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Population size structure and recruitment rate in *Pterocarpus angolensis*, an exploited tree species in miombo woodlands, Tanzania

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Abstract

Pterocarpus angolensis D.C. is a leguminous tree indigenous to the East African mainland. Its distribution corresponds well with that of the miombo woodlands, which is a vegetation belt that covers great parts of central, southern and eastern Africa. *P. angolensis* is widely used for several purposes, such as carving, timber and traditional medicine. It is being legally and illegally harvested, and since 1998 it is registered on the IUCN Red List as near threatened (NT). Since 2002 it is also forbidden by law to harvest it in Tanzania. My aim was to investigate the population size structure of *P. angolensis*, the recruitment of new individuals into the population, and the size at which the tree sets fruit. This study was carried out in east-central Tanzania.

The diameter distribution is truncated at 25-30 cm. The results indicate that during recent years an increase in the number of individuals in the bigger diameter at breast height (dbh) classes has occurred. The recruitment of new individuals into the population seems to be stable and more or less yearly, and in many of the study sites the seedling density is high. At a dbh of 13-15 cm the first fruit-bearing individuals appear, thus well below harvestable size, while in the size class of 25-27 we find the highest ratio of fruit-bearing individuals. The distribution of seeds and seedlings under mother trees differ from each other, and the latter were more common beyond 7 m from the tree.

Introduction

Miombo woodland is a term used to describe the vegetation belt that covers great parts of central, southern and eastern Africa. It is characterized by three genera from the Fabaceae family, subfamily Caesalpinioideae: *Brachystegia, Julbernardia* and *Isoberlinia* (Campbell 1996). The climate in the region alternates between dry and wet seasons, with rainfall, in the case of Tanzania, during November-April and hot and dry weather during the rest of the year. During the dry period, wild fires are frequent (Chidumayo 1997).

Miombo woodlands are nutrient poor but have a high plant biodiversity and offer many ecosystem services and products to the people living in the area, such as cultivation grounds, charcoal and timber. The human population density is still relatively low, and so is the livestock density (Campbell 1996). This is changing, though, with an increased human population cultivating the land and an increased demand for products produced in the miombo woodlands.

Pterocarpus angolensis D.C. (In English: African bleedwood, African teak. In Swahili: Mninga) is a leguminous tree in the subfamily Papilionoideae. It is indigenous to the East African mainland. The distribution range stretches over vast areas in central and southern Africa, with a southern limit in northern South Africa and a northern limit in northern Tanzania. There are populations in Malawi, Mozambique, Zambia, Zimbabwe and Botswana. Its occurrence in western parts of southern Africa is uncertain (Joker et al. 2000), although Boaler (1966) reports localities in Angola and Kongo-Kinshasa where the species has been collected. Its range corresponds well with that of the miombo woodlands (Boaler 1966). It has beautiful, reddish brown heartwood, which is considered one of the most valuable in south tropical Africa (Palgrave 1983). In Tanzania it has been widely used for several purposes such as furniture, construction and carving. The bark is rough and longitudinally fissured which makes it easily recognizable. The fruit is distinctive, with a hard seed case covered in sharp bristles and a papery wing that surrounds it (Palgrave 1983). The fruit is indehiscent, and needs external forces, such as fire, to open and germinate. A study carried out by Fors (2002) indicates that *P. angolensis* seeds are the most predated ones in comparison with some of the other common tree species in my study area.

Wind is the main seed dispersal agent and can on occasion spread the fruits for several kilometres (Vermeulen 1990). These events are rare, but could be of great ecological importance for the dispersal of the species. Once on the ground, it is estimated that only about 2% of the fruits will ever germinate (Boaler 1966). According to Boaler (1966), 81% of all fruit fall within ten metres from the mother tree, 92% fall within 15 m and 100% within 30 m in mature woodland. In regenerating woodland fruits travel a bit further. These numbers inspired Caro et al. (2005) to investigate the recruitment of *P. angolensis* in the wild. They measured the number of recruits within a radius of 20 m around 300 adult individuals. They only found recruits under 102 out of the 300 individuals. The first years after germination the seedling stays in a suffrutex stage, meaning that there is an annual die-back of the seedling every dry season. Most of the energy of the plant is located to the root which can extend 6-8 m radially (Vermeulen 1990). The plant stays in this stage for up to 14 years (Boaler 1966), until it has collected enough resources to grow sufficiently in order to survive the harsh dry season.

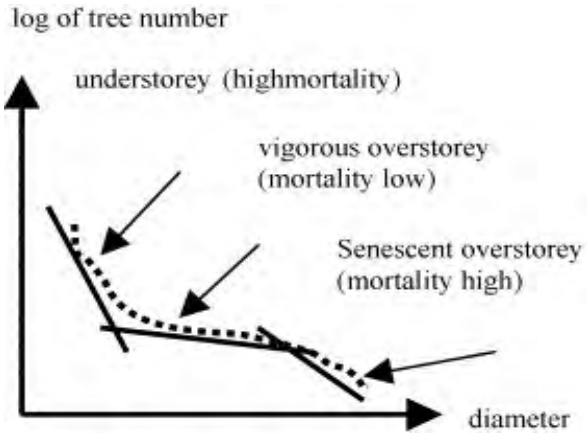


Fig. 1. The reversed J-shaped curve. From Goff & West 1975.

Population size structure is the size distribution of the individuals of a population. Size is often measured as diameter at breast height (dbh). For a population living under ideal conditions without any human influences, the distribution has a so called reversed J-shape (Fig. 1) (Goff & West 1975)

P. angolensis has been legally and illegally harvested at higher and higher rates since the market is constantly expanding (Schwartz et al. 2002). Since bigger trees give more wood, those are the ones to be cut down first, which has led to a truncated size class profile (Shackleton 2002). If trees are cut down before they become fertile, they will not have time to reproduce. Growth rates of *P. angolensis* have been studied by Therrell et al. (2007). They looked at the annual ring-width and found that on average, it takes 29 years (excluding the suffrutex stage) to reach a dbh of 10 cm, and an additional 22 years to reach 30-40 cm. Of course, this varies a lot depending on environmental factors. Studies by von Breitenbach (1973) and Vermeulen (1990) have noted a decline in the population density in all of southern Africa. Schwartz et al. (2002) created a matrix projection model which showed that the harvest rate far exceeded the seedling recruitment rate into the adult population. Although based on many assumptions, it still indicates that at least that particular population in the Rukwa region is severely threatened. After assessment in 1998 by the World Conservation Monitoring Centre, it was introduced on the IUCN Red List as near threatened (NT) (IUCN 2008). Since 2002 *P. angolensis* is on the list of protected species in the Tanzanian Forest Act (Mr. Ijumaa Singo, Tanzania Tree Seed Agency, pers. comm.). A way of saving the population would be to grow it commercially, but attempts were not very successful (Vermeulen 1990). This has to do with the way it grows, spending its first years in the suffrutex stage creating an elaborate root system. This creates problems when trying to grow them in nurseries.

Increasing harvesting rates together with the low germination rates make *P. angolensis* a highly vulnerable species and learning how to harvest it in a sustainable way is crucial to its survival in Tanzania. In order to get a sustainable harvest it is necessary to have a good picture of the population size structure and at what approximate size they reach reproductive maturity. That is what this study aims for, the main objective being to investigate the population size structure of *P. angolensis* and finding out at what size they reach reproductive maturity. A second objective is to look at the recruitment of new individuals to the population in this particular area.

Methods

The study area

The study area is located in east-central Tanzania, between and around the villages of Mikumi and Ihombwe in Mikumi Division, Kilosa district, Morogoro region. The starting point is Mikumi village, through which the highway from Dar es Salaam to Zambia runs. The majority of the study sites are concentrated along the Mikumi-Kilosa road. The remaining sites are located further west around Ihombwe village. The Kilosa road constitutes the western border of Mikumi National Park. In this area the main source of income is agriculture (Strömquist & Backéus 2009). More information about the area can be found in Holmborn (2003; soil conditions), Norrlund & Brus (2001; soil and agriculture), Thorén (2004; remote sensing of vegetation), Chilimo (2001; traditional use of forest products), Ahlberg (2003; bird fauna), Nordqvist (2009; butterfly fauna) and Backéus et al. (2009; landscape analysis).

Fieldwork was carried out between May 5 and June 5, 2008, in the end of the main rainy season. All fieldwork was coordinated with the fieldwork of another student studying the possibility of using the abundance and diversity of butterflies as an indicator of forest quality. The locations were selected based on the perceived degree of disturbance. The aim was to find sites ranging from highly disturbed to as close to undisturbed as possible. For a more detailed description of the sites, see Appendix I. Most of the sites are located in close proximity to the road going from Mikumi to Kilosa for both logistic and security reasons. See Appendix II for details. In each area, four transects of 100 m were laid out parallel to each other with a distance of 50 m between them. For the vegetation sampling and population size structure inventory the width of the transects was 10 m., while for the seedling inventory the width was kept at two metres due to the in many places high and dense grass which made recognition of the seedlings difficult. In order to randomize the placement of transects, they were, when possible, laid out in a north-south direction. Transects were made by walking in straight lines with help of a compass and a GPS receiver. The GPS location of each start- and endpoint was noted. Start- and endpoints were marked for easy recognition.

Mr. Boniface Mhoro, from the herbarium of the University of Dar es Salaam, accompanied us in the field during two whole days helping us to identify the most common tree species in the forest.

Vegetation sampling

To characterize and separate the areas, a sampling of the vegetation was made. Using transects and stopping every five metres, the grass and bush coverage were estimated in percent. Bush coverage was defined as all woody vegetation below 2 m of height. Small (2-7 m) and big (>7 m) trees were counted. For each transect, canopy projection (%) and grass height were estimated. The most common tree species in the area were noted.

Population size structure
For every *P. angolensis* individual (>2 m.) in transects, the presence of fruits was noted along with dbh. For individuals with multiple stems, only the stem with the largest dbh was considered.

Seedlings in transects
The same transects were used for seedlings, although this time only 2 m wide. The height of all seedlings (<2 m.) was noted.

Recruitment
Within every area, three fertile (with fruits) trees were selected. The intention was to find individuals standing at least 20 m from the nearest fertile tree. This was not always possible. In a radius of ten metres from the individual, the ground was checked for presence of seedlings/saplings, fallen fruits and other *P. angolensis* individuals. The distance limit was based on Boaler's (1966) information on spreading distances of the fruits. For every tree the diameter at breast height (dbh) and GPS location were measured. The amount of fruit in the canopy was noted as small, medium or high. Grass height, bush coverage, grass coverage and canopy projection were estimated for the whole plot.

Results

Vegetation sampling

Figures 2 and 3 show the results from the vegetation sampling. Site 7 had the lowest grass cover, but the highest bush and canopy cover and also the next highest number of big trees. On the other hand the site (site 2) with the highest grass cover also had a high canopy cover. Site 10 with the lowest bush cover had the highest number of trees, but such a pattern of opposing distribution was not regular as already mentioned.

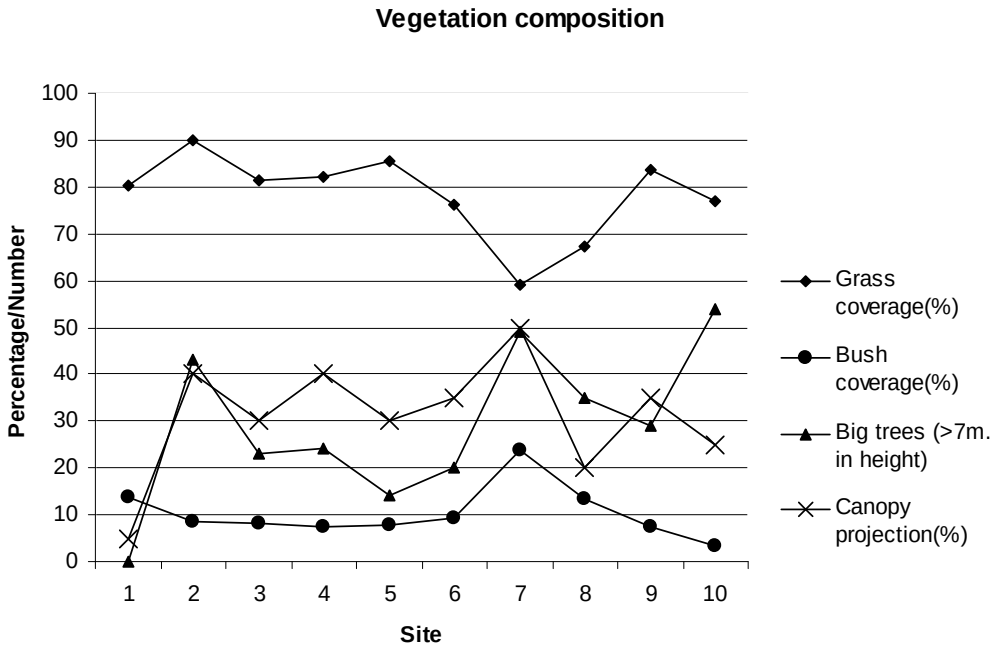


Fig 2. Average coverage (%) of grass layer, of bush layer and canopy projection, and number of large trees in the ten (1-10) study sites. Sites are sorted by distance to Mikumi, site one being the one closest to Mikumi and site ten being the one furthest away from Mikumi.

Sites 1, 5, 8, 9 and 10 had fewer small trees (2-7 m) than sites 2, 3, 4, 6, and 7. Site 7, with the low grass cover, had many small trees.

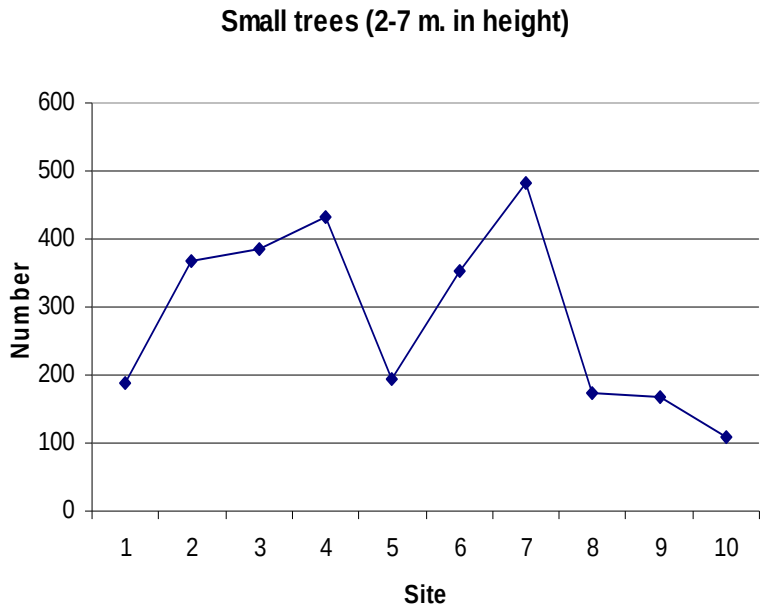


Fig 3. Number of small trees (2-7 m) in the ten study sites.

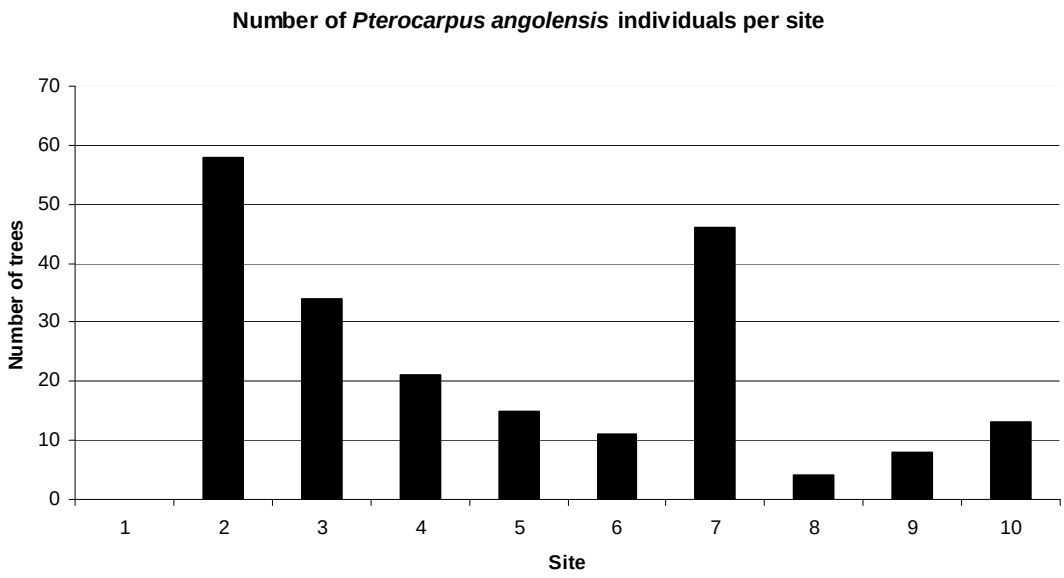


Fig. 4. Number of adult *Pterocarpus angolensis* per site. Sites are sorted by distance to Mikumi, site one being the one closest to Mikumi and site ten being the one furthest away from Mikumi.

Population size structure
Within the ten study sites, a total number of 210 *P. angolensis* individuals (>2 m.) were found. Out of these 66 had multiple stems (31%). Fig. 4 shows the number of individuals at the sites. Sites 2, 7 and also site 3 had a notably higher abundance of *P. angolensis* individuals than the rest. Site 1 is made up of bush land, which explains the total lack of trees.

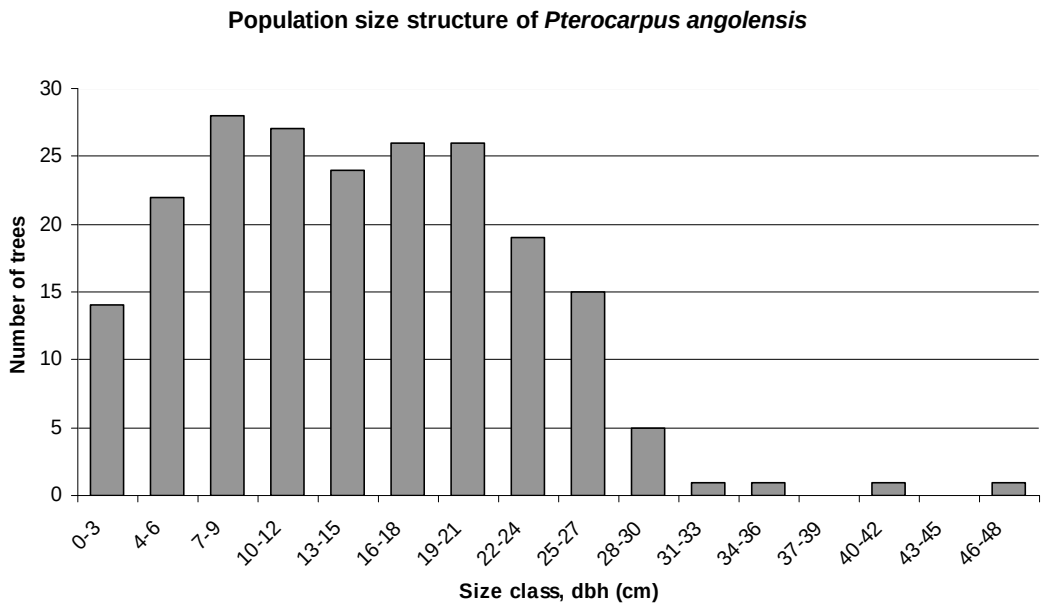


Fig. 5a. Population size structure for *P. angolensis* (>2 m.) in the whole study area. Based on the data from the four transects in each site. For the individuals with multiple stems, the stem with the largest dbh was used.

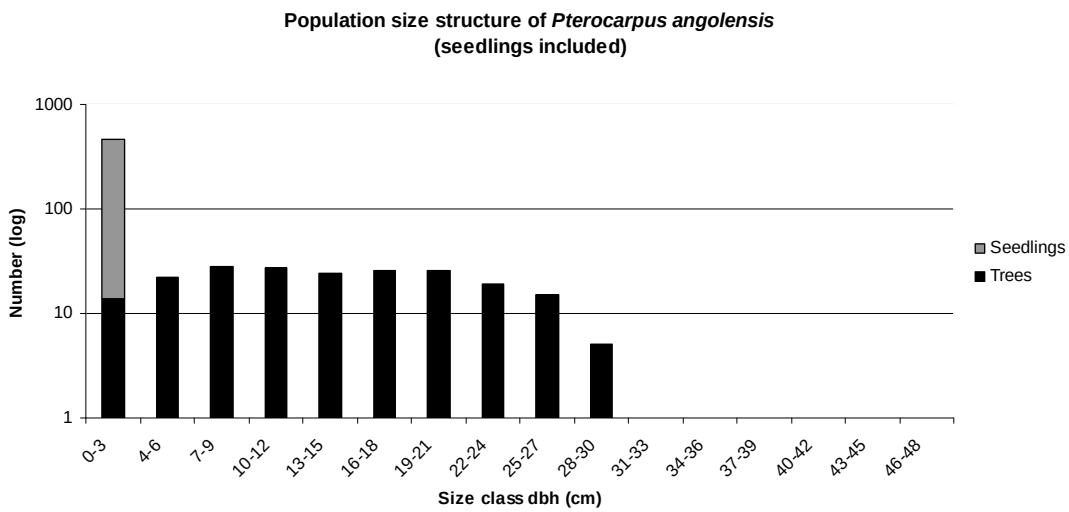
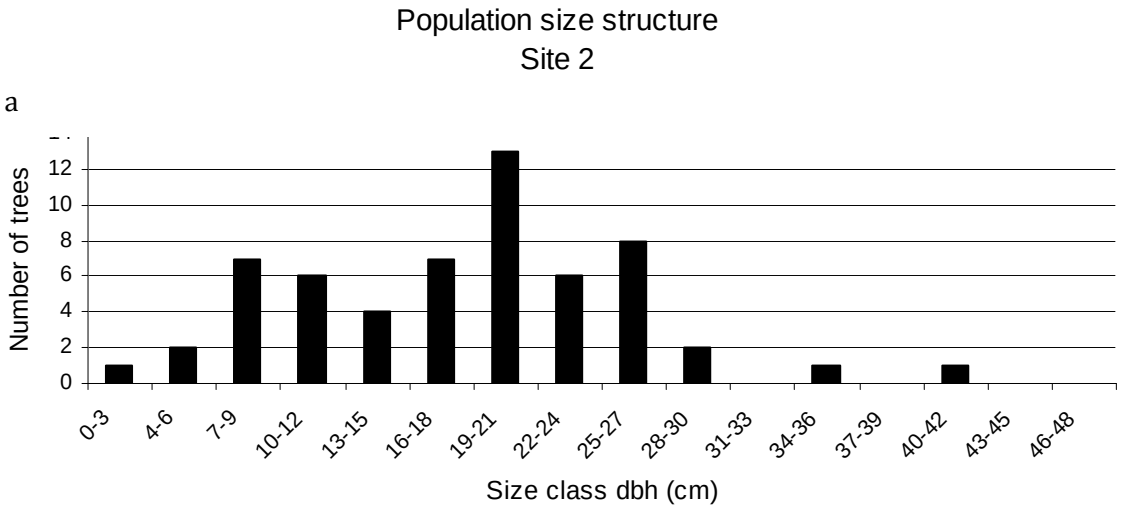


Fig. 5b. Population size structure for *P. angolensis* (all individuals) in the whole study area, based on the data from the four transects in each site. For the individuals with multiple stems, the stem with the largest dbh was used.

The size structure of the total investigated *P. angolensis* population higher than 2 m divided in 3 cm dbh-classes showed fewer individuals in the low classes than in the middle-size classes (Fig 5a). A drop in the abundance of trees can be seen between the dbh size classes of 25-27 cm and 28-30 cm. However, if including all individuals in the lowest diameter classes, also they below 2 m in height, it is clear that there were many small individuals (Fig 5b). There were only 4 individuals above a dbh of 30 cm (Fig 5a).

Fig. 6 a-i shows the population size structure in each site. The size distributions varied between the sites rather much. The total numbers of stems higher than 2 m differed between 4 stems in site 8 and 58 stems in site 2. 5 sites had 15 individuals or less. Several of the sites (sites 3, 6, 8 and 10) had no individuals in the lowest size class. The few big individuals were growing in sites 2 and 5. There was no obvious distribution pattern with distance to the city. The dbh class sizes are narrow, only 3 cm. Composing the dbh-size distribution classes to 9 cm (0-9 cm etc) shows that only a few sites, particularly sites 4 and 6 had the reversed J-shaped distribution curve. However, individuals lower than 2 m are not included. Sites 3, 7 and 9 had the highest number in the size classes 10-18 cm, site 2 (and 10) had the highest number in the classes 19-27 cm.

a



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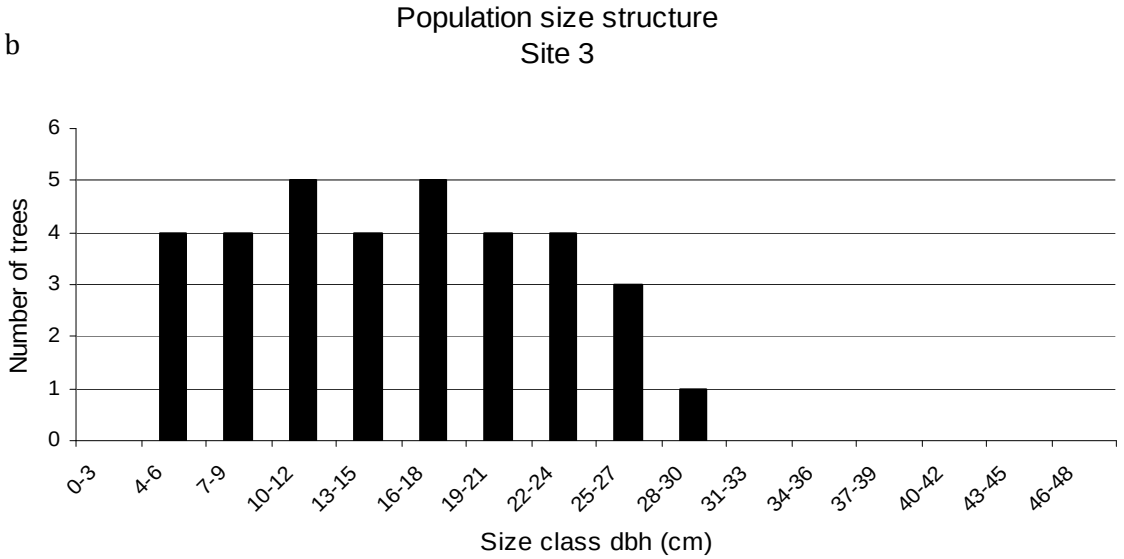

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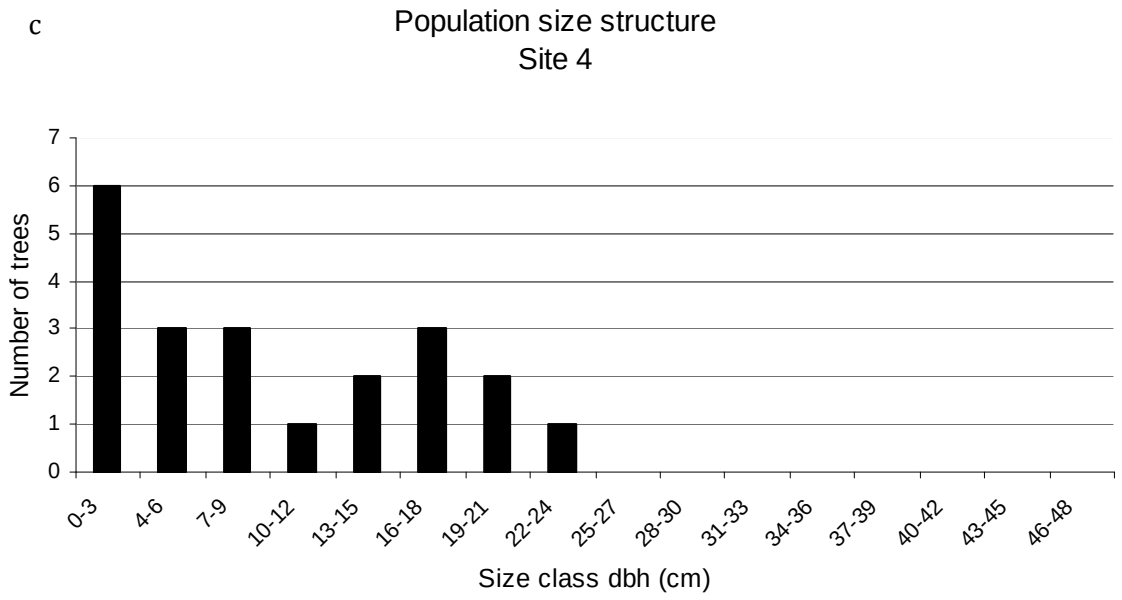
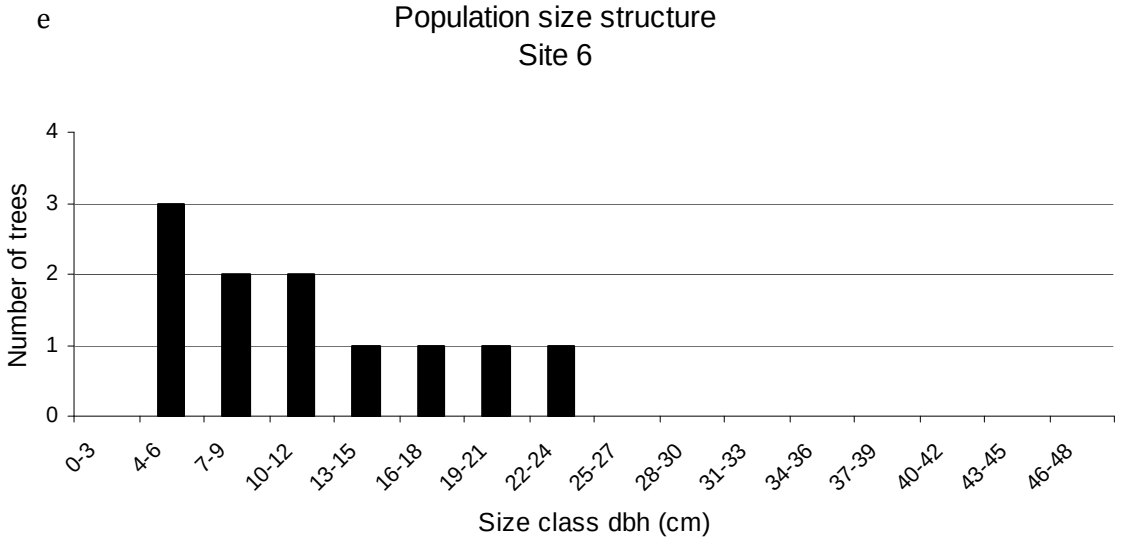

Population size structure
Site 4
Number of trees
0
1
2
3
4
5
6
7
0-3
4-6
7-9
10-12
13-15
16-18
19-21
22-24
25-27
28-30
31-33
34-36
37-39
40-42
43-45
46-48
Size class dbh (cm)

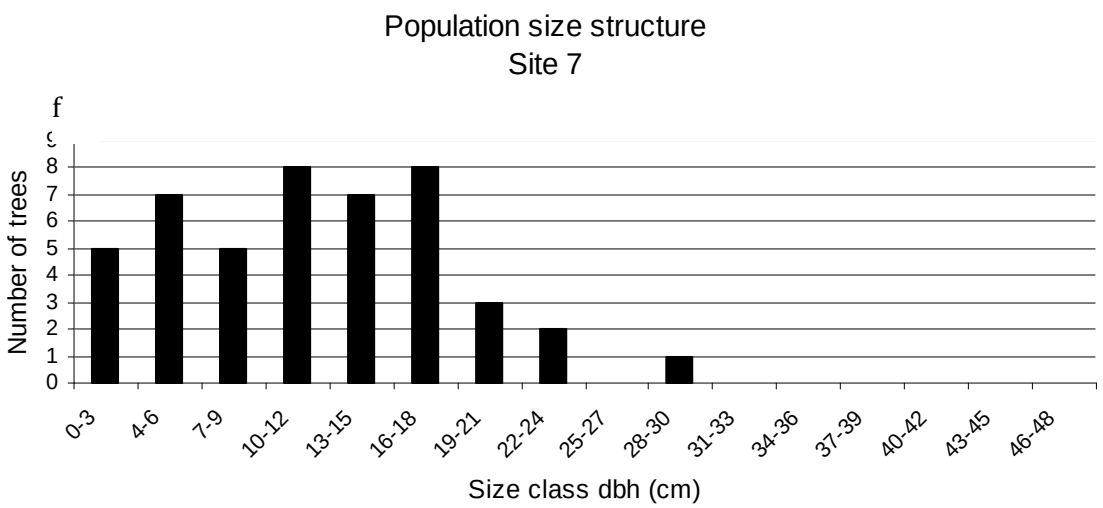
d


Population size structure
Site 5
Number of trees
0
1
2
3
4
0-3
4-6
7-9
10-12
13-15
16-18
19-21
22-24
25-27
28-30
31-33
34-36
37-39
40-42
43-45
46-48
Size class dbh (cm)

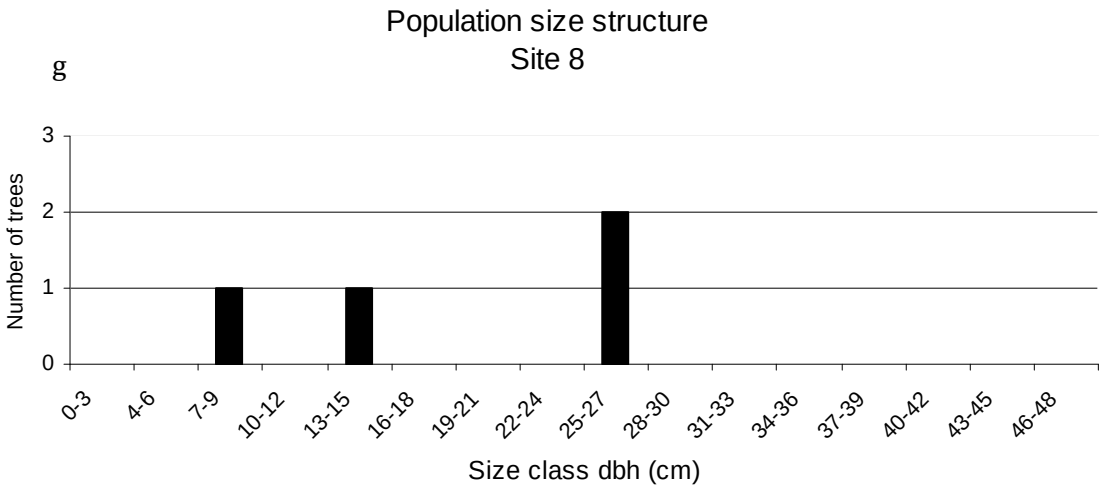
e

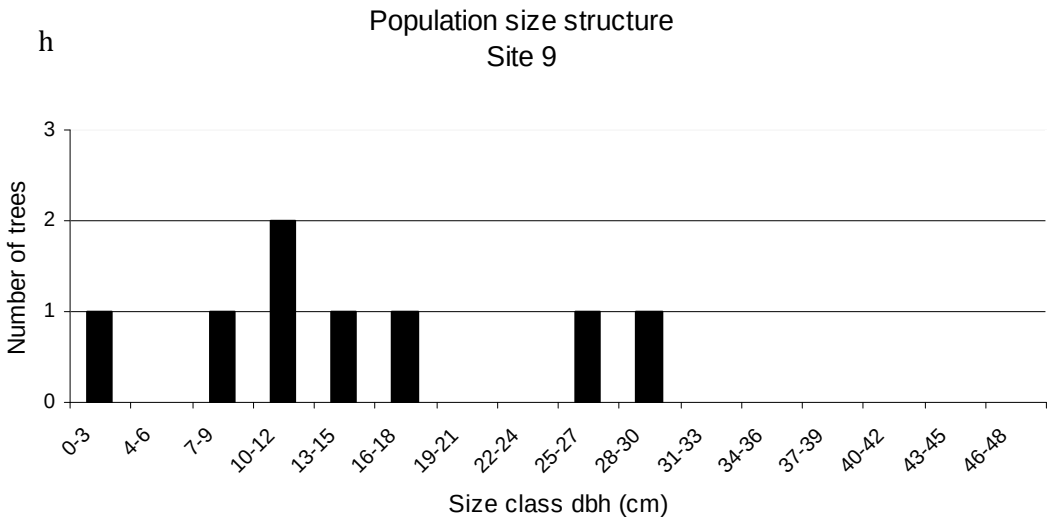

Population size structure
Site 6
Number of trees
0
1
2
3
4
0-3
4-6
7-9
10-12
13-15
16-18
19-21
22-24
25-27
28-30
31-33
34-36
37-39
40-42
43-45
46-48
Size class dbh (cm)

f


Population size structure
Site 7
Number of trees
0
1
2
3
4
5
6
7
8
9
0-3
4-6
7-9
10-12
13-15
16-18
19-21
22-24
25-27
28-30
31-33
34-36
37-39
40-42
43-45
46-48
Size class dbh (cm)

g


Population size structure
Site 8
Number of trees
0
1
2
3
0-3
4-6
7-9
10-12
13-15
16-18
19-21
22-24
25-27
28-30
31-33
34-36
37-39
40-42
43-45
46-48
Size class dbh (cm)



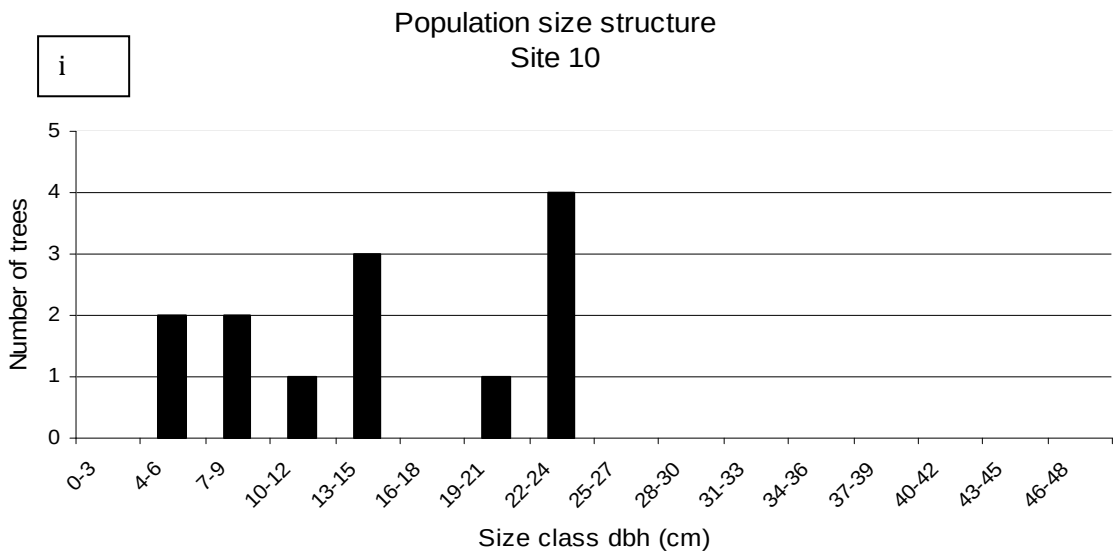


Fig. 6 a-i. Population size structure of *Pterocarpus angolensis* with a height above 2 m in each of the study sites 2 (Fig. 7a) to 10 (Fig. 7i), Site 1 is not represented since no individuals were found there.

Tree and seedling density

The total area inventoried for the adult individuals (trees >2 m in height) was 4 ha which gives a total density of 52.5 individuals/ha for the whole study area. A total number of 91 *P. angolensis* seedlings (<2 m) were found in the ten sites. The total area inventoried for seedlings adds up to 0.8 ha which gives a total density of 113.75 seedlings/ha. Fig. 7 shows the tree and seedling density for each site. Noteworthy is the fact that in all sites except for 2 and 4, the seedling density exceeds the tree density. Location 7 and 10 has notably higher seedling densities than the rest of the locations.

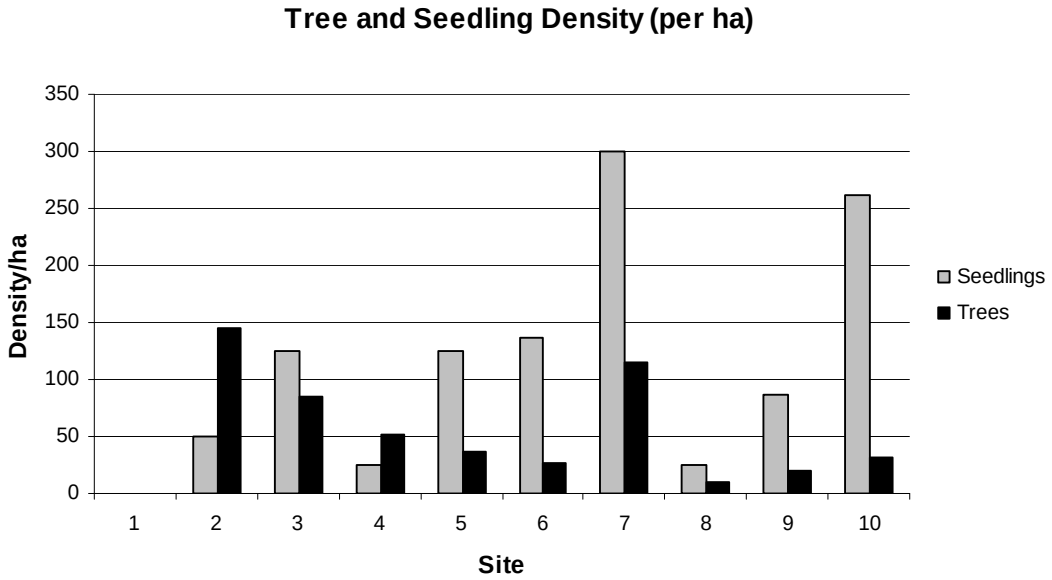


Fig. 7. Tree and seedling density per hectare for each site. In each site a total area of 0.4 ha was inventoried for the trees (>2 m.) while a total area of 0.08 ha was inventoried for the seedlings.

The first fruit-bearing individuals appear in the 13-15 cm size class (Fig. 8). In the size class 25-27 cm, the proportion of fruit-bearing individuals is the highest. The two individuals in the largest size classes do not bear fruit, but this could be seen as mere coincidence. Out of the 210 trees, 50 bore fruit (24%).

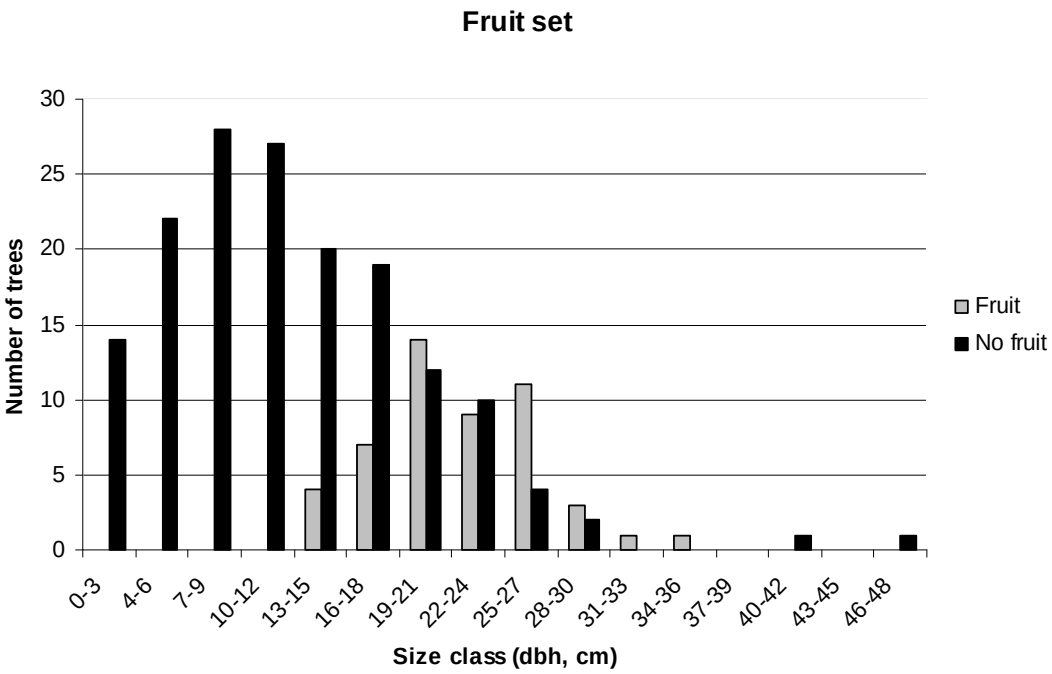


Fig. 8. The distribution of fruit-bearing and non-fruit-bearing trees among the size classes.

The height class distribution of the seedlings found in the transects is shown in Fig. 9. The majority of the seedlings belong to the three smallest height classes, 0-20 cm, 21-40 cm and 41-60 cm.

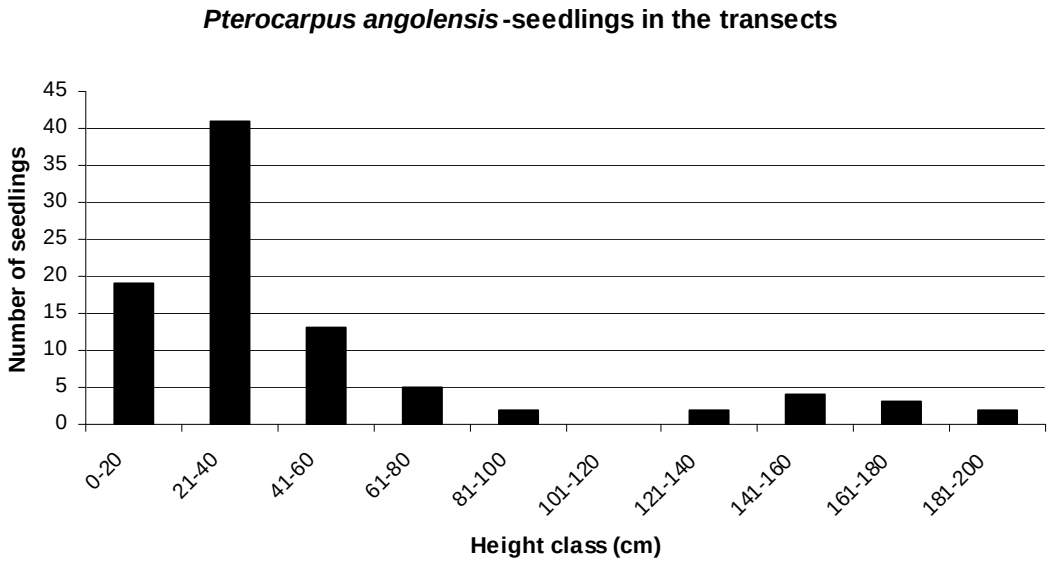


Fig. 9. Size structure of the seedlings found in the transects

Recruitment

Out of the 27 trees investigated, seedlings were found below 23 of them while fruits were found below 19 of the 27 trees. Below 11 of the 27 trees adult *P. angolensis* recruits were found. Seedlings and adult recruits combined, recruits were found under 25 out of the 27 trees. Fig. 10 shows the mean values of the number of seedlings, fruits and adult individuals found below the mother trees. Under each mother tree there is a mean of 5.6 fruits and a mean of 4.5 seedlings. No significant correlations (Pearson correlation, $p>0.05$) were found between number of seedlings and each of the environmental variables (grass coverage, bush coverage, canopy projection and dbh (cm)). There is a trend, though, in the correlation between number of seedlings and grass coverage (Pearson correlation, $p=0,272$).

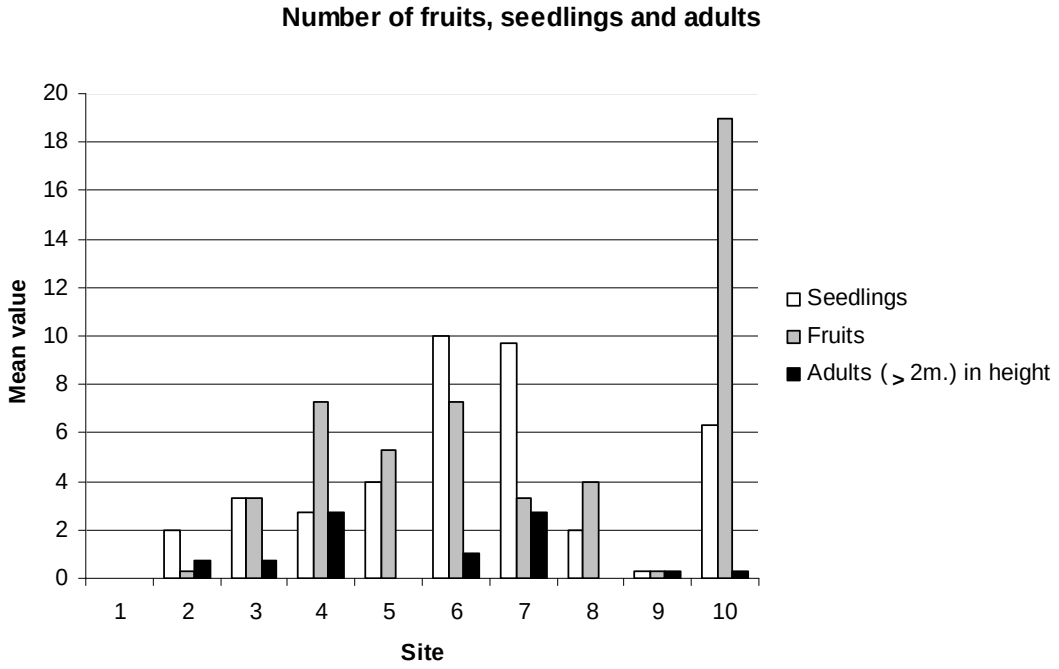


Fig. 10. Mean values of the number of fruits, seedlings and adults (＞2m) found below the mother trees. In site 1 no *P. angolensis* individuals were found.

Fig. 11 shows the dispersal distance of fruits and seedlings from the supposed mother tree within a radius of 10 m. The further away from the mother tree, the more seedlings were present. The opposite goes for the fruit, there is a clear peak at a distance of 2.1-3 m, but then the amount decreases further away from the tree.

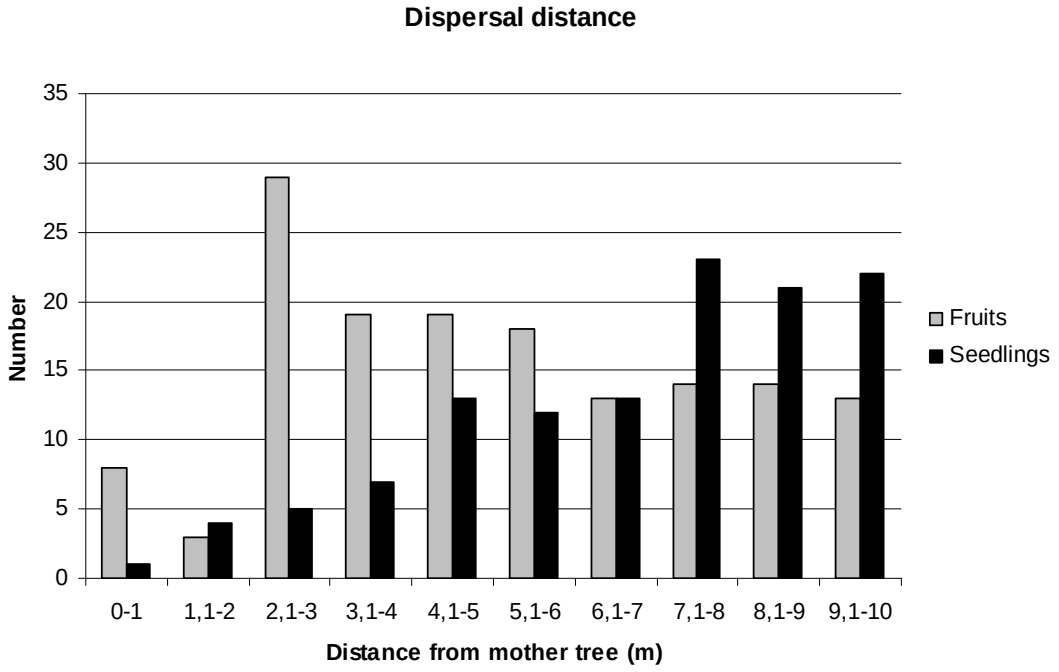


Fig 11. The distance of dispersal from the mother tree for fruits and seedlings. Based on data obtained from 27 such trees.

Discussion

Population size structure

The population size structure shown in Fig. 5 does not match the reversed J-shape mentioned in the introduction. The smallest size classes do not have the highest number of individuals. This is due to the fact that this is a population affected by logging. There is a sudden drop in the size structure after the size class 25-27 cm. Fig. 12 shows the population size structure of *P. angolensis* from a study in the same area conducted by Backéus et al. (2006) in 2000-2002. In this population size structure graph, the drop comes already at around 20 cm. This is an interesting observation and an indication that the law prohibiting cutting of *P. angolensis* which was implemented in 2002 actually had a positive effect and led to decreased harvest, although this result should be considered with caution since my data and the data from Backéus et al. (2006) are not from the exact same sites. The data from 2000-2002 were collected when a check-point had been established at Mikumi by the entrance of the Kilosa road which made smuggling of logs more difficult.

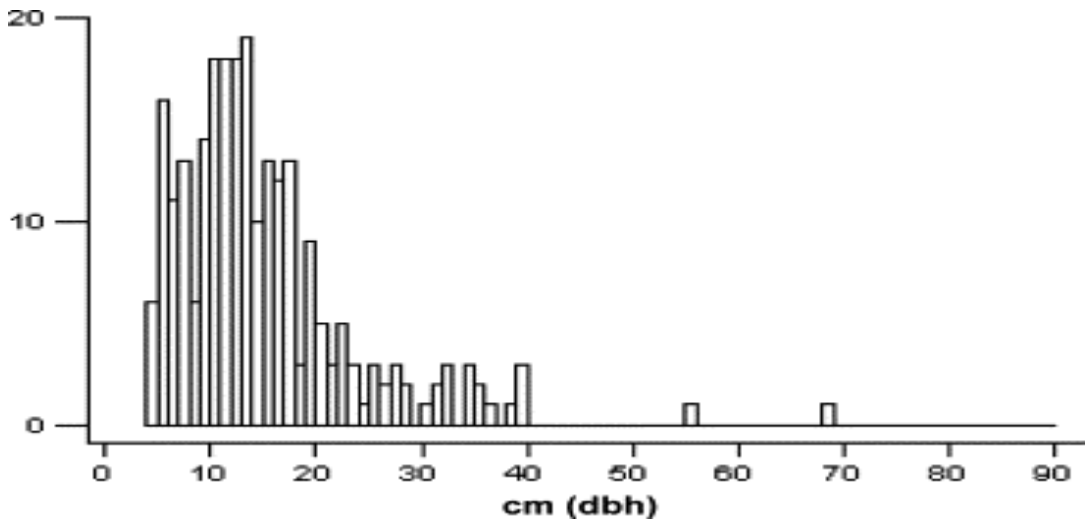


Fig. 12. Population size structure of *Pterocarpus angolensis* around Mikumi and Ihombwe villages. Data collected in 2000-2002 (From Backéus et al. 2006)

The size structures differ between the sites (Fig. 6). The site that really stands out is number 2, which has the highest abundance of *P. angolensis* individuals, but the size distribution is shifted towards the right and there are few individuals in the smaller size classes. Fig. 7 shows that the seedling density in site 2 is very low in proportion to the tree density. So, the recruitment is low in this area, but it is very difficult to see any reason for this with the data available. Generally, though, Fig. 6 shows that there was a more or less yearly regeneration in the area.

The known fact that small individuals of *P. angolensis* remain in a suffrutex stage for a number of years with yearly diebacks before elongated stem are established, is illustrated in Fig. 9. The population peak in the height class 21-40 cm is most likely due to this phenomenon. Once the saplings leave this stage they grow fast and pass quickly through the size classes.

Tree density
The number of *P. angolensis* individuals varies greatly between sites (Fig. 4). Site 1 is a heavily disturbed bush land very close to Mikumi village with no larger trees of any species. Most *P. angolensis* trees were found in site 2, and then the abundance of trees decreases with increased distance to Mikumi village. This pattern is broken with site 7, where the abundance is very high. The reason for this could be that this site is located very close to the intersection between the road to Kilosa and the road to Ihombwe, thus very visible from both roads, which could discourage illegal loggers. The terrain is also very flat which could be advantageous for easier establishment of the trees.

It is a known phenomenon that illegal logging is negatively correlated to human settlements and to visibility. The gradual decrease in population size with distance from Mikumi village might be explained in a similar way. Site 8 is located quite close to Ihombwe village. This was the only site with obvious signs of grazing animals. These facts combined with the topography of the site could explain the very low abundance of *P. angolensis.* Sites 8, 9 and 10 all have a different soil type from the other sites, grey sandy soil instead of red (see Nordlund & Brus 2004).

Site ten is the least disturbed, it is close to a forest reserve and also quite far from nearest village or road. This is supported by data from the vegetation analysis together with results from Nordqvist (2009) who studied the butterflies in the area. Her results show that site ten has the highest abundance of butterflies confined to forests, while it has a lower abundance of butterflies confined to grassland. The abundance of *P. angolensis* in this site is quite low, and the trees are not particularly big (Fig. 6i) However, my observation at the site was a higher abundance of big *P. angolensis* individuals in the area, although it does not show in my data. Explaining the difference in abundance between the areas is very complex, and it seems like the variables that we have noted are not sufficient. A detailed history of the land use in the particular sites in combination with environmental data such as pH, temperature and soil composition might be helpful.

Fruit set
Already in the size-class 13-15 cm the first fruit-bearing individuals occur. The fact that they set fruit early and that the proportion of fruit-bearing trees is high between the size-classes 19-21 dbh(cm) and 25-27 dbh(cm) (i.e. in size classes too small for logging, see Fig. 4) is a good sign for the future of this population. Individuals in these classes are abundant. It has to be taken into consideration that the fruit set can vary from year to year due to environmental factors.

The striking majority of the seedlings are less than 60 cm high (Fig. 9). The reason for this is the annual die-back of seedlings. During their first years they put all their energy into creating a large root system, and then when they have enough resources, they can grow a few metres in one season.

The results shown in Fig. 10 can be compared with the results of Caro et al. (2005). I found recruits below 25 out of the 27 trees (93%), while they found recruits only below 102 out of 300 trees (34%). It has to be taken into consideration that in their study, they inventoried an area with a radius of 20 m from the mother tree, while I just used a radius of 10 m. Their study was carried out in six protected areas, while my study took place in unprotected areas. So the low rate of recruits in their study could be due to the effect of browsing and trampling

by larger mammals, which should be greater in protected areas than in unprotected ones. In my area both wild and domestic cattle are few, the latter due to a prevalence of nagana sickness.

Fig. 11, which shows the dispersal distance from the mother tree, is interesting since there is a discrepancy between the distance at which the fruits fall and the distance at which the seedlings grow. One possible reason could be the competition with the mother tree – growing close to another tree means competition for light, nutrients and space. Another reason, for which there are no studies done on this particular species, would be the effects of allelopathy, the mother tree could send out substances which inhibit seeds from germinating close to the mother tree. The distribution also conforms with Janzen's (1970) theory on the relations between distance to mother tree, density of seeds and probability for a seed to be eaten. The number of both seeds and seedlings was still high at a distance of 10 m, which deviates from Boaler's (1966) results.

Vegetation sampling

It is difficult to draw any conclusions from the vegetation data, and no classification of the sites has been done. But a few things stand out. Fig. 3 shows that sites 2, 3, 4, 6 and 7 have a higher abundance of small trees than sites (1), 5, 8, 9 and 10. Undisturbed miombo woodland generally consists of an elaborate upper canopy while the sub-canopy layer is scarce or absent (Campbell 1996). According to that, then sites 5, 8, 9 and 10 would be less disturbed than the other five sites. Site ten also has the highest abundance of large trees (Fig. 2). This suggests that site ten would be the least disturbed site out of the ten.

Other interesting observations

We noted that often the abundance of *P. angolensis* individuals seemed to be higher closer to the roads. One explanation for this could be the risk for illegal harvesters of getting seen and caught when cutting trees close to the road. Many of our locations are located within a hundred metres from the road, and that was enough to note a decline in the abundance.
The most sought after *P. angolensis* individuals by harvesters are those with straight stems and a large diameter. This explains the fact that most of the individuals we saw in the area were small and/or with crooked or bended stems. It is therefore reason to consider the risk for "genetic erosion", i.e. the deterioration of the quality of the population that could take place when the best individuals are constantly removed.

On many seedlings and young trees there was a fungal infection on the leaves, manifested as small, circular black dots. Boaler (1966) mentions a fungus, *Phyllachora pterocarpi*, living on the leaves of seedlings and trees. Whether it is this fungus I have observed I cannot be certain of, neither can I say anything about the possible effects it has on the tree. At one site a parasitic plant was observed in the canopy of many of the individuals. Vermeulen (1990), and Boaler (1966) both mentions the occasional existence of a parasitic mistletoe, *Loranthus* spp. Loranthaceae is a family of hemi-parasitic shrubs, living on branches of other dicotyledons (Polhill & Wiens, 1999).

Suggestions for further studies

This study constitutes a good background for future studies on *P. angolensis* in this particular area. It would be interesting to go back to exactly the same sites in a few years time to

investigate whether the population has continued to grow stronger. And as mentioned before, with more environmental data and a detailed history of the land use in the study sites, a more detailed picture of the situation would emerge. It would have been interesting to combine this study with interviews with politicians, scientists, conservationists, loggers, the police etc, to get more insight into the legal and illegal logging industry in Tanzania. We knew that there is a forest reserve in the area, which supposedly would be undisturbed miombo woodland, but unfortunately we were not able to get to it. It would have been useful to have an undisturbed area for comparison.

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Appendix I Description of the ten study sites

Study site	Description of study sites	Most common tree species
1	Bush land close to Mikumi village. Very low density of trees, no large trees. Red soil. Many signs of human activities. Small road going through the area to a place for "stone breaking". A small ravine going through the area. Grass height: 1.3 m. Canopy projection: 5%.	*Acacia nigrescens* *Combretum* sp. *Brachystegia boehmii* *Diplorhynchus condylocarpon* *Commiphora africana* *Acacia* sp. *Dichrostachys cinerea* *Dalbergia melanoxylon* *Piliostigma thonningii* (2 unknown species)
2	A smaller road goes in from the Kilosa road. High density of trees, many large trees. *Pterocarpus angolensis* is undoubtedly the most common tree species. Many signs of trees being cut. Red soil. Grass height: 1.75 m. Canopy projection: 40%.	*Pterocarpus angolensis* *Brachystegia boehmii* *Annona* sp. *Xeroderris stuhlmannii* *Crossopteryx febrifuga* *Combretum* sp. *Maerua angolensis* (1 unknown species)
3	A small path goes in from the Kilosa road. High density of trees, intermediate numbers of large trees. A few shallow ravines. Red soil. Grass height: 1.25 m. Canopy projection: 30%.	*Pterocarpus angolensis* *Brachystegia boehmii* *Combretum* sp. *Pseudolachnostylis maprouneifolia* *Brachystegia spiciformis* *Acacia nigrescens* *Brachystegia microphylla* *Acacia* sp. *Xeroderris stuhlmannii* *Bridelia cathartica* (2 unknown species)
4	Located between the pipeline and a small road going in from the pipeline. High density of trees, intermediate numbers of large trees. Many signs of tree cutting in the area. Red soil. Grass height: 1.25 m. Canopy projection: 40%.	*Pterocarpus angolensis* *Brachystegia boehmii* *Xeroderris stuhlmannii* *Combretum* sp. *Diplorhynchus condylocarpon* *Dichrostachys cinerea* (1 unknown species)
5	In the intersection between the Kilosa road and the pipeline. Very flat terrain. Low density of trees, few large trees. Signs of human activities, e.g. places for charcoal production, many big stumps, small cultivations. Red soil. Grass height: 1.75m. Canopy projection: 30%	*Pterocarpus angolensis* *Brachystegia boehmii* *Diplorhynchus condylocarpon* *Xeroderris stuhlmannii* *Burkea africana* *Combretum zeyheri* *Combretum molle* *Crossopteryx febrifuga* (2 unknown species)

Study site	Description of study sites	Most common tree species
6	Between the pipeline and Kilosa/Ihombwe-intersection. High density of trees, few large trees. Many large stumps. Red soil. Grass height: 0.75 m. Canopy projection: 35%.	*Piliostigma thonningii* *Brachystegia boehmii* *Pterocarpus angolensis* *Bridelia cathartica* *Crossopteryx febrifuga* *Pseudolachnostylis maprouneifolia* *Xeroderris stuhlmanii* *Annona senegalensis* *Combretum* sp. *Byrsocarpus orientalis* *Brachystegia spiciformis* (1 unknown species)
7	Very flat terrain situated between two intersecting roads. High density of trees, many large trees, high bush cover. Signs of collection of firewood. Red soil. Grass height: 1.25 m. Canopy projection: 50%.	*Byrsocarpus orientalis* *Brachystegia spiciformis* *Pterocarpus angolensis* *Diplorhynchus condylocarpon* *Brachystegia longifolia* *Combretum* sp. *Burkea africana* *Dichrostachys cinerea* (2 unknown species)
8	Relatively open forest sloping down towards southwest. Low density of trees, intermediate number of large trees. A ravine cuts through the area. Signs of grazing cattle. Grey, sandy soil. Grass height: 0.88 m. Canopy projection: 20%.	*Bridelia cathartica* *Pterocarpus angolensis* *Byrsocarpus orientalis* *Acacia* sp. *Combretum zeyheri* *Diplorhynchus condylocarpon* *Dalbergia melanoxylon* *Dichrostachys cinerea* *Brachystegia spiciformis* (7 unknown species)
9	Situated by the small village Ibegezi II. Low density of trees, intermediate number of large trees. Area sloping towards the north, several smaller ravines. Close to various larger cultivations of rice, maize, sugarcane etc. Grey, sandy soil. Grass height: 1.95 m. Canopy projection: 35%.	*Diplorhynchus condylocarpon* *Brachystegia spiciformis* *Brachystegia boehmii* *Xeroderris stuhlmannii* *Burkea africana* *Dalbergia melanoxylon* *Combretum* sp. *Dichrostachys cinerea* *Acacia* sp. *Pterocarpus angolensis* (2 unknown species)
10	Close to the Forest reserve. Hilly area. Low total density of trees, but many large trees. A few signs of human activity, such as old paths and a few stumps. Grey sandy soil. Grass height: 1.4 m. Canopy projection: 25%.	*Brachystegia boehmii* *Pterocarpus angolensis* *Brachystegia spiciformis* and/or *Julbernardia globiflora* *Pseudolachnostylis maprouneifolia* *Xeroderris stuhlmannii* *Combretum* sp. *Diplorhynchus condylocarpon* (1 unknown species)

Appendix II

Map of the area, with study sites 1-10 marked. From Strömqvist & Backéus (2009).