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# Tree diversity and edge effects in Nhamacoa miombo forest, Mozambique



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## **Abstract**

Mozambique is to fifty percent covered by forest, most of which belongs to the biodiverse miombo woodlands. The last decades, Mozambique has been suffering from rapid deforestation. The once continuous forest cover has turned into a mosaic of forest patches, farmland, settlements etc. The remaining forest patches are in many cases very isolated. These forests have distinct edges towards the neighbouring land, which means that the edge zones have different environmental conditions (more light, higher temperatures etc.) and tree species composition than the interior. In order to examine how the forests of Mozambique are affected by edge effects, the highly isolated Nhamacoa forest was studied. An additional aim of the project was to make a floristic inventory of the forest in order to further assess its conservation status. Specimens were collected, pressed and photographed for identification. Edge effects were studied in plots at the edge and in the interior of the forest in a paired design. Trees inside the plots were identified, counted and measured (dbh (diameter at breast height) and height) to search for differences in species richness, diversity, biomass and height-to-dbh ratios. Environmental parameters (air temp., soil temp., light and slope) were also measured. In total, 76 species of trees were sampled and 44 (35 in the interior and 32 at the edge) of these were found inside the plots. The interior plots harboured significantly more individuals and species of trees than their paired edge plots. Additionally, biomass and height-to-dbh ratios were higher in the interior plots than in the edge plots. These differences strongly suggest that the Nhamacoa forest is affected by edge effects, although none of the measured environmental parameters could explain why. That the Nhamacoa forest is affected by edge effects goes in line with the research hypothesis and shows that it is important to maintain large and intact pieces of forest in order to preserve the Mozambican miombo forests. For future studies, additional environmental parameters (wind speed, humidity etc.) could be examined in order to better explain the presence of edge effects in the Nhamacoa forest.

## **Acknowledgements**

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Thanks to Inga Hedberg at Uppsala University for contacting the Pixley's, setting up this cooperation between Uppsala University and Trees4Moz and thereby making this study possible. Thanks also to Salomão Bandeira, Domingos Salomão Maguengue and co-workers at Eduardo Mondlane University for helping me with organisation and species identification.

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## Introduction

Around 50% of Mozambique is forested (FAO 2015), and a large part of this area is classified as Miombo woodland. Miombo woodlands are dominated by trees of the legume subfamily Caesalpinioideae, mainly belonging to the genera *Brachystegia*, *Julbernardia* and *Isoberlinia*. The Miombo woodlands are found in the Miombo ecoregion (Timberlake & Chidumayo 2001), which covers around 3.6 million km<sup>2</sup> in 11 countries in southern Africa, from Angola in the west to Mozambique in the east. The ecoregion covers areas with nutrient poor soils and a mean annual rainfall of 650 to 1400 mm. Most of the Miombo ecoregion is located at 800 to 1250 m altitude, but in its eastern parts (mainly in Mozambique) it occurs at altitudes of 200-300 m (Timberlake & Chidumayo 2001). The average annual maximum temperature is 24-27°C (Timberlake & Chidumayo 2001). The Miombo ecoregion harbours at least 8500 species of vascular plants, of which 54% are endemic to the region (Frost 1996).

With an average annual deforestation rate of 219 000 ha, 5.44 million ha (12.5%) of forest were lost in Mozambique between 1990 and 2015 (FAO 2015). This led to a 13% decrease in the carbon content of Mozambique's forests (above- and below-ground biomass, litter and soil carbon), resulting in carbon emissions of 420 million tonne (FAO 2015). An important reason for the rapid deforestation is illegal logging. According to official figures from Mozambique, the country exported 81.5% of its timber to China in 2018. However, China's reported timber import from Mozambique was eleven times higher than that. If these figures are correct, 91% of Mozambique's wood export to China in 2018 was illegal (ITC 2019).

The Manica province is located in the mid-western part of Mozambique, bordering Zimbabwe. In 2007, 55.5% (3.46 million ha) of the Manica province was covered by forest, making it the third most forested province of Mozambique (Marzoli 2007). However, the yearly deforestation rate for the Manica province (0.75%/year) was higher than the country's average (0.58%/year) between 1990 and 2002 (Marzoli 2007). According to Jansen *et al.* (2006), the deforestation rate for Manica was 0.81%/year 1990-2004, and when only the category "Forest and closed woody vegetation" is considered, the deforestation rate for the same period was 1.27%/year. A vast majority of the deforested land in Manica has been converted into farmland (Jansen *et al.* 2006, Marzoli 2007). Due to the high degree of deforestation, the remaining forests of Manica are highly fragmented with many distinct edges, mostly bordering farmlands.

Distinct edges cause different environmental conditions in the forest edge area compared to the forest interior - a phenomenon known as edge effects. Canopy cover is less dense at edges (Laurance 1991, Chen *et al.* 1992), causing higher photosynthetic active radiation, PAR, to reach the understorey (Kapos 1989, Matlack 1993) and raising air temperatures (Kapos 1989, Matlack 1993). Humidity (Kapos 1989) and soil moisture (Matlack 1993, Baimas-George 2012) are also affected and tend to be lower at forest edges. More light reaching the ground of edge areas leads to a higher understorey cover with more light-tolerant species (Brothers & Spingarn 1992, Matlack 1993). Alien species are usually light-tolerant and therefore more abundant at edges (Brothers & Spingarn 1992). The number of lianas, on the other hand, tend to be lower at edges (Laurance 1991). Different edge effects reach different depths of the forest and the above-mentioned effects have been reported to depths of 25-50 m (Kapos 1989; Laurance 1991; Brothers & Springarn 1992; Chen *et al.* 1992; Matlack 1993; Baimas-George 2012).

The live aboveground biomass of trees with dbh  $\geq 10$  cm has been shown to be significantly higher in the forest interior than at forest edges (Nascimento & Laurance 2004). The creation of edges makes the edge area more sensitive to weather phenomena such as heavy winds, heavy rains, floods, heat waves and wildfires which leads to a higher tree mortality near the edge (Nascimento & Laurance 2004). It also affects the physical composition of the trees that survive. For instance, the edge area gets more windthrows due to the lost wind protection and trees with shallow root systems and large height-to-dbh ratios are the most likely to blow down (Burton 2002). Forest interiors and edges are regarded as different habitats since they tend to have different species compositions. For example, tree species diversity, tree species richness and number of tree individuals have been reported to be higher in forest interiors than at forest edges (Kacholi 2014).

## **Aims and hypotheses**

The first aim of this study was to make an inventory of the trees of Nhamacoa forest, Manica province, Mozambique, in order to compare the floristic composition with Miombo forests in other areas. The second aim was to search for edge effects (differences in tree species diversity, tree species richness, tree species composition, tree numbers, live aboveground biomass and height-to-dbh ratios) and if any environmental parameters could explain any found edge effects. Because of its geographic placement, it was expected that Nhamacoa forest would have many floristic similarities to other Miombo forest areas, although strong influence from human activities may have made this connection less clear, i.e. through the introduction of alien species. Given studies of similar forests, the high occurrence of distinct edges towards neighbouring farms, its small size and irregular shape, Nhamacoa forest was assumed to be strongly influenced by edge effects.

## **Methods**

### Study site

Nhamacoa forest belongs to the Miombo ecoregion and is a small forest remnant (30 ha) of a once enormous forest area, estimated to have covered 30000 ha (O'D Pixley, pers. comm.). It is situated in the Manica province in central Mozambique, 100 km east of the Zimbabwean border, at an altitude of 450-500 m.a.s.l. No climate data for Nhamacoa are available, but the provincial capital Chimoio, situated 30 km northwest of the study site, has an average annual precipitation of 1080 mm (dec-mar: 199 mm/month, apr-nov: 38 mm/month) and an average annual maximum temperature of 27.3°C (Climate Data 2019).

Nhamacoa forest is highly isolated from other forested areas, surrounded by subsistence farmed fields, presently with maize. The shape of the forest is irregularly oblong (1x0.3km) and the edges towards the surrounding farmland are discrete. Uncontrolled fires are the biggest threat to Nhamacoa forest. Several firebreaks are maintained, both along the borders and inside the forest, where all vegetation is being cleared regularly. Nhamacoa forest has no official protection. It is privately owned and only protected from fires and illegal logging by the owners.

### Tree inventory and identification work

A tree inventory was carried out from October 24 to December 8, 2018. Trees were geotagged and specimens were photographed and pressed for later identification. As many parts of the tree as possible, i.e. leaves, stalks, flowers, fruits and bark, were collected and recorded (pressed and photographed). A home-made field press was used in the field and at the end of the day the material was transferred to another plant press.

Experts on the local flora (Bart Wursten from Flora of Mozambique and botanists from Eduardo Mondlane University) assisted in the identification process. Dried specimens are stored in the herbarium of Eduardo Mondlane University (LMU) in Maputo.

### Edge effect study

Edge effects on trees were studied by comparing plots (plot size = 20 x 20 m) from the forest interior with plots at the forest edge. A total of 18 plots, 9 in each habitat (interior and edge), were included in the study. The centre of the edge plots was placed 10 m from the forest edge and the centre of the interior plots was placed 60 m from the forest edge. Interior- and edge plots were placed on the same line, perpendicular to the forest edge, making up a total of 9 plot pairs. The placement of the plot pairs was randomly selected. In each plot, all trees with dbh  $\geq$  10 cm were recorded. Each species recorded for the first time was collected for later identification. Each specimen was given a number and, when known, the local name was recorded. The total number of trees as well as the number of each species was recorded for each plot in order to make calculations on species richness, diversity and evenness. For each individual tree, dbh was estimated by measuring circumference and dividing it by  $\pi$ . For multi-stemmed trees, the same procedure was implemented for each stem. Using a clinometer, tree height was estimated to the nearest 0.5 m.

### Environmental variables

In the centre of each plot, air temperature (30 cm above ground) and soil temperature (at 5 cm depth) was recorded. All the measurements were made in the shade and the temperature was recorded after 1 minute of measuring. The temperature measurements for the plots of each plot pair were made the same day, with a delay of approximately 10 minutes. Canopy cover estimations were made with the smart phone application "CanopyApp". Pictures were taken of the tree canopy 1.5 m above ground and from these pictures the canopy cover was estimated by the application. Three pictures were taken in each plot and the mean cover was calculated. Many of the plot pairs were located on steep slopes and therefore the slope was measured in each plot to see which effect it could have on the tree flora.

### Biomass calculations

Numbers on dbh and height were used to calculate the volume of each tree. Tree volumes were summed up to get the total live aboveground biomass of trees with dbh  $\geq$  10 cm in each plot. For tree volume calculations, the assumption was made that a tree is conical in its shape and thus the formula for calculating the volume of a cone (equation 1) was applied. The radius was obtained from the measurements of dbh. For multi-stemmed trees, a single value for dbh was obtained by taking the square root of each stem-dbh squared.

$$V = (\pi * r^2 * h) / 3$$

Equation 1. The volume of a cone. Hereby used to calculate tree volume based on the assumption that trees have a conical shape.  $V$  = tree volume ( $m^3$ ),  $r$ = dbh (m) / 2,  $h$  = tree height (m).

### Statistical analyses

The statistical analyses were computed in R Studio (RStudio Team 2018). For some of the analyses, the R Studio packages Vegan (Oksanen *et al.* 2019) and Vegan3d (Oksanen *et al.* 2018) were used. Species accumulation curves were made for forest interior and forest edge zones. Shannon-Wiener's diversity index (equation 2), Pielou's evenness (equation 3) as well as Simpson's reciprocal index (equation 4) were calculated in order to compare the diversity of the two zones.

$$H = -\sum [(p_i) * \ln(p_i)]$$

Equation 2. Shannon-Wiener's diversity index (H).  $p_i$ = Number of individuals of species "i" divided by total number of species.

$$J' = H/H_{\max}$$

Equation 3. Pielou's evenness ( $J'$ ).  $H$ = Shannon-Wiener's diversity index,  $H_{\max} = \ln(S)$ ,  $S$ =Number of species.

$$1/D = \sum (n/N)^2$$

Equation 4. Simpson's reciprocal index ( $1/D$ ).  $n$ =Number of individuals of a particular species.  $N$ =Total number of individuals of all species.

Paired t-tests were computed in order to compare the number of tree individuals, number of tree species, live aboveground biomass and height-to-dbh ratios between the zones. Tree communities were visualised with Non-metric multidimensional scaling (NMDS). Permutational analysis of variance (PERMANOVA) was used to statistically look for differences or similarities between the tree communities.



## Results

In this study, 76 species of trees were identified from Nhamacoa forest (Table 1) and 21 of these were legumes (Fabaceae). A total of 44 species were present in the plots and thus included in the edge study. Of these, 23 were present in both habitats, 12 solely in the forest interior and 9 solely at the forest edge.

Table 1. Tree species identified in Nhamacoa forest. Species present in the forest edge plots (32 species) are followed by the letter 'E' and species present in the forest interior plots (35 species) are followed by the letter 'I'. Species identified in the inventory but not present in any of the plots are not followed by any letter.

Species	Family	Edge	Interior
<i>Acacia</i> sp.	Fabaceae		
<i>Afzelia quanzensis</i> Welw.	Fabaceae	E	I
<i>Albizia adianthifolia</i> (Schum.) W. Wight	Fabaceae		
<i>Albizia glaberrima</i> var. <i>glabrescens</i> (Oliv.) Brenan	Fabaceae	E	I
<i>Albizia versicolor</i> Oliv.	Fabaceae	E	
<i>Annona senegalensis</i> subsp. <i>senegalensis</i> Pers.	Annonaceae		
<i>Bauhinia thonningii</i> Schum.	Fabaceae		I
<i>Bersama abyssinica</i> Fresen.	Meliantaceae	E	I
<i>Bobgunnia madagascariensis</i> (Desv.) J. H. Kirkbr. & Wiersema	Fabaceae		
<i>Brackenridgea zanguebarica</i> Oliv.	Ochnaceae		
<i>Breonadia salicina</i> (Vahl) Hepper & J. R. I. Wood	Rubiaceae		
<i>Bridelia micrantha</i> (Hochst.) Baill.	Phyllanthaceae	E	
<i>Burkea africana</i> Hook.	Fabaceae	E	I
<i>Caesaria gladiiformis</i> Mast.	Salicaceae		
<i>Cassia abbreviata</i> Oliv.	Fabaceae		
<i>Cassine aethiopica</i> Thunb.	Celastraceae		I
<i>Combretum adenogonium</i> Steud. ex A. Rich.	Combretaceae	E	I
<i>Combretum pisoniiflorum</i> (Klotzsch) Engl.	Combretaceae	E	I
<i>Crossopteryx febrifuga</i> (Afzel. ex G. Don) Benth.	Rubiaceae		I
<i>Croton sylvaticus</i> Hochst.	Euphorbiaceae		I
<i>Cussonia arborea</i> Hochst. ex A. Rich.	Araliaceae	E	I
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	Fabaceae		
<i>Diospyros mespiliformis</i> Hochst. ex A. DC.	Ebenaceae	E	
<i>Diospyros</i> sp. 1	Ebenaceae		
<i>Diospyros</i> sp. 2	Ebenaceae		I
<i>Diplorhynchus condylocarpon</i> (Müll. Arg.) Pichon	Apocynaceae	E	I
<i>Dombeya rotundifolia</i> (Hochst.) Planch.	Malvaceae	E	I
<i>Entada abyssinica</i> A. Rich.	Fabaceae		
<i>Erythrina abyssinica</i> DC.	Fabaceae		
<i>Erythrophleum suaveolens</i> (Guill. & Perr.) Brenan	Fabaceae	E	
<i>Ficus sur</i> Forssk.	Moraceae	E	I
<i>Flacourtia indica</i> (Burm. f.) Merr.	Salicaceae	E	
<i>Flueggea virosa</i> subsp. <i>virosa</i> (Roxb. ex Willd.)	Phyllanthaceae		I
<i>Gardenia ternifolia</i> Schumach. & Thonn.	Rubiaceae		
<i>Gymnosporia senegalensis</i> (Lam.) Loes.	Celastraceae		
<i>Heteropyxis dehniae</i> Suesseng.	Myrtaceae	E	I

<i>Hymenocardia acida</i> var. <i>acida</i> Tul.	Phyllanthaceae		
<i>Ixora narcissodora</i> K. Schum.	Rubiaceae		
<i>Khaya anthotheca</i> (Welw.) C. DC.	Meliaceae		
<i>Mangifera indica</i> L.	Anacardiaceae	E	
<i>Markhamia obtusifolia</i> (Bak.) Sprague	Bignoniaceae		
<i>Millettia stuhlmannii</i> Taub.	Fabaceae	E	
<i>Newtonia buchananii</i> (Baker) G. C. C. Gilbert & Boutique	Fabaceae		
<i>Ozoroa obovata</i> (Oliv.) R. Fern. & A. Fern.	Anacardiaceae		
<i>Parinari curatellifolia</i> Planch. ex Benth.	Chrysobalanaceae	E	
<i>Pericopsis angolensis</i> (Baker) Meeuwen	Fabaceae	E	
<i>Polysphaeria lanceolata</i> Hern. var. <i>Lanceolata</i>	Rubiaceae		
<i>Psidium guajava</i> L.	Myrtaceae		
<i>Pterocarpus angolensis</i> DC.	Fabaceae	E	
<i>Pterocarpus lucens</i> Lepr. ex Guill. & Perr.	Fabaceae		
<i>Pterocarpus rotundifolius</i> (Sond.) Druce	Fabaceae		
<i>Rothea myricoides</i> (Hochst.) Steane & Mabb.	Lamiaceae		
<i>Rothmannia</i> sp.	Rubiaceae	E	
<i>Sclerocarya birrea</i> (A. Rich.) Hochst. subsp. <i>caffra</i> (Sond.) Kokwaro	Anacardiaceae		
<i>Securidaca longipedunculata</i> Fresen.	Polygalaceae	E	
<i>Senegalia polyacantha</i> (Willd.) Seigler & Ebinger subsp. <i>campylacantha</i> (Hochst. ex. A. Rich.) Kyal. & Boatwr.	Fabaceae		
<i>Steganotaenia araliacea</i> Hochst.	Apiaceae	E	
<i>Stereospermum kunthianum</i> Cham.	Bignoniaceae		
<i>Strychnos madagascariensis</i> Poir.	Loganiaceae		
<i>Strychnos spinosa</i> Lam.	Loganiaceae		
<i>Syzygium guineense</i> (Willd.) DC.	Myrtaceae		
<i>Tabernaemontana elegans</i> Stapf	Apocynaceae	E	
<i>Tectona grandis</i> L.f.	Lamiaceae	E	
<i>Terminalia myrtifolia</i> (M. A. Lawson) Gere & Boatwr.	Combretaceae	E	
<i>Terminalia sericea</i> Burch. ex DC.	Combretaceae		
<i>Trema orientalis</i> (L.) Bl.	Cannabaceae	E	
<i>Turraea floribunda</i> Hochst.	Meliaceae		
<i>Vangueria infausta</i> Burch.	Rubiaceae		
<i>Vitex doniana</i> Sweet	Lamiaceae	E	
<i>Vitex payos</i> (Lour.) Merr.	Lamiaceae	E	
<i>Xeroderris stuhlmannii</i> (Taub.) Mendonca & Sousa	Fabaceae		
<i>Ximenia caffra</i> Sond.	Ximeniaceae		
<i>Zanha africana</i> (Radlk.) Exell	Sapindaceae	E	
<i>Zanthoxylum</i> sp.	Rulaceae	E	
Unidentified			

Species richness was marginally higher for the interior (35) than the edge (32), but since the Species accumulation curves (Figure 1) have not flattened out, more plots are needed to get reliable numbers on species richness.

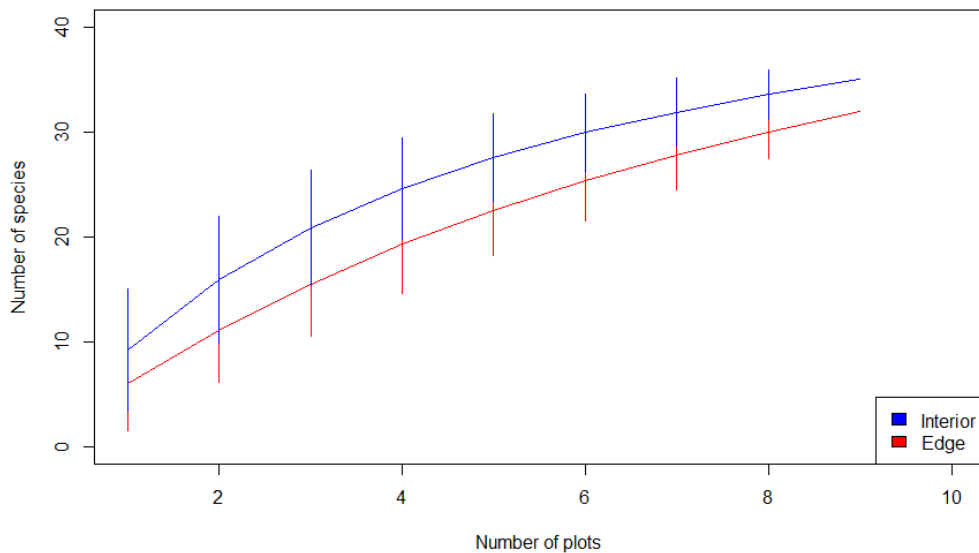


Figure 1. Species accumulation curves for the number of trees (dbh  $\geq$  10 cm) in 20 x 20 m plots at the edge (species richness = 32) and interior (species richness = 35) of Nhamacoa forest.

As shown in Table 2, tree species diversity is higher at the forest edge than in the forest interior as estimated using Shannon-Wiener's (means: edge =  $1.97 \pm 0.39$ , interior =  $1.63 \pm 0.50$ ) ( $t = 2.03$ ,  $df = 8$ ,  $p$ -value = 0.08) and Simpson's (means: edge =  $6.89 \pm 2.61$ , interior =  $5.07 \pm 2.31$ ) ( $t = 1.65$ ,  $df = 8$ ,  $p$ -value = 0.14) diversity indices, but none of these differences were statistically significant. Pielou's evenness did not differ between the habitats (means: edge =  $0.81 \pm 0.17$ , interior:  $0.82 \pm 0.17$ ) ( $t = -0.08$ ,  $df = 8$ ,  $p$ -value = 0.94).

Table 2. Diversity measures for trees in 20 x 20 m plots at the edge and interior of Nhamacoa forest. Displayed numbers are means of the diversity indices of all plots in each habitat. H=Shannon-Wiener's diversity index, D=Simpson's diversity index,  $J'$  = Pielou's evenness.

	H	D	$J'$
Edge	1.97	6.89	0.81
Interior	1.63	5.07	0.82

The forest interior plots harboured at an average twice the number of trees as the edge plots (edge:  $7.67 \pm 3.77$  individuals, interior:  $15.56 \pm 3.78$  individuals) ( $t = -3.81$ ,  $df = 8$ ,  $p$ -value = 0.01) (Figure 2) and also significantly more tree species (edge:  $6.00 \pm 2.35$  species, interior:  $9.00 \pm 3.12$  species) ( $t = -2.45$ ,  $df = 8$ ,  $p$ -value = 0.04) (Figure 3).

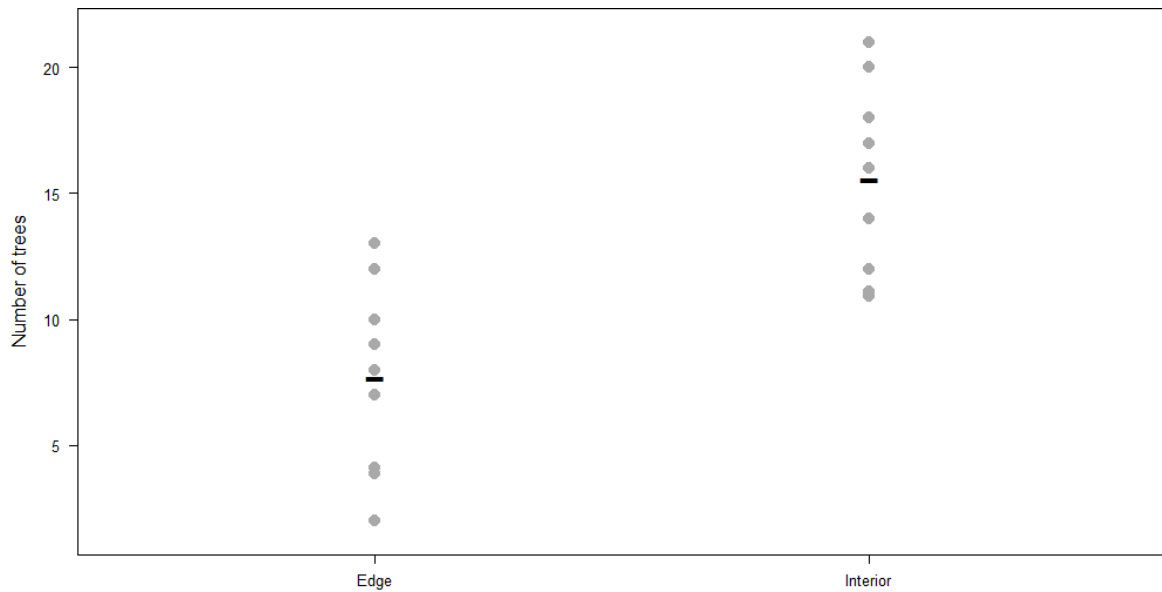


Figure 2. Comparison of number of trees in 20 x 20 m plots at the edge (mean =  $7.67 \pm 3.77$ , sample size = 9) and interior (mean =  $15.56 \pm 3.78$ , sample size = 9) of Nhamacoa forest.

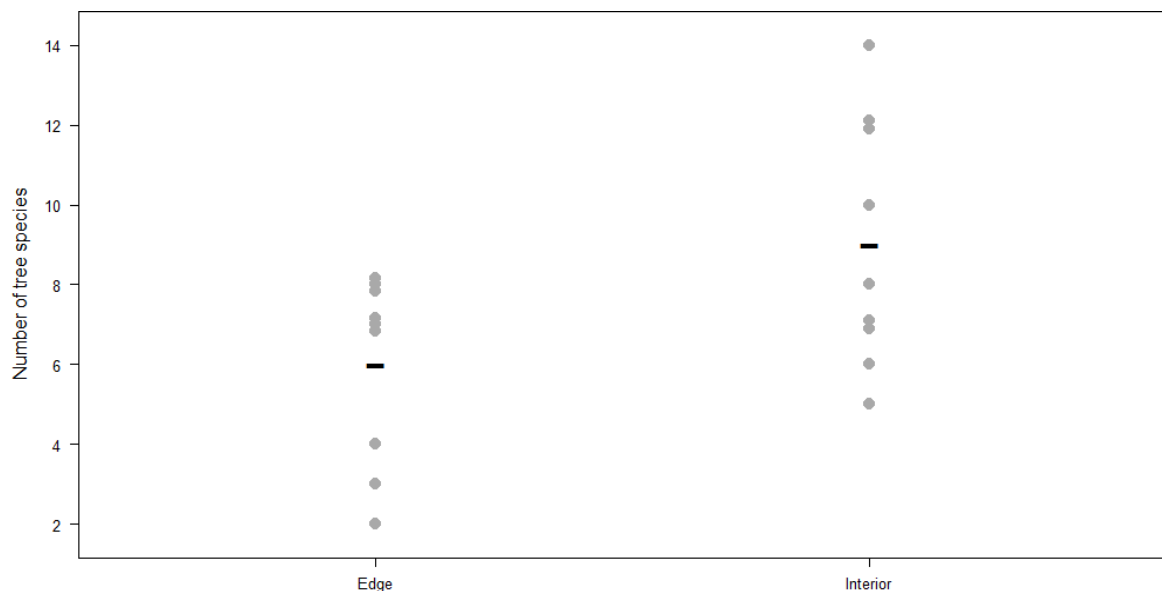


Figure 3. Comparison of number of tree species in 20 x 20 m plots at the edge (mean =  $6.00 \pm 2.35$ , sample size = 9) and interior (mean =  $9.00 \pm 3.12$ , sample size = 9) of Nhamacoa forest.

Canopy cover was denser in the forest interior than at the forest edge ( $t = -3.20$ ,  $df = 8$ ,  $p$ -value = 0.01) (Table 3). The data on slope gave a weak support of it being flatter at the interior than at the edge ( $t = 2.07$ ,  $df = 8$ ,  $p$ -value = 0.07). Air temperature ( $t = -0.02$ ,  $df = 8$ ,  $p$ -value = 0.98), and soil temperature ( $t = 0.64$ ,  $df = 8$ ,  $p$ -value = 0.54) was similar at the edge and in the interior of Nhamacoa forest.

Table 3. Environmental parameters measured in edge plots and interior plots in Nhamacoa forest.

	Canopy cover (%)	Slope (%)	Air temp. (°C)	Soil temp. (°C)
Edge	$51.38 \pm 23.80$	$24.72 \pm 15.88$	$29.61 \pm 5.84$	$24.57 \pm 1.81$
Interior	$68.23 \pm 13.13$	$16.11 \pm 8.49$	$29.62 \pm 5.85$	$24.40 \pm 1.77$

The live aboveground biomass was significantly higher in the forest interior compared to the forest edge ( $t = -2.69$ ,  $df = 8$ ,  $p\text{-value} = 0.03$ ) (Figure 4). Also, the height-to-dbh ratios were significantly higher for trees in the interior plots than for trees in the edge plots ( $t = -2.37$ ,  $df = 8$ ,  $p\text{-value} = 0.05$ ) (Figure 5).

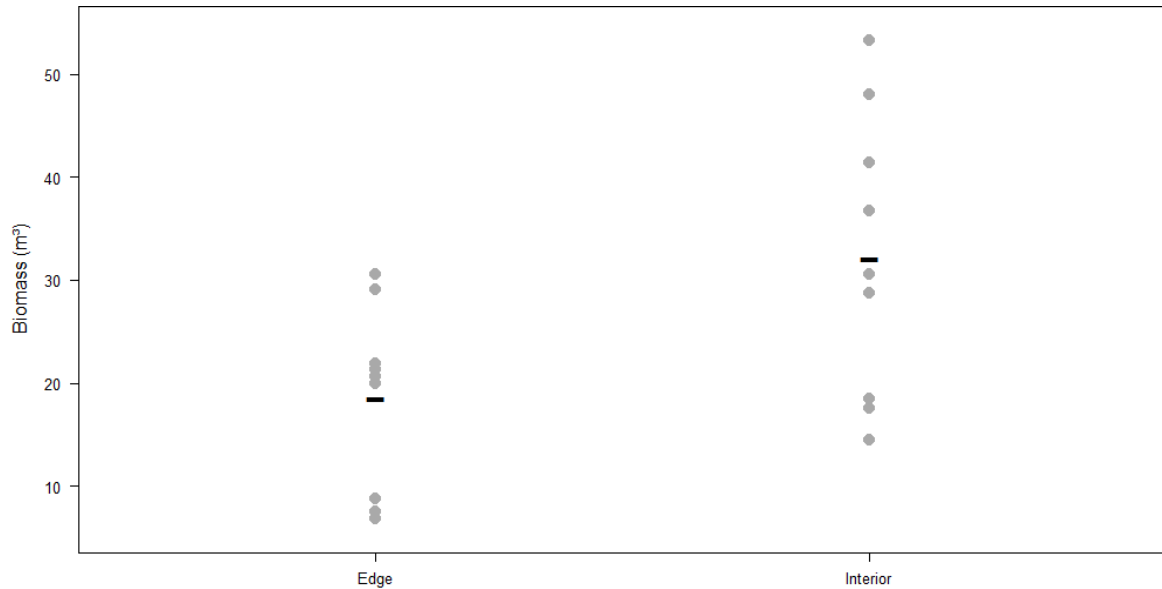


Figure 4. Comparison of the live aboveground biomass of trees with  $dbh \geq 10$  cm in 20 x 20 m plots at the edge (mean =  $18.56 \text{ m}^3 \pm 8.93$ , sample size = 9) and interior (mean =  $32.15 \text{ m}^3 \pm 13.83$ , sample size = 9) of Nhamacoa forest.

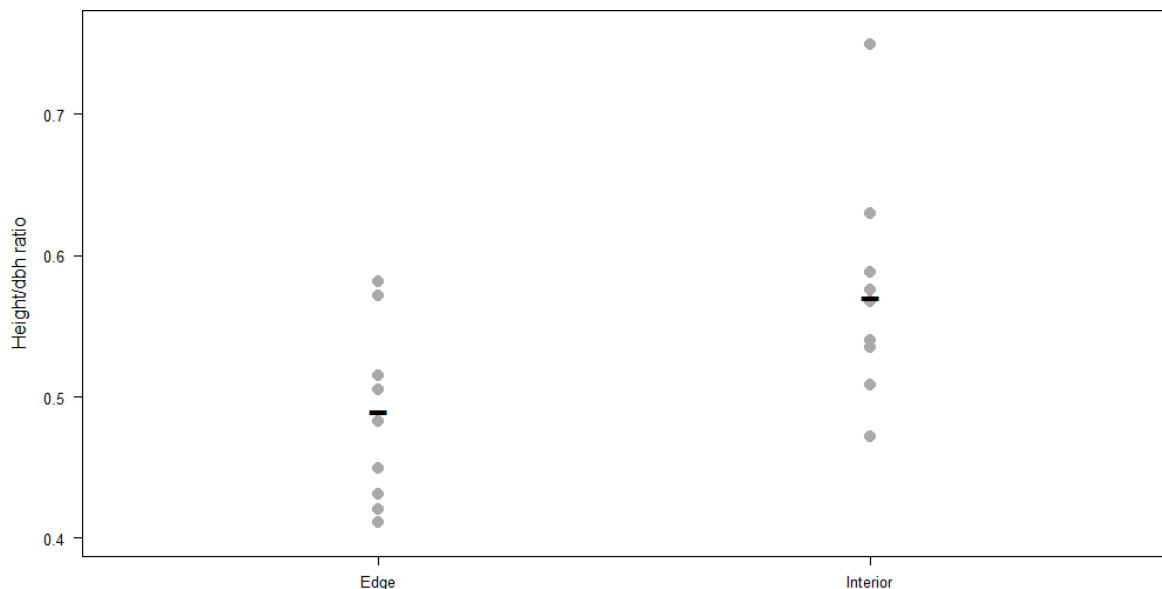


Figure 5. Comparison of mean height-to-dbh ratios for trees in 20 x 20 m plots at the edge (mean =  $0.49 \pm 0.06$ , sample size = 9) and interior (mean =  $0.57 \pm 0.08$ , sample size = 9) of Nhamacoa forest.

The distribution of trees within different diameter (dbh) classes was more even in forest edge plots compared to forest interior plots, where the two lowest diameter classes (10-15 and 15-20 cm dbh) were dominating (Figure 6 & 7).

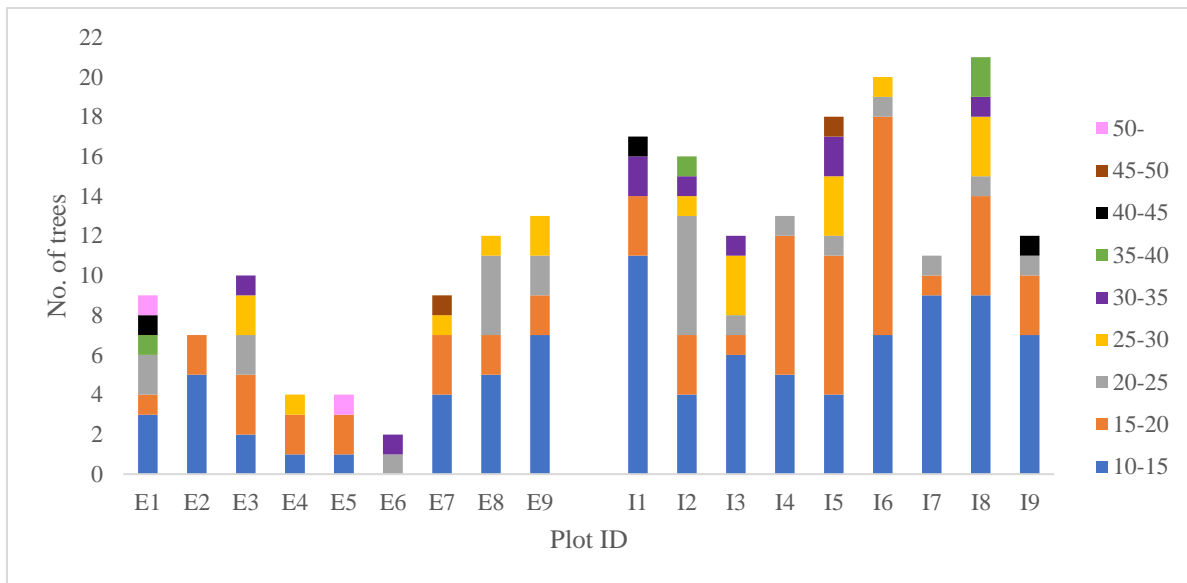


Figure 6. Number of trees per diameter (dbh) class in forest edge (E) and forest interior (I) plots (20 x 20 m).

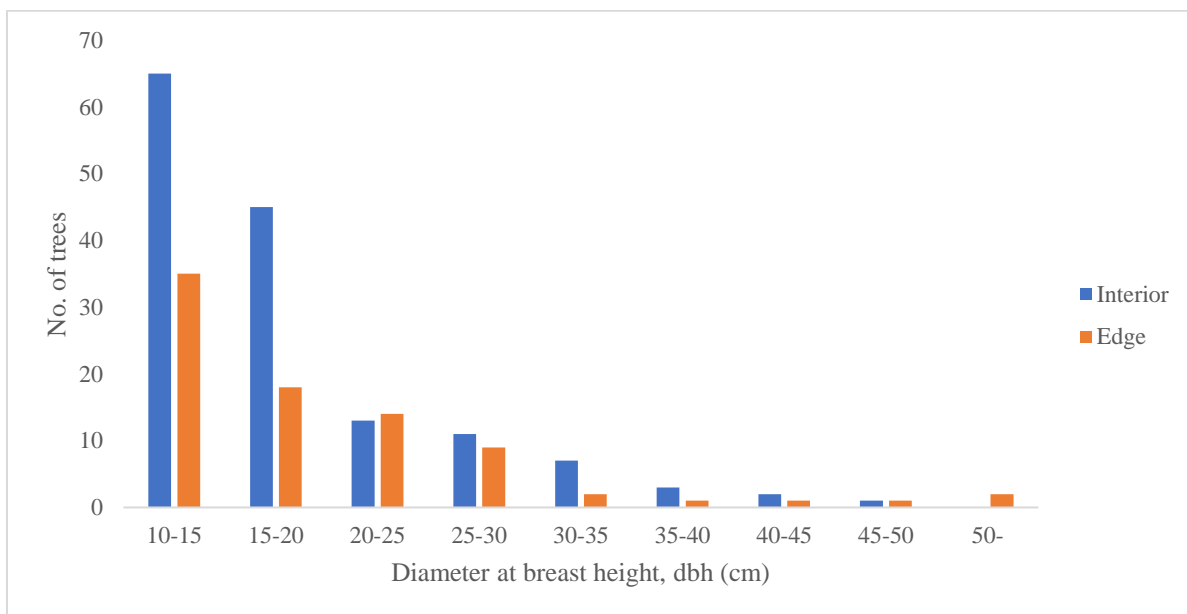


Figure 7. Total number of trees of different diameter (dbh) classes in forest interior plots and forest edge plots (20 x 20 m).

Visually, using non-metric multidimensional scaling (NMDS) (Figure 8), the tree species composition of forest edge and interior habitats appear rather similar. However, the permutation test (PERMANOVA) supports that the compositions are different in the two habitats ( $df=1$ ,  $p=0.05$ ). There is a weak support that soil temperature ( $df=1$ ,  $p=0.09$ ) could explain some of that distance, whereas air temperature ( $df=1$ ,  $p=0.23$ ), slope ( $df=1$ ,  $p=0.45$ ) and canopy cover ( $df=1$ ,  $p=0.42$ ) do not influence the tree species communities.

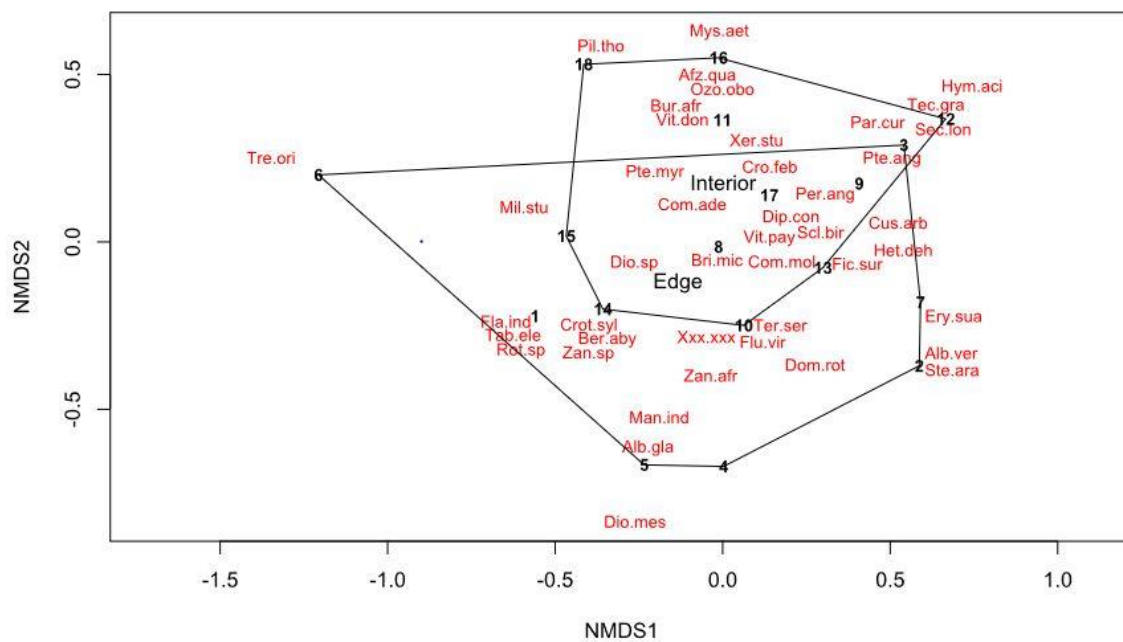


Figure 8. Non-metric multidimensional scaling (NMDS) with tree species (three letter codes, example: *Afzelia quanzensis* = Afz.qua), habitat (Edge: plots no. 1-9, Interior: plots no.10-18) and environmental variables. Sample size = 9, plot size = 20 x 20 m)

## Discussion

The forests of Mozambique are rapidly disappearing and becoming more and more fragmented. Forest fragmentation leads to edge effects, threatening forest ecosystems and species due to altered local environments. Nhamacoa forest is no exception. It is clearly affected by edge effects, which is in line with the hypothesis of this study. The tree flora of Nhamacoa forest is dominated by trees of the legume family. Although no trees of the genera *Brachystegia*, *Julbernardia* or *Isoberlinia* were found, I would still classify Nhamacoa forest as Miombo woodland since it is located in the Miombo ecoregion and there are trees of the above-mentioned genera in the surrounding areas (O'D Pixley pers. comm.). Being located in the eastern part of the Miombo ecoregion and having an unusual species composition, Nhamacoa forest is particularly valuable for conservation. Furthermore, it is one of the last patches of forest in the area and a full species inventory should be made.

### Species richness and diversity

The plot design of this study only managed to capture 44 out of the 76 identified species in Nhamacoa forest. With the present study design, the area between the forest edge and the forest interior is not included in the study. In this area, some of the missing species might be present. Narrow transects from forest edge to forest interior could be one way of solving this. Another solution could be to have several smaller plots along the transect. Instead of quadrats, other plot shapes (rectangles, circles etc.) could also be used.

The species accumulation curves did not reach their asymptotes. To reach them with the current method, more plots would have to be included in the study. However, this is not possible due to the small size and irregular shape of the forest.

The forest interior (35 species) supported more tree species than the forest edge (32 species). However, both diversity indices used in this study (Shannon-Wiener and Simpson), show that the forest edge of Nhamacoa forest harbours a higher species diversity than the forest interior. Most often a higher species richness means a higher diversity index score (e.g. Kacholi 2014), so the question is why the opposite shows here. The main reason is that in some of the interior plots there were some species with many individuals, which lowered the score on the diversity indices. In addition to species richness, diversity indices also include abundance and evenness. Diversity indices might because of this give a higher importance to the distribution of species diversity than the actual species diversity, which is what has happened here. Species richness is the central diversity measurement since diversity is ultimately dependent on the number of species. Hence, species richness should be given the highest importance. Similar studies (Laurance *et al.* 1997; Benitez-Malvido & Martinez-Ramos 2003; Kacholi 2014; Despoux & Bazerghi 2016) have shown a higher tree species diversity and higher diversity indices in the forest interior. The diversity numbers in this study are in line with the other studies, while the diversity indices showed the opposite. As mentioned above, the diversity indices for the interior in this study was affected by the high abundance of a few species which lowered the diversity index scores.

### Environmental variables

The large difference in number of tree individuals between the habitats could be due to edge effects. Edge zones are more sensitive to stresses such as winds, fires and droughts. Since we know that Nhamacoa forest is partly penetrated by fires every other year and that the forest owners are trying to fight these fires it is likely that the forest edges are affected by fire more often than the interiors. There were signs of old fires on trees in both habitats, but the only standing tree that was dead because of fire (and thus excluded from the study) was found in the edge plot of plot pair no. 6. That the slope tends to be greater at the forest edge could also be part of the explanation as to why there are less trees there than in the forest interior. Where the slope is greater, the land is more often affected by droughts, floods and erosion which could cause a high tree mortality and slow regeneration (Akema & Futai 2005). There were no differences in air- and soil temperature between the forest edge and interior and none of the differences found in species diversity, height-to-dbh ratios and live aboveground biomass could therefore be linked to these variables. However, the canopy cover was significantly higher in the forest interior which means less light reaching the ground there than at the forest edge.

For further studies, other environmental parameters such as soil moisture, humidity and wind speed should be studied, preferably during a time span of several years, in order to find better explanations to the observed edge effects in Nhamacoa forest.

### Tree communities

The tree species communities differ between the interior and the edge of the forest. In the NMDS-plot there is a big overlap, but the two habitats are still significantly different from each other. Differences in soil temperature could explain a small part of these differences. None of the other studied environmental/physical variables (canopy cover (light), air temperature and slope) could explain the differences.



In total, 44 tree species were recorded in the plots. Of these, 23 species were found in both habitats, while 12 were only found in the forest interior and 9 only in the forest edge. *Diospyros* sp. 2 and *Sclerocarya birrea* subsp. *caffra* were found in five interior plots and in none of the edge plots. *Sclerocarya birrea* subsp. *caffra* is not a pioneer species (early colonizer of a newly created habitat) (Dharani 2011), but no information has shown that it cannot grow at forest edges. *Diospyros* sp. 2 could not be identified to species level and its frequent presence in the interior plots could therefore not be analysed. A succulent tree species, *Cussonia arborea*, was found in four of the edge plots and only one of the interior plots. This goes in line with the hypothesis that the edge zone should be drier since *C. arborea* is drought resistant (De Villiers *et al.* 2010). There were 24 individuals (in 3 plots) of *Millettia stuhlmannii* in the interior plots compared to only 2 (in 2 plots) in the edge plots. Why it is so abundant in a few of the plots could be because it had been planted but it has also been reported to occur naturally in monospecific stands, probably because of the competition advantage it gets from the symbiosis with nitrogen fixing bacteria (MCDI 2013). *Trema orientalis* was only found in edge plot no. 6 and affects the NMDS-plot much. It is a pioneer tree (Dharani 2011) and thus much more likely to be found in forest edges than forest interiors.

#### Diameter class distribution

In the forest interior, the two lower diameter classes (10-15 and 15-20 cm dbh) are highly dominant, while the diameter class distribution of the edge zone is more even. The mean height-to-dbh ratio for the trees in the interior is higher, meaning that trees of the forest interior are on average taller and thinner than those in the forest edge. These differences may have several reasons. As mentioned in the introduction, trees with a large height-to-dbh ratio are more sensitive to the stresses caused by the creation of edges, for example higher wind speeds. Another explanation can be the stronger competition between trees in the interior. Since less light reach the ground here, each tree needs to grow tall much faster to get enough sunlight in competition with the other trees. Since the stems of the trees of Nhamacoa forest are generally narrow and homogenous regarding stem diameter (low dbh-values) it is likely that they were once planted or at least managed in some way.

#### **Conclusion**

Nhamacoa forest should be classified as Miombo woodland, even though it lacks some of the species normally found in this habitat. Furthermore, its placement in the outer range of the Miombo ecoregion, its non-typical species composition and the high tree species diversity make it particularly interesting for further studies. The species inventory of Nhamacoa forest should be completed in order to further explore its relationships to the Miombo ecoregion as a whole and to evaluate its conservation status. It would also be meaningful to further study different environmental parameters to find stronger evidence to what is causing the edge effects shown in this study.

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