ABUNDANCE, STRUCTURE AND USES OF BAOBAB (*ADANSONIA DIGITATA L*.) POPULATIONS IN OMUSATI REGION, NAMIBIA

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ABSTRACT

This study sought to determine the biology and the uses of baobab (*Adansonia digitata* L.) populations in Outapi and Onesi constituencies in Omusati Region, Namibia. As one of the important Non-Timber Forest Products (NTFPs)-providing species of ecological and socio-economic significance, there is need to have a better understanding of the biology and local uses of the species before its full potential and sustainable harvesting is realized. A comparison of densities, distribution patterns, structure, phenology, stem conditions and uses of baobabs between the two constituencies was done. Field data collection was conducted in April 2014. Road transects were used to sample baobabs in the two sites by purposively choosing the next road to gain access to the next focal tree. Circular plots with a radius of 30m from the edge of the canopy of each focal tree were demarcated. In each plot, diameter at breast height (dbh) of adult and sub-adult trees, height of adults, sub-adults and saplings and their stem conditions, number of fruits on each fruiting baobab tree, the Global Positioning System (GPS) waypoints and coordinates and the land-use types where baobabs occurred were recorded. The results revealed that there was no significant difference in the baobab densities (χ^2=2, df=1, $p>0.05$) and median fruit abundance (U=5550.5, $p>0.05$) between Outapi and Onesi constituencies. The Chi-square tests detected significant differences in the dbh-size classes (χ^2=33.038, df=8, $p<0.001$) and height classes (χ^2=16.295, df=4, $p<0.05$) between the two study sites. The bell-shaped distribution curve in dbh size-classes in the two sites showed poor recruitment. Onesi constituency had 77% damaged stems compared to 50% in Outapi constituency (χ^2=22.705, df=2, $p<0.001$). Onesi villagers make use of the baobab tree more extensively than Outapi residents (χ^2=31.022, df=9, $p<0.001$). Some of the common uses of baobabs in both study sites include human and livestock consumption and treating various ailments. Poor seedling survival resulting primarily from herbivory, human activities and climate variability hampers baobab recruitment. Considering the poor recruitment due to the above factors, the potential for commercialization of baobabs in the region may not be viable. Therefore, active planting in undisturbed areas, protection of seedlings from livestock coupled with community awareness are vital to ensure recruitment so that effective commercialization and subsistence use is realized and sustainable.

Key words: *Adansonia digitata* L; baobab; commercialization; NTFPs; populations; recruitment

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DEDICATION

In loving memory of my dad, Mr. Jonah Munyebvu who always reminded me even as a young girl that education is the key to success.

DECLARATION

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

………………………………. Date……………………………..

Faith Munyebvu

LIST OF ACRONYMS

ABS	Access Benefit Sharing
DBH	Diameter at Breast Height
ESRI	Environmental Systems Research Institute
GCS	Geographical Coordinate System
GIS	Geographic Information System
GNP	Gonarezhou National Park
GPS	Global Positioning System
GRN	Government of the Republic of Namibia
ICUC	International Center for Underutilized Crops
IPTT	Indigenous Plants Task Team
MAWF	Ministry of Agriculture, Water and Forestry
MCA	Millennium Challenge Account
MET	Ministry of Environment and Tourism
NBRI	National Botanical Research Institute
NTFPs	Non-Timber Forest Products
ODI	Overseas Development Institute
SCUC	Southampton Center for Underutilized Crops
UNCTAD	United Nations Conference on Trade and Development
UNAM	University of Namibia

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Non-Timber Forest Products (NTFPs) include any products other than timber derived from forest or trees and plants such as bark, fruits, gums and leaves (Schumann, Wittig, Thiombiano, Becker & Hahn, 2012). According to Schumann et al. (2012), in Africa and elsewhere in developing countries, rural households use several different NTFPs from a wide range of plant species for both subsistence and commercial use. These NTFPs significantly contribute to livelihood security and have traditionally been used by rural communities in the semi-arid tropics for subsistence and trade (Schumann et al., 2012). Marshall and Newton (2003) pointed out that NTFPs are particularly important for livelihood security in cash-poor households by ensuring food security, maintaining the nutritional balance in people's diets, meeting medicinal needs and providing a source of income.

According to Venter (2012), many poor and marginalized people who live in the savanna woodlands in Africa rely on plant products for their survival. As a result of the immense importance attached to these products, studies to date have increasingly focused on their sustainable harvest and management. Welford and Le Breton (2008) suggested that where these plant species are found in rural areas, commercialization is seen as an opportunity to uplift the livelihoods of the poor and marginalized who live there. A study conducted in Northern Venda, South Africa showed that out of the commercialization of the baobab (*Adansonia digitata* L.) products, all the 60 respondents mentioned that the income from the sale of baobab products was very important and helped alleviate poverty (Venter, 2012). However, overexploitation of some baobab products such as bark and leaves for commercial purposes will jeopardize the survival of parent trees as the trees will not be able to fully recover (Romero et al., 2001). Uncontrolled commercial bark and leaf harvesting will eventually hinder fruit production as the photosynthetically active parts are removed (Dhillion & Gustad, 2004).

Gruenwald and Galizia (2005) predicted a global growth in demand of NTFPs. Some of these NTFPs are from *Sclerocarya birrea* (A. Rich) Hochst (Marula), *Kigelia africana* Lam. *(*African Sausage Tree*), Trichilia emetica* Vahl *(*Natal Mahogany*)* and *Adansonia digitata* Linnaeus (Baobab) wild species (Gruenwald & Galizia, 2005). Due to the global increase in demand of these NTFPs, proper management of the resources is vital in order to avoid overexploitation. Therefore, before sustainable harvesting of these resources is mobilized, there is need to fully understand the biology of the species (Venter & Witkowski, 2010). According to Gouwakinnou, Kindomihou, Assogbadjo and Sinsin (2009), strong management decisions can be based on the use of population structures in investigating the demographic health of harvested populations together with information related to patterns of use and harvest. Therefore, this study focused on understanding the population structure of the baobab including the abundance and uses in order to influence management practices for more sustainable use and conservation of the species.

1.1.1 Study species

Adansonia digitata is one of the most important NTFP-providing species with significant ecological and socio-economic significance. It is among the nine global species of baobab in the genus *Adansonia* from the family Malvaceae and sub-family Bombacaceae (Venter & Witkowski, 2010). Most scientists believe the vernacular name ‘baobab’ which is used globally is derived from the Arabic name “buhibab” meaning fruit with many seeds (Diop, Sakho, Dornier, Cisse and Reynes, 2006). The genus name *Adansonia* is used in honor of the botanist Michel Adanson (1727–1806), whilst the species name *digitata* (hand-like) was selected in reference to the shape of the leaves (Esterhuyse, Von Breitenbach & Söhnge, 2001).

Apart from *Adansonia digitata* which is native to Africa, there is the Australian baobab, *Adansonia gibbosa* A. Cunn. and six other baobab species native to Madagascar namely *Adansonia grandidieri* Baill., *A. madagascariensis* Baill., *A. rubrostipa* Jum. & H. Perrier, *A. perrieri* Capuron, *A. suarezensis* H. Perrier. and *A. za* Baill. which is the most widespread baobab in Madagascar (Sidibe & Williams, 2002). The nineth species that was recently discovered in Africa through morphology, ploidy and molecular phylogenetics research is *Adansonia kilima* sp. nov. (Pettigrew et al., 2012). *Adansonia kilima* was found to be superficially similar to *A. digitata* though it could be differentiated on the basis of floral morphology, pollen characters and chromosome number (Pettigrew et al., 2012).

Adansonia digitata, in this case the baobab, is one of the widespread multi-purpose tree species in Southern Africa. It is popularly known as “Africa’s upside down tree” due to its structure. Throughout its range, the baobab makes important contribution to people’s livelihoods for food, fibre and medicine (Kamatou, Vermaak & Viljoen, 2001; Venter &Witkowski, 2009; Wickens & Lowe, 2008). Baobab trees form an important source of income, especially in the dry season and during times of drought (Duvall, 2007; Sidibe & Williams, 2002). According to Sidibe and Williams (2002), baobabs have an outstanding ability to withstand severe drought and fire, which are two major hazards to plant life in dry areas of Africa.

Although baobabs are mostly regarded as fruit-bearing trees, they are multipurpose, widely-used species with medicinal properties, numerous food uses of various plant parts, and bark fibres that are used for a wide range of purposes (Dhillion & Gustad, 2004; Wickens & Lowe, 2008). Up to 300 uses of the baobab were documented in Benin, Mali, Zimbabwe, Cameroon, the Central African Republic, Kenya, Malawi, South Africa and Senegal across 11 ethnic groups and 4 agro-ecological zones (Buchmann, Prehsler, Hartl & Vogl, 2010). The fruits and leaves are harvested during the harvesting periods and stored for consumption throughout the year (Buchmann et al., 2010). Fruit harvesting of baobabs normally starts from April to

May in Southern Africa and from October to November in West Africa (Sidibe & Williams, 2002). However, there are some baobab trees that can go for several years without fruiting or that do not produce fruit at all and such baobabs have been categorized as ‘poor producers’ (Venter & Witkowski, 2011) or in some areas as ‘male’ baobabs (Assogbadjo et al., 2009).

1.1.2 Bio-physical characteristics of baobabs

The baobab is a deciduous, tropical fruit tree which ranges between 6-10 meters in diameter for adult trees (Chadare, Linnemann, Hounhouigan, Nout & Van Boekel, 2009; Wickens, 1982). According to Schumann, Wittig, Thiombiano, Becker & Hahn, (2010), it is a large tree that can reach 23 m in height. The bark is smooth, reddish brown to grey, soft and fibrous. According to Diop et al. (2006), the baobab tree produces an extensive lateral root system which can extend up to 50 m from the trunk and down to a depth of 10 m. However, it is generally understood that the tree has a shallow root system that rarely extends beyond 2 m in depth for mature trees which allows the trees to collect and store massive amounts of water during the heavy but infrequent rainfalls and which could explain why the trees are often toppled in old age (Sidibe & Williams, 2002).

According to Schumann et al. (2010), the trunk is abruptly bottle-shaped or short and thick. Sidibe and Williams (2002) observed that the trunk of the tree contracts when the environment becomes dry and expands in the wet season. During the leafless period, physiological processes such as photosynthesis take place in the green inner layer of the trunk and branches, utilizing water stored in the trunk (Gebauer, El-Siddig & Ebert, 2002). Leaves of young trees are normally simple and the overall mature leaf size may reach a diameter of 20 cm.

The flowers of baobabs are generally large and showy and produced during both dry and wet seasons (Sidibe & Williams, 2002). According to Sidibe and Williams (2002), timing of flowering tends to differ between geographically isolated populations but the period between flowering and fruit ripening is still between 5 and 6 months, an observation they attributed to variability in regional climate. The fruit is often irregular in shape covered by velvety yellowish sometimes greenish hairs and can grow up to 12 cm or more in length (Wickens & Lowe, 2008). It is estimated that it takes between eight and 23 years before the baobab produces fruits, and the mature plant (over 60 years) can produce more than 160-250 fruits per year (Gruenwald & Galizia, 2005). Flowers and fruits are a rich source of food and are eaten by a variety of animals including insects, birds and mammals (Venter & Witkowski, 2011).

1.1.3 Estimation of ages of baobabs

Baobabs have an average life span of 1000-3000 years though studies have shown that they can reach up to 6000 years (International Center for Underutilized Crops

[ICUC], 2002). Carbon dating has been used to estimate the ages of baobabs and there seem to be no other quick method of verifying the age since the baobab does not produce annual growth rings (Wickens & Lowe, 2008). Radiocarbon dating of a baobab in Namibia indicated an age of about 1,272 years (www.kew.org/science-conservation/) which generally shows how old some baobabs can grow. According to Mashapa (2012), earlier research by Woodborne, Hall, Basson, Zambatis and Zambatis (2010) shows that very large specimens are not necessarily among the oldest trees, and that medium-sized individuals can also be very old, which makes it even more complicated to estimate the ages using size. According to Gebauer et al. (2002), rapid growth in diameter and height is possible under good conditions, reaching 2 m in two years and up to 15 m in twelve years. Since the baobab is known to shrink during times of drought (Sidibe & Williams, 2002), it is complicated to estimate age using the diameter at breast height.

1.1.4 Distribution and occurrence of baobabs

Despite the gaps in the knowledge about the distribution of baobabs, current data show that it is widely distributed in parts of western, north-eastern, central and southern Africa (Fig. 1), and has also found roots in Oman and Yemen in the Arabian Peninsula, Asia (Sidibe & Williams, 2002). Sidibe and Williams (2002) stated that the African baobab occurs naturally in most of the countries south of the Sahara and is especially associated with the drier parts of savanna or a minimum of 300 mm of annual rainfall. However, there are extensions of its distribution into forest areas associated with human habitation. In Africa, the plant grows at latitude of 16^o N and 25^o S in areas not receiving more than one day of frost per year (Kamatou, Vermaak & Viljoen, 2011).

It is generally accepted that the origin of the African baobab is tropical Africa, but it may have been introduced from one of the other regions. According to Tsy et al. (2009), phylo-geographic research shows that baobabs originated in West Africa and spread through human-assisted dispersal to the rest of Africa. It has been introduced to countries outside of Africa, including northern Australia and many Asian countries such as India, Sri Lanka, Indonesia and the Philippines and in some parts of the Middle East and the West Indies (Sidibe & Williams, 2002). The baobab is scattered relatively irregularly and patchily in the savanna and is often associated with human settlements (Schumann et al., 2010). It usually grows at low altitudes (450-700 m) and low mean annual rainfall (150-1500 mm) (Wickens & Lowe, 2008).

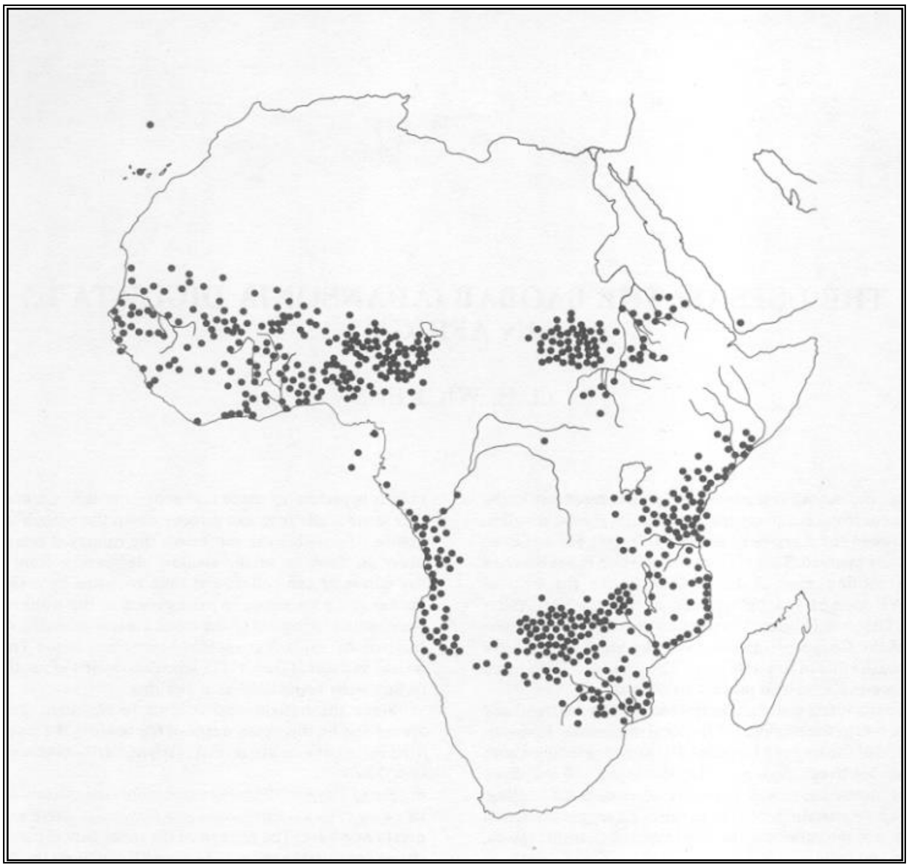


Figure 1: Distribution map of baobab populations in Africa (Wickens, 1982)

In southern Africa, the baobab occurs as a constituent of *Colophospermum mopane* (Mopane) woodland on the heavily-textured soils of Zambezi Valley, Zimbabwe. The baobab tree occurs in poorly drained soils of Zimbabwe's savanna region in *Cordyla Africana* (African Wild Mango)and *Kigelia africana* (Sausage tree) populations and in poorly drained plains of the Zambezi delta (Wickens, 1982). It is also found in the dry woodlands of Malawi and mountainous parts of Angola and Namibia where it occurs in the Mopane woodland. In South Africa, the species is a noticeable constituent of the Limpopo basin with a few scattered trees further south (Wickens, 1982).

1.1.5 Ecological importance

According to Whyte (2001), baobabs are a keystone species with ecological significance as they provide important ecosystem services. The trees reduce soil erosion and provide cover or shade with their canopies (Coates-Palgrave, 2002). The vitality of this tree is remarkable as the bark can be completely stripped from the lower trunk and still the tree is able to regenerate new bark (Palgrave, 2002). Their ability to withstand extreme stress from drought allows the trees to be grown on degraded or marginal lands where other species would not survive. Due to climate variability and change, weather extremes are being experienced and as such, the baobab's resilience to such extremities such as drought (Stucker & Lopez-Gunn, 2015) makes it a really vital resource in fulfilling its ecological function and providing essential ecosystem goods. Its spongy wood does not easily burn; therefore the plant is protected from fire. In areas where the baobab tree grows, there are traditions that prohibit communities from cutting them down, thus such norms play a pivotal role in nature conservation (Kurebgaseka, 2005).

Baobab trees add organic nutrients to the soil through leaf fall and through birds and mammals that leave droppings on the ground around the tree trunks (Wickens & Lowe, 2008). In Omusati region, Namibia, pig sties are constructed right at the edges of the baobab trunks to provide shade to the pigs whilst the soil is also being enriched by pigs' droppings.

The large white baobab flowers, which open at night, are pollinated by bats and other small mammals and the protection of these pollinators is important for the production of fruits (Whyte, 2001). According to Sidibe and Williams (2002), the flowers emit a scent that attracts bats. This pollination by bats has been confirmed in studies done in Indonesia as well as West and East Africa (Sidibe & Williams, 2002). The sour scent of the flowers also attracts certain flies and nocturnal moths as well as several species of bollworms that might result in some pollination (Sidibe & Williams, 2002). The hollow trunks provide shelter to many small animals and birds and offer ideal breeding sites (Whyte, 2001). Many animals such as *Macaca fascicularis* (Monkey), *Loxodonta africana* (African Elephant) and birds as well as humans are agents of baobab seed dispersal (Wickens & Lowe, 2008). The baobab tree is an important tree that improves biodiversity by its attraction of various pollinating species. Any decline in baobab population would have an effect on such species (Whyte, 2001).

1.1.6 Baobab populations in Namibia

Baobabs occur in sizeable populations of mature woodlands in the north-western and in smaller populations in the far north-eastern parts of Namibia. Specifically, baobabs in Namibia occur mainly in parts of Kunene, Omusati, Zambezi, Kavango West and Kavango East Regions as their distribution is restricted by climatic conditions and altitude. The baobab has an estimated coverage of 0.5% of the total land area in Namibia. In southern Africa, excluding Angola, Namibia has the least land area of approximately 4,125 km^2 with baobab populations (Phytotrade Africa, 2008).

This study focused on two constituencies in the Omusati Region namely Outapi and Onesi where significant populations of wild baobabs thrive. These two areas were selected based on the distinction in human population numbers and densities, human land-use activities and rainfall patterns. A thorough understanding of the biology and ecology of the baobab was needed for future sustainable harvesting of the products and general management of the species. Thus the study focused on 1) the abundance; 2) structure; 3) fruit production; 4) recruitment and 4) socio-economic uses of the baobab trees in Outapi and Onesi constituencies.

1.2 Statement of the problem

African indigenous plants have the potential to play a central role in addressing food insecurity and associated health concerns in Sub-Saharan Africa (Cordeiro, 2013). These indigenous plants such as baobabs help to sustain local communities by providing food and income (Sidibe & Williams, 2002). Therefore to ensure food security and enhancement of livelihood sources through the use of available indigenous resources such as the baobab, there is need to have a better understanding of the biology of the species and its current local uses in order to fully realize this potential.

The resource has been under-utilized in most parts of north-western and eastern Namibia where the species occurs since households use the plant on a subsistence level as they normally consume the fruit and throw away the seeds. The potential of this species and its products has not been fully realized in Namibia despite better utilization and value-addition in neighbouring countries such as Malawi and Zimbabwe. It is important that more knowledge be disseminated to the communities on the economic potential of this species. However, the initial step would be to understand the abundance in terms of the distribution and density, structure, fruiting and current uses of the baobab as pointed out by Venter and Witkowski (2010) that to manage these resources sustainably requires a thorough understanding of the biology and ecology of the tree. Strategic action on how the indigenous resource products can be sustainably harvested will then be taken according to the Biodiversity Strategic Plan of Namibia's aim towards sustainable use of natural resources (Barnard, Shikongo & Zeidler, 2001).

Since the conservation status of the baobab is not yet fully known in Namibia, this study will contribute in generating preliminary information needed for a nation-wide red list assessment of the species. Moreover, recruitment and reproduction of the species will also be assessed in order to understand the socio-economic and ecological potential of this resource and establish its conservation status.

Despite the vast regional knowledge from other countries available about the baobab tree, its multiple uses among other components, there is still a dearth of information about the species as data have not been adequately documented specifically in Namibia. A review paper on the synopsis of vegetation studies in Namibia revealed that minimal vegetation research has been undertaken in north-central Namibia (Burke & Strohbach, 2000). This explains that there has been a lack of documented information and as such, vegetation trends may not be easily monitored. Information is available on the general distribution of baobabs in Namibia, but limited research has been done on the physical characteristics and factors affecting the baobab populations especially in more arid conditions such as Namibia.

Therefore, the need to improve food security and livelihoods of local communities where baobabs occur through gaining preliminary understanding about the biological characteristics and the socio-economic uses attached to the baobab resources before further exploration of the resource is conducted prompted this study.

1.3 Objectives

The overall aim of the study was to assess the physical characteristics and uses of the baobab populations in Outapi and Onesi constituencies in northern Namibia.

The specific objectives were to:

(a) Quantify and compare the abundance of baobab populations in Outapi and Onesi constituencies;

(b) Determine and compare the structure of the baobab populations between the two sites;

(c) Assess the stem condition of the baobab populations in the two areas; and

(d) Document the uses of baobab trees in the two constituencies.

1.4 Research Hypotheses

(a) There is a significant difference in the abundance of baobab populations between the two sites with Outapi constituency having fewer trees than Onesi constituency since Outapi constituency contains a fast-growing town in terms of population and development.

(b) There is a significant difference in the population structure of baobabs between the two sites as more large-sized trees and more saplings are expected to occur in Onesi constituency where there is less population pressure on the baobabs and limited land developments than in Outapi constituency.

(c) It is expected that Onesi constituency as a more rural settlement will have higher levels of de-barking and stem damages because the villagers tend to rely more on the tree bark for various household uses and where livestock feed on the bark due to limited alternative sources than Outapi constituency which has more urban-influenced people.

(d) The uses of baobabs differ significantly between the two sites. The communal people in Onesi constituency are likely to have wider range of uses of the baobab products due to limited alternative livelihood sources than the urban-influenced people of Outapi constituency.

(e) There is a significant difference in the fruit abundance of the baobab trees between the two sites. It is predicted that more fruits will be found in Onesi than Outapi constituency since Outapi contains a commercial hub where on-going developments and human pressure are likely to disturb the growth of baobabs hence disrupting fruit production.

1.5 Significance of the study

As an attempt to shift the minds of people from resource exploitation to sustainable use is ongoing, it is important that understanding is gained on how highly valued indigenous trees such as the baobab are performing especially in arid and semi-arid zones despite human influence. Apart from adding knowledge on baobab, the tree carries potential to improve human livelihoods if the baobab products are fully but sustainably exploited in these areas. Moreover, the baobab was also listed among the species that may be of interest to the Indigenous Natural Products (INP) industry in Namibia (Millennium Challenge Account [MCA], 2008). This then warrants a study to explore the species' abundance, structure and uses in some parts of Namibia where the tree is commonly distributed.

Commercialization of the basket industry led to population structure changes in Makalani palm (*Hyphaene petersiana*) in Northwestern Botswana (Munondo, 2005). Additionally, *Berchemia discolor* whose bark is required for dying the baskets, has had its population decimated despite its wide conservation as a fruit species (Munondo, 2005). There is therefore a need to ensure that the baobab products are being harvested sustainably and the initial step will then be to secure knowledge of its abundance, population structure and uses. Venter and Witkowski (2009) suggested that management of these resources sustainably requires a thorough understanding of the biology and ecology of the tree.

It is also important to understand the conservation status of the baobab in Namibia in order to influence management strategies; therefore, this study will provide contributory data towards a country-wide red list assessment. The ecological information will be useful to monitor the trends and dynamics within the baobab populations. The communities will also be able to have wider understanding on the species abundance and viability in order to further engage in product development to improve the local livelihoods. It is also essential to comprehend not only the current utilization but also the potential for more product development from lessons learnt elsewhere. Omusati region represents a relevant study area since it has got a medium to high occurrence of baobab populations.

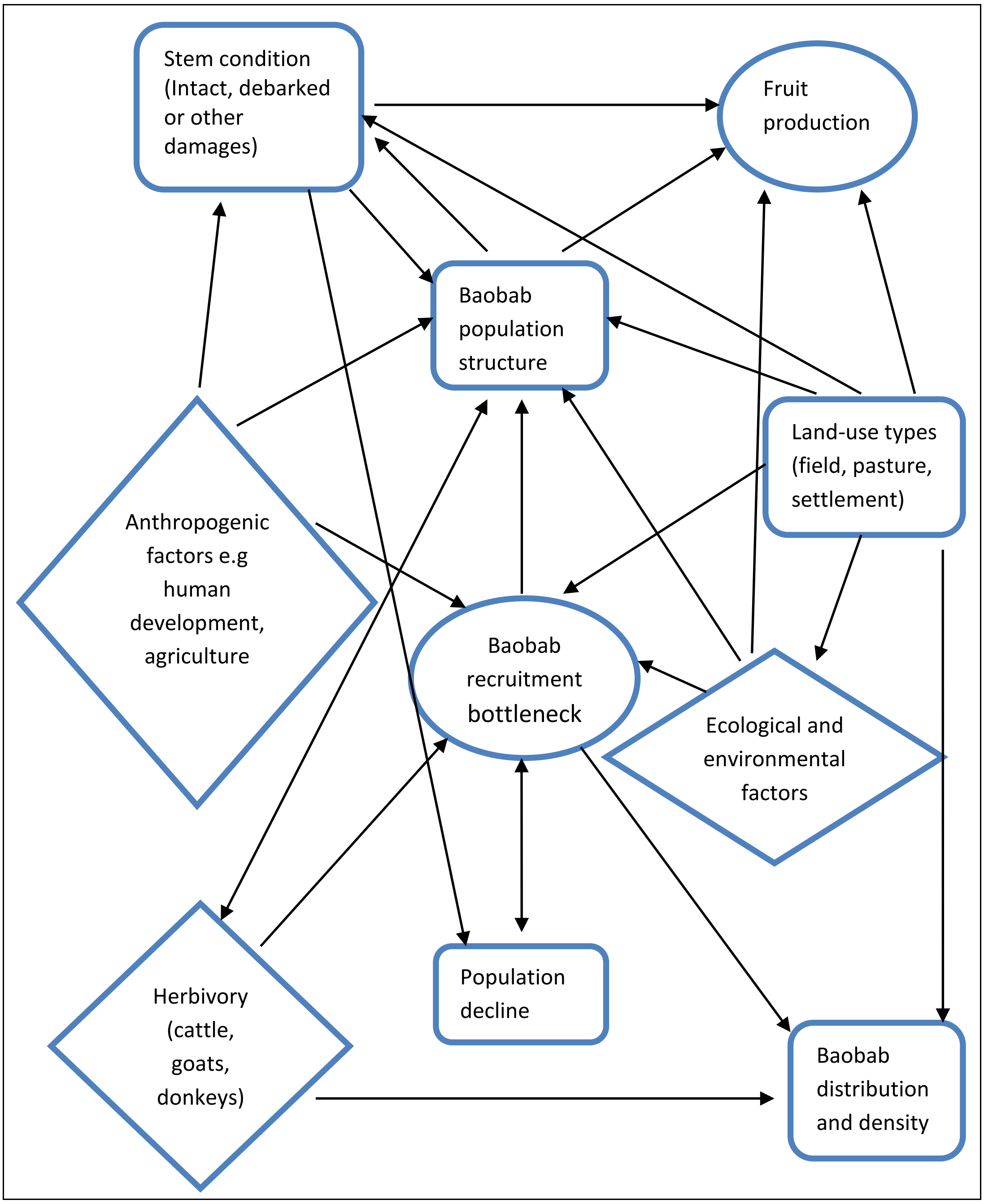


Figure 2: Conceptual Model of the baobab study

The diagram (Fig. 2) is a summary of the key issues that the study seeks to investigate including the various forces that are predicted to likely affect the baobab population structure, abundance, recruitment, fruit production and possibly population decline.

CHAPTER 2

LITERATURE REVIEW

2.1 Factors affecting baobab population abundance and structure

Certain disturbance regimes such as herbivory, fire and edaphic factors are likely to influence the state-and-transition dynamics in vegetation, thus explaining the patterns in population structure, abundance, distribution and regeneration potential (Mashapa, 2012). Several scholars have highlighted varying factors that are likely to affect the structure, abundance and distribution of baobab trees or other tree species. Swanepoel (1993) and Barnes, Barnes and Kapela (1994) concluded that juvenile baobab mortality is greatly influenced by elephant disturbance and utilization. When juvenile plants are destroyed, there tends to be a J-shaped size class distribution which is likely to affect the future of the species because of disrupted regeneration of the species. The Southampton Centre for Underutilized Crops [SCUC], (2006) stressed the need for the protection of baobabs against animals especially during juvenile state, the time when the plants are most vulnerable.

Surveys done on the long-term impacts of elephant browsing on baobab tree population in Ruaha National Park in Tanzania revealed that tree densities dropped between 1976 and 1982, but no significant changes occurred between 1982 and 1994 as a result of a decline in bull elephants due to poaching (Barnes et al., 1994). This explains that baobab populations declined with an increase in elephant numbers and increased with the decline in bull elephant numbers. Moreover, Mashapa (2012) noted that high elephant numbers in Gonarezhou National Park (GNP) in Zimbabwe were perceived to be accompanied by large-scale destruction of baobabs. According to Mashapa et al. (2014), the continued increase in elephant densities in GNP is likely to affect the baobab densities and distribution negatively in the future.

Apart from high elephant numbers, excessive elephant browsing due to the 1981-1982, 1991-92 and 2000-2001 drought periods could have affected baobab population demography in GNP (Mashapa, 2012). Due to drought, the negative influence on baobabs by elephants was amplified hence resulting in tree mortality. A study done at Mana Pools in Zimbabwe revealed that up to 24% of the baobabs were killed by elephants along the Zambezi River Frontage (Ndoro, Mashapa, Kativu & Gandiwa, 2014) whilst a study in Tsavo National Park, Kenya revealed that baobabs became rare where they were once common due to a drastic increase in elephant densities in the park (Whyte, 2001).

Edkins, Kruger, Harris and Midgley (2007) surveyed the baobab size-class distribution in the Kruger National Park, South Africa where they found out that the baobab population had a reversed J-shaped size class distribution with many small baobabs as the park had a declining elephant population. A study by Amahowé, Djossa, Adomou, Kabré and Sinsin (2012) in Benin showed that the structure of the vegetation exploited by elephants in the Djona Hunting Zone showed a high number of small trees while the number of large trees was low. This was said to be an adaptation of more stable natural ecosystems to animal disturbances (Amahowé et al., 2012). However, saplings and sub-adult baobabs are more likely to die from elephant disturbance than adult baobabs (Mashapa, 2012). This is because the saplings and sub-adults are not resilient enough to withstand browsing and trampling. Such observations tend to show that an increase or decrease in elephant population can have a drastic influence on the baobab size-structure.

In rural communities, large herds of *Bos taurus* (cattle) and *Capra aegagrus hircus* (goats) tend to affect the baobab population and recruitment patterns through processes such as browsing and trampling on the baobab seedlings and saplings. According to Romero et al. (2001), browsing by livestock in the Save-Odzi Valley in Zimbabwe was the major reason for the lack of recruitment of baobab. The seedlings were also reported to have been eaten by *Papio ursinus* (baboons) and monkeys. A study by Mudavanhu (1998) in Nyanyadzi and Birchenough Bridge area, Zimbabwe showed that baobab seedlings were apparently eaten and killed by cattle and goats but on game ranches where cattle and goats were excluded and where elephants were absent, seedlings were fairly abundant. These findings show that in areas where livestock, mainly cattle and goats are found, chances of baobab recruitment and seedling and sapling survival are also low. Additionally, Dhillion and Gustad (2004) stated that persistent browsing on baobabs in Cinzana, Mali hindered growth towards the threshold height where shoots were no longer reached by cattle which resulted in sapling mortality. Venter and Witkowski (2011) pointed out that where baboons were prevalent, they destroyed immature fruits which reduced seed production and they also pulled baobab seedlings and consumed the root tubers (Wickens, 1982).

According to Chirwa, Chithila, Kayambazinthu and Dohse (2006), baobab populations tend to form bell-shaped or positively skewed size-class distribution curves which shows a general lack of recruitment. This has raised some concerns that the populations could be vulnerable to severe disturbances such as wild fires, livestock browsing and clearing of fields, which have the potential to cause population collapse (Chirwa et al., 2006). Nevertheless, it should be emphasized that the apparent poor recruitment does not necessarily mean the population is in decline due to the long-lived, low and episodic mortality nature of the baobab (Venter and Witkowski, 2010).

A study conducted in Mokolodi Nature Reserve, Botswana postulated that soil resource gradient and elephant disturbance regime gradient in relation to proximity to natural perennial water sources played a major role in the abundance, structure and spatial distribution of vegetation (Aarrestad et al., 2011). This was because soil type or stratum could compensate or aggravate climatic aridity (Aarrestad et al., 2011). According to Mashapa (2012), a study conducted in GNP showed a significant difference in baobab height structure across soil substrates. The height of baobabs was influenced by edaphic factors such as soil nutrients and soil depth because where there was limited nitrogen, plants tended to be stunted with weak thin stems (Mashapa, 2012). A study by Mashapa, Zisadza-Gandiwa, Gandiwa and Kativu (2013) in GNP, Zimbabwe also attributed the significant demographic differences in baobab population to edaphic factors such as differences in soil nutrients, depth, drainage, moisture as well as climatic induced aridity droughts. This explains that edaphic factors can influence baobab size-structure and recruitment as Mashapa (2012) showed that sapling and seedling recruitment was critically low on malvernia soil substrate in GNP as a result of nitrogen deficiency.

2.2 Influence of temperature and rainfall on baobab population structure

A study conducted by Assogbadjo, Sinsin, Codjia and Van Damme (2005) on the productivity of baobab trees across three climatic zones in Benin confirmed significant differences in the sizes of the trees, number of fruits produced and the pulp, seed and kernel productivity between the climatic zones. Fruits collected in Burkina Faso, Mali and Niger were found to vary in mass along precipitation gradients (Parkouda et al., 2012) which explains the influence of rainfall on fruiting and growth. Venter (2012) stated that environmental cues such as light intensity, photoperiod, temperature and water availability are the main determinants of annual timing of leaf flush and flowering in baobab trees. This suggests that varying weather patterns in terms of rainfall and temperature are likely to affect the population structure and phenological characteristics of baobabs. Seventeen percent (17%) of the respondents that were interviewed in Burkina Faso attributed the decline in baobab tree populations to poor rainfall (Schumann et al., 2012).

According to Araujo et al. (2002), predicted changes in atmospheric CO_2 and climate are likely to affect the distribution and abundance of most species. The baobab tree is one of the species vulnerable to climate change because of its delayed maturation, low reproductive and dispersal rate which reduces its ability to recover from population reduction (Sanchez et al., 2011). According to Sanchez et al. (2011), the reduction in suitable baobab habitat due to climate change will result in the decline in baobab populations. Sanchez et al. (2011) predicted that the percentage of present baobab distribution range that will be suitable in the future varies from 5% to 69% in southern Africa. Namibia was among a few countries across Africa that were predicted to not having suitable habitat for baobabs in the future as a result of climate change (Sanchez et al., 2011) which explains the likely impacts of climate change on the distribution of baobabs. Vieilledent, Cornu, Sanchez, Pock-Tsy and Danthu (2013) investigated the vulnerability of baobab species to climate change in Madagascar where their results indicated that *Adansonia perrieri* and *Adansonia suarezensis* were severely threatened by climate change. Potential shifts in species distributions by shrinking habitats were also predicted as much of the areas that are currently ecologically suitable will no longer remain suitable in the future as a result of climate change (Vieilledent et al., 2013).

An investigation of the functional responses of baobab seedlings to drought by De Smedt et al. (2012) concluded that baobab seedlings from Mali showed more drought-avoidance characteristics as they tended to allocate more biomass to their root system whilst baobab seedlings from Malawi were able to retain and form more leaves during drought. This shows that the same baobab species found across varying ecological zones will respond differently to climate change thereby posing different structural effects on the baobabs. Even though there might be uncertainties about the predicted changes in habitat suitability, Sanchez et al. (2011) recommended the necessity of using the available data to carry out studies that will identify conservation measures.

2.3 Land-use and baobab population structure

Different land-use types have an influence on the baobab population structure. According to Duvall (2007), the baobab fruit in some parts of Africa is used in large quantities for domestic purposes and people protect the baobab seedlings such that recruitment is better in villages and fields than in untended areas such as parklands and fallows. A study conducted in Burkina Faso by Gijsbers, Kessler and Knevel (1994) also pointed out that there was a deliberate association of baobabs with the agricultural environment because of the tree uses, and that the regeneration may have depended on the trees being deliberately planted near settlements (Sidibe & Williams, 2002). This supports the idea that areas where there are high levels of human activities such as settlements and crop fields tend to have high baobab recruitment than in plains and rocky outcrops (Duvall, 2007).

In south-western Mali, abundant baobab recruits were found within the settlements compared to few recruits in fields and fallows (Duvall, 2007). According to Duvall (2007), the two processes that have been proposed to account for the apparent baobab-settlement association is firstly, the fruit use and consequent seed-bank development that may likely increase the baobab recruitment at settlement sites and secondly, humans may settle under pre-existing baobabs, presumably to access its resources. However these models have not been tested and hence, Wickens (1982) pointed out that the extent to which baobabs associate with settlements and *vice versa* remains unknown.

Assumptions made by Chirwa et al. (2006) were that severe disturbances to baobab recruitment were likely to be due to animal browsing and clearing of fields. It is in the villages and fields where domestic animals browse often and land is normally cleared for crop farming and settlement which will result in poor recruitment thereby affecting the population structure. According to Duvall (2007), although valuable indigenous trees such as baobab may be prominent in settlements and fields, no study has shown that this prominence represents significant spatial dependence in specific landscapes, rather than an observational bias. Several studies have come up with varying conclusions about the factors that affect the population structure and abundance of the tree species near and around human settlements but there is no definite factor to explain such patterns.

Another habitat type that was found to have good baobab recruitment in a study done by Wickens and Lowe (2008) is the rocky outcrops. Wickens and Lowe (2008) explained that the seeds were dispersed by baboons that tend to roost in the rocky areas and the recruited baobabs were also protected from elephants due to inaccessibility to rocky areas. According to Edkins et al. (2007) rocky outcrops are often inaccessible to elephants and thus act as refuge sites. Therefore, such a land unit type also tends to affect the baobab population structure.

2.4 Factors affecting baobab fruiting

A study done by Swanapoel (1993) showed that baobab trees in the wild went several years without fruiting which was probably due to ecological factors such as limited resources or fruit abortion. This could also be supported by the findings of Sidibe and Williams (2002) that baobab trees near habitations were 'protected' and therefore nurtured as they tended to receive more water than those in the wild. Furthermore, Venter and Witkowski (2011) revealed that fruit production has a tendency to be higher in human-modified landscapes and lower in natural landscapes in a study in Limpopo, South Africa. This could be as a result of limited predation on immature fruits in the settlement areas by animals such as baboons such that fruit production was undisturbed.

Apart from the land-use types, a study done in Nyanyadzi and Gudyanga, Zimbabwe showed that fruiting patterns of the baobab had been negatively affected by heavy de-barking (Wynberg, Van Niekerk, Kozanayi & Laird, 2012). Preliminary results from an ecological survey showed that at least 31% of the sampled trees did not produce any fruit during the 2010/11 fruiting season due to debarking, while the majority produced less than 200 fruits per tree that season (Wynberg et al., 2012). A survey that was done earlier before the level of debarking arose showed that on average, each baobab tree produced 450 fruits per season (Wynberg et al., 2012).

2.5 Ecological concerns and the conservation of the baobab

Villagers from selected villages in Burkina Faso tend to manage the baobab in a relatively sustainable way due to moderately low human population density, better access to the forest and adapting traditional management strategies (Schumann et al., 2012). The traditional management practices by rural communities are an effective strategy in conserving the baobab species across different land-use types and as such, more attention will need to be drawn to those areas where high levels of human development are taking place as such areas are more vulnerable to baobab decline when the declared towns start to expand.

A study conducted by Sanchez et al. (2011) concluded that some countries such as Namibia, Sudan, Botswana, Somalia and Ivory Coast will not have suitable habitats for baobab trees in the future due to the predicted climate change. Although there might be uncertainties about such predictions, Sanchez et al. (2011) pointed out that this should not justify taking no conservation action. Since the baobab withstands extreme conditions such as droughts, it is predicted that there will be a potential increase in utilisation pressure on the tree as other plant species fail to cope with predicted changes in climate; this will consequently lead to local extinction of some baobab populations in the future (Sanchez et al., 2011).

One of the better conservation strategies to ensure successful recruitment is the protection of baobab seedlings from herbivores through fencing (Sanchez et al., 2011). This is because the survival of baobab seedlings in many areas has been affected by animals that either consume or trample young plants. Besides protection from herbivores, other measures would include treating the baobab seedlings against insect infestation where insects might be the cause of seedlings mortality (Sidibe & Williams, 2002), and raising awareness among the local people about propagation and managing seedlings since in some cases people are to blame for seedling mortality.

Given the high potential that the baobab products have towards generating cash income, Wynberg et al. (2012) suggested the need to manage the resource base to avoid over-exploitation. One of the ways that was put in place in managing the baobab resource in Zimbabwe was the formalization strategy whereby the government through the Forestry Commission became fully involved in the management of the baobabs. According to Wynberg et al. (2012), the formalization initiative that was implemented was a strategy to curb the ecological concerns that were hindering the sustainable management of baobab species. The formalization process entailed issuing harvesting licenses, marketing levies and fines to non-compliers, Access and Benefit Sharing (ABS), as well as recognizing the role of local people and traditional authorities in the management of the resources. However, follow up surveys showed that the formalization process also had its ecological costs such as increased de-barking, removal of germ-plasm material as fruits were transported or seeds crushed during oil extraction and reduced fruiting as a result of excessive de-barking.

2.6 Baobab dietary and medicinal uses

Nordeide et al. (as cited in Sidibe & Williams, 2002, p.47) surveyed two villages and a town to compare rural and urban use of wild foods in southern Mali. The findings showed that out of over 100 rural households, 26% used baobab leaves in the rainy season, and 56% in the dry season; and out of over 150 urban households, 6% used baobab leaves in the rainy season and 13% in the dry season for various dietary and medicinal purposes. People from the villages tend to have diverse uses of baobab products as revealed in Burkina Faso where villagers' greatest use-value was found for the food category followed by medicine and construction, which indicated that knowledge about food uses was more homogenous (Schumann et al., 2012). It can also be suggested that the villagers might have used the baobab products mainly for food purposes due to limited alternative nutrition sources.

In the West African Sahel, rural populations make use of the baobab tree products almost daily as one of the main ingredients in their diets, medicinal, ethno-veterinarian and medico-magical applications (Schumann et al., 2012). According to Sidibe and Williams (2002), the protein and iron-rich fresh, young leaves can be cooked as spinach whilst the dried leaves are normally powdered and used as sauces over porridge or rice and as soup. The powdered leaves can be used as an anti-asthmatic and in treating fatigue, insect bites, dysentery and internal pains.

The fruit pulp is dissolved in water or milk to make a hot or cool drink and can be used as a fermenting agent in local brewing (Sidibe & Williams, 2002). It can also be used for making cream for baking or sauce. The seed kernels can be eaten fresh, dry or ground and used in cooking and oil extraction. The seeds can also be roasted and used as a substitute for coffee (Sidibe & Williams, 2002).

Both the stem and root bark are used for medicinal purposes as Sidibe and Williams (2002) noted that in the past, the baobab bark was exported to Europe for use as a fever treatment. Both the baobab leaves and pulp can also be used to treat fever. The baobab oil is used on inflamed gums and to ease diseased teeth whilst the seeds are used in cases of diarrhea or coughs (Sidibe & Williams, 2002).

2.7 Socio-economic values of the baobab tree and baobab products

A study conducted in Nyanyadzi and Gudyanga Wards in Zimbabwe’s Chimanimani district revealed that at least 70% of the 100 residents interviewed used baobab products (Wynberg et al., 2012). The commercialisation of the tree is centered on the fruit, seeds and its fibrous bark. Local residents of Nyanyadzi and Gudyanga produce craft items from the fibre and the exportation of the craft items to South Africa started since the early 1990s (Wynberg et al., 2012). According to Sidibe and Williams (2002), fresh and especially dried leaves provide revenue to rural women and gardeners in the dry season when other field crop production is low.

Baobabs have the potential to provide additional income to farmers especially women and were reported to be one of the tree species with the most valuable food by quantity in markets in Burkina Faso and Mali (Schumann et al., 2010). This is supported by Wynberg et al. (2012) who found that the residents of Nyanyadzi and Gudyanga sell the baobab fruits in the urban areas or sell the extracted pulp via export or to national confectioneries. According to Wynberg et al. (2012), the Overseas Development Institute [ODI] (2006) projected that the European market for baobab products could initially generate more than US$750 million annually for producer countries in southern Africa per year, making it the highest earner of all traded NTFPs in the region. This therefore means the baobab products have great potential in contributing towards the national economies and improving livelihoods of local communities that own and manage the species.

The fibre from the inner bark is particularly strong and durable and is widely used in southern, eastern and western Africa for making ropes, basket nets, snares, mats, fishing rods and for weaving (Sidibe & Williams, 2002). Shells from the fruit and seed cake are usually fed to livestock. In East Africa, the roots are used to make a soluble red dye whilst the hard fruit shell is used to manufacture containers for food or drink as well as for decorative craft work (Dovie et al., 2002).

According to Wickens and Lowe (2008), apart from utilising the fruit, bark and leaves, the size and shape of the tree lends itself to spaces that can be used for water storage, prisons, toilets, burial grounds, sleeping places, ritual sites and venue for prayers or community meetings among other uses. The Ombalantu Heritage Centre preserves a historical baobab tree which is approximately 1000 years old (Omusati Regional Council, 2010). The baobab tree is approximately 8 m in diameter and about 19 m in height with a hollowed out trunk that was used as a prison during war and has also been used as a chapel, a post office and a kindergarten. The Centre is now a tourist resort where people pay to enter and view the tree and hear about the history of the baobab and also purchase souvenirs from the kiosk. The Ombalantu baobab tree carries great socio- economic and cultural values.

2.8 The value chain

In the northern Venda area in South Africa, the commercial use of baobab fruit dates back to 2005 (Venter & Witkowski, 2010). According to Venter and Witkowski

(2010), unemployed women are the ones who normally collect the baobab fruit from the trees in the communal lands, fields and villages. Sidibe and Williams (2002) pointed out that the baobab products are normally sold in local, informal markets with the main products being leaves, fruits and crafts. The fruit is processed *in situ* and sold to local companies which are the intermediaries that make oil from the seeds and package the fruit pulp. Cosmetic and food ingredients industries are the target markets where the processed baobab products are sold. Venter and Witkowski (2010) further stated that similar arrangements occur throughout sub-Saharan Africa.

Figure 3 depicts the value chain for baobab products from Nyanyadzi and Gudyanga Wards in Zimbabwe, which is almost similar to the value chains briefly described above from elsewhere in southern Africa. The international, state and local bodies are linked to the harvesters of baobab products for various purposes such as proving financial, legal and technical assistance. The uses include for domestic (medicinal, nutritional, craft) and for sell to entrepreneurs, tourist and bulk buyers that will finally export to regional or international markets. At such markets, most of the processing into finished products is done before being sold to the end users.

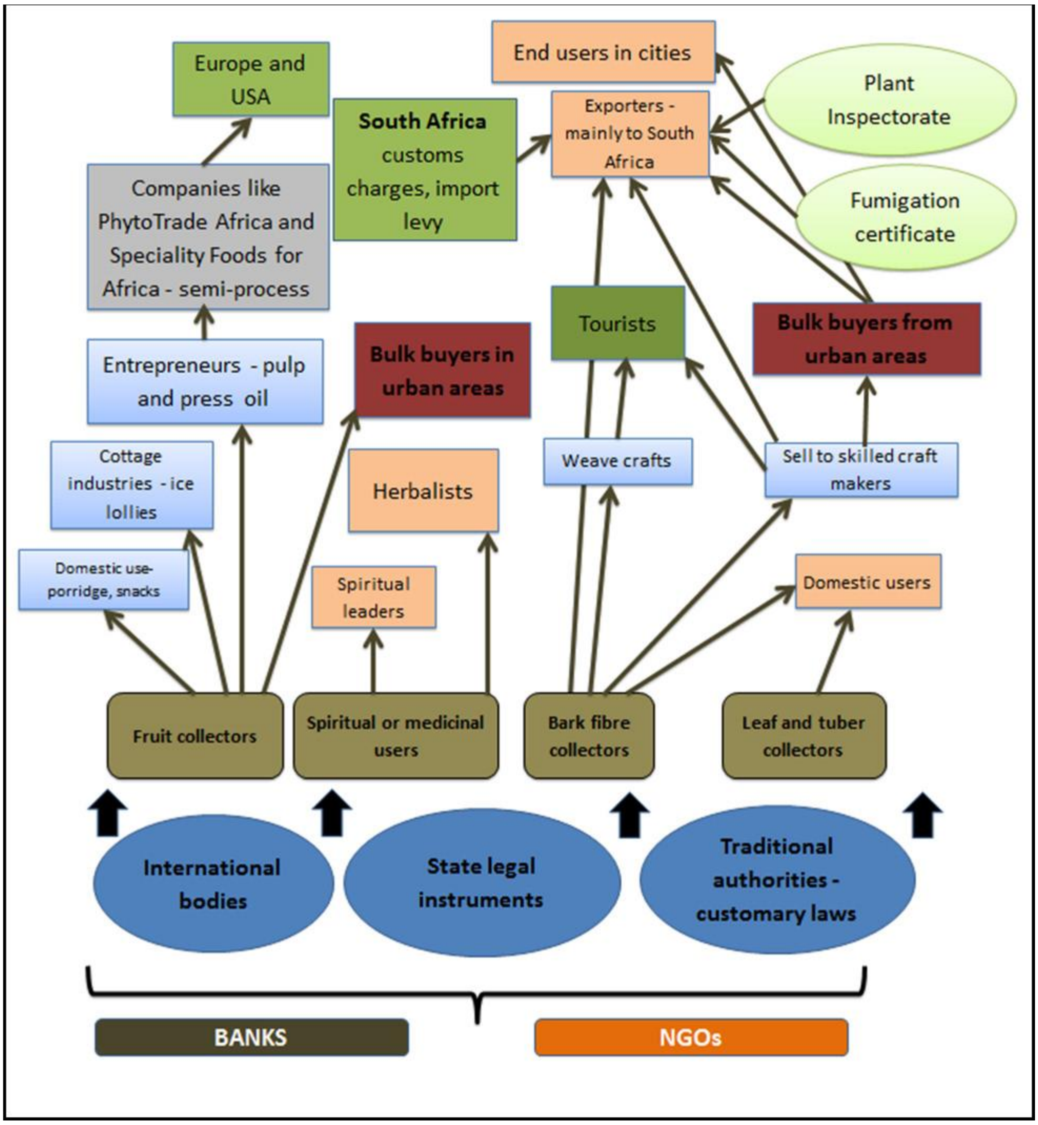


Figure 3: Value chain for baobab products from Nyanyadzi and Gudyanga Wards, Zimbabwe (Wynberg et al., 2012).

Despite the socio- economic and ecological values attached to the baobab resource and its resilience to droughts, there are still concerns about its sustainability due to anthropogenic, climatic (Sanchez et al., 2011) and ecological factors that tend to affect baobab density, distribution and structure (Mashapa, 2012) and disrupt recruitment (Chirwa et al., 2006) or fruiting (Venter, 2012). However, there are still gaps in knowledge regarding the value that the baobab has to the people who live where the species occur and the biological characteristics of baobab populations in more arid regions such as Namibia. Therefore, this study sought to investigate the distribution, density, structure, fruiting, stem conditions and uses of the baobab as well as the possible factors influencing the patterns in Outapi and Onesi constituencies in order to contribute to the available knowledge of baobabs across Africa. This study will assist in exploring the potential for commercialization in Namibia and ensuring that the best practices towards sustainable management of this multi-purpose and important species are implemented. In addition, the study will provide contributory data that will be used in conducting national red list assessment of the baobab.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location and extent

Omusati Region is in the north-central part of Namibia (Fig. 4). The region is one of the four administrative regions in north-central Namibia with the other three being Ohangwena, Oshana and Oshikoto regions. Omusati Region is 26 573 km^2 in size and has the second highest population after Khomas (Omusati Regional Council, 2010) of currently about 243166 and a population density of 9.2 people per km^2 (GRN, 2011). It is located about 794km northwest of Windhoek. There are 12 Constituencies in Omusati Region namely Anamulenge, Elim, Etayi, Ogongo, Okahao, Okalongo, Onesi, Oshikuku, Otamanzi, Outapi, Ruacana and Tsandi (Omusati Regional Council, 2010). The study focused on Outapi town and Onesi settlement and surrounding areas. These constituencies are located to the southern part of the border between Angola and Namibia.

Outapi is an urban centre which is the capital and economic hub of Omusati Region with the highest population in the Region. Currently, Outapi constituency has about 36934 people whilst Onesi constituency, a typical communal area has approximately 13 149 people (GRN, 2011). The incessant increase in the population in the region has put the environment within which the people live under severe pressure (Mendelsohn, Obeid & Robert, 2000).

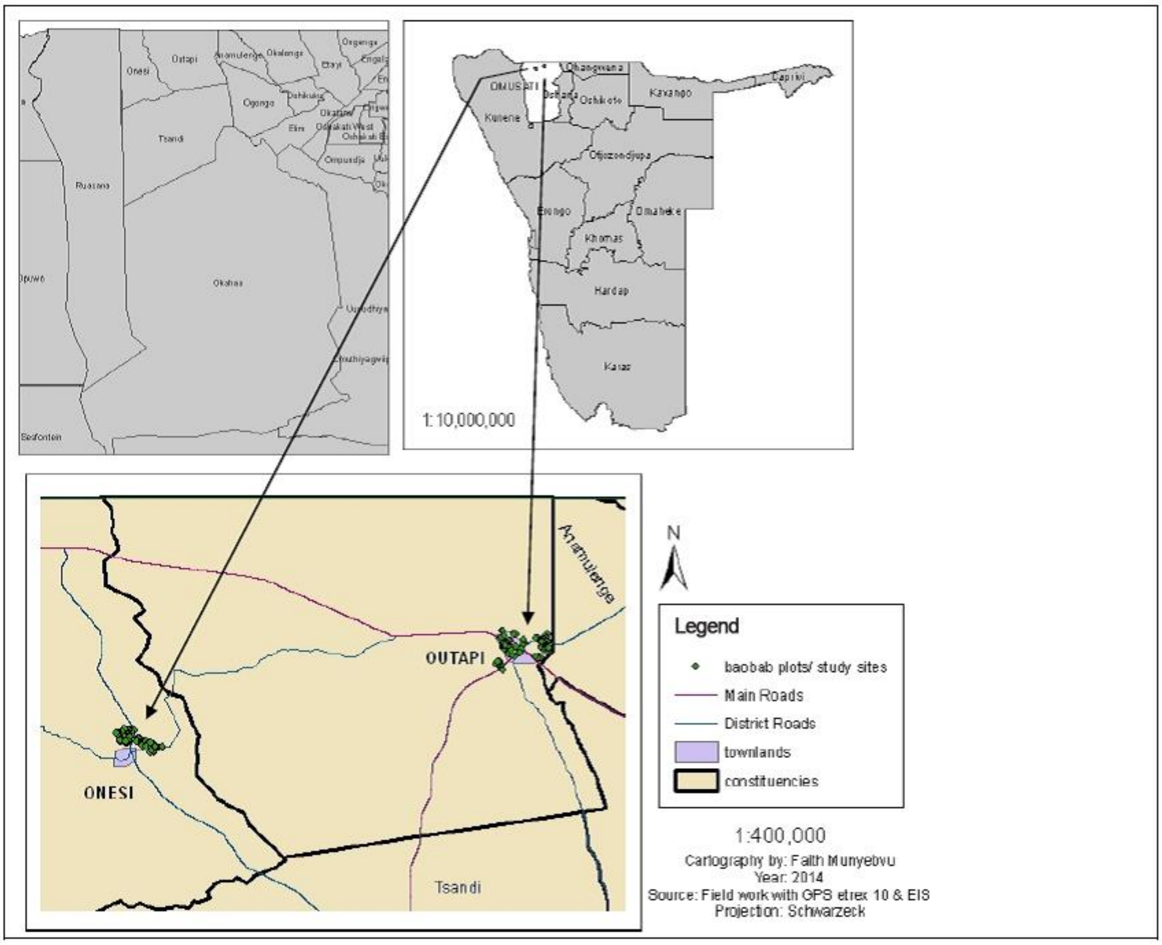


Figure 4: Location of study area and the position of sampled baobab individuals in Omusati region.

3.1.2 Climate

The climate of Omusati Region is generally described as semi-arid. Rainfall is restricted to the summer months (November to April) when the temperature is at its peak. Rainfall decreases from 550-600 mm per year in the north-east to 250-300mm per year in the south-western parts (Mendelsohn et al., 2000). Outapi constituency is also the hottest place in northern Namibia with an average annual temperature range of 26-30^{o}C and average maximum temperature of 40^{o}C (GRN, 2011). Omusati Region has a maximum average temperature range of between 34-36^{o}C and a minimum average temperature range of between 6-8^{o}C (Ministry of Environment and Tourism [MET], 2013).

Overall, Namibia's climate varies greatly from year to year which means that the country may experience years of good, poor or moderate rainfall in no particular order (Kangombe, 2010). According to Mendelsohn et al. (2000), wet and dry periods are a normal climatic feature of this environment which has been persistent for millions of years. The 2012-2013 rainfall season was very dry in Omusati region with a cumulated rainfall ranging from 0 to 150 mm between September 2012 and May 2013 (Hooker, Kayitakire, Urbano, Rembold & Kerdiles, 2013). This season was recorded the second driest in Namibia of the last 25 years (Hooker et al., 2013). The 2013-2014 season received normal to below normal rainfall in Omusati region which ranged from 80 mm to 320 mm between October 2013 and April 2014 (Ministry of Works and Transport, 2014).

The available water capacity is low due to the poor water holding capacity of the sandy soils in the area (Hangula, Angula, Mafwila & Shapi, 1998). This combined with high rates of rainwater evaporation and percolation and low levels of humidity which increases evaporation, means there is a consequent reduction in the water available for plant uptake.

3.1.3 Geology and soils

The region is located within the central plateau geographic landscape and has an average altitude of 1000 m above sea level. Omusati Region belongs to the very flat hydro-geological Cuvelai basin (Mendelsohn et al., 2000). The basin lies on an old continental base of granites, gneisses and volcanic rocks (Mendelsohn et al., 2000). Almost all the soils in north-central Namibia have been deposited by wind and water and a large proportion of the soils in this area are broadly categorized as arenosols or sandy soils (Mendelsohn, Jarvis, Roberts & Robertson, 2002). According to Mendelsohn et al. (2002), despite being poor in humus and plant available nutrients, soils in north-central Namibia have a fairly high suitability for crop cultivation, relative to other soil types in other parts of the country.

Specifically, Outapi constituency is dominated by cambisols that are highly suitable for crop cultivation whilst Onesi constituency has mainly arenosols that have low suitability (Omusati Regional Council, 2010). Both Outapi and Onesi constituencies fall within the Etosha National Park catchment and are dominated by oshanas that increase in number from the north east of Onesi into Outapi, Anamulenge, Okalongo and Ogongo constituencies. Clayey sodic sands dominate in the oshanas with sodic sands occurring on the surrounding higher grounds. Sands and loams occur largely to the south, north, east and west of the Cuvelai delta where wind and water have repeatedly reworked the soil to create a mixture of deposits (Mendelsohn et al., 2000). According to Mendelsohn et al. (2000), the high sodium content of clayey sodic and sodic sands is due to cycles of recurring floods and water evaporation.

3.1.4 Flora

The region is within the woodland savanna biome and the landscape is made up of a successive series of sand dunes of varying depths, separated by waterways. Mopane tree is the dominant species and is spread across the region on the shallower sand dunes. The vegetation is classified into four broad types (Selanniemi, Chakanga & Angombe, 2000) which are palm savanna, bush mopane savanna, seasonally flooded grasslands with patches of mopane and acacia, and open shrub savanna of mopane and acacia (Mapaure & Ndeinoma, 2011).

According to du Plessis (2001), vegetation in Omusati Region belongs to the Mopane savanna following Geiss (1998) classification of vegetation zones in Namibia. Mopane is an extensive vegetation type within the savannas in southern Africa (du Plessis, 2001). *Hyphaene petersiana* Klotzsch ex Mart. (Makalani Palms; Omilunga), *Ficus carica* Linnaeus (Fig trees; Omikwiyu) and *Sclerocarya birrea* L.

(Marula trees; Omigongo) are especially abundant in the eastern parts of the Region (Omusati Regional Council, 2010). The area has a significant population of *Adansonia digitata* which is mainly dominant in parts of Tsandi, Onesi and Outapi constituencies.

A fairly new land use initiative in the region that has led to sustainable conservation of flora is community forests. These are areas within the communal lands that are sustainably managed by local communities in order to protect the forest and its resources whilst at the same time improving the livelihoods of the caretakers (communities). This programme has been focused mainly on managing wood and non-wood plant resources (Ministry of Agriculture, Water and Forestry [MAWF], 2009). Four community forests have already been gazetted in the region namely Uukolonkadhi, Uukwaludhi, Ongandjera and Oshikushiithilonde (MAWF, 2009).

3.1.5 Fauna

Most of the wildlife in Omusati Region is found within the Uukwaluudhi Conservancy. The 5000 ha conservancy contains among others *Proteles cristata* (Aardwolf), *Felis silvestris lybica* (African Wild Cat), *Otocyon megalotis* (Bat eared Fox), *Diceros bicornis* (Black Rhino), *Aepyceros melampus petersi* (Black-faced Impala), *Connochaetes taurinus* (Blue Wildebeest), *Tragelaphus scriptus* (Bushbuck), *Loxodonta africana* (African Elephant), *Giraffa camelopardalis* (Giraffe), *Crocuta crocuta* (Spotted Hyena) and *Parahyaena brunnea* (Brown

Hyena), *Tragelaphus strepsiceros* (Greater Kudu), *Galerella nigrata* (Black Mongoose), *Oryx gazella* (Oryx), *Antidorcas marsupialis* (Springbok) and *Equus zebra hartmannae* (Mountain Zebra). Omusati Region is endowed with 430 bird species, 25 amphibian species (13 of these are largely dependent on riverine habitats), 67 species of reptiles and 71 fish species (Omusati Regional Council, 2010).

Within Omusati region is the Ogongo Game Park which is part of University of Namibia Ogongo Campus. The 1000 ha park attracts a rich diversity of wildlife and bird species (www.unam.edu.na/ogongo-campus). In 1997, the Ministry of Environment and Tourism stocked Ogongo park with animals that included springbok, ostriches, red hartebeest, oryx, zebras and giraffes (Shigwedha, 2007) and these are the species that are still found in the park (personal observation).

During the field survey, apart from livestock, bats, lizards, birds and small creatures such as ants were also encountered. No wild ungulates such as giraffes and sub-ungulates such as African elephants were encountered either in Outapi or Onesi constituency and the team was only informed about the presence of snakes inside some of the hollow trunks within the grazing area.

3.1.6 Socio-economic activities

Omusati Region, like the rest of Namibia, is home to many cultural groups including the Himba community and the cultural Kingdom of the Uukwaluudhi King, one of the last authentic Owambo kingdoms and the San (Omusati Regional Council, 2010). The main language groups living in the area are Oshiwambo- (oshi-kwaluudhi, oshi-mbalanhu and oshi-kolonkadhi dialects) and Oludhemba-speaking (Omusati Regional Council, 2010).

Despite high unemployment rate, poverty, socio-economic inequalities, skilled labour shortage and narrow industrial base (Nambwaya, 2014), Omusati Region holds promise to be developed into one of the leading agricultural regions in southern Africa (Mendelsohn et al., 2000). Subsistence farming is practiced by the majority of people in the region. In the villages, each household has a fence (made out of either barbed wire or mopane branches or both) around their crop-field, a homestead and a household grazing area that they were allocated by the Traditional Authority (Mendelsohn et al., 2000). Other farming practices include large-scale subsistence farming and commercial farming on privately owned land (Mendelsohn et al., 2000). Pearl millet, maize and sweet maize are already successfully cultivated and processed in the region. Several other products such as watermelons, sweet melons, butternuts, tomatoes, and bananas are exported to neighboring regions and countries (Omusati Regional Council, 2010).

Various irrigated crop farming projects have been established in the region based on results of successful experiments conducted. Animal husbandry consists mainly of cattle and goat farming. The general main economic activities in Omusati Region are agriculture and retail trade and the main sources of income for the communal people in the region are crop farming and livestock rearing (Omusati Regional Council, 2010). High valued trees such as baobab are preserved when land is cleared for agricultural production. Agro-silvo-pastoralism has proved to have greater benefits at community level as the people tend to diversify their sources of livelihoods.

The local delicacies of Omusati Region include *Gonimbrasia belina* (mopani worms) (roasted or dried), sorghum drink, fresh and dried fruits like marula, fig, baobab, *Voandzeia subterranean* L. *thouras* (bambara nuts) and many more (Omusati Regional Council, 2010).

3.2 Selection of study sites and experimental design

Data were collected in the month of April 2014 in two different constituencies within the Omusati Region where varying levels of human pressure in terms of social, economic and environmental activities take place. The study sites were selected based on the areas within the constituencies where the baobabs occur; one site in Outapi constituency and another site in Onesi constituency. Baobab trees occurring in the eastern area of Outapi constituency including trees within the nearby villages of Omusjii and Oukwa and Ombalantu (within the town area) were sampled. In Onesi constituency, baobabs at the eastern villages (Oshima, Ohalumbele and Oshihau villages) were sampled (Fig. 4).

Road transects were used to sample baobabs in the two sites by purposively selecting the next road towards the west of each constituency to gain access to the next focal tree following an approach by Mpofu, Gandiwa, Zisadza and Zinhiva (2012). The first transect was purposively laid where baobabs were occurring at the eastern part of each constituency. In the developed area of Outapi, all the available roads including foot paths were used to get to the next focal tree. A vehicle was used to traverse the selected roads and baobabs sighted on either side of the road within and outside homesteads were measured by demarcating circular plots of 30 m in radius from the edge of the canopy of each focal tree following an approach by Selanniemi et al. (2000) (Fig. 5). All the required data within the circular plot were collected and recorded on the field sheet (Appendix A) including checking for any other baobabs (adult, sub-adult trees or saplings) and creating a waypoint and logging in the position of the tree (Appendix B) using a Garmin Geographical Positioning System (GPS) unit before moving to the next focal tree encountered. A minimum target of 100 circular plots was reached in each of the two sites. A total of 118 baobabs were sampled in Outapi Constituency in 101 circular plots whilst 112 baobabs were sampled in Onesi in 100 circular plots. Each baobab plant was considered a sampling unit.

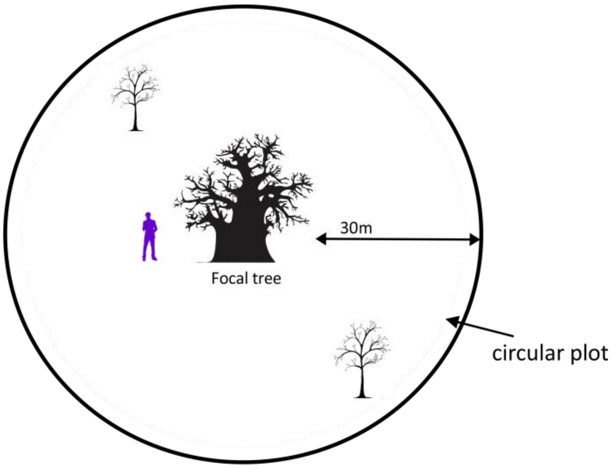


Figure 5: Demarcation of circular plots around the focal baobab tree (not to scale)

3.3 Assessment of population structure and abundance

In this study, adult trees were defined as having diameter at breast height (dbh) of equal to or more than 150 cm and sub-adults with less than 150 cm and more than 1 cm in dbh following Schumann et al. (2010). Saplings and seedlings were identified and distinguished from each other by their vegetative and morphological characteristics such as the number of leaves and the size of the plant (Fig. 6). Specimens were also used to do the matching. All baobabs (adults, sub-adults and saplings) identified within each circular plot were counted and their heights measured. The heights of seedlings and saplings were estimated using a 1 m measuring pole.

As for adult and sub-adult baobabs, a mark was placed on the 1m measuring pole at the length which was equivalent to the distance between the eye (cheekbone) and fingers when the arm was fully extended in front of the face. The enumerator would then move backwards until the top and the base of the tree were in line with the top and the base (marked point) of the measuring pole. A measuring tape was then used to measure the distance from the enumerator's eye to the base of the tree to determine the height of the tree. For adult and sub-adult trees, the dbh was measured using a forest tape whereby the trunk was measured at 1.3 m above ground level in accordance with the international practice (www.afcd.gov.hk/).

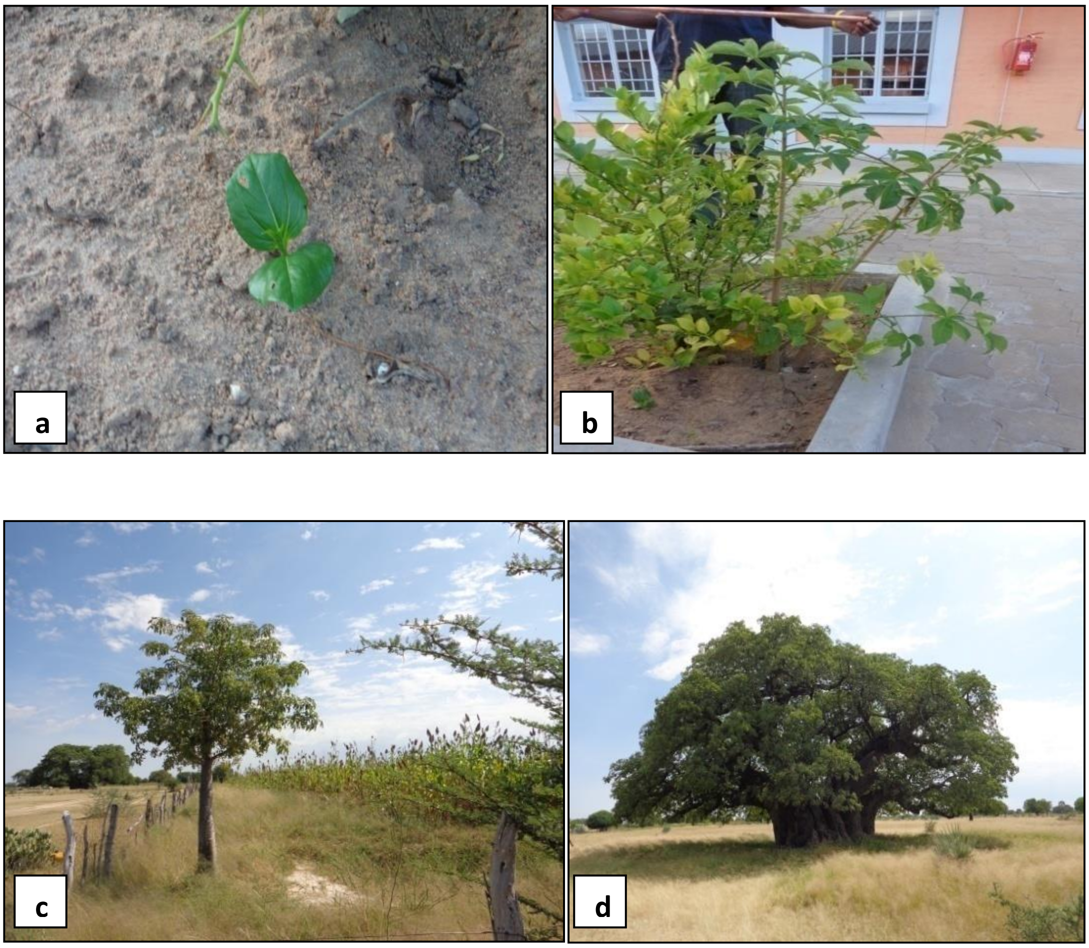


Figure 6: Different baobab size-structures identified in the study sites: seedling (a), sapling (b), sub-adult (c) and adult baobab (d). Photo credit: Ruben Ulbrich

3.4 Assessment of individual plant condition and phenology

Each tree (adult, sub-adult and sapling) encountered within each circular plot was assessed for any evidence of debarking, fire scars and any other disturbances. All baobabs (adults, sub-adults and saplings) that were assessed for any disturbances on the stems were assigned into one of the three different categories which were intact (those without any damages), de-barked (either old or new) and other. Other conditions referred to varying conditions on the stems such as termite infestation, human- induced cuts and natural holes.

Fruit counts were conducted in April 2014 when most of the baobab fruits had matured and almost ready for harvest. Fruit production was then determined by presence/absence assessment. Trees were categorized as fruiting or non-fruiting based on fruit presence or absence. Fruits per individual tree were estimated through randomly selecting and visually counting the fruits on 50% of crown cover and then multiplying by two to get an estimate of the whole tree. Total number of fruits was the sum of mature, immature or aborted fruits that were still attached to the tree and excluded any fallen mature, immature or predated fruits.

The type of land use where each sampled tree occurred was also noted (Fig. 7). The 3 major land-use types in the sampling sites were categorized as (a) field-the area where crop cultivation was being done, (b) pasture- the grazing area that includes paddocks and other open areas where livestock graze, and (c) settlement- this included people's yards or the area surrounding houses or huts following Schumann et al. (2010). The settlement area for Outapi as an urban centre included the business centre area as well as open spaces in between buildings. In Outapi constituency, a total of 32 baobabs were enumerated in fields, 27 in the pasture area and 59 in the settlement area. In Onesi constituency, 38 baobabs were enumerated in fields, 71 in the pasture area and 3 in the settlement area. In total, 230 trees were sampled, 70 in fields, 98 in the grazing area and 62 in the settlement.

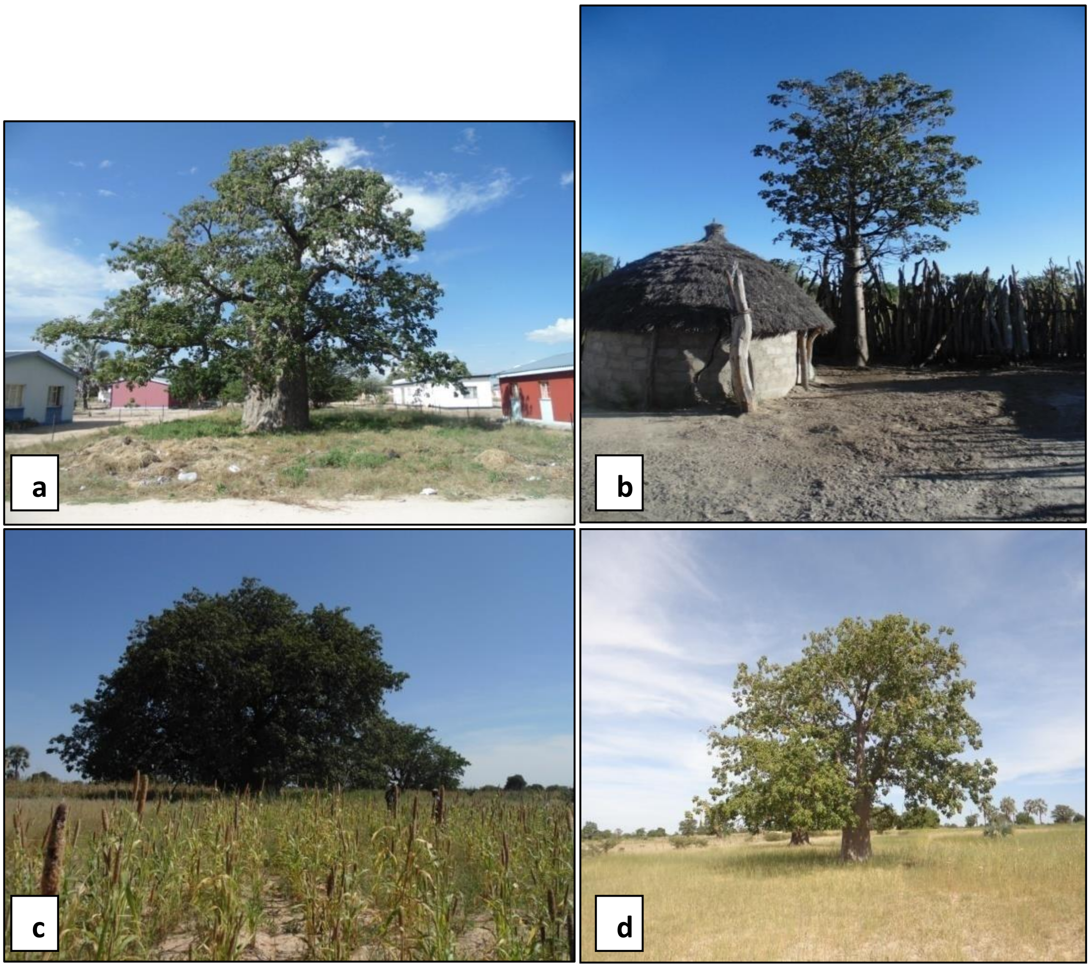


Figure 7: The main land-use types where sampled baobabs were encountered. Typical settlement in the town of Outapi (a), settlement in Onesi (b), field (c), pastures (d). Photo credit: Elisha Chambara

3.5 Socio-economic survey

Questionnaire (Appendix C) interviews with the nearby households or the households that had baobabs in their fields and or homesteads were conducted in order to understand the uses of baobab trees within and outside the farmlands (Fig. 8). Permission was sought from the Regional Councilors of both Outapi and Onesi constituencies to conduct the interviews. All the enumerators were also clipping name tags with the University logo and the name of the project for easy identification.

Respondents were purposively selected when the next focal tree was found within or nearby the respondent’s household or field. A total of 37 structured interviews with a combination of both open and close ended questions (Appendix C) were conducted in Outapi constituency and 30 in Onesi constituency. Fewer questionnaire interviews were conducted in Outapi constituency due to mainly the absence of people in the vicinity of the service centre (grouped under settlement) whilst in Onesi constituency it was mainly due to the ownership of more baobabs in one homestead. Interviews were conducted in the local language by a member of the field team that were conversant with the language spoken in the Region.

All the five enumerators would introduce themselves at every household before asking for permission to conduct the survey. Whilst one enumerator was conducting an interview, two members of the team were taking the measurements (dbh and height) with one team member doing the fruit counts and assessments (stem condition and land-use type) on the baobabs within that household and the fifth team member recording all the figures and notes including the GPS waypoints on the field sheet. All respondents were at least 18 years old and above, with the oldest respondent being over 80 years. The respondents were asked among other issues about the:

- number of baobab trees they have,
- main uses of the tree and the parts utilized,
- evidence of recruitment ever seen,
- factors affecting baobab sapling survival, and
- cultural importance (use) of the baobab.

Figure 8: Administering questionnaire interviews with the villagers in the study sites. Photo credit: Elisha Chambara

3.6 Data analyses

3.6.1 Population abundance and distribution

To determine the density of the baobabs, firstly, the total plot area per study site was calculated by converting the 30 m circular plot into square meters area size (2 826 m^2) and then converting it further to hectares (0.2826 ha). This was done to enable the conversion of tree numbers site into densities (plants/ha) (Venter & Witkowski, 2010). This was followed by summing up the total surface area of the 30 m radius circular plots demarcated in each site and then dividing it by the number of trees sampled per site.

The densities were then tested for any difference using the Fisher's Exact test since both density counts were less than 5. To display the spatial distribution patterns of the sampled baobabs in the two sites, GPS waypoints of sampled baobabs were downloaded from the Garmin etrex 10 into Arc Map 1.0 of Arc Geographic Information System (GIS) (ESRI, Redlands, CA). The distribution of baobab plots was mapped using Geographical Coordinate System (GCS) Schwarzeck. Omusati satellite imagery map was geo-referenced in GIS using Arc Map 1.0. Data were analysed in Arc Map 1.0 to produce the baobab distribution maps of Outapi and Onesi constituency.

3.6.2 Stem diameter frequency distribution

Each sampled adult and sub-adult baobab was assigned to one of the nine 100cm wide diameter at breast height classes, ranging from 1-100 cm, 101-200 cm and so on up to ≥ 801cm dbh. The dbh size class intervals used by Schumann et al. (2010) of 50 cm were modified to 100 cm because the baobabs in Omusati Region were much larger. Chi-Square test of Independence was used to test for differences in the dbh frequency distributions between Outapi and Onesi constituencies.

3.6.3 Height-class distribution

All sampled baobabs including the saplings were assigned to one of five height classes. The height classes were determined as 5 m increments in height, which was ≤ 5 m, 5.1-10 m, 10.1-15 m, 15.1-20 m and 20.1-25 m following Ravindranath and Ostwald (2008). Chi-Square test of Independence was used to test for differences in height classes of the baobab populations between the two study sites.

3.6.4 Stem condition

In order to check for any differences in the stem conditions between the two sites, a Chi-square test of Independence was used. The observed and expected frequencies were compared to indicate where the differences were. Chi-Square tests were conducted to test for any significant association between the stem condition and the dbh size-classes and between stem condition and land-use types.

3.6.5 Assessment of fruit production

All trees that had started fruiting were allocated into one of the seven fruit classes. The fruit classes were ranks of 0-4, 5-24, 25-49, 50-99, 100-199, 200-299 and 300-400 following Venter and Witkowski (2011). No tree exceeded 400 fruits at the time of the survey. The proportion of sub-adult and adult trees falling into each of the fruit production class was determined. All the adult trees (dbh>150 cm) that had reached the reproductive stage and had absence of fruits were also assigned into the fruit class 0-4. All sampled adult trees and fruiting sub-adults were used to compare fruit production between the two survey sites. In order to determine if there were significant differences in the medians within each fruit abundance range between the two sites, Mann Whitney *U*- test was used.

3.6.6 Assessments within different land-use types

Irrespective of sites, Chi-Square tests of Association were also performed to check for any significant association between different land-use types and dbh size-class distribution, land-use types and fruiting and land-use types and stem conditions.

3.6.7 Uses of baobabs

A total of 10 categories of the uses of baobabs in the two sites were identified and used to assign each use that was captured during the socio-economic survey. The counts of each use category were recorded based on the frequency the uses that fit in that particular category were mentioned by a respondent. The socio-economic characteristics of the respondents, knowledge of the baobab and its usage were presented using descriptive tools such as proportions and frequency counts. In order to determine the differences between the uses of baobabs in the two sites, Chi-Square test of Independence was used.

3.6.8 Baobab propagation and factors affecting seedlings and saplings survival

In order to determine any difference in baobab propagation between Outapi and Onesi constituencies, Fisher's Exact test was used. Chi-Square test of Independence was used to determine any differences in the factors mentioned by respondents in the two study sites to have affected the survival of baobab seedlings and saplings.

Pearson's Chi-square test of Independence or Association was used to carry out several analyses since data were categorical. It was used to identify any relationship between two categorical variables that were being analysed. Fisher's Exact test was only used to conduct a chi-square test only where one or more of the cells had an expected frequency of five or less. Mann Whitney *U*-test was also used to compare the medians. The statistical package IBM Corp SPSS 21.0 (SPSS Inc., Armonk, NY) was used for all the statistical analyses. The total area traversed in each site was calculated in Arc Map 1.0 through measuring the approximate length and width of the whole area within which baobabs were sampled.

CHAPTER 4

RESULTS

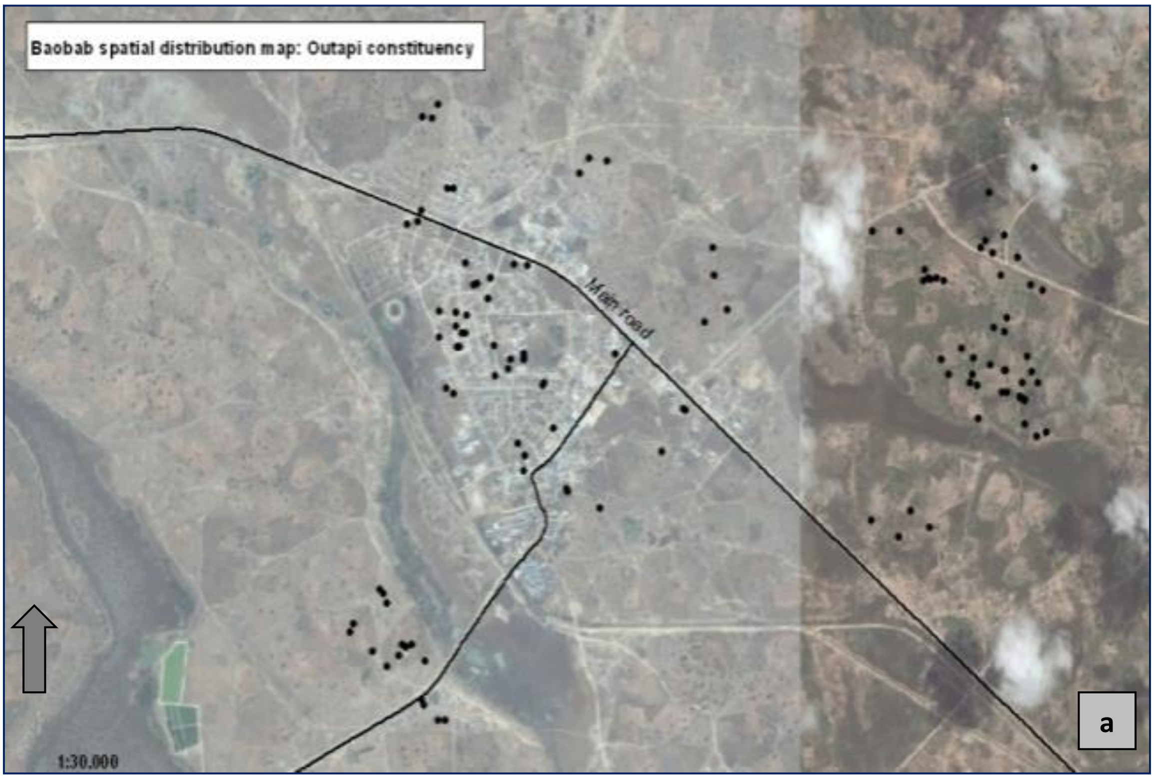
4.1 Population density and spatial distribution

The baobab densities of Outapi and Onesi constituencies were calculated and the results are displayed in Table 1 below. Fisher's Exact test results showed that baobab densities per plot did not significantly differ between the two sites (χ^2=2, df=1, p>0.05). Despite an apparent slightly higher baobab density in Outapi constituency of 4.13 trees/ha than in Onesi constituency of 3.96 trees/ha, the difference was not statistically significant.

Table 1: Baobab density results for Outapi and Onesi constituencies.

Site	**Total No. of plots**	**Area of 30 m radius plot (ha)**	**Total Area (ha)**	**No. of baobabs sampled**	**Density (plants/ha)**
Outapi	101	0.2826	28.54	118	4.13
Onesi	100	0.2826	28.26	112	3.96

The results showed that baobab abundance in each constituency was not evenly distributed across the habitats as some baobab stands were in a clustered pattern whilst some trees were more dispersed. In Outapi constituency, some baobabs especially to the east were more clustered whilst others were more sparsely distributed. Baobab stands in Onesi constituency mainly displayed a clustered distribution pattern on either side of the main gravel road (Fig. 9). In order to reach the total of 118 individuals in Outapi constituency, a total area of approximately 22.5 km^2 was traversed whilst in Onesi constituency, a total area of only about 6.45 km^2 was traversed in order to sample the 112 individuals which explain the observations noted above. Overall, baobabs in both Outapi and Onesi constituencies generally displayed more aggregated spatial distribution patterns.



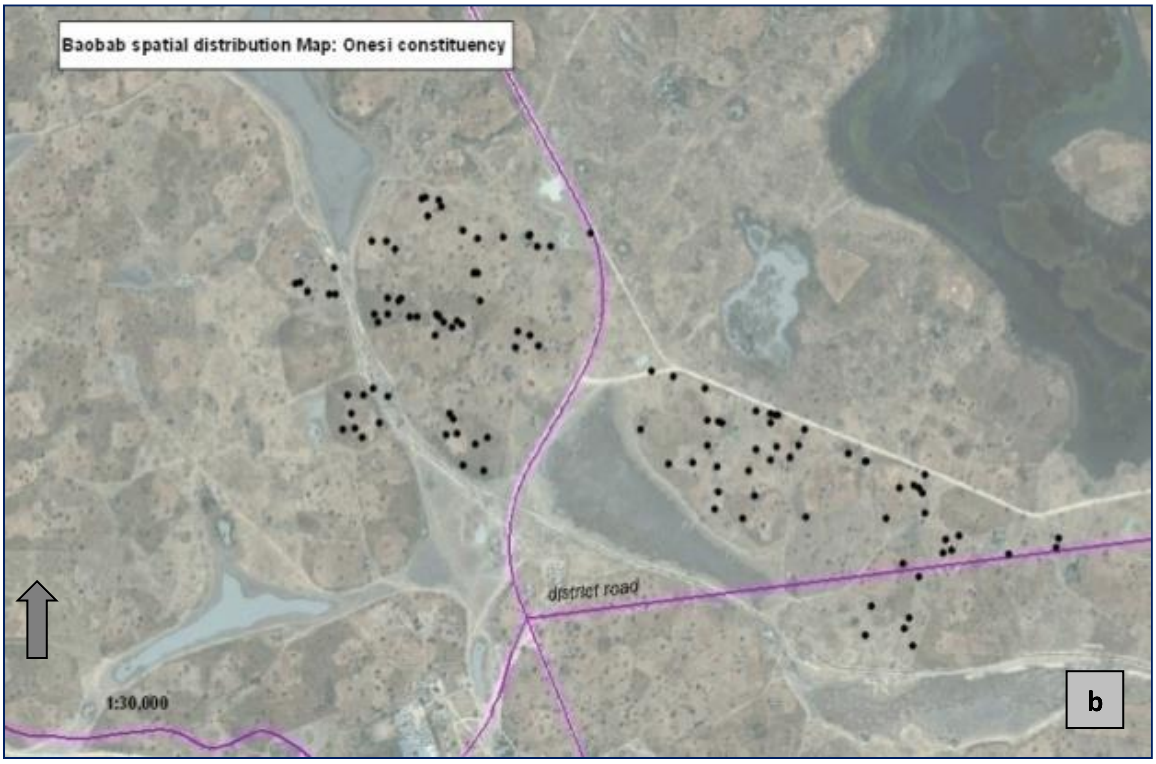


Figure 9: Comparison of the spatial distribution patterns of sampled baobabs in (a) Outapi and (b) Onesi constituencies (• symbol represents baobab individuals).

4.2 Comparisons of the size-class distributions

4.2.1 Comparisons between Outapi and Onesi constituencies

The largest baobab with about 1200 cm dbh was recorded in the settlement area of Outapi constituency. In Onesi constituency, the largest tree about 710 cm dbh was encountered in the pasture area. Both Onesi and Outapi constituencies had at least two saplings recorded in each site. In Outapi constituency, a total of eight sub-adult baobabs were recorded ranging between 10 and 100 cm in dbh. Thirteen sub-adults were encountered in Onesi constituency that ranged between 3 and 140 cm in dbh. The majority of the baobabs measured in both sites were of the adult size-class within the dbh 170-230 cm and 160-710 cm in Outapi and Onesi respectively (Fig. 10).

There was a significant difference in the dbh frequency distributions between Outapi and Onesi constituencies (χ^2=33.038, df=8, $p < 0.001$). The dbh size-classes of 101-200 cm and 201-300 cm had higher observed values than the expected in Onesi constituency by 5.8 % and 7.9 % respectively whilst in Outapi constituency the size-class >501 cm had much higher observed value than expected by 4.5%.

Conversely, Outapi constituency had much lower observed than expected values within the 101-200 cm and 201-300 cm dbh size-classes by 5.4% and 7.5% respectively. Figure 10 shows that Onesi constituency had the highest proportion of trees within the 201-300 cm dbh size-class while no trees were recorded in the largest size-class (>801 cm) in that constituency. In general, the largest proportion of the trees (52% in Outapi) and (68% in Onesi) were within the middle size-classes that ranged from 201 to 500cm in dbh. Resultantly, baobab trees in both Outapi and Onesi constituencies displayed a bell-shaped size class distribution (Fig. 10).

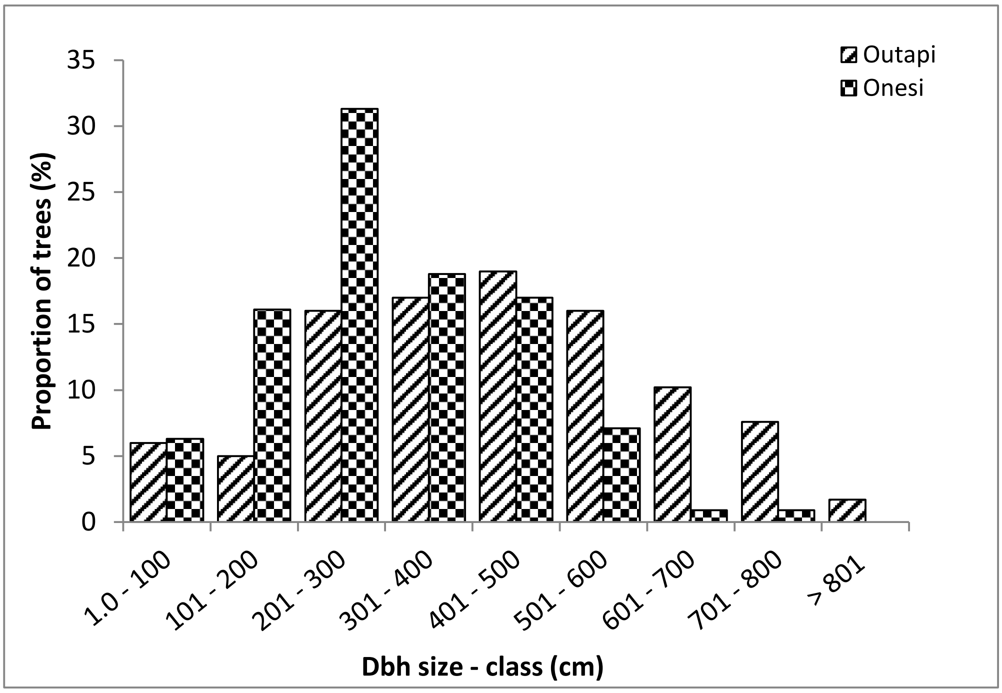


Figure 10: Comparison of proportions of baobab individuals within different dbh size-classes between the Outapi and Onesi constituencies.

4.2.2 Comparisons of size-class distributions among land-use types

There was no significant difference in the dbh size-class distribution within the different land-use types of Outapi and Onesi constituencies (χ^2=13.032, df=16, p>0.05). Onesi constituency had the highest proportion of trees in fields within the size-class of between 201-300 cm. Overall, the highest proportions of baobab stands in the fields in Outapi constituency were within 201-700 cm dbh size-classes whilst Onesi constituency had an overall higher proportion of trees between 1 and 500 cm dbh size-classes (Fig. 11 a). The pasture area that was sampled had no baobab stands within the 1-100 cm dbh size-class in both sites. Onesi constituency recorded the highest proportion of trees in the pasture area between 201-300 dbh size-classes (Fig. 11 b). Figure 11 (c) shows that in Outapi constituency, all the dbh size-classes of baobabs were represented within the settlement area whilst in Onesi 100% of the sampled baobabs were within the 1-100 cm dbh size-class with no other dbh size-classes represented in that land-use type, but there was no significant difference (p>0.05).

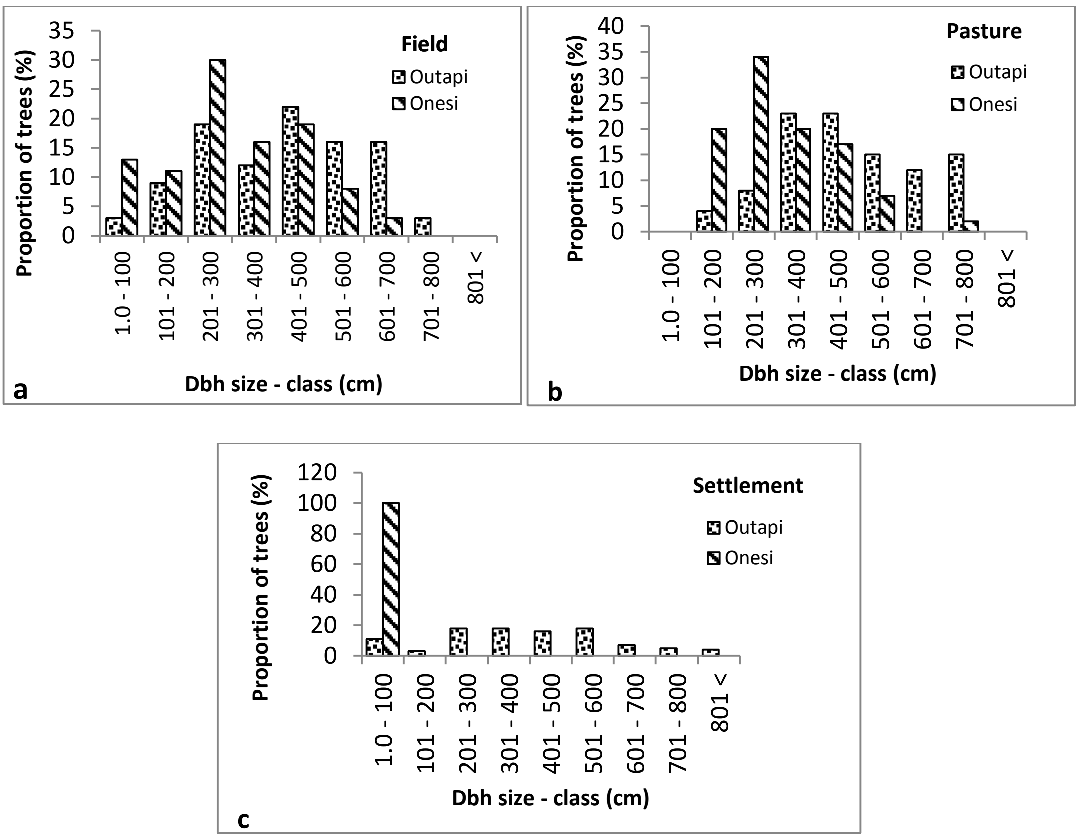


Figure 11: Proportions of baobab individuals within different size-classes (dbh in 100 cm intervals) in different land-use type: fields (a), pasture (b) and settlement area (c) in Outapi and Onesi constituencies.

4.3 Differences in the height structure between Outapi and Onesi constituencies

The heights of the saplings in Outapi constituency ranged from 0.4 m to 1 m, and 0.3 m to 0.4 m in Onesi constituency. For sub-adults, the heights ranged from 2.3 m to 14m in Outapi constituency and between 2 m and 20 m in Onesi constituency. The maximum height for adult trees in Outapi was 23 m and for Onesi it was 24 m. The two shortest adult trees recorded in Outapi and Onesi constituencies were 8 m and 11 m tall, respectively.

There was a significant difference in the height frequency distribution between the two sites (χ^2=16.295, df=4, $p<0.05$). The 11-15 m height-class had the highest observed than expected counts in Outapi by 8.1%. The significant difference ($p<0.05$) was also found within the 21-25 m height-class that had less than expected number of trees by 8.2% in Outapi whilst Onesi realized much higher observed than expected counts by 8.7% in the same height class.

As depicted in Figure 12, there was a gradual increase in the proportion of trees with increasing height-classes before a decrease in trees with the tallest height-class (21-25 m). More trees were recorded within the 10.1-25 m height classes than within the <10 m height-classes. Overall, the highest proportion of trees (40%) recorded in Onesi constituency were within the 15.1-20 m class whilst Outapi constituency recorded its highest tree proportion (38%) within the 11-15 m height-class (Fig. 12). In comparison, Onesi constituency had 31% of sample trees within the tallest height class (21-25 m) whilst Outapi constituency only recorded 14% of sample trees within the same height-class. In general, the height frequency distribution patterns of both sites are more negatively skewed as the highest proportions of trees were within the taller height-classes.

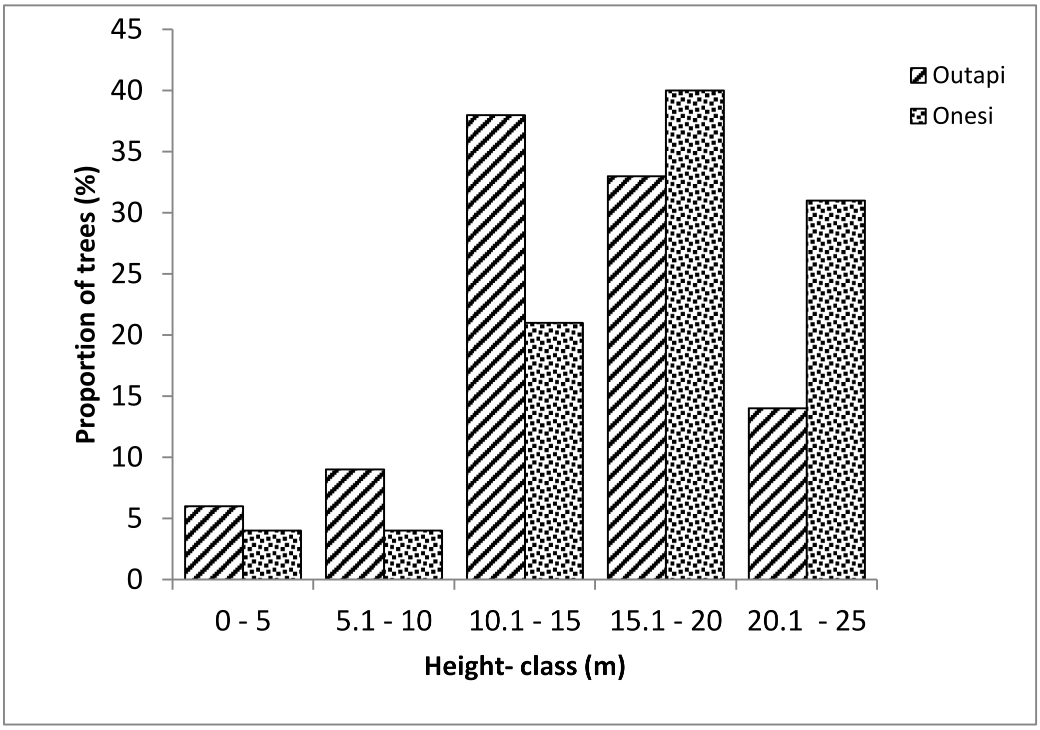


Figure 12: Comparison of proportions of baobabs within different height classes between the two study sites.

4.4 Comparison of stem conditions

4.4.1 Comparisons between Outapi and Onesi constituencies

There was a significant difference in the stem condition between Outapi and Onesi constituency (χ^2= 22.705, df=2, p<0.001). There was much higher observed than expected counts of intact individual stems by 13% in Outapi constituency than in Onesi constituency where the observed counts were much lower than the expected by 13.8%. In Outapi constituency, the number of stems with other disturbances (such as termite infestation, man induced cuts and natural holes) were fewer than the expected by 10.8% whilst the same stem conditions had higher observed than expected counts by 11.4% in Onesi constituency.

In Outapi constituency, about 50% of the total number of sampled baobabs was found to have intact barks. These were the trees that had not been exposed to some kind of visible damages or stem disturbances. All the sub-adult trees and saplings that were sampled in Outapi constituency had good stem condition (intact) except for two sub-adults that were found within the settlement area. One of the trees had some cuts on the stem whilst the other one had evidence of de-barking. On the other hand, Onesi had at least 23.2% of the sampled trees intact. In contrast to Outapi constituency, Onesi constituency had more than five sub-adult trees that had been debarked or had incurred other form of disturbances. Forty percent (40%) of the trees that were sampled in Onesi constituency had evidence of de-barking whilst a slightly lower proportion (36%) was recorded in Outapi constituency. Other type of disturbances identified on the baobab stems were on only 14% of the sampled baobabs in Outapi whilst Onesi had 37%. This shows that Outapi constituency had slightly fewer baobabs de-barked than Onesi constituency and had even much fewer trees with other stem disturbances than Onesi (Fig. 13).

A single fallen baobab was recorded in each site. Both of these baobab trees were hollow and were still growing leaves as some parts of their roots were still connected to the tree. About 21% of the adult baobabs in Outapi constituency and 8% in Onesi constituency had visibly hollow trunks, which could have been either human made or natural occurrence.

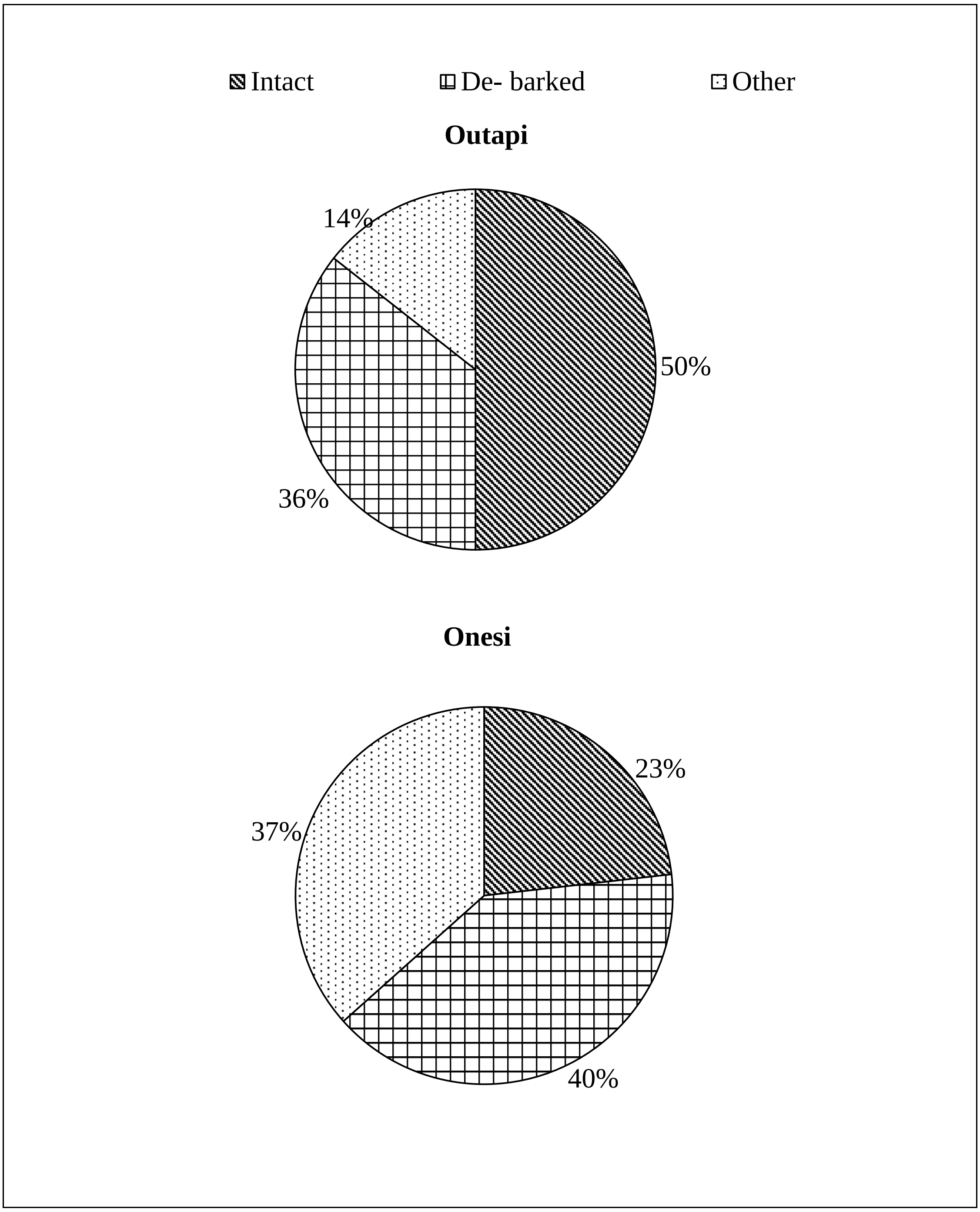


Figure 13: Proportions of baobabs with varying stem conditions in Outapi and Onesi constituency.

4.4.2 Stem condition and size-class distribution

Higher proportions of trees that were intact compared to those that were de-barked or had other conditions were within the 1-100, 401-500 and 501-600 cm dbh size-classes (Fig. 14). The least proportion of trees with evidence of de-barking and other disturbances was within the 1-100 cm dbh size-class. All the sample trees that were greater than 801 cm in dbh were intact. Figure 14 shows a more positive skew distribution pattern for mainly the de-barked and those with other conditions and an almost normal pattern for the intact stems. The highest proportion of trees between the small to medium dbh size-classes (101 and 500 cm) were either de-barked or had other disturbances whilst fewer large-sized trees ranging from 501 to >801 cm in dbh were disturbed.

There was no significant difference between the stem conditions in the different dbh size-classes (χ^2=14.337, df=16, p>0.05).The dbh size-class 301-400 cm had lower observed than expected counts by 3.2%, which was the highest margin for the intact stems. Contrary to intact stems, de-barked stems had higher observed than expected frequencies within the 301-400 cm by 4.6% whilst other stem conditions had less observed than expected in the 201-300 cm dbh by 12.1% and higher observed than expected by 11.8% within the 601-700 cm dbh size-class.

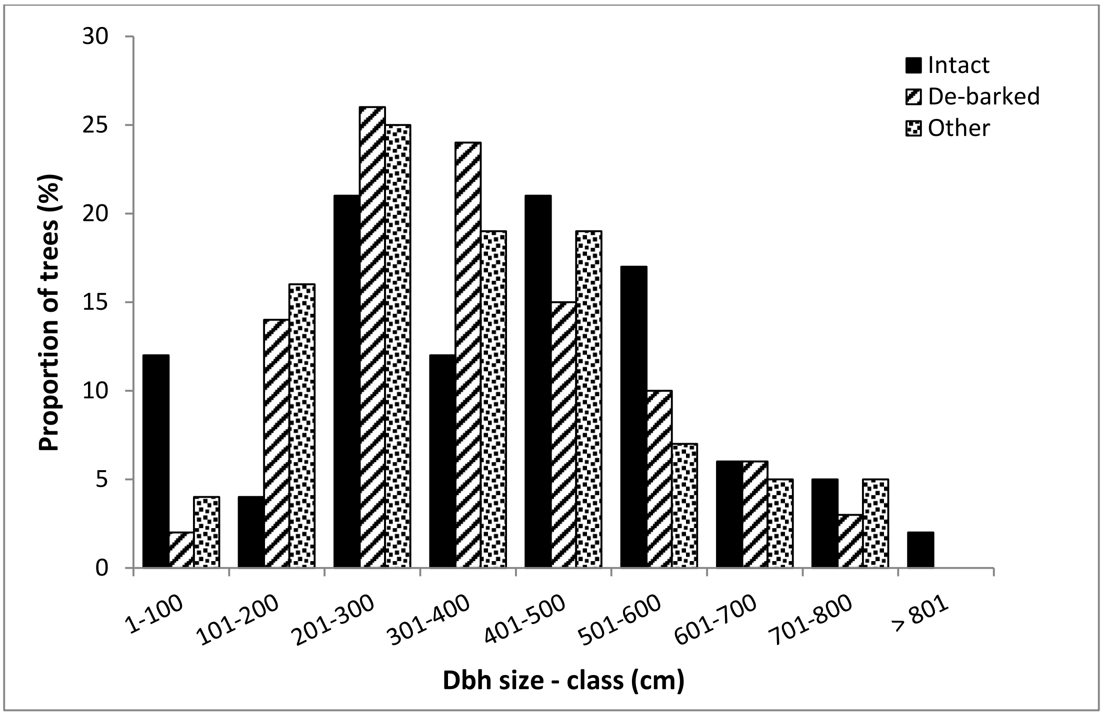


Figure 14: Proportions of baobabs within different stem conditions and dbh size-classes.

4.4.3 Stem condition and the land-use types

As is evident in Figure 15, there were more intact stems (44%) in the settlement area than those found in the field and pasture. The highest proportion of de-barked stems (45%) and those with other disturbances or conditions (52%) was observed in the pasture area whilst the settlement area had the least proportion of de-barked stems (18%). Among the lowest proportion of trees that had some form of stem damage was found within the settlement area where de-barked stems were 18% and other conditions 16% (Fig. 15).

A Chi-Square test of the association between stem conditions of sampled baobabs in the three land-use types showed a significant difference (χ^2=274.552, df=9, p<0.001). There were higher observed than expected number of trees with intact stems in the settlement area by 26.1% whilst the observed counts were less than expected for the debarked (by 8.6%) and other conditions (by 8.4%) within the same land-use type. The debarked stems had higher observed than expected counts within the field and pasture area by 11.3% and 5.4% respectively. Similarly, the stems with other conditions were more than the expected within the field and pasture area by 4.2% and 7.7% respectively.

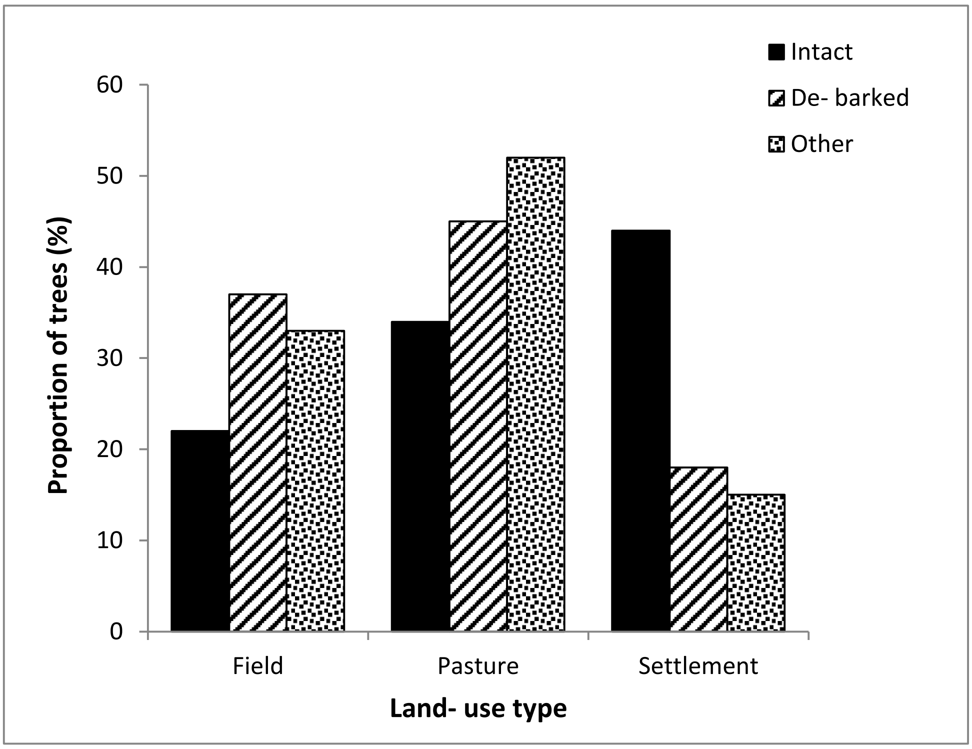


Figure 15: Proportions of baobabs with varying stem conditions within different land-use types.

4.7 Comparison of fruit production

4.7.1 Comparisons between Outapi and Onesi constituencies

There was no statistically significant difference between the medians of the mean fruits produced per tree at Outapi and Onesi constituencies (U=5550.5, $p > 0.05$). Figure 16 shows that the highest proportion of trees in Outapi constituency (26%) had 5 to 24 fruits whilst Onesi constituency had the highest proportion (30%) with 100-199 fruits. The lowest proportion of trees that had lowest fruit yield (0-4 fruits) was recorded in Onesi constituency. Both Outapi and Onesi constituencies had the same proportion of trees with 300-399 fruits (Fig. 16). Small proportions of trees were found in the lowest and the highest fruit production range.

In Outapi constituency, a total of six adult trees that had reached the reproductive stage did not have fruits whilst Onesi constituency recorded three such adult trees. Only one sub-adult tree in Outapi constituency that measured 90 cm in dbh was already producing fruits whereas five sub-adult baobabs ranging from 60 to 140 cm in dbh recorded between approximately 5 to 50 fruits in Onesi constituency. Interestingly, four trees per site had the highest number of fruits where about 300 fruits were enumerated per tree.

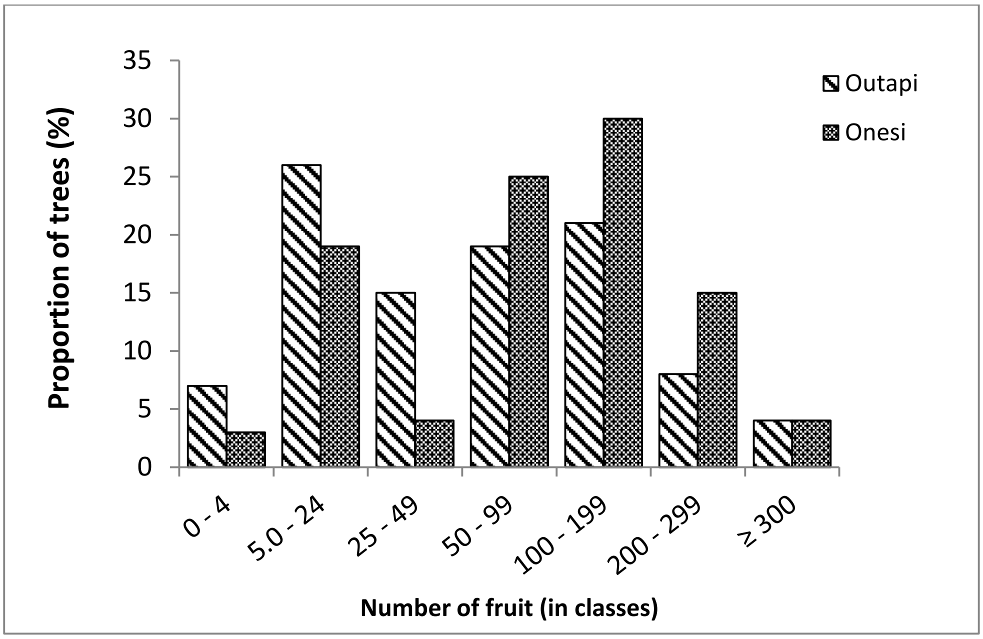


Figure 16: Comparison of proportions of baobab individuals in different fruit production classes between Outapi and Onesi constituencies.

The questionnaire interviews revealed that the majority of respondents from both Outapi and Onesi constituency (57 in total) harvested between 201 and ≥301 fruits per individual tree. Figure 17 generally shows that respondents from Onesi constituency harvested more fruits per tree than those from Outapi constituency. There was no significant difference in the number of fruits harvested per tree between the two sites ($\chi^2=6.681$, df=2, $p>0.05$). Close to 50% of respondents from both sites indicated that they normally harvest more than 300 fruits per tree (Fig. 17) even though the approximate counts in the field showed fewer fruit numbers before harvesting (Fig. 16).

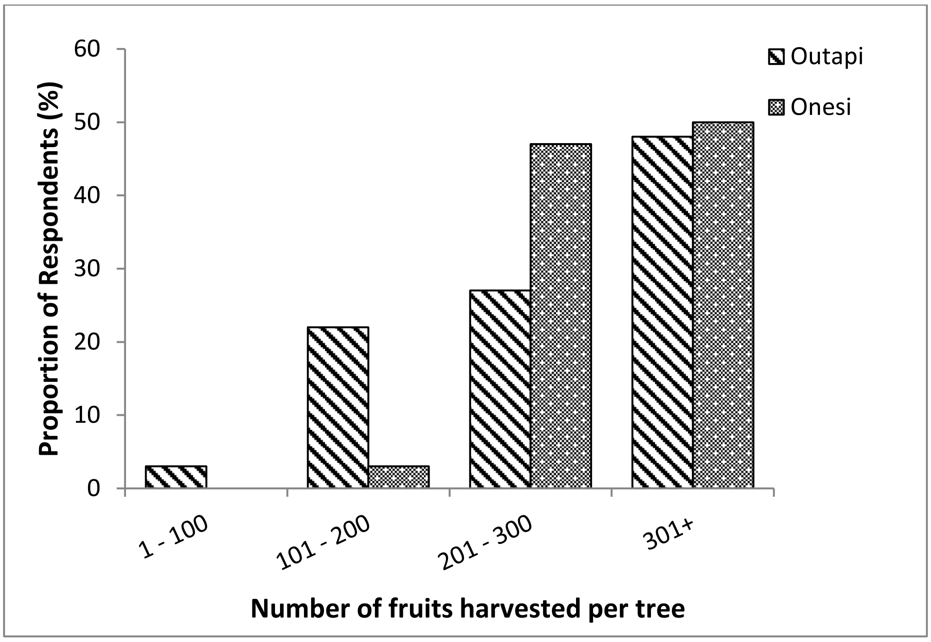


Figure 17: Proportion of respondents from Outapi and Onesi constituencies and the number of fruits (in classes) that they normally harvest per tree (Outapi: n= 37 Onesi: n= 30).

4.7.2 Comparison of fruit production within different land-use types

Irrespective of sites, about 11 baobabs sampled in the pasture and settlement areas had less than four fruits per tree whilst only eight trees had more than 300 fruits per tree in all three land-use types. As shown in Figure 18, no baobabs between the 0-4 fruit production class were recorded in the field. The highest proportion of baobabs (33%) within the 100-199 fruit production class was recorded in the fields. Less than 10% of the baobabs per each land-use type recorded more than 300 fruits per tree.

There was a significant difference between the fruit classes within the different land use types (χ^2=26.114, df=12, $p<0.05$). There was less observed than expected frequency in the fields within the 0-4 and 5-24 fruit production range by 5.7% whilst a higher observed than expected frequency of 7.5% was shown in the 100-199 fruit production range within the same land-use type. Conversely, the 0-4 fruit production range within the settlement area had higher observed than expected counts by 7.8%. In the pasture area, higher observed than expected counts by 5.6% were within the 5-24 fruit production range.

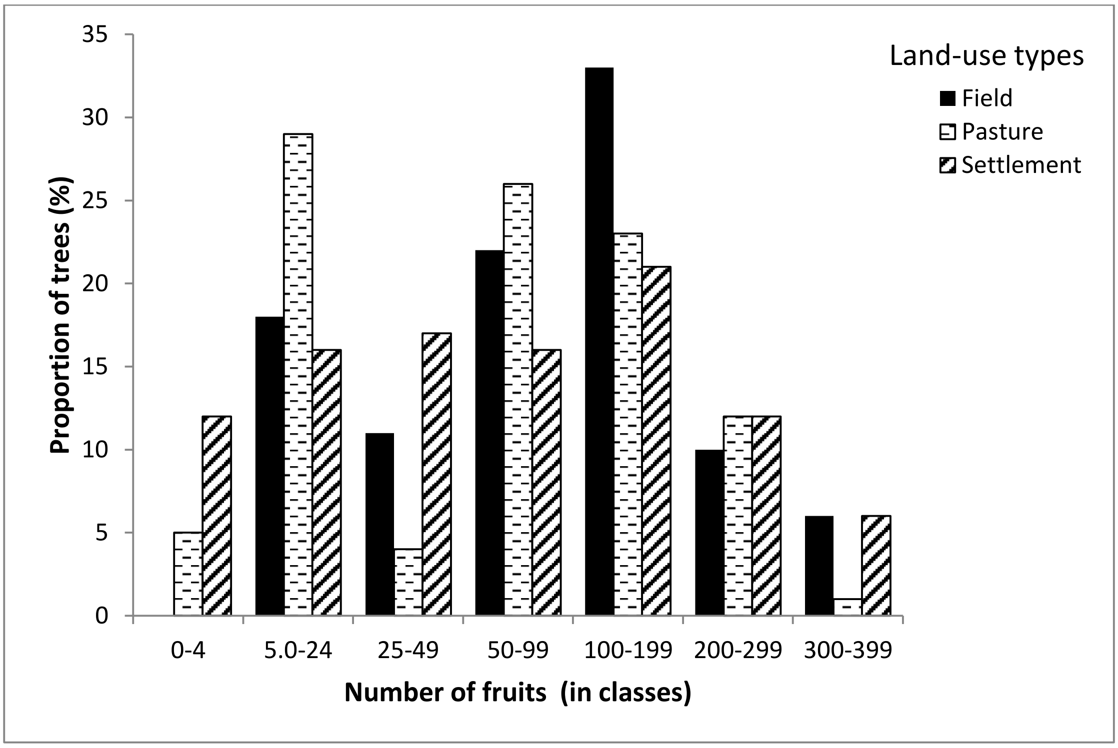


Figure 18: Comparison of proportions of baobabs in different fruit production classes within different land-use types of Outapi and Onesi constituencies.

4.8 Number of baobab trees owned

In terms of the number of baobabs that respondents owned, 49% of the respondents from Outapi constituency said they own at least one baobab with few respondents owning 4 or more baobab trees. In contrast, the lowest proportion of respondents from Onesi constituency included those that owned only one baobab. There was a significant difference in the number of trees owned between Outapi and Onesi constituencies (χ^2=10.060, df=3, $p<0.05$). About 20% of the respondents from Onesi constituency owned more than 4 baobab trees whilst Outapi constituency had only 8% of respondents owning in excess of 4 trees (Fig. 19). The highest number of baobabs owned per one homestead was found in Onesi constituency where 9 baobabs were recorded.

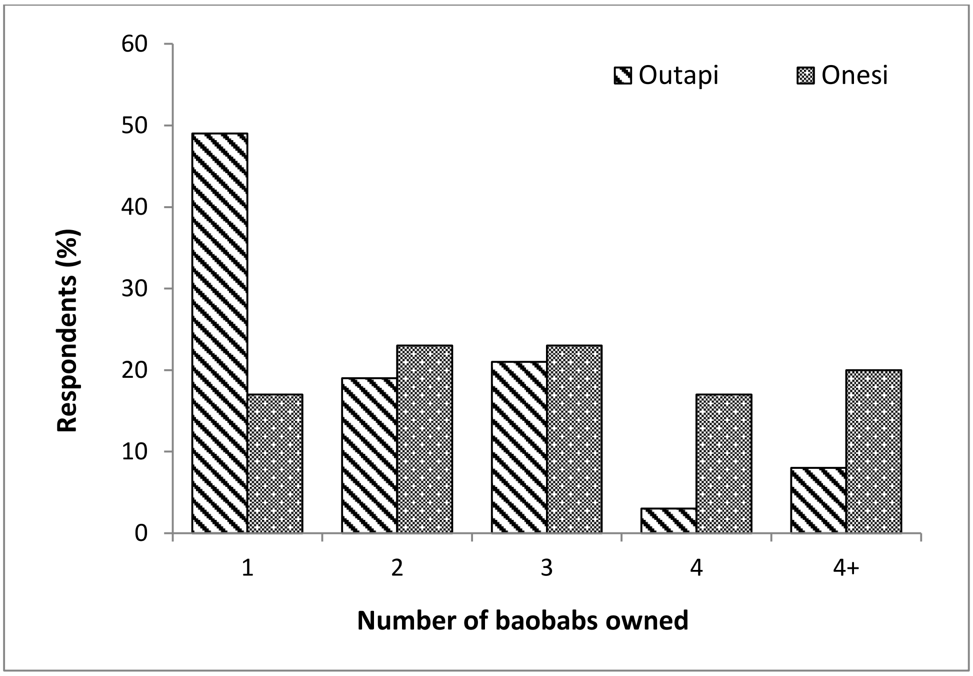


Figure 19: Proportions of the respondents from Outapi and Onesi constituencies and the number of baobab trees that they own (Outapi: n=37, Onesi: n=30).

4.9 Phenology

Figure 20 shows that there was a variation in the reported fruiting and harvesting months within and between sites. However, there was no significant difference in the reported start of the fruiting period between the two sites (χ^2=5.197, df=2, p>0.05).The respondents from Outapi constituency did not mention any fruiting season commencing in October. Figure 20 (a) shows that 67% of the respondents from Onesi constituency mentioned that the fruiting season of baobabs began in December. In Outapi constituency, almost 50% of the respondents mentioned that the fruiting season commenced in November whilst the rest mentioned December.

There was no significant difference in the reported start of the harvesting period between Outapi and Onesi respondents (χ^2=6.222, df=3, p>0.05). Most of the respondents that mentioned that fruiting began earlier (October) also mentioned an earlier start of the harvesting period (April and May). In Outapi constituency, most of the respondents started harvesting in May whilst the majority of the respondents in Onesi constituency start harvesting in June followed by those who start in May (Fig. 20 b). Generally, harvesting period in both Outapi and Onesi constituencies stretches from April to August depending on the fruiting period.

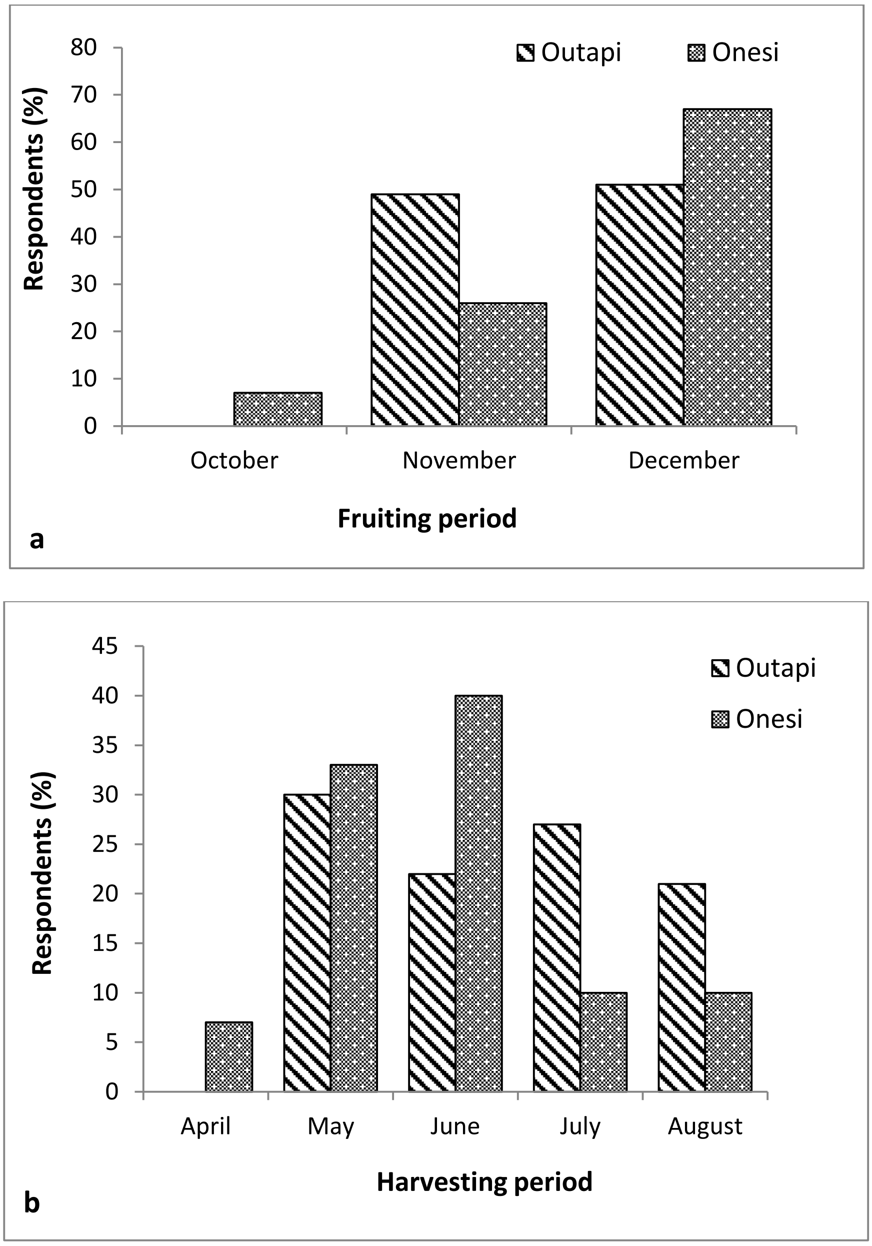


Figure 20: Proportions of respondents who mentioned the different months of (a) the on-set of the fruiting season and (b) the start of the harvesting season in Outapi and Onesi constituencies (Outapi: n=37, Onesi: n=30).

4.10 Propagation of baobabs and factors affecting sapling survival

All the respondents from both Outapi and Onesi constituencies mentioned that they normally see many baobab seedlings germinating naturally especially during the rainy season even though most of these seedlings do not survive. Using Fisher's Exact Test, the proportion of respondents that propagate baobabs was significantly different between the two sites (χ^2=10.528, df=1, $p<0.05$). Sixty seven percent (67%) of the respondents from Onesi constituency mentioned that they plant baobabs compared to 27% in Outapi constituency (Fig. 21 a). Some of the factors that affected the survival of baobab saplings and seedlings were domestic animals, insects, people or weather conditions. As shown in Figure 21 (b), domestic animals were mentioned by many respondents (73% in Outapi, 60% in Onesi) as the browsers that destroy the young baobabs. The factors that were mentioned by the informants that affected seedling and sapling survival were significantly different between the two sites (χ^2=13.617, df=3, $p<0.05$).

The study revealed that cattle and goats were the main browsers that consume the baobab leaves apart from other plant parts. Twenty percent (20%) of the respondents from Onesi constituency mentioned humans as another contributory factor affecting seedlings and sapling survival as they remove the plants during land clearing for crop farming, yet this was not mentioned in Outapi constituency. On the other hand, 16% of the informants from Outapi constituency stated extreme weather conditions such as droughts or floods as also affecting baobab survival which was not mentioned in Onesi constituency; this explains the significant variation in the factors mentioned between the two sites (Fig. 21 b).

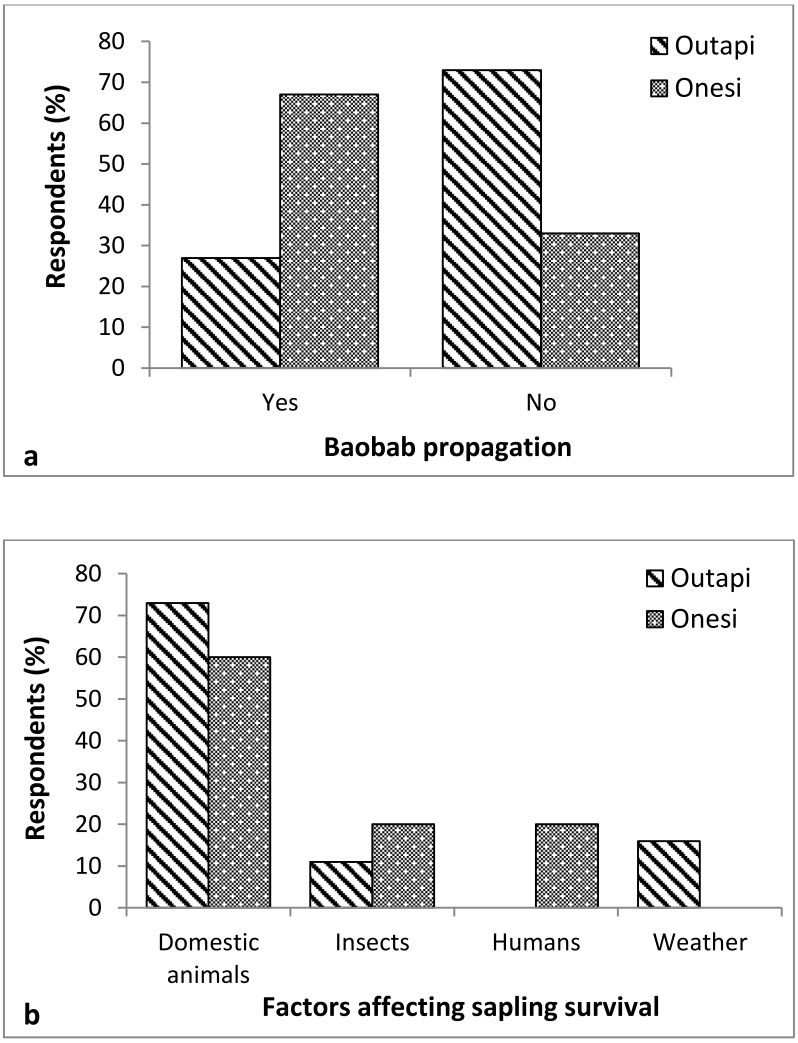


Figure 21: Proportions of respondents that have (a) propagated baobabs and (b) different views about the factors affecting the survival of the baobab saplings or seedlings in Outapi and Onesi constituencies (Outapi: n=37, Onesi: n=30).

4.11 Uses of baobabs

The number of times that uses of baobabs were mentioned in the two sites were significantly different (χ^2=31.022, df=9, $p<0.001$). The different uses of baobabs that were mentioned by respondents were assigned into 10 different categories which were consumption (human), medicinal (to cure diarrhea, coughs), sniffing, spiritual (e.g. to scare evil spirits), handicraft, medico-magical (e.g fast growth of premature babies), shade (human), shelter (animals), fodder and commercial purposes. As shown in Figure 22, the use of baobab that was mentioned most often by the respondents from both Outapi and Onesi constituencies was consumption by people followed by use of the baobab parts to feed the animals (fodder).

Outapi constituency respondents did not mention any medio-magical uses whilst the respondents from Onesi constituency did not mention shade as part of the uses of the baobab. This resulted in both sites only having a total of nine identical uses of baobabs. Medicinal, handicraft, commercial and spiritual uses were mentioned slightly more times by respondents from Onesi than those from Outapi constituency. Overall, Onesi constituency had the highest number of times that all the uses were mentioned in total (153 times) than Outapi constituency (127 times). Nineteen percent (19%) of the respondents in Outapi and 47% in Onesi constituency mainly sold the baobab fruits and the cash income was used to meet some household needs and to pay school fees.

The people of Outapi and Onesi constituencies mainly consume the fruit directly and at times they use it to make juice. Whole fruits or just the fruit pulp can be stored for months under dry conditions. The respondents from Onesi also pointed out that they put the baobab roots in the milk to preserve the milk. The respondents also mentioned that they feed their livestock with leaves. During the 2012-2013 drought period, they de-barked the stems in order to feed the livestock. Very few respondents from both Outapi and Onesi constituencies (30 in total) indicated that they planted baobab seeds within their yards and nurture them until they are 2-3 m tall before transplanting them along the edges of the cultivated fields.

For consumption, handicraft, commercial and spiritual uses, Outapi constituency recorded less observed than expected frequencies. The uses of baobabs for fodder and sniffing had more observed than expected frequencies by 5.9% and 4.4%respectively in Outapi. In contrast, Onesi constituency had less observed than expected frequencies for the uses of baobab for fodder by 4.8% and for sniffing by 3.7%. Even though almost all the uses were mentioned in both sites, the difference was that some of the uses were completely not mentioned in one site such as shade and medico-magical whilst some were stated more times in one site than in another such as consumption and sniffing (Fig. 22).

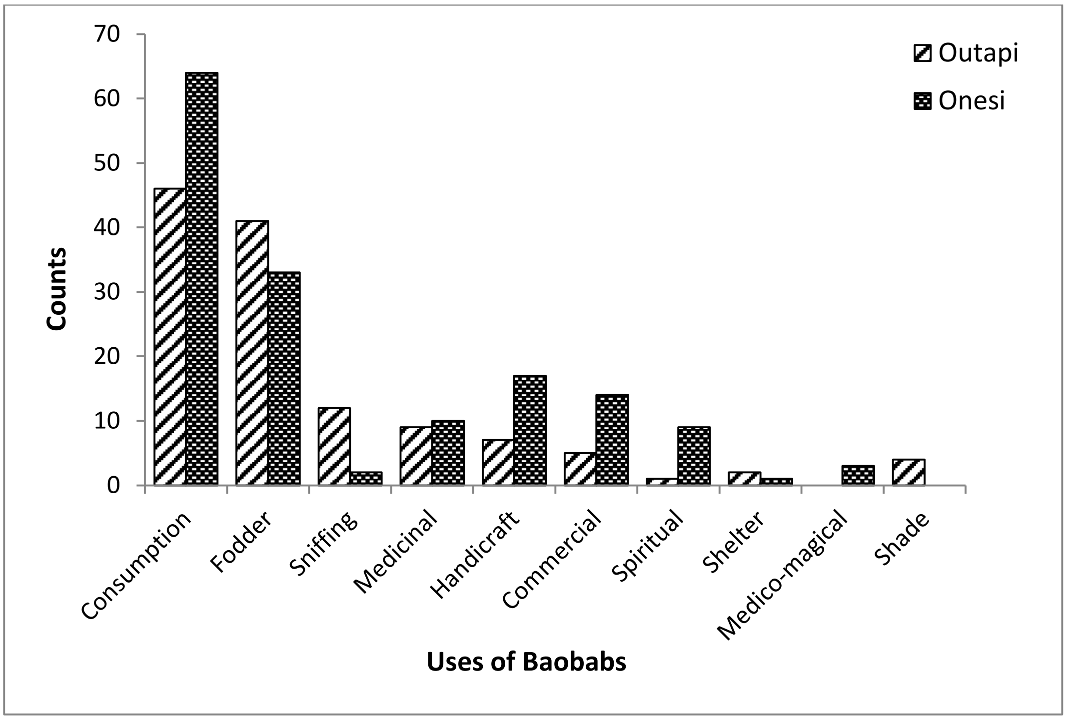


Figure 22: Comparison of the number of times the uses of baobabs were mentioned by respondents in Outapi and Onesi constituencies.

There are other uses of baobabs observed by the field team during data collection not mentioned by interviewees. One of these was the use of the hollow baobabs as a storage facility where the baobab owners kept their household belongings or scrap material. Rubbish (trash) could also be found in some hollow trees (Fig. 23) as evidence that they used the trees as a rubbish pit where they burnt the rubbish as there were traces of soot inside the hollows.

Figure 23: A hollow baobab tree that is being used as a rubbish (trash) pit in Outapi constituency. Photo credit: Ruben Ulbrich

In other homesteads, the baobab trees were being used to hang and dry hay to feed the livestock during dry periods. The trees were also used by livestock as a resting place when they escape from the scorching sun (Figure 24).

Figure 24: Livestock resting under the baobab tree shade in Onesi constituency. Photo credit: Elisha Chambara

CHAPTER 5

DISCUSSION

5.1 Comparisons of baobab density, spatial distribution and population structure

The no significant difference in baobab densities between Outapi and Onesi constituency (Table 1) and the similar distribution patterns (Fig. 8) in the two sites may imply that both sites experience comparable natural and anthropogenic factors. One of the factors that could have an influence on the similar population density and distribution in Outapi and Onesi constituencies (on all land-use types) is the competitive nature of the baobab as the extensive lateral roots that can extend up to 50 m (Diop et al., 2006) thereby drawing most of the nutrients to the tree.

Factors such as herbivory, agricultural activities and land development will tend to affect the baobab densities as some trees will be destroyed through trampling or browsing in the pastures and during land clearing for crop cultivation in the fields or for construction in the settlements. The high levels of urban development currently taking place in Outapi constituency affect the survival and consequently the density and spatial distribution of baobabs in the area. In Onesi constituency, large tracts of land are cleared for agricultural activities such that young baobabs can be easily destroyed in the process.

According to Edkins et al. (2007), spatial distribution patterns of baobabs can be attributed to herbivory, past human activities, droughts or soil character requirements. Additionally, Venter and Witkowski (2011) suggested that baobab densities are affected by a number of factors such as baboon mediated seed dispersal, soil characteristics and topography. On the other hand, the baobabs could have existed prior to human settlement such that people selectively elected to settle near or around the baobabs (Dhillion & Gustad, 2004). According to Duvall (2007), Manika-speaking people of West Africa discard baobab seeds around villages where they germinate and tend to be concentrated. This is a likely factor to have resulted in the villagers from Onesi constituency having more baobabs within their homesteads. More than 50% of the homesteads in Onesi constituency had more than two baobabs within their settlements together with the surrounding fields as the discarded seeds within the fenced areas recruited. This could explain why baobabs in Outapi constituency were distributed over a large area (22.5 km^2) whilst the same number of baobab were found on a much smaller area in Onesi constituency (6.45km^2).

The significant differences detected in the dbh size- and height-classes between Outapi and Onesi constituency (Figs. 10 & 12) indicate that human activities affect the population structure of baobab stands as discussed by Schumann et al. (2010). The dbh size-classes displayed a more bell-shaped curve whilst the height classes had a more J-shape in both study sites. Higher proportions of baobabs were found within the largest size classes in Outapi constituency which shows that more baobabs survive into larger-size classes whereas Onesi constituency had more baobabs within the smaller to medium size classes which explains that more recruitment took place in the recent past than in Outapi constituency (Fig. 10). Lack of smaller size classes (dbh:1-100 cm) in Outapi and Onesi constituencies indicates a population recruitment bottleneck caused by intensive exploitation (Rocky & Mligo, 2012) through livestock browsing and human disturbance or possibly extreme climatic conditions that disrupt seedling and sapling survival. Several authors (Chirwa et al. 2006; Hofmeyer, 2003; Venter & Witkowski, 2010) who conducted studies in Malawi and South Africa did not find any baobab seedlings in their study areas due to herbivory (Venter &Witkowski, 2013). These findings are consistent with the results of Nacoulma et al. (2011) in eastern Burkina Faso who found an unstable population structure of African mahogany (*Afzelia africana*) and African rosewood (*Pterocarpus erinaceus*) tree species in the parklands of Burkina Faso which was attributed to combined effects of human impact such as land clearing for agriculture, livestock grazing and or harvesting of fodder and medicinal products. The rarity of the seedlings in the both Outapi and Onesi constituencies could have been due to the baobab recruitment being highly dependent on rare favorable conditions.

Outapi constituency had higher proportion of trees within the lower to middle height classes (0 to 15 m) whilst the highest proportion of trees in Onesi constituency were enumerated within the taller height classes (16 to 25 m) which shows that Outapi constituency experiences much more favourable conditions that facilitate speedy growth of young trees (Acanakwo, 2010) such as higher rainfall during good years which is between 550 and 660 mm per year in north-east of Omusati where Outapi constituency is located than in south-western parts (250-300 mm per year) where Onesi constituency is situated (Mendelsohn et al., 2000). Taller heights of baobabs sampled in GNP were clustered on the granophyres derived soil group whilst baobabs on malvernia and rhyolite stratum were relatively shorter (Mashapa et al., 2013) which explains edaphic factors possibly having an influence on the significant difference ($p<0.05$) in baobab heights between Outapi and Onesi constituencies where cambisols and arenosols dominate respectively.

According to Shackleton (2002), differences in tree heights between sites could be explained by high intra- and inter- specific competitions for light and water. This can be applicable to those baobab individuals that were growing next to each other or growing together with Bird-plum (*Berchemia discolor*) (Klotzsch) Hemsl.trees,as is common in the two sites. Considering the extent of the baobab's lateral roots (up to 50 m), it can be a possible factor that competition for moisture will likely affect the height structures of the baobab population.

The study findings also revealed that all the few saplings, seedlings and some young baobabs (dbh:1-100 cm) that were encountered in both Outapi and Onesi constituencies were within the fields or settlement areas and not in the open pasture area (Fig. 11) suggesting that these habitats present better conditions for a viable baobab population (Dhillion & Gustad, 2004). Interestingly, in Onesi constituency, all the baobabs that were enumerated within the settlement areas were in the smallest dbh size-class (1-100 cm) because the villagers indicated during the interviews that they plant baobabs within their yards where they can easily nurture and protect the plants. This is in agreement with the studies done in West Africa where it was discovered that in some villages, baobabs are planted within the villages but with poor recruitment of baobabs outside villages (Assogbadjo et al. 2005). However, a study conducted in South Africa showed that more seedlings occurred outside human-modified areas especially in the rocky outcrops where the baobabs are inaccessible to herbivores (Venter &Witkowski, 2013). Owing to an absence of rocky outcrops in the study areas, the only sanctuary for seedlings and saplings is offered within the fenced compounds.

The major factor affecting the seedling survival which then resulted in a bell-shaped size-class distribution is herbivory as mentioned by the majority of respondents in Outapi and Onesi constituency. Most respondents mentioned that they had seen many young baobabs during the rainy season but they would not survive into saplings due to livestock browsing (Fig. 21 b). This was also suggested by Schumman et al. (2010) in a study done in Burkina Faso where they mentioned livestock browsing as negatively influencing the baobab population structure by causing seedling and sapling mortality. In the communally managed areas of South Africa, seedlings have been observed emerging in January yet none of these seedling persist into February and March as they are already consumed by goats (Venter & Witkowski, 2013). Similarly, Venter (2011) attributed the poor recruitment of baobabs in Northern Venda, South Africa to increasing livestock numbers, expansion of fields and villages and a dryer climate. Since the north-central and some parts of the north-eastern regions of Namibia have the highest stocking densities ranging between 100 to >180kg/ha (MET, 2003), it is possible that livestock contributes to baobab seedling and sapling mortality.

According to Rocky and Mligo (2012), changes in the plant population structure may be due to changes in recruitment of individuals at low diameter size-classes or exploitation either at large size-classes or throughout the different size-classes. Trampling by livestock is another likely cause of seedling mortality. A study done in a communally managed area in South Africa showed that saplings were more susceptible to goat browsing and that they died more quickly when only browsed than when only trampled (Venter & Witkowski, 2013 b). Therefore, direct browsing exerts a greater pressure on seedling survival than trampling.

Some of the respondents in Outapi and Onesi constituencies also mentioned herbivorous insects as contributory factor affecting seedling survival such as termites, grasshoppers and beetles. When the baobab seedlings are attacked by such insects, they tend to reduce the rates of shoot and root growth. This will then increase the susceptibility of plants to disease and mortality (Venter & Witkowski, 2013). According to Sidibe and Williams (2002), in Ghana, an unidentified black beetle damaged and eventually destroyed the baobab tree branches by girdling.

Additionally, in West Africa, there was a report of a longhorn beetle (*Aneleptes trifascicata)* which attacked and killed young baobabs by girdling. A caterpillar (*Gonimbrasia herlina)* is known to feed on the baobab seedling and sapling leaves (Sidibe & Williams, 2002).

Apart from the factors mentioned above, other stresses such as anthropogenic activities (Fig. 21 b) and edaphic factors also affect recruitment, for instance when farmers intentionally or accidentally cut recruiting baobabs when clearing land for crop farming and preserve mainly mature baobab trees of higher immediate value (Schumann et al. 2010) or when mass construction is taking place whereby large tracts of land have to be cleared. Such a pattern was recognized in Outapi and Onesi constituencies whereby adult baobabs were left standing when cultivating or developing the land which implied that any seedlings and saplings could have been removed in the process of land conversion.

A study conducted in GNP on the abundance and structure of baobabs across different soil types showed that the highest frequency of juvenile baobabs was found on granophyres soil group stratum than on malvernia and rhyolite soil group stratum (Mashapa et al., 2013). This explains that edaphic factors such as soil type, texture, depth and drainage capacity has an influence on baobab recruitment as baobabs are known to grow on a wide range of well-drained soils, from clays to sands, but not on deep unconsolidated soils, where the species is unable to obtain sufficient moisture or anchorage (Mashapa et al., 2013).

The higher proportion of baobabs that was found in Onesi constituency within the medium size-class (dbh: 201-300 cm) compared to Outapi constituency suggests that the baobabs within that size-class in Onesi constituency were not strongly affected at their seedling and sapling stages than those baobabs in Outapi constituency within the same size-class. This implies that there was not much disturbance from livestock and human activities during the juvenile stages of the baobabs in that area or the villagers played a role in protecting the baobabs.

As discussed by Rocky and Mligo (2012), the bell-shaped distribution is an indication that plant populations are likely to crush if any kind of intensive disturbance continues. This is the likely prediction in Outapi and Onesi constituencies where already at least two fallen aged baobabs were encountered and more particularly in Outapi constituency where increased developments are taking place that may in the future affect the survival of even the large size classes. Main threats such the practice of hollowing trunks, burning trash in the hollows as well as debarking with continuous poor recruitment may probably lead to population collapse in Outapi and Onesi constituencies. Mashapa (2012) pointed out that baobab losses will make the areas less visually appealing and unattractive to tourist as well as affect the biodiversity and ecosystem function where these losses occur.

Apart from the natural drivers, human management of the baobab in terms of baobab propagation and protection and avoiding overexploitation of the tree would be crucial to ensure sustainability of the species.

According to Venter and Witkowski (2010), low recruitment rates and bell-shaped or positively skewed size-class distributions which are typical of baobab populations across Africa have raised concern about the maintenance of baobab populations. However, this may be of less concern due to the long-lived nature of baobabs and extremely low adult mortality rate (Venter & Witkowski, 2010). This opinion was also expressed by Wickens and Lowe (2008) who pointed out that the longevity of baobabs means only a few recruits are necessary to maintain the current population of trees. Hofmeyer (2001) also concluded that there were sufficient baobabs in reproductive size-classes in Kruger National Park and as such, low number of small trees simply indicated a poor recruitment phase. Poor recruitment could be an indication that baobabs have lost importance for local people in recent years as seen in West Africa where no planting or active protection of the seedlings from livestock is practiced (Duvall, 2007). In Outapi constituency, the highest proportion of respondents (73%) indicated that they had not planted baobabs in the area which could explain that the baobab is losing importance in the area or people are just satisfied by seeing large baobabs in reproductive stages around (Fig. 21 a).

5.2 Comparisons of stem condition, fruit production and phenology

Based on the findings, the significant difference in the stem conditions whereby Outapi constituency had 50% of the sampled trees with intact stems and 50% of combined debarked and other stem disturbances compared to Onesi constituency that had 23% of sampled trees with intact stems and 77% with both debarked and other forms of stem damage (Fig. 13) explains that Outapi as a more urbanized constituency incurs less damages to baobab stems than the rural settlement area of Onesi constituency. This indicates that there is high pressure on baobabs by both humans and livestock in Onesi constituency. More respondents from Onesi than from Outapi constituency indicated that they de-barked the baobabs to feed livestock during droughts or dry periods (Fig. 13).

The higher pressure on baobabs in this constituency is indicative of the fact that villagers in Onesi constituency rely more highly on baobab NTFPs. Another reason for difference in stem conditions is that the villagers from the rural settlement of Onesi constituency tend to make use of the baobab products more than Outapi residents because there are limited socio-economic options and heavy reliance on natural resources in rural settlements compared to urban areas (Schumann et al., 2012). For instance people in a rural setting can easily harvest the baobab bark to treat a certain ailment or to feed livestock in times of drought whilst in a more urbanized setting, people are likely to access modern medicine from a walk-in pharmacy or buy livestock fodder respectively.

Irrespective of sites, de-barking was lowest (2%) in the smallest size-class and de-barking and other stem conditions were even absent in the largest size-class (Fig. 14). The almost bell-shaped distribution for all forms of damages (de-barked or other stem conditions) on trees despite the varying proportions of trees is an indication that medium-sized baobabs in both Outapi and Onesi constituencies are subject to bark harvesting for household uses as well as fodder purposes especially during dry periods as the trees have good quality and strippable bark that has not been previously harvested. This is supported by the results of Schumann et al. (2010) in Burkina Faso who found that de-barking of baobabs was lowest in the smallest and largest size-classes than in the medium size-classes. According to Munondo (2005), de-barked stems mainly in the medium to higher size-classes appear to conform to the logical explanation that in small size-classes, the concentration of active ingredients tends to be lower such that their barks are not exploited whilst the barks of older trees lose active ingredients and become too hard to exploit.

As the respondents highlighted, mainly cattle and goats are the livestock that feed on the baobab leaves and bark in drought periods. This explains why the highest proportion of trees that were either de-barked or had other conditions were found within the pasture areas (Fig. 15) where livestock can roam freely and de-bark or disturb the baobab stems without human control. Such exploitation of the baobab parts emphasizes the role of the baobab as a multi-purpose species (Schumann et al., 2010) despite being likely to affect the long term viability of the populations.

According to Delvaux et al. (2009), harvesting of vegetative structures (like leaves and bark) significantly threatens the survival of plant populations as the plant parts that effect photosynthesis are damaged or removed. This corroborates with the findings of Peters (1995) that when bark, fruit, wood and other parts of a species are harvested for various uses, there may be significant impacts on the population structure and distribution of the species.

Romero et al. (2001) attributed the mortality of adult baobab trees in the Save-Odzi Valle of Zimbabwe to excessive bark harvesting for weaving as harvesters were also de-barking the upper portions of the trunks which resulted in tree mortalities. The fact that harvesting of the baobab bark can be done at any time of the year raises concern especially when practised during dry periods when moisture levels are too low to enable speedy bark regeneration. Moreover, the findings that it takes from 6 to 10 years for a de-barked stem to be restored to its pre-harvested state (Romero et al., 2001) even prompts more concern about the future of baobabs where high levels of exploitation are currently taking place.

The lowest proportions of disturbed baobab stems enumerated in the settlement areas in both sites (Fig. 15) explains that baobabs within settlements are more protected by people through easy monitoring as well as fencing such that tree damages by livestock are limited. These findings contradict the results of Dhillion and Gustad (2004) who found that baobab disturbances in Mali were more intense in villages based on the reason that villagers had easy access to the trees. This implies that baobab de-barking can be higher or lower in settlements due to human influence and can also be higher in pasture areas as a result of livestock influence.

Overall, the stem condition patterns suggest that high proportions of sampled trees that were de-barked or had other stem disturbances in both Outapi and Onesi constituencies were within the middle size-classes, prominently between 201 to 400 cm dbh. This explains that stem disturbances partly depend on the size-class and to a certain extent on the land-use type. The findings tend to suggest that there is less concern about de-barking in the two sites because it was the lowest in the small size classes which are the most crucial in ensuring the future of the baobab populations. Moreover, the larger baobabs have the ability to regenerate the bark over a considerable period of time (6 to 10 years) (Schumann et al., 2012) or less when the climatic conditions are favorable even though climate variability seems to be a current concern that will affect the ability of baobab bark to regenerate speedily.

Although Outapi and Onesi constituencies had significant differences in the baobab population structure and stem condition, the findings showed that there was no significant difference in the fruit production between the two sites (Fig. 16). In both sites, certain adult baobabs that were enumerated did not yield any fruits. Such trees in adult life-stage were categorized as ‘poor producers’ in a study by Venter and Witkowski (2011) in Limpopo, South Africa. According to Venter and Witkowski

(2011), poor producing trees do not produce fruit every year whilst some do not produce fruit at all. The adult baobabs that were found without fruits in Outapi and Onesi constituencies either did not produce fruits at all or did not produce every year. Assogbadjo et al. (2009) described such trees as ‘male’ baobabs despite it being biologically a hermaphrodite plant. Swanepoel (1993) reported that baobabs in Mana Pools (Zambezi Valley) did not produce any mature fruit during a four year assessment which was attributed to trees not having enough reserves to produce fruit after leaf flush and flowering or elephant stripping the barks.

The no significant difference in fruit production could also be due to similar ecological or biological patterns such as insufficient pollination, resource limitation such as moisture, fruit abortion and predation (Berjano, De Vega, Arista Ortiz & Talavera, 2006). Berjano et al. (2006) suggested such factors to have affected fruit production in hermaphroditic plants as the low fruit-to-flower ratio is a common phenomenon in such plants. Selective abortion of lowest quality fruits occur when pollination is efficient and more fruits are initiated than the ones that can ripen and when there are limited resources (Berjano et al., 2006).

An observation that was made during field work of this study was that there were a lot of fallen premature fruits on the ground under the baobab canopies. The villagers attributed this to the windy weather combined with heavy rainfall which was experienced during the previous raining season in the two sites. Venter and

Witkowski (2011) reported that the year 2007/2008 that produced the fewest fruits in Limpopo, South Africa had the highest rainfall. The respondents highlighted that the trees normally produce more fruits than the quantities that were found during the fruit inventories. This explains the high inter-annual variability in fruit production due to the varying climatic patterns. However, to accept environmental conditions as the driving force behind a pattern of none producing and producing trees proves to be complex (Venter & Witkowski, 2011) because some of the baobabs that had no fruits or had a lot of fallen premature fruits were found close to baobabs that had intact healthy fruits, presumably sharing the same soil and water and experiencing the same environmental conditions. This then calls for the need to carry out genetic analysis of the species. Disparity in fruiting onset and patterns is common (Venter, 2012) as trees within the same habitat would have differing supply of resources due to internal competition.

The results showed that the pasture area had the lowest proportion of trees that had more than 300 fruits compared to field and settlement as people and livestock have easy access to the baobab trees on common property (Fig. 18). The significant difference across the two study sites in fruit production classes between land-use types showed that fruit production is to a certain extent influenced by habitat types. The open grazing areas tend to be more susceptible to fruit predation than the fenced fields and settlements. The study findings revealed that the greatest proportion of baobabs with less than 25 fruits was found in the pasture area (Fig. 18). The highest proportion of trees with higher fruit production between fruit production range 100-

399 was enumerated within the fields in the study sites as the trees are within the fenced fields where they are protected from predation. This is in line with the results of Venter and Witkowski (2011) who found a significant difference in mature fruits between land-use types in Limpopo, South Africa which was attributed to fruit predation. Venter and Witkowski (2011) reported that the proportion of fruit predated from trees outside human-modified areas was much higher than from those found in fields and villages. Therefore, as also revealed in this study, fruit production tended to be higher in human-modified landscapes such as fields and villages than in the wild where the fruits are more exposed to predation. Additionally, people tend to choose the most fertile areas for crop farming, and as such, baobab trees could also enjoy good soil nutrients that enhance growth and fruit production.

The commencement of the fruiting period varied from October to December in Omusati region even though only 7% of the respondents in Onesi constituency mentioned the month of October. Most of the baobab trees start to fruit in November and December because that is when the rainfall is nearing its peak. This supports the findings of Sidibe and Williams (2002) that fruiting period is between October and December in Southern Africa. A few respondents in Onesi (7%) mentioned that fruiting started as early as October which corresponds with the early harvesting period which a few respondents (7%) mentioned starts as early as April. Despite the differences in the onset of fruiting and harvesting, fruit production was not significantly different ($p>0.05$). Venter (2012) found that fruit production did not differ between trees that started fruiting in different months in Northern Venda, South Africa suggesting that baobabs are well adapted to cope with unpredictable seasons without a loss in fecundity. The results suggest that the baobabs that experience early fruiting are likely to be harvested earlier. There is a likely scientific reason that can be investigated to explain the earlier fruiting and consequent earlier harvesting on particular baobab trees within each study site as well as the general variation in the start of both fruiting and harvesting time between the two sites.

According to Chapman et al. (2005), several studies have shown significant variation (advanced or delayed) in onset dates of fruiting responses in tree species as a result of climate change. This is because global climate change may force variation in timing, duration and synchronisation of phenological events (Singh & Kushwaha, 2005). Singh and Kushwaha (2005) suggested that the vegetative and reproductive phases of tree species requires the availability of substantial amounts of resources within the trees such as energy, moisture and nutrients hence internal competition may lead to such variations in fruiting and harvesting onset as discovered between Outapi and Onesi and within each site (Fig. 20).

5.3 Uses of baobabs and the commercialization of baobab products

Generally, people in Onesi constituency reported higher frequencies of baobab usage than people in Outapi constituency. Out of all the interviewees from Outapi constituency, 59% of them were either formally or informally employed whilst

Onesi constituency enumerated only 17% in some form of employment. Outapi constituency, as the economic hub of the region, absorbs more people into various sectors of employment such that higher income households are found in town that don’t fully make use of indigenous tree products, hence, the study findings revealed that the highest frequency of baobab usage was in Onesi than in Outapi constituency. One instance in Onesi constituency is the use of baobab roots to preserve milk. This could probably be so since it is a typical rural settlement where some villagers do not have any modern modes of preserving the food hence they still rely on the traditional methods. According to Omotesho, Sola-Ojo, Adenuga and Garba (2013), households with higher income are less likely to make use of the baobab due to the fact that they are likely to see the baobab as an inferior product. Another reason is that the majority of the respondents in Outapi constituency (65 %) were 40 years and younger whilst the majority in Onesi constituency (78%) were 41 years and older such that younger age groups may not be fully versed in various socio-cultural uses of baobabs. A study conducted in Kenya on the determinants of sustainable utilization of plant resources showed that older people from the former Kakamega district had more access to indigenous ethno-botanical knowledge than the younger respondents (Shisanya, 2011).

The interviewees emphasized the high importance of the baobab tree for the local people of Outapi and Onesi constituencies. Even though the different baobab parts are used for various purposes, the baobab fruit was shown to be the most important and commonly used part for people and livestock. The use of baobab fruits for consumption by local people was mentioned 64 times in Onesi compared to 46 times in Outapi constituency (Fig. 22). This shows how the baobab fruit is a highly valued food source as pointed out by Schumann et al. (2012) in a study conducted in Burkina Faso. The current study showed that the baobab leaves are mainly used as forage for livestock in Omusati region (Fig. 22) despite having other numerous domestic uses elsewhere in West Africa such as their use as a vegetable, sauce or a powder to garnish various foods (Schumann et al., 2012).

Medicinal uses were much less mentioned than food and fodder uses which demonstrates that baobabs play a major role for nutritional than for medicinal purposes. This corroborates findings by with Buchmann et al. (2010) that baobabs' nutritive uses (consumption) were more often cited than other uses in West Africa. However, the findings reveal that the local people in Omusati region have not fully explored the various nutritive and medicinal values of baobab products, which are the vital uses of the tree. The significant difference in the uses of baobabs explains that Onesi constituency as a rural settlement makes use of the baobab more than Outapi constituency which is attributed to the heavy reliance on natural resources for dietary and livelihood sources in the rural settlements than in more urbanized areas.

Some respondents from Outapi and Onesi constituencies were not aware of any other socio-cultural importance and uses of baobabs. This explains the lack of knowledge and awareness in Omusati region about the multiple uses of baobabs that are already being exploited in other countries. In a survey conducted by Omotesho et al. (2013) in Kwara State, Nigeria, about 71 % of the 198 respondents were constrained by inadequate knowledge of methods of processing the baobab into various useful forms. Moreover, poor levels of awareness also proved to be a drawback. Overall, the study findings revealed that people from Outapi and Onesi constituencies do not extensively make use the baobab tree for various purposes when compared to other neighbouring and West African countries. For instance in Zimbabwe, the seeds are extracted for oil that is exported or sold locally (Wynberg et al., 2012) whilst in Burkina Faso, the seeds are roasted and crushed to make a spice (Schumann et al., 2012), yet in Omusati region, the villagers discard the seeds after consuming the fruit pulp.

The people of Outapi and Onesi constituencies use the baobab fruit and bark to treat certain ailments such as cold, flu and diarrhea among others. Such medicinal uses have been documented elsewhere in Africa, for instance the people of Gulimanceba, Burkina Faso use the baobab for the treatment of cough, diarrhea and as a strengthening agent for babies (to be energetic) (Schumann et al., 2012). The use of baobab roots to make strings to tie around premature babies in order to speed up growth and the use of baobab hollow as a rubbish dumpsite are described and documented for the first time in this study. However, one might tend to acknowledge the limited knowledge on diverse uses of baobabs in Omusati region as indirect way of conserving the species due to some negative effects that some particular uses have on the baobab. According to Dhillion and Gustad (2004), some uses such as consuming the seedlings and harvesting leaves have negative impacts on recruitment and fruit production, respectively.

In terms of the ownership of baobabs, Onesi constituency had the highest proportion of villagers that own more than 4 baobab trees per individual homestead, hence a resulting significant difference between Outapi and Onesi constituency (Fig. 19). This shows that more trees tend to occur within a single household in rural settlements as the villagers own larger tracts of land that include the farming area than in more urbanised settlements where a few square meters are apportioned per household plot. The other factor is in reference to the issue of propagation of baobabs which showed a significant difference between Outapi and Onesi constituencies. Sixty-seven percent (67%) of the respondents from Onesi constituency are involved in baobab propagation compared to only 27% in Outapi constituency (Fig. 21 a) which means more baobab trees will be found where more planting and protection is taking place.

The question that may arise is why people from the rural settlements are more keen to plant baobabs than those from the urban areas such as Outapi? According to Schumann et al. (2012), the baobab plays an essential role in maintaining the livelihoods of a lot of different rural communities all over Africa. This is because the rural communities have limited alternative nutritional and medicinal sources to maintain their livelihoods such that they turn to indigenous products. Additionally, rural people tend to have more indigenous knowledge on the various uses of native plants such that those species of value are highly regarded in society hence planting them will ensure resource sustenance.

In Outapi constituency, an important conservation measure was that most of the baobabs found within the urban settlement areas where new developments are taking place were being preserved such that portions of land around the trees were left as open spaces without cutting down the trees, despite some root damages on some baobabs. This also applied in the fields of both study sites where sub-adult and adult baobabs were left undisturbed as land was being cleared for crop cultivation. In Outapi constituency, all the surrounding households could harvest from the baobab trees on open spaces and could also use the trees to park their cars as the baobab canopies provide good shade. According to Augusseau, Nikiema and Torquebiau (2006), to maintain the important ecosystem services, some frequently used tree species in West Africa such as the baobab are protected when land is cleared for agriculture because the species are of high local and regional value for the human population. Since some households (67% in Onesi, 27% in Outapi) are attempting to propagate baobabs despite low survival rates, it shows that there are some people in Omusati region who are aware of the value of indigenous species and the need for their conservation.

Respondents from Outapi constituency (19%) and from Onesi constituency (47%) mentioned that they sell baobab fruits and the income was an important contribution towards buying basic household items and paying school fees. This shows how baobab fruits are a significant source of livelihoods to some villagers who commercialize the product even though most villagers merely use the baobabs for subsistence. A study conducted in Northern Venda, South Africa revealed that all the sixty respondents did sell baobab fruits and the income was very important in alleviating poverty (Venter, 2012). A study conducted in Gudyanga and Nyanyadzi wards, Zimbabwe divulged that local residents make crafts from the baobab bark that are exported or sold locally whilst the fruit and the processed fruit pulp are either sold to national confectionaries or exported (Wynberg et al., 2012). According to Venter (2012), the relative importance of such income may be higher in arid environments than in moister areas where there will be greater variety of NTFPs and reliable subsistence agriculture. In Omusati region, despite a few villagers from Onesi constituency (47%) and even fewer respondents from Outapi constituency (19%) having mentioned that they commercialize the baobab fruit, it can still be concluded that the rural communities highly regard the income from selling baobab fruits than in urban areas such as in Outapi constituency.

Cavendish (2000) pointed out that cash is becoming more important in maintaining standards of living and alleviating poverty while Venter (2012) concluded that the contribution of commercial baobab harvesting plays an important role not only in alleviating poverty but also in empowering marginalized people to keep up with the ‘modern’ world or as a stepping stone to a more secure livelihood. Thus despite the generally low abundance of baobabs in Namibia, if fully explored, commercialization of baobab fruits in the country can go a long way in securing many households’ livelihoods as it has been experienced in other places in southern Africa where the sale of baobab fruit for commercial purposes has been reported to increase monthly cash income of individuals by 250% (Gruenwald & Galizia, 2005). In Northern Venda, the annual cash income from selling baobab fruits made up 38% of the total annual sales of all NTFPs (Venter 2012). Since baobab fruit and seed harvesting exhibits higher degrees of tolerance (Emanuel et al., 2005) as it does not damage or kill trees (Venter, 2012), commercialization of the baobab will tend to be more sustainable. There will be a need to enhance awareness within communities about the economic and nutritive importance of the baobab products and at the same time share information on sustainable harvesting to prevent overexploitation and population collapse due to the already existing low baobab recruitment.

A positive negative implication of the large-scale commercialization of baobab products is that once the communities are improving in terms of generating income, outsiders start trickling in to explore opportunities on how they themselves can benefit from these NTFPs especially when there are no strict rules (Venter, 2012). In the long run, commercialization may turn communal resources into resources ‘owned’ by the powerful elites, business men and even outsiders (Venter, 2012). Therefore, before further explorations on the large-scale commercialization potential of the baobab in Namibia are undertaken, the negative repercussions on the species itself and implications that do not favour Access Benefit Sharing (ABS) have to be taken into consideration.

5.4 Human land-use activities and their threat to baobab survival

Root damage was found on several baobabs (17%) that were sampled in Outapi constituency where building construction was intensive. This is a potential threat to the survival of baobabs in the future in that area as the roots are essential for nutrient and water uptake. In Omusati region, the study indicated poor recruitment and poor sapling survival in both study sites. Twenty percent (20%) of the respondents from Onesi constituency suggested that human beings contribute to the seedling and sapling mortality apart from livestock and other factors which imply that humans bring in various activities such as developmental projects that tend to affect the survival of baobabs.

The ongoing changes in both land usage and cultivation techniques reduce regeneration niches (Jurisch, 2012). Mwavu and Witkowski (2008) stated that human land-use activities influence growth conditions for plants by altering various abiotic factors such as nutrient availability and water supply. According to Schumann et al. (2010), human activities alter demographic parameters such as germination, seedling and sapling growth, survival and mortality rates and alter the structure and stability of populations. Several studies in West Africa have reported a strong influence of land use on population structures and a significant decrease in seedling population density due to human pressure.

Both Outapi and Onesi constituencies exhibited poor recruitment into small size classes, a condition that can be attributed to herbivory by domestic animals that consume or trample on the seedlings. According to Hean and Ward (2012), African savannas are subject to frequent herbivory, while the occurrence of fire is highly variable and Namibia is not spared. Domestic animals such as goats and cattle were the lead factors affecting seedling and sapling survival in both sites where it was mentioned by 73% of respondents in Outapi constituency and 60% in Onesi constituency. According to Jurisch (2012), the grazing and browsing of livestock may tend to influence the reproductive output by decreasing flowering or seed-set as a result of consumption or damage of juveniles through trampling. Therefore, human land-use activities such as construction when the land is being developed and agricultural activities when land is cleared or livestock is introduced seem to have a greater influence on the survival of baobab seedlings and ultimately on the population structure of the baobab in Omusati region.

Despite the potential threats to baobab survival, a preliminary conservation status of the baobab was given early in the year as LC (Least Concern) (S. Loots, personal communication, October 22, 2014). This explains that the species is currently not under extinction threats though lack of recruitment is still a conservation concern as it is likely to affect future populations of Omusati region where this study was conducted. In order to conduct a full red list assessment, a regional assessment of the species across its distribution range in Namibia is crucial. This is because extrapolations using data from Omusati region only may not be a true representative of all the populations across Namibia (S. Loots, personal communication, October 22, 2014).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Overall, the results show that there were significant structural differences of baobab populations between Outapi and Onesi constituencies. Despite the land conversions currently taking place in Outapi constituency, the area still has large-sized baobab trees which are explained by the fact that the land developers deliberately leave out adult baobabs during any developments. Other factors responsible for the structural differences between the two sites that should be considered include the land-use type, soil characteristics and ecological and climatic conditions. Elephants are not a cause for concern in the study sites which shows that other factors other than elephants influence the population structure.

The bell-shaped size-class distribution in Outapi and Onesi constituencies shows that there is poor recruitment which was postulated to be mainly hampered by livestock browsing. This explains that the baobab seedlings and saplings that grow on areas that are not protected from livestock such as grazing areas are not likely to survive into mature stages and this according to Schumann et al. (2010) could indicate a population in decline. The results indicated that the saplings and seedlings in both study sites were only found within the settlements where they are protected from livestock and farming disturbances. Apart from livestock browsing, human development and extreme weather conditions due to climate change maybe foreseen to be the main causes of baobab seedling and sapling mortality in the near future if proper action is not taken. For example the current developments and expansion of the town in Outapi constituency is likely to encroach into those areas where baobabs had better chances of surviving if well protected. Results from the study supports the hypothesis that there is a significant difference in the baobab population structure between Outapi and Onesi constituency hence concluding that there are more sub-adults and taller baobabs in Onesi constituency compared to Outapi constituency which has more large-sized baobabs which could be due to anthropogenic, biotic or abiotic factors. In future studies, it will be important to investigate the various factors such as the habitat type, soil type, species characteristics among other parameters in order to understand the drivers of the structural differences between the study sites so as to adopt appropriate management strategies to ensure sustainable baobab populations.

It was predicted that there would be a significant difference in the baobab population abundance as fewer baobabs would be found in Outapi constituency but the findings showed that the baobab densities between the two study sites were not significantly different. This could suggest that baobabs in Outapi and Onesi constituencies are uniformly affected by certain disturbance regimes that occur in both sites such as herbivory, climatic conditions among other variables. Apart from these regimes, another factor that could play a role in determining the baobab density and distribution is human activities (Mashapa, 2012). The baobabs in Outapi constituency showed a clustered as well as dispersed distribution than the more clustered pattern found in Onesi constituency. It can be concluded that the high levels of human development taking place in Outapi constituency has disturbed recruitment and caused a reduction in baobab trees to make way for development. The hypothesis that baobab abundance significantly differs between the two sites was rejected as the difference in baobab densities was not significant thus assuming that the baobabs in Outapi and Onesi constituency may be responding similarly to certain biotic and abiotic factors.

The median fruit abundance did not differ significantly between Outapi and Onesi constituencies. Therefore, the baobab trees from the two study sites produce comparable quantities of fruits per individual tree which explains that these study sites experienced similar ecological and biological patterns that enabled or limited pollination, fruit abortion, resource availability or the trees to have enough reserves after leaf flush. It shows that similar patterns that either hamper or increase fruit production were experienced the study sites. Both Outapi and Onesi constituency recorded an equal number of adult trees that had no fruits. It should be noted that the factors that affect fruit production may vary with seasons such that similar fruit production patterns found in Outapi and Onesi constituency may not be consistent from one fruiting season to the other. Hence, fruit counts and assessments can be conducted over more than one season. The hypothesis that there will be a significant difference in median fruit abundance between the two constituencies was rejected.

Stem conditions were significantly different between the two sites. Onesi constituency had higher proportions of baobab trees that were debarked or had other kinds of stem disturbances than Outapi constituency where the higher proportion of baobabs with intact stems was found. This study concluded that the people of Onesi constituency make extensive use of the baobab bark for medicinal, craft, spiritual and other uses as well as for livestock feeds than the people of Outapi constituency who have a wider array of alternatives such that the baobab stems are less disturbed. The higher proportions of baobabs that were de-barked and had other stem disturbances were found within the pasture areas as it shows that livestock tend to de-bark the trees when they fail to access other sources of food during dry periods. The prediction that there will be a significant difference in the stem condition between Outapi and Onesi constituencies was therefore accepted.

Results showed a significant difference in the number of times the different uses were mentioned between the two sites. It was predicted that the respondents from Onesi constituency would have wider uses of baobabs but findings showed that the two sites had an equal number of uses yet the difference was that Onesi constituency respondents highlighted some uses more frequently than the respondents of Outapi constituency. The people of Onesi constituency use the baobab mainly for consumption, commercialization, medicinal and spiritual uses more than the respondents of Outapi constituency who mainly use it for fodder and sniffing. It can be concluded that the people from the rural settlements extensively make use of the indigenous resources than those in a more urbanized area. Generally, only a few households from both sites do commercialize the baobab fruit even though it can generate cash to sustain the rural livelihoods as it has been the case in Malawi and Zimbabwe. Moreover, the baobab uses are not as wide compared to the 300 uses that have been documented in some studies conducted in elsewhere in Africa. The hypothesis that there would be a significant difference in the uses of baobabs between the two sites is accepted as it was found that Onesi constituency people widely make use of the baobab than those from Outapi constituency.

In as much as the potential for commercializing the baobab products on a larger scale is anticipated to foster financial benefits to rural communities in Omusati region, the sustainability of the resource itself must be taken into consideration. Moreover, considering the poor recruitment in the study sites, higher debarking levels in Onesi constituency and possible fluctuating fruit production due to varying climatic patterns and ecological and biological factors, the potential for commercialization of baobabs in the region appears untenable.

6.2 Recommendations

(a) Due to poor baobab recruitment, efforts should be made by the MAWF's Directorate of Forestry to encourage baobab propagation including planting in areas away from villages in order to spread the risk of losing trees due to urban expansion such as in Outapi constituency and natural catastrophes, such as droughts or flooding. This also means that training programmes on how to propagate the baobabs and practice traditional agro-forestry system in order to curb destruction of baobab juveniles during land tilling would be necessary. Additionally, farmers may need training on identifying germinating baobab seedlings.

(b) In order to enhance baobab recruitment, protection of young seedlings in areas where the seedlings are easily monitored and better protected such as within fenced fields and villages is crucial. Conservationists should lobby for the enforcement of legislation that calls for the protection of young plants on common property.

(c) Since the people in Omusati Region have not fully explored the numerous uses of the baobab compared to other countries in southern Africa and most particularly in West Africa where the baobab tree is highly valued, the Indigenous Plants Task Team (IPTT) of Namibia should take up the role of disseminating information to local people on the wider uses of baobabs at the same time promoting sustainable utilization of the resource.

(d) Further research or assessments are also recommended in the following areas:

(i) Long-term continuous assessments of the baobab populations by the Directorate of Forestry's Forestry Research Division in order to identify the dynamics and the trend in the population structure whilst at the same time investigating the factors influencing such trends. This can also now include a control site within non-human modified sites such as the north-eastern part of Etosha National Park in order to effectively tease out recruitment factors when compared with human-modified areas.

(ii) A detailed scientific investigation on the variable causes of the significant structural differences between the constituencies and within land-use types such as edaphic and climatic factors can be led by the University of Namibia's Biological Department. Disturbance regimes could also be investigated by establishing experimental baobab plots in sample sites to enable the scientific monitoring of baobab stands in order to determine baobab responses to different disturbances.

(iii) Incorporate advanced technology such as aerial surveys, remote sensing and Geographic Information System (GIS) so that even baobab satellite imageries will be retrieved and used in monitoring the abundance and distribution of baobabs.

(iv) Explore the factors including genetic ones that are causing phenological variations between and within sites whilst on-going assessments will be able to denote if such patterns vary from season to season.

(v) Country-wide inventories and data collection could be done by the National Botanical Research Institute (NBRI) in order to capture all necessary data of the baobab populations across Namibia. This will enable a full red list assessment to be conducted and to make well informed decisions about the management and extensive commercialization potential of the species.

(v) Taxonomists have reported on a new species of *Adansonia* in southern Africa named *Adansonia kilima.* It will be interesting if a research on the floral morphology, pollen characters and chromosome numbers is done in order to determine the species occurrence in Namibia and in which bio-geographic zones.

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APPENDICES

Appendix A

Sample Field Data Sheet

Field data Sheet: Baobab Project

Field Assistant Initials:……………………………………. **Date:**…………………………………

Constituency (village):…………………………………….. **Land use:**…………………………....
(e.g field, settlement, pasture)

Plot No: ……..…………(e.g 1 or 2) **GPS Waypoint:**………………………

Variables	**Adult tree (dbh >150 cm)**	**Sub- adult tree (dbh 1- 150 cm)**	**Sapling (dbh< 1 cm)**
DBH (cm)	*	*	
Height (m)	*	*	*
Stem /Plant condition	*	*	*
Fruits (1- presence; 0- absence)	*	*	
No. of Fruits	*	*	

Notes:

………

………

Appendix B

GPS Coordinates of the sampled baobabs

Waypoint I.D.	y-coordinates	x-coordinates	Waypoint I.D	y-coordinates	x-coordinates
009	17.496045	15.015832	047	17.504811	14.983474
010	17.497235	15.013098	048	17.505487	14.984468
011	17.499333	15.014071	049	17.505161	14.985263
012	17.499941	15.012663	050	17.505446	14.98525
013	17.500246	15.013372	051	17.505428	14.985281
014	17.499622	15.012949	052	17.5063	14.983561
015	17.501297	15.013847	053	17.506638	14.986454
016	17.500437	15.014824	054	17.506744	14.986416
017	17.501806	15.015604	055	17.505911	14.984333
018	17.503418	15.014201	056	17.509581	14.984902
019	17.504115	15.014061	057	17.510204	14.985292
020	17.503903	15.013404	058	17.51099	14.985242
021	17.50541	15.0122	059	17.522266	14.979123
022	17.504918	15.011521	060	17.522505	14.979273
023	17.505471	15.010282	061	17.523311	14.980142
024	17.506188	15.012104	062	17.5233	14.980575
025	17.506755	15.012391	063	17.520346	14.979369
026	17.506647	15.012006	064	17.520097	14.977757
027	17.506191	15.010684	065	17.520608	14.977046
028	17.508364	15.012523	066	17.519705	14.978184
029	17.50574	15.013183	067	17.519573	14.978556
030	17.506024	15.014031	068	17.519545	14.977958
031	17.50712	15.014178	069	17.519899	14.976216
032	17.507118	15.013948	070	17.518547	14.975068
033	17.507965	14.994915	071	17.51891	14.974852
034	17.507924	14.994833	072	17.517494	14.977061
035	17.510008	14.993523	073	17.516991	14.976864
036	17.512806	14.989849	074	17.516796	14.976628
037	17.505223	14.990715	075	17.511844	14.987816
038	17.500815	14.985481	076	17.512015	14.987902
039	17.500763	14.984647	077	17.508885	14.987016
040	17.49868	14.97893	078	17.506874	14.980634
041	17.498783	14.9783	079	17.507174	14.981016
042	17.500718	14.981734	080	17.504355	14.980198
043	17.501737	14.98248	081	17.50385	14.981181
044	17.5018	14.9822272	082	17.503161	14.981154
045	17.501485	14.983282	083	17.503308	14.981827
046	17.502501	14.983129	084	17.503079	14.98017

Waypoint I.D.	y-coordinates	x-coordinates	Waypoint I.D	y-coordinates	x-coordinates
085	17.504822	14.981432	123	17.57388	14.680673
086	17.504875	14.981225	124	17.573243	14.681288
087	17.504184	14.981541	125	17.573349	14.681781
088	17.504205	14.981747	126	17.573253	14.681923
089	17.49813	14.979106	127	17.573987	14.682342
090	17.493509	14.979172	128	17.573974	14.682663
091	17.493563	14.979772	129	17.569223	14.68371
092	17.492861	14.980149	130	17.569103	14.683059
093	17.497007	14.980694	131	17.56913	14.682907
094	17.497001	14.981077	132	17.569886	14.683149
095	17.495564	14.989202	133	17.569493	14.683823
096	17.495667	14.990254	134	17.570906	14.680549
097	17.496288	14.988585	135	17.570901	14.681232
098	17.512934	15.008419	136	17.571244	14.681614
099	17.513787	15.009539	137	17.577246	14.681265
100	17.514219	15.007736	138	17.576909	14.680599
101	17.513415	15.006079	139	17.571994	14.678779
102	17.570558	14.690815	140	17.573076	14.678819
103	17.57109	14.688307	141	17.573066	14.678553
104	17.570619	14.687987	142	17.572971	14.677553
105	17.570694	14.687909	143	17.572565	14.677178
106	17.571109	14.688959	144	17.572636	14.676966
107	17.570722	14.686715	145	17.577195	14.679409
108	17.570789	14.685526	146	17.577221	14.680165
109	17.570455	14.684807	147	17.578334	14.680894
110	17.572207	14.685512	148	17.578948	14.680113
111	17.572185	14.685373	149	17.578582	14.679751
112	17.572219	14.685335	150	17.578631	14.679184
113	17.573348	14.68564	151	17.577952	14.679564
114	17.574169	14.68455	152	17.576249	14.693683
115	17.574341	14.684749	153	17.576418	14.694668
116	17.574437	14.6843	154	17.578238	14.696319
117	17.574229	14.683909	155	17.578291	14.696806
118	17.573984	14.683661	156	17.578318	14.69699
119	17.573911	14.683591	157	17.576954	14.69616
120	17.574752	14.683491	158	17.579409	14.698552
121	17.573875	14.681282	159	17.579886	14.699251
122	17.574194	14.680816	160	17.578346	14.699273

Waypoint I.D.	y-coordinates	x-coordinates	Waypoint I.D	y-coordinate s	x-coordinates
161	17.578008	14.699608	200	17.583052	14.712755
162	17.578008	14.699509	201	17.583552	14.70775
163	17.577978	14.699246	202	17.583683	14.707359
164	17.57786	14.698576	203	17.583125	14.707484
165	17.581322	14.698524	204	17.575188	14.688374
166	17.582279	14.697944	205	17.57474	14.687969
167	17.580306	14.698206	206	17.574598	14.68742
168	17.579956	14.695615	207	17.575258	14.687289
169	17.580041	14.694461	208	17.578156	14.684353
170	17.578608	14.693143	209	17.57795	14.684192
171	17.579274	14.696288	210	17.578799	14.684518
172	17.58015	14.696729	211	17.579235	14.685375
173	17.581152	14.696828	212	17.57896	14.68595
174	17.581855	14.696652	213	17.580277	14.685798
175	17.578628	14.700845	214	17.580107	14.684832
176	17.579737	14.700163	215	17.578845	14.684016
177	17.579344	14.69957	216	17.50301	14.997447
178	17.579256	14.700553	217	17.503604	14.996076
179	17.579604	14.702917	218	17.501339	14.996627
180	17.582214	14.700918	219	17.499963	14.996622
181	17.580991	14.705293	220	17.499114	15.007763
182	17.580892	14.705982	221	17.499173	15.006143
183	17.58045	14.706516	222	17.50107	15.009252
184	17.581013	14.706231	223	17.501596	15.009235
185	17.581228	14.706365	224	17.501456	15.009493
186	17.582067	14.706496	225	17.501546	15.009627
187	17.582276	14.704666	226	17.501473	15.009976
188	17.58411	14.705486	227	17.501592	15.010402
189	17.587064	14.703723	228	17.50928	15.015992
190	17.587477	14.7059433	229	17.50746	15.015286
191	17.586758	14.705545	230	17.507522	15.015241
192	17.586338	14.705782	231	17.507374	15.015013
193	17.584672	14.706237	232	17.507322	15.014978
194	17.585856	14.70401	233	17.50869	15.015265
195	17.5799	14.703768	234	17.506033	15.014139
196	17.579905	14.703686	235	17.505318	15.015411
197	17.582944	14.708083	236	17.506051	15.015693
198	17.583718	14.71042	237	17.506644	15.015134
199	17.583479	14.712646	238	17.506594	15.016063

Appendix C

Sample Questionnaire

SOCIO-ECONOMIC QUESTIONNAIRE

MASTER OF SCIENCE: BIODIVERSITY MANAGEMENT AND RESEARCH

RESEARCH TOPIC: **ABUNDANCE, STRUCTURE AND USES OF BAOBAB (*Adansonia digitata* L.) POPULATIONS IN OMUSATI REGION**

STUDENT NAME: FAITH MUNYEBVU
STUDENT No.   : 201212263

Interviewer's name/initials:……………………Date of Interview: [ ]

Respondent No: [ ]

Constituency & village/location name: [ ]

Respondent's details: (no names shall be disclosed for confidentiality)

Gender (F/M): [ ]   Age: [ ]

Occupation:……………………………

Length of period lived in the area: [ ]

Survey Questions:

1. How many adult baobab trees do you have/own?..

2. What do you use the baobab for? (list)…………………………………………

…………………………………………………………………………………

3. Do you sell any baobab products? (Yes/No) [ ]

4. If yes, which part(s) of the tree?...

5. What do you use the income from baobab sell for?...

6. Which part of the tree do you mainly make use of in general ?.............................

7. Approximately how many baobab fruits do you harvest per tree?..........................

8. Are there any other uses that you know of that you have not practiced?................

…………………………………………………………………………………………

9. What is the fruiting period?..

10. What is the fruit harvesting period?……………………………………………

11. Do you see many young baobabs (1 - 3 year old)? (Yes/ No) ☐

12. If not, what do you think affects their survival?

Wild animals	Domestic animals	Insects	People	Weather	Other (specify)
☐	☐	☐	☐	☐	☐

13. Was there a time when you saw many young baobabs? (Yes/No) ☐

14. If yes, when was it if you can recall?...

15. Have you planted any baobabs in this area before? (Yes/ No) ☐

16. If yes, did they survive? (Yes/ No) ☐

17. Which animals normally consume or destroy the baobab?..................................

18. Which part of the tree do those animals consume?...

19. What are the cultural importance of the baobab tree in your area?....................

…………………………………………………………………………………………

20. Is there anything else you would like to mention?..

…………………………………………………………………………………………

Thank you for your cooperation.