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Tree Stock, Structure and Use of Common Woody Species of a Town Neighboring Forest Reserve in Tanzania: Implication for Managing Carbon Accumulation

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Additional information is available at the end of the chapter

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Abstract

Town neighboring forests in the tropics suffer high human pressure owing to unregulated harvest to supply domestic energy and equipment. Although this causes considerable source of income among communities, it poses significant deforestation, thus, jeopardizing carbon accumulation potentials of most of the forests. This study therefore assessed the stock, structure and use of common woody species in a town neighboring forest reserve to elucidate the reserve's carbon accumulation potential amid pressures from surrounding communities. It was found out that the structure of the forest had been altered following unregulated tree harvest. There were selective harvesting and removal of valued timber trees, and key species that otherwise are responsible in regulating the ecosystem functioning of the reserve. It was apparent that the unregulated harvest is likely to jeopardize the ecosystem functioning and carbon accumulation potential of the reserve. Thus, to manage the reserve sustainably, awareness education on forest biodiversity conservation among surrounding local communities is recommended. We also recommend exploration of the reserve for ecotourism potentials. This might stimulate ecotourism activities in the area and provide an alternative source of income among the local population. This would add value and sense of ownership and stimulate self-mobilization for protection of the reserve.

Keywords: miombo, savanna, harvest, exploitation, community, tropics, Africa

1. Introduction

The ecosystems of tropical natural forests are undergoing rapid destruction due to increasing of many factors including anthropogenic activities, natural catastrophes and climate change. Understanding in detail the drivers of such destruction and implied effects on carbon accumulation is of vital importance for conservation [1]. The majority of the forest ecosystems especially in the tropic are never been stable following anthropogenic pressures, climatic, and geo-morphological influences [2]. Overall, the threats facing the tropical forests due to anthropogenic activities are habitat modification and destruction [3] of which burning and harvesting are the most pressing [3–9]. The reasons behind burning are many including attainment of higher visibility to evade wild carnivores, to find prey among hunters and initiation of off-season re-growth of perennial fodders [5, 6]. Harvesting, on the other hand, comes in many forms to fulfill needs such as firewood, building materials, domestic items (e.g., mortar, bow, arrow handle, spear handle), fencing materials, among others. While these forms of use of forest products cause significant source of income for many small scale farmers in developing countries, they pose significant deforestation [10]. For example, in the 1990s, there were approximately 40 million people living in Africa's miombo woodlands—all with an additional 15 million urban residents depending on the woodlands for domestic fuel—especially charcoal [11]. Moreover, the building materials and fuel energy are needed in high supply particularly for forests neighboring residential areas [1, 10]. In Kenya, for instance, some tree species such as *Brachylaena huillensis* and *Dalbergia melanoxylon* are highly sought and have been depleted in forests near towns [12]. In Tanzania, tree species such as *Pterocarpus angolensis*, *Milicia excelsa*, *Azizelia quanzensis*, *Khaya anthotheca* and *D. melanoxylon* are categorized as protected trees due to overexploitation and harvesting them even on private land requires the government authorization [13, 14].

Some studies indicate that valued timber trees such as *P. angolensis* suffers high human pressure and are highly sought throughout south-central Africa [15, 16], such that the stock in most places has been depleted to vulnerable numbers [17, 18], and the structure has been damaged beyond repair in the near future in some reserves [19]. In Msagania Forest Reserve for example, Schwartz et al. [18] reported that loggers have reduced the population density of *P. angolensis* from 11.4 to 3.7 trees/ha, whereby, trees are left standing only if they are not of harvestable size yet. This kind of selective use has a profound impact on tree stock and structure and can jeopardizes the forests carbon accumulation potential [20] as well as the general biodiversity [21, 22]. The fact that most important sites and habitats in Tanzania are not included in a reserved areas system, and most of those under the reserved areas system are not well protected [1, 23], the forests are likely to continue experiencing unregulated exploitation from surrounding communities [1, 23, 24], thus jeopardizing their carbon accumulation potential.

This study therefore aimed at assessing the stock, structure and use of common woody species in a town neighboring forest reserve to elucidate its carbon accumulation potential and put forward management recommendations. The forest, hereby referred to as Ndege Forest Reserve (NFR) is a small reserve located about 10 km north of Morogoro Municipality, Tanzania (**Figure 1**). The surrounding local communities have depleted its biological and ecological resources to unprecedented level. There is widespread tree felling, encroachment and bushfires [14]. The northwest slope of the reserve is already completely deforested and its

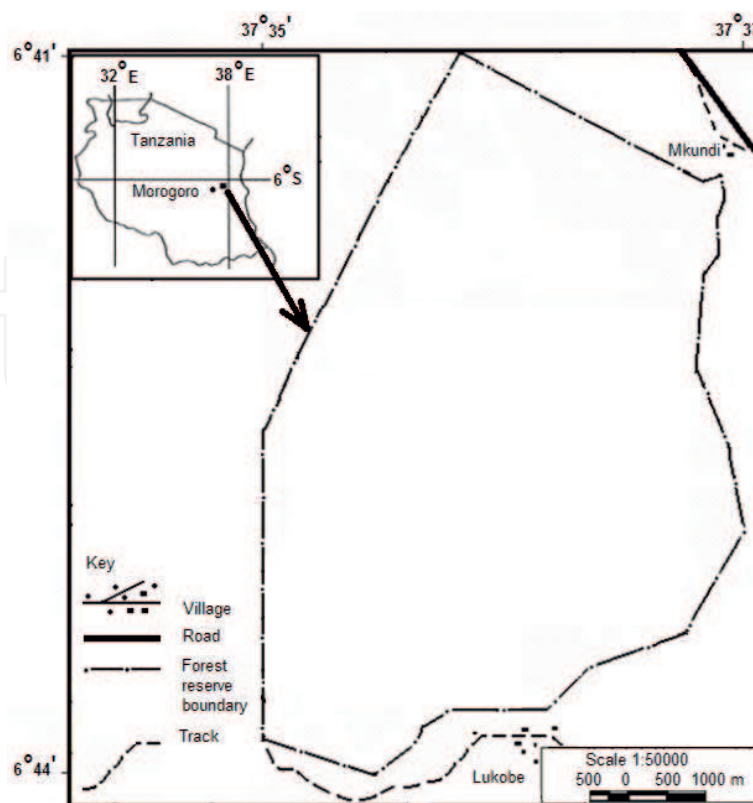


Figure 1. Map showing location of the study area: modified after national tree seed programme in Tanzania, NTSP [30].

entire valued tree has been wiped out [25]. However, there is lack of information on natural stands of different plant species in this reserve. The fact that information on threats facing trees is usually scanty and anecdote, assessment of tree stock, structure and human use for the NFR may shade light on our knowledge on carbon accumulation potential of the reserves neighboring towns in tropical Africa.

2. Materials and methods

This study was conducted in Ndege Forest Reserve (NFR). This reserve is found between 6°41' to 6°44' S and 37°35' to 37°37' E [25, 26]. It is a small reserve covering an area of about 36.14 km² and is located about 10 km north of Morogoro Municipality, Tanzania (**Figure 1**). The rainfall is estimated at 850 mm/year and the temperatures range from 20–25°C [25]. The vegetation of the area is mainly woodlands [25, 26]. The dominant tree species of the reserve are *Brachystegia microphylla*, *Brachystegia boehmii* and *Julbernardia globiflora*. Some other trees include *Albizia harveyi*, *Brachystegia spiciformis*, *Sterculia africana*, *Sterculia quinqueloba* and *Xeroderris stuhlmannii*. Important timber species in the reserve are *Brachystegia* spp., *P. angolensis* and *Afzelia quanzensis* [26].

During data gathering, we sampled 50 sites in which we took vegetation measurements and indices of tree use. The detailed study design and vegetation sampling procedure is explained in Modest et al. [14]. In brief, we measured diameter at breast height (dbh), crown

diameter and height of trees and counted saplings (dbh $1 \leq 10$ cm) and trees (dbh > 10 cm). The stump diameters were as well measured. This data was collected within 50 quadrats measuring 20 by 20 m spread randomly in the study area. Furthermore, additional 50 quadrats measuring 5 by 5 m were established within the 20 by 20 m quadrats for sampling seedlings which were regarded as small trees with dbh < 1 cm [27, 28]. We also recorded the global positioning system (GPS) data for each quadrat for use in determining the distribution of valued timber tree species in the reserve.

We analyzed the data, first by determining the floristic composition of all woody species through preparing a checklist; then, using previously published literature, we assigned the tree species in their respective families and defined their habit. Second, from the checklist we determined the common woody species using the Important Value Index (IVI) criteria following Kent and Coker [29], as follows:

$$IVI = \text{relative dominance} + \text{relative frequency} + \text{relative density}$$

where

$$\text{Relative dominance} = (\text{Sum of basal area of the } i\text{th species} / \text{total basal area of all species}) \times 100.$$

$$\text{Relative density} = (\text{Number of stems/ha of the } i\text{th species} / \text{total number of stems/ha of all species}) \times 100.$$

$$\text{Relative frequency} = (\text{Frequency of the } i\text{th species} / \text{total frequency of all species}) \times 100.$$

Here, the first 10 species with the highest IVIs were picked as common species and the rest of the discussion in this chapter refers to them.

We proceeded in assessing the stock, structure and use of common woody species by determining their population structure, conservation priority, level of exploitation and spatial distribution. The population structure was assessed based on tree population density, tree dbh, density distribution of seedlings, saplings and mature trees and canopy diameter as well as canopy area. The population density on the other hand was calculated as number of individual plants/ha [29, 31, 32]. The tree dbh were categorized into 10 classes from class 1 dbh 0–4.9 cm, class 2 dbh 5–9.9 cm, class 3 dbh 10–14.9 cm, class 4 dbh 15–19.9 cm, class 5 dbh 20–24.9 cm, class 6 dbh 25–29.9 cm, class 7 dbh 30–34.9 cm, class 8 dbh 35–39.9 cm, class 9 dbh 40–44.9 cm and class 10 dbh above 45 cm [33, 34]. The dbh were also grouped into three categories following Jones [35] to determine the density of seedlings, saplings and mature trees as follows:

seedlings, individuals with dbh < 1 cm

saplings, individual with dbh $1 \leq 10$ cm and

trees, individual with dbh > 10 cm

Moreover, the canopy diameters were standardized and presented as mean canopy diameter \pm SE, while the canopy area (CA) was calculated following Cunningham [33] as shown below:

$$CA = W1/2 \times W2/2$$

where W1 = widest canopy diameter and W2 = perpendicular diameter to the widest diameter.

The conservation priority for each of the 10 common woody species was determined using the IVI classes and the regeneration status based on density of seedlings and saplings following Shibru and Balcha [36]. For this case, the IVIs were categorized into five classes:

Class 5 = IVI (<1)

Class 4 = IVI (1–10)

Class 3 = IVI (10.1–20)

Class 2 = IVI (20.1–30) and

Class 1 = IVI (>30)

The seedlings and saplings on the other hand were grouped into three classes:

Class 1: species with 0 individual seedling and saplings ha⁻¹

Class 2: species with 0 > 50 individual seedlings and saplings ha⁻¹

Class 3: species with <50 individual seedlings and saplings ha⁻¹

To assess the level of exploitation of the trees, we determined the basal area of the stumps. First, the stump diameters were converted into dbh using this linear regression equation presented in Luoga et al. [37]; $dbh = -3.17 + 0.961SD$, where SD = stump diameter. Then, the resulting dbh were used to calculate the basal area following Martin [38] as follows; $BA = \pi(dbh/2)^2$, where dbh is diameter at breast height. Finally, we assessed the distribution of the highly valued timber species *P. angolensis* using the ArcView computer software version 3.2.

3. Results and discussion

3.1. Floristic composition and population structure of the common woody species

A total of 102 woody species were recorded in the reserve and were represented by 30 families as presented in **Table 1**. The most dominant family was Fabaceae with 31 species, whereas several other families were represented by only one species. Of the 102 woody species recorded, 78 were trees while 24 were shrubs. The first 10 common woody species determined using the IVI classification procedure were *Acacia nilotica*, *Brachystegia boehmii*, *Brachystegia microphylla*, *Combretum molle*, *Dalbergia boehmii*, *Diplorhynchus condylocarpon*, *Julbernardia globiflora*, *Lannea welwitschii*, *Pteleopsis myrtifolia* and *Pterocarpus angolensis*. The

SN	Species name	Family	Habit	
			Shrub	Tree
1	<i>Ozoroa insignis</i> Del.	Anacardiaceae	*	
2	<i>Ozoroa reticulata</i> (Baker F.) R. Fern. & A. Fern.	*	*	
3	<i>Lannea schimperi</i> (A. Rich.) Engl.	*		*
4	<i>Lannea welwitschii</i> (Hiern) Engl.	*		*
5	<i>Sclerocarya birrea</i> (A. Rich.) Hochst.	*		*
6	<i>Sorindeia madagascariensis</i> Baill	*		*
7	<i>Annona senegalensis</i> Pers	Annonaceae		*
8	<i>Steganotaenia araliacea</i> Hostchst.	Apiaceae	*	
9	<i>Diplorhynchus condylocarpon</i> (Muell-Arg.) Pichon	Apocynaceae		*
10	<i>Kigelia africana</i> (Lam) Benth.	Bignoniaceae		*
11	<i>Markhamia obtusifolia</i> (Baker) Sparague	*		*
12	<i>Stereospermum kunthianum</i> Cham.	*		*
13	<i>Bombax rhodognaphalon</i> K. Schum.	Bombacaceae		*
14	<i>Ehretia amoena</i> Klotzsch	Boraginaceae		*
15	<i>Commiphora africana</i> (A. Rich.) Engl.	Burseraceae	*	
16	<i>Boscia salicifolia</i> Oliv.	Capparidaceae	*	
17	<i>Maerua triphylla</i> A.Rich	*		*
18	<i>Maytenus senegalensis</i> (Lam.) Excell	Celastraceae		*
19	<i>Parinari excelsa</i> Sabine	Chrysobalanaceae		*
20	<i>Garcinia huillensis</i> Welw	Clusiaceae		*
21	<i>Combretum adenogonium</i> Steud. ex A. Rich	Combretaceae		*
22	<i>Combretum collinum</i> Fresen.	*		*
23	<i>Combretum molle</i> R.Br. ex G. Don	*		*
24	<i>Combretum padoides</i> Engl. & Diels	*		*
25	<i>Combretum zeyheri</i> Sond.	*		*
26	<i>Pteleopsis myrtifolia</i> Engl. & Diels	*		*
27	<i>Terminalia sericea</i> Burch. ex DC	*		*
28	<i>Diospyros consolatae</i> Chiov.	Ebenaceae	*	
29	<i>Diospyros zombensis</i> (B.L. Burt) F. White	*	*	
30	<i>Diospyros kirkii</i> Hiern	*		*
31	<i>Diospyros mespiliformis</i> Hochst. ex A. DC	*		*
32	<i>Drypetes gerrardii</i> Hutch	Euphorbiaceae	*	
33	<i>Bridelia cathartica</i> Bertol.F.	*		*
34	<i>Croton macrostachyus</i> Hochst. ex Delile	*		*

SN	Species name	Family	Habit
35	<i>Croton megalocarpus</i> Hutch	*	*
36	<i>Margaritaria discoidea</i> (Baill.) Webster	*	*
37	<i>Pseudolachnostylis maprouneifolia</i> Pax	*	*
38	<i>Spirostachys africana</i> Sond	*	*
39	<i>Suregada zanzibariensis</i> Baill.	*	*
40	<i>Acacia pentagona</i> (Schumach.) Hook. F.	Fabaceae	*
41	<i>Bauhinia petersiana</i> C. Bolle		*
42	<i>Cassia abbreviata</i> Oliver	*	*
43	<i>Dichrostachys cinerea</i> (L.) Wight & Arn	*	*
44	<i>Ormocarpum kirkii</i> S. Moore	*	*
45	<i>Acacia goetzei</i> Harms.	*	*
46	<i>Acacia goetzei</i> subsp. <i>microphylla</i> Brenan	*	*
47	<i>Acacia nigrescens</i> Oliver	*	*
48	<i>Acacia nilotica</i> (L.) Willd.ex Del	*	*
49	<i>Acacia polyacantha</i> subsp.	*	*
50	<i>Azelia quanzensis</i> Welw.	*	*
51	<i>Albizia harveyi</i> Fourn	*	*
52	<i>Albizia petersiana</i> Oliver	*	*
53	<i>Brachystegia boehmii</i> Taub.	*	*
54	<i>Brachystegia microphylla</i> Harms	*	*
55	<i>Brachystegia spiciformis</i> Benth	*	*
56	<i>Dalbergia boehmii</i> Taub	*	*
57	<i>Dalbergia melanoxylon</i> Guill.& Perr	*	*
58	<i>Dalbergia nitidula</i> Baker	*	*
59	<i>Dalbergia obovata</i> E. Mey.	*	*
60	<i>Erythrina abyssinica</i> Lam.ex DC	*	*
61	<i>Erythrophleum africanum</i> (Benth.) Harms	*	*
62	<i>Julbernardia globiflora</i> (Benth.) Troupin	*	*
63	<i>Lonchocarpus bussei</i> Harms	*	*
64	<i>Millettia usaramensis</i> Taub	*	*
65	<i>Pterocarpus angolensis</i> DC.	*	*
66	<i>Pterocarpus tinctorius</i> Welw.	*	*
67	<i>Scorodophloeus fischeri</i> (Taub.) J. Leon	*	*
68	<i>Swartzia madagascariensis</i> Desv.	*	*
69	<i>Xeroderris stuhlmannii</i> (Taub.) Mendoca & Sousa	*	*

SN	Species name	Family	Habit
70	<i>Pterocarpus rotundifolius</i> (Sond.) Druce	*	*
71	<i>Strychnos spinosa</i> Lam.	Loganiaceae	*
72	<i>Ficus bussei</i> Mildbr. & Burret	Moraceae	*
73	<i>Ficus exasperata</i> Vahl	*	*
74	<i>Ficus sycomorus</i> L.	*	*
75	<i>Treculia africana</i> Decne. ex Trecul	*	*
76	<i>Ochna leptoclada</i> Oliver	Ochnaceae	*
77	<i>Ximenia americana</i> L.	Olacaceae	*
78	<i>Ximenia caffra</i> Sond.	*	*
79	<i>Ziziphus mucronata</i> Willd	Rhamnaceae	*
80	<i>Crossopteryx febrifuga</i> (G. Don) Benth.	Rubiaceae	*
81	<i>Gardenia ternifolia</i> Schumach. & Thonn.	*	*
82	<i>Pavetta crassipes</i> K. Schum	*	*
83	<i>Vangueria infausta</i> Burch.	*	*
84	<i>Catunaregam spinosa</i> (Thumb) Tirveng.	*	*
85	<i>Grumilea riparia</i> K. Schum & K. Krause	*	*
86	<i>Toddalia asiatica</i> Baill.	Rutaceae	*
87	<i>Zanthoxylum chalybeum</i> Engl.	*	*
88	<i>Allophyllus africanus</i> P. Beauv.	Sapindaceae	*
89	<i>Deinbollia borbonica</i> Scheff.	*	*
90	<i>Haplocoelum inopleum</i> Radlk	*	*
91	<i>Lecaniodiscus fraxinifolius</i> Bak.	*	*
92	<i>Zahna africana</i> (Radlk.) Exell	*	*
93	<i>Synsepalum brevipes</i> (Baker) T.D. Penn	Sapotaceae	*
94	<i>Harissonia abyssinica</i> Oliv.	Simaroubaceae	*
95	<i>Dombeya cincinnata</i> K. Schum. ex Engl.	Sterculiaceae	*
96	<i>Dombeya rotundifolia</i> (Hochst.) Planch.	*	*
97	<i>Sterculia africana</i> (Lour.) Fiori.	*	*
98	<i>Sterculia quinqueloba</i> (Garcke) K. Schum	*	*
99	<i>Grewia ectasicarpa</i> S. Moore	Tiliaceae	*
100	<i>Grewia bicolor</i> Juss.	*	*
101	<i>Heteromorpha trifoliata</i> (Wendl.) Eckl. & Zeyh.	Umbelliferae	*
102	<i>Vitex payos</i> (Lour.) Merr.	Verbenaceae	*

Table 1. Checklist for the tree species recorded during field survey. Under the “Family” column, the star “*” denote that the species belongs to the family mentioned above it. The same star under the “Habit” column denote that the species is either a Shrub if the star is under the “Shrub” column, otherwise the species is a Tree.

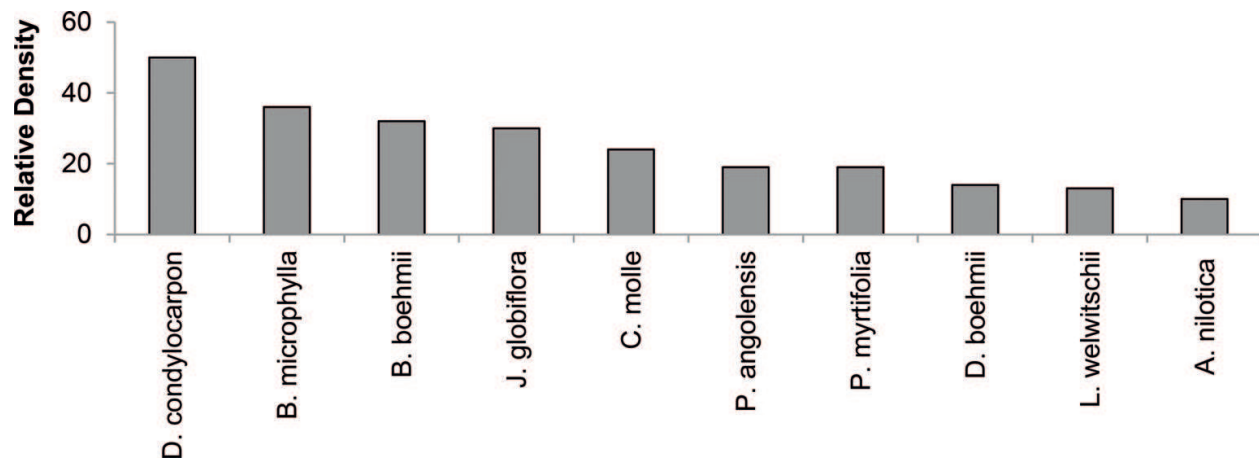


Figure 2. Relative density of the common woody species in NFR.

relative density of these common woody species for stems with dbh > 4 cm is presented in **Figure 2**, whereby, *D. condylocarpon* had the highest relative density of 50 stem/ha, while *L. welwitschii* had the least density that is, 13 stem/ha.

The population structure of the common woody species in NFR was assessed based on dbh class size distribution, mean crown diameter and area, and density distribution of seedlings, saplings and mature trees. The dbhs of the common woody species recorded during the study are presented in **Figure 3**. All the 10 representative woody species had more individuals in their first classes with an abrupt drop beginning in the following class indicating the characteristic inversed J-shapes. However, except for *C. molle* of which its graph had a smooth inversed J-shape, the graphs for the rest of the species seemed interrupted. This is an indication of selective removal of individuals, especially those at pole size stages and the mature ones. The Morogoro region in which NFR is located has a history of human exploitation of tree species. For example, Wells and Wall [39], reported that, between 1970 and 1980 Morogoro Region was the source of much of the hardwood timber going to the Dar es Salaam market, but from early 1990s, the Morogoro region was exhausted of valued timber species such as *P. angolensis* and the production shifted to Tabora region, and even further west to Rukwa Region by late 1990s. Therefore, this denotes that, NFR being in Morogoro region, its quality timber trees has long been extracted, which is also evidenced by small dbhs in almost all the common tree species **Figure 3**. Moreover, the trend in dbh classification of the 10 common woody species (**Figure 3**) indicates that the graphs of some species such as *B. microphylla* are almost flat for individuals from the sapling stage. This is not a health state for the NFR since it is evident that trees are harvested in all stages from sapling to mature trees. Newton [40] pointed out that, when there is a very few trees recorded in lower dbh classes, extracting of large sized trees is detrimental to the future populations. Therefore, if unsustainable harvest continues in NFR, it is likely that the knock-off effect of the forest valuable trees will occur within a short span of time.

Figure 4 shows that of the common woody species *B. microphylla* had the biggest mean canopy diameter while that of *C. molle* was the smallest. Moreover, the mean canopy area was also the biggest for *B. microphylla* and the smallest for *C. molle* as shown in **Table 2**. The bigger crown diameter and area of *B. microphylla* as well as its higher density are indication that the species is potential especially in influencing the ecosystem functioning of the reserve. Thus, *B. microphylla* can be regarded as a foundation species for the NFR. By definition, a

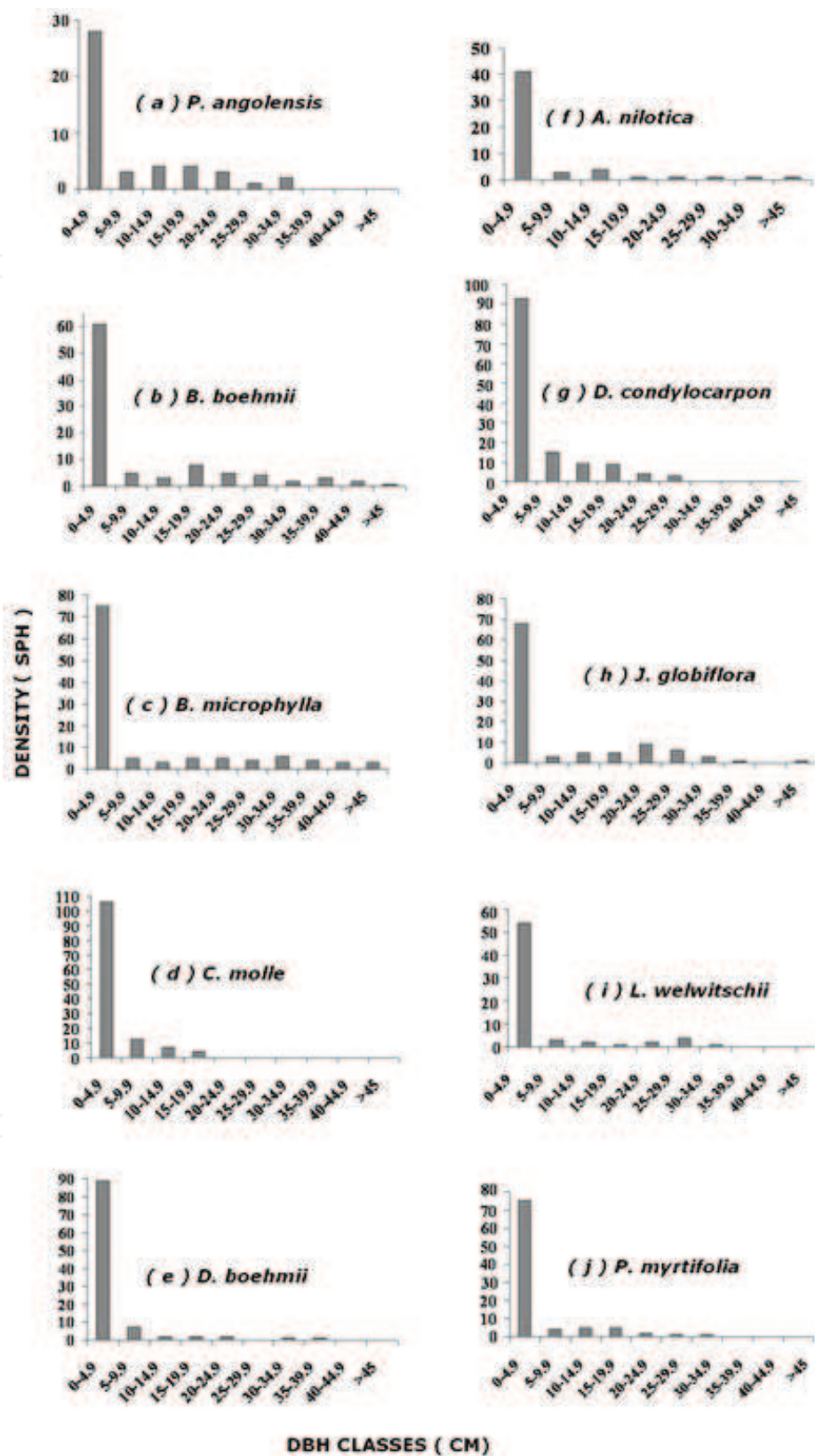


Figure 3. DBH class distribution of the common woody species recorded in NFR.

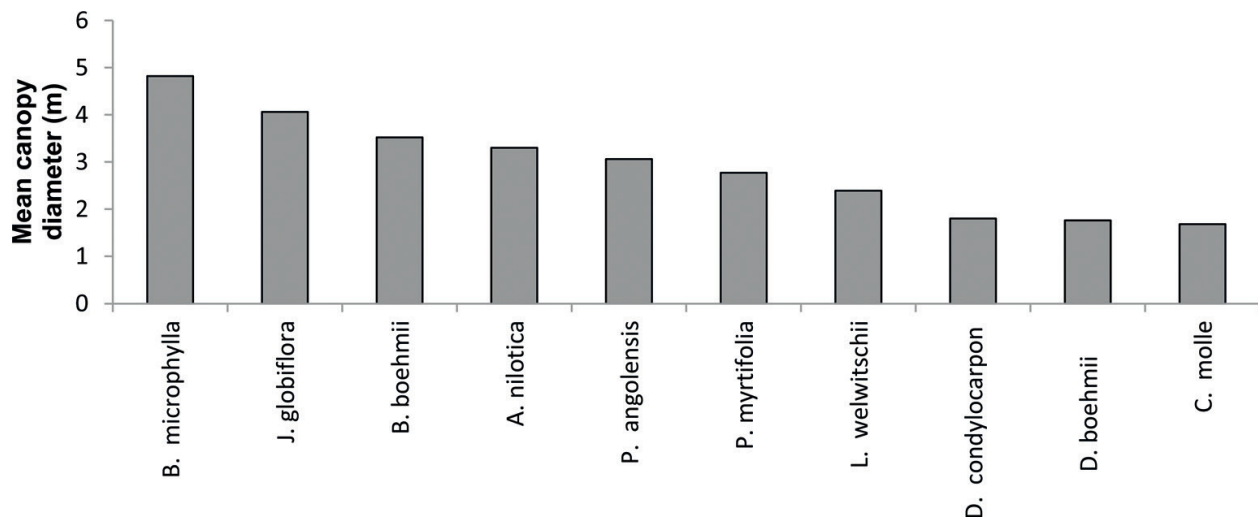


Figure 4. Mean canopy diameter of the common woody species.

Scientific name	Mean canopy area/ ha (m ²)	Std. error of the mean (SEM)	Lower 95% conf. limit	Upper 95% conf. limit
<i>B. microphylla</i>	11.55	1.46	8.64	14.46
<i>J. globiflora</i>	8.19	0.94	6.31	10.08
<i>B. boehmii</i>	6.26	0.79	4.46	7.84
<i>A. nilotica</i>	5.44	0.94	0.40	13.74
<i>P. angolensis</i>	4.70	0.82	3.05	6.35
<i>P. myrtifolia</i>	3.42	0.04	2.42	4.37
<i>L. welwitschii</i>	3.40	0.89	01.58	5.21
<i>D. boehmii</i>	1.85	0.53	0.78	2.63
<i>D. condylocarpon</i>	1.51	0.14	1.23	1.79
<i>C. molle</i>	1.37	0.17	1.04	1.72

Table 2. Mean canopy area/ha (m²) of the common woody species recorded in NFR.

foundation species is “a single species that defines much of the structure of a community by creating locally stable conditions for other species and by modulating and stabilizing fundamental ecosystem processes” [41, 42]. These kinds of species with greater influence on ecosystem usually possess greater repercussions on ecosystem functioning in case they disappear [43]. Therefore, for NFR *B. microphylla* can be regarded as a candidate foundation species, and in case it disappears there could be far reaching consequences [43]. Probably the species we see today in NFR especially the shade tolerant ones are a masterpiece of *B. microphylla*. Thus, if *B. microphylla* vanishes from NFR the species composition is likely to change with cascading effects on carbon accumulation potential of the reserve.

The classification of stems into seedlings, saplings and mature trees showed the least number of seedlings/ha for the highly valued timber species *P. angolensis* **Figure 5**. The 24 seedlings/ha of *P. angolensis* were far less compared to that of *C. mole* and *D. condylocarpon* (88/ha) respectively. This could be an indication that there are difficulties in seedling germination in NFR for this species. Probably fires, damages from tree felling activities and rolling logs, or all of these combined are hampering the regeneration of the species. Other common woody species namely *B. boehmii*, *B. microphylla*, *J. globiflora* and *P. myrtifolia* had a bit higher number of seedlings but the saplings seemed to suffer a high mortality. This could be an indication that the saplings are removed to cater for different purposes such as house construction or instrument making [10].

3.2. Tree conservation priority

The tree conservation priority was assessed based on IVI classes and regeneration status (**Table 3**). Categorization of the common woody species into conservation priority classes based on IVI criteria placed *L. welwitschii*, *D. boehmii*, *P. angolensis* and *A. nilotica* in class 4. This means that these species have insufficient stock and are recommended for conservation priority, for example, Zegeye et al. [44], Kacholi [45]. The IVI criterion is used in determining the conservation priority of species whereby those with low IVI values are considered of main concern for conservation [44]. Therefore, the management of NFR should place special consideration in protecting *A. nilotica*, *D. boehmii*, *L. welwitschii* and *P. angolensis* against anthropogenic pressures for their persistence. On the other hand, the remainder of the common woody species recorded in NFR, that is, *J. globiflora*, *B. boehmii*, *D. condylocarpon*, *C. molle*, *P. myrtifolia* and *B. microphylla* are of less conservation concern since they fall under a higher IVI class value. However, the management of NFR is not advised to relax as protection of every single species in the reserve is paramount. As pointed out earlier, *B. microphylla* has been categorized by this study as a foundation species, thus, despite the fact that this species appears common, it still deserves special consideration for protection in respect of its ecological implication in case it disappears.

Moreover, classification of the 10 common woody species into regeneration status placed the highly valued timber species *P. angolensis* in class 2 denoting that the species had insufficient number of seedlings and saplings (**Table 4**). This suggests that either the species recruitment is insufficient or the seedlings and perhaps the saplings suffer high mortality before making it to maturity, the phenomena which are likely to jeopardize its long-term persistence in the reserve. As pointed out earlier, *P. angolensis* had the least number of seedlings observed among the 10 common woody species and this is attributed to a collective number of factors including disturbances brought about by tree felling activities, or fires. Omeja et al. [34] claims that human disturbance influence seed dispersal mechanisms, fruiting, germination and regeneration of tree species. Thus, disturbance by activities involved during charcoal burning (see **Plate 1 a** and **b**) perhaps contributes in killing young seedlings as logging was observed almost everywhere in the reserve especially on lower altitudes. Similarly, van Daalen [46], pointed out that very high intense fire reduces the viability of seeds of *P. angolensis* limiting their germination potential. Thus, the intense fires that the NFR faces (Personal Communication) could be killing more seeds of *P. angolensis*, allowing only a few to germinate.

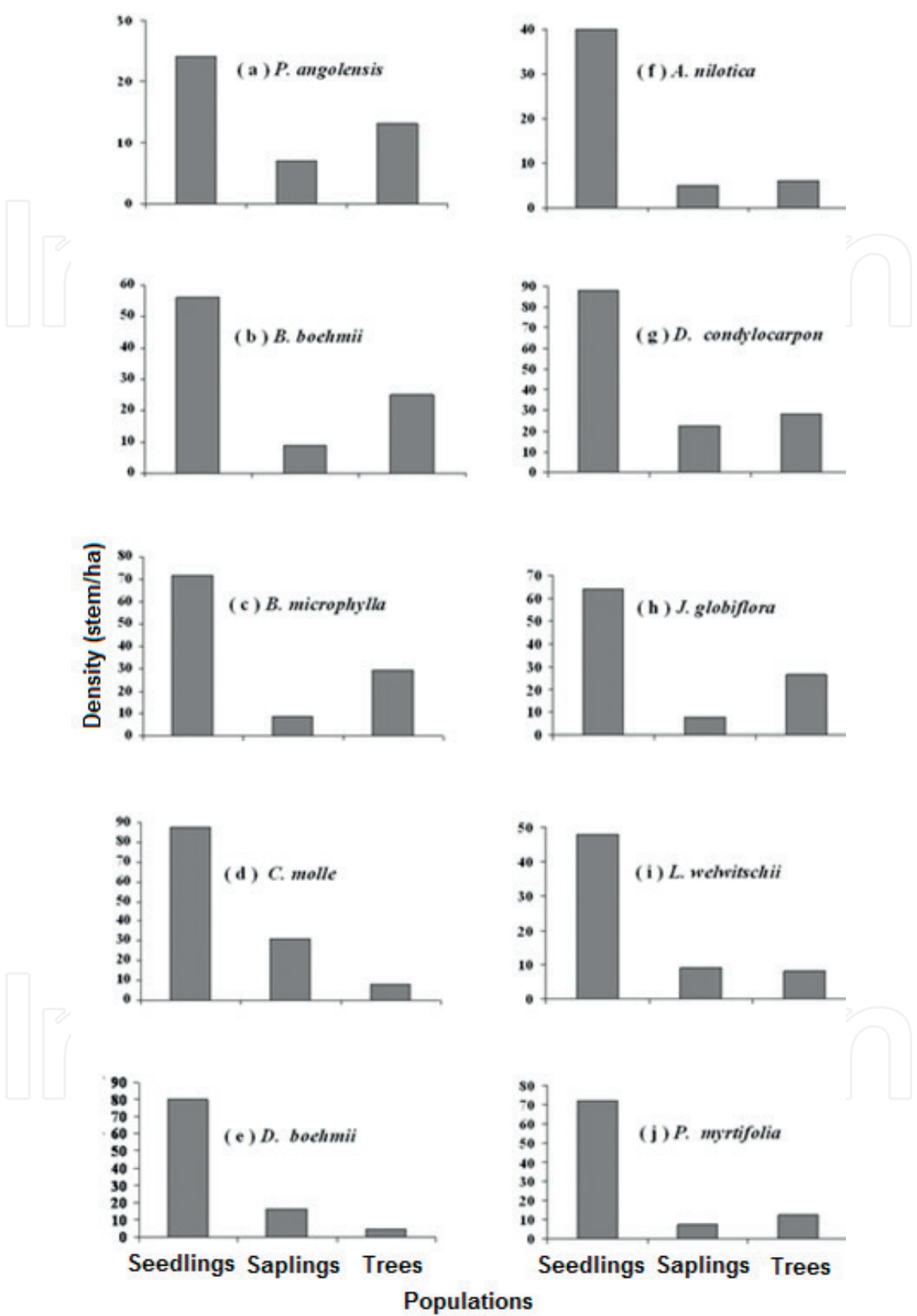


Figure 5. The population of seedlings, saplings and mature trees of the common woody species recorded in NFR.

IVI priority classes	IVI value class	Species
5	<1	—
4	1–10	<i>L. welwitschii</i> <i>D. boehmii</i> <i>P. angolensis</i>
3	10.1–20	<i>A. nilotica</i> <i>J. globiflora</i> <i>B. boehmii</i> <i>D. condylocarpon</i> <i>C. molle</i> <i>P. myrtifolia</i>
2	20.1–30	<i>B. microphylla</i>
1	>30	—

Table 3. IVI priority classes for the 10 common species recorded in NFR.

Class 1	Class 2	Class 3
0 individuals ha ⁻¹	0 > 50 Individuals ha ⁻¹ <i>P. angolensis</i>	<50 Individuals ha ⁻¹ <i>B. microphylla</i> <i>D. condylocarpon</i> <i>J. globiflora</i> <i>B. boehmii</i> <i>D. boehmii</i> <i>A. nilotica</i> <i>P. myrtifolia</i> <i>C. molle</i> <i>L. welwitschii</i>

Table 4. Regeneration status of the 10 common woody species based on individual seedlings and saplings/ha.

3.3. Exploitation and spatial distribution of the common woody species

Harvesting rate of the common woody species was evaluated based on basal area/ha of the cut trees. During this study, some stumps could not be identified simply because most of them had already lost identification evidences such as barks and had no sprouts. Of the 10 common woody species, stumps were recorded for *B. microphylla*, *C. molle*, *J. globiflora*, *P. angolensis* and *P. myrtifolia* (Table 5). From this perspective, the total basal area for the harvested species seemed to be small (0.32 m/ha). Of the common woody species found harvested, *J. globiflora* seemed to be the highly preferred species accounting for 0.14 m²/ha followed by *P. angolen-sis* with 0.10m²/ha, while *B. microphylla* was the least harvested. The fact that this study has



Plate 1. (a) Pieces of wood found cut for charcoal burning in NFR, (b) the kiln previously used for charcoal burning.

Scientific name	Basal area/ha (m²)	Percentage	Rank
<i>J. globiflora</i>	0.14	43.34	1
<i>P. angolensis</i>	0.10	32.00	2
<i>C. molle</i>	0.03	10.70	3
<i>P. myrtifolia</i>	0.03	8.41	4
<i>B. microphylla</i>	0.01	4.54	5

Table 5. Basal area/ha of the common woody species found harvested in NFR.

considered *B. microphylla* as a foundation species following its bigger canopy area, the removal of this species though at a smaller scale triggers alarm. As pointed out earlier, this species has a high chance of influencing other species especially in suppressing shade intolerant species. Therefore, if harvest continues for *B. microphylla*, there is a high possibility of seeds for other species that were being suppressed to start emerging and this could change the species composition and ultimately the ecosystem functioning and carbon accumulation potential of the area. Some previous studies pointed out that increasing ground illumination through felling bigger canopy trees has many consequences including allowing colonization of new plant species and development of new communities such as grasses [9, 20], thus impairing the ecological succession and carbon accumulation potential of the affected area [20]. Therefore, exploitation of trees in NFR especially among key species needs to be monitored by the responsible authorities for stability of ecosystem processes in the reserve.

One of the important questions under the current study concerned the distribution of valued timber species in NFR. This was so in order to elucidate the probable influence of the surrounding community on the reserve’s valued biological resources. To understand this, we plotted the spatial distribution of the highly valued timber species *P. angolensis* on the reserve’s map as shown in **Figure 6**. From the map, it was apparent that quadrats into which *P. angolensis* were recorded concentrated more in the higher altitudes of the reserve to the interior. We did not

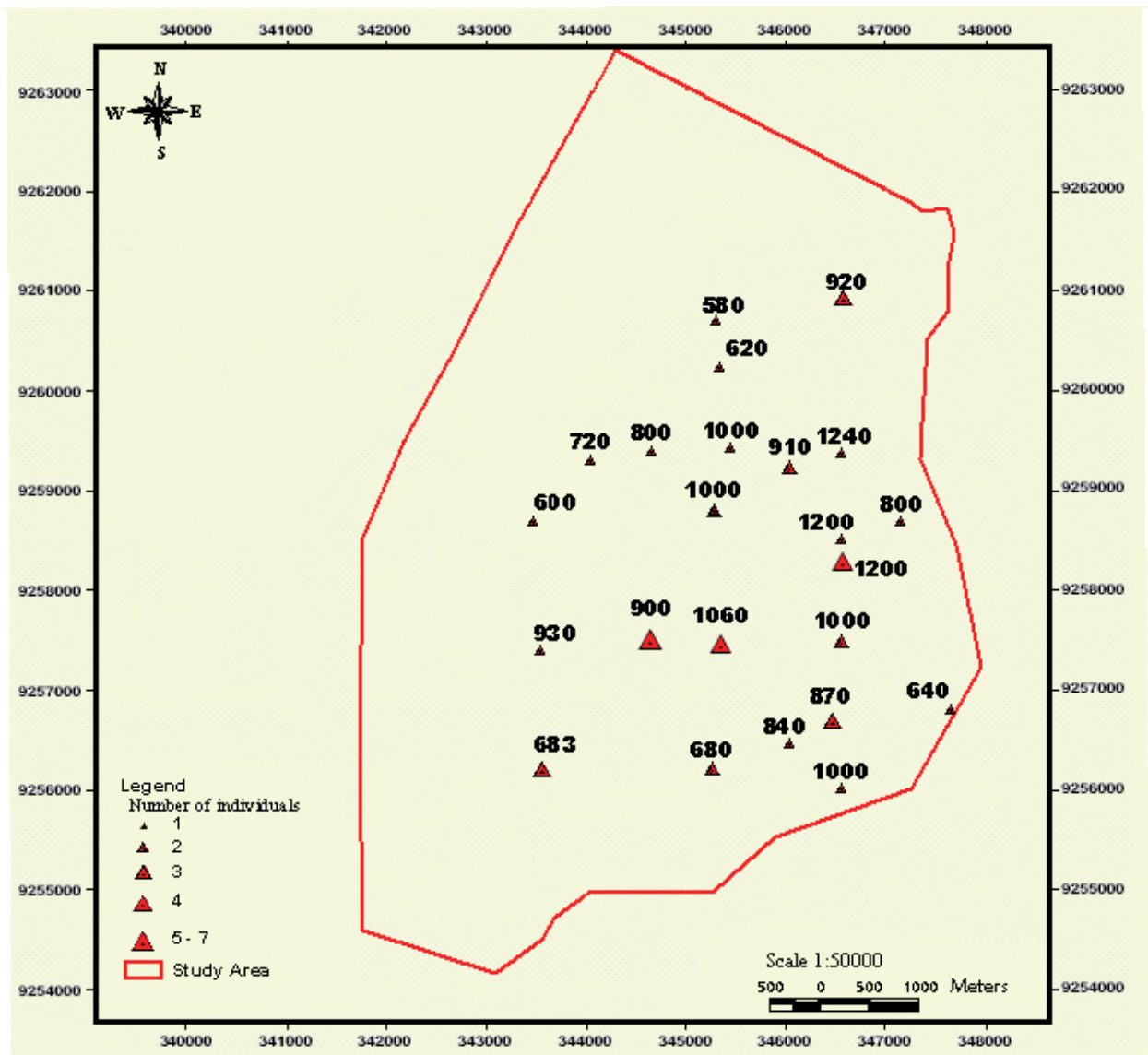


Figure 6. Map of the study area showing the distribution of *P. angolensis* as displayed by the ArcView version 3.2 computer software. Numbers inside the map boundaries show the altitudes while triangles represent plots where *P. angolensis* was recorded.

record *P. angolensis* from the northern, western or southern parts of the reserve. Moreover, the range at which *P. angolensis* occurred in NFR was between 600 to 1240 m a.s.l. The absence of *P. angolensis* especially in the northern, western and southern parts of the reserve perhaps was a result of selective logging, fires or edaphic factors. The eastern part of NFR consists of steep slopes and difficult terrain. This could be a reason why mature *P. angolensis* were recorded just close to the boundary of the eastern part of the reserve—perhaps tree loggers might be experiencing difficulties in accessing this area. According to Lovett et al. [26], the edges of NFR face fire incidences, deforestation for charcoal making and tree cutting for timber sawing. The villagers at Mkundi and Lukobe also disclosed that people prefer poaching trees for charcoal making and timber just a few hundreds of meters from the edges of the reserve in fear of the forest officers who usually conduct ambush patrols (Personal Communication). Therefore, tree cutting and frequent fires in the edge of NFR are probably the root of mortality

and poor re-establishment of *P. angolensis* in the northern, western and southern parts of the reserve. Although *P. angolensis* is considered to be resistant to fires, heavy and/or frequent fires damage seedlings and prevent them passing to sapling stages [47].

4. Implications of the results on carbon management

The information we have provided in this chapter is expected to guide the authority responsible in overseeing NFR on managing carbon in the forest. Specifically, implementation of the recommendations on fire control and halt of tree cutting highlighted later is necessary to allow for tree restoration, hence increased capacity of the forest in capturing carbon. Awareness raising campaign on biodiversity conservation also insisted later under the recommendations section is essential on deviating the interest of the surrounding communities from overdependence on the forest's biodiversity—to allow the forest to regenerate and augment its capacity in seizing carbon.

5. Conclusion and recommendations

This study concludes that the population structure of the common woody species in NFR did not show a natural stand. Fires and selective logging seemed to influence the distribution of timber trees as our model timber species that is, *P. angolensis* was not found in fire prone part of the reserve and the species was as well recorded mostly in hard to reach places. Of the 10 common woody species on the other hand, *B. microphylla* can be regarded as a foundation species in NFR and its removal should be regulated as when it disappears for example, the ecosystem functioning and the carbon accumulation potential of the reserve might be jeopardized. To manage the tree species sustainably in NFR, this study recommends awareness education on forest biodiversity conservation among surrounding local communities. Regular patrol in the reserve is also needed to stop illegal logging. Fire control is needed to allow for regeneration of the vegetation in the reserve and to minimize seed mortality in order to attain maximum recruitment of the tree species. A study to compare dry and wet season status is required in order to explore the species in its full life cycle as this will take care of the individuals that might be overlooked during dry seasons while in their underground shoot-die back stages. A study to investigate if edaphic factors apart from fires and human disturbances do influence the distribution of the preferred timber species that is, *P. angolensis* is also recommended. Finally, we recommend an exploration of the ecotourism potential of NFR to be undertaken. This might stimulate ecotourism activities in the reserve to provide an alternative source of income and generate jobs among the local population. This would add value and sense of ownership and stimulate self-mobilization among the surrounding communities for protection of the reserve.

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Conflict of interest

The authors declare no conflict of interest for publication of this study.

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