Assessing the dependence and pressure on forest resources in Limpopo National Park (Mozambique): the case of Mopane woodlands

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ABSTRACT

Mopane woodland is dominated by Mopane, *Colophospermum mopane* (Kirk ex Benth ex J. Leonard), a strongly light-demanding tree species. This study was carried out in Limpopo National Park (LNP), Mozambique, where communities living under extremely low socio-economic conditions, depend on Mopane woodland for fuel wood and poles, and other traditional activities such as agriculture. This study focused on assessing how resource use dependence and pressure affect the structural composition and regeneration status of Mopane woodland across different identified species associations under different land use and stand development stages. An inventory was carried out to collect data from 50 temporary plots covering four stand development stages. Population structure of Mopane and other species showed variation related to different land use practices, even-aged stand development stages, canopy and sub-canopy tree species and regeneration. Mopane and other canopy tree species in stand development stages 3 and 4 showed a good spread of stems from 9 cm DBH and larger. Stand development stages 1 and 2 showed a higher concentration of trees in sizes <4m height (good regeneration) with few larger stems. Identified ecosystem dynamics of Mopane woodland provide a basis for sustainable resource use management strategies for harvesting Mopane products for building material and firewood and clearing for crop cultivation. Areas need to be zoned for each activity to allow for a quick system recovery and to contribute to woodland productivity, quality products and reducing used areas.

**Keywords:** *Colophospermum Mopane*, Sustainability, Conservation, Distribution, Diversity.
INTRODUCTION

The general perception is that rural resource use and changed land use can cause the degradation and loss of resources and biodiversity, and fragmentation of the resource base (Campbell, 1996, Burgess et al., 2004, Chidumayo & Gumbo, 2010, Ribeiro et al., 2015, Syampungani et al., 2016, Chichinye et al., 2019). However, seasonal woodlands (dry forests) in Africa contribute to the livelihoods of millions of rural people, which reinforces the need for sustainable resource use management (Kowero, 2011). Such woodlands cover extensive areas within the Zambezian Center of Endemism in southern Africa: Mopane woodland, Miombo woodland and Undifferentiated Zambezian woodland are the three main components of the Zambezian woodlands (White, 1983, Geldenhuys & Golding, 2008, Geldenhuys, 2015).

Mopane woodland is dominated by *Colophospermum mopane*, one of the best-known and valuable tree species indigenous to Southern Africa. It extends over 550,000 km² within the Zambezian woodlands, and forms one of 11 eco-regions in Mozambique. Mopane plays a major ecological and social-economic role in the region. It is a unique species which grows in pure stands in hot and dry landscapes and soils (Chidumayo, 2013). It can occur as tall trees of up to 20 m or shorter trees of 2-5 to 10 m, or as Shrubland Mopane within the Zambezi valley (Timberlake, 1996; Marzoli, 2007, Sitoe et al., 2012). The leaves release a sweet substance known as *Arytaina mopane* that attracts endangered and vulnerable species such as baboons, monkeys, birds, and large herbivores such as elephant, black rhino and kudu (Makhado et al., 2014). It is also used as fodder for livestock. The Mopane worm (*Imbrasia belina*) is used as supplementary diet resource and supports over 10,000 people with income exceeding $3000 per annum (Ghazoul et al. 2016). The medicinal benefits are also significant. The *C. mopane* protects the dry and clay-rich soils from erosion (Ribeiro et al., 2015).

In the Limpopo National Park (LNP) in Mozambique, Mopane woodland, dominated by *Colophospermum mopane*, is one of the main vegetation formations. People depend on traditional slash and burn agriculture, and extensive areas of Mopane woodland are cut to open agricultural areas. In these areas all trees are burned to fertilize the areas and increase crop production. Crop production is good during the early years, but over time production declines, fields are abandoned, and new areas are opened (Geldenhuys, 2015). The unremoved rootstocks regenerate and regrow a vegetation system with trees at different stages of development. In the early stages, the vegetation looks degraded or deforested. Four general stand development stages for woodlands (a fifth stage, preceding Stage 1, can be considered) were defined based on factors such as stand height, stem density, number of stems per plant, crown shape, and dominant species, and relate to the use value of the stems in each development stage (Geldenhuys, 2014; see Figure 4 for Mopane woodland). Each stage may have sub-stages present (Geldenhuys & Monareng, 2020):
Stage 1 is the initial recovery stage of Mopane in abandoned cultivation areas, with many small trees and multiple stems developing on cut stumps and rootstocks. Tree height is up to 2 m and stem diameter is generally <2 cm. Stage 2 is an intermediate stage, with many small dead stems and focus of growth in stronger growing stems and fewer stems per plant. Stand height varies between 2.5 m and 4 m and mean stem diameter is 2 to 5 cm. Stage 3 is advanced secondary woodland with young trees in a wide range of stem diameters between stage 2 and stage 4 and up to about 25 cm, and fewer stems per plant. Tree height varies from 4.5 m to 6 m. Tree crowns still show a cone shape. Stage 4 is a mature woodland with canopy trees developing spreading, umbrella-shaped crowns, with stem diameter >25 cm and canopy height >7 m.

Forest degradation is a temporary or permanent change in species composition, stand structure, and biomass through different uses such as logging, hunting, and opening of agricultural areas, or fires (Chazdon, 2016). Most forest systems in southern Africa can recover and adapt after cessation of a disturbance through regeneration from seed or vegetative sprouting from cut stumps and rootstocks, contributing to the presence of a mosaic of habitats and a more diversified landscape (Chidumayo & Gumbo, 2010; Chirwa et al., 2015, De Carvalho, 2016). Geldenhuys (2015) indicated that what looks good, such as mature woodland in protected areas, may be ecologically bad, but what looks bad, such as a fragmented landscape in different stages of clearing and recovery, may be ecologically very good. Woodland areas in recovery over a period of 15+, showed the best recovery of plant diversity, productivity and resource use value after charcoal production and traditional slash-and-burn agriculture, when compared to single-tree timber harvesting and protection (Syamopungani et al., 2016; Chichinye et al. 2019).

Successful regeneration varies with the magnitude and impact of different anthropogenic and natural disturbances (Rutherford et al., 2012; Chazdon, 2016, Makhado et al.; 2018) that contribute to differences in stem size class distribution (Profile) of dominant tree species and the system. The general shapes are the Bell-shaped and Negative exponential or Inverse J-shaped profiles (Geldenhuys, 2010, Syampungani et al., 2016, Chichinye et al., 2019). The bell-shaped profile represents a low density of stems in the smaller and larger size classes, with a higher density in the intermediate size classes. Such profiles represent sporadic good conditions for regeneration, such as large gaps for strongly light demanding species, or cessation of fire for fire-sensitive species. Stems in such sporadic regeneration events are even-aged, but some stems grow much faster than the average stems, and some become suppressed and may not grow and die. The Inverse J-shaped profile represents a high density of stems in the smaller size classes, through regular regeneration, with a continuous decline
in stem density towards the larger size classes. A Static profile has few stems in most size classes because of irregular regeneration (Geldenhuys, 2010).

Excessive protectionism inhibit the regeneration of the many light-demanding tree species of these woodlands (Geldenhuys, 2010, 2015). This was shown in a time series study in Zambian Miombo woodland over a period of 15 years after specific land uses were abandoned (Syampungani et al., 2016). Recovery of regeneration of canopy tree species, biodiversity and system productivity was better in charcoal and slash-and-burn agricultural areas, because many species are strongly light-demanding. Similar findings were reported by Gondwe (2020) in a study in Malawian Miombo woodland, comparing recovery of species composition between co-managed and government managed (protected) reserves. Recovery through regeneration of the many light-demanding canopy species were best in areas disturbed through collection of trees for firewood and construction material, and abandoned cultivation areas. In Zimbabwean Undifferentiated Zambezhian Woodland, Chichinye et al. (2019) showed that some light-demanding species, such as *Pterocarpus angolensis*, regenerated more effectively in disturbed areas after harvesting of timber, poles and firewood.

The population status of individual species and floristic-structural composition of the tree system are affected by the natural and anthropogenic disturbance-recovery processes operating in the system. The three main anthropogenic drivers of perceived woodland degradation in southern Africa are the harvesting of poles and fuel wood and clearing of woodland for growing of crops. It is important to understand how such practices affect the structural composition of Mopane woodland and its dominant species. Most such studies focused on Miombo woodland but very few studies were done on the impact of resource use and land use changes on Mopane woodland. Little is known of the factors that determine the biodiversity (species composition), eco-physiological characteristics (foliage nutrient quality, and phenology) and structure (stem density, height,) of Mopane woodlands in Mozambique. No studies were done on the impact of land use activities on species composition, stand structure and regeneration dynamics of Mopane woodlands in Mozambique. The assumption is that the biodiversity and regeneration of Mopane woodlands in LNP in Mozambique is affected by both natural factors (sites factors such as climate, topography and soils, and disturbance-recovery processes), and anthropogenic factors (resource use, clearing). This variation in vertical structure is unclear although some studies point to landscape, soil type, moisture and anthropogenic activities (Ribeiro, et al., 2015). Observations suggest that Mopane is a strongly light-demanding species and successful regeneration requires large gaps (Geldenhuys & Monareng, 2020).

Therefore, there is need for detailed studies on *C. mopane* distribution, diversity and population structure to provide policy direction on management and conservation of Mopane.
woodland. Other knowledge gaps include studies on biomass and carbon recovery in Mopane woodland to predict the stock density and ecosystem resilience (Ribeiro et al., 2015), together with studies on land use land cover change, to help to understand the effects of anthropogenic activities on biodiversity, structure and spatial characteristics of Mopane under different land use regimes and stage of recovery development. Mopane has many uses (exploration of biofuels, timber, agriculture, food, etc.) which reflect a certain socio-economic and cultural dynamics, but with few studies (Musvato et al., 2007; Makhado et al., 2012; Makhado et al., 2014, Ryan et al., 2016) and with few analyses in the context of Mopane woodland biodiversity and stand dynamics (Sitoe et al., 2010). Understanding the relationship between the dependence of local communities on mopane woodland resources and the composition and structure of Mopane woodlands, will provide a basis for sustainable use management and conservation of Mopane woodland.

The objective of this study is to assess the dependence of local communities on Mopane woodland and how this affects the structural composition of the identified species associations within Mopane woodland. This is addressed through the following questions:

1. How does the stem size class distribution of Mopane, other canopy tree species and sub-canopy tree species vary across the identified tree species associations at community level?
2. How does the stem size class distribution of Mopane, other canopy tree species and sub-canopy tree species vary across the sub-communities of communities dominated by Mopane?
3. What is the relationship between the variation in stem size class distributions across the communities and sub-communities, and the associated land use practices and stand development stages?
4. How can the results from this study be used to develop guidelines towards an integrated and sustainable resource use management system of Mopane woodland in the LNP?

**MATERIAL AND METHODS**

**Study area**

This study was conducted in the Limpopo National Park (LNP), Massingir district, Gaza Province in Mozambique. It falls within the Zambezian Regional Center of Endemism biogeographical zone (White, 1983; Geldenhuys, 2015). The total area covers about 11,235 km² (Cambule et al., 2014, Mitader, 2018). It is located between the parallels 22° 25’ 00” south and 24° 10’ 00” south and between the meridians 31° 20’ 00” and 32° 40 ‘00” east.
LNP is a conservation area established in 2001 and since 2002 it forms a part of the Great Limpopo Transfrontier Conservation Area (GLTFCA). Before the establishment of the conservation area, this part was occupied by more than 35,000 people, with about 25,000 people (close to 3,500 families) living in the Tampa area and around 10,000 people (1,800 families) living along the Shingwedzi Valley. In 2003, the population resettlement program was drawn up because it was considered that they conflict with some conservation activities and 485 families were resettled.

Three seasons are recognized: wet season (November to April), cold and dry season (May to August); dry season (September to November). The average annual temperature is around 24ºC, with January and February being the warmest months (27ºC) and July the coldest month (19ºC). Average maximum temperatures are around 34ºC during the hottest months, while average minimum temperatures can be around 10ºC in June and July, suggesting important annual temperature ranges.

Non-timber forest products (NTFPs) such as firewood and poles for construction, are collected from Mopane woodland in the LNP in Mozambique, using axes to cut trees at different heights. Trees of good quality, without deformation, cut for use as poles in house construction, range in DBH (stem diameter at breast height, i.e. at 1.3 m above ground level) between 5 to 25 cm. People collect firewood and construction material in one area, and when
the resource is exhausted, they move to new areas. For cultivation of crops, they cut all trees and burn all cut trees (Figure 2). Since LNP is a conservation area, charcoal production is illegal, but only sporadically applied (because people fear the conservation authorities).

**Figure 2.** Mopane trees are cut to open cultivation areas (a), with trees piled in heaps for drying and burning (b) and burned, without using the stems for poles for construction or firewood (c).

The species data collected on the 50 sampled plots for this study (see next section), were used to group the sampled stands into 5 communities and 10 sub-communities based on the number of stems per species per plot (Figure 3; De Sousa, in preparation). A total of 1745 stems of 29 species were recorded. The most dominant species were *Colophospermum mopane* (1477 stems), *Combretum apiculatum* (107 stems), *Boscia albitrunca* (49 stems), *Combretum* sp (22 stems), *Acacia* sp (19 stems), *Acacia nigrescens* (13 stems), *Euclea divinorum* (9 stems) and *Dichrostachys cinerea* (6 stems). The total dominance of Mopane stems required that four Mopane surrogate species be used in the classification of the sampled stands, to differentiate stand composition by stem size of Mopane trees, as follows: Mopane species 1 = <5.0 cm DBH; Mopane species 2 = 5.0 - 14.9 cm DBH; Mopane species 3 = 15.0 - 24.9 cm DBH; and Mopane species 4 = >25.0 cm DBH. The Mopane communities and sub-communities were associated with land use regime and stage of development (Figure 4). Communities 1 and 2 were mostly associated with abandoned cultivation areas (ACA). Most other sub-communities were associated with Mopane tree harvesting (MHT) and resettlement of abandoned areas (RAA), except for sub-community 5.2 in which all sampled plots occurred on RAA sites. Communities 1 and 2, and sub-community 3.1 were associated with stand development stage 1, sub-community 3.2 with stage 2, and communities 4 and 5 and sub-community 3.22 with stage 3 (even though in reality some of the stage stands could be in early stage 4.
Figure 3. Dendrogram of subdivisions of plots sampled in LNP, Mozambique, into communities and subcommunities (De Sousa, in preparation).

Figure 4. Mopane woodland stand development stages identified in NLP.

Sampling design and data collection

The sampling was designed to cover ten sites considered to be under greatest pressure, such as areas with tree harvesting, areas abandoned by resettlement and abandoned
cultivation areas, and to cover four woodland stand development stages (Figure 4). The height categories for stand development stages were not strictly applied, because the same area may include transitional states between two stages (mainly between stages 2 and 3). A total of 50 temporary nested circular plots were sampled. In each selected site, five plots were located 100 m apart on a wandering line transect (not straight) to cover homogenous points in the vegetation.

Each nested circular plot consisted of 3 circles around the same midpoint (Figure 5): the main plot with a radius of 25.2 m (0.2 ha), to record stems >25 cm DBH; the intermediate subplot with 11.3 m radius (0.04 ha) to record trees 5 to 25 cm DBH; and an inner plot of 5.65 m radius (0.01 ha) to record regeneration stems in three size categories based on height as the main criterion: seedlings up to 0.5 m height, saplings of 0.5-0.9 m height, and poles of 1.0 m height to 4.9 cm DBH. Stems ≥5 cm DBH were recorded by stem sequence number, species, DBH and height. Stems <5 cm DBH were counted by the three regeneration size categories. Stem diameter (DBH) was measured using a tape measure, while heights were measured by a graduated pole (Geldenhuys, 2005). For trees with more than one stem ≥5 cm DBH, the DBH was recorded separately for each stem, but the same stem sequence number was used for all the stems of that tree. The advantages of circular plots are that they are easy to lay out and provide fewer errors in recording boundary trees. Additional information was recorded for each plot: Geographic coordinates, by GPS; Stand development stage (Figure 4), Geomorphology (ridge, upper slope, middle slope, foot slope, valley bottom, stream gallery); Soil / substrate geology (clay, rock, sand); Stand canopy condition (smooth, uneven, rough, no gaps, small gaps, large gaps) and general comments of plot.

Figure 5. Nested plot design for collecting data of different size.
Data processing and structural analysis

Field data were electronically captured in Excel (version 2016). All recorded species were identified by their scientific names, according to Van Wyk & Van Wyk (2013). The sampled plots were grouped into more uniform species associations (5 communities and 10 sub-communities) based on the number of stems per species per plot (Section 2.1, Figure 3). The most dominant species were *Colophospermum mopane* (1477 stems), *Combretum apiculatum* (107 stems), *Boscia albitrunca* (49 stems), *Combretum* sp (22 stems), *Acacia* sp (19 stems), *Acacia nigrescens* (13 stems), *Euclea divinorum* (9 stems) and *Dichrostachys cinerea* (6 stems).

Population structure of a species was compared across communities or sub-communities. It was based on the number of stems per ha of a species across eight size class categories: 1 = stems <1.5 m height; 2 = 1.5 m height to <5 cm DBH; 3 = 5.0 - 8.9 cm DBH; 4 = 9.0-12.9 cm DBH, 5 = 13.0-16.9 cm DBH; 6 = 17.0-20.9 cm DBH; 7 = 21.0-24.9 cm DBH; and 8 = ≥25 cm DBH. The calculation of stem density per ha per size class was based on the number of plots in a community or sub-community and the plot size in the nested plot used for the specific plant size, i.e. 0.01 ha for stems <5 cm DBH; 0.04 ha for stems 5.0 to 24.9 cm DBH, and 0.2 ha for stems ≥30 cm DBH. Comparisons included canopy and sub-canopy tree species.

■ RESULTS

Size class distributions were compared for different species and species groups across communities and sub-communities.

Variation in the size-class distributions across communities

The size class distribution for the regeneration (stems <5 cm DBH) and trees (stems ≥5 cm DBH) were compared for Mopane, other canopy species and sub-canopy species, across the communities (Figure 6). Community 1 is dominated by the regeneration and small-sized trees of other canopy species (mainly *Combretum apiculatum* and *Boscia albitrunca*), with low presence of Mopane and sub-canopy tree species. Community 2 is dominated by regeneration of Mopane, sub-canopy tree species and some other canopy tree species, with no Mopane trees and few trees of other species. Communities 3 to 5 are dominated by Mopane but vary in stem density within the two regeneration categories (mostly stem <1.5 m height) and the dominant stem diameter category. Community 3 almost lack other tree species, and particularly other canopy tree species. Community 4 has a relatively higher stem density of
regeneration and trees <9 cm DBH of sub-canopy species, which almost lack in Community 5. However, Community 5 has a good range of tree sizes particularly of Mopane but also of other canopy tree species.

**Figure 6.** Comparison of stem size class distribution (regeneration and trees) of Mopane, other canopy tree species and sub-canopy tree species across communities.
Variation in size class distributions across sub-communities of communities 3 and 5

The density of Mopane stems shows a general lack of regeneration ≥1.5 m height, a decreasing density of regeneration stems <1.5 m height, and an increasing density and size range of trees of Mopane, from sub-community 3.11 (almost no trees) to sub-community 3.22 (with a strong inverse J-shaped stem diameter class distribution across all size classes of trees) (Figure 7). Sub-communities 3.11 and 3.12 have no regeneration or trees of other canopy tree species, but sub-communities 3.21 and 3.22 have more regeneration (particularly <1.5 m height) but few tree stems. Stem density of Mopane is relatively low in sub-communities of community 5, but regeneration of other canopy tree species decreases in stems <1.5 m height from sub-community 5.11 to sub-community 5.2. Only sub-community 5.2 has regeneration stems ≥1.5 m height at a relatively high density for other canopy tree species. Stem density of Mopane trees show a typical inverse J-shaped distribution across all stem diameter classes that are generally similar across the three sub-communities. The difference between the three sub-communities is the variation in the stem density of other canopy tree species across the stem diameter classes, with sub-community 5.12 having relatively fewer stems than the other two sub-communities.

Figure 7. Comparison of stem size class distribution (regeneration and trees) of Mopane and other canopy tree species across sub-communities of communities 3 and 5.
DISCUSSION

Size class distribution of species and species groups across communities and sub-communities

The good regeneration of canopy species other than Mopane, and poor regeneration of Mopane and sub-canopy tree species in community 1 (considered as stage 1) can be related to the resource use practices. This community occurs in the Mavodze village with extensive open areas due to the felling of trees for agriculture and cattle grazing. The high regeneration of other canopy tree species may be an indication of recruitment of shoots or regrowth of trunks not removed during the opening of fields, also noted by Chidumayo (2013). The poor regeneration of Mopane may be linked to practices of cutting trees followed by the removal of the trunks and their burning for the fertilization of fields, aimed at increasing crop productivity. Geldenhuys (2015) and Syampungani et al. (2016) indicated that with slash-and-burn agriculture, good crop harvesting is obtained in the early years due to the increase in nutrients in the soil, which then decline over time. The high density of stems 5-9 cm DBH may indicate rapid regrowth and recovery. This is also shown by Syampungani et al. (2016), Chichinye et al. (2019) and Geldenhuys & Monareng (2020) in which practices of slash-and-burn agriculture, charcoal production, firewood collection and cutting poles for construction that are generally perceived to degrade the woodlands, rather contribute to a rapid recovery and maintenance of biodiversity (De Sousa, in prep) and productivity, better than protection and conservative tree harvesting practices.

The abundant regeneration of Mopane and sub-canopy tree species and the general lack of trees of Mopane and other tree species in Community 2 relate to the situation in the Macavane area. This area was abandoned after population resettlement and shows Mopane in recovery. The high density of Mopane stems <5 cm DBH shows good recovery of Mopane woodland after being disturbed by human activities, such as harvesting Mopane, opening agricultural areas, burning and other activities. The few stems >5 cm DBH may be trees that had been left in the fields during clearing of fields for cropping. Opening of small clearings and stem thinning to reduce stem density of regeneration can be a management strategy to reduce competition for light, moisture and nutrients, to maintain good regeneration and stimulate fast tree development with desired quality, as suggested by Chichinye et al. (2019).

Community 4.0 shows a development within stand development stage 3, dominated by smaller to intermediate sized trees of Mopane (stems >9.0 cm DBH), and some other canopy tree species. This community occurs near the village of Bingo with little disturbance of Mopane woodland.
The stem size class distributions of communities 3 and 5 are discussed here in terms of their sub-communities. Community 3 is found in the buffer zone of Chibotane Village and the southern part of Macavane and Canhane Villages, where communities freely harvest Mopane products. The few stems of other canopy and sub-canopy tree species may relate to the density of Mopane with reduced light and moisture conditions. The high density of stems <5 cm DBH and of stems 5-9 cm DBH of Mopane but few stems of other canopy and sub-canopy tree species in Community 3 may relate to resource use activities. The strong decrease in stem density of Mopane regeneration <1.5 m height and strong increase in stem density of particularly trees <9 cm DBH, but also larger tree sizes may indicate stand development from sub-community 3.11 to 3.22. Initially there are no regeneration of other canopy tree species (sub-communities 3.1), but then there is an increase in regeneration of other canopy species in sub-communities 3.2, with added density of the larger regeneration (≥1.5 m height) in sub-community 3.22, but with very few trees of other canopy tree species. Community 5 has a good range of tree sizes of Mopane but has low stem density of Mopane regeneration, most likely because of the shady conditions.

Stem density of Mopane is relatively low in sub-communities of community 5, but regeneration of other canopy tree species decreases in stems <1.5 m height from sub-community 5.11 to sub-community 5.2, but a relatively high regeneration density in stems ≥1.5 m height. This suggests an increasing development of stand development stage 3 towards stage 4, from sub-community 5.11 to 5.2, but with variable contribution in terms of density and size range of the other canopy tree species, which differentiate the three sub-communities of community 5, occurring in the villages of Machamba and Bingo. The sub-communities show a trend towards mature stands, and the regeneration and small stems may be suppressed stems of mature Mopane trees.

The variation in size class distributions from community 1 to community 5 show how this can be used to determine the success or failure of different land use practices in terms of the regeneration and development of tree species in the tree systems (Geldenhuys, 2010). It shows the importance of the regeneration of species towards species recovery and maintenance of biodiversity and productivity to supply of products of use value (Batistella & Moran 2005; Akinyemi & Kgomo 2019). Mopane structure is strongly influenced by anthropogenic activities that influence recovery through stand development stages with associated species composition. These results give an opposing view of the general perception that agricultural practices, charcoal production and other resource use activities contribute to negative changes in forest cover and composition of tree species (Mansour et al., 2017).
General discussion

The information obtained from this study has relevance for better resource management from Mopane woodland. It has to be incorporated into the resource harvesting practices of the rural farmers within Mopane woodland. Species developed regeneration strategies to survive disturbances from stochastic events and land use, and associated changes in vegetation cover influencing vegetation structure, complexity and functionality (Mazon et al. 2019). Regeneration is an important factor in maintaining biodiversity and productivity of forests for the sustainable supply of products and services of desired value. Singh et al. (2017) emphasized this and indicated that 20-40% of land is lost in conversion to other types of land use, such as agriculture and grazing, and affects the structure and composition of vegetation. In conservation areas, such as the LNP, with large herbivores such as elephant, kudu and giraffe present, and on rural farms with cattle and goats present, the browsers impact on the sprouting response of cut Mopane stems.

Field observations showed a variation in the regeneration response of Mopane to different resource harvesting strategies. In some areas trees are cut and burnt to prepare fields for cultivating crops (Figure 2). In resettlement areas, Mopane regenerates by seedlings from dispersed seeds (Figure 8a), followed by seedling establishment. However, regeneration from seed is relatively poor because of drought and seed removal by birds for food. Sometimes sprouting develops when roots below the ground are damaged (Figure 8b). In many areas, people harvest Mopane products by cutting trees between 40 cm and 60 cm above ground level (Figure 8c). In such stumps, regeneration occurs by vegetative sprouting at different positions on the remaining stems (Figure 8c). Silvicultural thinning could be applied to improve the development of remaining trees or developing shoots from cut stems. Some trees do not sprout or the stems are eaten by termites (Figure 9a). Some stems of bad form or quality should be removed by thinning or pruning of branches (Figure 9b) and suppressed stems. Sprouting from cut stumps can be thinned to reduce competition and focus growth on the better shoots (Figure 9c).

Figure 8. Regeneration strategies of Mopane in different situations: Regeneration from seed (a); Sprouting from spreading rootstocks below the ground (b); Sprouting at different positions on cut stumps (c).
Rural communities use forest products from preferred species. In the study area, *Colophospermum mopane* and *Combretum apiculatum*, species with high importance values in this Mopane study, are preferred species for fuelwood, charcoal production and building material. This study has shown that after different resource use practices, the natural vegetation and the preferred species regenerate abundantly and develop through the stand development stages. Such recovery needs to be silviculturally managed to facilitate a faster recovery of the system through the identified stand development stages.

## CONCLUSIONS AND RECOMMENDATIONS

Mopane resources have extremely high socio-economic, cultural and traditional values. Local communities depend on wood harvested from Mopane woodland for infrastructure and firewood collection, and as a main source of income, and clearing for crop cultivation.

The first perception about the condition of *Colophospermum mopane* woodland in NLP was that the woodland system is degraded due to the high pressure and dependence for clearing for crop cultivation and harvesting for fuel wood and of poles for construction, and that this leads to faster depletion of biodiversity, with implications for conservation. However, this study showed that there is good recovery through regeneration dynamics of Mopane woodland. This happened despite the socio-economic dynamics and challenges within the LNP, which is characterized by extreme dependence on slash and burn agriculture and consumption of wood for construction poles and biomass for energy, and low levels of education. The recovery of Mopane woodland via stand development stages maintains species diversity (De Sousa in prep), viable population structures, productivity and use value of the system.

The development of environmental forest resource management policies should include feasible resource management strategies by the communities. This should include capacity development amongst community resource managers in simple silvicultural management techniques such as selective stem thinning in developing stands in stages 1 to 3, and cutting...
of stands in stage 4 in groups to facilitate rapid sprouting of the cut stems with adequate light conditions. This would require the zonation of the LNP into areas for the main resource use activities of the communities that would guarantee their socio-economic development. The zoning could include areas for agricultural crop cultivation, for the collection of firewood and construction material, or integration of all three main resource use activities to maintain productive stand dynamics in line with the natural disturbance-recovery processes of Mopane woodland.

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▱ REFERENCES


