from the table that within the period under review, of the 78 completed studies only 2 (2.5%) were carried out in the Kavango regions and no vegetation-environmental studies were done in the Kavango. This highlights the need for studies within the Kavango regions and especially vegetation-environmental studies. Two other review publications were written on the ecology of two of the study species namely *Pterocarpus angolensis* (Graz, 2004) and *Schinziophyton rautanenii* (Graz, 2002). These reviews described the ecology of the respective species including their growth requirements.

**Table 1: A summary and collation of vegetation studies completed in Namibia between 1966 and 2000, adopted from Burke and Strohbach (2000) and other vegetation studies completed since 1971**

| **Description of studies completed between 1966 and 2000** | **Number or proportion of studies** |
|---|---|
| Total number of vegetation studies completed in Namibia (1966-2000) | 78 |
| Number of vegetation studies completed in Namibia including Kavango | 10 (%) of the total 78 |
| Vegetation studies completed in the Kavango regions | 2 (2.5%) done by Page (1979/1980) and De Sousa Correira and Bredenkamp (1986) |
| Vegetation-Environmental studies completed in Namibia | 17 (%) of the total 78 |
| Vegetation-Environmental studies completed in Kavango regions | 0 |
| | |
| **Other vegetation studies completed in Namibia since 1971 (Not focusing on regeneration)** | **Authors and dates** |
| Vegetation map of Namibia | Giess (1971) |
| Vegetation of the Kavango Region and factors controlling the distribution of savannah trees in Namibia | Burke (2002 and 2006) |
| Impacts of different burning regimes | Geldenhuys (1977) |
| Vegetation of the central Kavango woodlands in Namibia | Strohbach and Petersen (2007) |
| Description of the vegetation in Mashare | De Cauwer (2013) |
| Trade-offs between timber and Carbon values, of *Pterocarpus angolensis* | Moses (2013) |
| Vegetation of the Okavango River valley in Kavango West, Namibia | Strohbach (2014) |
| Rangeland dynamics at increasing distances from the Kavango River | Boys (2015) |

In the early 2000s a number of forestry inventories were undertaken in the country in line with the establishment of the community forestry programme. Some community forests were also established in the Kavango region. The inventories gave an idea of the forest resources within those gazetted areas including two of the study sites for this particular study (Kanime, 2004; Kanime & Laamanen, 2002).

A study by Burke (2006) investigated the distribution of selected woody species in Namibia in relation to environmental influences that drive these species' distributions. The study highlighted some of the study species of this particular study including *Baikiaea plurijuga*, *Burkea africana* and *Pterocarpus angolensis*. Although the focus was more of a distribution study, it showed how the species distribution related to several environmental aspects including soils, rainfall, temperature and frost among others.

It is however also vital to understand the regeneration trends and influences. A masters' thesis by Shoopala (2008) investigated the influences of fire on regeneration in the Hamoye state forest of the Kavango region, which is one of the study sites of this particular study. New studies are in progress in this regard including one MSc thesis that was just completed by Kayofa (2015), which focused on the regeneration of *Pterocarpus angolensis*. Two other post graduate studies are underway focusing on seed banks and natural regeneration in fallows (Hilukwa, 2016) and on assisted regeneration of woody species (Chaka, 2016). The national guidelines on forest fire management in Namibia of 2001 identified basic and applied research fields that would be beneficial for the fire management plan. These fields included among others: the influence of fire on regeneration of woody species, fuel loads, the structure of vegetation and agricultural alternatives to the more conventional slash and burn agriculture practice (Trigg & Le Roux, 2001)

Despite the aforementioned studies, more still needs to be done in terms of vegetation studies in the woodlands of Namibia. As a result of international research projects such as The Future Okavango (TFO) and the Southern African Scientific Service Centre for Climate Change and Adaptive Land Use (SASSCAL) some vegetation studies are on-going in the Kavango regions looking at various aspects. This particular study was funded and carried out under Task 038 of the SASSCAL project. The task is aimed at Forest regeneration, growth, threats and trends in different forest types. With such studies, the gap in knowledge of the woodlands' regeneration will potentially be reduced.

## 1.4 Aim

The main aim of this particular study was to assess the density of natural regeneration of woody species and to further relate these densities to selected environmental and anthropogenic aspects (Fire frequency, vegetation cover (herbaceous, shrub and canopy) and distances to roads, settlements and rivers (Kavango and the dry rivers/Omiramba)) in different sites of the Kavango Regions.

## 1.5 Specific objectives

The specific objectives of the study were as follows:

1. To determine the density and height class distributions (HCD) of the valuable woody species regeneration in the different sites.
2. To determine the seedling to sapling ratios and for the different species within the different sites.
3. To assess multi stems as an indication of regeneration mode of the valuable woody species.
4. To assess the influence of fire frequency, vegetation cover and distances to rivers, settlements and major roads on regeneration of valuable woody species in the different areas.

## 1.6 Key questions and hypotheses

To fulfil the objectives of the study, the following questions were answered in order to determine seedling density and regeneration mode of the valuable species and further to assess how seedling density changes in relation to fire frequency, vegetation cover and distance proximities. The corresponding hypotheses are listed below each question.

1. **Is the density and height class distribution (HCD) for each of the selected woody species regeneration (seedlings) variable in the five different sites?**

    ***$H_0$:*** *Regeneration (seedlings) densities are the same for each of the study species in the five different sites.*

    ***$H_a$***: *Regeneration densities (seedlings) are different for each of the study species in the five different sites.*

2. **What is the regeneration occurrence for each of the selected woody species within the sampled plots of the five study sites and the entire region as a whole?**

    ***$H_0$:*** *The occurrence of seedlings for each of the selected woody species within the sampled plots of the five study sites and the entire region as a whole is the same.*

***$H_a$**: The occurrence of seedlings for each of the selected woody species within the sampled plots of the five study sites and the entire region as a whole is different.*

3. **How are seedlings, saplings and trees of each study species distributed within the size class distributions and are such distributions similar across species in the different areas**

    ***$H_o$**: The distribution of seedlings, saplings and trees within the size class distributions are the same for all the valuable woody species*

    ***$H_a$**: The distribution of seedlings, saplings and trees within the size class distributions are different for the valuable woody species*.

4. **What proportion of each of the surveyed species is multi stemmed within the entire study area?**

    ***$H_o$**: The proportions of multi-stems for each of the valuable woody species are the same in the entire study area.*

    ***$H_a$**: The proportions of multi-stems for each of the valuable woody species are different in the entire study area.*

5. **How do factors like fire frequency, vegetation cover and distances to rivers (Kavango and dry rivers/Omiramba), settlements and roads relate to regeneration density in the study area?**

    ***$H_0$**: Fire frequency has no influence on regeneration density in the study area*

    ***$H_a$**: Fire frequency has an influence on regeneration density in the study area.*

    ***$H_0$**: Vegetation cover has no influence on woody species regeneration in the study area.*

    ***$H_a$**: Vegetation cover has an influence on woody species regeneration in the study area.*

    ***$H_0$**: Woody species regeneration does not increase with increased distance from rivers (Kavango and dry rivers/Omiramba), settlements and roads in the study area.*

    ***$H_a$**: Woody species regeneration increases with increased distance from rivers (Kavango and dry river/Omiramba), settlements and roads in the study are.*

# 2. Literature Review

## 2.1 Natural Regeneration

Natural regeneration has been defined by Borghetti and Giannini (2002) as the process by which the forest renews itself. This is perhaps the most open definition one can get of the process. Pardos, Ruiz del Castillo, Cañellas and Montero (2005) on the other hand define it as “the renewal of a forest stand by natural seeding, sprouting, suckering, or by layering seeds that may be deposited by wind, birds or mammals”. It is interesting that both definitions have incorporated the idea of renewing in their definitions.

Natural regeneration is viewed as an unreliable regeneration mode (Nunamaker & Valachovic, 2007). Despite its unreliability, it is considered better than assisted regeneration as it requires less human input, promotes genetic diversity and the new recruits adapt easily to the natural environment (Borghetti & Giannini, 2002). Based on the regeneration research needs compilation by Hardwick et al. (2000) assessing seedling density is insufficient, but looking at germination probabilities and size classes provides a better picture. This consideration includes as mentioned earlier the ecological or environmental aspects related to the regeneration densities.

Reseeding or resprouting are means by which forests or woodlands respond to disturbance or senescence (Kruger, Midgley, & Cowling, 1997).These are processes that aid in ensuring the continued survival of populations. Vegetation studies however seem to be biased in the sense that they tend to omit the small size classes (Midgley, Lawes, & Chamaillé-Jammes, 2010), which technically make up the regeneration size classes.

Disturbances tend to influence the mode of regeneration and it is thought that the mode of regeneration could have an influence on regeneration success (Kennard et al., 2002) within an area. Two modes of natural regeneration will be described in the next sections in detail, namely the asexual or vegetative regeneration and the sexual regeneration or germination.

### 2.1.1 Asexual regeneration (Vegetative)

Many studies have focused on studying seed properties and viability. While few have been dedicated to understanding the process of species resprouting in the wake of disturbances. These can be considered important in recruitment as they do not take too long to establish and fill up gaps that have been left open by fallen or cleared trees (Bond & Midgley, 2001; Luoga, Witkowski, & Balkwill, 2002). Most studies that have focused on this aspect have however looked at intense disturbances that can cause fatal damages to the plants, such as fire, land clearing, drought, herbivory and many others (Bond & Midgley, 2001).

This is a very important strategy that helps in maintaining genetic diversity (Bond & Midgley, 2001).It is however limited by resprouting species' inability to pioneer in uninhabited areas. Kruger, Midgley and Cowling (1997) suggest that resprouts take long to grow, in terms of height, as they invest most of their energy into producing buds for coppicing.

Bond and Midgley (2001) further implied that some species require disturbances and this then necessitates the disturbance to a certain extent or intensity which is required for the establishment of the species. It has been noted that quantifying a species sprout response is a tedious task as the responses are quite variable in relation to disturbance intensity and frequency (Bond & Midgley, 2001). It is nonetheless a worthy task considering the portrayed value of resprouts in natural regeneration.

For a species to resprout, it needs to have living meristem and stored energy reserves (Bond & Midgley, 2001). This helps ensure that the individual is able to re-establish itself once it has been disturbed. Species that have resprouting abilities tend to produce fewer seeds, limited seedbanks and mature at slow rates, and their seedlings don't always survive to the next stage (Bond & Midgley, 2001). This is the case for *Pterocarpus angolensis* which matures slowly and has poor seedling survival (Vermeulen, 1990) despite having many seeds

Hoffmann (1998) found that fire seemed to have an impact on vegetative reproduction and not on sexual reproduction, once again highlighting the fact that vegetative reproduction is a result of disturbance, including fire. Hoffmann's study further highlights the suffrutex nature of some species in early development stages, whereby in response to fire they are forced to die back and not reach sexual maturity in one growing season but over several growing seasons which could be up to a decade in the case of *P. angolensis* (Vermeulen, 1990). Hoffmann (1998) further notes that species that are not able to reproduce vegetatively are not always able to survive fires.

Resprouts are considered more viable in fire frequent environments such as the Kavango because they are more likely to withstand fire impacts and survive to sexual maturity compared to seedlings (Hoffmann, 1998). He also emphasized that resprouts have the ability to grow after fires whereas new seedlings are unable to do so.

#### *2.1.1.1 Multi-stems as an indication of resprouting*

It is generally thought that in response to disturbance many species will resprout and one of the response mechanisms is to produce multi-stems. Although there is great variation in how several factors influence the production of multi-stems (Ye et al., 2014). It is considered that multi-stemmed individuals are usually resprouts (Kruger et al., 1997). They however also acknowledge that some resprouting species may lose some of the stems as they grow and later on become single stemmed individuals. Subsequently the ability to form multi-stems is dependent on the species (Ye et al., 2014).Some species are however multistemmed as a result of germinating from multi seeded fruits. For the purposes of this study such germination characteristics were not investigated and could therefore not be alluded to.

Multi-stems are however thought to be poorer in formation in tall forests compared to single stems due to the fact that growth resources are shared amongst more stems (Kruger et al., 1997). This then brings us to the growth forms of some species, whether they naturally grow as tall trees or short trees that sometimes only grow to shrub level which tends to raise their chances of becoming multi-stemmed in response to disturbance (Ye et al., 2014). Even though this is a study that was carried out in a temperate Chinese forest, the principle could be considered the same but at variable rates. The study further recognises the need to carry out similar studies in different environments and to investigate other influencing factors including herbivory and light. This highlights the need for studies in African savannahs and woodlands at large to investigate the ecology of multi-stems in such environments.

A Zimbabwean study by Ncube and Mufandaedza (2013) found that fire enhanced shoot production in *Baikiaea plurijuga* and *Pterocarpus angolensis* and also promoted the formation of multi-stems in the two species. Further emphasizing the idea that being multi-stemmed is a disturbance response and can hence be considered part of vegetative reproduction.

### 2.1.2 Sexual regeneration (Germination)

Seedling establishment is important for the regeneration of any species (Basyal, Lekhak, & Devkota, 2011). Woody species that are able to regenerate through sexual reproduction are believed to have the ability to produce more seedlings at a time (Kruger et al., 1997) compared to individuals that reproduce vegetatively. This ability therefore ensures continued seed production for sexual regeneration.

Hoffmann (1998) indicated that fire reduced the number of seeds produced by some of his study species, an indication that seedling production can be easily hampered and therefore limit sexual regeneration. The same study also showed that the survival of seedlings that germinated was hampered.

Germination is a more complex process as it requires the right environmental conditions to germinate, including soil moisture, light intensity and seed viability (Basyal, Lekhak, & Devkota, 2011; Kruger et al., 1997b). Kruger et al.(1997) furthermore argued that seedlings grow faster as they invest more resources into growth compared to resprouts that invest more in bud-banks.

### 2.1.3 Tree communities and vegetation structure

Forest composition, structure and diversity are important ecological attributes that are associated with environmental conditions (Ingvar, Pettersson, Stromquist, & Ruffo, 2006; Rawat, Gairola, Sekar, & Rawal, 2014). This implies that features of an area's vegetation are influenced by the area's climatic conditions. However, some aspects of the vegetation might have an influence on other vegetation features.

Classifying individuals into size classes gives an idea of the population structure of a species and a further idea of the survival of individuals from one stage to the next size class or growth stage (Luoga, Witkowski, & Balkwill, 2004; Modest, Maganga, Hassan, Mariki, & Muganda, 2010). Forests are characterised by three main life stages in plants namely, (1) **seedlings**, which are newly emerged plants, (2) **saplings,** established plants between seedlings and trees and (3) **trees** which are the mature version and are normally undisturbed by micro environmental conditions (Rawat et al., 2014). The life stages can be allocated into different size classes and this study used the three life stages to determine regeneration status of the various species and the size class distributions to show population structure.

## 2.2 Factors that influence regeneration

Different species have variable environmental requirements for establishment, even though species co-exist in the same environment, they will require different intensities or exposure levels to certain things such as light, moisture, disturbance and more. It was noted by Grubb (1977, as cited in (Bond & Midgley, 2001) that species might have the same life form, phenology and habitat but they differ when it comes to seedling requirements. As has been noted, regeneration is a complex process that is influenced by several factors including seed availability, light, gaps, water availability and herbivory amongst others.

Hoffmann (1998) noted that disturbance is an important aspect of forest dynamics in the sense that it helps in improving conditions for the establishment of seedlings. Such improvements are in the form of litter removal to make provision for new growth and availing resources for new individuals to grow. Even though Hoffmann (1998) suggested that disturbance was good for regeneration, some of it has been found to have negative impacts. Findings by Kennard et al. (2002) concur with this and reiterate that disturbances could lead to changes in species composition.

There are many factors that have an influence on regeneration, but many of them are not clearly understood, especially their influence on resprouting (Busby, Vitousek, & Dirzo, 2010). This section reviews a few of them that are pertinent to the objectives of this study.

### 2.2.1 Fire

Fire is a critical aspect in woodlands and savannahs, with the latter reported to have been shaped by fire (Ncube & Mufandaedza, 2013). The impacts of fire on vegetation provide never ending debates about which season is best for burning or what frequency and intensity of burning is best or least damaging for an area. Many studies have been carried out in efforts to understand the impacts of fire season, frequency and intensity on vegetation (Higgins, Bond, & Trollope, 2000; Mapaure, 2013; Ncube & Mufandaedza, 2013; Nepolo & Mapaure, 2012; Ohl, 2005; Sheuyang, Oba, & Weladji, 2005; Shoopala, 2008; Smit et al., 2010). Not many of these studies have however been carried out in the north eastern part of Namibia.

Like many other aspects of fire, there are conflicting ideas about intervals between burning, Govender et al. (2006 as cited in (Smit et al., 2010) found no significant differences in fire intensities in areas that burned annually, or had intervals of two, three or four years. Smit et al. (2010), also concur with such findings and further state that the intervals between burning have no influence on fire intensity and hence do not reduce vegetation cover. Mapaure (2013) however suggested that frequent fires pose greater impacts to the growth of woody species while reducing the frequency of fires tends to aid in the growth of such woody species. He further states that the impacts of fire are more prominent in the shrub layer than the tree layer.

The country was split into different fire zones (Figure 1) in order to aid in fire management (Trigg & Le Roux, 2001). It is also pointed out that a small fraction of the fires in the Kavango are caused by lightning and the rest are anthropogenic (Stellmes et al., 2013; Trigg & Le Roux, 2001). In the same report, they describe the reasons why people start fires in the area, which include among others clearing land for crop farming and enhancing new grass growth. Trigg and Le Roux (2001) further noted that fire zone 6 receives the highest amount of rainfall (500-700 mm) resulting in medium to very high biomass produced and eventually the fastest fire return period with medium to high intensity fires.

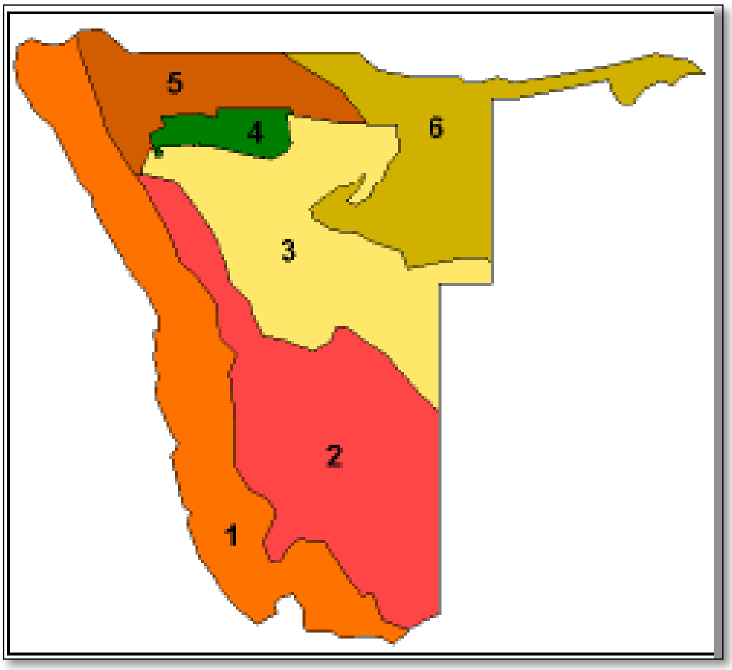


**Figure 1: The fire zones of Namibia based on the different fire regimes, developed to make fire management more appropriate to different areas (Trigg & Le Roux, 2001).**

Another long standing point of debate when it comes to fire has been the season of burning. Is it better to burn at the end of the dry season or the wet season? Smit et al. (2010) and Geldenhuys (1977) found that late dry season burning had more severe impacts on the vegetation compared to early dry season burning. Their study further showed that burning in the spring season, (October in the southern hemisphere) caused the greatest vegetation reduction. The reason for this is suggested to be because of the presence of dry plant material in the area especially in the absence of rainfall (Smit et al., 2010). This is also supported by Banda, Schwartz and Caro (2006) who are of the opinion that early burning may enhance germination and recruitment of vegetation in the wild. Banda, Schwartz and Caro (2006) are also of the opinion that early season fires are cooler and cause less damage to seeds. This is a similar idea as that of Smit et al. (2010) who propose early season burning to reduce the possibility of high intensity fires later on. Fire is considered an important stimulant for germination or resprouting of species (Ncube & Mufandaedza, 2013), but this is however variable according to species. Some species are considered fire tolerant and as such these would be found in areas where the fire intolerant species are not (Ingvar et al., 2006).

Although these studies have been conducted, the implications of their findings towards forest management have not been fully clarified (Ncube & Mufandaedza, 2013). This view is shared by Banda, Schwartz and Caro (2006b) who suggest that understanding the impacts of fire on different life stages of plants requires focal studies before definitive conclusions can be drawn on the subject.

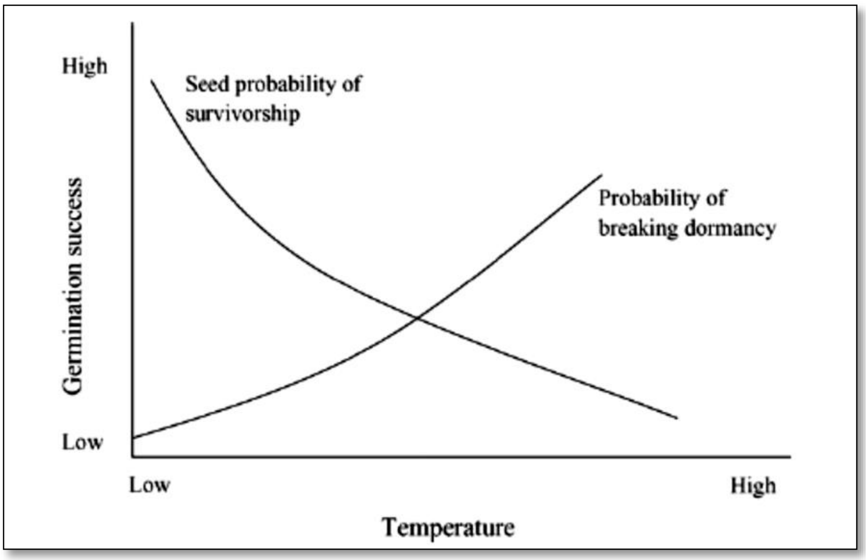


**Figure 2: A conceptual framework of how the germination success of *Pterocarpus angolensis* responds to fire temperature (Banda et al., 2006b).**

From Figure 2 it can be noted that the framework suggests that *P. angolensis* germinates at intermediate fire temperatures. It also suggests that in order to break dormancy, the seeds of *P. angolensis* require exposure to fire. These conditions, although feasible for *P. angolensis,* might not be suitable for another species such as *S. rautanenii* whose seedlings are noted to be killed by fire (Graz, 2002)

Ncube and Mufandaedza (2013) are of the opinion that the effects of fire on resprouts have not been fully assessed. Smit et al. (2010) however found that the fire frequency impacts individuals in the shorter height classes whereas fire intensity impacts individuals in the taller height classes. An indication that seedlings are more susceptible to frequent fires.

It is therefore important for local communities and for forestry managers to understand that managing fire season and intensities (Smit et al., 2010) is important as their combination impacts on vegetation at different stages of their growth. Sheuyange, Oba and Weladji (2005) concluded in their study that integrating local knowledge of people who work in the field such as cattle herders with that derived by scientists could go a long way in helping answer some of the uncertain questions regarding fire in the savannah ecosystem.

### 2.2.2 Distances to rivers, settlements and roads

Most of the settlements in the Kavango Region are found close to the Kavango River or along some of the dry *Omiramba* found in the region. This means there is a larger concentration of people close to water bodies. Distances to rivers or settlements can be used as indirect measures of the amount of pressure exerted by humans on wood resources (Sullivan, 1999). Figure 3 depicts the distribution of settlements or villages in the Kavango region in relation to the location of the Kavango River and to Omiramba (dry riverbeds) highlighting the strong influence water sources have on settlement site selection.

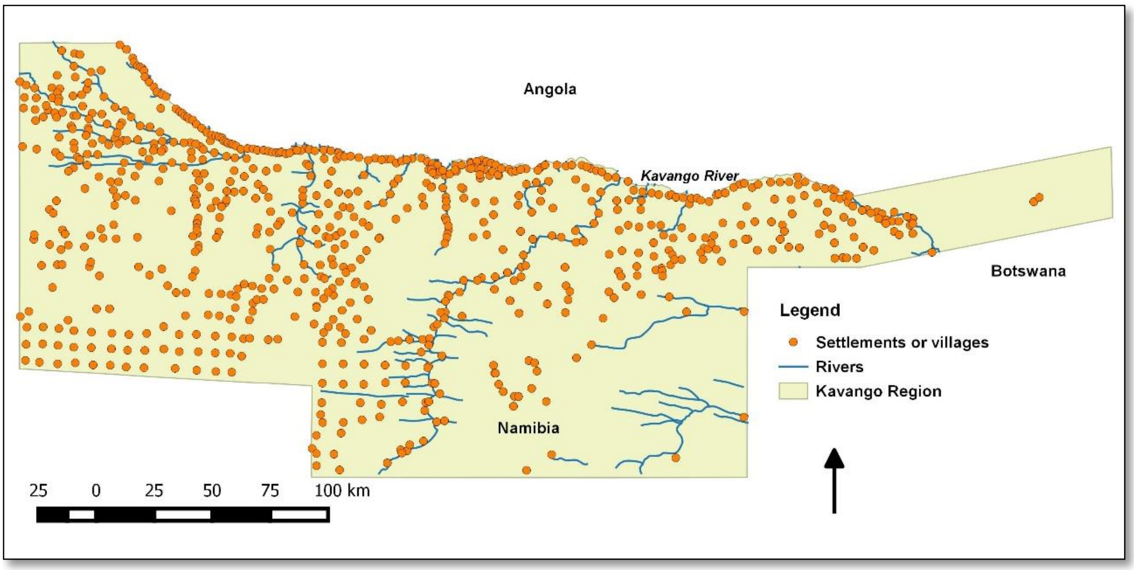


**Figure 3: A map depicting settlements or villages in the Kavango and their proximity to the Okavango River which forms the border between Namibia and Angola, and also to Omiramba in the area. The rivers in the map legend refer to the perennial Kavango River and the dry rivers (Omiramba) in the area.**

A study in a South African communal area found that the density of stems increased with increasing distance from settlements (Shackleton, Griffin, Banks, Mavrandonis, & Shackleton, 1994). This concurs with another study which found that vegetation cover increased with increasing distance from settlements (Fisher et al., 2012). These studies support the idea that close proximity to settlements allows for easy access to forest resources and hence encourages exploitation. Using distance to settlements and rivers as proxies for disturbance also links with aspects such as livestock grazing and selective harvesting of species. It is noted that the areas that are at greater fire risks in terms of both frequency and return period, are areas that have low or no grazing pressure (Kamminga, 2001). This means that if an area is farther away from settlements it implies an absence of livestock and therefore low or no grazing intensity, and in turn a higher fuel load that promotes intense fires.

In the Kavango region, the presence of forest roads serve as firebreaks which are crucial tools for forest fire management in the region. Some of the communities in the Kavango region were trained in managing firebreaks and this is noted to have reduced some of the fire extent (Trigg & Le Roux, 2001).

#### *2.2.2.1 Felling or selective harvesting and land clearing*

Selective harvesting of species of certain sizes has the potential to alter the size structure of the harvested species (Luoga, Witkowski and Balkwill, 2004). Fire suppression and timber harvesting of large trees led to a change in species composition and structure of a mixed-conifer forest in California  (Gray, Zald, Kern, & North, 2005).

Wiafe (2014) gathered that the trees that are left unharvested in the natural environment have an influence on regeneration rather than the ones that are removed. This is because the remaining trees produce the seed rain for the forest and their distribution determines whether there is ample space for these seeds to germinate and if they will be able to receive enough light or shade that will enhance their germination. A Ugandan study by Omeja, Obua and Cunningham (2004) pointed out that intensive harvesting creates excessive gaps which in the long run, lead to ample space for growth of the herbaceous layer which might cause suppression of woody species regeneration.

A Tanzanian study found that many loggers indicated that hollow trunks or bent stems of *P. angolensis* were not harvested as they are considered poor quality whereas most large and straight stems were harvested as more saw planks could be produced from them (Schwartz, Caro, & Banda-Sakala, 2002). This gives the implication that as a result of logging or harvesting only poor quality parent trees are left in nature and in the end poor genetic populations are left.

A study in Burkina Faso (Zida, Tigabu, Sawadogo, Tiveau, & Per Christer Oden, 2009) found that selective tree harvesting reduced the tree density  over time and they attributed this to several factors including the reduction in seed production as a result of the removal of mature trees and the continuous creation of gaps which are easily colonized by the herbaceous layer which leads to increased competition for resources with seedlings. The same study (Zida et al., 2009) also highlighted that due to the removal of mature trees, grass growth is promoted and this increases the fuel load, causing fires with high intensity which ultimately leads to seedling mortality. Meanwhile Ncube and Mufandaedza (2013) concluded that trees of 30-40 cm diameter at breast height (DBH) might be harvested more than the larger classes as they are more resilient to fire damage than the much larger trees. While Midgley (2010) reiterates the importance of diameter sizes and bark thickness in a tree’s resilience towards fire. This therefore implies that selective harvesting has the potential to alter size structures of species’ populations especially when coupled with other disturbance impacts.

Shackleton, Guthrie and Main (2005) recommend that fruit harvesting be done in a more sustainable manner as intensive harvesting could have impacts on the recruitment of species. Fruit harvesting is considered a more sustainable way of using forest resources although intense harvesting can reduce the number of seeds available for continued recruitment. The practice also disperses seeds in close proximity to settlements and increases the number of fruit trees close to settlements, which is a good thing for food production but alters the community structure of species in nature. Intensive harvesting has also been found to reduce seed sources through the harvesting or felling of parent plants (Omeja et al., 2004).

#### *2.2.2.2 Herbivory and vegetation cover*

According to Midgley, Lawes and Chamaillé-Jammes (2010), savannahs have been extensively studied but there is no definite consensus on the influences of herbivory and fire on vegetation and how they affect different life stages. This is an aspect of vegetation ecology that is of importance as grazing and browsing are an integral part of the savannah ecosystem.

Different species will have different response mechanisms to browsing and this has an influence on their survival as well. Species that coppice are considered to be able to survive browsing better than their non-sprouting counterparts (Bond & Midgley, 2001). This has however not been studied fully but it is thought that the root carbohydrate reserves could be a supporting factor in this idea. A study by Kayofa (2015) noted that root carbohydrates are impacted by regular fires and this in turn restricts resprouting.

The stage of growth of a plant and the diet and size of browsers found in an area has an influence on whether a species is browsed or not. It has been noted that small browsers find seedlings more preferable in their diet due to their size and energy requirements (Midgley, Lawes, & Chamaillé-Jammes, 2010). That means it makes sense for a duiker to browse on seedlings than to try and browse on full grown trees due to size and energy requirements. A study in Sudan pointed out that ruminants do not always cause damage to seeds but smaller animals such as rodents and squirrels are able to break the seed kernel (Daldoum, Massaud, & Adam, 2012) which renders the seeds unviable for germination.

In another study, Graz (2004) suggested that heavy grazing of the herbaceous layer can have an advantage for the woody plants as it reduces competition for new seedlings that germinate and grow into a system. This implies that by reducing the herbaceous layer through grazing, resources are more available for the seedlings. Gambiza, Campbell, Moe, & Mapaure, (2008) suggested that employing herbivores in woodlands could reduce the fuel loads and lead to reduced fire frequencies in the long run.

Basyal, Lekhak and Devkota (2011) noted that when seedlings grow under a layer of shrubs, they can be damaged or destroyed as a result of competition. The study also showed that seedlings do not always grow to the next growth stage as a result of competition with the herbaceous layer.

The removal of the herbaceous layer or litter is noted to hamper seedling growth (Hoffmann, 1998) as the seedlings might become over exposed to harsh conditions such as intense sunlight, wind and rain. The accumulation on the other hand could lead to an increased competition for resources and an increased fuel load for fires.

## 2.3 Valuable woody species in Namibia

It is noted that Namibia despite being a forest limited country, has woodland resources that provide valuable ecological and socio economic resources which are important for many of the rural communities. Such communities depend on these resources for wood, timber, and other non-timber resources (Benkenstein, Hengari, & Mbongo, 2014) which are important for their daily activities.

There are several woody species that are valued highly in north eastern Namibia. These valuations differ based on how they are utilised and the scale at which they are used. The considered species are used on different levels for variable purposes, some uses are localised within the communities and some support continental markets for woodland resource supply.

Table 2 lists the species that were selected for this study including their families and uses. This summarises the uses of each of the species, which will later be described in more detail.

**Table 2: a summary of the selected species, including the names, family and common uses, Information sourced from Curtis and Mannheimer (2009).**

| **Species** | **Common name** | **Family** | **Uses** |
|---|---|---|---|
| *Baikiaea plurijuga* | Zambezi teak/ Rhodesian teak | Fabaceae (Caesalpinioideae) | Timber, canoes, medicine |
| *Burkea africana* | Sand syringe | Fabaceae (Caesalpinioideae) | Timber, tools, carvings |
| *Pterocarpus angolensis* | Kiaat | Fabaceae (Papilionoideae) | Timber, carvings, medicine, |
| *Schinziophyton rautanenii* | Manketti/Mangetti | Euphorbiaceae | Drums, edible fruits |
| *Strychnos cocculoides & Strychnos pungens* | Monkey oranges | Strychnaceae | Edible fruits, basic tools |

### 2.3.1 Economic valuation

Economic values are always seen as indications of development. The use values of plant resources range from direct and indirect use values which are derived locally, for subsistence or sold on both small and large scales (Barnes et al., 2010). Kamminga (2001) describes the types of benefits that local communities in the woodland areas are able to derive from the resources, and cash income is one of them, although the market opportunities are noted to be limited. A study found that about 50% of the household income in the Kavango is derived from forest resources, while only 22% is derived from harvested crops (Proepper et al., 2015).

In the past decades, resources such as saw timber of species like *Baikiaea plurijuga, Pterocarpus angolensis, Guibourtia coleosperma* and *Burkea africana* were harvested (Barnes et al., 2010) especially in the north and the north eastern part of the country. There is however a current moratorium on harvesting of saw timber in Namibia (Barnes et al., 2010) which is not fully respected just like in Tanzania (Luoga et al., 2004).

It's important to realise that the economic value of forest resources varies according to the geographic and social dynamics of the area (Benkenstein et al., 2014). For example if resources are in an area that is inaccessible then their economic potential cannot be fully explored as people cannot access such resources.

It is noted in a report by Sebukeera (n.d.) that trade in forest products is dominated by unprocessed products which reduces the potential value of the products. This is a case in many parts of Africa and is experienced in the Kavango region as well. In the Kavango there are no large markets or facilities for large scale production of forest products, hence the potential value is reduced in the export process of sending most of the raw materials to the capital or other countries. There is however a focus on the craft industry in the region.

Despite the fact that there is a wide variety of tree species in the Kavango for use, it seems the most utilised species is *Pterocarpus angolensis* which has been widely harvested for its timber and it supports the majority of the crafts market in Kavango (National Statistics Agency, 2012). The size and quality of trees especially of stems is noted to be an important factor in determining the uses of the trees (Nshubemuki, 2007).

An economic assessment of the forest resources of Namibia that was done in 2004 gives an account of how much forest resources the country has and what was their value at the time by using the net present value method, the assessment also assumed that the forest stocks or resources are stable and the patterns at which they are used can be predicted (Barnes et al., 2010).The forest resource assessment also noted that restraints such as isolation, transport and restricted markets are factors that can hinder the economic viability of wood resources (Barnes et al., 2010).

### 2.3.2 Social or cultural valuation

Many cultures practise the use of plants for medicinal or other cultural beliefs. These practises could form the difference between whether a species is utilised sustainably or not within the community.

In the Kavango Regions, the most valuable commodity that most people own is livestock (Kojwang, 2000) especially cattle. Cattle are considered to be a form of social status among community members and the more one has the richer they are and the higher their status. Cattle are also used as an exchange commodity, are sold to earn money for school fees and are highly used in traditional ceremonies such as marriages. To sustain these cattle, requires grazing and land (Kojwang, 2000), of which they tend to impact on as pointed out in section 2.2.2

It is pointed out that more than 90% of rural communities in Africa, rely on fuel wood for energy (Sebukeera et al., n.d.). This reiterates the strong dependence of rural communities on forest resources for their daily lives. Sop, Oldeland, Schmiedel, Ouedraogo and Thiombiano (2011) also state that in many developing countries majority of the communities rely on forest resources on a daily basis.

For most of the rural communities in Africa, medical care is always difficult to access and as a result, there is a strong reliance on the medicinal values of plants. Some of the valuable species that were selected for this study have medicinal values as can be seen from Table 2, relating this to the fact that a large population base of the Kavango regions is rural means that traditional medical practices are a more feasible approach compared to the distant travels to clinics or hospitals for modern medication.

The detailed description of uses for the study species in their relevant sections also highlights the social values that people place on them.

### 2.3.3 Ecological valuation

Forests and woodlands have a crucial role in the environment and provide essential ecosystem services that help in combating land degradation and minimising the impacts of climate change and Carbon sequestration (Proepper et al., 2015).

In other African countries such as South Africa, Zimbabwe, Kenya, Zambia and several other countries, plantations for timber provision are a lucrative economic activity (Sebukeera et al., n.d.). This not only helps in improving economies and ensuring a constant supply of timber but also reduces pressure on natural and indigenous forest resources. In Namibia, timber plantations are almost non-existent. There are a few small Eucalyptus plantations, which are initiatives of the Department of Forestry, although they are not used for timber provision.

Based on the role of forests and woodlands in Carbon sequestration, there has been an increase in what is termed Carbon trading and many companies in developed nations are making investments towards this approach in African countries (Sebukeera et al., n.d.). This approach is believed to have economic benefits (Turpie, Barnes, Lange and Martin, 2010) especially for developing nations.

An increased demand for food supply means more farmers expanding areas for agricultural production in order to meet these demands (Sebukeera et al., n.d.). This increase in agricultural lands exerts pressure on forest resources by clearing large areas of natural and indigenous woody vegetation which requires many years to recover.

### *2.3.4 Baikiaea plurijuga*

*Baikiaea plurijuga* commonly known as Zambezi teak is a tall tree that grows up to about 20 m height and is described as producing excellent wood which is thought to be one of the best timbers in the study area (Curtis & Mannheimer, 2005; Thelaide, Sekeli, Hald, & Graudal, 2001). It is this good quality timber that leads to the species being so sought after in many countries of its distribution. It is used for various purposes including construction, making canoes, sledges, furniture, pestles and many other items (Curtis & Mannheimer, 2005).

The species is believed to grow well on soils that are well drained, such as Kalahari sands which have high water retention abilities (Thelaide et al., 2001). In its Southern African range the species is limited to areas with mean annual rainfall of 1000 mm in its northern range and extends to about 600 mm in its southern range (Thelaide et al., 2001). Namibia is probably in its southern most range. Its distribution in Namibia is however also limited to the far northern and north eastern parts of the country.

*Baikiaea plurijuga* is believed to have nearly disappeared from its Zambian range due to exploitation for timber and land clearing for agriculture (Thelaide et al., 2001). Similar threats are noted in its Namibian distribution, it is however protected by forestry legislation in Namibia (Curtis & Mannheimer, 2005) and is placed under the IUCN list for near threatened species due to threats from urban expansion, browsing ,fire and agriculture (Craven & Loots, 2002).

Chitempa and Shingo (1986) as cited in Thelaide et al. (2001) pointed out that the most influential aspects for the species' regeneration in plantations include, fire, competition, small mammal browsing, frost and poor establishment. Could these factors be the reason why there are no large scale plantations for the species? (Thelaide et al., 2001). There are no current known attempts to regenerate the species on a large scale in Namibia.

### *2.3.5 Burkea africana*

*Burkea africana* is one of the woodland species found in north and north eastern Namibia. It is described as a medium sized tree species that ranges in height from 8-10 m (Coates-Palgrave, Drummond, & Moll, 1977). It has however been noted to grow to heights of about 20 m (Mannheimer & Curtis, 2009) in other areas of its distribution which extend from southern Africa to as far north as Ethiopia and further west to Nigeria (Wilson & Witkowski, 2003) The species is noted to produce heavy, tough wood which has variable colours but is described as being susceptible to wood borers (Coates-Palgrave et al., 1977) and 85% of all trees are believed to be hollow and sand-filled (Mannheimer & Curtis, 2009)

It is described as being a small timber tree, therefore limiting its uses to furniture and flooring because of its short timber length (Coates-Palgrave et al., 1977). . In Namibia it is found in the central north and  north eastern parts of the country and southwards to the Gobabis area (Mannheimer & Curtis, 2009).

Among its diverse uses the species has medicinal values, including treatment of septic sores (Coates-Palgrave et al., 1977). It is used in enhancing alcoholic brews, as a fish poison when crushed and produces an edible resin (Mannheimer & Curtis, 2009).The species has hardwood which can be easily sawn, and is mostly used in making floor tiles, furniture, poles and pestles for pounding Mahangu (Mannheimer & Curtis, 2009).

Like the other study species, it is found to occur in savannahs and woodlands with dry and sandy soils (Wilson & Witkowski, 2003). Like the other species once again, no large scale attempts are being made in regenerating or growing the species in Namibia. It is considered difficult to cultivate and its seedlings have a low survival rate and poor seed germination (Mannheimer & Curtis, 2009)

*Burkea africana* is also described as having an adaptation whereby it is able to resprout from its growing points in response to disturbance such as fire or herbivory. It was also found to be able to resprout from seedlings in response to fire which they are susceptible to (Wilson & Witkowski, 2003).

The species can be easily confused with other species such as *Erythrophleum africanum* but it is always distinguished by its characteristic red tips (Coates-Palgrave et al., 1977).

### 2.3.6 *Pterocarpus angolensis*

*Pterocarpus angolensis* is listed as one of the most valuable timber species (Craven & Loots, 2002) and is probably the most extensively studied of the selected species, although it is not fully understood. Several studies have been carried out on various aspects of the species' ecology (Caro, Sungula, Schwartz, & Bella, 2005; De Cauwer, Muys, Revermann, & Trabucco, 2014; Graz, 2004; Kabajani, 2013; Kayofa, 2015; Moses, 2013; Therell, Stahle, Mukelebai, & Shugart, 2007; Thunstroem, 2012) including a very detailed monograph by Vermeulen (1990). It is described as an important species in Namibia's wood carving industry (Graz, 2004). It is however protected by forestry legislation in Namibia (Curtis & Mannheimer, 2005) for this reason, harvesting of the species is not allowed. This is also the case in other countries for instance in Tanzania but many people do not obey this decree (Luoga et al., 2004). It is also listed as a vulnerable species under the IUCN red list due to declining populations and threatened by fire, agriculture and expansion of urban areas (Craven & Loots, 2002)

The species is distributed across some regions in the northern parts of Namibia, occurring mostly on deep Kalahari sandy soils (Graz, 2004; Mannheimer & Curtis, 2009) .

*Pterocarpus angolensis* is a leguminous small to medium sized tree species that is considered valuable for its timber (Banda et al., 2006b; Mannheimer & Curtis, 2009). Other uses include, medicinal use for burns and injuries, inflammations, malaria and black water fever (Mannheimer & Curtis, 2009). Due to the durability of its wood and its contrasting markings the wood of the *P. angolensis* is favoured for use in carvings and making furniture (Mannheimer & Curtis, 2009).

Germination of the species is considered a rare event (Banda et al., 2006) and is noted to be poor under natural conditions (Vermeulen, 1990). The species is noted to be a good resprouter and this is thought to be a good option to regenerate the species in the wild (Graz, 2004) Germination experiments in Namibia were initiated in the 1980s but were terminated around 1994 (Graz, 2004). Some studies have recently been conducted to look at the seed viability and germination (De Cauwer & Younan, 2015) of woody species in abandoned fields (Hilukwa, 2016) including *Pterocarpus angolensis.*

The growth of the species is interesting in the sense that after germination the seedlings will continuously die-back for a number of years before they grow into saplings, this is known as the suffrutex stage. This can continue for a period of up to 10 years before they eventually grow into saplings (Vermeulen, 1990). It however seems that only a few seedlings actually survive to sapling stage, about 4% of the seedlings on a 51 200 $m^2$ area in Tanzania survived past the seedling stage (Boaler, 1966 as cited in Vermeulen, 1990).

### *2.3.7 Schinziophyton rautanenii*

*Schinziophyton rautanenii* is a large deciduous tree that can grow up to about 25 m in height with a large trunk of about 1 m (Rønne & Jøker, 2006).

*Schinziophyton rautanenii* is a useful species in the local communities of the Kavango region. It occurs in several countries, including Namibia and its neighbouring Angola, Botswana, South Africa, Zambia and Zimbabwe (Rønne & Jøker, 2006). In Namibia it is found in the central north and the north eastern parts of the country on sandy soils (Mannheimer & Curtis, 2009).

Despite its socio-economic importance, its full value is not fully documented in Namibia (Graz, 2002). A recent video production was made for The Future Okavango (TFO) project and it highlighted the nutritional and economic value of the nuts of *S. rautanenii.* The species is noted to occur in mixed stands with other species such as *Baikiaea plurijuga, Burkea africana, Guibourtia coleosperma, Strychnos cocculoides*, *Terminalia sericea* and *Combretum species* (Graz, 2002).

The wood has a light wood about 210 kg/m$^3$ but it is considered to be strong and is used extensively for canoes, tools, carvings and many other items (Rønne & Jøker, 2006). The fruits are also a very important part of the plant that is used in many of the communal households to produce oils or eaten fresh and can be kept for up to 8 months (Rønne & Jøker, 2006). This means that *S. rautanenii* has the potential to help in the dietary needs of many of the rural communities for many months of the year. The fruits are considered to be a good source of Potassium, Thiamine and Carbohydrates (Rønne & Jøker, 2006). With a high percentage of the population in the region being rural and with a high unemployment rate (National Statistics Agency, 2012) any source of nutrients that can be acquired cheaply is important for these communities.

*Schinziophyton rautanenii* is noted to germinate well in sandy soils, with half shade and temperatures above 7 degrees Celsius and it reaches maturity for fruit production at around 20 to 25 years but this tends to be different in nursery conditions and the maturing age reduces to around 4 years (Rønne & Jøker, 2006).

Seeds are believed to maintain some level of dormancy for about 1 year or more (Rønne & Jøker, 2006). The structure of the seed makes it difficult for the seeds to germinate fairly easily, so if germination is to be enhanced, the woody endocarp needs to be removed and some pre-treatment is required to ensure germination, especially in nursery conditions. The species germination is however very unreliable but once it has occurred the seedlings do not need to be attended to (Rønne & Jøker, 2006).

The species is a declared protect species under the forestry legislation of Namibia (Graz, 2002; Mannheimer & Curtis, 2009). So by law the species should not be cut down, which is something that seems to be a regular occurrence as observed in the field.

### *2.3.8 Strychnos cocculoides* and *Strychnos pungens*

There are five different *Strychnos* species in Namibia but *Strychnos cocculoides* and *Strychnos pungens* have a wider range of distribution and are more common than *Strychnos madagascariensis*, *Strychnos potatorum* and *Strychnos spinosa* (Mannheimer & Curtis, 2009). This wider distribution range also means wider use potential by local communities. Because of the fact that these two are the same genus and are both used mostly for their fruits. *Strychnos cocculoides* and *Strychnos pungens* will be reviewed together.

*Strychnos cocculoides* is a small tree or shrub of 2-8 m high with a rounded crown (Orwa, Mutua, Kindt, Jamnadass, & Anthony, 2009). It is widely distributed in countries such as Botswana, Kenya, Namibia, South Africa, Tanzania, Uganda, Zambia and Zimbabwe (Orwa et al., 2009). In Namibia its distribution is in the northern and north eastern parts of the country within the dry woodlands of Namibia.

*Strychnos pungens* is also a small semi-deciduous (Mannheimer & Curtis, 2009) tree 6-8 m tall, with a grey brown granular bark, not corky and smooth on branches (Mwamba, n.d.) like that of *S. cocculoides.* It is found within a similar distribution range in Namibia.

*Strychnos cocculoides* is known to occur naturally in woodlands, mixed forests, deciduous woodlands and lowlands (Orwa et al., 2009). For the species to grow it requires climatic conditions of temperatures between 14 and 28 ℃ and average rainfall of 600 – 1200 mm (Orwa et al., 2009). This means conditions in Namibia's woodlands are conducive for the growth of the species. It is further noted to grow well on deep sandy soils that are well drained with pH levels of about 4-6 (Mwamba, n.d.). Species of the *Strychnos* genus are described as hardy, being able to survive in harsh conditions of poor soils and dry climates (Mwamba, n.d.). These are conditions that are also found within the study area. It has been observed that the *Strychnos* species are some of the species that are always left standing when areas have been cleared for crop farming. It is therefore expected to be abundant in disturbed areas such as crop fields and the abandoned crop fields.

Orwa et al. (2009) noted that the saplings of *Strychnos* species are sensitive to fire and competition from weeds and should thus be protected from such exposure, this was however noted for environments in which the species were semi cultivated. Mwamba (n.d.) also states that *Strychnos* species are semi cultivated in many countries, but their largest populations are in the wild. Individuals can be killed by fire but *S. cocculoides* regenerates readily from shoots or from seeds held onto the trees that have survived fire, it coppices easily from stumps and is described as being capable of fruiting after fire, saplings can be killed by fire but not trees (Mwamba, n.d.) meaning that fire has greater impact on the seedlings than on adult individuals.

Both species are favoured for their fruits, which are globose (1-7 cm in diameter), with a smooth hardy wood shell that is dark green to yellow when ripe (Orwa et al., 2009) for *S. cocculoides. Strychnos pungens*'  fruits are 5-10 cm in diameter, blue green turning orange or yellow when ripe (Mannheimer & Curtis, 2009; Mwamba, n.d.).

The *Strychnos* species  provide a nutritional service to the communities as they contain about 30% fat, 45% crude fibre, carbohydrate, citric acid and vitamin C (Mwamba, n.d.). *Strychnos pungens* and *Strychnos cocculoides* can be dried and in Namibia and southern Angola a strong alcoholic drink called “Kashipembe” is distilled from Strychnos fruits. A small enterprise was set up in Kavango in 1989 to develop this further (Mwamba, n.d.) but it has since then stopped operating.

The *Strychnos* species do not have good timber quality and their wood is therefore not highly exploited but is used on small scales for making basic tool handles and other small items (Mwamba, n.d.). They have however become an important cash crop (Mannheimer & Curtis, 2009) as their fruits are informally sold within the region and in other regions of the country . They also have some medicinal values as *S. cocculoides'* unripe fruits can be crushed in order to induce vomiting and *S. pungens'* leaves are used in reducing coughs (Mannheimer & Curtis, 2009; Mwamba, n.d.).

To increase the valuation of *Strychnos* species, domestication of *S. cocculoides* is under investigation in Botswana, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe by identifying suitable genetic variations (Mwamba, n.d.). This is a possible consideration for Namibia which might be helpful in enhancing the livelihoods of some of the local people and help extend the period of income generation from the sale of *Strychnos* fruits and products.

# 3. Study area

The study was carried out in the north eastern part of Namibia within the Kavango region. Officially the region was split into two regions in 2014, to form the Kavango East and Kavango West regions. For the purposes of this study, the two regions will both be referred to as the Kavango region as the study was well underway when the name changes were made and most of the existing literature or studies that refer to the area refer to it as the Kavango region

## 3.1 Location

Five sites were surveyed for this study, shown on the map in Figure 4. The sites are from west to east, the Kahenge Community forest, Katope community forest, Hamoye state forest, Ncaute community forest and the Mashare communal area.

Data were collected from 2013 to 2014. The 2013 data set was collected in the Kahenge and Katope Community forests in western Kavango (Figure 4) between the months of June and August while the 2014 data set was collected in Mashare, Hamoye state forest and Ncaute community forest in eastern Kavango during the months of May to September.

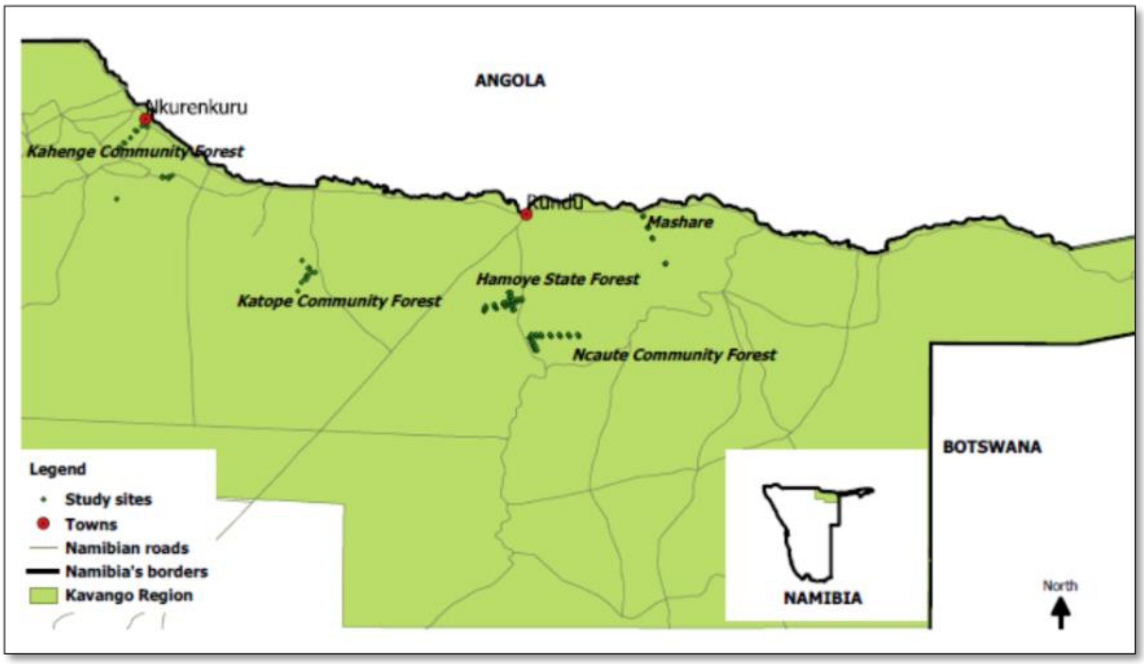


Figure 4: Location of the study sites in the Kavango Region in north eastern Namibia, the major towns of the region and the roads (primary and secondary).

## 3.2 Geology and soils

Most of the soils in the Kavango Region are eolian Kalahari sands which are considered poor in water retention and can easily be eroded (De Sousa Correira & Bredenkamp, 1986).. Most of these Kalahari sands are characterised by low Carbon and Nitrogen amounts making the soils nutrient poor (Groengroft, Luther-Mosebach, Landschreiber, & Eschenbach, 2013; Strohbach & Petersen, 2007)

The Omiramba or dry riverbeds on the other hand are categorized by soils that are slightly less acidic than the deep Kalahari sands, and they have a higher nutrient composition including Potassium, Phosphorus and Magnesium which renders them nutrient richer than the deep sands (Groengroft et al., 2013). This makes the soils along the Omiramba more favorable for growing crops than the deep sands of the interior. It can be observed in the study area that many people settle along the Omiramba (dry riverbeds). The land use practices in the area especially the slash and burn agriculture contribute to the loss of soil Carbon, during the conversion of woodlands to agricultural land, about 10-24 t. $ha^{-1}$ in the Namibian woodlands (Proepper et al., 2015).

### 3.3 Climate and weather

The climate in Mashare which is part of the Kavango region is described as that of a semi-arid area with an average temperature of 22.3 ˚C, with October being noted as the hottest month and July being the coldest month with temperatures of 26.2 ˚C and 16.2 ˚C respectively (Weber, 2013). Mean temperatures in the Kavango range between 22 and 25 degrees celsius (Figure 5). Frost can also be expected in the area especially in June (De Sousa Correira & Bredenkamp, 1986)

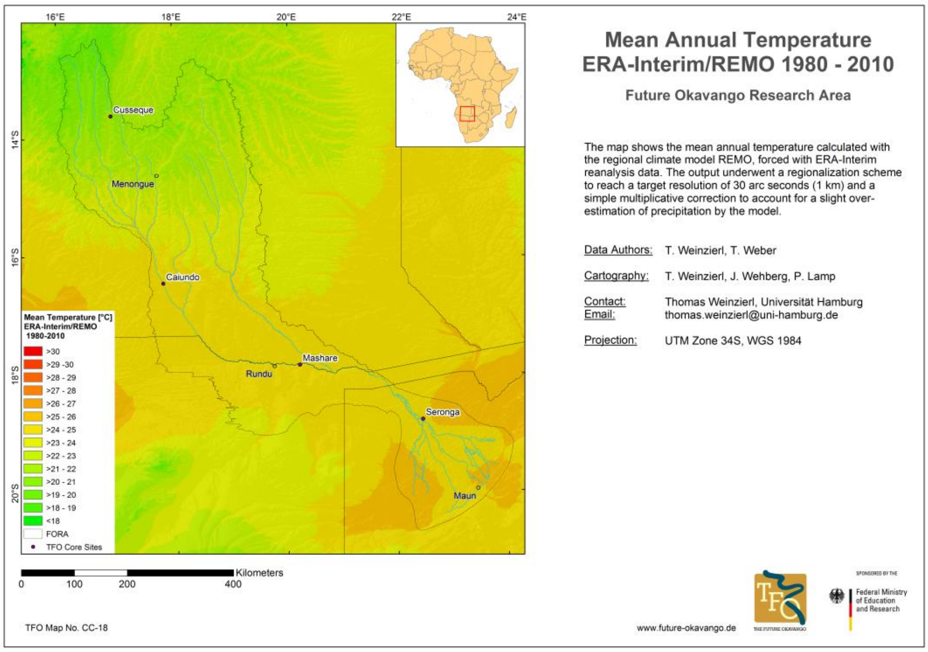


**Figure 5: Mean annual temperature for the period 1980-2010 for the Okavango basin which the Kavango is part of (Weinzierl, Wehlberg & Lamp, 2015)**

Rainfall in the area is mostly during the summer months, that is from October to April (De Sousa Correira & Bredenkamp, 1986), the Kavango region has a recorded mean annual rainfall of 571 mm for the period 1971 to 2000 (Weber, 2013). Figure 6 shows mean annual precipitation for the period of 1980 to 2010 which shows that the region only falls under two isohyets of rainfall.

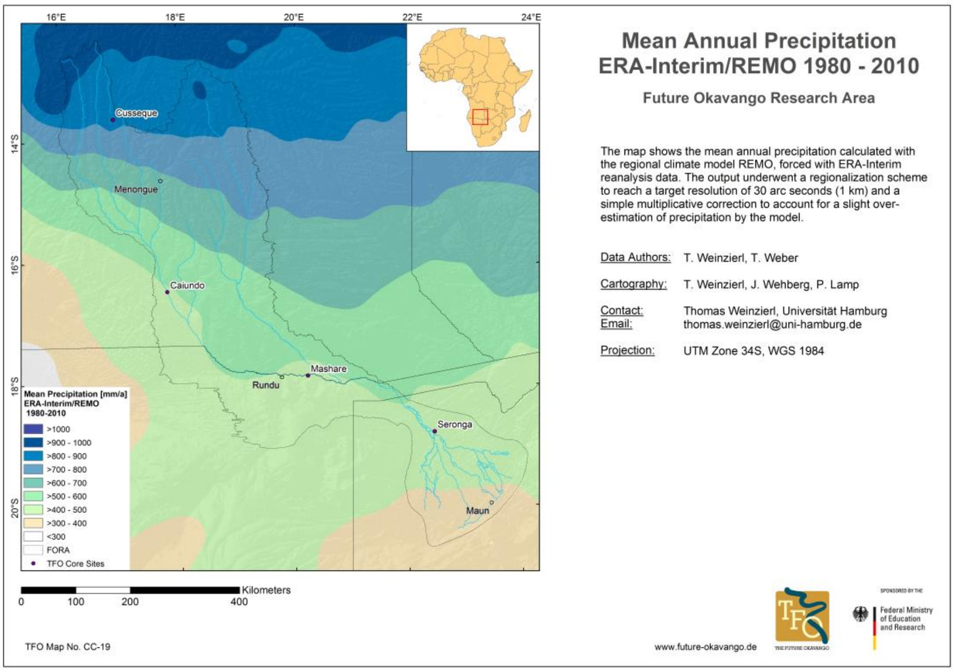


**Figure 6: Mean annual precipitation for the period 1980-2010 for the Okavango basin which the Kavango region is part of (Weinzierl, Wahlberg & Lamp, 2015)**

### 3.4 Vegetation description

Burke (2002) noted that the north eastern part of Namibia as being the only part of the country that has extensive woodlands. To highlight the importance of these woodlands (Geldenhuys, 1996) indicated the various resources available in these areas including, timber wood, grazing, wild forest product to mention a few. De Sousa (1986) mentioned the common species which are found in the Kavango and among these species were some of the focal species for this study such as *Baikiaea plurijuga, Schinziophyton rautanenii (Ricinodendron rautanenii) and Pterocarpus angolensis.*

The vegetation zone is the forest savannah and woodland on the map legend of Figure 7, as described by Giess (1971) with stands of characteristic tree and shrub species which include the six species which were assessed in this study. There are however several arguments on classifying the Namibian woodlands especially based on dominant species, Strohbach and Petersen (2007) suggest that the woodlands be called the Burkeo-Pterocarpetea.

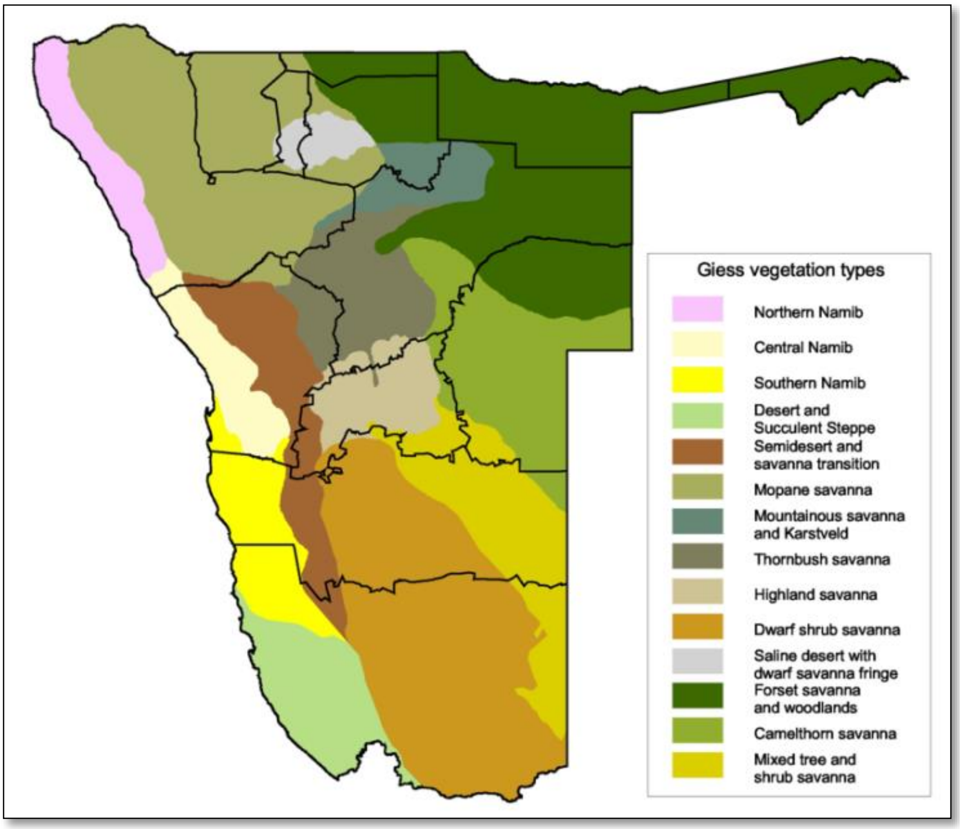


**Figure 7: The vegetation zones of Namibia after (Giess,1971)**

It is noted that the woodland communities are mostly influenced by disturbance, and slightly by aspect variations at sites (De Cauwer, 2013). A similar suggestion was made by Burke (2002) who noted that disturbance patterns and landform greatly influence vegetation types.

In a description of the Mashare vegetation De Cauwer (2013) described five different plant communities namely the *Baikiaea plurijuga-Schinziophyton rautanenii* community, the *Terminalia sericea* community, *Combretum psidioides* community, *Burkea africana* community and the *Pterocarpus angolensis* community.

Kanime and Kakondo (2003) highlight species like *Burkea africana, Pterocarpus angolensis* and *Guibourtia coleosperma* as the dominant species in the area. In the Katope community forest *Baikiaea plurijuga* is highlighted as the dominant tree species (Angombe, 2003). This inventory was however only based on three commercially important species including *Pterocarpus angolensis* and *Guibourtia coleosperma*. This highlights the distribution of these species across the Kavango region.

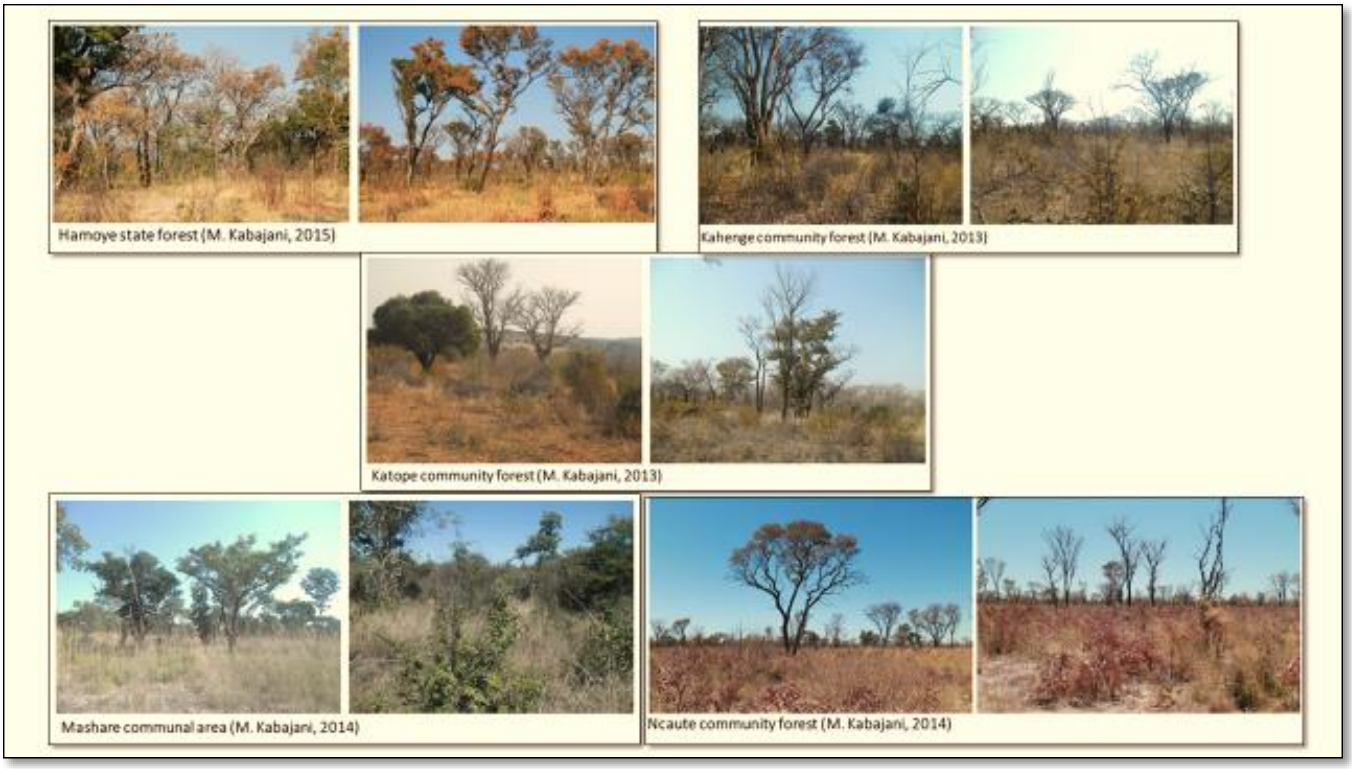


**Figure 8: Vegetation structure in the surveyed study sites. These are samples of what some of the areas look like especially in terms of vegetation structure.**

The general trend for vegetation in the different areas is average canopy cover ranging from 20 % in Ncaute to 34 % in Hamoye, as per this study's field data, with variations in vegetation structure (Figure 8). It's interesting to note that some areas such as Ncaute, are characterised by a dominant shrub. In a report for the mapping of natural resources for the Kavango, it was deemed difficult to map what is termed as potential natural vegetation because of disturbances or external influences mostly caused by humans (Burke & Simmonds, 2000).

### 3.5 Human dynamics

Population growth in the Kavango is at an annual rate of about 1% (National Statistics Agency, 2012), this is believed to be influenced by the influx of people from southern Angola since the 1970s (Ministry of Lands and Resettlement, 2010). According to the latest census report of 2011, the Kavango region has a total population of 223 352 people with 71% of this number living in rural areas (National Statistics Agency, 2012). Such a large population in rural areas means a strong dependence on natural resources for daily sustenance with 84% of the population noted to be dependent on wood or charcoal for cooking (National Statistics Agency, 2012). Figure 9 shows that people are mostly distributed along rivers and water courses, a sign of reliance on water availability to meet their daily needs, including the agricultural ones.

Life in Mashare is focused on subsistence agriculture with the Kavango River being the main source of water for the communities (Kowalski, Azebaze, Domptail, Groebe, & Proepper, 2013). In their study Kowalski et al. (2013) found that the majority of their sample size (88%) practise arable agriculture, highlighting the importance placed on agriculture by the local communities where there is a 50% regional unemployment rate, which is the highest in the country (National Statistics Agency, 2012). It is noted that a third of the population sell their excess produce to generate a cash income. The Census report indicates that 43% of the population in the Kavango region are engaged in farming activities as a main income source (National Statistics Agency, 2012).

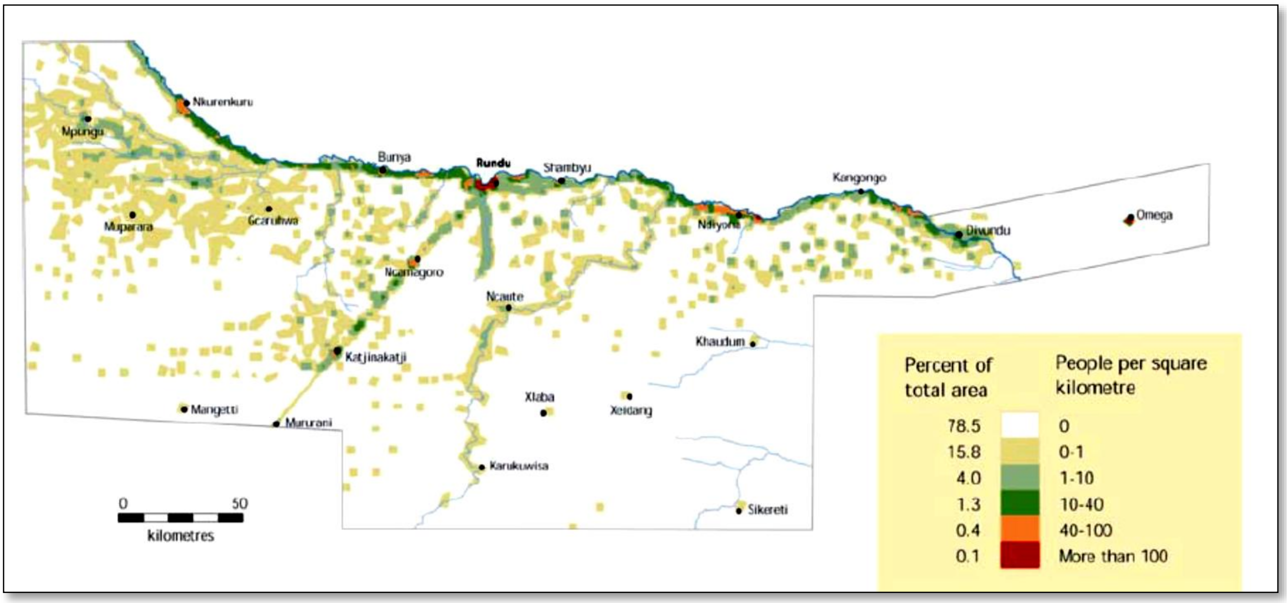


**Figure 9: The distribution of people in the Kavango Region. Map sourced from the Kavango land use planning framework (Ministry of Lands and Resettlement, 2010).**

### 3.6 Land use

According to the land use plan for the Kavango, about 80% of the area is reserved for agricultural activities. Agriculture is however not that lucrative especially the small scale farming mostly because of the poor quality sandy soils of the region (National Statistics Agency, 2012).

Most of the people inland from the river tend to settle along or close to the Omiramba (Otjiherero for dry riverbeds) these are characterised by better soils for agricultural activities (Groengroft et al., 2013). This is concurred by Burke (2002) who also described a scenario where Omiramba are used as main access routes for agricultural areas in the Kavango. Agriculture is an important sector as has been indicated in the above section with both small and large scale agricultural activities being exercised in the region. Strohbach & Petersen (2007) highlight the two important land uses in the region as being crop and livestock farming.

Based on a collaborative initiative with the German Development Services (DED) several community forests were established in the early 2000s with the first 13 community forests being gazetted in 2006. This was done in a bid to improve and ensure sustainable and equitable use of natural forest resources (Benkenstein et al., 2014). The region also has a number of other conservation areas such as communal conservancies and national parks. Most of the land in the north eastern part of the country is noted to be under traditional and subsistence agricultural use (Barnes et al., 2010).

Based on the forestry act of 2001, communities were given the mandate to establish manage and use forest resources and areas to derive benefits for their communities in order to improve their livelihoods (Benkenstein et al., 2014)

The focal point of the study was to look at natural regeneration; it was however a challenge to find pristine forests or woodlands in the study areas that could give a clear indication of natural regeneration in an undisturbed system. The sites for the study were therefore selected based on accessibility, land use and some on distance gradients in an effort to investigate natural regeneration in various conditions. Although the differences in these study sites were not considered as direct influences the minor variabilities in terms of land use, management, fire frequencies, distance to roads, settlements and rivers were used to determine indirect influences. The areas that were sampled were different in terms of management; including a state forest (Hamoye) gazetted community forests (Kahenge, Katope and Ncaute) and an open communal area (Mashare). Although this was not a factor used to select the different study sites it was also used to an advantage to investigate the possible impacts that different land uses could have on natural regeneration.

# 4. Materials and methods

## 4.1 Sampling design

A systematic-random design was used for the sampling. An array of plots were systematically mapped out beforehand and a selected number was surveyed by randomly locating them in the field and then following the arrangement of surveying three of them along a short transect. Figure 10 shows the locations of the sample plots in the different areas and also gives an illustration of the distribution of the sites within the region. Table 3 shows the number of plots sampled in each area and the months and year in which sampling was done.

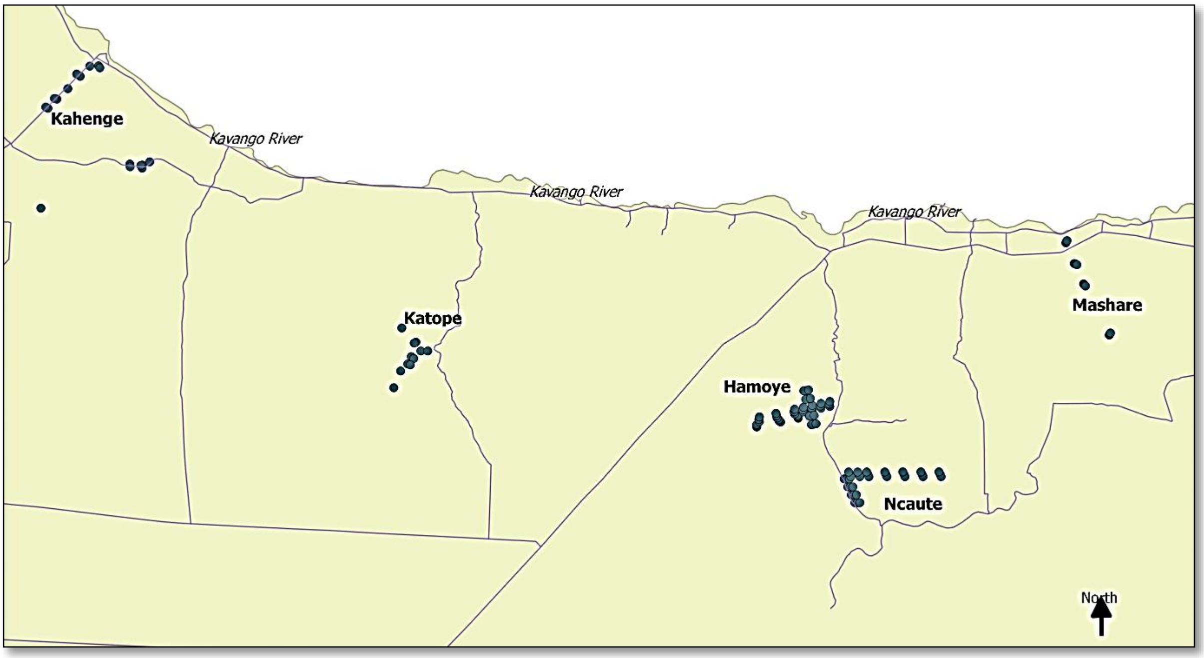


Figure 10: The location of the sample plots in the different study sites. Note the location of the sites ranging from far west at Kahenge and eastwards to Mashare.

The number of plots varies in the study sites as a result of different sampling intensities. The Kahenge and Katope plots were sampled in 2013 as part of an honours student project. Hence the dates and smaller number of plots in the areas.

Table 3: Summary of the number of inventory and regeneration plots sampled in the different sites for this study and other studies, whose data were used for analysis and interpretation.

| **Area** | **Sampling dates (month and year)** | **Total number of inventory plots** | **Number of 5 m radius regeneration plots** |
|---|---|---|---|
| Hamoye | May, August and September 2014 | 45 | 57 |
| Katope | August 2013 | **12** | **12** |
| Kahenge | June and August 2013 | 16 | 16 |
| Mashare | May 2014 | 12 | 24 |
| Ncaute | August and September 2014 | 33 | 33 |
| **TOTAL** | | **118 inventory plots** | **142 regeneration sub-plots** |

It is vital to clarify at this point that accessibility to different areas played a role in site selection. Doing research in a vast area such as the Kavango Regions, it is important to realize that a lot of time can be lost in simply getting to the sampling plot. This study therefore took a biased decision in this regard and ensured that not too much time was lost in locating plots, but that it was spent on actual sampling.

At each of the points three plots were placed in a line, about 140 metres away from each other's central points (Figure 11). The plots that were sampled in 2013 only had two plots per transect and not three as depicted in the figure.

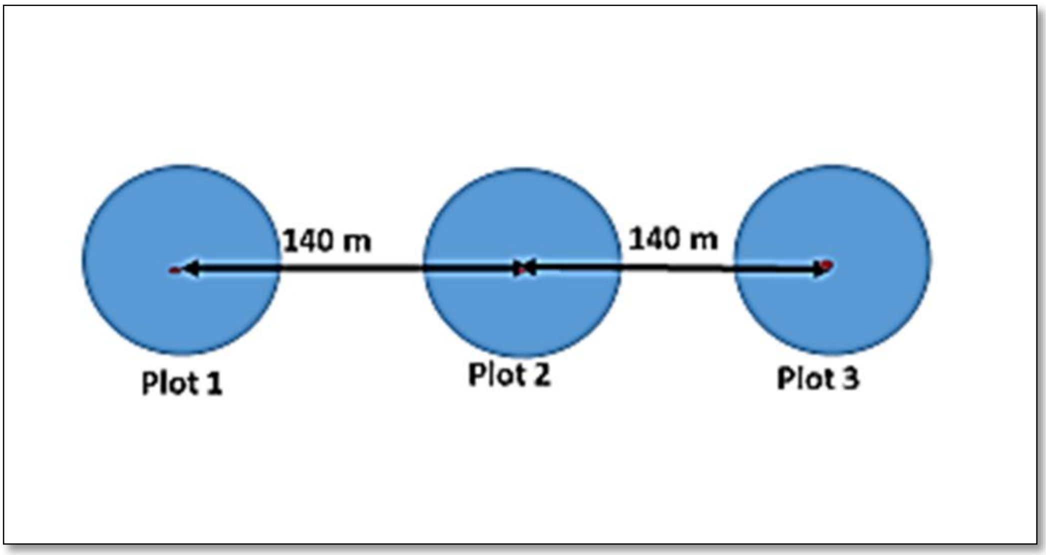


**Figure 11: An illustration of the plot arrangement and distances between sample plots. The distance between the plots, is actually from the plot centre of the first plot to the centre of the next plot, and so forth.**

## 4.2 Plot design

The plot design was that of a concentric circular plot of 30 m radius (area = 2 827 m$^2$) was used (Figure 12). This method was adapted from the national forestry inventory (Burke, Juola, & Korhoneni, 1996) but modified for this study. A study in the 1970s by Geldenhuys used a similar method using a 30 m radius plot (Geldenhuys, 1977).

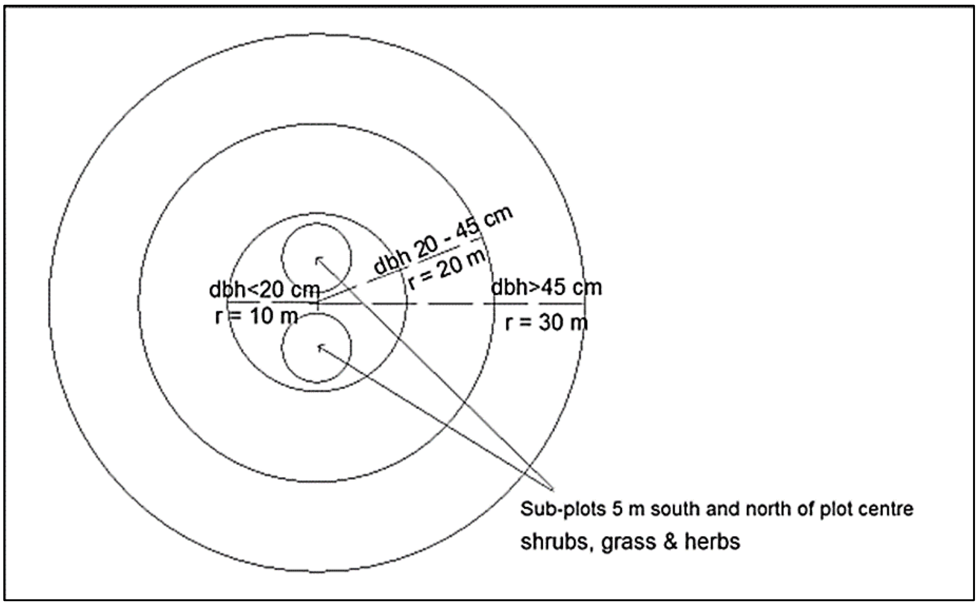


Figure 12: Sample plot design that was used for this study (Burke et al., 1996).

Concentric circular plots are considered better than square plots as they reduce the potential skewing of the boundary lines by obstacles (Kuru, Thorp, & Ata Marie Group Ltd, 2015). They are moreover considered as appropriate for dry forests as the vegetation is open and they are easy to set up in open forests than the rectangular plots which are more feasible for dense forests (Müller & Nyambe, 2015). This makes the use of concentric circular plots in the Namibian woodlands a practical approach. Each of the concentric circles was used to sample different variables as outlined in the following sub-sections.

### 4.2.1 Thirty meter (30 m) plot radius

The 30 meter plot radius was used to measure the biophysical data and stand description for the plot. The stand description of each plot was a descriptive of the conditions within the radius of the plot or the immediate surroundings of the plot. The geographical location and the elevation of the plot were taken using a Geographical Positioning System (GPS) unit. The stand description included descriptions of land type, land use, vegetation cover, anthropogenic and environmental influences on vegetation, as outlined in the NFI guidelines (Burke et al., 1996). Within this plot, only trees with a Circumference at Breast Height (CBH) of more than 141 cm equating to a Diameter at Breast Height (DBH) of more than 45 cm were measured (see Appendix A for field datasheet outlining all variables recorded).

### 4.2.2 Twenty meter (20 m) plot radius

Within this plot radius trees with CBH between 62.8 cm and 141 cm which is DBH between 20 and 45 cm were surveyed. The diameter at breast height of each individual tree within the category was measured. The trees were all identified to species level.

### 4.2.3 Ten meter (10 m) plot radius

Within this radius of the plots individuals with a CBH between 15.7 cm and 62.8 cm (equating to DBH between 5 cm and 20 cm were measured. For all these individuals the diameter of each was measured and each individual was identified to species level. For all trees measured within the three plot radii, other variables such as height, timber quality and more were recorded (see Appendix B for data sheet listing recorded variables)

### 4.2.4 Five meter (5 m) plot radius

The two subplots that were used to measure the seedlings and shrub data. The two subplots were placed in a north to south direction (Figure 12). All individuals with a DBH of 0-5 cm were counted in these plots. These were tallied into different height classes and were used for the seedlings assessments (see Appendix C). The sub-plots were placed in a north-south direction within the plot.

## 4.3 Density and size classes of seedlings.

The size classes of the regeneration were assessed using height classes within the 5 m radius sub-plots. This was done by using a PVC or collapsible ruler (Figure 13) pole and then tallying into height classes (0-50 cm, 51 – 100 cm, 101 – 150 cm, 151 – 200 cm, 201 – 250 cm, 251 – 300 cm, greater than 300 cm) used by the NFIs (Burke et al., 1996). For the purposes of this study all individuals with a DBH less than 5 cm were not considered as trees and were therefore sampled as regeneration if they occurred in the 5 m radius regeneration sampling sub-plot. It is considered practical to have a minimum DBH that can be included in regeneration surveys as a cut off point for seedlings (Hardwick et al., 2000).

In this study, individuals with a DBH of less than 5 cm are referred to as seedlings while individuals with a DBH of 5-10 cm were referred to as saplings and all individuals with a DBH more than 10 cm were considered as trees. The seedlings ranged in height from < 1 cm to more than 300 cm. Other studies have used such classification but in other cases they have classified individuals of 5 cm DBH as saplings (Tabuti, 2007).

Figure 13: Measuring seedling height using a 5 m collapsible ruler (Photo: N. Baptista, 2014)

The density of the regeneration was obtained by using the number of individuals counted in each of the plot and then transforming it by multiplying with an expansion factor of 127.3 based on the 5 m radius of the sub plots. This transformation then gave the number of seedlings per hectare.

To further assess the distribution of regeneration within the different areas, the regeneration occurrence was determined. This is a percentage indication of the number of plots in which a species regeneration occurs out of the total plots. This provides an indication of the distribution of the species regeneration across an area and is considered a better indication than density, since density can be dominated by large numbers from one plot. In short the regeneration occurrence is derived from the following formula.

***Regeneration occurrence = number of plots containing regeneration of species A / Total number of plots sampled in survey area * 100***

This can be altered and done for the overall area or calculated by study site. In this case it was done for both the study sites and the overall area

## 4.4 Diameter class distribution and regeneration status of valuable woody species

Because the sub-plot to assess regeneration was only a small portion of the sample plot, hence only providing a snapshot of the regeneration. The regeneration is also a sensitive growth stage as individuals can be affected by browsing, fire, land clearing or go into the suffrutex stage. This means that regeneration individuals might be existent in one season and non-existent during the following season. It is with this in mind that the DBH measurements were very crucial in this study. Within each plot, the individual trees were identified to species level and the DBH of each individual stem with a DBH of more than 5 cm was measured using a diameter or measuring tape (Figure 14). This DBH group was classified as saplings (5-10 cm) and trees (>10 cm).

**Figure 14: Measuring DBH on a *Pterocarpus angolensis* tree with a diameter tape, note fire damage to the tree's bark.**

The DBH was measured at a height of 1.3 m which has been set as an international standard. Provision was however made to deviate from this height in cases whereby an abnormality occurred but under the following circumstances the standard 1.3 m was still applied

1.) The tree had two stems and the split of the branches was below 1.3 meters, these were measured as two stems
2.) The split of the two stems was above 1.3 meters; these were measured as one stem.

This approach was also used by Wiafe (2014) in his regeneration study in tropical rainforests of Ghana. He however considered the two stems as separate trees and not just stems while this study considered them separate stems an approach that is also considered by DBH measurement approaches (see Figure 15) in some manuals (Burke, Juola, & Korhoneni, 1996; Kuru et al., 2015).

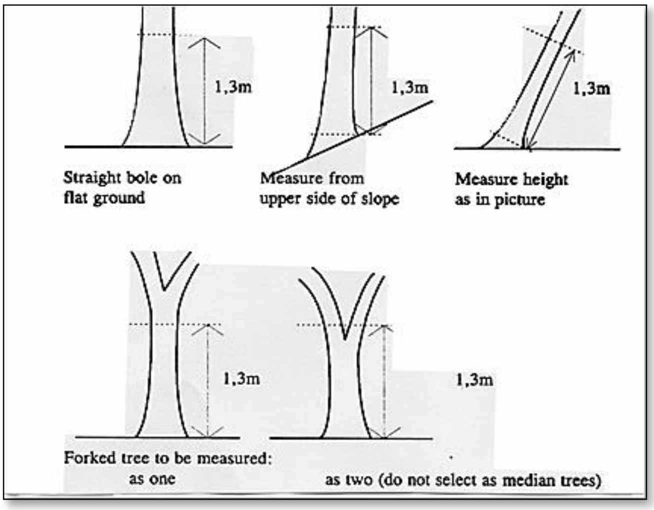


Figure 15: DBH measurement guidelines as outlined by the NFI guidelines (Burke et al., 1996) which were used for this study.

By assessing the diameter distributions of the species it can be seen whether a population has enough recruitment (regeneration) or not and further determine the stability of the population. Several aspects can also be inferred from diameter distributions, including growth requirements, past disturbances, future trends, population status, recruitment and survival chances of recruits (Adou Yao et al., 2011; Oni, 2013; Tom-Dery, Schroeder, & Struwe, 2014).

Once again the densities of the species were obtained by using the expansion factors as indicated in **Error! Reference source not found.**.

Table 4: The expansion factors used for the different plot radii and DBH to attain densities for the trees.

| Plot radius (m) | DBH class (cm) | Plot area ($m^2$) | Expansion factor (individuals/ha) |
|---|---|---|---|
| 5 | 0-5 | 78.54 | 127.3 |
| 10 | 5-20 | 314.16 | 31.830 |
| 20 | 20-45 | 1256.64 | 7.958 |
| 30 | >45 | 2827.43 | 3.537 |

Maingi and Marsh (2006) however caution the use of diameter distribution as indicators of age, based on the fact that a positive relationship is necessary for the stem-size and age of a population. They further highlight the need for determining the amount of time it would take a tree to growth through all size classes (Ogden, 1981 in Maingi and Marsh 2006). But variation is bound to occur in such cases, depending on growth conditions and species.

## 4.5 Mode of regeneration for valuable woody species.

To determine the mode of regeneration it would be ideal to distinguish seedlings from resprouts. This is however a difficult distinction to make especially when non-destructive sampling methods are employed. The best way to be able to distinguish between seedlings and resprouts is by excavating or digging the roots to ascertain the regeneration mode especially for those individuals that are not clearly attached to parent plants or stumps (Busby et al., 2010; Kruger et al., 1997). However for this study, all efforts were made to avoid causing damage to the recruits, so a PVC pole that was used to measure the heights of the seedlings was used to poke to a certain level on the base of each individual. The individuals that had regrown from a previously grown root had a bump at the point where the old growth stopped, this was the deepest point that the pole was poked. This was then used to assess which mode of regeneration was more prevalent for the species. This however also proved to be a challenge especially in the dry season as soils had hardened and the pole could no longer penetrate. This was therefore aborted as a regeneration mode determinant as it was only done for the 24 plots that were sampled in May 2014.

For all the sampled tree and sapling individuals (> 5 cm DBH) it was noted if the individuals in the plots were multi stemmed and if so, how many stems there were. This gives an inferred indication of whether the individual grew from a seedling or from coppice (Kruger et al., 1997) which some studies consider to be a result of disturbance (Gandiwa, 2011; Ncube & Mufandaedza, 2013; Ye et al., 2014). It is suggested that individuals growing from coppice often end up being multi stemmed and those that grow from seedlings are mainly single stemmed (Kruger et al., 1997). This was then used as a proxy to infer resprouting as a regeneration mode for the species. However it was only assessed for the four crown species which are *Baikiaea plurijuga*, *Burkea africana*, *Pterocarpus angolensis* and *Schinziophyton rautanenii* and not for the two *Strychnos* species. The two *Strychnos* species were excluded from this assessment due to their shrub like growth form and the fact that they are not used as a timber species.

By assessing the proportion of single and multi-stemmed individuals for each species in the different areas, the probability of the species to have resprouted were determined.

## 4.5 Factors that influence natural regeneration of valuable woody species.

The biophysical aspects of the plot as indicated above were used to determine the effects or relationships that any of them had on the regeneration of species in the plots. The distance effect of rivers and water bodies, settlements and roads, fire frequency and other disturbances were vital in this regard. This was used to assess whether regeneration of species increases or decreases with distance from rivers, settlements or Omiramba, and so indirectly from human impact.

For this, some terrestrial assessments, remote sensing and Geographical Information Systems (GIS) data were used to obtain the different data for the variables under investigations. These are described in the next sub-sections.

### 4.5.1 Fire

Fire frequency in this study refers to the number of times there has been a fire in a plot. GIS data were used for this. MODIS data for the years 2000 to 2013 were used to assess the influence of fire frequency on the seedling densities in the study sites. The fire frequency in this case was the number of years that an area had burnt during the 13 year period. Based on the data set that was used for this study one value was given per plot for each of the recorded years regardless of whether there were two fires in one year. The fire frequency data were therefore not spread out by the months of the year to stipulate several fires in one year. If fire occurred in several months of one year, it was simply considered as an occurrence of fire for that particular year.

The fire gap was also related to seedling densities, the fire gap in this case was defined as the longest duration in years, that an area or in this case a plot did not burn. Similar to fire frequency, the available data set gave a single value per plot during the recorded period. It is worth noting that it is not just a sum of all the years that had no fires recorded but the number of gaps in years in which there was no fire. For example if a fire occurred in Plot 1 in the years 2000, 2004 and again in 2013. Its longest fire gap without fire is 9 years.

MODIS Burned Area (BA) data were used to derive the number of years with fire for each sample plot. These data sets were derived by Stellmes et al. (2013) of the University of Trier in Germany. The BA product is considered a reliable data source as it shows the change that is caused in spectral surface properties by the burning of fuels and the remaining residues of fires (Stellmes et al., 2013). The BA product has a 500 m spatial resolution and detects burn scars (Stellmes et al., 2013).

The MODIS data provided the number of fires that have occurred in each of the plots over the period 2000 to 2013. This was then used to relate to the current densities of regeneration for each of the plots. This gives an idea of how the past fire frequencies relate to the regeneration density.

The fire frequency data were further used to classify the frequencies into three categories listed below. An approach that was also used in a fire frequency and vegetation structure study done in the Hamoye state forest (Shoopala, 2008). The categories were used to describe the regeneration characteristics in relation to different fire frequencies. The following categories were used:

0 years of fire = none
1-3 years = low
4-7 years = medium

### 4.5.2 Vegetation cover

Vegetation cover was also assessed for each plot. Percentage covers were assessed for tree crowns, shrubs, grass, herbs and bare soil. Tree and shrub cover was assessed by using the variable plot method, commonly known as the Bitterlich method. This does not require plots or transects to be set out for measurements (Cooper, 1957). The observer basically uses a point as an assessment point; in this case the observer would stand in the centre of the circular sample plot and take the observations for canopy and shrub cover from there. The observer holds the Bitterlich gauge close to the cheek (Figure 16) and counts “all trees with a diameter larger than the cross piece” (Holck, 2008). The number of individuals was tallied by species. The number of individuals was later used to determine the percentage cover by using a predetermined formula for obtaining percentage cover depending on the dimensions of the device that was used.

Figure 16: Measuring vegetation cover using the Bitterlich gauge (Photo: R. Schulz, 2014)

Based on the dimensions of the gauge that was used for this study, the cover was determined by using the following formula:

***Percentage cover = N*5***

Where **N** is the number of individuals of a species that were counted within a plot and 5 is a constant based on the dimensions of the bitterlich gauge used in this study. In this case the distance or width between the two pins which was 33.54 cm.

To avoid a subjective assessment of shrub and grass cover, a line intercept method was employed. This method was used for the 24 plots that were sampled in May (Hamoye and Mashare) and the ones sampled in between August and September of 2014 (Hamoye and Ncaute). A measuring tape was laid in a straight line measuring 60 m across the diameter of the circular plot. Along each 60 m line, it was measured how much of the line was intercepted by, grass, forbs, shrubs, bare ground and dead wood. Each interception was recorded to the nearest 10 cm initially and then later on the distance along the line was simply recorded and used to obtain the percentage cover for each substrate on the line. This is visualised in Figure 17. This was however adjusted for the 24 plots that were measured in May of 2014, as they were only 20 m in radius, their lines were in the same way only 40 m long.

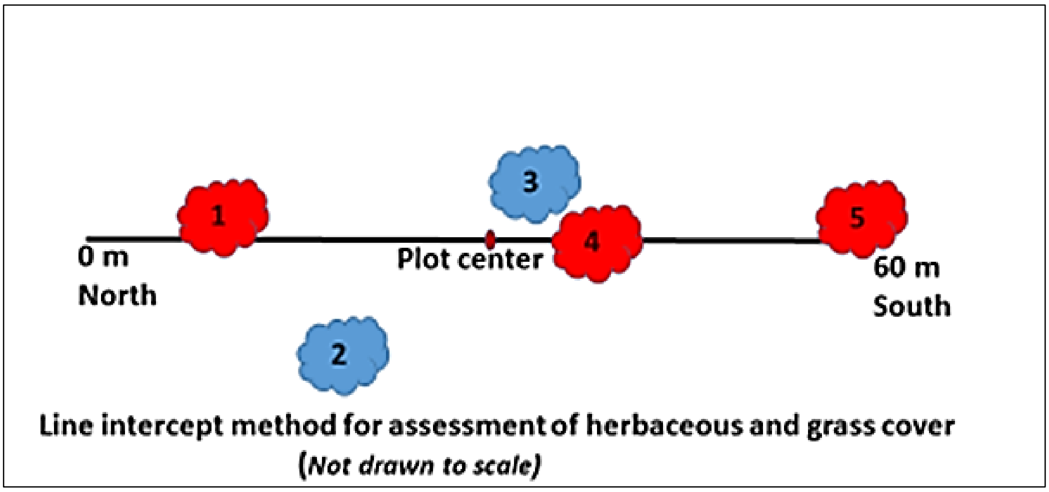


**Figure 17: A schematic diagram of the line intercept method that was used to estimate the grass and herbaceous cover within the plots. The red clouds symbolise plants whose extent along the line would be measured and the blue ones would not be measured as they do not at any point intercept on the line.**

### 4.5.3 Distance to rivers, roads and settlements

Distances to rivers and other water bodies, settlements and roads were derived using QGIS open source software. The derived distances were then used to assess the influence of distances on regeneration densities.

The distances to the settlements were derived by using the distance matrix analysis tool in QGIS. A specific distance was derived for each sample plot. Each plot fell within a certain buffer zone, which was a certain distance from the river or roads. This was then used to relate seedling densities to the buffer distance, providing a description of how distances to roads, rivers and settlements relate to the current surveyed seedling densities. The derived distances are provided in Appendix J.

The distance to the nearest roads was obtained through QGIS. This was done by rasterising the vector file of the roads to create 50 m by 50 m raster pixels. Then the proximity distance under the analysis tab was used to extract distances within a 20 km range.

## 4.6 Data analysis

### 4.6.1 Seedling density

Seedling densities were calculated by using the expansion factor (127.3) for the 5 m radius circle for each of the six valuable woody species within each of the five areas. These were then averaged for each species per site and were then used to plot the graphs for average density in Microsoft excel. A Shapiro Wilk's test for normality was used on the densities and they were all found to be not normally distributed where upon the Kruskal-Wallis test was used to test for differences in each species 'average density within the different areas. A post hoc test was run to determine between which areas these differences were observed. The findings were considered significant at the 95% confidence interval ($p<0.05$).The normality test and the test of difference were both done using the statistical software PAST (Hammer, Harper, & Ryan, 2015). In order to avoid type I errors which lead to an erroneous rejection of a correct null hypothesis ($H_o$) as a result of several hypotheses (Sop et al., 2011), the p-values were adjusted using the Bonferroni correction, in order to make provision for realistic p-values. The same was done for total species densities for the whole Kavango area.

#### *4.6.1.1 Regeneration occurrence*

The percentage occurrence for each of the five species within the five areas was graphically compared. An average occurrence percentage for each of the species was then computed for the entire study area. This was further compared with a Kruskal-Wallis test coupled with the post hoc Mann Whitney pairwise test to determine which species had different occurrence frequencies across the entire study area. This provided an idea of the proportion of plots that contained the regeneration or seedlings of certain species.

#### *4.6.1.2 Height class distribution*

In order to get an idea of the structure of the seedlings, the height class distributions were computed for each species in each area. The height classes from the sampling method (0-50 cm, 51-100 cm, 101-200 cm, 201-300 cm and >300 cm) were used in this part of the analysis. The Height structure of the regeneration was assessed by calculating the regression slopes for each species in each area following the method described by Sop et al. (2011), using the average density **($d_i$)** as the dependent variable and the midpoint of the height classes **($m_i$)** as the independent variable. The resulting regression slopes were then used to compare the height class distributions for the seedlings in the different areas.

### 4.6.2 Diameter class distribution of study species

The size class distribution (SCD) for the species within the different areas was analyzed by firstly allocating the diameters into 12 diameter classes with 5 cm intervals. These were then used to calculate ordinary least squares regressions (OLS) (Lykke, 1998; Mwavu & Witkowski, 2009; Sop et al., 2011) for each species in each of the five sites. The SCD slopes were computed by using the natural log (ln) transformed density of the size class (**$\ln(d+1)$)** as the dependent and the natural log transformed midpoint **($\ln(m_i+1)$** of each corresponding size class as the independent variable (Mwavu & Witkowski, 2009)**.** This was done to reduce the skewness in the data and to be able to plot more linear regressions for the SCDs. The natural log transformation plus one was to compensate for zero values in the densities. The obtained SCD slopes coupled with graphical representation of the diameter size classes were used to describe the population structures (Lykke, 1998; Mwavu & Witkowski, 2009; Sop et al., 2011; Traoré et al., 2012).

The SCD slopes of recruiting species with many individuals in small diameter classes are characterized by negative slopes, species with poor recruitment are characterized by flat SCD slopes close to zero (Condit, Sukumar, Hubbell, & Foster, 1998; Mwavu & Witkowski, 2009) and species that are dominated by more adult individuals are characterized by positive slopes (Mwavu & Witkowski, 2009).

#### *4.6.2.1 Seedling to sapling ratio*

By using the densities of the seedlings and the saplings. A seedling to sapling ratio was calculated for each of the species within the different areas and for the whole study area at large. This was done to infer the probability of survival from seedling stage to sapling stage. This was done by dividing the density of seedlings over the density of saplings i.e.

***Seedling to sapling ratio = (Density of seedlings for species A in area X / density of saplings of species A in area X)***

A species with a seedling to sapling ratio that is greater than 1 is considered to be a recruiting species. If it has a ratio that is less than or equals to 1 it is considered to have low recruitment (Mwavu & Witkowski, 2009).

### 4.6.3 Proportion of multi-stemmed individuals

A proportion of the multi-stemmed individuals was computed for each of the species within the different areas. The ratio was obtained by dividing the number of multi-stemmed individuals in a plot by the total number of individual trees in the same plot (Example under Appendix I).

Proportion of multistems = Number of trees with multistems in plot X / Total number of trees in plot X

This was further multiplied by 100 to derive percentages. These values were further averaged to give average proportions for each species in each site (Gandiwa, 2011).

### 4.6.4 Factors influencing regeneration density

To assess the influencing factors of regeneration, multi variate regression models were carried out on the density of each of the species across the whole area. Despite the general assumption that data has to be normally distributed to carry out a regression, the multivariate linear regression was used following an ordinary least squares approach, which is thought to be the best unbiased linear estimator. It was also used as the residuals of the seedling densities were not correlated to the independent variables. The seedling densities for the species were used as the dependent variables and modelled against the following combinations of independent variables:

1. Fire frequency and fire gap (fire)
2. Tree cover, shrub cover and herbaceous layer cover (vegetation cover)
3. Distance to the Kavango river, to Omiramba, to villages/settlements and to roads (Proximity measures)

This was done to assess for collective influences of the variables and also for each of the variables while controlling for the others. This was done in PAST.

# 5 Results

## 5.1 Seedling density

### 5.1.1 Density of seedlings in different areas

The average densities were computed for each of the species within the different areas of the Kavango region and for the total area of the Kavango as well. The average densities for the species in the whole area were found not to be significantly different (P=0.1) based on a Kruskal-Wallis test.

*Baikiaea plurijuga* was present in all five sites (Figure 18), with average densities ranging from 11.9 seedlings per hectare in Ncaute to 266.2 Seedlings per hectare in Mashare. From the Kruskal-Wallis test, it was found that there was a significant difference in *Baikiaea plurijuga* mean densities in the five areas (*p=0.005*).With this, the null hypothesis of no difference in *B. plurijuga* mean density within the sites is rejected. So the mean densities of *B. plurijuga* are different in the various sites. The Mann-Whitney pairwise post-hoc test showed that the differences were between Ncaute and Mashare (Bonferroni corrected *p=0.0006*) and between Ncaute and Katope (Bonferroni corrected *p=0.02*).

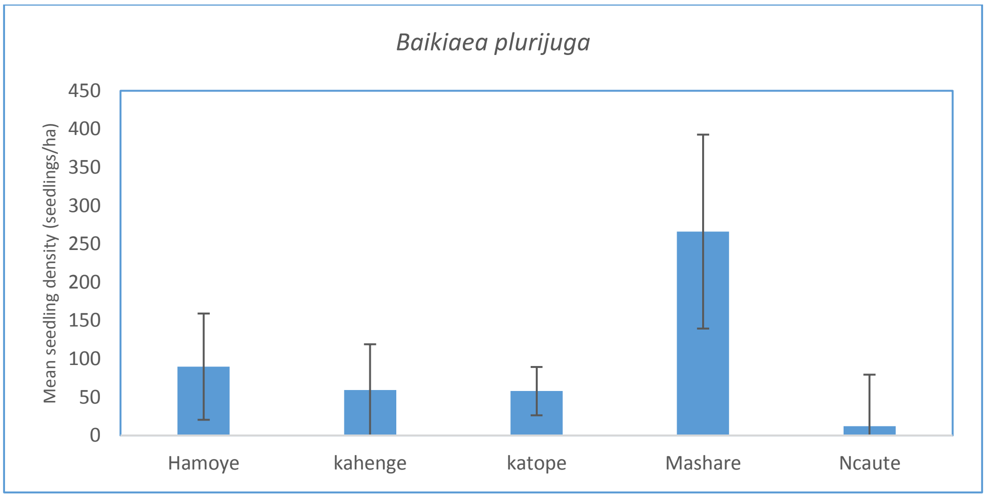


**Figure 18: Mean density for *Baikiaea plurijuga* in the different sites of the Kavango region (error bars are 5% standard error).**

The average densities for *Burkea africana* on the other hand ranged from 8.4 seedlings per hectare in Kahenge to 807.7 seedlings per hectare in Ncaute (Figure 19). The tests on the average density of *Burkea africana* in the different areas was also found to be significantly different (p=0.00001). Hence the null hypothesis of no difference in *B. africana* mean density is rejected, so the mean densities of *B. africana* are different within the various sites. The Mann-Whitney pairwise test with Bonferroni corrected p-value showed that the differences were between Hamoye and Kahenge (p=0.02), Kahenge and Ncaute (p=0.00006) and Katope and Ncaute *(p=0.008)*

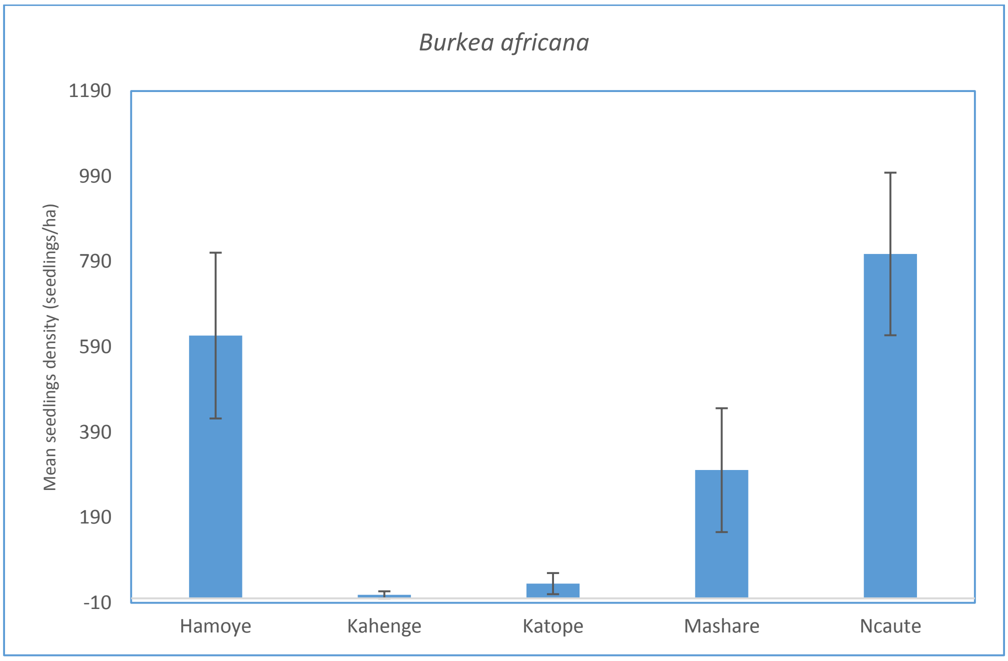


**Figure 19: Mean density of *B. africana* in the different areas of the Kavango Region (error bars are 5% standard error).**

*Pterocarpus angolensis* seedlings were found in all sites (Figure 20), even though its average densities were low ranging from 7.7 seedlings per hectare in Ncaute to 39.7 seedlings per hectare in Kahenge. These mean densities were found to be non-significantly different based on the Kruskal-Wallis test (p=0.92). Hence the null hypothesis is not rejected, suggesting that the differences in *P. angolensis* mean densities within the sites are not statistically significant.

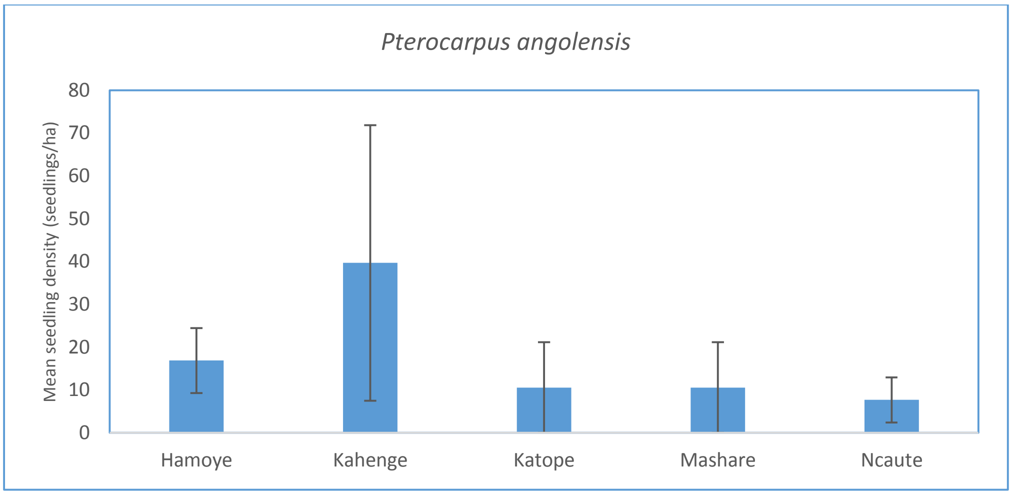


**Figure 20: Mean densities of *P. angolensis* in the different areas of the Kavango region (error bars are 5% standard error).**

*Schinziophyton rautanenii*'s average densities ranged from 25.5 seedlings per hectare in Hamoye to 128.4 seedlings per hectare in Katope. There was however an absence of *S. rautanenii* seedlings in the Mashare plots (Figure 21). The mean densities were found to be non-significantly different between the five areas (p=0.74). Similar to *P. angolensis*, the null hypothesis is not rejected.

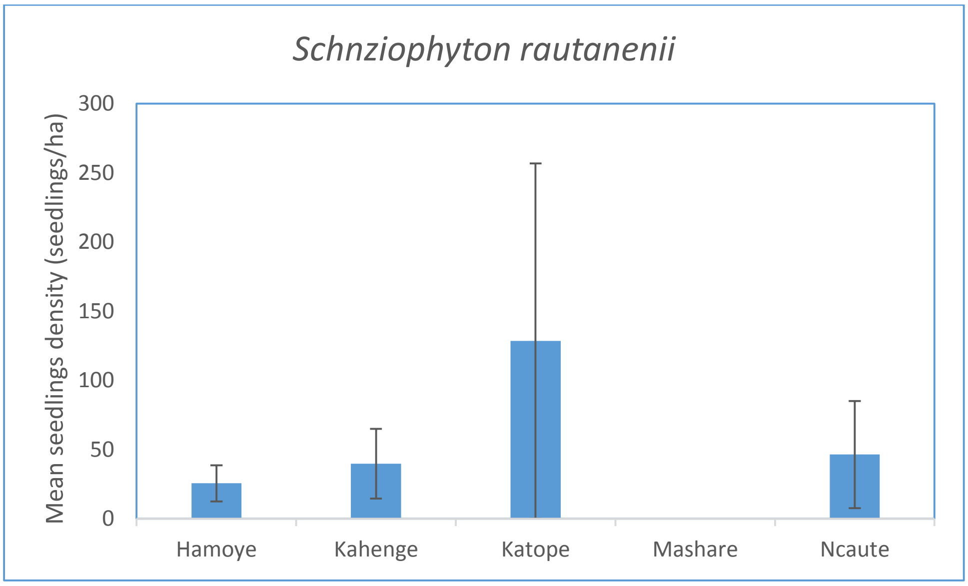


**Figure 21: The mean densities of *S. rautanenii* in the different areas of the Kavango Region (error bars are 5% standard error).**

*Strychnos cocculoides* only recorded seedlings in the Hamoye (mean = 87.7 seedlings/ha) and Ncaute (mean = 81 seedlings/ha) areas (Figure 22 left) and not in the other three sites. *Strychnos pungens* on the other hand recorded densities in all five sites (Figure 22 right) with average values ranging from 15.9 seedlings per hectare in Kahenge up to 223.7 seedlings per hectare in the Ncaute area. Based on the Kruskal-Wallis test, the mean densities of *S.cocculoides* were found to be not significantly different (p=0.99) while those of *S. pungens* were found to be significantly different (p= 0.000002). The null hypothesis is rejected for *S. pungens* implying that the mean densities for the species are different within the sites. The mean densities of *S. pungens* were then tested with the Mann Whitney post hoc test to determine in which areas the differences occurred. The post-hoc test showed that the differences were between Ncaute and three of the other areas including Hamoye (Bonferroni corrected p=0.00005), Kahenge (Bonferroni corrected p=0.005) and Katope (Bonferroni corrected p=0.04).

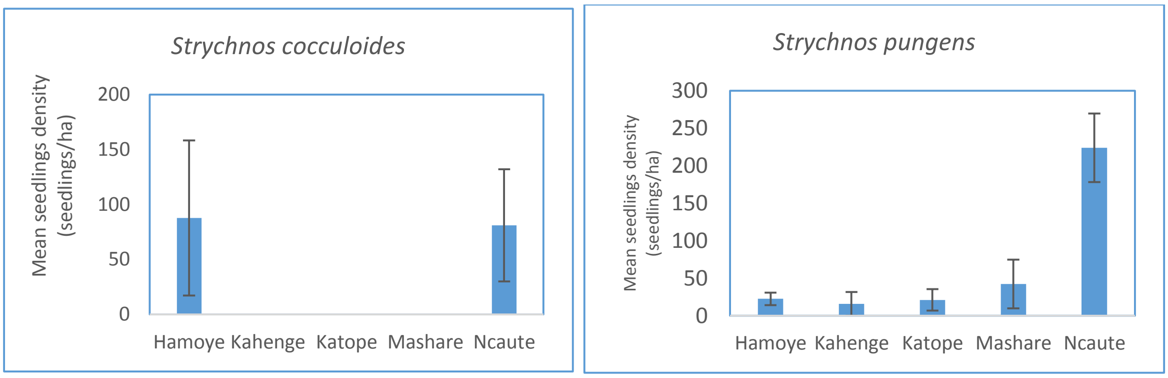


**Figure 22: The mean densities of S. *cocculoides* (left) and *S. pungens* (right) in the different areas of the Kavango Region (error bars are 5% standard error).**

The mean densities of three species (*B. plurijuga*, *B. africana* and *S. pungens*) were found to be significantly different within the study sites in the region. Due to the fact that density can be influenced by the presence of seedlings in one or a few plots, a seedling occurrence assessment was done to evaluate the probability of finding seedlings in the different sites.

### 5.1.2 Regeneration occurrence assessment

In order to get an overview of the distribution and the occurrence of the regeneration in the different areas and over the entire study region an occurrence test was done. This was to show the percentages of occurrence in the sampled plots within the different sites and further to highlight the percentages of all the plots in which the species regeneration occurred.

The results of this showed that *P.angolensis, S. rautanenii* and *S. cocculoides* in general had low frequencies of occurrence in the study sites occurring in less than 20% in all sites. Species like *B. plurijuga, B. africana* showed considerable occurrence percentages, occurring in 72% of the plots in Ncaute (**Error! Reference source not found.**). *Strychnos pungens* also recorded low occurrence values in four of the sites (less than 20% of all plots) except in Ncaute where it was found in 60.2% of all plots. The occurrence data were then collated to produce average values per species for the region.

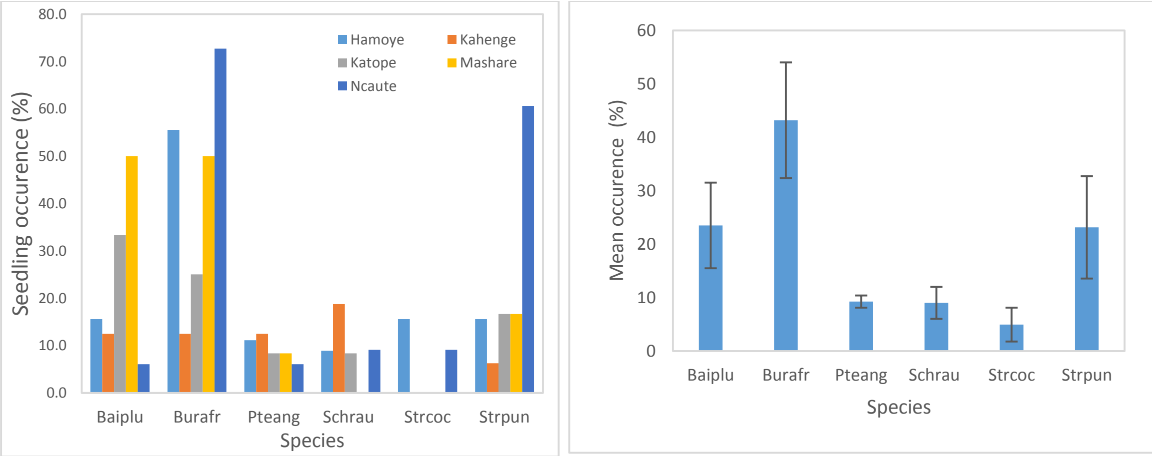


**Figure 23: The occurrence of seedlings of the selected woody species within the different areas (legend) and the average occurrence across the whole region, error bars are standard error (95%).**

From the collated data (Figure 23 right) it can be seen that *Burkea africana* seedlings seem to be more widely distributed, found in about 43% of the total number of plots surveyed followed by *Baikiaea plurijuga* (23.5%) and *Strychnos pungens* (23.1%). The species with the lowest occurrence percentages were found to be *Pterocarpus angolensis* (9.2%), *Schinziophyton rautanenii* (9.01%) and lastly *Strychnos cocculoides* (4.9%). To test for differences in the mean occurrence a Kruskal-Wallis test was run and it showed that there were significant differences in the mean percentage occurrence values for the species (p=0.04). The null hypothesis of no difference in the mean occurrence frequencies was therefore rejected. The Mann-Whitney pairwise post hoc test on the mean percentage occurrence values showed that the differences were between the following species:

| | |
|---|---|
| *Burkea africana* and *Pterocarpus angolensis* | (P=0.01) |
| *Burkea africana* and *Schinziophyton rautanenii* | (p=0.02) |
| *Burkea africana* and *Strychnos cocculoides* | (p=0.02) |
| *Strychnos cocculoides* and *Strychnos pungens* | (p=0.04) |

This shows that the regeneration study species have different occurrences percentages within the study areas, some species regeneration can be considered more abundant within the study area such as *Burkea africana* while others such as *Strychnos cocculoides* are not as abundant.

### 5.1.3 Height classes of seedlings

The seedlings were categorized into height classes in order to have an idea of how the species are distributed in terms of height classes. Appendix D shows the total density of each species in the different height classes for the different areas. It can be seen that the densities in the different height classes are variable, some species have representation in all height classes e.g. *Baikiaea plurijuga* in Mashare while some, such as *Strychnos cocculoides* are only represented by one height class (0-50 cm) in Ncaute. *Baikiaea plurijuga* and *Burkea africana* have higher average densities in most of the height classes compared to *Pterocarpus angolensis*, *Schinziophyton rautanenii* and the two *Strychnos* species. *Pterocarpus angolensis* had no recorded individuals in the 0-50 cm height class, the same with *S. rautanenii* which only had such record in Hamoye.

For the total Kavango area, *B. plurijuga*, *B. africana* and *S. pungens* show distributions that have more individuals in the smaller height classes and decrease towards the larger height classes (Figure 24). The other species, *P. angolensis, S. rautanenii* and *S. cocculoides* have distributions that are characterized by low average densities and trends with more individuals in the middle classes.

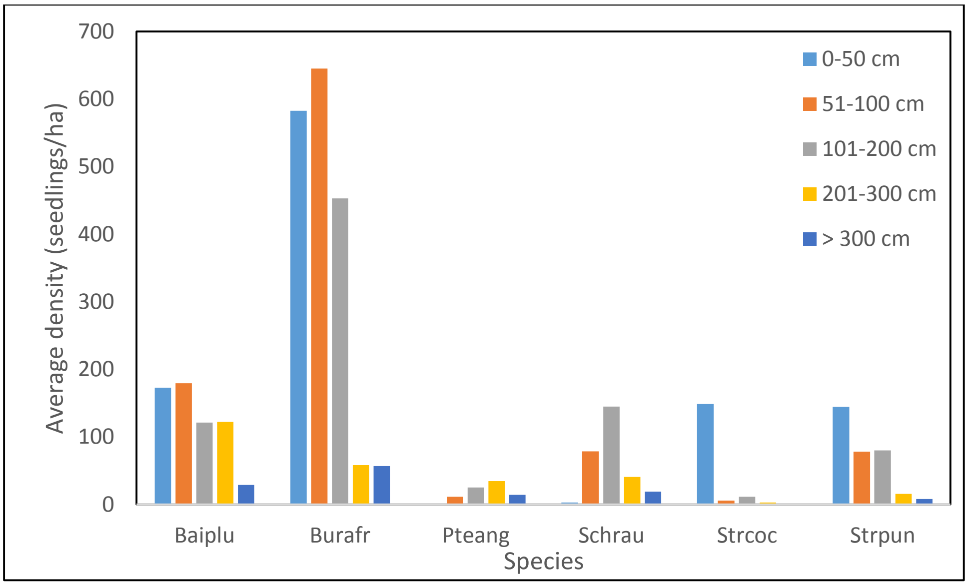


**Figure 24: The height class distributions using average density for the selected species in the different areas (Baiplu=*B.plurijuga*, Burafr=*B. africana*, Pteang= *P. angolensis*, Schrau= *S. rautanenii*, Strcoc= *S. cocculoides* and Strpun=*S. pungens*).**

The height class distributions were then determined from these densities and the HCD slopes, $R^2$ values and p-values were derived for each of the species across the Kavango study area and also for the different areas. Negative slopes indicate species that have more individuals in the shorter height classes and less in the taller height classes (Sop et al., 2011; Traoré et al., 2012). The regeneration structure gives an indication of the potential that the seedlings have to survive to the next life stage.

The HCD slopes for the total Kavango area, show that only *B. plurijuga*, *B. africana* and *S. pungens* have negative slopes (Table 5), although only *S. pungens* was found to be a significantly negative slope (p=0.05). This means it has a height structure of a recruiting population. *Pterocarpus angolensis,* had a significantly positive slope (p=0.04) which means it has a height structure with less individuals in the smaller height classes than in the larger classes.

**Table 5: Height class distributions for the study species, the HCD data were derived from the height classes of the study species.**

| Species | Slope | Intercept | $R^2$ | P-value |
|---|---|---|---|---|
| *B. plurijuga* | -0.92725 | 11.009 | 0.46484 | 0.2 |
| *B. africana* | -0.65604 | 9.9637 | 0.65149 | 0.09 |
| *P. angolensis* | 0.49057 | 4.1993 | 0.78485 | 0.04 |
| *S. rautanenii* | 0.36953 | 4.1289 | 0.30822 | 0.3 |
| *S. cocculoides* | 0.36953 | 4.1289 | 0.30822 | 0.3 |
| *S. pungens* | -0.71529 | 8.4086 | 0.7554 | 0.05 |

A considerable number of the seedling populations in the study areas had poor recruitment structures (positive slopes) and some had good recruitment structures (negative slopes), although only a few of them had significant p-values (Appendix E), notably *Burkea africana* in Hamoye (-0.008), Kahenge (-0.001), Mashare (-0.007) and Ncaute (-0.013) and *Strychnos pungens* in Hamoye (-0.001), Mashare (-0.002) and Ncaute (-0.008). These show a continuous representation of individuals in the height classes. This therefore symbolizes a recruitment pattern whereby individuals grow into the next height classes, unlike *P. angolensis* for example where the 0-50 cm height class is missing in all the sites.

## 5.2 Size class distribution of valuable woody species in the study areas

It is important to understand regeneration by focusing on seedling but in order to obtain the full picture of the population including past disturbances on the population it is important to look at diameter distributions.

The size class distributions for the species had negative slopes, showing that they have more individuals in the smaller diameter classes than in the larger ones. *Schinziophyton rautanenii* had positive slopes in Hamoye (0.2369) and Mashare (0.1147), which shows that the species had less individuals in the smaller diameter classes than the larger classes. This means a poor recruitment trend for the species within those sites

The species with the negative slopes show that they have good recruitment trends, indicating that there are more individuals with small diameters than those in the large diameter classes. The SCD slopes ranged from -2.8 for *Baikiaea plurijuga* in Kahenge to almost flat slopes of

0.2 for *Schinziophyton rautanenii* in Hamoye. Most of the species had significant negative size class distribution slopes, implying differences in the size classes for the species.

By looking at the diameter distribution for *B. plurijuga,* it shows the almost inverse j-shaped curve which is characteristic for species that have good recruitment (**Error! Reference source not found.**). Its curves for Kahenge, Katope and Hamoye, have small declines in the middle size classes and (between 20 and 30 cm) but then picks up at the 35-40 cm class. The areas with the largest size class for the species are Hamoye (32.7 trees/ha) and Katope (7 trees/ha) the rest have no individuals in the said class, in fact the largest individuals for Mashare were in the 35-40 cm diameter size class. The SCD slopes for the species are all significant negative slopes, implying recruiting populations except in Ncaute where the species was not recorded.

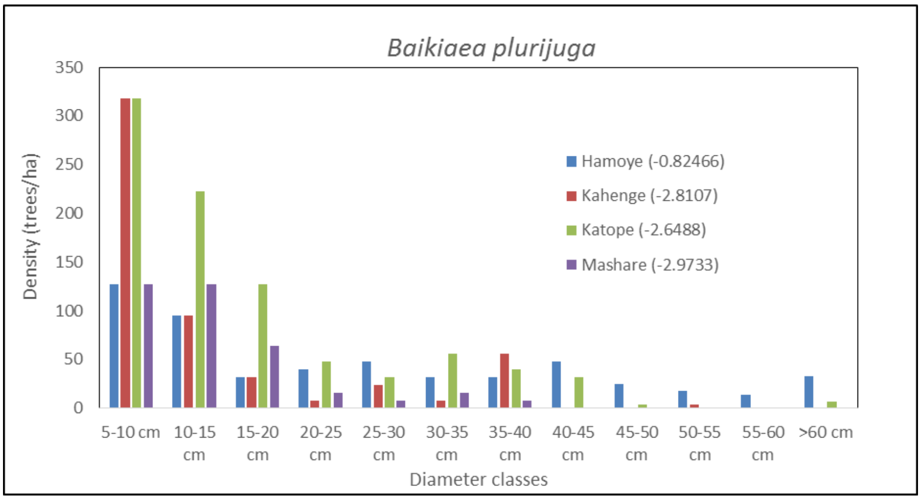


**Figure 25: The diameter distributions for *B. plurijuga* in the study areas, with diameter classes on the x-axis and density on the y-axis. The SCD slope values are also indicated in brackets next to each site name in the legend (only four areas or sites are graphed, due to the absence of the species in Ncaute).**

The diameter curves for *Burkea africana* exhibited the inverse j-shaped curves in Hamoye and Ncaute and a clearly declining curve in Kahenge while the other areas maintained low numbers in most of the size classes (**Error! Reference source not found.**). Its SCD slopes however indicated that the species is recruiting, all its slopes were significant for negative slopes ranging from -3.32 in Ncaute to -1.8 in Kahenge.

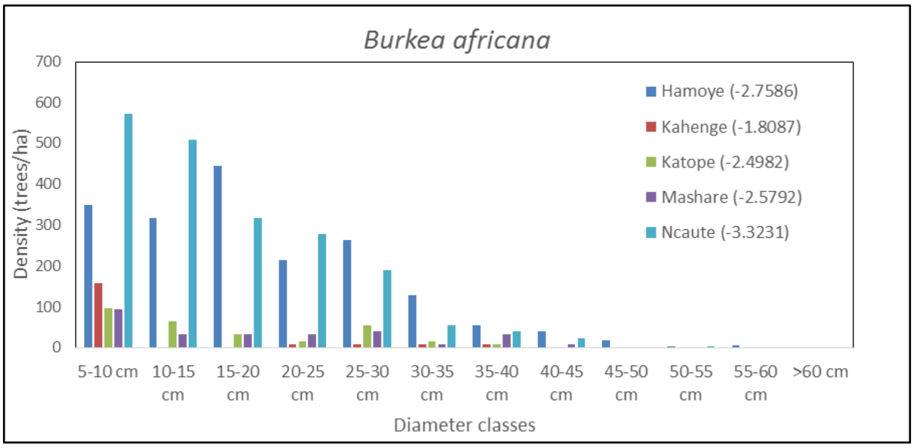


**Figure 26: The diameter distributions for *B. africana* in the study areas, with diameter classes on the x-axis and density on the y-axis. The SCD slope values are also indicated in brackets next to each site name in the legend.**

*Pterocarpus angolensis* also showed the inverse j-shaped curved for all sites although it showed a sudden increase in the 15-20 cm diameter class in Hamoye (Figure 26). The curve for Mashare had a gap between the 10 and 20 cm classes. While the Ncaute one showed a slight decline at the 10-15 cm size class but picked up again in the next class. The species' SCD slopes were found to be significant for negative slopes except for the Mashare one.

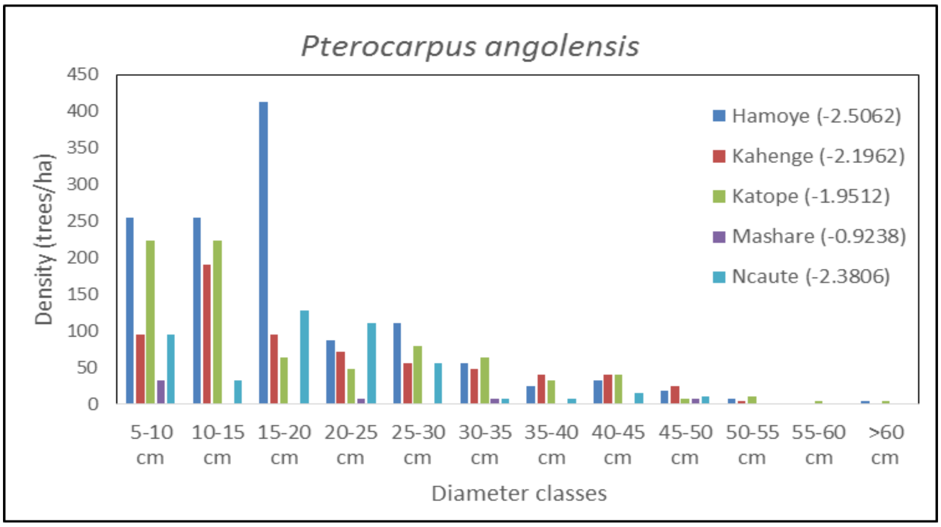


**Figure 27: The diameter distributions for *P. angolensis* in the study areas, with diameter classes on the x-axis and density on the y-axis. The SCD slope values are also indicated in brackets next to each site name in the legend.**

The curves for *S. rautanenii* were found to be patchy in most areas (Figure 27), with many gaps especially in the middle classes and then all areas had individuals in the 35-40 cm diameter class and some had no individuals beyond the said class. Only the SCD slopes for Katope (-1.74) and Ncaute (-1.41) were negatively significant implying recruiting populations where as Hamoye (0.23) and Mashare (0.11) had positive SCD slopes an indication of populations that had more individuals in the larger diameters than in the smaller ones (Sop et al, 2011; Mwavu and Witkowski, 2009).

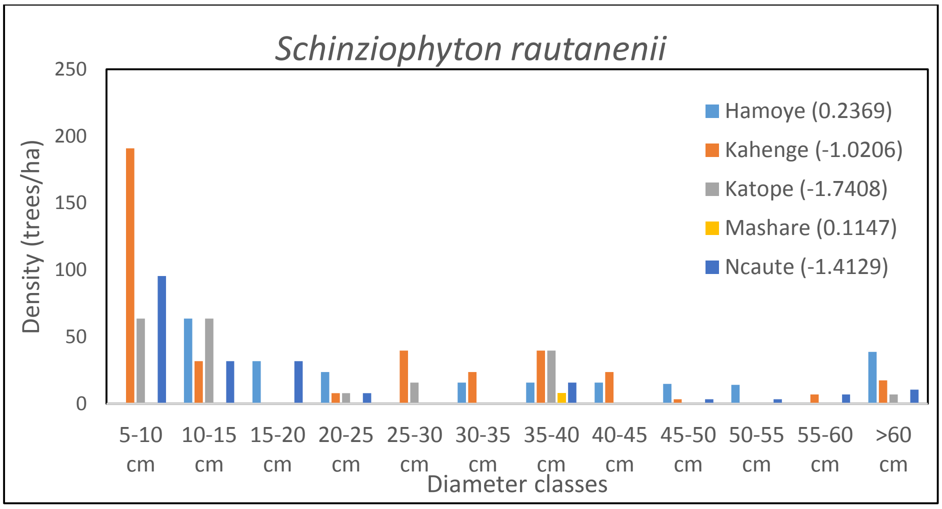


**Figure 28: The diameter distributions for *S. rautanenii* in the study areas, with diameter classes on the x-axis and density on the y-axis. The SCD slope values are also indicated in brackets next to each site name in the legend.**

Diameter distributions for *Strychnos cocculoides* were extremely patchy with no particular trend (Figure 28). The species only had individuals in the smallest diameter class in Kahenge. Hamoye was the only area that had individuals in all size classes and showed a slightly inverted j-shaped curve starting from the 10-15 cm diameter class. The SCD slopes for the species were however significant for negative slopes, ranging from -2.47 for Hamoye to -1.38 for Kahenge. This trend might be attributed to the presence of individuals in the smallest diameter class, which would be considered as an indication of establishment for the populations.

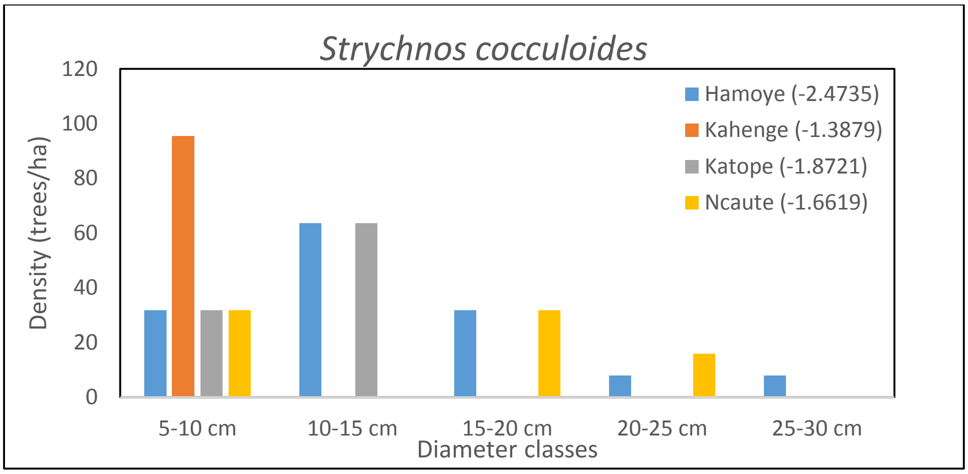


**Figure 29: The diameter distributions for *S. cocculoides* in the study areas, with diameter classes on the x-axis and density on the y-axis. The SCD slope values are also indicated in brackets next to each site name in the legend (note the four areas graphed, as a result of the species' absence in Mashare).**

*Strychnos pungens* (Figure 30) had diameter curves that were almost similar to those of *S. cocculoides.* The species exhibited a trend in Ncaute similar to the one of *S. cocculoides* in Hamoye (Figure 29). The species was not recorded in the Kahenge area. The SCD slopes for the species were significant for negative slopes, again this is a possible result of the presence of individuals in the initial size class of 5-10 cm. The slopes ranged from -3.084 in Hamoye to -1.06 in Mashare.

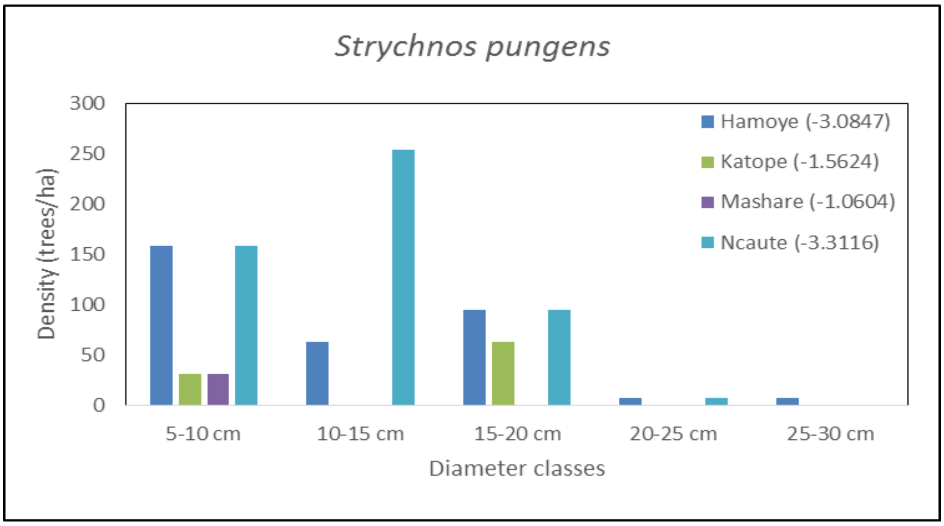


**Figure 30: The diameter distributions for *S. pungens* in the study areas, with diameter classes on the x-axis and density on the y-axis. The SCD slope values are also indicated in brackets next to each site name in the legend (note the four areas graphed, as a result of the species' absence in Kahenge).**

A Kruskal-Wallis test showed no significant difference (p=0.11) between the size class distributions for the six species within the 5 different areas of study. Therefore the null hypothesis of no difference in SCDs was not rejected. This means that the size class distributions of the species were not different in all areas.

### 5.2.1 Seedling to sapling ratio of the valuable woody species

To further have an idea of the survival of seedlings to the next growth stage the seedling to sapling ratio was assessed and this showed that most species had good transition ratios of more than 1 from seedlings to saplings (Table 6). *Strychnos cocculoides* was the only one that recorded three zero values in Kahenge, Katope and Mashare. These figures symbolise that even though some of the species have gaps in the height class distributions, the ratio of seedlings to sapling indicates that they have potential to survive to the next stage. While a species like *B. plurijuga* had an absence of saplings and this led to its high ratio. Although it's not definite that all seedlings will transition to sapling stage.

**Table 6: The seedling to sapling ratios of the of the six study species within the five different areas.**

| Area | Species | Number of individuals / hectare | | |
|---|---|---|---|---|
| | | Seedlings | Saplings | Seedling:Sapling ratio |
| **Hamoye** | *Baikiaea plurijuga* | 4456 | 127.32 | 34.9 |
| Kahenge | | 1145 | 318.3 | 3.5 |
| Katope | | 891.275 | 318 | 2.8 |
| Mashare | | 4329.05 | 127.32 | 34 |
| Ncaute | | 636.625 | 0 | 636.6 |
| | **Total** | **11457** | **890.9** | **12.8** |
| | | | | |
| Hamoye | *Burkea africana* | 27502 | 350.13 | 78 |
| Kahenge | | 270.6 | 159 | 1.7 |
| Katope | | 1103 | 95.49 | 11.5 |
| Mashare | | 3862 | 95.4 | 40.5 |
| Ncaute | | 26761.4 | 572.94 | 46 |
| | **Total** | **59499** | **1272.9** | **46** |
| | | | | |
| Hamoye | *Pterocarpus angolensis* | 763.9 | 254.64 | 3 |
| Kahenge | | 636.6 | 95.4 | 7 |
| Katope | | 127.3 | 222.81 | 0.5 |
| Mashare | | 127.3 | 31.83 | 4 |
| Ncaute | | 254.6 | 95.49 | 3 |
| | **Total** | **1909.7** | **700.14** | **2.7** |
| | | | | |
| Hamoye | *Schinziophyton rautanenii* | 1145.9 | 0 | 1145 |
| Kahenge | | 636.6 | 190.98 | 3.3 |
| Katope | | 1540.6 | 63.66 | 24 |

| | | | | |
|---|---|---|---|---|
| Mashare | | 0 | 0 | 0 |
| Ncaute | | 1527.9 | 95.49 | 16 |
| | **Total** | **4851** | **350.05** | **13.8** |
| | | | | |
| Hamoye | *Strychnos cocculoides* | 3947.1 | 31.83 | 124 |
| Kahenge | | 0 | 95.49 | 0 |
| Katope | | 0 | 31.83 | 0 |
| Mashare | | 0 | 0 | 0 |
| Ncaute | | 2673.8 | 31.83 | 84 |
| | **Total** | **6620.9** | **190.8** | **34** |
| | | | | |
| Hamoye | *Strychnos pungens* | 1018.6 | 159.15 | 6.4 |
| Kahenge | | 254.7 | 0 | 255 |
| Katope | | 254.7 | 31.83 | 255 |
| Mashare | | 509.3 | 31.83 | 16 |
| Ncaute | | 7384.9 | 159.15 | 46 |
| | **Total** | **9422.2** | **381.9** | **24.6** |

## 5.3 Proportion of multi-stemmed individuals as an indication of resprouting

### 5.3.1 Proportion of multi-stemmed individuals

The multi stem proportions were only assessed for the canopy species which are valued for their timber. Multi-stem proportions are in this case used as a proxy for resprouting and can therefore be used to infer the regeneration mode. This was however only inferred for all individuals with a DBH of 5 cm and more.

The proportions of multi-stemmed individuals show that *Schinziophyton rautanenii* had the highest proportion of multi-stemmed individuals (100%) recorded in Mashare. This means all individuals surveyed in Mashare were multi stemmed. The species portrayed higher proportions in all sites when compared to other species (**Error! Reference source not found.**).

*Burkea africana* in general recorded low proportions across all sites with values below 20%. *Pterocarpus angolensis* also portrayed low proportions of multi-stemmed individuals with its highest proportion of 23 % recorded in Hamoye. *Baikiaea plurijuga* recorded considerable proportions with its highest value of 41% recorded in Katope. The species had no proportion record in Ncaute due to its absence in the surveyed plots in Ncaute.

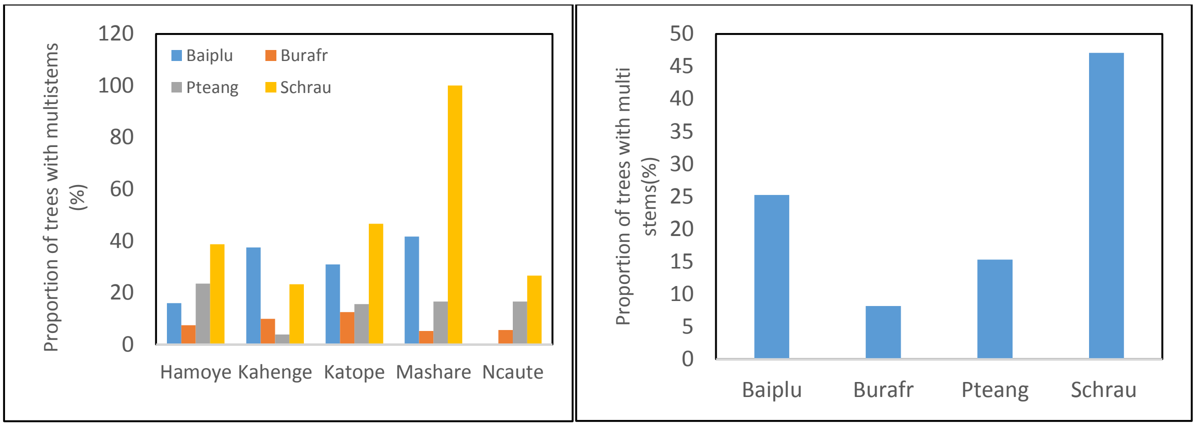


**Figure 31: The proportions of trees with multi-stems in the different sites (left) and for the region (right) for the four canopy species. (Legend: *Baiplu = Baikiaea plurijuga, Burafr = Burkea africana, Pteang = Pterocarpus angolensis and Schrau = Schinziophyton rautanenii)***

For the larger area the proportions (Figure 31 right) for the species were compared to determine whether they are similar across the whole area or they are different. This was found to be significantly different (p=0.01) based on a Kruskal-Wallis test. A Mann-Whitney test with Bonferroni corrected p-values showed that the differences were between *B. africana* and *S. rautanenii* (p=0.01) and also between *P. angolensis* and *S. rautanenii* (p=0.02). The null hypothesis of same multi-stem proportions among all species was rejected as the multi-stem proportions are significantly different among the species.

## 5.4 Factors influencing regeneration

### 5.4.1 Seedling density and fire frequency

Conditions in the areas are variable and looking at the fire frequencies of the different areas it can be seen that their fire gaps are closely related ranging from 7 years in Katope and Mashare to 9 years in Hamoye and Ncaute (Table 7). On average that's the longest period during the 13 years that each area had no fire recorded. With the fire frequency it can be seen that on average the plots have only burnt between one (Hamoye, Mashare and Ncaute) and three times (Katope) during the period 2000 to 2013. Some of the areas had long periods of no fire considering the regular fire occurrences of the region.

**Table 7: Mean values for the fire gap in years and the fire frequency in years with standard errors given in years.**

| Area | Fire gap (years) | Fire frequency over a 13 year period (years) |
|---|---|---|
| Hamoye | 9 | 1 |
| Kahenge | 8 (+/-1) | 2 (+/-0.4) |
| Katope | 7 (+/-1) | 3 (+/-1) |
| Mashare | 7 (+/-1) | 1 (+/-0.4) |
| Ncaute | 9 (+/-0.5) | 1 (+/-0.1) |

A multi variate linear regression with fire frequency and seedling densities of the study species as the independent variables was found to be non-significant for the all species (p=0.33). However controlling for all other species it was found to be significant for *S. rautanenii* seedlings (p=0.05). This means that fire frequency is linked to *S. rautanenii* seedling density, with a slope of 174.4 so for every increase of a year in fire frequency, the seedling density of *S. rautanenii* increases by 174.4 seedlings/ha

The fire frequency was further used in categories as shown in Figure 32. This shows that some species do well in low fire frequencies such as *B. africana* while others such as *S. rautanenii* are more prevalent in medium fire frequencies. The frequencies are only up to medium because the period used was for 13 years and as such some of the years could therefore be used in the high fire frequency category.

A Kruskal-Wallis test was run on the data set for the different categories and it was found to be non-significantly different.

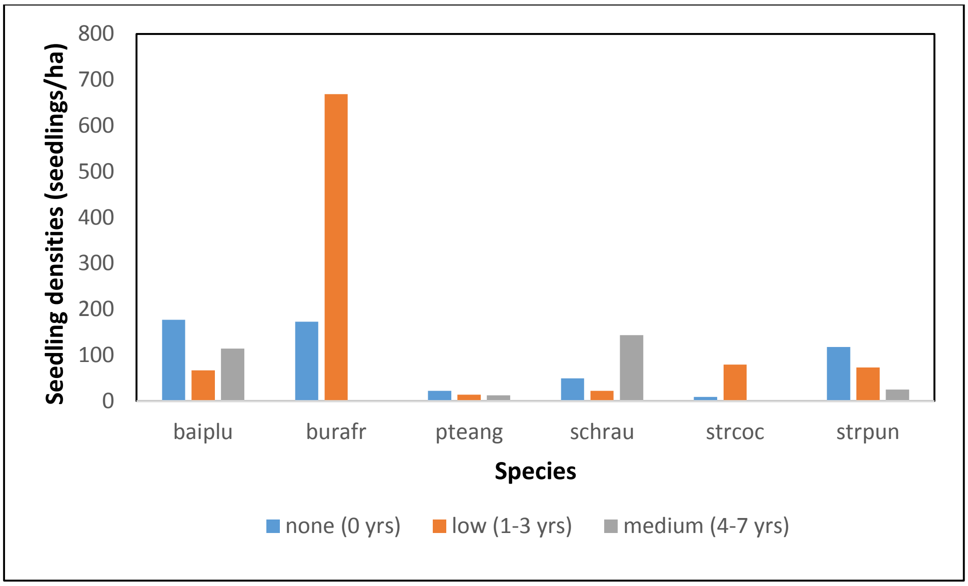


**Figure 32: Seedling densities of the valuable species in different fire frequency categories.**

### 5.4.2 Seedling density and vegetation cover

Vegetation cover was comprised of different layers or strata of cover namely the tree layer, the shrub layer and the herbaceous layer which was grasses and herbs combined. It can be seen that tree cover ranged from 20.2% in Ncaute to 34.1% in Hamoye (Table 8), this shows that the areas were not very dense in terms of tree cover. Shrub cover was slightly less than tree cover for all sites and it ranged from 9.7% in Hamoye to 27.1% in Katope, this shows that like the tree layer, the shrub layer was not very dense. The herbaceous layer ranged from an average of 3.6% in Hamoye to 42.8% in Kahenge.

**Table 8: The mean values for distances to various features in the different areas with their standard errors given in brackets.**

| Area | Tree cover (%) | Shrub cover (%) | Herbaceous cover (%) |
|---|---|---|---|
| Hamoye | 34.1 (+/- 2.0) | 9.7 (+/- 0.9) | 3.6 (+/- 0.7) |
| Kahenge | 29.7 (+/-2) | 26.3 (+/-2.6) | 42.8 (+/-2.7) |
| Katope | 30 (+/-2.1) | 27.1 (+/-2.4) | 38.8 (+/-3.1) |
| Mashare | 32.9 (+/-2.4) | 13.5 (+/-2.9) | 9.6 (+/-2.3) |
| Ncaute | 20.2 (+/-1.5) | 14.7 (+/-1.8) | 6.9 (+/-1.3) |

The multivariate linear regression for the vegetation cover variables and the valuable species seedling densities gave the following results. Collectively, herbaceous cover was significant (p=0.04) for seedling densities in the Kavango area (Table 9). It was further found to be significant for *B. africana* (p=0.05) and *S. rautanenii* (p=0.03). *Burkea africana* is projected to decrease by 10.36 seedlings/ha with an increase in herbaceous cover while *S. rautanenii* is projected to increase with an increase in herbaceous cover.

**Table 9: Results of the multi variate linear regression for herbaceous cover and seedling densities of the valuable woody species in the Kavango Region.**

| Species | Slope | Intercept | R | p |
|---|---|---|---|---|
| *B. plurijuga* | 0.6205 | 88.408 | 0.030177 | 0.7 |
| *B. africana* | -10.36 | 639.53 | -0.17482 | **0.05*** |
| *P. angolensis* | 0.48591 | 9.3691 | 0.13554 | 0.14 |
| *S. rautanenii* | 15.259 | -65.149 | 0.19802 | **0.03*** |
| *S. cocculoides* | -0.90017 | 68.737 | -0.04647 | 0.61 |
| *S. pungens* | -1.4602 | 100.33 | -0.14373 | 0.12 |

The multi variate linear regression for shrub cover and the seedling densities of the valuable woody species was found to be non-significant (p=0.7). The outcomes for the species are provided in Appendix F.

The same regression was found to be significant for tree cover (p=0.01) and the seedling densities of the valuable species. Although the individual species had weak r values, *B. africana* (p=0.01) and *S. pungens* (p=0.006) were found to be significant. With every percentage increase in tree cover, the seedling density of *B. africana* decreases by 19.6 seedlings/ha while *S. pungens* decreases by 3.5 seedlings/ha (Table 10).

**Table 10: Results of the multi variate linear regression for tree cover and seedling densities of the valuable woody species in the Kavango Region.**

| Variable | Slope | Intercept | r | P |
|---|---|---|---|---|
| *B. plurijuga* | 4.1749 | -24.244 | 0.14403 | 0.1 |
| *B. africana* | -19.642 | 1065.2 | -0.23511 | **0.01*** |
| *P. angolensis* | 0.14055 | 12.1 | 0.02781 | 0.76499 |
| *S. rautanenii* | 3.9139 | 35.136 | 0.036029 | 0.69851 |
| *S. cocculoides* | 0.099762 | 53.209 | 0.003653 | 0.96868 |
| *S. pungens* | -3.5983 | 184.44 | -0.25124 | **0.006*** |

### 5.4.3 Seedling density and distances to roads, settlements, the Kavango River and Omiramba

The proximity measures for the distances are summed up in Table 11. The table shows that on average plots in Mashare were closest to settlements (1.2 km) and the farthest ones were in Ncaute. Plots in Kahenge were on average closest to roads (0.79 km) and the Mashare ones were on average farthest from roads. In relation to the Kavango River, plots in Mashare were on average nearest to the river (6.8 km) while the Ncaute ones were on average farthest (31.7 km). The plots in Mashare were on average closest to Omiramba (2.5 km) and the plots in Katope were on average farthest (4.6 km)

**Table 11: The mean distance values for the different areas with their standard errors given in brackets.**

| Area | Villages/settlements (km) | Roads (km) | Kavango River (km) | Omiramba (km) |
|---|---|---|---|---|
| Hamoye | 6.5 (+/-0.5) | 5.4 (+/-0.4) | 20 (+/-0.3) | 3 (+/-0.5) |
| Kahenge | 2.2 (+/-0.2) | 0.79 (+/-0.3) | 13.4 (+/-1.8) | 3 (+/-0.9) |
| Katope | 2.5 (+/-4.6) | 3.8 (+/-7) | 22.7 (+/-1) | 4.6 (+/-0.7) |
| Mashare | 1.2 (+/-0.1) | 5.7 (+/-1.2) | 6.8 (+/-1.4) | 2.5 (+/-0.4) |
| Ncaute | 8.3 (+/-0.1) | 3.7 (+/-0.5) | 31.7 (+/-0.2) | 3.3 (+/- 0.5) |

The multi variate linear regressions for distances to roads (p=0.44) and that of distances to Omiramba (p=0.65) were found to be non-significant against the seedling densities of the valuable woody species (Outcomes for the regressions are under Appendix G)

The multi variate regression for distances settlements (p=0.0003) and to the Kavango River (0.000007) were found to be significant. Based on the regression, an increase in distance to the settlements is linked to an increase of 91.9 seedlings/ha for *B. africana* and 16.4 seedlings/ha for *S. pungens* (Table 12).

**Table 12: Results of the multi variate linear regression for distance to settlements and seedling densities of the valuable woody species in the Kavango Region**

| Species | Slope | Intercept | r | p |
|---|---|---|---|---|
| *B. plurijuga* | -16.191 | 186.41 | -0.15899 | 0.08 |
| *B. africana* | 91.987 | -13.119 | 0.3134 | **0.0005*** |
| *P. angolensis* | 0.080022 | 15.744 | 0.004507 | 0.96137 |
| *S. rautanenii* | -9.3657 | 200.56 | -0.02454 | 0.79195 |
| *S. cocculoides* | 2.2764 | 43.555 | 0.023727 | 0.7987 |
| *S. pungens* | 16.42 | -10.706 | 0.32633 | **0.0003*** |

Based on the regression for the Kavango River and seedlings density for the valuable woody species. Once again *B. africana* and *S. pungens* and *B. plurijuga* were found to be significantly linked to the distance to the Kavango River. It is projected that an increase in distance to the Kavango is linked to a decrease in the seedling density of *B. plurijuga* by 11.1 seedlings/ha.

While *B. africana* is projected to increase by 29.8 seedlings/ha and *S. pungens* by 8 seedlings/ha (Table 13).

**Table 13: Results of the multi variate linear regression for distance to the Kavango River and seedling densities of the valuable woody species in the Kavango Region**

| Variable | Slope | Error | r | p |
|---|---|---|---|---|
| *Baikiaea plurijuga* | -11.119 | 3.6327 | -0.27337 | 0.002743 |
| *Burkea africana* | 29.865 | 10.526 | 0.25475 | 0.005371 |
| *Pterocarpus angolensis* | -0.80117 | 0.65421 | -0.11298 | 0.22319 |
| *Schinziophyton rautanenii* | -5.0383 | 14.145 | -0.03305 | 0.72236 |
| *Strychnos cocculoides* | 3.8458 | 3.5399 | 0.10036 | 0.27954 |
| *Strychnos pungens* | 8.0258 | 1.7107 | 0.39935 | 7.47E-06 |

# 6. Discussion

Based on the results of this study the selected species showed different trends in terms of densities, size class distributions and occurrence in the region. They further showed different response patterns to factors such as fire frequencies, fire gaps, vegetation cover and distances to various features. With such variations as exhibited in the results section it can be seen that the valuable woody species of the Kavango regions portray different patterns in terms of natural regeneration. This section further discusses each of the species, their regeneration trends and how they respond to the aforementioned variables.

## 6.1 *Baikiaea plurijuga*

Based on the results of this study, the species showed significant differences in seedling densities within the five sites (p=0.005). A closer look at the trends in the natural regeneration of the species, it can be seen that it had considerable densities in the different sites including the Ncaute community forest.  The Ncaute area had no records of any adult *Baikiaea plurijuga* and as such it is considered to be re-establishing itself in the area with an occurrence value of less than 10 % in the 33 sampled plots within Ncaute and an overall 23.5 % in the region. Despite the low occurrence values recorded in this study, the species has been described as a dominant species in its distribution range (Thelaide, et al., 2001). The absence of large trees in Ncaute can therefore be attributed to exploitation. Especially considering that in a previous inventory, adult trees were recorded in the area (Kanime and Kakondo, 2003). Intensive utilisation might also be attributed to the trend in the size class distribution of the species in the Mashare area. A decline in the 35-40 cm diameter class was recorded and this is the size of stems or individuals that people would largely exploit. In Zambia individuals of more than 30 cm diameter were reported to be heavily utilised or harvested (Thelaide, et al., 2001). A similar description is given for the species in Botswana, where it is also heavily utilised (Botsheleng, Mathowa, & Mojeremane, 2014).

From the results of this study the species shows a recruitment pattern based on the size class distributions which had significant negative slopes. The populations of the species in the different areas can be considered to be recruiting. This is a similar trend with the height class distributions for the species in the region. This shows recruitment as the species showed more individuals in the shorter height classes than the taller ones. The presence of more individuals in the 0-50 cm class is a good sign for the regeneration.

The species has been described in Zambia to be preferred by livestock and wildlife (Thelaide, et al., 2001). A study in the Kavango region however found that *B. plurijuga* is one of the species that livestock do not prefer (Boys, 2015). This however does not rule out the possibility that the few wild small mammals that occur in the region do not browse on the seedlings.

The seedlings of *B. plurijuga* have been noted to invest more in taproots from the onset of germination by growing taproots that are up to 40 cm when they are only 6-7 cm in height (Jøker & Jepsen, 2003). This therefore highlights that by having individuals that are more than 50 cm high, the species has seedlings that are well established in terms of being able to withstand disturbances. The taproot feature of the species is interesting when considering that the seedling densities of the species was found to be significantly influenced by distance to the Kavango River.

The seedling density for the species were found to decrease in relation to an increase in distance to the Kavango River. This means that the species recorded higher densities in close proximity to the Kavango River especially in the Mashare area. This is contrary to the findings of a Zimbabwean study which found that the density of shrubs increased with increasing distance from natural water points (Mukwashi, Gandiwa, & Kativu, 2012). The difference in findings might be as a result of the fact that the Zimbabwean study was in relation to natural water points. This particular study also assessed distances to Omiramba and this was found to be non-significantly influential for the species. It further showed no significant influence of distances to roads and settlements. This is interesting as one would expect harvesting to be more intense in close proximity to settlements and further from settlements.

Based on the proportion of multistems for the species it was found that the species does have multi stemmed individuals and it had its highest proportions in Kahenge. Considering that this was a proxy for resprouting, it can therefore be considered that the species does have resprouting abilities. It has been noted to coppice well (Thelaide, et al., 2001) especially in environments that are disturbed. The production of multistems for the species and the other study species can therefore be considered to be a disturbance response (Gandiwa, 2011).

From the tests to determine the influence of environmental factors on the seedling densities for the species. It was found that the species was not significantly influenced by fire frequency and fire gap. This was the case for all other species except *Schinziophyton rautanenii*. It is well documented that fire influences the regeneration of the species, along with other factors such as competition, frost and browsing (Thelaide, et al., 2001). The non-significant influence for all the species could be attributed to the fact that the data for both fire frequency and fire gap that was used in this study was for the period 2000 to 2013 and the vegetation data were collected in 2013 for Kahenge and Katope and in 2014 for the other three sites. The variation in the seasons in which the vegetation and fire data possibly lead to the non-significance as they were not derived for one season. The species is however described as a fire sensitive species (Thelaide, et al., 2001; Burke, 2006; Shoopala, 2008). Its low occurrence might therefore be attributed to the fact that fire is one of the biggest threats to vegetation in the Kavango region (Trigg & Le Roux, 2001).

It is however noted that the seedlings of the species are easily outcompeted by dense grass and shrub cover (Thelaide, et al., 2001). Herbaceous cover, shrub cover and tree cover were all found to be non-significantly influential for the species in this study. The low vegetation cover in general might be attributed to the fact that all layers recorded percentage covers that were below 50 % in the different sites. It has however been noted that open canopy covers increase the amount of light reaching the ground and promotes the growth of grasses and shrubs which have the potential to outcompete the species (Thelaide, et al., 2001).It is further thought that a dense herbaceous layer could lead to a limit in recruitment (Traore et al, 2012; Proepper., et al., 2015; Thelaide, et al., 2001) because it burns faster and easily (Graz, 2004) hence it promotes burning and in turn limits recruitment of the fire sensitive *B. plurijuga.*

Even though the species recorded seedling densities that were quite considerable especially for Hamoye and Mashare. The transition from seedling to sapling stage is low, indicating that seedling establishment might be good for the species but survival of such seedlings to the next stage is low. Which might ascertain the fact the species is fire sensitive (Burke, 2006) easily outcompeted by grasses and shrubs (Thelaide, et al., 2001) and affected by rodents (Thelaide, et al., 2001) which were observed in most of the sites by the presence of their burrows.

## *6.2 Burkea africana*

The seedling densities of the species were found to be significantly different for all sites. With the highest densities in Ncaute and the lowest in Kahenge. This is in line with both the size class distributions and the height class distributions which showed that the species is recruiting.

*Burkea africana* seems to be maintaining its population structure in the Ncaute community forest where it recorded the highest density in a 2003 inventory and it had an inverse j-shaped curve (Kanime and Kakondo, 2003). A similar trend of an inverse j-shaped curve was reported for the species in Kanovlei (Graz, 2004) and Nylsvlei in South Africa (Wilson & Witkowski, 2003). The SCDs for this study were however very pronounced in Ncaute while the other sites had SCDs that had gaps. Once again it is important to look at such gaps in relation to possible influencing factors such as harvesting and past histories (Wilson & Witkowski, 2003). The absence of some size classes in SCD curves portray some trends about the populations, for example it might signify heavy utilization of that particular size class (Mwavu & Witkowski, 2009; Vermeulen, 1996). *Burkea africana* had no individuals in the diameter classes between 10 and 20 cm in Kahenge. This might be an indication that the individuals of such size classes have been harvested especially for their timber values. It is important to make sure that some large individuals are left when harvesting occurs, this is important for continued seed production to aid in recruitment (Mwavu and Witkowski, 2009). Focused harvesting of species tends to impact SCDs (Graz, 2004).

The SCD for Ncaute goes in line with the species' seedling occurrence in the area which was about 70 % of the surveyed plots. This shows that there was a large number of seedlings in the area. The transition ratio between seedlings and saplings was however low for the species. Once again highlighting the fact that although many seedlings are able to germinate, their survival to the next stage is not guaranteed.

Based on the relation to environmental factors, the species was found to be significantly influenced by herbaceous cover and tree cover. With both causing a decrease in seedling densities. This is described by Wilson and Witkowski (2003) who found that variations in canopy cover between sites influenced the seed availability of the species and ultimately influenced recruitment of the species in Nylsvlei. While the same study also found that a thick layer of litter mostly comprised of grasses, herbs and leaves reduces seed density. The herbaceous cover in the Kavango region might be higher than required for the species, thereby causing the seedling density decrease. This can however be considered a cyclic impact as herbaceous cover easily changes with the occurrence of fire (Thelaide, et al., 2001) and browsing. The same study by Wilson and Witkowski (2003) showed that with an increase in herbaceous cover, one intense fire occurred and caused a reduction in the number of individuals that germinated during that growing season, creating a long term gap in the size class distribution for the species.

Distances to settlements and to the Kavango River were significantly influential,both leading to increases in seedling densities for *B. africana.* This implies that the species regenerates well as you move further from the Kavango River and from villages. In the Kavango region, the two are almost paired as most people settle close to the river for easy access to water and proximity to fertile soils (Groengroft, et al., 2013). Close proximity to villages also means close proximity to disturbances such as harvesting which lead to patchy heterogeneity (Wilson & Witkowski, 2003) and *B. africana* is noted to be easily influenced by such disturbances. It is however noted by Boys (2015) to be one of the species that livestock do not prefer to browse on in the Kavango region. That therefore eliminates browsing but depending on animal densities, trampling might affect the seedlings. .

The multistems proportion for the species was low with about 20% in the region. This shows that the proportion of individuals that have grown from resprouting is low in comparison to the large seedling densities for the species in the region. It is however noted to be able to resprout after fire, frost and herbivory (Wilson & Witkowski, 2003). So it has the potential to grow in response to fire, which is a common occurrence in the region and to frost, which also occurs in some parts of the region for example Mashare (Weber, 2013) and Hamoye.

*Burkea africana* is a noted high fire frequency tolerant species (Shoopala, 2008; Burke, 2006). Despite it being described as such it was also found not to be significantly influenced by fire. The Nylsvlei study however did find that the species was influenced by the frequency of fires and these were evident in the size class distributions (Wilson & Witkowski, 2003).

By focusing on seedlings the species can be considered to be recruiting well. But looking at the transition ratio between the seedlings and the saplings, it is a similar scenario to that of *B. plurijuga.* Survival to the next growing stage is not guaranteed although its SCD slopes also show a recruiting population, the environmental influences cannot be ignored for this species as they were found to be influential in seedling densities which in the long run will affect the population structure of the species.

## 6.3 Pterocarpus angolensis

The Seedling densities of *P. angolensis* were not significantly different with the lowest in Ncaute and the highest in Kahenge. The species recorded some of the lowest densities among the study species and as has been described in some studies, the establishment of *P. angolensis* seedlings is a rare event (Banda, Schwartz, & Caro, 2006).

*Pterocarpus angolensis* seedlings also showed low occurrence in the region with 9.2%. This further supports the suggestion that the species does not regenerate readily. The low occurrence of seedlings could be attributed to the species requirements for establishment including open areas (Caro, Sungula, Schwartz, & Bella, 2005),and fire to break seed dormancy (Vermeulen, 1990). The species also showed low seedling sapling ratios compared to other species. This indicates low recruitment and a low transition from seedling to sapling stage.

Height class distribution had low densities with an absence of individuals in the 0-50 cm height class. With significantly positive slopes. The positive slopes imply that the height structure of the seedlings does not have a transfer trend where the smaller individuals transition to the next stage (Mwavu & Witkowski, 2009). *Pterocarpus angolensis* is noted to be a species that goes into suffrutex before it finally garners enough reserves to grow to the next stage (Vermeulen, 1990; Caro et al., 2005). This could possibly explain the absence of the 0-50 cm height class individuals. The suffrutex nature of the species allows individuals to survive frequent fires in their seedling stage until they are able to grow to sapling stage where they can become more resilient to fires (Graz, 2004). Considering the season in which all surveys were done was during the dry season (between May and September). It is a strong possibility that the smallest individuals could not be counted due to this feature. Two studies in Tanzania (Thunstroem, 2012; Caro et al., 2005) observed similar trends and attributed them to the suffrutex nature of the species. While a South African study (von Malitz & Rathogwa, 1999) also made the same suggestion, they further observed that some of the seedlings were shorter than they were during the initial assessment. This further supports the die back theory for the species.

The size class distribution was significantly negative slopes, with gaps between 10-15 cm in Mashare and 15-20 cm in Ncaute. Once again such gaps in the size class distribution show possible intensive utilisation as was noted in *Baikiaea plurijuga*. Its structure for Mashare however had low numbers of individuals in all diameter classes. The Tanzanian study (Caro et al., 2005) observed an inverse j-shaped diameter curve although its diameter was larger than the diameters for this particular study. Another study (Thunstroem, 2012) observed diameter curves that had many gaps in them, some with several classes missing. Both studies suggested that selective harvesting led to the missing diameter classes.

It is possible that the fact that Mashare is an open communal area in close proximity to Rundu, the Kavango River and the Trans-Caprivi highway might have escalated the heavy utilization of the species for timber and led to its low numbers. A study by Modest et al. (2010) found an inverse j-shaped diameter distribution curve for *P. angolensis* in Tanzania. Their study also recorded low values which were all below 10 stems/ha for the size classes from 5 cm. The findings of this study for Mashare concur with those found in Tanzania with the exception that this study measured density as trees/ha and not stems/ha. In essence the values in Tanzania might be less than the Mashare ones considering provision for multi-stemmed individuals.

The species recorded its highest proportions of multistems in Hamoye implying that most of its individuals in the Hamoye area are possible resprouts. *Pterocarpus angolensis* is considered a good resprouter and it was found that 92% of its stumps in a Tanzanian study resprouted (Luoga, Witkowski, & Balkwill, 2004). The species is also believed to resprout well especially in the seedling stage (Graz, 2004; Caro et al., 2005). Another study on *Colophospermum mopane* also supported the idea of multi-stems as a response to disturbance (Mapaure & Ndeinoma, 2011) while Nzunda (2007) further supported this with a finding that low light and high disturbance frequency result in multi-stems.

The species recorded no significant influences in relation to any of the environmental variables. This might be attributed to the very low density records and mostly no records in the different areas. The species is noted to tolerate fire temperatures of 400-450 degrees celsius while other species die off at such temperatures (Graz, 2004). *Pterocarpus angolensis* is however protected from fire damage by a thick bark, once the bark is damaged, they become susceptible to fire (Graz, 2004). Fire tolerance helps *P. angolensis* establish in open areas which favour herbaceous layer and frequent fires.

Although it was found not to be influenced by any of the environmental variables *P. angolensis* is noted to be a species that has certain environmental requirements before it can germinate (Vermeulen, 1990), therefore the environmental conditions in the areas might not have been optimal for seed germination during the surveyed growing season.

## 6.4 Schinziophyton rautanenii

Size class distribution slopes were negative in Katope and Ncaute and positive in Hamoye and Mashare. *Schinziophyton rautanenii* recorded no individuals in the smallest size class of 5-10 cm Hamoye and also had no individuals in most of the size classes in Mashare, this obviously led to its positive SCD slope, which implies that the species has more individuals in the larger size classes than the small ones. The species can be viewed as under threat due to the absence of saplings or the small size classes. The absence of such individuals means that it is under threat of being removed from the area depending on continued use (Mwavu and Witkowski, 2009). Such removals lead to changes in vegetation structure and might lead to shrub dominated vegetation types which are fire resistant and less valuable (Lykke, 1998). Such an environment would not be ideal for the growth and establishment of the species. Fire has notable damage to stems of the species and this is normally observed in the field as most trees have burn scars or hollow trunks as a result of fire.

Proportion of multistems was highest in Mashare and highest in general for the whole region. *Schinziophyton rautanenii* has been noted as a resprouting species with a suffrutex nature like *P. angolensis* although this has not been documented (Graz, 2002), it was observed in the Mashare area from the excavation of one seedling that it has sprouting scars. This implies that it might have similar responses as *P. angolensis*. It has been described by Chimbelu (1983, cited in Graz, 2002) that the species tends to grow shorter stems and more branches when it's on disturbed sites. The suspected resprouting nature of the species might allow it to invest in growth after fire disturbance. It is however not certain as to how fire impacts on the species (Graz, 2002). It was however the only species which was found to be significantly influenced or related to fire with a projected increase in seedling density. This finding is in contradiction to Geldenhuys' (1977) report of the species requiring total protection from fire. This would be ideal for the species as its light wood burns easily and it sometimes burns at the trunk and can no longer support its crown therefore it breaks and the splinters further enhance the burning (Graz, 2003).

Herb cover was also found to be significantly influential for *S. rautanenii* seedling densities. This suggests that the seedlings of the species are able to compete with the herbaceous layer and establish themselves. Tree cover was however found to be non-significantly influential, although a study found that the seedlings of the species grow best in conditions of 50 % canopy cover, while less shading would inhibit their growth (Graz, 2003). Not much is known however about the seedling establishment of *S. rautanenii* (Graz, 2003) and other species as well.

## 6.5 *Strychnos cocculoides* and *Strychnos pungens*

The seedling densities for the *S. cocculoides* were found to be non-significantly different, occurring only in Hamoye and Ncaute with a percentage of less than 9% while that of *S. pungens* were found to be significantly different. With its highest density found in Ncaute. The two species despite being of the same genus and basically being used for the same major purpose by local communities, had differences in their regeneration trends and population structures.

The height class distributions of *S. cocculoides* showed positive slopes while size class distributions were found to be negative. This implies that the seedlings size structure for the species exhibits a low recruitment pattern. The species had no seedlings in three of the sites and this is in the long run not a good scenario for a population. The species had seedling to sapling ratios of less than one, further indicating its low recruitment pattern for in the region. Although its size class distribution showed a recruiting pattern, there is cause for concern when looking at the seedlings and the saplings for the species.

For the two *Strychnos* species distances to roads and settlements can be considered very important as the disturbance levels with proximity to roads are higher than further away as roads provide easy access to markets (Graz, 2004, Proepper., et al., 2015).This is both for selling the harvested products like fruits and for accessing the much needed social care services for rural communities. With a species like *S. cocculoides* with seedling densities that were also found to decrease with increased distance from roads. It is possible that the fact that it's an important fruit species means its dispersal is aided in areas that are close to roads and settlements. The fruit is commonly sold along the main roads in Kavango and as such seed dispersal tends to be in close proximity to such areas, increasing the probability of seedling establishment. (Schwartz & Caro, 2003). A study by Schwartz and Caro (2003) in Tanzania found that some species decreased with increased distance from the roads.

For *S. pungens* the species was found to have a higher occurrence in the region than *S. cocculoides.* Whereas its height class distribution showed that the seedling structure for the species is recruiting and the same with its size class distributions. This is an interesting scenario in relation to the two species as they are usually considered similar. But this reiterates the idea that although most of the species are thought to have similar responses to conditions, they are influenced by micro conditions such as soils and bio-climates in different sites (Burke, 2006).

A population that only records individuals in the small size classes could be an indication of the exploitation of the larger individuals (Modest, Maganga, Hassan, Mariki, & Muganda, 2010). This might be the case for *S. pungens* in Kahenge. It is however not possible that individuals of *S. pungens* have been exploited into decline because the species is not a timber species like *B. africana* and the other crown species. The species should actually be more abundant as it is a fruit producing species. It has been observed left in crop fields even after other species have been cleared to make way for crop production, its skew population in Kahenge might therefore be an indication of an establishing population, considering its low numbers.

In contradiction to the results of *S. cocculoides,* tree cover was found to be significantly influential in reducing seedling densities for *S. pungens* implying that seedling establishment for the species is better in open areas with low canopy cover. Recruits are thought to increase in areas with open canopies (Caro et al, 2005), *Strychnos pungens* was in this case found to decrease in relation to tree cover. This shows that the findings on the species concurs with the finding by Caro et al. (2005).

Proximities to settlements was also found to be significantly influential leading to an increase of 16.4 seedlings per hectare. This can be considered ideal for the species as was indicated previously that proximity to villages is an important feature for the two species. Distance to the Kavango River was also found to be significantly influential leading to an increase in seedling densities (8.02 seedlings/hectare) as one moves away from the river.

From the results *S pungens* was found to have seedling densities that increase as one moves towards settlements, which are hives of human activities. The finding on *S. pungens* would be expected as close proximity to settlements entails disturbances such as harvesting, land clearing and high probabilities of fire. It is also thought that close proximity to Omiramba is closer to water and nutrients or good soils. (Groengroft, 2013).This is especially important in the Kavango as its Kalahari sands are nutrient poor (Burke, 2006; De Sousa-Correira & Bredenkamp; Groengroft, 2013).

## 6.6 Natural regeneration in the Kavango region

In general the variations highlighted the fact that regeneration density is not merely a spot assessment but comparisons across areas can reveal differences in the densities, even when the areas might be considered similar. In this regard, looking at the densities and their variations might bring to light certain considerations to explain the variations; firstly the areas of assessment had different management systems and therefore different focal land uses. For example Hamoye is a semi-protected area, the state forest is set aside and not to be used for communal harvesting of wood. Therefore human influence is limited although illegal harvesting still occurs in the forest and fires occasionally burn across communal areas into the state forest as has been observed during the study. A study in Burkina Faso on land use and its influences on seedling establishment found that regeneration was higher in protected areas (Traore et al, 2012). The management of the area might therefore be one of the unassessed factors contributing to seedling densities.

The Ncaute community forest on the other hand also exhibited the presence of seedlings of all study species. Ncaute and Hamoye are in close proximity to one another. Could environmental conditions in the two areas be similar and be favourable for the establishment of seedlings of all the species? This has been alluded to by Burke (2006) citing bio climatic conditions and soils as some of the driving factors for vegetation characteristics in the region. Similar to density the occurrence of seedlings also highlighted the spatial distribution of the species regeneration in different areas of the Kavango region.

The low seedling numbers such as those found in species like *P. angolensis*, *S. rautanenii*, *S. cocculoides* and *S. pungens* across the areas could be an indication of certain factors including, poor seedling germination. This could be a reason of low seed rain for a particular species (Mwavu & Witkowski, 2009). Seed rain in turn is caused by several factors including environmental stress especially in dry forests and savannahs (Ceccon et al, 2012). Environmental stress is a common phenomenon in the woodlands of north eastern Namibia, especially fire, land clearing (Burke, 2006) and herbivory.

For seed rain to be available, mature trees are required to produce the seeds. For three of the four canopy species (*B. africana, P. angolensis and S. rautanenii*) mature individuals of up to 50 cm in diameter were recorded at all sites except for *B. plurijuga* which was not recorded in Ncaute although its seedlings were recorded.

Seedling establishment or germination (Traore et al, 2012) is an important aspect for the growth of a species. Looking at the height classes used in this study, an important class is the 0-50 cm height class as this is the establishment class. Assessing the height classes therefore points out any hindrances that might occur in the establishment stage (Sop, et al. 2011) of regeneration. Taking this into account, the height classes of *P. angolensis* and *S. rautanenii* highlight the concern of having no recorded individuals in the 0-50 cm height class.

The fact that the two species have no records in the 0-50 cm height class could be a case of concern or just another normal phenomenon in the growth of the species. In a system like the Kavango where fires are frequent (Trigg & Le Roux, 2001), it is possible that the 0-50 cm class being small and more vulnerable to burning (Traore, et al. 2012) could have been burnt to below ground level.

Fire is not the only threat for the 0-50 cm height class, in a dynamic environment such as the Kavango, there are other threats. New seedlings are preferred by livestock and wildlife for their palatability hence it is possible that they are browsed or simply trampled down. During a study in Burkina Faso it was observed that mortality of seedlings in the small height classes was a result of herbivory and trampling (Sop, et al. 2011).

A higher number of individuals in the height classes beyond the first class also serves as an indication of the growth and survival of individuals into the next classes as individuals might grow quickly in order to evade the threats faced by the small height classes and become less susceptible to the disturbances (Sop et al. 2011) that impact the small height class. This is a feature that was also quite variable when considering the seedling to sapling ratios of the species.

The results of the size class distributions show that all species exhibited certain levels of recruitment with most of their SCD slopes being significant for negative slopes, which are indications of recruiting populations. Some species like the two Strychnos species showed negative slopes, regardless of the patchiness of their curves. Some species also had gaps in the middle size classes of their curves, for example *S. rautanenii* in Kahenge, Katope and Mashare. Despite these gaps they still had significant negative SCD slopes. It is however advised to use SCD slopes with caution as conclusions cannot be made sorely based on size distribution to determine future trends without taking into account species growth rates (Condit, Sukumar, Hubbell, & Foster, 1998) especially of their seedlings. This is important as it has been found that plants of the same diameter might not necessarily be of the same age (Graz, 2004) as some species grow quickly depending on environmental conditions and species. The use of woody species by cutting also has the potential to alter population structures of such species (Sullivan, 1999) which is a trend that can be seen in the SCD results of this study.

Species that are widely distributed or abundant are less susceptible to declining and therefore stand a better chance of continued existence (Tabuti, 2007). This can be assumed of *B. africana, S.pungens and B. plurijuga* in this study. While some of the most crucial influencing factors for the distribution of some of the species were not assessed in this study, it is thought that *B.plurijuga* is influenced by soils and ground water, *B. africana* by bioclimatic conditions and fire and *P. angolensis* by bioclimatic conditions and fire as well (Burke, 2006).

Regeneration mode in species is an important aspect but it is also a bit challenging to determine especially because it usually involves a destructive method of excavating plants. It can be used to understand the ecology of species but it is also used to understand disturbances and forest structure as it influences the growth and survival of species following disturbance (Kennard, Gould, Putz, Fredericksen, & Morales, 2002; Maingi & Marsh, 2006).

The proportions of multi-stemmed individuals in this regard were used to infer disturbance responses in growth structures. This is because resprouters are often considered to grow into multi stemmed individuals (Kruger et al., 1997; Nzunda, 2008). It is therefore considered that multi stemmed individuals have grown from resprouts and therefore give an indication of the mode of regeneration for a species.

This study found that the four canopy species all had variable proportions of multi-stems. The multi-stems indicate that the areas experience some forms of disturbance. A study in Zimbabwe found that there were more multi-stemmed individuals in burnt sites than in unburnt sites (Gandiwa, 2011). The same study further pointed out that species that are fire tolerant tend to respond to burning by resprouting and producing multi-stems. This could be the case for *B. africana* in this study.

It is considered an advantage for species to resprout especially in savannahs because resprouts tend to be less susceptible to environmental stress (Ceccon, Huante, & Rincon, 2006) and establish quickly due to available carbohydrate reserves (Kennard et al, 2002). Aside from being able to survive disturbances better than seedlings (Moyo, 2013) resprouters also help to increase the number of species in an area as they are more tolerant of different conditions (Nzunda, 2008). Species which do not produce multi-stems are in most cases harvested for their good quality timber (Mapaure and Ndeinoma, 2011) hence their existence in the wild is not guaranteed.

Another study concluded that fire influences shoot production in *B. plurijuga* and *P. angolensis* leading to multi-stemmed individuals (Ncube and Mufandaedza, 2013). This is an indication that in response to fire the mentioned species can produce multi-stems as a response mechanism to ensure survival.

It was observed that most single stemmed individuals encountered in the field had poor quality timber and there was evidence of recently harvested stumps of *Pterocarpus angolensis* in Ncaute. This was confirmed by Leopoldine Njaviki, (pers. Comm, 2015) who pointed out that despite the declining numbers of timber trees, people still harvest illegally in the area.

## 6.7 Factors influencing regeneration

Although the statistical test on different fire frequencies was not significant it is of importance to note that species have variable tolerance levels for fire. Frequent fires determine how much time a species has to recover from the previous disturbance or damage before the next one occurs (Gandiwa, 2011; Graz, 2004). Species in the Kavango area have to be more resilient in this regard as fire is a noted threat in the region (Burke, 2006; De Sousa and Bredenkamp, 1986).

The frequency of fires leads to certain impacts on vegetation, for example frequent burning may lead to plants with similar diameter classes even though they are of different ages (Graz, 2004) which jeopardizes the use of SCDs as indicators of age structure. The impacts of fire also depend on age or size structure of plants in an area as size classes differ in their susceptibility to fire (Graz, 2004). Small size classes are more prone to fire damage than the much larger size classes that have developed resilience over the years, A study by Smit et al. (2010) showed that frequent fires affect the shorter height classes more than the taller ones, this might explain the absence of some of the seedlings in the shortest height class. Frequent fires also promote resprouting in many plants (Nzunda, 2007) and with this comes an increase in multi stemmed individuals (Gandiwa, 2011). Fire frequency therefore has the potential to alter vegetation structure in an area.

Fire however also includes intensity, which also has the potential to impact certain stages of plant growth. Fire intensity can cause damage to seeds and reduce their viability (Graz, 2004). The intensity is increased by the fact that if an area does not burn often (long fire gaps), the fuel load in the form of the herbaceous and shrub layers increase and when a fire occurs at that stage, it is more intense and causes more damage to plants especially the small size classes. This might explain some of the absence of small size classes in seedling height class distributions.

Vegetation cover is an important aspect in woodlands as it tends to influence the establishment of seedlings of other species. Some species' seedling densities are predicted to increase with increase in herbaceous cover e.g. *S. rautanenii*. While others such as *B. africana* are predicted to decrease.

Proximity measures to different features have the potential to influence certain aspects of vegetation structure. Some of the features are influential in the types of disturbance that occur in the area. When considering valuable species, it is logical to consider the human aspect as they harvest or use the species for certain uses. These uses can therefore be related to features such as roads, settlements and water sources. These are features that attract the human population and with an attraction of the human population, exploitation of resources is bound to occur. In the Kavango region all these are features that are present.

The vegetation along the Kavango River and Omiramba is described as being in a secondary state as a result of human activities (De Sousa and Bredenkamp, 1986). Most settlements in the region are in close proximity to the Kavango River or Omiramba and this is because of the good prospects of water availability and the good soils (De Sousa and Bredenkamp, 1986; De Cauwer, 2013).

De Cauwer (2013) pointed out that woodlands that are further from the river are used for grazing, timber harvesting and for hunting. This is probable as harvesting is currently banned in the region so most people would have to do it illegally. It is possible that to avoid being caught harvesting illegally close to the village, people would rather harvest further away reducing parent trees and leading to a decline in seed rain as you move further from Omiramba, which are in most cases close to settlements.

Close proximity to settlements and roads has been attributed to over harvesting of some valuable species for example in Tanzania the over harvesting of *Dalbergia melanoxylon* was linked to the study area's close proximity to Dar Es Salaam, (Modest et al,2010) which is the country's capital city. Close proximity to villages therefore has the potential to either increase or reduce the establishment of seedlings, depending on activities and land use patterns. This was noted in this study for species like *S. pungens* and *B. africana.*

Roads would be associated with increased fire frequencies because the road reserves need to be cleared regularly and sometimes to avoid the labour intensive manual work of clearing the reserves are burnt and the fires can spread over distances away from the road. This therefore creates conditions of dense herbaceous cover which in turn promote burning and such are conditions that are feasible for *B. africana* establishment. This assumption is however contradictory to the findings by Smit and Asner (2012) who found that woody cover increased in close proximity to roads in the Kruger National Park. This was attributed to a moisture gradient created by runoff from the road, allowing woody plants to make use such moisture to grow beyond the normal growing season. Some of the sites in this study had been not been burnt in decades but the findings were overall similar (Smit & Asner, 2012).The study was in a National park, where fire would only be used for management purposes and in a controlled manner, while in the Kavango there is no regulated fire system, especially in the inland rural areas. This therefore means that a combination of proximity to roads and fire occurrence could have an influence on woody vegetation along roads.

# 7. Conclusion

In conclusion this study found that the regeneration densities of the study species are significantly variable in different areas of the Kavango region and their size structures are also variable as has been outlined. Species like *B. africana* are characterized by height class distributions that indicate growth in the size structure whereas species like *P. angolensis* and *S. rautanenii* are characterized by height class distributions, which show declines in the growth of the size structures. It is however important to highlight that this study was mostly focused on seedling densities and this is a growth stage which is susceptible to seasonal changes and some of the variations might therefore be attributed to seasons in which the study was carried out.

This study also showed that although species can be considered to be regenerating based on the presence of seedlings, their size class distributions and seedling to sapling ratios are important aspects in determining the possible future trends of such species. The size class distributions of the valuable woody species using diameter distributions also highlighted the significance that selective harvesting of certain size classes can have on the size structure of a species like *B. africana* in Kahenge and *P. angolensis* in Mashare.

It was also found that the four crown species in this study have the ability to produce multi-stemmed individuals which is a trait that is associated with disturbance and is therefore considered a response mechanism or a mode of regenerating after disturbance. This therefore indicated that all the canopy species in this study are able to resprout although species such as *S. rautanenii* are better resprouters than others, based on their percentages of being multi-stemmed as was shown in this study.

In relation to environmental conditions' influence on regeneration densities. It was found that some species can thrive in different conditions while some are hindered by similar conditions. With regards to fire, it was found that only *S. rautanenii* was significantly influenced by fire whereas all the other species were not. This however does not ultimately mean that fire is not an important feature for the other species in the region as was discussed in earlier sections.

With regards to vegetation cover, it is more a case of whether it is herbaceous cover, shrub cover or tree cover as their impacts are determined by their ability to burn and to provide cover for seedlings. Some of the species such as *S. rautanenii* and *B. africana* were found to increase and decrease in response to increased herbaceous cover respectively while *S. pungens* and *B. africana* were found to decrease in relation to tree cover. This emphasizes the importance of competition and patchiness of sites in promoting or suppressing seedling establishment.

The proximity measures showed that human influence is a major driving factor in vegetation exploitation and this is in relation to the fact that human settlements are influenced by proximity to water supply, fertile soils for agricultural production and accessibility to markets and major towns. *Burkea africana* and *Strychnos pungens* seedling densities were found to increase in relation to increased distances to both settlements and the Kavango River.

This study has therefore demonstrated that regeneration of valuable woody species is a complex aspect that is driven by several factors. For the Kavango region, these factors include, fire frequency, vegetation cover, human exploitation and water availability.

It can hereby be concluded that the valuable woody species have the potential to regenerate but management of the areas needs to be made more active in order to ensure improvements in conditions that are feasible for seedling establishment. These management approaches include among others, active fire management, grazing systems, improved agricultural practices and planned harvesting measures to avoid distortion of population size structures.

# 8. Recommendations

Based on the experiences and outcomes of this study, the following recommendations are made for future studies.

- This study was based on seedling densities in one growing season for each of the areas, this gives an idea of the trends for that particular season. In order to do critical regeneration assessments, long term monitoring of seedlings is required over several seasons in order to fully understand which environmental variables are important for seedlings of different species. In relation to this as well, soil and rainfall data are crucial in regeneration studies as has been pointed out that soils and bio-climatic conditions are driving factors for vegetation in Kavango (Burke, 2006).
- The mode of regeneration in this study was inferred from multi stem production by species, some of the species might have this as a natural growing feature and to be able to do objective regeneration mode assessments. Long term studies are once again important especially by using permanent sample plots, which would help in keeping records of all individuals in the plots and how they change over time and in response to disturbances.
- Fire monitoring need should be an important aspect of study in the Kavango regions. Considering that the fire data which was used in this study was from 2000 to 2013 and the vegetation data were from 2013 to 2014. This means the two sets were not well paired. It is therefore important to have records of fire data on an annual basis. Once again permanent plots would be helpful in this regard. As an outcome of this study 33 plots were marked in Hamoye for long term monitoring. This is only a small portion and more plots are required. With the ongoing conflict of fire aspects and their influences on vegetation, it is highly recommended that studies be developed to assess how fire impacts on vegetation, in order to help provide information on such important aspects. The fire season and intensity should be considered (Smit et al., 2010) in this regard.
- From observation during this study it was found that some of the fire breaks in the area are not well maintained and as a result large areas burn. It is therefore important to evaluate the fire breaks in the region and to strategically place future roads so that they serve as fire breaks and help in reducing the spread of fires
- Economic valuation should be placed on the valuable species and this might help encourage the protection of recruits and further influence studies in propagation measures for the valuable species.
- Management plans are needed for the valuable species in order to provide guidelines on how best to manage and monitor them and their influencing factors. The current management approaches don’t seem to be very effective in forest resources management.

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# Appendices

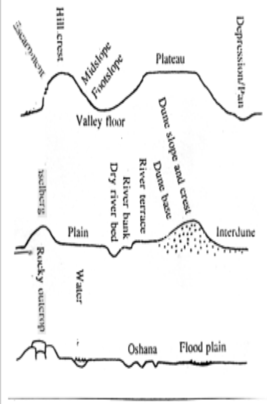
## Appendix A

**STAND INFORMATION**

| | |
|---|---|
| **Plot no** | |
| Area | |
| Date | |
| Team | |
| **Lat** | |
| **Long** | |
| Accuracy (m) | |
| Elevation (m) | |
| Land type | |
| Land use | |
| **Crown coverage trees** | |
| **Crown coverage shrubs** | |
| **Grass coverage** | |
| **Herb coverage** | |
| **Bare soil coverage** | |
| **Human influence** | |
| **Domestic mammals** | |
| **Damage by forest fire** | |
| **Other damages : cause** | |
| **Main cause damage plot** | |
| **Ptan nearby (0/1)** | |
| **Max. tree height plot** | |
| **Remarks** | |

**Land type**

1 = Escarpment (steep, long ridge, extending over more than 10 km)
2 = Hill crest (top of a ridge)
3 = Mid slope
4 = Foot slope
5 = Valley floor
6 = Plateau
7 = Depression/Pan
8 = Inselberg (isolated mountain)
9 = Plain
10 = Dry river bed
11 = River bank (current)
12 = River/alluvial terrace (old bank)
13 = Dune base
14 = Dune slope and crest
15 = Interdune (always sand, between dunes)
16 = Rocky outcrop
17 = Water course
19 = Flood plain
18 = Oshana




**Land use**

1 = Naturally vegetated land (including farmland used for grazing)
2 = Agro-silvopastoral (Agro-Forestry)
3 = Forestry (commercial tree production, plantation)
4 = Agriculture (crop production)
5 = Mining
6 = Bare soil

**Cause damage**

1 = Forest fire
2 = Mammals wild
3 = Mammals domestic
4 = Insect
5 = Human
6 = Frost
7 = Drought
8 = Erosion
9 = Storm
0 = Unknown
10=fungi

0 = No damage/influence
1 = Mild damages, not affecting the trees
2 = Moderate damages, decreasing vitality of trees
4 = Fatal damages, several trees are dying or dead

**Damage by forest fire** : 0 = no signs of fire, 1 = Recent, ashes visible, 2 = Old

(*) based on classical sample scheme DoF : Radius 20m : cbh > 62.8cm ; Radius 10m : cbh > 15.7 cm

# Appendix B

**TREES**

Plot no 0

Radius 30m: cbh >141 cm ; Radius 20m : cbh > 62.8cm ; Radius 10m : cbh > 15.7 cm

| no | Species | cbh/dbh (cm) | Alive | Dist (m) | Timb_q | l_log (m) | Crown_cl | Phenol. | Height(m) | Damage | Cause_dam | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | |
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| 29 | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | |

**Alive**

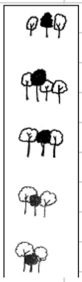
1 = Alive tree
2 = Standing dead tree
3 = Dead, lying
4 = Stump
5 = stump with coppice

**Timber or pole quality**

4 = Expected good
5 = Expected medium
6 = Expected poor
7 = no timber or pole quality

**Crown class**

1= Open crown
2 = Dominant
3 = Co-dominant
4 = Intermediate
5 = Overtopped



**Phenology**

L(eaves),Fl(owers),Fr(uits)

**Damage** : see sheet 1

**Cause damage**

1 = Forest fire
2 = Mammals wild
3 = Mammals domestic
4 = Insect
5 = Human
6 = Frost
7 = Drought
8 = Erosion
9 = Storm
0 = Unknown
10=fungi

**Important during data entry (otherwise Makro's will not work) :**

For trees with multiple stems : list the stem with the largest cbh first, complete row for each stem, give each stem same number as first stem and do not repeat species name under column "Species" (leave blank)

Remove number of row after last tree

There should be no column for bearing and two columns for canopy

First tree should be on row 6

Use correct abbreviations for tree species (3 first letters of genus, 3 first letters of spec) !!!

# Appendix C

| SHRUBS & REGENERATION | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot no | | | | | | | | | | | |
| Shrubs and regeneration | | | | | | | | | | | |
| Species | Height | | | | | TOTAL | Crown class | | | | |
| | 0-50cm | 51-100cm | 101_200cm | 201_300cm | >3m | | 0-50cm | 51-100cm | 101_200cm | 201_300cm | >3m |
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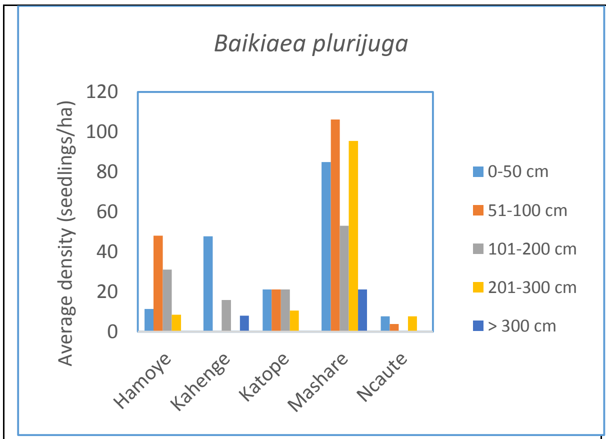
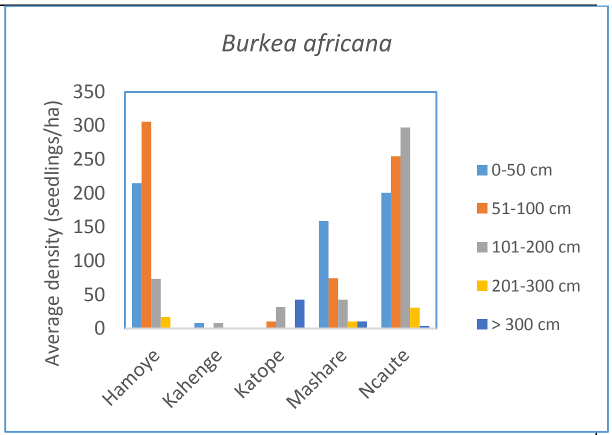
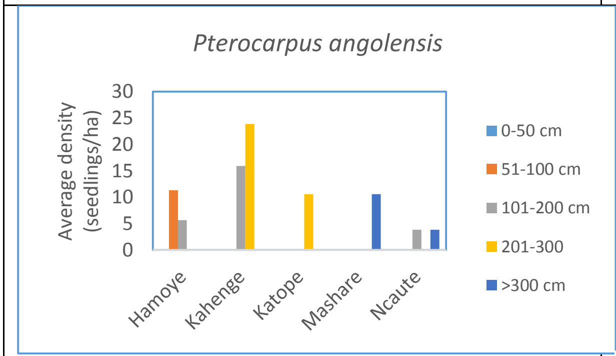
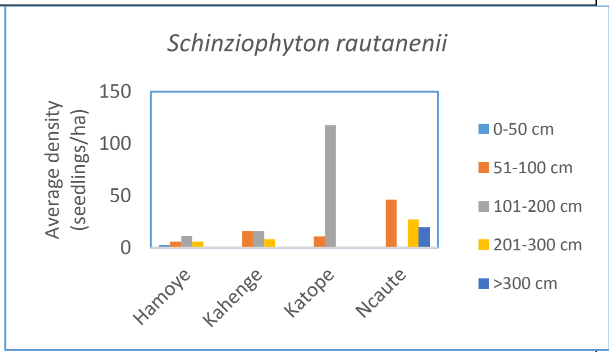
## Appendix D

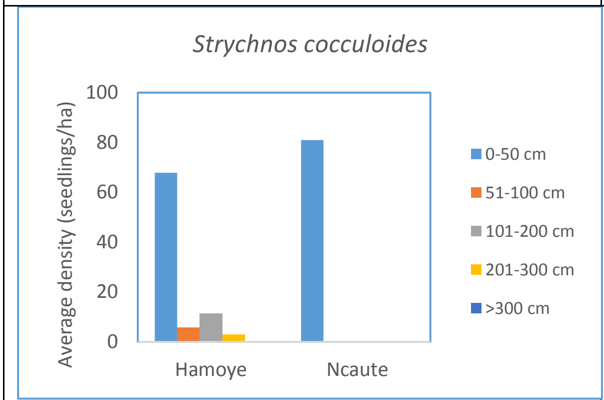
Height class distributions for the seedlings of the valuable woody species in different areas.

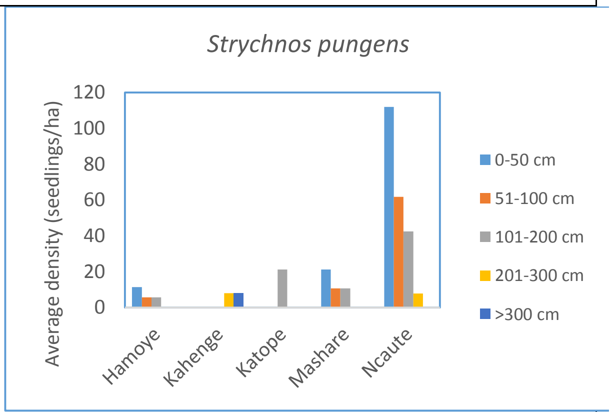


## Appendix E

Height class distributions for the study species, the HCD data were derived from the height classes of the study species (The significantly different ones are denoted with asterisks after the p-values)

| Species | Area | Slope | R2 | P-value |
|---|---|---|---|---|
| *Baikiaea plurijuga* | **Hamoye** | **-0.001** | **0.68** | **0.09** |
| | Kahenge | 0.000 | 0.03 | 0.80 |
| | **Katope** | **-0.001** | **0.30** | **0.34** |
| | **Mashare** | **-0.003** | **0.20** | **0.45** |
| | Ncaute | 0.000 | 0.24 | 0.40 |
| *Burkea africana* | **Hamoye** | **-0.008** | **0.84** | **0.03*** |
| | **Kahenge** | **-0.001** | **0.33** | **0.31** |
| | Katope | 0.001 | 0.03 | 0.78 |
| | **Mashare** | **-0.007** | **0.97** | **0.00*** |
| | **Ncaute** | **-0.013** | **0.89** | **0.02*** |
| *Pterocarpus angolensis* | **Hamoye** | **-0.001** | **0.19** | **0.46** |
| | Kahenge | 0.001 | 0.17 | 0.50 |
| | Katope | 0.001 | 0.19 | 0.46 |
| | Mashare | 0.001 | 0.46 | 0.21 |
| | Ncaute | 0.000 | 0.26 | 0.38 |
| *Schinziophyton rautanenii* | Hamoye | 0.000 | 0.30 | 0.34 |
| | Kahenge | 0.000 | 0.00 | 0.91 |
| | **Katope** | **-0.001** | **0.09** | **0.62** |
| | Ncaute | 0.001 | 0.11 | 0.59 |
| *Strychnos cocculoides* | **Hamoye** | **-0.001** | **0.60** | **0.12** |
| | **Ncaute** | **-0.002** | **0.43** | **0.23** |
| *Strychnos pungens* | **Hamoye** | **-0.001** | **0.92** | **0.01*** |
| | Kahenge | 0.001 | 0.83 | 0.03* |
| | Katope | 0.000 | 0.00 | 0.94 |

| | | | |
|---|---|---|---|
| **Mashare** | **-0.002** | **0.88** | **0.02*** |
| **Ncaute** | **-0.008** | **0.97** | **0.00*** |

# Appendix F

**Size class distributions (SCD) parameters (slope,$R^2$ (%) and p-value) for each of the selected woody species in the different areas. SCDs are based on data for individuals with a DBH of more than 5 cm.**

| Species | Area | Slope | $R^2$ (%) | p-value |
|---|---|---|---|---|
| *Baikiaea plurijuga* | Hamoye | -0.82466 | 71.1 | 0.000566* |
| | Kahenge | -2.8107 | 75.8 | 0.000228* |
| | Katope | -2.6488 | 73.7 | 0.000347* |
| | Mashare | -2.9733 | 88.3 | 0.000005* |
| *Burkea africana* | Hamoye | -2.7586 | 83.0 | 0.000014* |
| | Kahenge | -1.8087 | 59.5 | 0.001994* |
| | Katope | -2.4982 | 86.4 | 0.000004* |
| | Mashare | -2.5792 | 84.7 | 0.000008* |
| | Ncaute | -3.3231 | 85.5 | 0.000005* |
| *Pterocarpus angolensis* | Hamoye | -2.5062 | 74.2 | 0.000314* |
| | Kahenge | -2.1962 | 59.9 | 0.003135* |
| | Katope | -1.9512 | 80.1 | 0.000084* |
| | Mashare | -0.92386 | 19.9 | 0.14564 |
| | Ncaute | -2.3806 | 64.9 | 0.001547* |
| *Schinziophyton rautanenii* | Hamoye | 0.23696 | 0.9 | 0.76142 |
| | Kahenge | -1.0206 | 16.7 | 0.18575 |
| | Katope | -1.7408 | 36.6 | 0.037065* |
| | Mashare | 0.11475 | 1.26 | 0.72756 |
| | Ncaute | -1.4129 | 34.6 | 0.044153* |
| *Strychnos cocculoides* | Hamoye | -2.4735 | 83.0 | 0.000037* |
| | Kahenge | -1.3879 | 42.6 | 0.021209* |
| | Katope | -1.8721 | 60.2 | 0.002996* |
| | Ncaute | -1.6619 | 48.1 | 0.012361* |
| *Strychnos pungens* | Hamoye | -3.0847 | 87.6 | 0.000007* |
| | Katope | -1.5624 | 41.9 | 0.022741* |
| | Mashare | -1.0604 | 42.6 | 0.021209* |
| | Ncaute | -3.3116 | 81.6 | 0.000056* |

## Appendix G

The output for the multi variate regressions for the different environmental variables against seedling densities of the species.

| **Fire gap** | Slope | Error | Intercept | Error | r | p |
|---|---|---|---|---|---|---|
| Baiplu | -4.6508 | 9.3065 | 136.41 | 85.067 | -0.04635 | 0.61821 |
| Burafr | -43.002 | 26.553 | 857.52 | 242.71 | -0.14869 | 0.10807 |
| Pteang | 1.9751 | 1.6139 | -0.50222 | 14.752 | 0.1129 | 0.22351 |
| Schrau | -44.09 | 34.674 | 521.43 | 316.94 | -0.11725 | 0.20607 |
| Strcoc | 2.9848 | 8.7725 | 30.891 | 80.186 | 0.031575 | 0.73429 |
| Strpun | 0.067665 | 4.6031 | 79.276 | 42.075 | 0.001365 | 0.9883 |
| **Shrub cover** | Slope | Error | Intercept | Error | r | p |
| Baiplu | 0.72867 | 2.9632 | 85.836 | 56.197 | 0.022826 | 0.80619 |
| Burafr | -8.773 | 8.5038 | 629.96 | 161.27 | -0.09535 | 0.30438 |
| Pteang | -0.07464 | 0.51671 | 17.341 | 9.7993 | -0.01341 | 0.88539 |
| Schrau | 13.536 | 11.037 | -60.58 | 209.31 | 0.11315 | 0.22249 |
| Strcoc | -2.7458 | 2.7806 | 98.604 | 52.735 | -0.0913 | 0.32546 |
| Strpun | -1.6647 | 1.4563 | 105.61 | 27.618 | -0.10554 | 0.25535 |
| **Distance to roads** | Slope | Error | Intercept | Error | r | p |
| Baiplu | -10.187 | 9.726 | 140.14 | 52.283 | -0.09679 | 0.29708 |
| Burafr | 35.827 | 27.967 | 342.87 | 150.34 | 0.11811 | 0.20273 |
| Pteang | -0.66823 | 1.7025 | 19.008 | 9.152 | -0.03642 | 0.69542 |
| Schrau | -48.076 | 36.348 | 351.97 | 195.39 | -0.12189 | 0.18855 |
| Strcoc | -4.5723 | 9.1961 | 75.422 | 49.434 | -0.04612 | 0.61999 |
| Strpun | 2.1982 | 4.8238 | 70.563 | 25.93 | 0.042273 | 0.64946 |
| **Distance to Omiramba** | Slope | Error | Intercept | Error | r | p |
| Baiplu | -13.082 | 10.22 | 137.14 | 44.928 | -0.11802 | 0.20307 |
| Burafr | 35.383 | 29.48 | 385.94 | 129.6 | 0.11075 | 0.23249 |
| Pteang | -0.9083 | 1.7923 | 18.964 | 7.8793 | -0.047 | 0.61328 |
| Schrau | -35.855 | 38.426 | 258.6 | 168.92 | -0.08631 | 0.35271 |
| Strcoc | -0.87527 | 9.6953 | 58.787 | 42.622 | -0.00838 | 0.92822 |
| Strpun | 2.3937 | 5.0801 | 72.525 | 22.333 | 0.043707 | 0.63839 |

## Appendix H

The plot locations for the sample plots that were used in the study.

| plot | Area | lat_DD | long_DD |
|---|---|---|---|
| HAMP 1 | Hamoye state forest 1 km | -18.1986 | 19.71644 |
| HAMP 10 | Hamoye state forest 10 km | -18.216 | 19.63392 |
| HAMP 11 | Hamoye state forest 10 km | -18.2141 | 19.63381 |
| HAMP 12 | Hamoye state forest 10 km | -18.2124 | 19.63381 |
| HAMP 2 | Hamoye state forest 1 km | -18.1963 | 19.71561 |
| HAMP 3 | Hamoye state forest 1 km | -18.1946 | 19.71589 |
| HAMP 4 | Hamoye state forest 3 km | -18.2022 | 19.69897 |
| HAMP 5 | Hamoye state forest 3 km | -18.2005 | 19.69842 |
| HAMP 6 | Hamoye state forest 6 km | -18.1986 | 19.69742 |
| HAMP 7 | Hamoye state forest 6 km | -18.2082 | 19.67142 |
| HAMP 8 | Hamoye state forest 6 km | -18.2065 | 19.66878 |
| HAMP 9 | Hamoye state forest 6 km | -18.2046 | 19.66836 |
| MASP 1 | Mashare 2 km | -17.9269 | 20.1195 |
| MASP 10 | Mashare 20 km | -18.0717 | 20.18767 |
| MASP 11 | Mashare 20 km | -18.07 | 20.18844 |
| MASP 12 | Mashare 20 km | -18.0684 | 20.18953 |
| MASP 2 | Mashare 2 km | -17.925 | 20.12028 |
| MASP 3 | Mashare 2 km | -17.9234 | 20.12128 |
| MASP 4 | Mashare 5 km | -17.9594 | 20.13272 |
| MASP 5 | Mashare 5 km | -17.9601 | 20.13489 |
| MASP 6 | Mashare 5 km | -17.9612 | 20.13681 |
| MASP 7 | Mashare 10 km | -17.9913 | 20.14739 |
| MASP 8 | Mashare 10 km | -17.9932 | 20.14867 |
| MASP 9 | Mashare 10 km | -17.9945 | 20.15028 |
| HAM 1 | Hamoye | -18.2077 | 19.63802 |
| HAM 2 | Hamoye | -18.2017 | 19.6657 |
| HAM 3 | Hamoye | -18.1956 | 19.69336 |
| HAM 4 | Hamoye | -18.1926 | 19.70712 |
| HAM 5 | Hamoye | -18.1897 | 19.72102 |
| HAM 6 | Hamoye | -18.1866 | 19.73482 |
| HAM 7 | Hamoye | -18.1837 | 19.74863 |
| HAM 8 | Hamoye | -18.2041 | 19.63718 |
| HAM 9 | Hamoye | -18.1981 | 19.66485 |
| HAM 10 | Hamoye | -18.1921 | 19.6925 |
| HAM 11 | Hamoye | -18.1891 | 19.70633 |
| HAM 12 | Hamoye | -18.1861 | 19.72016 |
| HAM 13 | Hamoye | -18.1831 | 19.73397 |
| HAM 14 | Hamoye | -18.1801 | 19.74785 |
| HAM 15 | Hamoye | -18.2002 | 19.63808 |
| HAM 16 | Hamoye | -18.1946 | 19.66406 |

| plot | Area | lat_DD | long_DD |
|---|---|---|---|
| HAM 17 | Hamoye | -18.1881 | 19.69335 |
| HAM 18 | Hamoye | -18.185 | 19.70721 |
| HAM 19 | Hamoye | -18.182 | 19.72104 |
| HAM 20 | Hamoye | -18.179 | 19.73487 |
| HAM 21 | Hamoye | -18.176 | 19.74868 |
| HAM 22 | Hamoye | -18.1587 | 19.71162 |
| HAM 23 | Hamoye | -18.1719 | 19.71445 |
| HAM 24 | Hamoye | -18.1984 | 19.72075 |
| HAM 25 | Hamoye | -18.2117 | 19.72333 |
| HAM 26 | Hamoye | -18.1593 | 19.70771 |
| HAM 27 | Hamoye | -18.1726 | 19.71072 |
| HAM 28 | Hamoye | -18.199 | 19.71673 |
| HAM 29 | Hamoye | -18.2123 | 19.71972 |
| NCA 30 | Ncaute | -18.3349 | 19.78792 |
| NCA 31 | Ncaute | -18.3225 | 19.78238 |
| NCA 32 | Ncaute | -18.31 | 19.77681 |
| NCA 33 | Ncaute | -18.2975 | 19.77125 |
| NCA 34 | Ncaute | -18.3349 | 19.79196 |
| NCA 35 | Ncaute | -18.3225 | 19.78649 |
| NCA 36 | Ncaute | -18.31 | 19.78094 |
| NCA 37 | Ncaute | -18.2975 | 19.77541 |
| NCA 38 | Ncaute | -18.3349 | 19.79601 |
| NCA 39 | Ncaute | -18.3225 | 19.79048 |
| NCA 40 | Ncaute | -18.31 | 19.78491 |
| NCA 41 | Ncaute | -18.2975 | 19.77935 |
| NCA 42 | Ncaute | -18.2901 | 19.92193 |
| NCA 43 | Ncaute | -18.2902 | 19.89353 |
| NCA 44 | Ncaute | -18.2903 | 19.86517 |
| NCA 45 | Ncaute | -18.2903 | 19.83679 |
| NCA 46 | Ncaute | -18.2903 | 19.80844 |
| NCA 47 | Ncaute | -18.2904 | 19.79423 |
| NCA 48 | Ncaute | -18.2904 | 19.78002 |
| NCA 49 | Ncaute | -18.294 | 19.9235 |
| NCA 50 | Ncaute | -18.294 | 19.89513 |
| NCA 51 | Ncaute | -18.2941 | 19.86675 |
| NCA 52 | Ncaute | -18.294 | 19.83837 |
| NCA 53 | Ncaute | -18.2941 | 19.81002 |
| NCA 54 | Ncaute | -18.2941 | 19.79585 |
| NCA 55 | Ncaute | -18.294 | 19.78162 |
| NCA 56 | Ncaute | -18.2865 | 19.92009 |
| NCA 57 | Ncaute | -18.2866 | 19.89172 |
| NCA 58 | Ncaute | -18.2866 | 19.86331 |
| NCA 59 | Ncaute | -18.2867 | 19.83498 |

| plot | Area | lat_DD | long_DD |
|---|---|---|---|
| NCA 60 | Ncaute | -18.2867 | 19.80662 |
| NCA 61 | Ncaute | -18.2868 | 19.79241 |
| NCA 62 | Ncaute | -18.2868 | 19.77821 |
| NCA 63 | Ncaute | -18.158 | 19.71522 |
| NCA 64 | Ncaute | -18.1712 | 19.71819 |
| NCA 65 | Ncaute | -18.1978 | 19.72416 |
| NCA 66 | Ncaute | -18.211 | 19.72709 |
| KAH56 | Kahenge | -17.8047 | 18.66852 |
| KAH57 | Kahenge | -17.8095 | 18.66826 |
| KAH58 | Kahenge | -17.8031 | 18.64896 |
| KAH59 | Kahenge | -17.8073 | 18.64944 |
| KAH60 | Kahenge | -17.6488 | 18.59966 |
| KAH61 | Kahenge | -17.652 | 18.60183 |
| KAT62 | Katope | -17.6653 | 18.57087 |
| KAH63 | Kahenge | -17.6618 | 18.5654 |
| KAH64 | Kahenge | -17.6493 | 18.58596 |
| KAH65 | Kahenge | -17.6847 | 18.55153 |
| KAT66 | Katope | -18.0828 | 19.09844 |
| KAT67 | Katope | -18.0843 | 19.09574 |
| KAT68 | Katope | -18.0605 | 19.07623 |
| KAH70 | Kahenge | -17.8724 | 18.50922 |
| KAH71 | Kahenge | -18.0967 | 19.1061 |
| KAT72 | Katope | -18.1055 | 19.0911 |
| KAT73 | Katope | -18.1084 | 19.09499 |
| KAT74 | Katope | -18.1172 | 19.08553 |
| KAT75 | Katope | -18.1185 | 19.08953 |
| KAT76 | Katope | -18.1544 | 19.06367 |
| KAT77 | Katope | -18.1281 | 19.07444 |
| KAT78 | Katope | -18.0967 | 19.11702 |
| KAT79 | Katope | -17.7011 | 18.53429 |
| KAH80 | Kahenge | -17.7001 | 18.53051 |
| KAH81 | Kahenge | -17.7156 | 18.52028 |
| KAH82 | Kahenge | -17.7137 | 18.51692 |
| KAH83 | Kahenge | -17.8054 | 18.66627 |
| KAH84 | Kahenge | -17.7997 | 18.68006 |

## Appendix I

**An example of the calculation for multi-stem proportions using *Baikiaea plurijuga*.**

| Species | Area | number of trees | number of multistemmed individuals | single stemmed individuals | proportion of multi stemmed individuals (plants with multistems/total plants in plot) | percentage |
|---|---|---|---|---|---|---|
| Baiplu | Hamoye | 50 | 8 | 42 | 0.16 | 16 |
| Baiplu | Kahenge | 24 | 9 | 15 | 0.375 | 37.5 |
| Baiplu | Katope | 42 | 13 | 29 | 0.30952381 | 30.95238 |
| Baiplu | Mashare | 12 | 5 | 7 | 0.416666667 | 41.66667 |
| Baiplu | Ncaute | 0 | 0 | 0 | 0 | 0 |

## Appendix J

The derived distances to nearest features for the sample plots (units are meters but converted to km for analysis

| Area | villages (m) | roads (m) | rivers (m) | Omiramba (m) |
|---|---|---|---|---|
| Hamoye | 12745.45 | 10864.85 | 23000 | 7000 |
| Hamoye | 7292.594 | 6103.278 | 22000 | 6500 |
| Hamoye | 5945.532 | 5080.354 | 20000 | 8000 |
| Hamoye | 4481.192 | 3985.599 | 20000 | 0 |
| Hamoye | 3127.919 | 2735.416 | 19000 | 0 |
| Hamoye | 1694.259 | 1453.444 | 19000 | 0 |
| Hamoye | 12853.23 | 11002.84 | 18000 | 0 |
| Hamoye | 10169.41 | 8615.393 | 23000 | 6500 |
| Hamoye | 7393.343 | 6260.391 | 22000 | 6500 |
| Hamoye | 5916.823 | 5271.148 | 20000 | 7500 |
| Hamoye | 4510.698 | 4057.709 | 19000 | 0 |
| Hamoye | 9802.558 | 8176.337 | 19000 | 0 |
| Hamoye | 3143.107 | 2785.678 | 18000 | 0 |
| Hamoye | 1687.803 | 1450 | 18000 | 0 |
| Hamoye | 6202.216 | 5431.621 | 23000 | 6000 |
| Hamoye | 5499.004 | 5097.548 | 21000 | 6000 |
| Hamoye | 4203.563 | 3250 | 20000 | 7500 |
| Hamoye | 3305.941 | 2150.581 | 19000 | 0 |
| Hamoye | 6607.905 | 5869.625 | 18000 | 0 |
| Hamoye | 5895.061 | 5439.209 | 18000 | 0 |

| | | | | |
|---|---|---|---|---|
| Hamoye | 4545.559 | 3580.503 | 17000 | 0 |
| Hamoye | 3678.729 | 2462.214 | 16000 | 7500 |
| Hamoye | 7048.662 | 5798.276 | 17000 | 0 |
| Hamoye | 5827.404 | 4801.042 | 20000 | 0 |
| Hamoye | 4315.209 | 3764.306 | 21000 | 0 |
| Hamoye | 2894.346 | 2528.339 | 16000 | 7000 |
| Hamoye | 5805.775 | 5088.467 | 17000 | 8000 |
| Hamoye | 5106.058 | 4732.071 | 20000 | 0 |
| Hamoye | 3937.227 | 3000 | 22000 | 0 |
| Hamoye | 2930.173 | 1890.106 | 16000 | 7500 |
| Hamoye | 1636.973 | 1234.909 | 17000 | 0 |
| Hamoye | 12886.28 | 10999.66 | 20000 | 0 |
| Hamoye | 9984.018 | 8412.045 | 21000 | 0 |
| Hamoye | 4595.567 | 3580.503 | 20000 | 0 |
| Hamoye | 13138.16 | 11164.68 | 24000 | 7500 |
| Hamoye | 13158.86 | 11194.31 | 24000 | 7500 |
| Hamoye | 13169.21 | 11214.72 | 24000 | 7000 |
| Hamoye | 4809.196 | 3841.875 | 20000 | 0 |
| Hamoye | 4845.834 | 3890.051 | 20000 | 0 |
| Hamoye | 6207.378 | 4900.255 | 21000 | 0 |
| Hamoye | 6327.489 | 5085.519 | 21000 | 0 |
| Hamoye | 6505.653 | 5273.756 | 21000 | 0 |
| Hamoye | 9050.494 | 7390.027 | 22000 | 7500 |
| Hamoye | 9369.065 | 7720.104 | 22000 | 7500 |
| Hamoye | 9450.187 | 7795.03 | 22000 | 7000 |
| Kahenge | 849.8903 | 316.2278 | 7000 | 8000 |

| | | | | |
|---|---|---|---|---|
| Kahenge | 977.2551 | 150 | 6000 | 7500 |
| Kahenge | 1708.259 | 269.2582 | 6000 | 7000 |
| Kahenge | 1831.686 | 150 | 5000 | 6500 |
| Kahenge | 2665.453 | 984.8858 | 22000 | 0 |
| Kahenge | 2669.831 | 1166.19 | 21000 | 0 |
| Kahenge | 1728.56 | 390.5125 | 21000 | 0 |
| Kahenge | 1691.392 | 250 | 22000 | 0 |
| Kahenge | 4016.701 | 250 | 18000 | 0 |
| Kahenge | 2559.881 | 5634.936 | 1000 | 4000 |
| Kahenge | 1989.867 | 2263.846 | 23000 | 7000 |
| Kahenge | 4452.058 | 141.4214 | 17000 | 0 |
| Kahenge | 3210.018 | 212.132 | 15000 | 0 |
| Kahenge | 3379.894 | 141.4214 | 16000 | 0 |
| Kahenge | 1094.973 | 250 | 7000 | 8000 |
| Kahenge | 786.2929 | 180.2776 | 8000 | 0 |
| Katope | 1124.02 | 282.8427 | 20000 | 0 |
| Katope | 3024.22 | 3180.016 | 21000 | 5500 |
| Katope | 3250.471 | 3432.929 | 21000 | 5500 |
| Katope | 5715.103 | 6328.507 | 18000 | 3000 |
| Katope | 3286.564 | 4032.679 | 24000 | 6500 |
| Katope | 3339.31 | 3761.981 | 24000 | 7000 |
| Katope | 1901.775 | 4956.309 | 25000 | 6500 |
| Katope | 2166.669 | 4551.099 | 25000 | 6500 |
| Katope | 1089.043 | 8184.283 | 29000 | 2000 |
| Katope | 176.9223 | 6208.462 | 26000 | 5500 |
| Katope | 837.6394 | 1128.051 | 23000 | 8000 |

| | | | | |
|---|---|---|---|---|
| Katope | 4301.748 | 180.2776 | 17000 | 0 |
| Mashare | 1968.974 | 1118.034 | 1000 | 1500 |
| Mashare | 1105.788 | 12026.01 | 14000 | 3000 |
| Mashare | 1094.254 | 12180.72 | 14000 | 2500 |
| Mashare | 1088.172 | 12397.28 | 14000 | 2500 |
| Mashare | 1802.32 | 1252.996 | 1000 | 1000 |
| Mashare | 1636.748 | 1281.601 | 1000 | 1000 |
| Mashare | 1109.901 | 2661.297 | 5000 | 5000 |
| Mashare | 1158.455 | 2862.254 | 5000 | 5000 |
| Mashare | 1206.392 | 3085.855 | 5000 | 5000 |
| Mashare | 1117.498 | 6532.419 | 7000 | 1500 |
| Mashare | 874.6833 | 6779.75 | 7000 | 1500 |
| Mashare | 704.9948 | 6983.552 | 8000 | 1500 |
| Ncaute | 6190.739 | 180.2776 | 35000 | 6500 |
| Ncaute | 7594.433 | 250 | 33000 | 8000 |
| Ncaute | 9043.49 | 291.5476 | 32000 | 0 |
| Ncaute | 8916.75 | 158.1139 | 31000 | 0 |
| Ncaute | 5862.953 | 583.0952 | 35000 | 6500 |
| Ncaute | 7286.682 | 700 | 33000 | 8000 |
| Ncaute | 8752.955 | 667.0832 | 32000 | 0 |
| Ncaute | 9039.443 | 538.5165 | 31000 | 0 |
| Ncaute | 5551.487 | 961.7692 | 35000 | 6000 |
| Ncaute | 7003.561 | 1092.016 | 34000 | 7500 |
| Ncaute | 8487.763 | 1059.481 | 32000 | 0 |
| Ncaute | 9175.686 | 948.6833 | 31000 | 0 |
| Ncaute | 8189.661 | 7350 | 33000 | 2500 |

| | | | | |
|---|---|---|---|---|
| Ncaute | 7999.823 | 8234.227 | 32000 | 3500 |
| Ncaute | 8991.97 | 8161.648 | 31000 | 4000 |
| Ncaute | 9120.254 | 6911.765 | 31000 | 6000 |
| Ncaute | 9379.211 | 4079.828 | 30000 | 0 |
| Ncaute | 9164.258 | 2685.61 | 30000 | 0 |
| Ncaute | 8461.955 | 1320.038 | 30000 | 0 |
| Ncaute | 7817.783 | 7200 | 34000 | 3000 |
| Ncaute | 7557.147 | 7769.492 | 33000 | 3500 |
| Ncaute | 8536.57 | 7823.363 | 32000 | 4500 |
| Ncaute | 8728.577 | 6914.658 | 31000 | 6000 |
| Ncaute | 8926.184 | 4159.928 | 31000 | 0 |
| Ncaute | 9432.689 | 2720.294 | 30000 | 0 |
| Ncaute | 8899.946 | 1297.112 | 30000 | 0 |
| Ncaute | 8531.854 | 7550 | 33000 | 2500 |
| Ncaute | 8425.865 | 8646.965 | 32000 | 3000 |
| Ncaute | 9452.538 | 8563.439 | 31000 | 3500 |
| Ncaute | 9504.073 | 6912.308 | 30000 | 6000 |
| Ncaute | 9620.377 | 4067.247 | 30000 | 0 |
| Ncaute | 8716.626 | 2711.549 | 30000 | 0 |
| Ncaute | 8015.451 | 1341.641 | 29000 | 0 |