STRUCTURAL DIVERSITY OF PRUNUS AFRICANA IN THE EASTERN HIGHLANDS OF ZIMBABWE

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ABSTRACT

This study assessed the structural diversity of *Prunus africana* in the Eastern Highlands of Zimbabwe through the use of structural indices. The indices used include mingling (DMi), and diameter and height differentiation. Adaptive cluster sampling was applied which involved the identification of *P. africana* reference trees as a starting point. Cluster sampling then followed once the reference trees were located. A structural group of four consisting of a *P. africana* reference tree and three other neighbours was used in sample plots in three case study sites namely Nyanga National Park, Cashel Valley Estate and Chirinda Forest Reserve.

For the determination of regeneration, seedlings within a radius distance of 14 m from the mother tree were counted. A total of 251 *P. africana* trees were identified and used for calculations of structural indices, diameter and height class distributions as well as population structure. The highest DBH and height (p< 0.05) were recorded for Chirinda Forest Reserve and was significantly different (P< 0.05) from those recorded for the other two sites, i.e. Nyanga National Park and Cashel Valley Estate. The tallest trees (P< 0.05) were recorded again from Chirinda Forest Reserve, followed by Cashel Valley Estate and then Nyanga National Park. For all the three sites, a positive and smooth allometric relationship (r² = 0.381, P < 0.001, n= 244) was obtained between *P. africana* DBH and height. Results from the sites indicated *P. africana* to have high positive diameter and height differentiations with only a small number of reference trees having smaller DBH and being shorter than their neighbours. All sites showed 100% of the DMi class 1 for the structural group of four and Nyanga National Park had a relatively high proportion of the DMi class 1.00 (87%) and a smaller proportion of the 0.67 (13%). Recruitment and regeneration was very poor in all the three sites with seedlings and saplings being recorded on only a few clusters in all the three sites i.e. Cashel Valley Estate, Chirinda Forest Reserve and Nyanga National Park. The three sites recorded an unusual size class distribution was dominated by mature *Prunus africana* trees with very few seedlings or without any seedlings at all. In general, regeneration and recruitment was low in all the three sites studied. The results indicate that even though *P. africana* it is not under bark exploitation in Zimbabwe *P. africana* is not replacing itself at a rate which is sufficient enough to maintain its current density which implies that the species is naturally declining.
DEDICATION

I dedicate this research project to my late mother, IRENE H. NGOROYEMOTO for all her
tireless efforts to make me the person I am today. MOM your memory will forever be
cherished for without you life wouldn’t be the same. Your wishes will be fulfilled.

“ALWAYS LOVED”.
ACKNOWLEDGEMENTS

I would like to convey a very special thank you to my supervisor, lecturer and friend, Dr. Luke Jimu for coming up with the idea and the immense effort he placed in this research to make it a success. I did not have confidence in what I was doing but he made the work appear easy. I would like also to extend my sincere gratitude to all those who were at the battle front collecting the much needed data, Mr. Ndalem (project photographer, Mr Mushore, Mr Mureva and Mr. Matuvhunye, driver of the project. Thank you guys for a job well done and for the warm and dark moments shared because the light moments rendered the work easy to do. I would like to extend my gratitude to all those who in way assisted directly and indirectly towards the successful completion of this research.

It is true that behind every successful man is a woman, I will not forget the love of my life, my dear wife for all the encouragement and support she gave me. Dear, your prayers have not come to naught. My children, Celeste, Alcides and Ariel, guys, thank you for enduring having a father who spent most of his time away from home. I promise to be always there for you.
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CHAPTER ONE

INTRODUCTION

1.0 Background to the Study

Human life depends on the goods and services provided by nature, especially vegetation. Life is not possible without nature. Food, air and shelter are basic requirements for humans which are derived from the environment yet the impacts of the very same humans on ecosystems continue unabated. The human population has ever been increasing and continues to increase and this places a strong strain on nature’s goods and services. There is an increased level of consumption and emergence of novel human afflictions. This in turn has translated into an increased demand for the goods and services provided by nature thereby pushing against the limits of sustainability (McRoberts et al., 2008) when the main goal of natural resource management is sustainability (Kumar et al., 2011).

The world is faced with a plethora of environmental problems which range from forest deforestation, global warming, ozone layer depletion, air pollution and natural disasters. Forest destruction results in very serious consequences the most prominent being habitat destruction which culminates in the extinction of both plant and animal species (Farwig et al., 2007). A number of international bodies have been set up as a result of the overexploitation of biodiversity with the objective of promoting the regulation of exploitation, conservation and trade of biodiversity species (MacRoberts et al., 2008; Ingram et al., 2009). The Convention of Biological Diversity (CBD) and the Convention on International Trade in Endangered species of wild fauna and flora (CITES) are the most prominent of such bodies.

Forest and wetland ecosystems are considered as “free goods” by national governments as noted by the Global Biodiversity Strategy (WRI, 1992). In this context, their degradation does not count as depreciation on a nation’s basic capital stock in calculations of the Gross National Product (GNP). There is need for environmental accounting considering the exploitation of nature’s goods and services. In this way a comparison can be made of the economic benefits of goods harvested and the real costs involved. Local people and traditional leaders are well aware of these costs. This knowledge is available through consultations with members of local communities, especially traditional medicine.
practitioners, forest users such as hunters and beekeepers, community forest managers and patrols, and by commercial exploiters (Jimu, 2011).

In nature, the presence or absence of a given species at a given time is regulated by diverse mechanisms which interact as constraints (Betti, 2008). The notion of constraints illustrates that all is not possible for a given species according not only to its proper nature, but also to many other pressures faced by the species. Such constraints could either be external or internal constraints (Betti 2008).

At global level, the ecological impact of the exploitation of forest resources is a function of the social factors or preference. Examples include economic factors (trade), the floristic composition of the forest and the nature of the exploited species (Cunningham, 1994, Peters 1997 cit. Betti, 2008). In this regard, the most threatened species are those which are more popular because of their economic attributes, those which grow slowly, those which encounter difficulties in their production system, those which have preferential habitats e.g. fragile or threatened habitats and those whose distribution area has a limit (Cunningham and Mbenkum, 1993; Okafor and Ham, 1999).

A typical example of such threatened species is *Prunus africana* which has a patchy distribution and is highly concentrated in areas with big empty gaps between rich patches because of its high light requirements (Hall *et al.*, 2000; Betti, 2008).

**1.1.0 General Description**

*Prunus africana* (Hook f) Kalkman (Rosaceae) commonly known as the African cherry or by its synonym *Pygeum africanum* or Pygeum is indigenous to Africa and is endemic to high conservation and catchment value mountain forests (Cummingham and Mbenkum, 1993; Hall *et al.*, 2000; Orwa *et al.*, 2009). The low species densities and the shrinking and increasing degraded montane ecosystem and high levels of trade led to its classification as a “vulnerable” species (ICRAF/IRAD, 2008; Ingram *et al.*, 2009).

Several studies including those by (Cunningham and Mbenkum, 1993; Hall *et al.*, 2000) have described *P. africana* as a tall (from 6-45m), long-lived, dense wooded evergreen tree which is patchily distributed in montane forests, forests remnants or forest margins. It occurs
naturally on mountains, normally at high altitudes (above 800m) where access is difficult and there are very few species of interest for exploitation. The tree is native to higher elevations of Central and Southern Africa (Orwa et al., 2009; Cunningham and Mbenkum 1993). In most forest areas where *P. africana* is found, apart from over-harvesting, other physical threats include encroachment by agriculture, invasive alien species, cattle and goat grazing and fire damage (WHINCONET, 2005; Ingram et al., 2009).

### 1.1.1 Taxonomy

*Prunus africana* belongs to the genus *Prunus* which is made up of about 400 species most of which are distributed in the North Temperate zone of America, Europe and Asia. Many of the species can be cultivated or harvested from the wild for their edible fruits (Mabberly cit. Ndam et al., 2000). Such species include *Prunus persica*, *P. armenica*, *P. avium*, *P. cerasus*, *P. dulcis* and *P. almond*. Of the 400 species, only 75 are tropical species in Asia and America and *P. africana* happens to be the only Sub-Saharan Africa species of the genus. The tree formerly known as *Pygeum africanum* was renamed *P. africana* after the work of Kalkman in 1965 (Nkeng et al., 2010). The species belongs to the family Rosaceae subfamily Amygdaloidal syn. Prunoidea sub genus of Laurocerasus (Kalkman cit. Nkeng et al., 2010). The name Prunus is derived from the shape of its fruit which is referred to as a ‘prune’ or ‘prunus’ in Roman (Graham cit. Nkeng et al., 2010). *Prunus* has numerous vernacular names in areas in which it is found (Cunningham and Mbenkum, 1993). Local names given to *P. africana* by location include Wotango, Iluo. Vla (Cameroon), Mueri (Kenya) and Muchati/Muchambati in Zimbabwe only to mention but a few (Orwa et al., 2009). Figure 1 below shows a picture of a fully grown *P. africana* tree taken from Chimanimani in the Eastern Highlands of Zimbabwe.

The tree is classified as a medium size to large canopy, reaching 30-45m in height. It has an immense spreading crown in older individuals as can be seen in Fig 1. A dark platy, resinous bark is found in older trees (Fig 2.) whilst young trees possess a smoother bark with prominent lenticels (Nkeng et al., 2010). One of the rare abilities possessed by *P. africana* is its ability to regenerate the bark if the cambium is not destroyed (Stewart, 2003). A cherry odour is usually emitted from the leaves, twigs, fruits and bark when they are crushed. The odour is due to cyanogenic glycosides present in these tissues (Fraser et al., 1999).
Fig 1: A picture showing a fully grown *P. africana* tree taken from Chimanimani in the Eastern Highlands of Zimbabwe
1.1.2 Botanic description

*Prunus africana* is an evergreen tree (6-45) m in height with a stem diameter of 1-1.5 m (Hall *et al.*, 2000; Cummingham and Mbenkum, 1993). The bark of the tree is blackish-brown and rugged as shown in Fig 2.

![Image of Prunus africana bark](image)

**Fig 2:** The blackish-brown, platy and rugged bark of *P. africana*

The branchlets of *P. africana* have dots of breathing spots with knobbly twigs. The deeply fissured bark of the tree is of very economic importance because it is the one which is usually harvested, and then ground into a powder that can be used to treat symptomatic Prostatic Enlargement (PE) (Betti, 2008; Nkeng *et al.*, 2010). According to both chemical analysis and pharmacological studies *Pygeum africanum* has been found to contain three categories of active ingredients. These ingredients include phytosterols (particularly betasitosterol),
pentacyclic triterpenes (volatile oils) and ferulic acid esters (especially \textit{n}-docosanol) (Thorne Research, 2002; Ingram et al., 2009).

The tree has heavy shining foliage which is composed of alternate, simple leaves which can be oval or lance shaped and measure 5-15 x 2-6 cm. The leaves have a shiny deep green colour on top and dull and lighter on the lower side. The leaf veins are highly conspicuous and have a distinct midrib which is prominent on the underside. The leaf margins can be finely toothed (serrated) or untoothed and the petiole is about 2 cm long. Figure 3 shows \textit{P africana} leaves (Ndam et al., 2000).

\textbf{Fig 3:} \textit{P. africana} leaves, courtesy of the Eye Magazine (Acworth, 2003, 34)
1.1.3 Pollination and Breeding System of *Prunus africana*

*Prunus africana* has small, white or greenish, hairy, fragrant and haemaphrodite flowers which are borne abundantly in bundles i.e. has several raceme (Nkeng *et al.*, 2010, Cunningham, 2009). They are 5-7.6 cm long and are found in the axis of leaves or on the side of shoots. The flowers can be solitary or branched auxiliary sprays which are 3 -7 cm long (Ndam *et al.*, 2000; Nkeng *et al.*, 2010). Both the calyx and petals are small. The flower has 10-20 stamens. The flower of *P. africana* is shown in Figure 4.

![Prunus africana flowers](Image)

**Fig 4** *Prunus africana* flowers. (C) Bekele- Tesemma. World Agroforestry Centre,(2004).

The fruits of *P. africana* are drupes, spherical, bitter and about 7mm long, 1.3 cm broad and pinkish-brown in colour (Cunningham, 2009; Betti, 2008). They are also bilobed with a thin, dark red to reddish brown pulp when ripe. Figure 5 shows some *P. africana* fruits (Nkeng *et al.*, 2010)
Fig 5: Leaves and berries of *P. africana*, courtesy of Briza Publications (Ben-Erik van Wyk 2000).

### 1.1.4 Phenology of *P. africana*

The phenology of *P. africana* is variable from year to year as from area to area depending on the location (Ndam *et al.*, 2000; Betti, 2008, Cunningham, 2009). In its natural habitat, *P. africana* flowers between the months of November and February although in some areas the flowering pattern can be sporadic all year round (Ndam *et al.*, 2000; Betti, 2008; Ingram *et al.*, 2009; Nkem *et al.*, 2010). The tree species produces sticky, light, spherical and elongated pollen which measures 35 um in diameter (Betti, 2008; Nkeng *et al.*, 2010). The pollen grains have 90% viability after anthesis (Nkeng *et al.*, 2010). The species is both out crossing and self fertile although out crossing is proportionally higher than self pollination (Ndam *et al.*, 2000, Betti, 2008). The tree produces dimorphic flowers which are insect pollinated (Cunningham and Mbenkum, 1993, Nkeng *et al.*, 2010). The fruits develop within 4 to 6 months and are highly relished by birds and monkeys which are the main agents of their dispersal (Orwa *et al.*, 2009). According to Ndam *et al.*, (2000), Seedlings from clustered parent trees are more vigorous than those from isolated parents and this supports the notion that cross pollination is the breeding system preferred by *P. africana.*
1.1.5 Ecological Distribution

The species *Prunus africana* has a pan african distribution since it has been recorded in 22 countries in Africa (Cerrullo *et al.*, 2008; Nkeng *et al.*, 2010) as shown in Fig 6. It is found naturally occurring in Central and Eastern Africa, the Indian Ocean specifically in Madagascar and the Comoros Islands (Ingram *et al.*, 2009). The species is found distributed patchily in the countries where it is found. *Prunus africana* stands are also present in South Africa, Angola, Burundi, Ethiopia, Fernado Po, Equatorial Guinea, Democratic Republic of Congo, Nigeria, Rwanda, Sao Tome and Principe, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe (Cunningham *et al.*, 1993; Hall *et al.*, 2000; Nkeng *et al.*, 2010). Mount Cameroon has the largest wild remaining population of *Prunus africana* (Cunningham and Mbenkum, 1993). It is found in 6 of the 10 provinces of Cameroon. The tree is found in association with other tree species which include *Albizia gummifora*, *Cassipourea malosa*, *Celtis africana*, *Podocarpus falcatus* and *Polyscias kikuyuensis*. The tree species has a high light requirement and usually grows best in forest gaps (Orwa *et al.*, 2009).
Fig 6: Map showing the distribution of *Prunus africana* in Africa (Nkeng et al., 2010).
1.1.6 Ecology and Habitat of *P. africana*

*Prunus africana* is a hardwood species whose distribution is greatly influenced by the following factors, altitude; rainfall and cloud cover (Hall *et al.*, 2000). Although the species can be found at lower altitudes, generally it is found between 900 and 3000m above sea level (Dorthe cit. Nkeng *et al.*, 2010). The annual temperature and annual rainfall preferences of this afro-montane tropical species are between 18°C and 26°C and 2000mm respectively (Achoundong cit Nkeng *et al.*, 2010). Afro-montane forests are associated with humic cambisols and nitrosols according to the FAO-UNESCO (1977) classification of soils (Nkeng *et al.*, 2010). According to Cunningham and Mbenkum (1993), *P. africana* is only one of few rare species that can get well adapted to montane savanna and resist bush fires.

1.2.0 Traditional and Modern Utilisation of *P. africana*.

*P. africana* has been widely known to have medicinal properties in East, Central and South African countries (Cunningham and Mbenkum, 1993; Betti, 2008). In Cameroon and on the island of Bioko, traditional healers use the bark and leaves of *P. africana* for medicinal practices (Sunderland and Nkefor, 2009). The bark is used in cattle as a purgative (Kalkman) cit. Nkeng *et al.*, 2010). *P. africana* is the 4th most popular medicinal plant in the Mt Cameroon region where it is used to treat ailments like malaria, stomach ache and fever (Nsom and Dick, 1992 cit (Betti, 2008). The bark of *P. africana* is said to regulate blood pressure, increase human immunity and is also able to treat asthma, mental disorders, and urinary tract problems and also is also believed to play a role in blood purification(Emmanuel, 2010; Tsobeng, 2008). The bark of *P. africana* can also be mixed with *Trichillia sp.* and *Olea capensis* to be used against syphilis (Ndam and Ewusi 1999 cit, Ndam *et al.*, 2000).

The species has high value timber, a hardwood with a specific gravity 0.70 the wood is usually exported for veneer and panelling (Brown 1978 cit Fraser *et al.*, 1999). Farmers in Cameroon and Kenya use it as a source of axe and hoe handles, agricultural implements and construction because of its durable nature (Vivien and Faure, 1985 cit Ndam *et al.*, 2000). Others uses include forehood, charcoal, furniture, poles, utensils like mortars, bee forage,
shade, ornamentation, windbreak and timber (Mbuya et al., 1999, Katande et al., 1995, Ndam, 1998 cit. Ndam et al., 2000). Beer pots for making banana beer have been made from *P. africana* in Kenya (Cunningham and Mbenkum, 1993).

### 1.2.1 Modern Utilisation

Interest in the species by Europeans started in the 1700s when the palliative effects of *Pygeum* bark on bladder pains was discovered (Ndam et al., 2009; Emmanuel, 2011). This led to Dr Jacques Debat, a French entrepreneur to lodge the first patent of *Pygeum* bark in 1966 (Cunningham and Mbenkum, 1993, Ewusi et al., 1992).

Prostate Gland Hypertrophy and Benign Prostate Hyperplasia (BHP) affect men around 40 years and above and so the efficacy of *P. africana* bark was patented against the above disease which is very common in western countries (Cunningham et al., 2002; Bodeker, 2005, Cerrillo et al., 2008; Emmanuel, 2010). Benign Prostatic Hypertrophy is an enlargement of the prostate and problems associated with this disorder include, high urination frequency, inability to empty the bladder, pain in passing out urine and post urine dribbling (Garnick, 1994 cit. (Fraser et al., 1999).

*Prunus* bark is now being processed by many companies to form tablets and mostly capsules as the final product (Ndam et al., 2000; Ingram, 2007). The *P. africana* products come under different names depending on the company as shown in Table 1 below.
Table 1. Capsules produced from *P. africana* bark, their trade/brand names and country of manufacture

<table>
<thead>
<tr>
<th>Brand / Trade Name</th>
<th>Company</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cartiz drags</td>
<td>Labotarios</td>
<td>Argentina</td>
</tr>
<tr>
<td>Bridolar</td>
<td>Spyfarma</td>
<td>Spain</td>
</tr>
<tr>
<td>Prohitrol</td>
<td>Informa</td>
<td>Spain</td>
</tr>
<tr>
<td>Pigenil</td>
<td>Inverni della</td>
<td>Italy</td>
</tr>
<tr>
<td>Prostenin</td>
<td>Baldacci</td>
<td>Brazil</td>
</tr>
<tr>
<td>Tadenan</td>
<td>Dictohelm 5080</td>
<td>Switzerland</td>
</tr>
<tr>
<td></td>
<td>Zurich</td>
<td></td>
</tr>
<tr>
<td>Tadenan</td>
<td>Laboratoire</td>
<td>France</td>
</tr>
<tr>
<td>Tadenan</td>
<td>Diamant</td>
<td>Portugal</td>
</tr>
<tr>
<td>Tadenan</td>
<td>Boehringer</td>
<td>Austria</td>
</tr>
<tr>
<td>Tadenan</td>
<td>Roussel</td>
<td>Italy</td>
</tr>
<tr>
<td>Trialnol</td>
<td>Lek</td>
<td>Yugoslavia</td>
</tr>
<tr>
<td>Tazunil</td>
<td>Carulla Vekar</td>
<td>Spain</td>
</tr>
<tr>
<td>Foudaril</td>
<td>Cap</td>
<td>Greece</td>
</tr>
</tbody>
</table>

Adapted from Ndam and Ewusi (1999)

Due to the growing international demand for its bark, *P. africana* was included in Appendix II of the Convention of International Trade in Endangered Species (CITES) as an endangered species in 1995 (Stewart 2003). This decision had a significant impact on the revenues produced from this non timber forest product (Bellewang, 2005. Since October 2007, the European Commission has banned the importation of *P. africana* coming from Cameroon in Europe (Ewusi et al., 1992). This had major impacts both on the economic operators and the local people for whom *P. africana* represents an important non timber forest product (Bellewang, 2005).

Despite its high economic importance in third world countries, its high medicinal value and its over-utilisation, very little has or nothing at all has been documented about *P. africana* in Zimbabwe and the tree has not been considered in plant breeding programmes. Taking into cognisance its multiple uses, *P. africana* can be a valuable agroforestry tree species in Zimbabwe and can play a bigger role in poverty alleviation in Zimbabwe and many other African countries where it is not being exploited. For the plant breeding programs to be successful in Zimbabwe there is need to study the wild environment in which *P. africana* thrives well, i.e. the ecology and threats to this particular tree species.
1.3.0 Problem Statement and Justification

Prunus africana trees are an essential component of the montane ecosystem. Tree deaths from bark stripping affects the integrity of the forest and reduces food resources for rare birds and animals leading to extinction (Cunningham and Mbenkum, 1993; Farwig et al., 2006; Betti, 2008). The tree’s interaction with its environment is of paramount importance and should be understood with precision considering the precarious status of the tree (Ndam, 2000). Knowledge of P. africana’s ecology and threats to its survival provide the answer in determining and exploiting opportunities for domesticating and cultivation of the tree both for conservation and trade purposes (Tchouto, 1996). With the high demand for the bark, the cultivation of P. africana can be a business venture which is remaining untapped in Zimbabwe. A thorough study of the tree’s structural diversity, ecology and associated threats could lead to more meaningful recommendations being made about its sustainable exploitation and domestication.

Prunus africana should not be harvested in Zimbabwe considering its endangered nature and thus intensive regeneration is required (African Regional Workshop, 1996). Ecology as a scientific study of the processes regulating the distribution and abundance of P. africana and the interactions among the species within the population and with other species. The study of how such interaction in turn mediates the transport and transformation of energy and matter in the biosphere is preliminary in efforts to conserve and domesticate the endangered species. With such an understanding currently there is little information on how such a tree with promising potential interacts with its environment. Again such questions as to why the tree species has a significantly low population even in undisturbed areas of Zimbabwe needs clarity and the suitable answer is studying the ecology of the tree species. With the growing reality of climate change it is thus necessary to understand the ecological factors which promote the growth of this species and how these factors are affected by climate change and thus place mitigatory measures and have accurate predictions of the behaviour of the species behaviour after such change in climate.
1.3.1 Main Objectives

The main objective of this research was to determine the structural diversity of *Prunus africana* in the Eastern Highlands of Zimbabwe.

1.3.2 Specific Objectives

The search had some specific objectives which are stated below:

- To determine the regeneration and recruitment rates of *Prunus africana* in the Eastern Highlands of Zimbabwe
- To determine population structure and size-class distribution of *P. africana* in the Eastern Highlands of Zimbabwe.
- To determine mingling, DBH and height differentiation of *P. africana* in the Eastern Highlands of Zimbabwe.

1.4 Hypotheses

The research had the following hypotheses

- *Prunus africana* populations in the Eastern Highlands of Zimbabwe show a normal population structure.

- *Prunus africana* has a high regeneration and recruitment rate in the eastern Highlands of Zimbabwe.
CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

The earth’s land surface is made up of 22%-30% forest and wooded lands (FAO, 2006, GFW, 2006 cit. McRoberts et al., 2008) and also it has been noted that of the 12 major habitats of the earth, 6 are characterised as forests and two thirds of the world’s terrestrial ecoregions are within the six types (McRoberts et al.,2008). It is clear that forests are very critical in the maintenance of biodiversity. They are home to a myriad of species which are beneficial to humans in a direct or indirect manner Pappoe et al., 2010). Derived from forests are food, medicine, timber not forgetting non timber forest products which are obtained from forest (Pappoe et al., 2010). Indirect benefits from biodiversity obtained from the ecosystem include some of the following, protection of watershed, regeneration and climate regulation (Pappoe et al., 2010).

2.1.1 Forest Succession

There is a strong link between wildlife and forests such that the abundance of the two has always been parallel to each other throughout history (www.wildlife.state.nm.us). If there is no disturbance, an open field will be invaded by shrubs. The shrubs will later on be replaced by saplings which develop into young trees and eventually into a mature forest (www.environthonpa.org). In forestry the phases are referred to as the grass and forbs stage, scrub and sapling stage, pole stage and mature forest. This progression of forests in an orderly and predictive manner is what is termed forest succession (www.environthonpa.org). The rate of forest succession is variable since it is dependent on many variables which include soil conditions, topography, frequency of natural disturbance, number of animals and the amount of competing vegetation (www.environthonpa.org).

Through succession, the forest changes and so does its structure (www.environthonpa.org). The vertical structure of a forest consists of the overstory, understory, shrub and herbaceous
strata. In here, a variety of plants and animals can coexist (www.environthonpa.org). The maintenance of this structure results in a variety of wildlife since wildlife species divide their habitat vertically.

Structural diversity is all about the variety, size and shape of both living and non living organisms which include large standing trees and fallen dead trees. Both plant species diversity and vertical diversity all contribute towards structural diversity (www.environthonpa.org). Elements of structural diversity which include rotting logs and snags provide a hiding place for wildlife and attract insects and fungi eaten by wildlife. This on its own contributes to species richness and ecology of an area (www.environthonpa.org).

Forests provide other goods and services which go far beyond timber and this has led to the use of the idea of sustainable and multifunctional forestry. This is because of the significance of environmental and other services derived from forest ecosystems. Sustainability of forest communities can only be evaluated through the use of indices and one of the most important for such purpose is species diversity (Rad et al., 2009). Measurements of biodiversity generally focus on species level and as such species diversity is an important index in evaluating ecosystems at different levels (Ardakam cit. Rad et al., 2009). Forests have been fragmented into small patches worldwide and this has greatly influenced forest structure and species composition since habitats have been lost (Echeverria et al., 2006). Habitat reduction has been described as one of the main causes of the ever dwindling biological diversity in the tropics (Santos et al. cit. Wassie et al., 2010). Fragmentation of forests has had an impact on species richness and composition (Farwig et al., 2007).

2.1.2 Factors affecting Recruitment and Regeneration in Forest Communities

Forests fragmentation has various effects on remnant communities which include species loss (Laurance cit. Cordeiro et al., 2009). Fragmentation of forests brings about ecological changes which affect tree species in either a positive or negative manner. There is modification of abiotic conditions, poor representation of mutualists or increased effects of predators or pathogens all which results in altered ecological interactions (Cordeiro et al.,
Some tree species get extinct whilst some increase in number due to an increased competitive advantage especially those well served by long distance pollinators of dispersal agents or by opportunists (Cordeiro et al., 2009). These cascades of interactions overwhelm some species and prediction of the fate of rare and uncommon species is difficult to make (Cordeiro et al., 2009).

In some research (Cordeiro et al., 2009) it was observed that seeds which were not in the vicinity of their parents would develop into trees unlike those under parents which experienced a high mortality level and a lower transition success to juvenile sizes than those 10-20 m away from parent crowns. The scarcity of dispersal agents may lead to reduced seed dispersal and limited recruitment in a tree species (Schupp cit Cordeiro et al., 2009). An increase in seed predation by rodents or birds can also affect plant recruitment in forest patches (Terborgh et al. cit. Cordeiro et al., 2009). The limitation of pollinators or resources can also have adverse effects on fecundity in fragments. Limitation of resources, maternal effects or inbreeding depression can have an effect on seed quality and quality, (Young et al. cit Cordeiro et al., 2009). Seeds can also fail to perform under altered conditions of small fragments where there is more light availability and humidity is lower due to edge effects (Kapos cit Cordeiro et al., 2009).

Research has been carried out on *Prunus africana* a tree which is found abundant on disturbed sites especially along forest margins and according to some research carried on *Prunus africana* the trees have an average density of > 20 cm DBH. These surveys also revealed that seedlings are most abundant where there is good light penetration into the forest where undergrowth is sparse (Nkeng et al., 2010). In sample sites of surveys, there was unusual size-class distribution indicating low or sporadic recruitment (Ewusi et al., 1992, Ndam et al., 2000). The results show the episodic nature of natural regeneration which is a result of forest disturbance.

For *Prunus africana* it has been observed that regeneration and recruitment is effective but rather difficult (Cunningham et al., 1998). Major constraints are weed competition, limited light, insect damage which cause dieback and blockage of *P. africana* seedlings development and consequently restriction of recruitment and regeneration of *P. africana* in the forest (Ndam et al., 2000).
2.1.3 The concept of structural diversity

The Rio declaration in 1992 defined biodiversity as “the variability among living organisms from all sources” and the “diversity within species, between species and of ecosystem”. Other authors like Kimmions cit. Bohl and Lanz (2007) simply understand it as species richness and dominance in a system. This makes the making the monitoring of biodiversity a challenge because of the need to take into account many aspects of the ecosystem (Bohl and Lanz, 2007). McRoberts et al., (2008) refers to biological diversity as variety, abundance and genetic composition of species in the context of communities, ecosystem and regions they occur. According to Mitterbach cit. Lei et al., 2009) relationships between species diversity and ecosystem productivity are of long standing relevance to ecology. The numerous international agreements, protocols and processes which include the 1992 United Nations Conference on Environment and Development, the Montreal Protocol, 2006 and Ministerial Conference on the Protection of Forests of Europe (MCPFE 2002) is testimony of the relevance of biodiversity (McRoberts et al.,2008).

When discussing sustainability, diversity is a very important issue since the resilience and stability of forest ecosystems is often linked to the level of diversity (Pommerening, 2002, Ruprecht et al., 2009). Some interdependence do exist between the structural, functional and compositional attributes of a forest stand meaning that attributes for one group are surrogates from another (Franklin et al.,cit. Ruprecht et al.,2009).

Positioning, mixture and competition bring about the vertical and horizontal differentiation and this determines the variation in terms of space in microclimatic conditions, the supply of nutrients and structural complexity (Ruprecht et al., 2009). It is clearly understood that the presence and abundance of species is directly and indirectly affected by vertical and horizontal differentiation (Dhar et al., 2008). The composition and horizontal and vertical variation within forests defines the structural diversity of species (Ruprecht et al., 2009). The arrangement of these dimensions in relation to each other is what spatial diversity deals with. Trees grow as a reaction to their spatial context and growth processes determine the spatial forest structure (Dobbertin cit. Ruprecht et al., 2009). The growth process influences the spatial forest structure (Boungiorno, 1994). Spatial forest structure is modified by biotic and abiotic impacts which include humans (Pommerening, 2006). A sound understanding of these factors i.e. the relationship between biotic and abiotic and those impacts caused by humans
on the spatial structure is vital for the generation of activities to do with the management of forests and conservation measures (Ruprecht et al., 2009). This is usually true particularly for those species on the verge of extinction (Dhar et al., cit. Ruprecht et al., 2009).

2.1.4 Quantification of spatial forest structure

When referring to a stand level index of structural complexity, it is a mathematical construct that summarises the effects of two or more attributes of structure in one index value (Rad et al., 2009). An index if properly designed can be a reliable indicator of stand level biodiversity and can provide a means of ranking stands in terms of their potential contribution to the maintenance of biodiversity (Parkard and Radike, 2007). Indices have been used to study local diversity which include species richness and the indices serve as indicators of the complexity of the understory communities and also serve as information sources of the stability of the system to any future changes of the environment (Magurran cit, Rad et al., 2009).

2.1.5 Diversity Measurement tools

It is now nearly a century since diversity measurements have come into existence. Measures of species or age and other accepted metrics which include; ecosystem function, spatial arrangement and height and diameter differentiation have been used to describe diversity (Kohyana, 2003). Fig 7 shows the major components of ecological diversity.
According to Spie cit. Moser and Hansen (2006), important constituents of the forest structure are the following: (1) tree size/age distribution, (2) vertical foliage distribution, (3) horizontal canopy distribution and, (4) dead wood.

There has been a wide use of diversity indices for sampling procedures within stands (Sterba, 2008). Stand structural attributes like measures of abundance, richness, size variation and spatial variation have been used in forest quantification (Sterba, 2008). Indices such as skewness and coefficient of variation of dbh distribution, the Shannon index and the mingling index have been used to analyse species and species diversity of forest stands (Bilek et al., 2011).

Ecosystem diversity is divided on a spatial and areal scale into alpha, beta, gamma and delta diversity (MacArthur, Whittaker cit. Pommerening, 2002). Alpha diversity operates within forest stands whilst beta diversity deals with variation between forest stands. Larger scales are dealt with by gamma and delta. The increase in demand for alpha diversity particularly the spatial distribution of trees and their attributes (Ferris and Humphrey cit. Pommerening, 2002) has led to development of structural indices which describe certain horizontal aspects
of forest stand structure as mean values. Alpha diversity has three subdivisions, namely, (i) Diversity of tree positions, (ii) Tree species diversity and (iii) Diversity of tree positions (Pommerening 2002).

The relationship between competition and viability of a tree species can be assessed using structural indices like mingling, tree–tree distances, diameter and tree height differentiation (Ruprecht et al., 2009). Table 2 below shows some of the most important individual tree indices in use today. The resilience and stability of a forest ecosystem is usually a function of the biodiversity.

A number of indices have been developed for use in quantifying the spatial forest structure (Pommerening, 2002, Weigelt and Jollife, 2003, LeMay and Staudhammer, 2005) and with these indices; the effects of inter-specific and intra-specific competition on tree species viability can be identified. There is also provision of valuable information on the evolution of a stand and the underlying processes (Pommerening, 2006; Saunders and Wagner, 2008).

Sound forest management activities and strategies are only possible when there is a good understanding of the dependencies between the biotic, abiotic and human induced impacts on spatial forest structure. This is very relevant especially when dealing with endangered species (Dhar et al., 2008).

The environmental conditions of the population, its regeneration status and causes of declination have always been the focus of research studies on endangered species (Vacik et al., cit. Ruprecht et al., 2009). There have been few studies done using structural indices in identifying the effects of inter-specific and intra-specific competition on the viability of tree species in danger of extinction (Sohrabi et al., 2011).

The removal of tree species can either result in an increase or decrease in species diversity and can also alter the spatial pattern among stems or species and (or) change the size distribution of trees within a stand (Montes et al., cit. Saunders and Wagner, 2008). The maintenance of and creation of stand structural complexity using silvicultural intervention has now become the dominant theme in forest management. This aims to protect ecosystem functions and to conserve biodiversity (Saunders and Wagner, 2008). A common argument is that biodiversity can be maintained by way of managing the structural diversity of stands (Buongionio et al., 1994, Franklin et al., cit. Lei et al., 2009). Measures of stand diversity are
important in that they are indicative of the overall biodiversity and for use in predicting future stand growth and development (Kumar, 2006; Pretzsch cit. Lei et al., 2009).

The relationships between species diversity and ecosystem productivity are relevant in ecology (Mittelbach et al. cit. Lei et al., 2009). The maintenance of biodiversity and productivity is necessary for the management of forests in a sustainable manner (Lei et al., 2009). Stand structural diversity especially the variations in tree height and diameter is an important consideration in the conservation of forest biodiversity. According to Noss cit. Lei et al., 2009, composition, structure and function are the components of biological diversity which in turn affect other components of biodiversity. The components affected include compositional and functional diversity and consequently, economical, ecological and social values of practices of forest management (Kumar et al., 2011).

On the other hand, structural diversity is understood as a combination of tree species and tree height classes (Dhar, 1997). Structural diversity is defined as one or a combination of spatial distribution, species diversity and variation in tree dimensions such as the size and height (LeMay and Staudhammer 2005, Pommerening, 2002). Structural biodiversity indicates the overall species diversity for forested ecosystems. A number of growth patterns are related to structural complexity.

The diversity of trees in stands is referred to as stand structural diversity and it saves as an indicator of the overall biodiversity and the idealness of the habitat. This information is important when forecasting the growth of the stand (LeMay and Staudhammer, 2005). Structural complexity brings about different growth pattern on forest stands (Klopicic, and Boncina, 2011). The diversity of a habitat has three components i.e. structure, composition and function (McCleary and Mowart, 2002).

Spatial indices can be of use in comparing point patterns and in interpreting the ecology of species (Davis et al., 2000). Basing on tree attributes like species and tree size, a number of indices of stand structure have been proposed (LeMay and Staudhammer, 2005). Linked to structural diversity indices, competition indices have also been developed for use in modifying tree growth. For both types of indices, tree attributes like tree size and spatial arrangements are summarised as an index. The desirable characteristics of structural indices are that the indices should: (1) Be clear, specific and relevant to the intended uses. (2) Have known mathematical properties. (3) Be invariable to size differences (e.g. tree size for
competitive indices versus area size for structural indices). (4) Be unaffected by the specifics of the data gathered. (5) Be invariant to differences in frequencies. (6) Be standardised relative to a useful and universal standard (Weigelt and Jolliffe 2003).

The description of a stand structure is done using three components namely: (i) spatial pattern or positioning of stems of trees (ii) degree of mingling or intermixing of tree species and (iii) the degree of size differentiation among neighbours (Pommerening, 2002).

2.2.0 Factors affecting Growth

The amount of growth in height realised by a tree at a given stage is a result of a combination of the growth potential of the tree and the factors which limit the growth (Froese et al., 2002). Interaction of the genetic makeup of the tree and the environment in which the tree will be growing determine the growth potential of the tree. One major factor limiting the growth of a tree species is the competition for resources.

Site characteristics and competitive status of a tree determine its growth.

2.2.1. Measures of Size

Height increases is affected by the current growth rate and this is indicated by the height. The seedling stage has the lowest growth rate and the rate increases in the sapling stage only to slow down as tree matures (Zedaker et al., cit. Froese, 2002). Higher increases in height were observed in larger saplings than in small ones (Williams et al., cit. Froese, 2002). Diameter at Breast Height (DBH) is the diameter outside the bark of a given tree measured at about 1.3 m above the ground (Froese et al., 2002). Trees with a better competitive position happen to have larger diameters and greater height increments.

2.2.2. Topographic Effects

Different and varied factors are responsible for the diversity of plants in a region. The diversity of plant species is influenced by a number of topographic gradients and climatic gradients (De, 2007). The general observation is that areas with high species diversity are found in the middle latitude, particularly in the tropics because of the favourable climatic,
edaphic and other factors found in this area (De, 2007). Changing topology from place to place has a great influence on the composition of the forest (Singh et al., cit Bijalwan 2010)

The amount of sunlight received by any particular site is influenced by the aspect. More light is received by south and southwest facing slopes which will be exposed. These sites are warmer than the north and northeast (protected) slopes which also happen to be cooler (Karbrik and Larsen 1999). Soil properties are also affected by aspect. According to Stathers et al., cit. Froese et al., 2002, the slope and aspect together significantly influence the amount of solar radiation received by a site.

Light interception is a result of the slope and aspect. This can also affect soil runoff and infiltration which in turn influence moisture status and nutrient availability (Zedater et al cit. Froese et al., 2002). The number of growing degree days available to trees in a stand are also affected by the elevation. It has also an effect on the frequency of late and early frosts and average temperatures. The amount of moisture received by a site is correlated with elevation and moisture generally increases as elevation increases.

Some tree species like Prunus africana require light to promote regeneration (Ewusi et al., 1992) but the light also inhibits germination and seedling development (Sunderland and Nker, 1997). P. africana has generally been reported as a secondary forest species. Direct sunlight inhibits Prunus africana seed germination and seedling development up to a certain age and requires 50% shade.

2.2.4 Location

Precipitation, solar radiation, air temperature, humidity and wind are all affected by climate. This indirectly affects soil properties and thermal regime (Stathers et al cit. Froese et al., 2002). The information of the location is a reflection of the regional and local variation i.e. modification of climatic effects by topography.

The easting is the UTM (Universal Transverse Mercator) coordinate of the plot centre. Measurement of site location is done from west to east (Froese et al., 2002).

The northing is the UTM coordinate of site from the north to the south.
2.2.5 Stand density/Competitive status

Accessibility of available resources shared with neighbours determines the competitive ability of a plant. According to Begon *et al.* Welgelt and Jolliffe (2003), competition is an interaction of individuals arising as a result of a limited supply of shared resources which lead to a reduction of the performance (for example survival, growth and reproduction) of one of the competing individuals. Incorporated within competitive indices are factors describing the ability of trees in exploiting available resources (Dale *et al*., cit. Froese *et al*., 2002). Carbon resources are allocated to plant parts which increase the survival chances of a plant and in stress conditions resources are allocated to growth, both above and below ground so as to increase chances of accessing resources (Chen *et al*., 1996).

Variation of allocation depends on the stressor (Waring and Schlesinger cit. Froese *et al*., 2002). Shoot growth is inhibited by moisture stress and growth will be focussed on the roots. Deficiencies in nutrition may retard the formation of photosynthetic enzymes thereby reducing the development of tree canopy and shoot development will be slow. Height growth and increase in lateral branch growth is reduced by light sources which are restricted.

The Height to Diameter Ratio (HDR), is the ratio of height (cm) divided by the diameter (cm) According to Opio *et al* cit. Froese *et al*., 2002), HDR is an individual tree-based index. The HDR is lower in free growing trees and higher in a tree limited by competitive stress (William *et al*., cit. Froese, 2002).

2.2.6 Environmental Effects

The growth of a tree depends on the moisture content of the soil. The growth of a tree is usually low when there is moisture stress.
2.2.7 Interactions

Competition indices are specific to both species and site (Burton, 1993). The actual competition index of a given tree cannot be observed.

Wetter sites on exposed sites are often associated with more productivity while dry sites are more productive on protected aspects. An increase in elevation also increases the influence of exposed and protected sites.
CHAPTER THREE
MATERIALS AND METHODS

3.1 Description of Study Sites

The eastern highlands of Zimbabwe where we find Nyanga National Park (18°17′; 32°44′), Chirinda forest Reserve (20°24′; 32°43′) and Cashel Valley (19°31′; 32°48′) is part of the montane forest mosaic ecoregion (Jimu, 2011). The ecoregion stretches from the Cape Province and the Drakensberg in South Africa through to the Eastern Highlands of Zimbabwe, the Nyika Plateau of Malawi, the Rift Mountains along Lake Tanganyika and the isolated massifs of East Africa and finally the Ethiopian Highlands in the north. The Eastern Highlands of Zimbabwe forms the border between Zimbabwe and Mozambique and it stretches from Nyanga Highlands in the northern part, through Vumba Highlands, Chimanimani Mountains and the Chipinge Highlands in the Southern part (Jimu, 2011). This ecoregion experiences highly variable rainfall which ranges from 741 to 2997 mm. It is characterised by low cloud cover and early morning mist and heavy dew. It experiences relief rainfall which falls mostly in the summer months from November to April and is dry in the winter months from May to June. The annual mean temperatures range from 9°C to 12°C with 25°C to 28°C being the maximum temperatures experienced in the ecoregion. Extensive grassfires occur in high elevation grasslands from August to November due to the very hot weather (Jimu, 2011). The vegetation of the region is predominantly sub-montane and montane grasslands. A typical rain forest of the moist tropics consisting of five strata: the canopy, the sub-canopy, the sapling layer, the shrub layer and the ground layer is found in some parts (Jimu, 2011). The most common trees include Chrysophyllum gorungosanum, Craibia brevicaudata, Khaya anthotheca, Trichilia dregeana, Tannodia swynnertonii, Strychnos mellodora, Drypetes gerrardii, Heinsenia diervilleodes, Rothmannia urcelliformis and Pleiocarpa pycantha. Scattered through the ecoregion are Miombo woodlands dominated by deciduous Brachystegia, spiciformis, Brachystegia tamarinodoides and Uapaca kirkiana as well as grass species like Digitaria spp, Diabonalis spp, Londelia simplex and Themeda triandra (Jimu, 2011). Bordering Nyanga national park are forest estates like Erin from which Acacia mearnsii, Pinus patula and eucalyptus species all of which are invasive species are spreading causing a threat to biodiversity in the park and surrounding areas. Fig 7 below shows the area where this study was conducted.
3.2 Research design.

Adaptive cluster sampling was used which involved the identification of *P. africana* reference trees as a starting point (Jimu, 2011). Local knowledgeable people assisted with the identification of reference trees. Cluster sampling then followed once the reference trees were located and all *P. africana* trees in the cluster were done when no *P. africana* neighbours could be seen within a radius of 500 m (Jimu, 2011). The condition that trees are at least 3cm DBH and 2 m height could not be adhered to since large mature trees characterised all the clusters. The use of adaptive sampling technique was based on the assumption that every identified *P. africana* reference tree/ unit *i* in population *U* had a well defined neighbourhood made up of one or more other units (Jimu, 2011). This method is considered ideal because it is difficult to estimate the density of endangered and clustered
populations using conventional sampling designs. Adaptive cluster sampling has been found to be the most ideal in maximizing the efficiency of surveys compared to more conventional designs such as simple random sampling (Thompson and Seber, 1996; Jimu, 2011).
Table 2. *Prunus africana* clusters and their geolocation, elevation and size

<table>
<thead>
<tr>
<th>Site</th>
<th>Cluster Number</th>
<th>Geo-location</th>
<th>Elevation (m.a.s.l)</th>
<th>Cluster Size (Number of <em>P. africana</em> trees)</th>
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<td>Nyanga National Park</td>
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<td>3</td>
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<td>1809-1817</td>
<td>4</td>
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<td>1821-1837</td>
<td>3</td>
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<td>1778-1818</td>
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<td>1784-1795</td>
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<td>7</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td><strong>251</strong></td>
</tr>
</tbody>
</table>
3.3 Structural indices

Each *P. africana* tree was considered for neighbourhood analysis because of the small size of the clusters which ranged from 2-16 *P. africana* trees. Measurements of tree height were carried out using a sunto Hypsometer and measurements DBH of *P. africana* and the three neighbouring trees were done using a measuring tape. The computational units for the calculation of structural indices was the structural group of four (*P. africana* trees and their three neighbours). The structural indices calculated using this unit includes species mixture (mingling), DBH and height differentiation and distance to neighbours (Ruprecht *et al.*, 2009; Jimu, 2011). The species mixture of *P. africana* and its neighbouring trees is described by Mingling (DMi). Diameter differentiation (TDi) and height differentiation (HDi) was used to describe the relationship between *P. africana* and the surrounding trees in respect to diameter at breast height tree height (Ruprecht *et al.*, 2009; Jimu, 2011). According to Ruprecht *et al.*, 2009, diameter and height differentiation allows one to interpret the relationship between the reference tree and its neighbouring trees in respect to competition.

3.4 *Prunus africana* regeneration

The number of *P. africana* seedlings smaller than 150 cm height was recorded with the seedling population being split into 5 classes. The classes were as follows: seedlings under 1 year with embryonic leaves, seedlings with differentiated leaves and smaller than 5 cm height, seedlings 5.1-20 cm height, 20.1-50 cm and 50-150 cm high. Seedlings within a radius distance of 14m (the furthest distance within which seedlings were recorded during the study) from the mother tree were counted.

3.5 Data analyses

Height and DBH comparisons across study sites were carried out through one way analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SPSS) Version 17.0 (2006). The allometric relationship between DBH and height across the three sites i.e. Chirinda Forest Reserve, Cashel Valley Estate and Nyanga National Park was calculated using a regression analysis using (SPSS) Version 17.0 (2006).

Mingling (DMi), DBH differentiation (TDi) and height (HDi) were calculated using the equations which follow:
\[ DMI = \frac{1}{n} \sum_{j=1}^{n} V_{ij} \]

Where \( n \) is the number of neighbours. \( V_{ij} = \begin{cases} 0 & \text{tree } i \text{ and neighbour } j \text{ of the same species} \\ 1 & \text{tree } i \text{ and neighbour } j \text{ of different species} \end{cases} \)

\[ TDI = \frac{1}{n} \sum_{j=1}^{n} (1 - r_{ij}) \]

Where \( r_{ij} \) = smaller DBH/higher DBH; \( n \) = number of sampled trees.

\[ HDI = \frac{1}{n} \sum_{j=1}^{n} (1 - r_{ij}) \]

Where \( r_{ij} \) = biggest tree height/smallest tree height; \( n \) = number of sampled trees.
CHAPTER FOUR
RESULTS

4.1 Prunus africana Population

4.1.0 Population Structure

The population structure for the three sites was calculated and the results obtained of tree size abundance are shown in Table 3 below.

Table 3: Population status of 3 P. africana populations calculated from all individuals recorded during the study.

<table>
<thead>
<tr>
<th></th>
<th>Cashel Valley Estate</th>
<th>Chirinda Forest Reserve</th>
<th>Nyanga National Park</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>122</td>
<td>136</td>
<td>171</td>
</tr>
<tr>
<td>% mature trees</td>
<td>44.3</td>
<td>79.4</td>
<td>52.0</td>
</tr>
<tr>
<td>% seedlings 50.1-150 cm high</td>
<td>23.8</td>
<td>14.7</td>
<td>4.1</td>
</tr>
<tr>
<td>% seedlings 20.1-50 cm high</td>
<td>18.0</td>
<td>2.2</td>
<td>9.9</td>
</tr>
<tr>
<td>% seedlings 5.1-20 cm high</td>
<td>9.0</td>
<td>2.9</td>
<td>24.6</td>
</tr>
<tr>
<td>% seedlings ≤5 cm height</td>
<td>4.9</td>
<td>0.7</td>
<td>9.4</td>
</tr>
<tr>
<td>% embryonic seedlings</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The table shows the population structure of P. africana for the three sites. Mature P. africana trees formed the bulk of the population for the three sites. Nothing was recorded for embryonic seedlings. Generally there were few young P. africana seedlings in all the three sites studied. Chirinda Forest Reserve recorded the highest mature P. africana trees (75%) followed by Nyanga National Park with 52% and the least number was recorded for Cashel Valley Estate with 44.3%. Cashel Valley had the highest number of seedlings in the cluster of 50.1-150 cm with 23.8% followed by Chirinda Forest with, 14.7% with the least number of 4.1% being recorded for Nyanga National Park.

4.2. Structural Indices

For the calculation of mingling and DBH and height related structural indices, a total of 251 P. africana trees each with 3 neighbours were used. There were 54 from Cashel Valley Estate, 108 from Chirinda Forest Reserves and 89 from Nyanga National Park.
4.2.1 *Prunus africana* DBH and Height differentiation across sites

Height and DBH variations across the three sites are shown in Table 4. The highest average DBH was recorded for Chirinda and was significantly different (P<0.05) from those recorded for the other sites, that is, Cashel Valley Estates and Nyanga National Park considering height. The tallest trees (P <0.05) were recorded in Chirinda Forest followed by Cashel Valley Estates and then Nyanga National Park.

<table>
<thead>
<tr>
<th>Site</th>
<th>DBH (cm) (SD)</th>
<th>Height (m) (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cashel Valley</td>
<td>38.45 (7.88)</td>
<td>21.61 (5.74)</td>
<td>54</td>
</tr>
<tr>
<td>Chirinda Forest</td>
<td>51.73 (20.41)</td>
<td>26.71 (6.60)</td>
<td>108</td>
</tr>
<tr>
<td>Nyanga National</td>
<td>41.70 (20.73)</td>
<td>16.54 (5.47)</td>
<td>82</td>
</tr>
<tr>
<td>Significance</td>
<td>df=2; F=10.08; P&lt;0.05</td>
<td>df=2; F=64.47; P&lt;0.05</td>
<td></td>
</tr>
</tbody>
</table>

The same trends in table 4 could also be seen in Fig. 9 and 10 which show DBH and height class distributions across the study sites respectively. The least and highest DBH measurements in the 3 sites were, as follows;

Cashel Valley 6.7 and 82.8 cm, 6.4 and 102.5 cm in Chirinda and Nyanga National Park had 2.2 and 124 cm. In terms of the least and highest height measurements, 10 and 36 were recorded for Cashel Valley Estates, 10.5 and 45 m for Chirinda and 2 and 27 m were recorded for Nyanga National Park. Chirinda Forest had *P. africana* trees in the highest DBH classes in comparison to those in Cashel Valley Estate and Nyanga National Park (Fig.8 and 9). In terms of height class distribution Chirinda Forest Reserve trees occur in the higher classes, followed by those from Cashel Valley Estate and then Nyanga National Park.
Fig 9: *Prunus africana* DBH class distributions across the three sites
From Fig. 10, it can be seen that the allometric relationships between *P. africana*, DBH and height was smooth and positive (r² = 0.381, P< 0.001, n= 244).
All the 4 structural groups in the 3 sites had results indicated \textit{P. africana} having a high positive diameter and height differentiation as shown in Figs. 12 and 13. Only a small number of reference trees had smaller DBHs and were shorter than their neighbours. When comparing the threes sites it could be appreciated that Chirinda Forest Reserve had trees with a high positively differentiation in diameter compared to those in Cashel Valley Estate and Nyanga National Park which recorded as low as -0.8 and -0.75 differentiations respectively. As depicted in Fig. 13 Chirinda Forest Reserve had -0.35 as the lowest diameter differentiation. A similar trend was also observed for height distance where Chirinda Forest and Cashel Valley Estates recorded -0.25 as the least difference whilst -0.90 was the least recorded for Nyanga National Park.
Figure 12. *Prunus africana* height differentiation for the three study sites.
4.2.2 Mingling

All the three sites showed 100% of the DM$_i$ class 1.00 for the structural group of four. The Mingling value DM$_i$ for the structural group of four was 100% of the DM$_i$ class 1.00, whilst in Nyanga National Park there was a relatively high proportion of the DM$_i$ class 1.00 (87%) and smaller proportion of the 0.67 (13%). This information is shown in Fig. 14.
Figure 14: Mingling Values for the three study sites.
CHAPTER FIVE

DISCUSSION

According to Betti (2008), *P. africana* has been regarded as a rare species, but findings from this study seem to suggest otherwise. A very small proportion of the Eastern Highlands, the Afro-montane region with favourable conditions for the study species the three study sites had a high number of clusters and individual *P. africana* (Jimu, 2011). The high dominance of mature trees as evidenced by the distribution of *P. africana* and the DBH and height classes in all the three sites is clear evidence of the high potential for natural regeneration under conducive conditions (Jimu, 2011). The bulk of tree species has been observed to occur in the middle to high classes which is a sure sign of poor recruitment of *P. africana*. This has further been evidenced by the low numbers of seedlings and saplings recorded in all three sites (Jimu, 2011).

Forest fragmentation and disturbance have long term consequences which are hardly understood even though these are of paramount importance with regards to conservation (Farwig *et al.*, 2006). Key processes such as pollination and seed dispersal are in a way affected. Visits of fruiting trees by frugivores and seed dispersal can greatly influence the persistence of a plant species (Da Silva and Tabarelli cit. Farwig *et al.*, 2006). Maintenance of frugivores communities is influenced by the presence of fruiting trees. Research has been done on the influence of forest fragmentation on seed dispersal and they have shown that fragmentation can lead to a decline in dispersal agents (Cordeiro and Howe cit. Farwig *et al.*, 2006). This could be another explanation to what was observed on *Prunus africana* in this research. In a study carried in the Kakamega forest in Kenya by Farwig but there was a general decline of frugivores but this not consistent with our findings since most of the *P. africana* trees and seedlings identified in this research where located where the forest had been disturbed particularly on road margins and near plantations. Our results coincide with findings of a research on *Prunus africana* on Mount Cameroon (Cunninghama and Mbenkum, 1993, Nkeng *et al.*, 2010).

The limited degree of regeneration for *P. africana* could be due to frequent fires which occur almost on a yearly basis. This kills mostly low height and DBH classes and seedlings/saplings of *P. africana*. Invasive alien species especially *Acacia mearnsii* and *Pinus*
*patula* seem to further aggravate the situation since they cause thick deposits of litter as deep as 15cm in some places which makes it difficult for the small (length: 8.1mm, width: 6.1mm, height: 5.5, mass: 0.15) *P. africana* seed to germinate (Farwig, 2006). According to Betti (2008), poor establishment conditions for the seedlings are the main cause of *P. africana* population decline. This is consistent with findings from Mount Cameroon where *P. africana* showed poor recruitment and also research on the Island of Bioko in Equatorial Guinea showed poor regeneration for *P. africana* (Sunderland and Nkefor 1996). The possible explanation would be that since *P. africana* is a light demanding species and the tree canopy would be limiting the amount of sunlight reaching the tree thereby reducing seedling development.

Ndam *et al.*, (2000) reports that *P. africana* is a fallow or secondary forest species whose seeds are usually abundant in conditions of good light penetration and less dense undergrowth. This is consistent with our findings because no seedlings could be seen in densely forested areas in all the sites under study. Only those trees which were at the edge of the forest had seedlings. For the three sites, only mature *P. africana* trees were discovered in areas covered by tree canopies. Poor recruitment in all the three study sites could be attributed to limited penetration of light. In a study carries out by Farwig *et al.*, (2006) in the Kakamega in Kenya forest to investigate the consequences of fragmentation and forest disturbance on *Prunus africana*, it was discovered that there was more dispersal in fragmented forest. The findings of this research is also consistent with our findings since seedlings were found at forest edges where the forest had been disturbed by either a plantation or a road.

According to Ewusi *et al.*, (1999), natural regeneration of *P.africana* is sporadic and also recruitment levels are very low and results of this research concur with previous studies with regards to *P. africana*. According to Ewusi *et al.*, (1999) *P africana* in its natural environment has an unusual size class distribution and it is clear that the tree species is not replacing itself at a sustainable rate (Ewusi *et al.*, 1999) so that it can maintain its density. This has serious implications on the *P. africana* populations which are naturally declining whether being exploited or not (Ewusi *et al.*, 1999). Similar results have also been recorded on the island of Bioko in Equatorial Guinea where low recruitment levels of *P. africana* have been associated with the species temperament (Sunderland and Tako, 1999; Hall *et al.*,2000)
On comparing the three sites, *P. africana* trees in Chirinda forests Reserve are distributed in higher DBH and height classes and this is due to the high level of protection given to trees in reserves unlike in national parks and Forest Estates of Zimbabwe where there is no monitoring of illegal logging since it is felt that their sole mandate is to protect wild animals and exotic plantations respectively. Chirinda Forest Reserve has a long history of protection and this is the reason for the occurrence of older and bigger *P. africana* trees compared to Cashel Valley Estate and Nyanga National Park. However it is important to acknowledge that *P. africana* and other endangered trees are better conserved in forest reserves and national parks compared to communal areas.

By making use of the diameter and height differentiation, the relationship between the reference tree and its neighbouring trees in respect to competition can be interpreted (Ruprecht *et al.*, 2009). The right skewing of *P. africana* height and diameter differentiation is an indicator of the dominance of most reference trees in their vicinity with only a few being surrounded by bigger neighbours. Thus only a few *P. africana* individuals are suppressed and the majority occur as dominant and codominant. This means that interspecific competition poses no threat to the species in all the three sites, ie even in Nyanga National Park which has 75% of the clusters under invasion from *Acacia mearnsii* and *Pinus patula* which were not tall enough to compete with *P. africana* for space and light (Jimu, 2011). The sparse distribution of *P. africana* rules out interspecific competition occurring among *P. africana* individuals. When positive diameter and height differentiation distribution was compared across sites, higher relative frequencies were observed for Chirinda Forest Reserve which is consistent with diameter and height class distributions and thus show limited interspecific competition compared to Cashel Valley Estates and Nyanga National Park.

Poor establishment conditions are presumed to be the main cause for the poor regeneration of *P. africana* recorded for all the three sites, Chirinda Forest Reserve, Cashel Valley Estates and Nyanga National Park. It is a common phenomenon for natural forests to be fragmented by anthropogenic pressure (Tripathi *et al.*, 2010) and fragmentation can have either negative or positive effects on tropical tree species (Cordeiro *et al.*, 2009). *P. africana* has been known to increase its regeneration capacity in fragmented forest than unfragmented ones (Farwig *et al.*, 2006). The tree species like *Leptonychia usambarensis* in Tanzania recorded a decline in juvenile recruitment due to forest fragmentation (Cordeiro *et al.*, 2009). It is a fact from these two scenarios that plant and animal responses to fragmentation and disturbances are highly
variable (Farwig et al., 2006). High seed mortalities could be caused by trampling by grazers and unfavourable microclimatic conditions in forests there by reducing the regeneration of some affected tree species. Insufficient light penetration to the ground, thick litter and wild fires are likely to kill seedlings than mature trees as is the case with *P. africana* in all the studies carried out on it for the seeds happen to have a limited tolerance to ranges of light, temperature and humidity (Rees cit, Tripathi et al., 2010). In Cameroon, poor seedling establishment conditions were found to be the main causes of *P. africana* decline (Betti, 2008). Seeds were seen to be abundant where there was good light penetration into the forest and sparse undergrowth (Ewusi et al., cit Betti, 2008). According to Sunderland and Nkefor cit. Betti, 2008, *P. africana* represents a relic population from mid-late successional processes with little or no reproductive future without significant disturbance and opening successional opportunities. This theory seems to be supported by the fact that Chirinda Forest Reserve is a mature forest coupled with poorer natural regeneration compared to the other two sites.

The mixing of species of *P. africana* and the neighbouring trees was described by mingling (DMi) values. According to the mingling distributions, *P. africana* showed very high DMi class 1.00 for Chirinda (100%), Cashel Valley Estates (100%) and Nyanga National Park (87%). For Nyanga National Park it means the reference trees (*P. africana*) had 3 neighbours of different species surrounding them. This site had 13% of *P. africana* reference trees with a *P. africana* neighbour and 2 other species. High inter-specific competition is usually shown by high DMi classes (Ruprecht et al., 2009) but in this situation according to the DMi together with diameter and height differentiation distribution, the results show high species mixture as indicated by mingling distributions but there is very little inter-specific competition basing on the diameter and height differentiation distributions for all the three sites.
Table 5. Species associated with *P. africana* recorded from the 3 study sites

<table>
<thead>
<tr>
<th>Species</th>
<th>Family</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Albizia adianthifolia</em></td>
<td>Mimosoideae</td>
</tr>
<tr>
<td><em>Albizia antunesiana</em></td>
<td>Mimosoideae</td>
</tr>
<tr>
<td><em>Albizia schimperana</em></td>
<td>Mimosoideae</td>
</tr>
<tr>
<td><em>Allophylus chaenostachys</em></td>
<td>Sapindaceae</td>
</tr>
<tr>
<td><em>Alsophila capensis</em></td>
<td>Cytaceae</td>
</tr>
<tr>
<td><em>Alsophila dregei</em></td>
<td>Cytaceae</td>
</tr>
<tr>
<td><em>Bosqueia phoberos</em></td>
<td>Moraceae</td>
</tr>
<tr>
<td><em>Bridelia micrantha</em></td>
<td>Euphobiaceae</td>
</tr>
<tr>
<td><em>Catharinus queinzii</em></td>
<td>Rubiaceae</td>
</tr>
<tr>
<td><em>Catharinus pauciflorum</em></td>
<td>Rubiaceae</td>
</tr>
<tr>
<td><em>Celtis africana</em></td>
<td>Ulmaceae</td>
</tr>
<tr>
<td><em>Chrysophyllum gorungosum</em></td>
<td>Sapotaceae</td>
</tr>
<tr>
<td><em>Chrysophyllum viridifolium</em></td>
<td>Sapotaceae</td>
</tr>
<tr>
<td><em>Coffea ligustroides</em></td>
<td>Rubiaceae</td>
</tr>
<tr>
<td><em>Coffea zanegiariae</em></td>
<td>Rubiaceae</td>
</tr>
<tr>
<td><em>Croton sylvaticus</em></td>
<td>Euphorbiaceae</td>
</tr>
<tr>
<td><em>Ensente ventricosum</em></td>
<td>Musaceae</td>
</tr>
<tr>
<td><em>Dovyalis lucida</em></td>
<td>Flacourtiaceae</td>
</tr>
<tr>
<td><em>Dovyalis Macrocalyx</em></td>
<td>Flacourtiaceae</td>
</tr>
<tr>
<td><em>Erythrina lysistemon</em></td>
<td>Papilionoideae</td>
</tr>
<tr>
<td><em>Ficus spp</em></td>
<td>Moraceae</td>
</tr>
<tr>
<td><em>Macaranga spp</em></td>
<td>Euphorbiaceae</td>
</tr>
<tr>
<td><em>Maytenus spp</em></td>
<td>Celastraceae</td>
</tr>
<tr>
<td><em>Newtonia buchananii</em></td>
<td>Mimosoideae</td>
</tr>
<tr>
<td><em>Ochna spp</em></td>
<td>Rubiaceae</td>
</tr>
<tr>
<td><em>Protea spp</em></td>
<td>Proteaceae</td>
</tr>
<tr>
<td><em>Rauwolfia caffra</em></td>
<td>Apocynaceae</td>
</tr>
<tr>
<td><em>Rhus spp</em></td>
<td>Anacardiaceae</td>
</tr>
<tr>
<td><em>Rubus rigidus</em></td>
<td>Rosaceae</td>
</tr>
<tr>
<td><em>Rothmania spp</em></td>
<td>Rubiaceae</td>
</tr>
<tr>
<td><em>Strychnos spp</em></td>
<td>Loganiaceae</td>
</tr>
<tr>
<td><em>Syzygium cordatum</em></td>
<td>Myrtaceae</td>
</tr>
<tr>
<td><em>Syzygium guineense</em></td>
<td>Myrtaceae</td>
</tr>
<tr>
<td><em>Trichilia dregeana</em></td>
<td>Meliaceae</td>
</tr>
<tr>
<td><em>Uapaca kirkiana</em></td>
<td>Euphorbiaceae</td>
</tr>
<tr>
<td><em>Vernonia spp</em></td>
<td>Compositae</td>
</tr>
<tr>
<td><em>Vitex spp</em></td>
<td>Verbenaceae</td>
</tr>
</tbody>
</table>
CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

1.0 Conclusions

In conclusion, there is existence of more mature trees compared to juveniles in all the three sites as evidenced by the DBH and height class distributions and the population structure figures. This a clear sign of poor regeneration and recruitment. The structural group of four showed a high species mixture and sparse distribution of *P. africana* in all the three sites. The low inter-specific competition was shown by the positive skewness of the diameter and height differentiation distributions

6.1 Recommendations

The research has come up with the following recommendations in order to shed more light on the species under study.

1. Taking into account the structural diversity of *P. africana* in the Eastern Highlands of Zimbabwe, there is need to focus more attention on the genetic diversity of *P. africana* in Zimbabwe.

2. Zimbabweans need to be educated about the importance of the tree species and the benefits of its domestication

3. Accurate maps on the distribution of *Prunus africana* in Zimbabwe need to be drawn.
REFERENCES


Sterba, H (2008). Diversity indices based on angle count sampling and their interrelationships when used in forest inventories. Forestry, Volume 81, No. 5.


Pygeum africanum (Prunus africana) (African plum tree)


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