Global Ecology and Conservation 14 (2018) e00386

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Original Research Article

Assessment of the African baobab (*Adansonia digitata L.)* populations in Namibia: Implications for conservation

K. Lisao [a, b, *], C.J. Geldenhuys [b], P.W. Chirwa [b]

[a] *Directorate of Forestry, P.O. Box 1971, Ngweze, Namibia*
[b] *Postgraduate Forest Programme, Department of Plant & Soil Sciences, University of Pretoria, South Africa*

A R T I C L E I N F O

Article history:
Received 24 July 2017
Received in revised form 6 April 2018
Accepted 6 April 2018

Keywords:
Conservation
Life-stages
Population dynamics
Stem density
Stem diameter distribution

A B S T R A C T

This study assessed the population structure of baobabs (*Adansonia digitata)* in Kunene, Omusati, Otjozondjupa and Zambezi Regions in northern Namibia. Data were collected from 240 trees in randomly selected baobab clusters. The stem girth at breast height (gbh, converted to stem diameter), height and crown diameter were recorded for each individual tree. Any sign of damage on the stem was recorded. Average stem densities were determined and compared between regions. Stem number per diameter classes were presented in histograms. The highest baobab density (6.7 stems per ha) was observed in Omusati Region and the lowest (0.2 stems per ha) was observed in Otjozondjupa Region. A J-shaped stem diameter distribution was observed in Zambezi Region and an inverse J-shaped distribution in Kunene Region. Bell-shaped distributions were observed in Otjozondjupa and Omusati Regions. The percentage of damaged stems in the sampled populations showed more damaged than undamaged baobabs in Kunene (63%), Omusati (83%) and Otjozondjupa (95%), but in Zambezi there were fewer damaged (46%) stems. Elephant damage accounted for 41% of the damaged stems whereas human damage was 59%. Selective protection of large baobabs by communities may attribute to the high densities and occurrence of trees in larger size classes in comparison to juveniles. Overall, the baobab population is currently considered as stable in Namibia. However, factors that negatively affect recruitment and establishment of baobab need to be monitored to ensure that a higher proportion of young trees survive. The study recommends protection and propagation of baobab seedlings in order to maintain viable populations of the species. Sustainable harvesting practices of baobab bark is also recommended.

1. Introduction

It has been generally found, in a number of studies on baobab (*Adansonia digitata*) population structure and size classes, that there is a lack of young trees (Chirwa et al., 2006; Schumann et al., 2011; Mashapa et al., 2013; Venter and Witkowski, 2013; Munyebvu, 2015). This has led to the current study in Namibia to establish if the situation is the same, and if so, to devise conservation strategies. Furthermore, although we did not study the causes specifically, we elaborate on factors that may have an impact on the population structure.

* Corresponding author. Directorate of Forestry, P.O. Box 1971, Ngweze, Namibia.
E-mail addresses: klushetile@gmail.com (K. Lisao), cgelden@mweb.co.za (C.J. Geldenhuys), paxie.chirwa@up.ac.za (P.W. Chirwa).

https://doi.org/10.1016/j.gecco.2018.e00386

The stem size distribution of a population serves as an important determinant of population stability (Shen et al., 2013). A stable population shows a higher proportion of young individuals and the size class distribution reveals an inverse J-shaped distribution curve. Lower proportions of young individuals may be an indication of low recruitment or a declining population. However, long-lived species, like the baobab, may display a bell-shaped distribution, *i.e.* a higher proportion of trees in the middle size classes (Venter and Witkowski, 2010). The bell-shaped distribution could be a result of episodic recruitment and considered normal for baobab (Venter and Witkowski, 2010).

Desertification and land degradation are major threats to sustainable land use in Namibia (Pröpper et al., 2010). Moreover, agricultural expansion and livestock farming, which are major drivers of land change in Southern Africa, are also widespread in Namibia (Biggs et al., 2008; Kamwi et al., 2015). This may result in unsustainable population structures for non-timber forest product (NTFP) species, such as baobab that has multiple uses, because of such disturbances. Furthermore, international interest in NTFP's has resulted in an increase in the species that are being commercialized for their NTFP's in Namibia. The recorded number of species providing non-timber products for commercial uses has increased from one species (*Acanthosicyos horridus*) in 1990 (Erkkila and Siiskonen, 1992) to close to 10 species in 2014 (Cole, 2014). Examples of such species include *Sclerocarya birrea* (Marula), *Harpagophytum procumbens* (Devil's claw) and *Ximenia americana* (Blue sour plum). The current study will provide quantitative information of the baobab to understand the potential for this resource in Namibia.

The increase in human population growth has further increased pressure on exploited plant resources for subsistence use and resulted in a reduction of some species in Namibia. Some of these species have become locally extinct in commonage areas (owned by more than one person) and only available in adjacent protected areas (Kangombe, 2012). Lushetile (2009) observed the scarcity of *Bobgunnia madagascariensis,* a sought after medicinal plant in Zambezi Region (north-eastern Namibia). The species was not available in areas around Sachinga but abundant on the adjacent protected government farm. Rural communities selectively protect and conserve important indigenous tree species due to the contribution to their livelihood (Shackleton et al., 2015). However, such multipurpose species are faced with disturbances such as unsustainable harvesting practices, removal as development extends to pristine areas, herbivory or destruction by fire (Arnold and Perez, 1998; Alfaro et al., 2014; Ticktin, 2015). This warrants conservation efforts to maintain the population of important species such as the baobab.

Baobabs are distributed in the savannas of Africa where it functions as a keystone species (Whyte, 2001; Wickens and Lowe, 2008), and provides important non-timber forest products to rural communities (Assogbadjo et al., 2005; Diop et al., 2005; Chirwa et al., 2006; Buchmann et al., 2010; Venter and Witkowski, 2010; Cuni Sanchez et al., 2011; Schumann et al., 2011; Munthali et al., 2012; Munyebvu, 2015; Lisao et al., 2017). Every part of the baobab tree is believed to be useful to local communities as a food source, fiber, medicine or for spiritual welfare (Sidibe and Williams, 2002; De Caluwe et al., 2009; Kamatou et al., 2011). According to Lisao et al. (2017), the bark is the most important part of the baobab in Namibia. It is harvested by humans for fodder and medicinal purposes. Elephants (*Loxodonta africana)* also commonly strip the bark. This may potentially increase vulnerability of baobab trees to diseases and increase mortality rates of trees with smaller stem diameters (Wilson, 1988; Mudavanhu, 1998; Romero et al., 2001; Kassa et al., 2014).

Several studies have shown that the population structure of the baobab is influenced by land use and human activities through economic and socio-cultural uses of the tree (Wilson, 1988; Schumann et al., 2011). The baobab seems to thrive well in human settlements, crop fields and rocky outcrops in Mali while in other areas it is only in well protected areas or rocky outcrops, supposedly with little human disturbance (Assogbadjo et al., 2005; Duvall, 2007). In West Africa, there is a high population of baobabs in human dominated landscapes especially near homesteads (Duvall, 2007; Schumann et al., 2011).

The baobab is native to the Sudano-Zambesian drier areas that receive 200–800 mm of rain (Wickens, 1982). It is found in a range of habitats but Sidibe and Williams (2002) argue that its distribution is mainly restricted by a certain minimum annual rainfall. In Namibia, baobabs mainly occurs in the northern part of the country in *Colophospermum mopane* woodlands (Giess, 1998). Curtis and Mannheimer (2005) states that in Namibia, it is restricted to hot, dry woodland on stony, well-drained soils and in frost-free areas that receive low rainfall.

Baobab is currently listed as Least Concern (LC) according to the IUCN Red List Criteria (The IUCN Red List of Threatened Species, 2016). However, there are records of increased reduction in baobab populations across Africa (Leach et al., 2011). A study by Cuni Sanchez et al. (2010) predicted that there will be no areas in Namibia suitable for baobab growth in future due to effects of climate change caused by change in land use and global warming. In Namibia, the baobab is protected under the Forest Act No 2 of 2001 due to extensive uses by humans and animals (Government Republic of Namibia, 2015). However, the high demand for baobab products and associated changes in land use (exacerbated by human activities and climate change) are major factors that may threaten the occurrence of baobabs (Dhillion and Gustad, 2004; Venter and Witkowski, 2010; Schumann et al., 2011).

Despite the importance of the baobab to local communities in Namibia, data on the population structure of the species is limited (Lisao et al., 2017). There exists only one study on the population structure of baobab in Namibia (Munyebvu, 2015). The study was limited to Omusati Region where a bell-shaped distribution for the baobab population was observed. The aim of this study was therefore to describe the population structure of baobab populations in four selected areas in northern and north-eastern Namibia where the species occurs in relative abundance. The study assessed tree density and population structure (stem diameter class distribution) of baobab along a rainfall gradient, in order to develop site specific management guidelines for conservation interventions. It addresses the following study questions: Is the population structure of baobabs in Namibia stable? What conservation strategies will improve sustainability of the baobab population in Namibia?

2. Methods

2.1. Study areas

The study areas covered variable environmental parameters and a rainfall gradient that increases from the western to the eastern regions in northern and north-eastern Namibia (Fig. 1, Table 1). Generally, Namibia is a hot and dry country with high climatic variability. There is a variation in soil types across the country; the majority of this is poor and therefore not suitable for crop production (Coetzee, 2003). The study area lies in the woodland vegetation type as classified by Giess (1998). Land tenure is communal with traditional administration through customary law.

2.2. Study site selection and sampling design

Sites for data collection were selected based on knowledge of the distribution of baobab, and herbarium specimens of baobabs from the Windhoek Herbarium (WIND) (Curtis and Mannheimer, 2005). Baobab also occurs in other regions (Oshana, Ohangwena and Kavango Regions) but field observations indicated that they occur in limited numbers and therefore would not have made sufficient plots for data analysis.

Ground-truthing was done prior to data collection to verify the presence of baobab as well as a test for identification of baobab trees from the satellite images (using Google Earth images). Baobab has a disjunct spatial distribution; therefore selection of data collection sites was done through stratified sampling of areas with variable rainfall and occurring in different geographic regions of Namibia. Geographic areas of baobab presence were identified and marked on a satellite image obtained from Google Earth (Assessment date, 10 October 2014). This was done to ensure that the major populations of baobabs in different rainfall regimes were included and had an equal chance of being selected. From each marked baobab population, major baobab clusters were marked and numbered in each rainfall regime (Fig. 2). Four clusters were randomly selected from each marked baobab population per region/rainfall regime, *i.e.* 16 clusters in total. The geographic coordinates were determined at the centre of each cluster, and entered into a GPS to be located in the field for data collection.

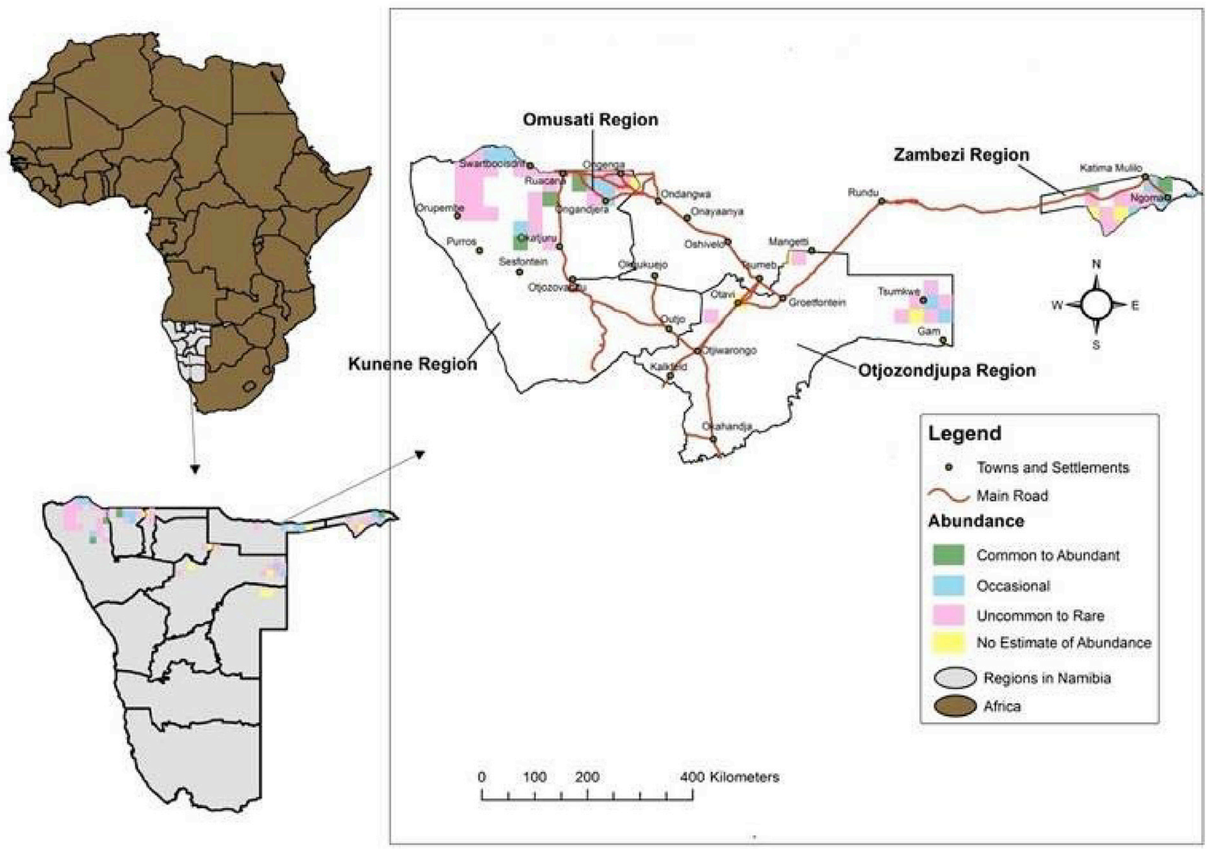

Fig. 1. Map indicating the study areas and distribution of baobab in Namibia.
(Source: National Remote Sensing, 2015; Curtis and Mannheimer, 2005).

Table 1
Important environmental and anthropogenic features in the four baobab study areas in northern and north-eastern Namibia.

Study area	Kunene	Omusati	Otjozondjupa	Zambezi
Landscape features	Rocky mountains, high species diversity and endemism	Seasonal water bodies, degraded landscape	Water pans, high bird diversity and wildlife	Rivers, associated flood plains, woodlands and wildlife
Rainfall, mm	100–200	250–300	500–650	660–750
Minimum temperature, °C	13	14	13	15
Maximum temperature, °C	26	32	29	31
Soil formation	Rocky outcrops	Cambisols	Arenosols	Arenosols and Cambisols
Vegetation types	Mopane Woodland	Mopane Woodland	Tree savanna and woodland	Tree savanna and woodland
Natural disturbances to vegetation	Fire, herbivory	Seasonal flooding	Fire, herbivory	Seasonal flooding, fire, herbivory
Crop cultivation	Limited	Common	Limited	Common
Human population density per km^2	0.8	9.2	4.6	6.2
Baobab populations	Wild	In and around human settlements	Wild	Wild, human settlements

(Mendelsohn et al. 2002; Namibia Statistical Agency, 2011; Namibia Meteorological Services, 2015).

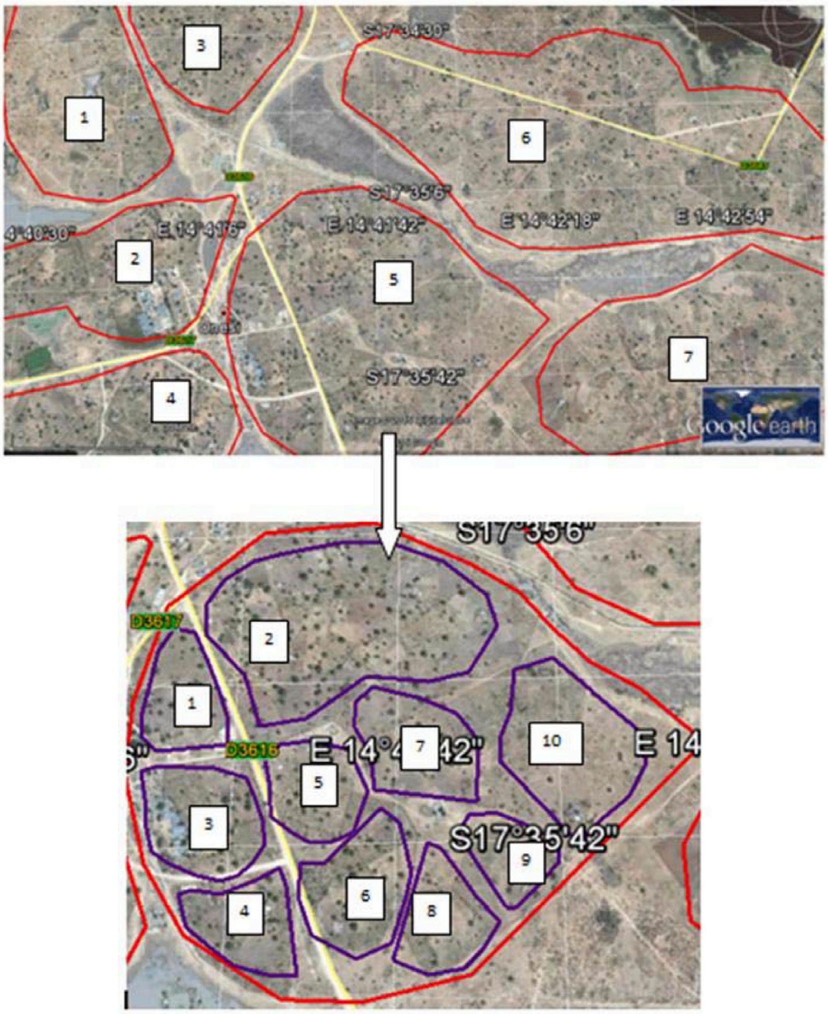

Fig. 2. Example of mapping major baobab populations in an area (top photo), marking of clusters (bottom photo) in population 5, from which baobab clusters were selected for data collection.

Table 2
Descriptive statistics of variables in different study areas (with annual rainfall between brackets) and ANOVA results.

Variable (Mean)	Kunene (166 mm/a)	Omusati (285 mm/a)	Otjozondjupa (617 mm/a)	Zambezi (740 mm/a)	F	P
Stem diameter: dbh range (m)	1.4 (0.61–2.7)	4.1 (0.64–8.8)	4.5 (1.9–8.6)	1.6 (0.03–9.1)	60.7	0.046
Height (m)	12.7 ± 3.5	16.6 ± 4.7	19.8 ± 4.7	14.3 ± 6.3	23.7	0.009
Crown diameter (m)	9.6 ± 5.2	20.2 ± 5.9	19.9 ± 5.3	10.5 ± 7.7	53.3	0.00002
Stems/ha	5.8 ± 2.5	6.7 ± 2.5	0.2 ± 0.08	2.7 ± 5.7	3.7	0.042

2.3. Data collection and analysis

Stand density and population structure was based on a fixed number of 15 baobab plants around the sampling point because of the variable distance between trees in the clusters. Plot size was determined from the distance from the random sampling point to the 15th plant. The stem diameter, tree height and crown diameter of each tree were recorded. A 50-m tape measure was used to measure the girth of the stem at 1.3 m height above the ground (Girth at breast height). A clinometer was used to measure tree height, from ground level to highest point of the crown. Crown diameter was calculated as the mean of two cross sectional lengths, *i.e.* the narrowest and widest diameters of the crown, measured with a tape measure. Fieldwork was carried out during the wet season (February and March 2015) for easy identification of young baobab trees and to observe seedlings that have just germinated. Data collection in all areas was done in the same season for consistency and precise comparison between different areas because baobab stem diameter is typically variable between the wet and dry seasons (Patrut et al., 2007). Each individual stem was assessed for bark damage and recorded when a fresh scar was present. The damage to stem by elephants and humans was differentiated by the distinction in the scars. Scars by humans have clear geometric lines into the bark because of the sharp objects normally used (e.g axe, panga or hoe). Scars by elephants have no clear hard horizontal lines and often extends much higher into the tree.

Data were analysed using SPSS Statistics 20 and Microsoft Excel 2010. All stem girth measurements were converted to stem diameter (dbh) for analyses. Trees were categorized into stem diameter classes of 1 m interval (Munyebvu, 2015). Life stage classifications were adopted from Venter and Witkowski (2013). Baobab saplings of <5 m height were considered as juveniles. Trees ≥5 m height and ≤1 m dbh with developed crowns were classified as sub-adults. Adult trees were trees with >1 m dbh.

The average baobab tree densities were determined using the following formula:

$$Baobab\ stem\ density = Number\ of\ individual\ trees/Area\ of\ plot.$$

The area of the plot, A, was calculated using $A = \pi r^2$, where r was the distance from the centre of the plot to the 15th tree (furthest away from the centre).

A test for normality of the data was carried out using the Kolmogorov-Smirnov Test, before ANOVA procedures. Data that was not normally distributed (dbh) were transformed before being analysed. One-way ANOVA test was used to determine if there were significant differences in tree density, dbh, height and crown diameter in different regions, at a 0.05 significant level. Baobab dbh class distributions across study sites were presented as histograms derived from analysis using Microsoft Excel (2010).

3. Results

3.1. Description of baobab populations in different regions

Baobab plants were observed mainly in small patches of dense stands and as isolated trees further away from the dense stands. In Kunene Region, baobab trees were observed in dense clusters on mountains, showing a disjunct distribution between clusters. Observed plants were categorized into juvenile (<5 m height), sub-adult (5 m height to <1 m stem diameter) and adult (1 + m stem diameter) life stages after Venter and Witkowski (2013). The number of baobabs with damaged stems, by both elephants and humans in the different regions, was presented in graphs.

Trees were growing on highly elevated mountain slopes and crests from up to 1351 m to 1450 m above sea level but occasionally at the foot of mountains, in areas south of Orumana and north of Okavare, Okatomba and south of Orokatundu. All observed trees in Kunene Region were wild populations. In Omusati Region, the baobab populations were mainly observed in human settlements in the Outapi, Tsadi, Onesi and Ewunda areas. They were mainly in crop fields or homesteads that were fenced. In Otjozondjupa Region, baobab populations were observed east of Tsumkwe settlement towards the border with Botswana. Baobab populations in this Region are wild, occurring in *Acacia* thickets and open woodlands. Baobabs were observed around areas such as Djxohoe, Makuri and around a pan known as Gura. In Zambezi Region, baobabs were observed in the eastern part of the region, with dense baobab populations in the Ioma, Muyako and Sikanjabula areas. It is evenly spread in the mopane belt across Salambala Conservancy. Trees were observed in crop fields, in the wild and around human settlements.

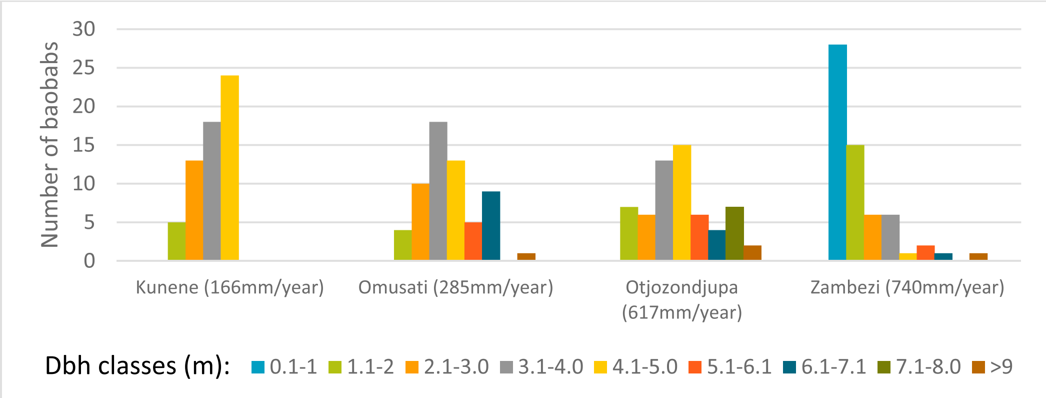

Fig. 3. The population structure of baobab in different rainfall regimes.

Descriptive statistics for stem diameter, tree height, crown diameter and stand density are summarised in Table 2. The ANOVA showed that stand density, dbh, tree height and crown diameter were significantly different between regions ($p < 0.05$). The highest mean density of 6.7 stems per ha was recorded in Omusati Region, and. the lowest mean density of 0.2 ± 0.1 stems per ha in Otjozondjupa Region. Zambezi Region with highest annual rainfall, had the second lowest baobab density, whereas Kunene Region with the lowest rainfall had the second highest baobab population density. The tallest trees were recorded in Otjozondjupa Region. The widest crowns were observed in Omusati Region. From field observations, dense baobab extends over relatively larger areas in Omusati Region in comparison to other regions.

Signs of sooty mould disease were observed on one tree in Omusati Region. Up to 3% of the observed trees had natural beehives, and 10% had bird nests. Dead trees only made about 2% of the population. The causes of death was assumed to have been caused by fire.

3.2. Dbh size class distributions of baobabs in different regions

In the Omusati and Otjozondjupa Regions (250–650 mm rainfall), the trees showed the typical Bell-shaped stem diameter class distributions, *i.e.* fewer trees in the smaller and large size classes than trees in the intermediate size classes (Fig. 3). The population in the Zambezi Region (660–750 mm) showed J-shaped distribution with a left peak, *i.e.* more young trees and fewer trees in the adult size classes. The population in Kunene Region (100–200 mm) revealed an inverse J-shaped distribution, the number of trees in the largest size class were higher than those in the smaller size classes.

3.3. Regeneration

Categorising all baobab trees into life stages gave insights into the lack of regeneration (Fig. 4). Juvenile baobabs were only found in Zambezi Region with the highest annual rainfall (>600 mm annual rainfall). The results indicate that there are no

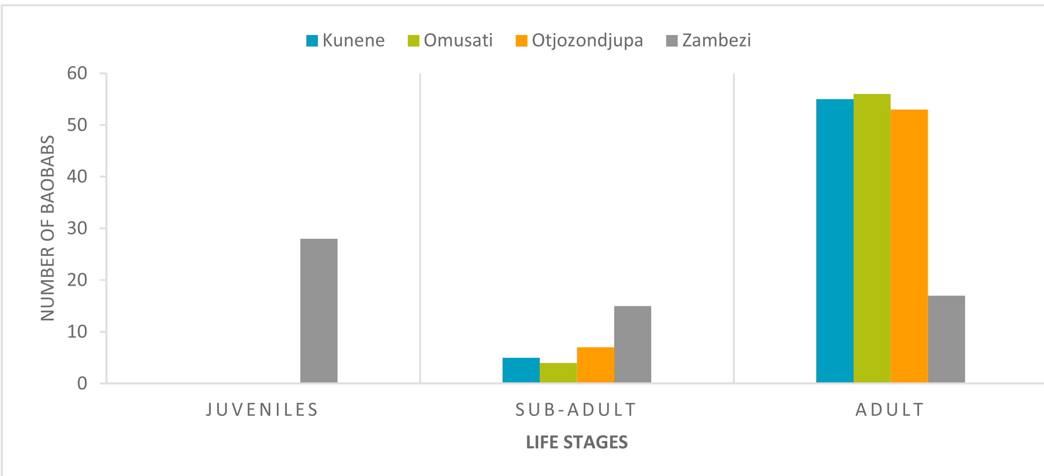

Fig. 4. Percentage of total number of recorded stems of baobab in different life stages in the different geographic regions.

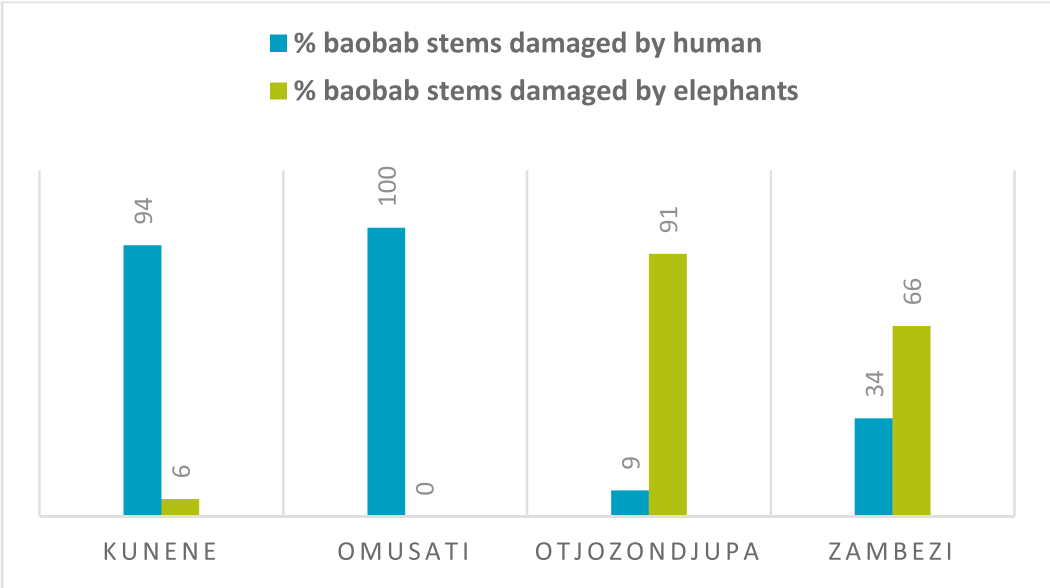

Fig. 5. Proportion of intact and damaged stems in different size classes.

baobab plants in the juvenile life stage in Kunene, Omusati and Otjozondjupa Regions (Fig. 4). Regeneration is poorest in Otjozondjupa Region, where plants in the sub-adult life stage were absent. Generally, there were more individuals in the adult stage in all areas in relation to the juvenile and sub-adult stages.

3.4. Damage to bark of baobabs in different regions

The percentage of damaged baobab stems in the sampled populations were higher than the percentage of intact stems in Kunene (63%), Omusati (83%) and Otjozondjupa Regions (95%), but were lower (46%) in Zambezi Region. There were significant differences between stem conditions of sampled baobabs in different regions ($\chi^2 = 49.261$, df = 3, $P < 0.001$). The trend observed in all regions was that the larger the tree the higher the rate of damage. Larger trees are more preferred for bark harvesting than smaller trees. Overall, 72% of observed plants had scars on the stem, 59% by humans and 41% by elephants. All trees in Omusati Region were damaged by humans (Fig. 5). The highest damage by elephants was recorded in Otjozondjupa Region.

4. Discussion

4.1. Factors that affect baobab stem density in different rainfall regimes

The overall mean density for the four sampled regions was variable and ranged from 0.16 to 6.73 stems per ha. This is within range of other recorded baobab densities in other African countries (Venter and Witkowski, 2010; Ndoro et al., 2014). The observed significant differences in stand density between different regions were not related to causal factors for the differences. These were assumed to be caused by differences in the micro-environmental conditions, land-use types and arability of soil as well as biological factors such as herbivory and fruit predation. These assumptions need further investigation.

The highest stem densities were observed in the Omusati Region with a relatively low annual rainfall. High annual rainfall may therefore, not necessarily be the primary factor in determining high densities. However, the occurrence of seasonal pans in the region may have contributed to the high density. Wetter areas have relatively high baobab densities in comparison to dry areas (Edkins et al., 2007; Mashapa et al., 2013; Mpofu et al., 2012).

The densities in Omusati Region were higher than the densities of 3.96 and 4.13 stems per ha recorded in two areas in the Omusati Region by Munyebvu (2015). The variation may be due to differences in sampling units, however stand density also varies between clusters in the same area. Land use is known to impact on baobab population structure (Schumann et al., 2011; Venter and Witkowski, 2010). With a population density of 9.2 people per square kilometer, Omusati Region is the most densely populated region in the study areas (Namibia Statistical Agency, 2011) and yielded the highest baobab stem density. The baobab is also highly associated with human settlements. This may explain the high density of baobab observed in Omusati Region. The protection is due to the benefits that the local communities derived from the mature trees (Lisao et al., 2017).

Abundant elephants in the sampled areas of Otjozondjupa Region may account for the low baobab density in comparison to other regions. Elephants are highly associated with baobab populations and believed to negatively affect baobab populations (Edkins et al., 2007). They have been observed to reduce baobab densities by destroying young baobab trees by trampling or feeding on them (Barnes, 1996, Edkins et al., 2007, Ndoro et al., 2014).

4.2. Factors that affect size class distributions in different rainfall regimes

Bell-shaped size class distributions for Omusati and Otjozondjupa may not necessarily be an indicator of an unstable population. Baobab can sustain population levels with low or sporadic recruitment (Venter and Witkowski, 2013). The lack of baobab plants of <2 m dbh in Otjozondjupa Region indicates high rates of seedling mortality that may be due to elephant damage and human use of baobab seeds. The lack of plants in some size classes may be a result of a natural disaster such as drought, flood, fire or diseases as this may result in death of cohorts.

The J-shaped distribution in Kunene and Zambezi Regions are an indication of successful recruitment, but may be short-lived because of the dynamics of the vegetation. Long-term monitoring of these populations may yield results that will assist in understanding baobab population dynamics in Namibia.

There were no juvenile baobabs in all regions, except Zambezi Region. The lack of juveniles is a common observation for baobab (Eltahir et al., 2015). The low numbers of sub-adult trees in comparison to juveniles in Kunene and Zambezi Regions indicates good recruitment. The observed higher numbers of sub-adult size classes than juveniles in Omusati and Otjozondjupa Regions indicates poor recruitment. The factors that determine the life stages are variable in different regions. The absence of both juveniles and sub-adults in the 400–500 mm rainfall zone in Otjozondjupa Region may be due to a combination of various factors such as destructive use of seeds, destruction and trampling of seedlings by animals, and agricultural activities.

Land use type is a major factor that impact on the population structure of baobabs (Schumann et al., 2011; Venter and Witkowski, 2010). Agricultural cropping may result in fewer seedlings because baobab seedlings are normally removed when clearing new sites for growing crops, to reduce competition with their crops (Lisao et al., 2017). Similar observations have been made in other countries, including Malawi (Dhillion and Gustad, 2004) and South Africa (Venter and Witkowski, 2013). However, the adult trees are normally retained, resulting in more adult trees than those in the juvenile stages. Traditionally, important large trees, such as baobab, are protected by cultural norms in African communities (Sidibe and Williams, 2002; Lisao et al., 2017). This may contribute to the high ratio of mature trees to juveniles. The same trend was observed in previous studies by Munyebvu (2015) in Namibia and other parts of Africa (Cuni Sanchez et al., 2010; Schumann et al., 2011; Venter and Witkowski, 2010; Edkins et al., 2007; Chirwa et al., 2006; Assogbadjo et al., 2005; Dhillion and Gustad, 2004).

Cattle (*Bos taurus*) and goats (*Capra aegagrus hircu*) are common domestic animals that occur in all sampled regions. While these are dispersers, they may also destroy seeds when feeding and therefore negatively impact on recruitment. Seeds may also be dispersed to areas where suitable germination conditions are not met and therefore fail to establish. Venter and Witkowski (2013) indicated that baobab seedlings may be destroyed by repeated browsing by livestock, contributing to lack of juveniles. In Otjozondjupa Region, the lack of juveniles may indicate a high rate of destruction of seeds before establishment or destruction of fruits before maturing, resulting in reduction of viable seeds.

Rainfall is an important factor for successful recruitment of baobab seedlings. The higher annual rainfall in Zambezi Region may be the causal factor for the observed best regeneration, possibly due to increased source of moisture to break dormancy of baobab seeds and providing nourishment for young seedlings. Cuni Sanchez et al. (2011) compared seedlings with varying amounts of moisture received. Seedlings exposed to higher moisture conditions (rainfall or watering) establish and grow faster than those under lower moisture conditons.

The slow growth of seedlings in the more arid study areas (Kunene, Omusati and Otjozondjupa) may expose seedlings to more disturbances before growing beyond the juvenile stage, and cause reduced numbers of juveniles. In a study in Benin, seedlings of seeds from wetter provenances grew faster, whilst seedlings from more arid provenances allocated more resources to the taproot, a characteristic related to drought adaptation (Cuni Sanchez et al., 2011). Venter and Witkowski (2013) attributed seedling mortality to infrequent rainfall in South African.

The Zambezi Region has a higher plant diversity than the other regions (Giess, 1998), providing alternative options for available feed for animals. This may reduce browsing pressure on young baobab plants. Seedlings may also find refuge in thickets, which are difficult to access by animals (Venter and Witkowski, 2010), and increasing successful recruitment. This is different in Omusati Region because of degraded and overgrazed landscapes. It is likely that geminated baobab seedlings may be browsed by cattle, goats and donkeys (*Equus africanus asinus*) which are found in high densities in that region.

Communities in Kunene, Omusati, Otjozondjupa and Zambezi Regions use baobab seeds as food and therefore reduce the number of viable seeds that may potentially establish (Lisao et al., 2017). Additionally, fire scars observed on stems may potentially destroy juveniles before recruiting into larger trees, which are more resilient to fire.

4.3. Assessment of baobab stem condition

The majority of baobab stems were damaged. In northern Namibia, the bark is harvested by humans, mainly for use in administering various ailments (Munyebvu, 2015; Lisao et al., 2017). Elephants are also a major contributor to baobab bark damage, especially in the dry seasons (Weyerhauser, 1985; Romero et al., 2001). As a succulent, it can serve as a source of water. Mudavanhu (1998) suggests a relationship between bark harvesting and sooty disease. However, Romero et al. (2001) could not determine any relationship between harvesting intensity and presence of sooty disease. Ndoro et al. (2014) observed that 98% of baobab trees in a National Park in Zimbabwe were damaged by elephants. Elephants strip damage the bark of older baobab trees, weakening the tree and making them more prone to diseases, fire and infections. A study in Zimbabwe has indicated that some trees may not produce fruits for up to a period of four years due to depleted resources as a result of elephant damage to the bark (Swanepoel, 1993). A study into the effects of bark harvesting of baobab trees in the variable landscape where baobab occurs in Namibia is recommended.

The high rate of damage of stems in Otjozondjupa Region is a combination of stripping by elephants and harvesting of bark by humans. The trees in Kunene Region had the lowest rate of damage, possibly due to the difficult access to these trees that occur on rocky mountains. This supports findings by Edkins et al. (2007) who indicated that damage by elephants to baobabs decreased with increasing slope and rockiness. Baobab bark is the most important part of the baobab tree used across the study areas (Lisao et al., 2017), but the use of baobab bark needs to be regulated. Sustainable harvesting is recommended with recovery periods of 8 years for bark thickness and 12 years for fibre quality (Romero et al., 2001).

4.4. Implications for conservation

Overall, the baobab population is currently considered as stable. However, if factors that affect regeneration are not monitored, the population of baobab may become threatened. Nevertheless, protection is accorded to adult trees by locals and therefore this contributes positively to the population structure of baobab. The study identified that baobab populations in the Otjozondjupa and Omusati Regions may be exposed to local extinction. Investigation of seedling refugia in these regions is critical for conservation of baobab. Regardless of the resilient nature of the baobab stems, excessive bark harvesting increases the vulnerability of the trees to diseases (Kassa et al., 2014). The observed rates of damage to the baobab trees may not be sustainable. Recovery periods is recommended to allow the bark to fully recover before harvesting. Since water is a limited resource in Namibia, *in situ* conservation of the baobab needs to be incorporated into conservation strategies. Active protection of established baobab seedlings and transplanting seedlings to desirable areas by local communities is recommended in order to ensure successful recruitment. This may also contribute to conservation of the local genetic pool in future populations.

Studies to investigate population genetics is critical to ensure genetic diversity is maintained and for better conservation strategies. Overall, data from this study will generate knowledge that will be used in value addition, domestication and revision of the IUCN status of baobab in Namibia for conservation. Additionally, baobab trees play important ecological roles as a keystone species. This is supported by the presence of bee hives and bird nests observed on the trees. Conservation of this species is therefore important in maintaining stability in the ecosystem.

5. Conclusion

The study assessed the baobab population structure in different regions in northern Namibia and found significant differences in densities between different regions. The results revealed that there is a lack of baobab trees in the juvenile life stage in three of the four regions. Stem diameter class distributions revealed fewer young trees than adults in Otjozondjupa and Omusati Regions, whereas a higher number of young than adult trees were observed in Zambezi and Kunene Regions, indicating a young and stable population. Trees with smaller diameters were observed in areas that were hard to access in Kunene and Zambezi Regions. This may provide a shield to elephants and other animals from damaging the young seedlings. The study indicated that a significant number of trees have damaged stems, making them vulnerable to infections of the damaged stems. Though baobab recruitment is sporadic, factors that disturb and reduce numbers of baobab seedlings need to be monitored to ensure higher proportions of young trees in order to conserve baobab in Namibia.

Conflicts of interest

None.

Acknowledgements

This work was supported by the Ministry of Agriculture, Water and Forestry in Namibia. Our gratitude goes to the staff of the Directorate of Forestry for logistical assistance during field work. We thank the field assistants for their support.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.gecco.2018.e00386.

References

Alfaro, R.I., Fady, B., Vendramin, G.G., Dawson, I.K., Fleming, R.A., Saenz-Romero, C., Lindig-Cisneros, R.A., Murdock, T., Vincet, B., Navarro, C.M., Skropa, T., Baldinelli, G., El-Kassaby, Y.A., Loo, J., 2014. The role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change. For. Ecol. Manag. 318, 71–77.

Arnold, J.E.M., Perez, M.R., 1998. The role of non-timber forest products in conservation and development. In: Wollengerg, E., Ingles, A. (Eds.), Incomes from the Forest, Methods for the Development and Conservation of Forest Products for Local Communities. Center for International Forestry Research, Indonesia, pp. 17–42.

Assogbadjo, A.E., Sinsin, B., Codjia, J.T.C., Van Damme, P., 2005. Ecological diversity and pulp, seed and kernel production of baobab (*Adasonia digitata*) in Benin. Belg. J. Bot. 138, 47–56.

Barnes, R.F.W., 1996. The conflict between humans and elephants in the central African forests. Mamm Rev. 26, 67–80.

Biggs, R., Simons, H., Bakkenes, M., Scholes, J., Eickhout, B., Vuuren, D., Alkemade, R., 2008. Scenarios of biodiversity loss in southern Africa in the 21st century. Global Environ. Change 18, 296–309.

Buchmann, C., Prehsler, S., Hartl, A., Vogl, C.R., 2010. The importance of baobab (*Adansonia digitata* L.) in rural west african subsistence—suggestion of a cautionary approach to international market export of baobab fruits. Ecol. Food Nutr. 49, 145–172.

Chirwa, M., Chithila, V., Kayambazinthu, D., Dohse, C., 2006. Distribution and Population Structures of Adansonia Digitata in Some Parts of Ntcheu, Dedza and Mangochi Districts, Malawi. Report No.06002. Forestry Research Institute of Malawi, Zomba.

Coetzee, M., 2003. Characteristics of Namibian soil in a nutshell. Ministry of agriculture, water and foresty. Spotlight on Agriculture No 65, Namibia.

Cole, D., 2014. Creating an enabling environment. In: Indigenous Natural Products of Namibia. (Ed. D. Cole). John Meinert, Windhoek, Namibia.

Cuni Sanchez, A.C., Osborne, P.E., Haq, N., 2010. Identifying the global potential for Baobab tree cultivation using ecological niche modeling. Agrofor. Syst. 80, 191–201.

Cuni Sanchez, A.C., Osborne, P.E., Haq, N., 2011. Variation in *Baobab* seedling morphology and its implications for selecting superior planting material. Sci. Hortic. 130, 109–117.

Curtis, B.A., Mannheimer, C.A., 2005. Tree Atlas of Namibia Windhoek. National Botanical Research Institute, Windhoek.

De Caluwe, E., De Smedt, S., Assogbadjo, A.E., Samson, R., Sinsin, B., Damme, Van P., 2009. Ethnic differences in use value and use patterns of Baobab (*Adansonia digitata* L.) in Northern Benin. Afr. J. Ecol. 23, 433–440.

Dhillion, S.S., Gustad, G., 2004. Local management Practices influence the viability of the Baobab (*Adansonia digitata* L.) in different Land use types, Cinzana, Mali. Agric. Ecosyst. Environ. 101, 85–103.

Diop, A.G., Sakho, M., Dornier, M., Cisse, M., Reynes, M., 2005. African baobab (*Adansonia digitata* L.): principal characteristics and utilisation. Fruits 61, 55–69.

Duvall, C.S., 2007. Human settlement and Baobab distribution in south-western Mali. J. Biogeogr. 34, 1947–1961.

Edkins, M.T., Kruger, L.M., Harris, K., Midgley, J.J., 2007. Baobabs and elephants in the Kruger National Park, nowhere to hide. Afr. J. Ecol. 46, 119–129.

Eltahir, M.E.S., El Khalifa, K.F., Taha, M.E., Darr, D., Gebauer, J., Elamin, H.M.A., Adlan, O.S., 2015. Scanty regeneration of baobab (*Adansonia digitata*) in west Kordofan state, Sudan. Int. J. Agri. Forest. Fish. 3, 206–212.

Erkkila, A., Siiskonen, H., 1992. Forestry in Namibia 1850 – 1990. University of Joensuu, Faculty of Forestry, Joensuu.

Giess, W., 1998. A Preliminary Vegetation Map of Namibia, third ed., vol. 4. Dinteria, pp. 1–112.

Government Republic of Namibia, 2015. Government Notice No. 170 Forest Regulations: Forest Act, 2001.

Kamatou, G.P.P., Vermaark, I., Viljoen, A.M., 2011. An updated review of *Adansonia digitata*, a commercially important African tree. S. Afri. J. Bot. 77, 908–919.

Kamwi, J.M., Chirwa, P.W.C., Manda, S.O.M., Graz, F.P., Katsch, C., 2015. Livelihoods, land use and land cover change in the Zambezi Region, Namibia. Popul. Environ. 36, 1–24.

Kangombe, F.N., 2012. The Vegetation of Omusati and Oshana Regions, Central-northern Namibia. M.Sc. Thesis. University of Pretoria, South Africa.

Kassa, B.D., Fandohan, B., Azihou, A.F., Assogbadjo, A.E., Oduor, A.M.O., Kidjo, F.C., Babatound, S., Liu, J., Kakai, R., 2014. Survey of *Loxodonta Africana* (elephantidae)- caused bark injury on *Adansonia digitata* (malavaceae) within pendjari biosphere reserve, Benin. Afr. J. Ecol. 52, 385–394.

Leach, H.B., Van der Stege, C., Vogl, C.R., 2011. Baobab (*Adansonia digitata* L.) and tamarind (*Tamarindus indica* L.) management strategies in the midst of conflict and change, a dogon case study from Mali. Hum. Ecol. 3, 597–612.

Lisao, K., Geldenhuys, C.J., Chirwa, P.W., 2017. Traditional uses and local perspectives on baobab (*Adansonia digitata*) population structure by selected ethnic groups in northern Namibia. South Afr. J. Bot. 113, 449–456.

Lushetile, K., 2009. Vegetation Description of Sachinga Livestock Development Centre and Surroundings, Caprivi, Namibia. B.Sc. Honours Mini Dissertation. University of Pretoria, South Africa.

Mashapa, C., Zisadza-Gandiwa, P., Gandiwa, E., Kativu, S., 2013. Abundance and structure of african baobab (*Adansonia digitata*) across different soil types in gonarezhou National Park, Zimbabwe. Int. Biodivers. Conserv. 2013, 1–7.

Mendelsohn, J., Jarvis, A., Roberts, C., Robertson, T., 2002. Atlas of Namibia, A Portrait of the Land and its People. David Phillips Publishers, South Africa.

Mpofu, E., Gandiwa, E., Zisadza-Gandiwa, P., Zinhiva, H., 2012. Abundance, distribution and status of African Baobab (*Adansonia digitata* L.) in dry savanna woodlands in southern Gonarezhou National Park, southeast Zimbabwe. Trop. Ecol. 53, 119–124.

Mudavanhu, H.T., 1998. Demography and Population Dynamics of Baobabs (*Adansonia Digitata*) Harvested for Bark in South-eastern Zimbabwe. MSc Dissertation. University of Zimbabwe, Harare.

Munthali, C., Chirwa, P., Akinnifesi, F., 2012. Phenotypic variation in fruit and seed morphology of *Adansoni digitata* L. (Baobab) in five selected wild populations in Malawi. Agrofor. Syst. 85, 279–290.

Munyebvu, F., 2015. Abundance, Structure and Uses of Baobab (*Adansonia Digitata* L.) Population in Omusati Region, Namibia. MSc Dissertation. University of Namibia, Namibia.

Namibia Meteorological Services, 2015. Climate Data for Kunene, Omusati, Otjozondjupa and Zambezi Regions (2004-2014). Ministry of Works and Transport, Namibia.

Namibia Statistical Agency, 2011. Regional Profiles for Kunene, Omusati, Otjozondjupa and Zambezi Regions. Windhoek, Namibia.

National Remote Sensing, 2015. Distribution of Baobab (*Adansonia digitata*) in Namibia. Directorate of forestry, Ministry of Agriculture, Water and Forestry, Namibia.

Ndoro, O., Mashapa, C., Kativu, S., Gandiwa, E., 2014. A comparative assessment of baobab density in northern Mana Pools National Park, Zimbabwe. Afr. J. Ecol. 53, 109–111.

Patrut, A., von Reden, K.F., Lowy, D.A., Alberts, A.H., Pohlman, J.W., Wittmann, R., Gerlach, D., Xu, L., Mitchell, C.S., 2007. Radiocarbon dating of a very large African Baobab. Tree Physiol. 27, 1569–1574.

Pröpper, M., Gröngröft, A., Falk, T., Eschenbach, A., Fox, T., Gessner, U., Hecht, J., Hinz, M.O., Huettich, C., Hurek, T., Kangombe, F.N., Keil, M., Kirk, M., Mapaure, C., Mills, A., Mukuya, R., Namwoonde, N.E., Overmann, J., Petersen, A., Reinhold-Hurek, B., Schneiderat, U., Strohbach, B.J., Lück-Vogel, M., Wisch, U., 2010. Causes and perspectives of land-cover change through expanding cultivation in Kavango. In: Hoffman, M.T., Schmiedel, U., Jürgens, N. (Eds.), Biodiversity in Southern Africa. Vol 3, Implications for Land Use and Management. Klaus Hess Publishers, Windhoek, pp. 1–31.

Romero, C., Dovie, D., Gambiza, J., Luoga, E., Schmitt, S., Grundy, I., 2001. Effects of commercial bark harvesting on *Adansonia digitata* (Baobab) in 131 Save-Odzi Valley, Zimbabwe, with considerations for its management. In: Cunningham, A.B., Campbell, B.M., Luckert, M.K. (Eds.), Advances in Economic Botany. Botanical Garden Press, Bronx, New York, USA, pp. 95–114.

Schumann, K., Wittig, R., Thiombiano, A., Becker, U., Hahn, K., 2011. Impact of land-use type and harvesting on population structure of a non-timber forest product-providing tree in a semi-arid savanna, West Africa. Biol. Conserv. 9, 2369–2376.

Shackleton, C.M., Ticktin, T., Pandey, A., 2015. Introduction: the need to understand the ecological sustainability of non-timber forest product harvesting systems. In: Shackleton, C.M., Pandey, A., Ticktin, T. (Eds.), The Ecological Sustainability for Non-timber Forest Products, Dynamics and Case Studies of Harvesting. Earthscan, London, pp. 3–11.
Shen, Y., Santiago, L.S., Ma, L., Lin, G., Lian, J., Cao, H., Ye, W., 2013. Forest dynamics of a subtropical monsoon forest in Dinghushan, China, recruitment, mortality and the pace of community change. J. Trop. Ecol. 29, 131–145.
Sidibe, M., Williams, J.T., 2002. Baobab Adansonia Digitata, Southampton, UK. International Centre for Under-utilised Crops.
Swanepoel, C., 1993. Baobab damage in Mana Pools National Park, Zimbabwe. Afr. J. Ecol. 31, 220–225.
Ticktin, T., 2015. The ecological sustainability for non-timber forest products harvest, principles and methods. In: Shackleton, C.M., Pandey, A., Ticktin, T. (Eds.), The Ecological Sustainability for Non-timber Forest Products, Dynamics and Case Studies of Harvesting. Earthscan, London, pp. 31–52.
Venter, S.M., Witkowski, T.F., 2010. Baobab (*Adansonia digitata* L,) Density, size class, distribution and population trends between four land-use types in northern Venda, South Africa. For. Ecol. Manag. 261, 630–640.
Venter, S.M., Witkowski, T.F., 2013. Where are the young Baobabs? Factors affecting regeneration of *Adansonia digitata* L, in a communally managed region of southern Africa. J. Arid Environ. 92, 1–13.
Weyerhauser, F.J., 1985. Survey of elephant damage to baobabs in Tanzania's lake manyara National Park. Afr. J. Ecol. 23, 235–243.
Whyte, I.J., 2001. Headaches and Heartaches, the elephant management dilemma. In: Schmidtz, D., Willot, E. (Eds.), Environmental Ethics, Introductory Readings. Oxford University Press, New York, pp. 293–305.
Wickens, G.E., 1982. The Baobab - Africa's upside-down tree. Kew Bull. 37, 173–209.
Wickens, G.E., Lowe, P., 2008. The Baobabs, Pachycauls of Africa, Madagascar and Australia. Springer, London, UK.
Wilson, R.T., 1988. Vital statistics of the baobab (*Adansonia digitata*). Afr. J. Ecol. 26, 197–206.