Dependence, pressure and recovery of forest resources in Limpopo National Park (Mozambique): the case of Mopane woodlands

Dependência, pressão e recuperação de recursos florestais no Parque Nacional do Limpopo (Moçambique): o caso das florestas de Mopane

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Abstract

The general perception is that forest resources exploitation can cause degradation and loss of resources and biodiversity, promoted by landscape fragmentation and pressure over habitats. An assumption that might not be adjusted to contexts where long term exploitation by traditional communities is based on management strategies adapted to recovery, adjusting pressure to kept resources available. In this work, we assess the recovery of the Mopane woodlands considering different land use practices and stand development stages on areas explored by local communities in the Limpopo National Park (LNP), in Mozambique. In detail, we want to explore: i) changes on stem size across plant comunities dominated by Mopane; and ii) the relationships between the variation in stem size across communities and the associated land use practices and vegetation stand development stages. To answer those questions, data was collected from 50 nested temporary circular plots of different sizes covering four stand development stages. Results for the structure of Mopane communities showed differences related to stand development stage, as expected. The initial stages show good regeneration, indicating that recovery is not hampered by the exploitation regime in use. A result that points to an equilibrium between resources exploitation practices and Mopane woodlands recovery, but also that ecosystem dynamics of Mopane woodland has a deep influence on the way that local communities manage harvesting of Mopane products for different uses. So, management of such resource is critical to ensure sustainable resource use and guarantee provision for future generations.

Keywords: *Colophospermum mopane*, sustainable use, vegetation dynamics, tropical dry forests.

Resumo

Em contextos em que a exploração tradicional de recursos florestais por comunidades locais está baseada numa gestão adaptada à recuperação dos recursos florestais, ajustando a pressão para assegurar a sua disponibilidade, pode não ocorrer degradação e perda de recursos e biodiversidade. Neste trabalho é avaliada a capacidade de recuperação das florestas de Mopane tendo por referência diferentes práticas de exploração de re-

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cursos e estádios de desenvolvimento da vegetação em áreas exploradas por comunidades locais no Parque Nacional do Limpopo (Moçambique). Com este trabalho pretende-se explorar: i) diferenças estruturais em comunidades dominadas por *Colophospermum mopane*; ii) as relações entre as condições estruturais, as práticas de exploração de recursos e os estádios de desenvolvimento da vegetação. Para tal, foi recolhida informação em 50 pontos, com base em parcelas circulares aninhadas de 3 tamanhos diferentes, considerando quatro estádios de desenvolvimento da vegetação. Como esperado, os resultados relativos à estrutura das comunidades dominadas por Mopane apresentam diferenças claras considerando o estádio de desenvolvimento da vegetação. Ao nível da dinâmica destas comunidades, o estádio inicial apresenta boa regeneração, indicando que o processo de recuperação não está comprometido pelas práticas de exploração dos recursos vigentes. Um resultado que aponta para um equilíbrio entre as práticas de exploração e a capacidade de resposta das florestas de Mopane, indicando que a dinâmica destas florestas tem influência no modo como as comunidades gerem a exploração dos diferentes produtos. Neste contexto, e considerando os objetivos de conservação vigentes, justifica-se a identificação de áreas (zonamento) dentro do parque dedicadas à exploração destes recursos, no sentido de assegurar a disponibilidade de recursos para futuras gerações reduzindo as áreas em exploração.

Palavras-chave: *Colophospermum mopane*, uso sustentável, dinâmica da vegetação, florestas tropicais secas.

1. Introduction

The general perception is that natural resources exploitation and changes on land use can cause the degradation and loss of resources and biodiversity, along with fragmentation of the resource base (Burgess et al., 2004; Campbell, 1996; Chichinye, Geldenhuys, & Chirwa 2019; Chidumayo & Gumbo, 2010; Ribeiro, Syampungani, Matakala, Nangoma, & Ribeiro-Barros 2015; Syampungani, Geldenhuys, & Chirwa, 2016). However, and for renewable resources, the establishment of an exploitation regime in balance with the recovery capacity might ensure the sustainable use. That is of critical importance for communities of low income that depends on forest resources, such as those depending on seasonal woodlands (dry forests) in Africa, where forest resources contribute to the livelihoods of millions of rural people, which reinforces the need for sustainable resource use management (Kowero, 2011).

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, promoting temporary or permanent changes in species composition, stand structure, and biomass through different uses such as logging, hunting, and opening of agricultural areas using fire (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, Larwanou, Syampungani, & Babalola, 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 interesting. Woodland areas in recovery over a period of 15 years 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 (Chichinye et al., 2019; Syamopungani et al., 2016).

The success rate of regeneration, dependent on the magnitude and impact of different anthropogenic and natural disturbances (Chazdon, 2016; Makhado, Potgieter, & Luus-Powell, 2018; Rutherford, Powrie, & Thompson, 2012), promotes differences in stem size – profile - of dominant tree species. Considering the profile, the general shapes are the *bell-shaped* and *inverse J-shaped* profiles (Chichinye et al., 2019; Geldenhuys, 2010; Syampungani et al., 2016). 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 profile 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 inhibits 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 the abandonment of specific land uses (Syampungani et al., 2016). Recovery 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 ligth-demanding canopy species was higher in areas disturbed through collection of trees for firewood and construction material, and abandonned cultivation areas. In Zimbabwean Undifferentiated Zambezian 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.

Most studies focused on Miombo woodlands, and little is known about the factors that determine the biodiversity (species composition), eco-physiological characteristics (foliage nutrient quality, and phenology) and structure (stem density, height,) of Mopane woodlands, namely in Mozambique, as well as the impact of resource exploitation and land use changes on species composition, stand structure and regeneration dynamics of such woodlands.

2. Mopane woodlands

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 crops. And very few studies were focused on the assessment of impacts from such activities on Mopane woodlands, namely how such practices affect the structural composition of Mopane woodlands and related dominant species.

Mopane woodlands cover extensive areas within the Zambezian Center of Endemism in southern Africa, and are one of the dominant types of Zambezian woodlands, together with Miombo woodlands and Undifferentiated Zambezian woodlands (Geldenhuys, 2015; Geldenhuys & Golding, 2008; White, 1983).

The Mopane woodlands are southern African dry forests known by the development of even-aged stands, dominated by the light-demanding *Colophospermum mopane* (Kirk ex Benth ex J. Leonard), one of the best-known and valuable tree species indigenous to southern Africa. It extends over 550.000 km^2 within the Zambezian woodlands, and forms one of 11 eco-regions in Mozambique. It is a unique species that 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 5 to 10 m, or as shrubland Mopane within the Zambezi valley (Marzoli, 2007; Sitoe, Salomão, & Wertz-Kanounnikoff, 2012; Timberlake, 1996).

Mopane woodlands play a major ecological and social-economic role in the region, being of high value to local populations, considering the high diversity of resources exploited. Local communities, living under extremely low socio-economic conditions, depend on Mopane woodlands for firewood, charcoal and poles, food resources (eg., Mopane worm), source of medicional substances and also as fodder for livestock. (Ghazoul et al., 2016; Sousa et al., 2019). Such woodlands, important to protect clay-rich soils from erosion (Ribeiro et al., 2015), considering the dry climatic conditions, area also critical as habitat. The presence of sweet substances related to small larvae of winged insects on the leaves attracts endangered and vulnerable species such as baboons, monkeys, birds, and large herbivores, such as elephants, black rhinos and kudus (Makhado et al., 2014).

But the areas occupied by such woodlands are also ground for different land uses, such as agriculture and grazing. 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 promote communities with trees at different stages of development, creating a degraded appearance during the early stages of recovery. Considering such context, and according Geldenhuys and Monareng (2020), four general stand development stages, with sub-stages, can be considered for Mopane woodlands (Figure 3), based on different criteria (stand height, stem density, number of stems per plant, crown shape, dominant species):

- Stage 1: 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: 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: 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: mature woodland with canopy trees developing umbrella-shaped crowns, with stem diameter >25 cm and canopy height >7 m.

Stages that can be related to the use value of the stems (Geldenhuys, 2014) considering different applications. And, despite the many uses of Mopane, which reflect a certain socio-economic and cultural dynamics, few studies (Makhado et al., 2012; Makhado et al., 2014; Musvoto, Mapaure, Gondo, Ndeinoma, & Mujawo, 2007; Ryan et al., 2016) explore their impact on 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 such formations.

The assumption is that 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). Variation in vertical structure is unclear, although some studies point to soil type, moisture and the influence of antrophogenic activities (Ribeiro et al., 2015). And observations suggest that Mopane is a strongly light-demanding species and successful regeneration requires large gaps (Geldenhuys & Monareng, 2020). But more detailed studies on *C. mopane* distribution, woodlands' diversity and population structure are necessary to provide guidelines on management and conservation of Mopane woodlands. Along with studies on biomass and carbon recovery to predict the stock density and ecosystem resilience (Ribeiro et al., 2015), as well as studies on land use and 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. The objective of this study is to assess the capacity of Mopane woodlands to recover after disturbance, and how their structure and composition is linked with vegetation dynamics of such woodlands. This is addressed through the following questions:

- How stem size of Mopane and other canopy and sub-canopy tree species vary across the identified associations at community level, namely on those dominated by Mopane?

- What is the relationship between the variation in stem size across the communities and the associated land use practices and stand development stages?

- 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?

3. Material and methods

3.1. Study area

This study was conducted in the Limpopo National Park (LNP), located in the Massingir district - Gaza Province, in Mozambique, a conservation area established in 2001, and part of the Great Limpopo Transfrontier Park since 2002. It falls within the Zambezian Regional Center of Endemism biogeographical zone (Geldenhuys, 2015; White, 1983). The total area covers about 11, 235 km^2 (Cambule, Rossiter, Stoorvogel, & Smaling, 2014; Mitader, 2018). It is located between the parallels 22º 25' 00'' and 24º 10' 00'' South and between the meridians 31º 20' 00'' and 32º 40' 00'' East.

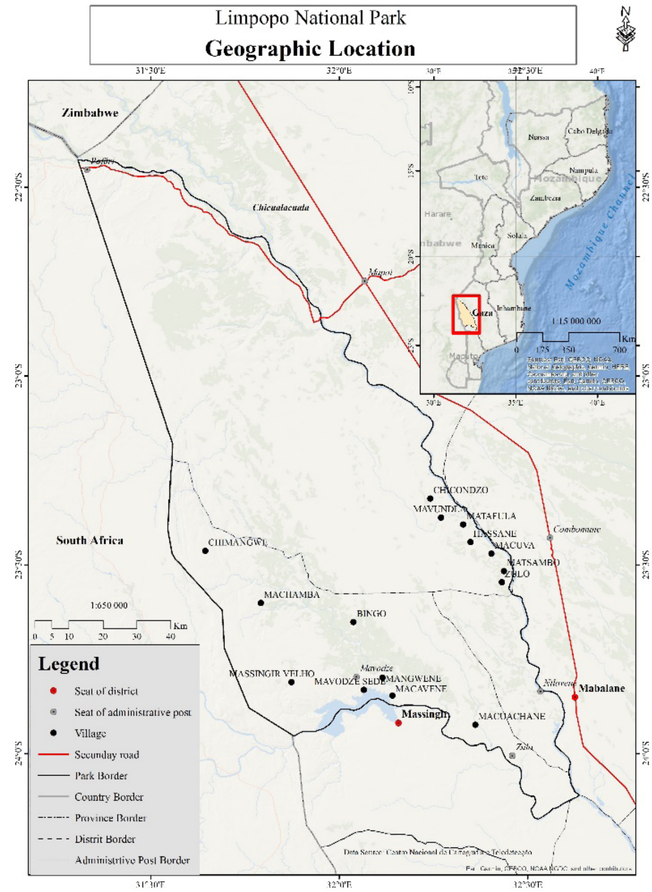

Figure 1
Geographic location of the study area in Mozambique.

LNP is a conservation area established in 2001, and since 2002 it forms part of the Great Limpopo Transfrontier Conservation Area (GLTFCA). Before the establishment of the conservation area, the territory was occupied by more than 35.000 inhabitants, 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, and considering that the presence of human population within the park promoted conflicts with some conservation activities, a resettlement program was drawn up, and 485 families were resettled.

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

The Mopane woodland is one of the main vegetation formations within the Limpopo National Park (LNP). Within the park, non-timber forest products (NTFPs), such as firewood and poles for construction, are collected from Mopane woodland, using axes to cut trees at different heights. Trees of good quality, without deformation, are used as poles in house construction, ranging in DBH (stem diameter at breast height, i.e. at 1.3 m above ground level) between 5 and 25 cm. People collect firewood and construction material in one area, and when the resource is exhausted, they move to new areas. For crops cultivation, trees are cutted (Figure 2a) and burned (Figure 2b), very often without using the stems as poles for construction or firewood (Figure 2c).

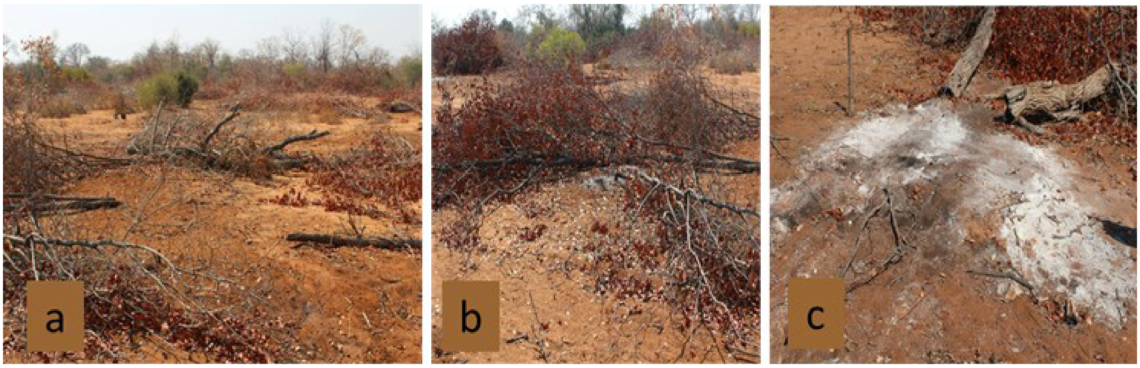

Figure 2
Land preparation for crop cultivation: a) cutting trees, b) piled trees in heaps for drying and burning, c) burned trees.

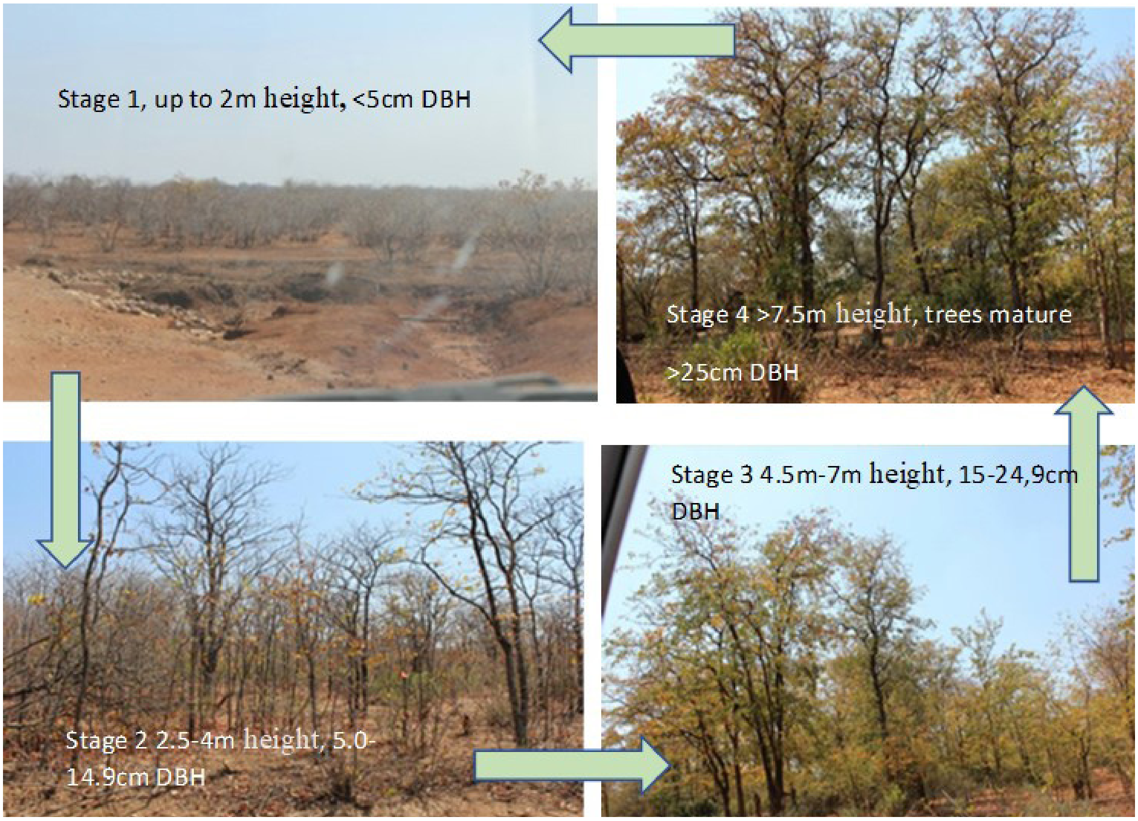

Figure 3
Mopane woodland stand development stages identified in LNP.

Since LNP is a conservation area, charcoal production is illegal, and only sporadically found .

4. Sampling design and data collection

The sampling was designed to cover sites considered to be under greatest pressure, such as areas with tree harvesting, areas abandoned by resettlement, and abandoned cultivation areas. In terms of vegetation dynamics, four stand development stages were considered (Figure 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. The advantages of circular plots are that they are easy to lay out and provide fewer errors in recording boundary trees.

Each nested circular plot consisted of 3 circles around the same midpoint (Figure 4): the main plot (Figure 4 - A) with a radius of 25.2 m (0.2 ha), to record stems >25 cm DBH; the intermediate subplot (Figure 4 - B) with 11.3 m radius (0.04 ha) to record trees 5 to 25 cm DBH; and an inner plot (Figure 4 – C) 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 height was measured using a graduated pole (Geldenhuys, 2005). For trees with DBH≥5 cm, DBH was recorded separately for each stem, but the same stem sequence number was used for all the stems of that tree. Additional information was recorded for each plot: Geographic coordinates, stand development stage, topographic position (ridge, upper slope, middle slope, foot slope, valley bottom, stream gallery), soil / geological substrate (clay, rock, sand), stand canopy condition (smooth, uneven, rough, no gaps, small gaps, large gaps) and general comments for the plot.

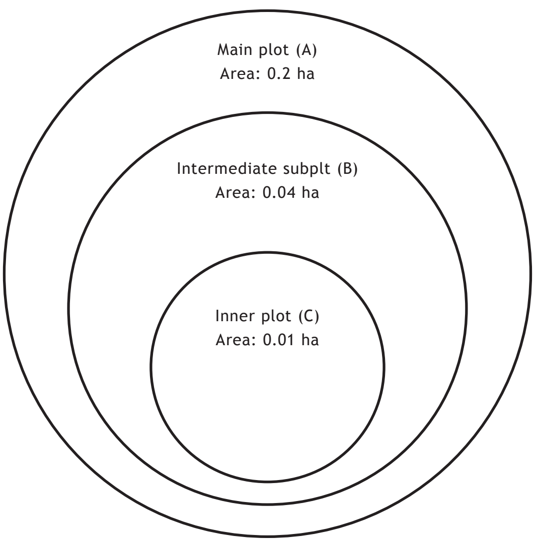

Figure 4
Nested plot design for collecting data.

5. Data processing and structural analysis

All recorded species were identified by their scientific names, according to Van Wyk and Van Wyk (2013). The species data collected on the 50 sampled plots for this study was used to group the sampled plots into 5 communities and 10 sub-communities based on the number of stems per species per plot (Figure 5). The total dominance of Mopane stems required that four Mopane surrogate species were 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 3).

Population structure of a species was compared across communities or sub-communities. It was based on the number of stems per ha for 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-communinity 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 ≥25 cm DBH. Comparisons included canopy and sub-canopy tree species.

6. Results

The dominant species on the sampled plots was *Colophospermum mopane* (1477 stems), an expected result considering the dominance of mopane woodlands within the LNP and the monospecificity of such woodlands. With lower prevalence, other species were registered, namely *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). In total, 1745 stems were recorded for 29 species.

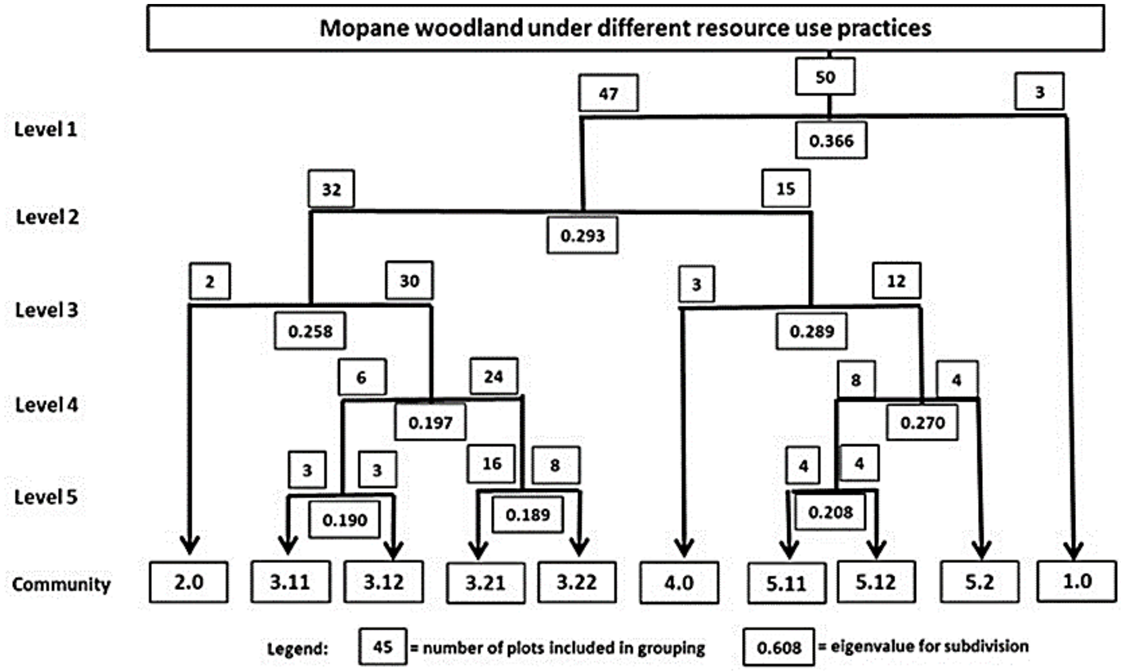

Figure 5
Dendrogram for subdivisions of sampled plots into communities and subcommunities (De Sousa, in preparation).

Considering the communities obtained from sampled plots, communities 1 and 2 were mostly associated with abandoned cultivation areas (ACA). Other sub-communities were associated with Mopane tree harvesting (MTH) 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 and early stage 4.

Population structure (size class distribution of trees) showed variation related to stand development stage, canopy and sub-canopy tree species composition and use pratices. Stand development stages 3 and 4 showed a good prevalence of stems from 9 cm DBH and larger, while stages 1 and 2 showed a higher concentration of trees in sizes <4 m height (good regeneration) with few larger stems, confirming that stands are even-aged.

6.1. Size-class distributions across communities

The size class distribution for the regeneration class (stems <5 cm DBH) and trees (stems ≥5 cm DBH) were compared for Mopane, other canopy and sub-canopy species, across the communities (Figure 6). Significant diferences were detected for the 5 communities identified, supporting diferentiation. 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, varying 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, among other canopy tree species.

On communities dominated by Mopane (3 and 5), and considering relative sub-communities, the density of Mopane stems shows a general lack of regeneration for the ≥1.5 m height class, a decreasing density of stems with <1.5 m height, and an increasing density

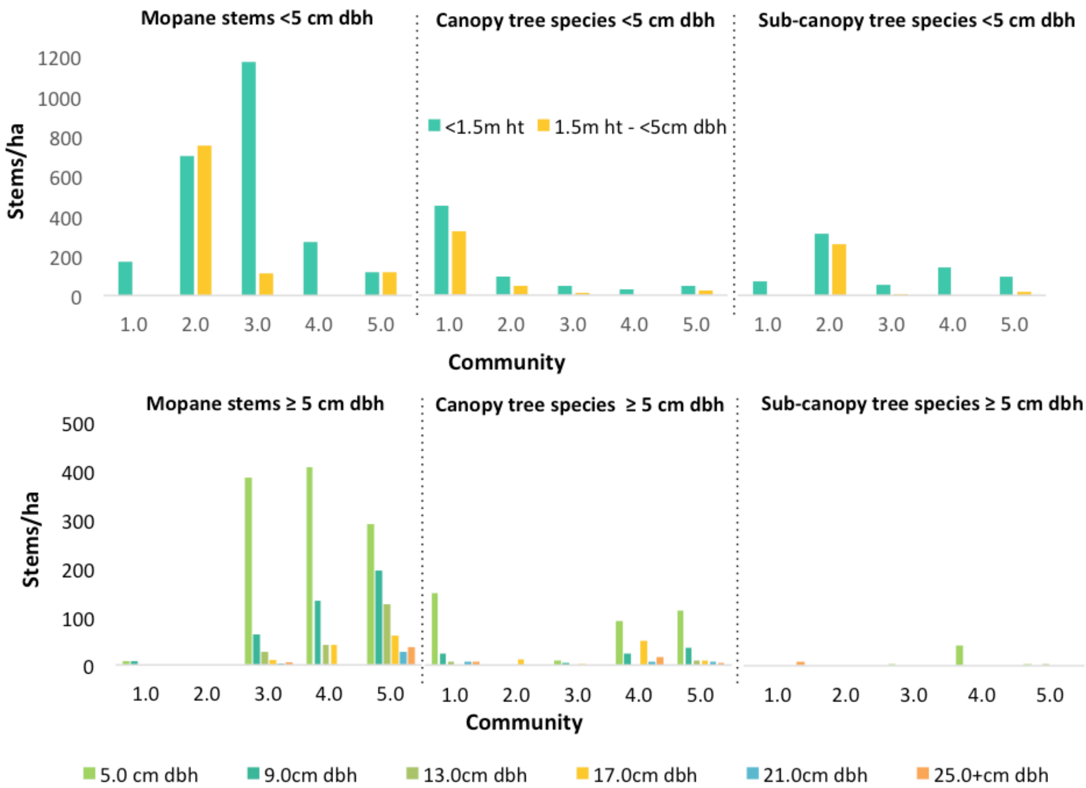

Figure 6
Stem size class distribution across communities.

and size range of Mopane trees, 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.

7. Discussion

The good regeneration of canopy species other than Mopane and the poor regeneration of Mopane and sub-canopy tree species in Community 1 can be related to the resource use practices. This condition is common around the Mavodze village, where extensive open areas are dedicated to agriculture and cattle grazing, and vegetation conditions can be interpreted at stage development 1, indicating higher degree of disturbance. The high regeneration of other canopy tree species in this community may be an indication of recruitment of shoots or regrowth from trunks not removed during the opening of fields, also noted by Chidumayo (2013). The lower 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, aiming to increase 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

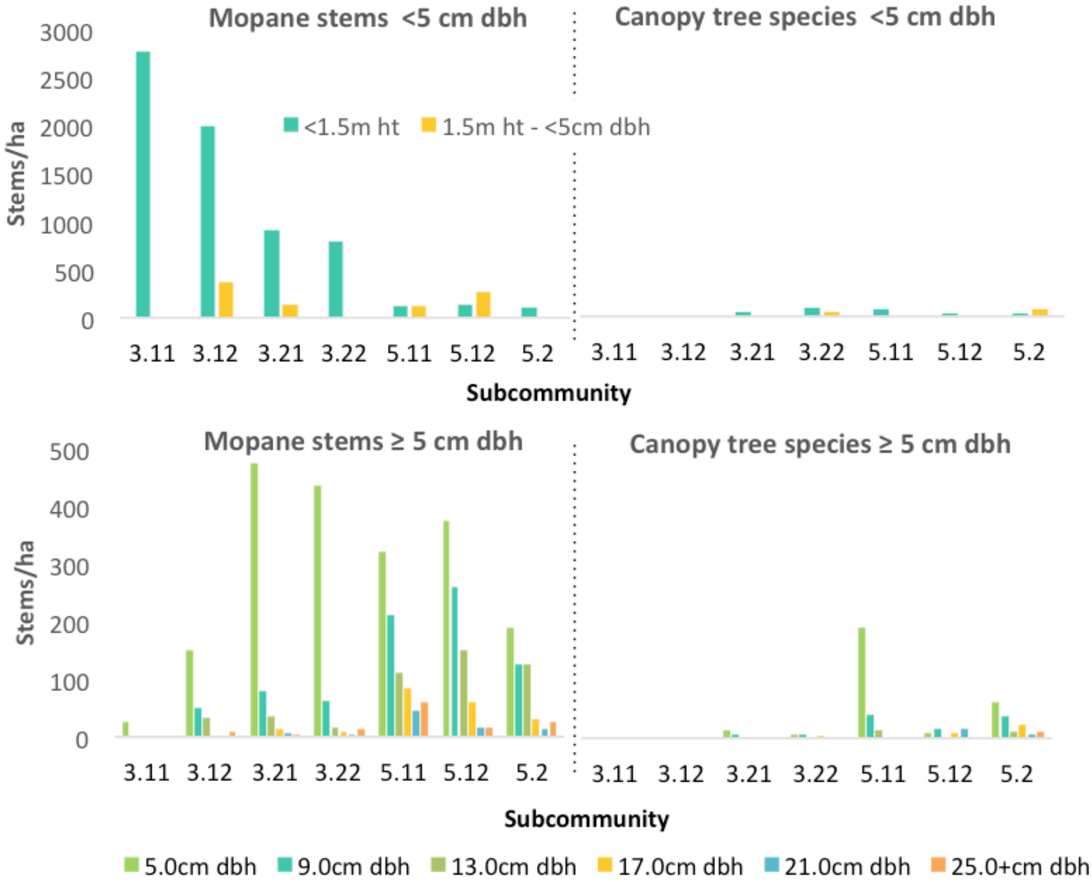

Figure 7
Stem size class distribution for canopy tree species across sub-communities of communities 3 and 5.

stems 5-9 cm DBH may indicate rapid regrowth and recovery after pressure reduction. This is also shown by Syampungani et al. (2016), Chichinye et al. (2019) and Geldenhuys and Monareng (2020), supporting the idea that practices of slash-and-burn agriculture, charcoal production, firewood collection and cutting poles for construction, are not hindering the capacity of such woodlands to recover and guarantee the maintenance of biodiversity (De Sousa, in prep) and productivity after abandonment (agriculture) or pressure reduction. This is a conclusion strongly supported by results from Community 2. In this case, an abundant regeneration of Mopane and sub-canopy tree species, along with a general lack of trees, can be identified. Such condition is particularly clear in the Macavane area, an area that was abandoned after population resettlement. Here, 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 correspond to trees that had been left in the fields during clearing of fields for cropping, a strategy that promotes faster recovery of vegetation.

Considering the results for community 1 and 2, and having by reference the level of disturbance and conditions (structure and composition) associated to each development stage, it is quite clear that resources exploitation is not limiting the recovery of vegetation. In fact, pressure reduction over the resources, or temporary abandonment after disturbance (e.g.: slash-and-burn agriculture), promoting lower degree of disturbance, allow recover of structure and biodiversity of the woodlands. Such conclusion is also supported from results for Community 4, where the lower disturbance levels allow the presence of woodlands dominated by smaller to intermediate sized trees of Mopane (stems >9.0 cm DBH), and some other canopy tree species (stand development stage 3).

Communities 3 and 5, dominated by mopane trees and presenting lower levels of pressure, are more diverse, a condition that supports the identification of 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 higher density of Mopane and reduced light and moisture conditions. However, the high density of Mopane stems with DBH <5 or 5-9 cm, but few stems of other canopy and sub-canopy tree species, may also be related to resource use activities, once Mopane is a sprouter, and reacts to cutting, while other species might be subjected to negative selection.

Considering sub-communities, differences in composition and structure might support an interpretation that helps to assign pressure and recovery. The strong decrease in stem density of the Mopane regeneration class (<1.5 m height) and strong increase in stem density of trees (<9 cm DBH and larger sizes) between sub-communities 3.11 and 3.22 may indicate stand development towards mature stands. A conclusion that can also be drawn from results about regeneration of other canopy tree species. Considering the fact that negative selection promotes reduction of propagules pressure, it is expected that species that are less interesting in terms of provided resources took more time to recover. The evolution towards more mature stages promotes the increase in regeneration for other canopy species (sub-communities 3.2), sometimes with added density of the larger regeneration (≥1.5 m height) (sub-community 3.22), but always with very few trees at the canopy level.

Considering the evolution to more mature stages of the Mopane woodlands, the Community 5 would include the sampled plots with higher maturity. Such conclusion is based on the presence of good range of tree sizes of Mopane and lower stem density for Mopane regeneration classes, a common condition on mature stands. Along with the relatively lower stem density of Mopane in sub-communities of community 5, the relatively high regeneration density in stems ≥1.5 m height for other canopy tree species, and a decrease on regeneration in stems <1.5 m height, a trend clear from sub-community 5.11 to sub-community 5.2, are other arguments that support the idea of higher maturity. The density and size range of the other canopy tree species support the differentiation of the three sub-communities of community 5, occurring mainly around the villages of Machamba and Bingo.

The variation in size class distributions from community 1 to community 5, and its relationship with land use, shows that results can be used to determine the success or failure of the regeneration and development of tree species, considering different land use practices, and assess woodlands recovery (Geldenhuys, 2010). It shows the importance of species regeneration for woodlands recovery, maintenance of biodiversity, but also the necessary productivity to supply of products of valuable use (Batistella & Moran 2005; Akinyemi & Kgomo 2019). It also shows that Mopane woodlands structure exhibits the influence of anthropogenic activities, supporting the idea that traditional land use systems, structured in equilibrium with environmental conditions, are not limiting the capacity to recover, challenging the general perception that agricultural practices, charcoal production and other resource use activities always contribute to negative changes in forest cover and composition of tree species for the long term (Mansour et al., 2017). For that, it is important the fact that Mopane and other species developed regeneration strategies to survive disturbances from stochastic events, which promote changes in vegetation cover, vegetation structure, complexity and functionality (Mazon, Silva, & Watzlawick, 2019). A clear proof is the fact that such vegetation is adapted to predation by native fauna (large herbivorous), an adaptation that might support recover under land use practices of low pressure or intermittent regime that do not promote full elimination of the native vegetation (Singh, Sagar, Srivastava, Singh, & Singh, 2017). The prevalence of sprouters and light-demanding species in woodlands composition are also attributes that contribute to such recovery capacity. In fact, such regeneration is an important factor in maintaining biodiversity and productivity of forests for the sustainable supply of products and services of desired value.

Despite the fact that results point to a good recovery capacity of Mopane woodlands, some practices might be adjusted to guarantee forest resources provision with lower pressure and reduce areas in

Figure 8
Regeneration strategies of Mopane: from seed (a); sprouting from spreading rootstocks below the ground (b); sprouting on cut stumps (c).

Figure 9
Resource harvesting practices: trees showing no signs of sprouting and cut stumps are eaten by termites (a); Stems of poor form and quality in trees with multiple stems need to be cut (b); Sprouting stems on cut stems can be thinned to remove stems of.

use. 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).

In adition, 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).

8. Conclusions and Recommendations

The exploitation of forest resources (fuelwood, charcoal production and building material) from selected species (*Colophospermum mopane and Combretum apiculatum*) and intermittent (slash-and-burn-agriculture) or low-pressure (grazing) activities are not limiting the capacity of such species to recover. However, and aiming to reduce habitat fragmentation and improve biodiversity conservation, on areas subject to exploitation, such recovery needs to be silviculturally managed to facilitate a faster recovery of the system, in order to guarantee availability of resources with smaller areas in use.

Mopane resources have extremely high socio-economic, cultural and traditional values for local communities of the Limpopo National Park, once they depend on wood harvesting from Mopane woodlands for infrastructure and firewood collection, as a main source for income, and to create open areas, based on 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. A pattern of exploitation that would leads to faster depletion of biodiversity, with implications for conservation. However, this study showed that there is good recovery through regeneration dynamics of Mopane woodlands. 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 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 cultication, 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. The zonation of Mopane woodlands within the Park, considering different land uses, might enhance a quick recovery system on specific areas and contribute to woodland productivity, good quality products and reduce used areas, promoting habitat conservation.

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