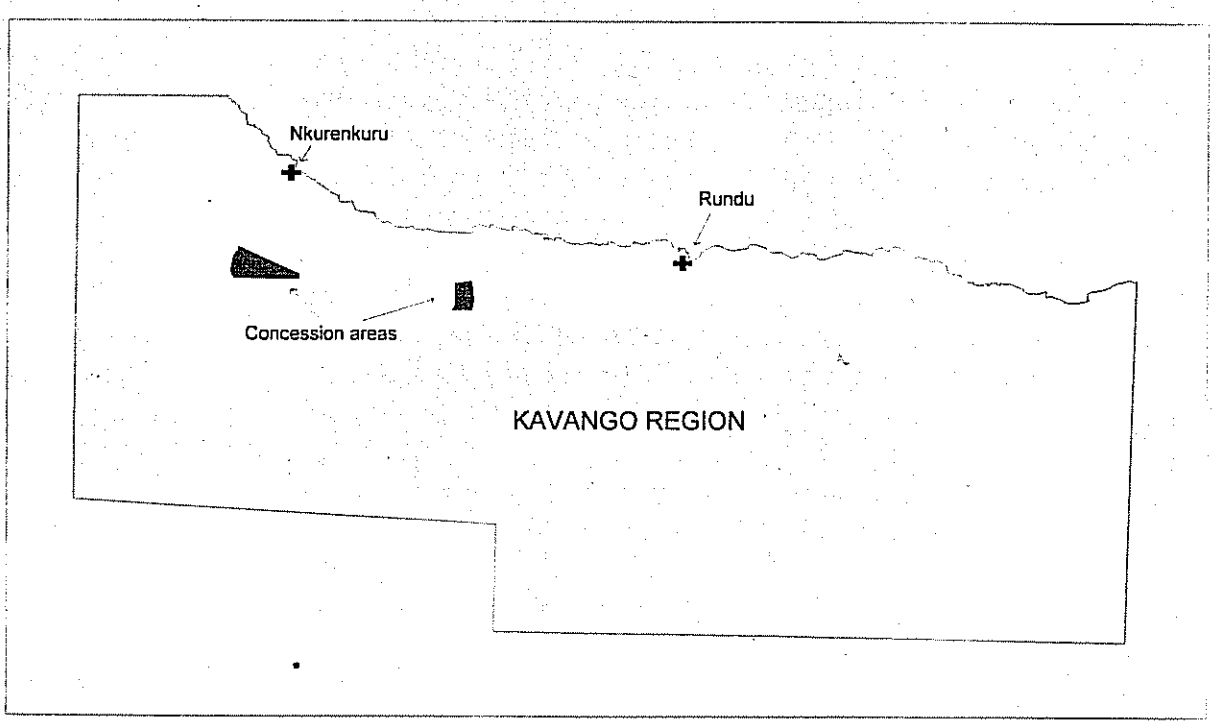
Dr. Stig Johansson

Ministry of Environment and Tourism
Directorate of Forestry

Forest Inventory Report

of

NKURENKURU CONCESSION AREA



Namibia Finland Forestry Programme
National Forest Inventory Sub-component

Compiled by M. Chakanga, T. Selänniemi

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1. BACKGROUND

The Concession area (Appendix 1) is about 120 Km west of Rundu in Nkurenkuru area, Okavango Region.

The growing stock was estimated with systematic cluster sampling. In Area 1 the clusters of sample plots were located on a grid of 4 Km in the North/South direction and 1.5 by 1.5 km in the East/West direction. In Area 2 the clusters of sample plots were located on a grid of 1.5 km by 1.5 in the North/South direction and 3 by 3 km in the East/West direction. Thus Area 1 had a total of 15 clusters or 45 plots, and Area 2 had a total of 26 clusters or 78 plots. For both areas there were 3 plots in each cluster with a distance of 100 m from each other.

All trees inside the circular plot were measured. The size of the plot depends on the size of the tree so that the radius of the plot is 30 m for trees with breast height diameter (DBH) more than 45 cm; 20 m for trees with 20 < DBH < 45 cm; and 10 m for trees with 5 < DBH < 20 cm. Diameter, location, species, crown class, quality, length and quality of possible saw log were measured and recorded for each tree (called enumeration trees). Height, diameter of canopy, crown height, damages and phenology were recorded for all the trees on the first plot of each cluster (i.e. for one third of all the trees). These trees are called sample trees.

In addition, shrubs and regeneration were measured using two 3.99 m radius circular plots. Woody plants with diameter at breast height less than 5 cm were recorded on the shrub and regeneration field form and bigger woody plants (DBH => 5 cm) on the sample and enumeration tree field forms. Several variables describing the site, soil and tree cover were observed for each plot. Coverage of grasses and herbs were also measured. All the measurements are described in detail in the field instructions (Field Instructions Western Bushmanland 1996).

Volume and biomass functions for *Burkea africana*, *Combretum collinum*, *Lonchocarpus nelsii*, *Pterocarpus angolensis* and *Terminalia sericea* derived from trees felled in West Tsumkwe were used for volume calculations. For other species one of these functions was applied for estimating volumes and biomass. The estimated volume and biomass functions are in Appendix 2.

2. GENERAL DESCRIPTION OF THE AREA

The area belongs to the Forest Savanna and Woodland vegetation zone in the classification of Giess (National Atlas of South West Africa).

The boundaries of the two selected concession areas (Appendix 1) were delineated on the Vegetation Maps and digitized in MapInfo to calculate the area, since growing stock volume information is related to land area. The total land area for Area I is 5 643.84 ha for Area II 12 171.06 ha. According to the Vegetation Maps (Directorate of Forestry) the area is classified as:

AREA I

Stratum (Vegetation unit)	Area in Ha
Fo-Mx	3400.00
Sm1-Mx	144.60
Fm-Mx	1928.00
Sm2-Ac	9.79
Fd-Mx	141.10
E-Fo-Mx	20.35
Total	**5643.84**

AREA II

Stratum (Vegetation unit)	Area in Ha
Fm-Mx	7706.00
Fm-Mx	312.10
Fm-Mx	13.61
Fm-Mx	312.50
Fv-Mx	2728.00
Fv-Mx	46.40
Fv-Mx	47.96
E-So2-Mx	1.04
E-So2-Mx	58.43
E-Fm-Mx	55.72
E-Fm-Mx	21.83
E-Fo-Mx	51.02
E-Fm-Mx	103.60
E-Fo-Mx	74.57
E-Fo-Mx	73.32
E-Fo-Mx	338.40
E-Fv-Mx	127.70
E-Fo-Mx	98.86
Total	**12171.06**

The codes in the vegetation units stand for:

Impact/Land use
E = Extensive agriculture, <10% cultivated

Wood height
F = Forest woodland > 5 m
S2 = High shrub/savanna 2 - 5 m
S1 = Low shrub/savanna < 2 m

Wood density
d = Dense canopy cover >70%
m = Medium canopy cover 40-70%
o = Open canopy cover 10-40%
v = Very open canopy cover 2-10%

Dominant species
Ac = Acacia species
Mx = Mixed species

The data from the inventory provides detailed geo-referenced species composition and other information that can be used to revise the forest cover maps of these areas and to make maps showing the geographical distribution of the growing stock.

The forest inventory results are presented in the following two sections of the report.

SECTION 1

Area Number 1

3.0 FOREST INVENTORY RESULTS FOR AREA I

3.1 Measured data

A total of 45 plots on 15 clusters were measured. After post-stratification on the vegetation maps, 18 of the plots were on the stratum Fm-Mx and 27 on the stratum Fo-Mx. Thus, each plot in the Fm-Mx stratum represented 197.86 ha and each plot in the Fo-Mx stratum represented 77.13 ha.

A total of 383 trees with diameter at least 5 cm were measured on the plots. Out of these, 120 were sample trees. Table 1 shows the number of measured trees by species. Note that the number of measured trees includes the sample trees.

Table 1. Number of measured trees and sample trees by species.

Species	No. of measured trees	% of measured trees	No. of sample trees	% of sample trees
Baikea plurijuga	115	30.0	38	31.7
Burkea africana	49	12.8	24	20.0
Combretum collinum	16	4.2	3	2.5
Combretum engleri	1	0.3	1	0.8
Combretum psidioides (dinteri)	6	1.6	1	0.8
Combretum psidioides (psidioides)	2	0.5		
Combretum zeyheri	1	0.3		
Dialium engleranum	1	0.3		
Guibourtia coleosperma	20	5.2	3	2.5
Lonchocarpus nelsii	3	0.8		
Ochna pulchra	18	4.7	7	5.8
Ozoroa schinzii	7	1.8	2	1.7
Pterocarpus angolensis	114	29.8	29	24.2
Schinziophyton rautanenii	10	2.6	9	7.5
Strychnos cocculoides	2	0.5		
Strychnos pungens	8	2.1	1	0.8
Terminalia sericea	10	2.6	2	1.7
Total	**383**	**100.0**	**120**	**100.0**

3.2 Area estimates

The Vegetation Structural Type were derived for each vegetation unit with data from measured sample plots. The derivation of the Vegetation Structural Type is based on measured height of tree, shrub and grass cover and on measured coverage of each of these layers (Edwards 1983).

Table 2 shows the area and percentage of the different Vegetation Structural Types. Woodlands (definition: tree cover > 0.1 % and shrub cover < 10 % if shrub height more than 1 m) cover 88 % of the area. The woodlands are mostly in the category Short Closed Woodland (definition: tree cover 11-75 % and tree height 5-10 m).

Table 2. Area by Vegetation Structural Types.

Vegetation structural Type	Area in ha	Area in %
Short Closed Woodland	4950	88
Short Thicket	463	8
Short Bushland	231	4
Total	5644	100

The crown coverage of each species was calculated for each cluster. The dominant and second dominant species were derived from these crown coverage estimates. Table 3 shows the areas and percentages of dominant species. Pterocarpus angolensis is the most common dominant species on 3 068 ha or 54% of the area followed by Baikieae plurijuga as the second most common species on 1 519 ha or 27% of the area.

Table 3. Area in hectares and percent by dominant species.

Species	Area in ha	Area in %
Baikea plurijuga	1519	27
Burkea africana	825	15
Guibourtia coleosperma	231	4
Pterocarpus angolensis	3068	54
Total	5644	100

Table 4 shows the occurrence of second dominant species for each dominant species in area number 1. For example, if B. Plurijuga is the dominant species most often the second dominant species is P. Angolensis and vice versa. When B. Plurijuga is the dominant species then P. Angolensis is the second dominant species in 69.5% of the B. Plurijuga dominated forest and savanna. When P. Angolensis is the dominant species then B. plurijuga is the dominant species in 58% of cases.

Table 4. Occurrence of dominant and second dominant species.
(Numbers in the table are percentages of the area of the first dominant species covered by the second dominant species).

First Dominant Species	Second dominant species				
	B. plurijuga	B. Africana	C. collinum	G. coleosperma	P. angolensis
Baikea plurijuga		15.2	15.2		69.5
Burkea africana					100.0
Guibourtia coleosperma					100.0
Pterocarpus angolensis	58.0	7.5		34.4	

Table 5 shows the distribution of crown cover classes by dominant species. Pterocarpus dominated areas are most often in the cover classes 5-10%, 10-15%, 20-25%, 30-35% and 45-50%. Most of the Baikieae dominated areas are in cover classes 20-25%, 30-35%, 35-40% and 40-45%.

Table 5. Percentage of crown cover classes by dominant species.
The numbers in the table are percentages of the area of the dominant species in the table.

Species	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
Baikea plurijuga				30		15	39	15	
Burkea africana			72		28				
Guibourtia coleosperma						100			
Pterocarpus angolensis	8	34		19		19			19

3.3 Total tree volume and number of stems

Tree volume here means the volume of the trunk and branches. Table 6 shows the total tree volumes, mean tree volumes, total number of stems and average number of stems per hectare for the whole area by species. Only living trees are included in the table. The most common species is B. Plurijuga (on average 35.9 stems per ha) followed by P. Angolensis (35.2 stems per ha), B. Africana (15.4 stems per ha) and Ochna pulchra (10.6 stems per ha).

The area is rich in Pterocarpus Angolensis and Baikieae Plurijuga. P. Angolensis has the highest mean and total tree volume, 17.1 m3/ha with 96 500 m3. The second highest mean tree volume is for Baikieae plurijuga, 12.7 m3/ha, followed by Burkea africana, 4.8 m3/ha. There are about 788 thousand trees in the inventory area number 1 of which 203 and 199 thousand are B. Plurijuga and P. Angolensis respectively.

Table 6. Number of stems and tree volume per hectare and for the whole area by species.

Species	No. of stems, 1000	Stems/ha	% of Stems	Total volume, 1000 m3	Mean volume/ha	% of volume
Baikea plurijuga	203	35.9	25.8	71.7	12.7	26.5
Burkea africana	87	15.4	11.1	27.2	4.8	10.0
Combretum collinum	43	7.6	5.4	5.3	0.9	2.0
Combretum engleri	2	0.4	0.3	0.4	0.1	0.1
Combretum psidioides (dinteri)	22	3.9	2.8	2.7	0.5	1.0
Combretum psidioides (psidioides)	9	1.6	1.1	0.1	0.0	0.1
Combretum zeyheri	6	1.1	0.8	0.1	0.0	0.0
Dialium engleranum	2	0.3	0.2	0.5	0.1	0.2
Guibourtia coleosperma	22	3.8	2.7	33.4	5.9	12.4
Lonchocarpus nelsii	5	0.9	0.7	1.4	0.3	0.5
Ochna pulchra	60	10.6	7.6	12.4	2.2	4.6
Ozoroa schinzii	33	5.8	4.1	0.7	0.1	0.3
Pterocarpus angolensis	199	35.2	25.2	96.5	17.1	35.7
Schinziophyton rautanenii	8	1.4	1.0	11.2	2.0	4.1
Strychnos cocculoides	13	2.2	1.6	0.3	0.1	0.1
Strychnos pungens	32	5.7	4.1	3.6	0.6	1.3
Terminalia sericea	43	7.6	5.4	3.0	0.5	1.1
Total	**788**	**139.5**	**100.0**	**270.8**	**48.0**	**100.0**

Table 7 shows the total tree volumes and total number of stems by diameter classes for Pterocarpus angolensis and Baikieae plurijuga in the inventory area number 1. The diameter distribution for dominant species is also shown in graphical form in Figure 1. The DBH is in 5 cm classes and the class midpoints are indicated on the x-axis.

Table 7. Total tree volume and number of stems by diameter classes for P. angolensis and B. Plurijuga.

	P. angolensis			B. plurijuga		
Dbh class, cm	Volume, 1000 m3	Total No. of stems, 1000	% of stems	Volume, 1000 m3	Total No. of stems, 1000	% of stems
5-10	0.6	15.1	7.6	0.4	12.5	6.2
10-15	2.1	21.0	10.6	5.2	52.3	25.8
15-20	12.9	70.3	35.4	10.0	59.3	29.2
20-25	3.8	13.7	6.9	8.3	28.2	13.9
25-30	8.5	17.5	8.8	7.4	16.5	8.2
30-35	9.1	13.4	6.7	10.6	16.6	8.2
35-40	17.5	19.1	9.6	5.0	5.3	2.6
40-45	26.3	21.4	10.7	10.3	7.7	3.8
45-50	6.1	3.6	1.8	4.7	2.9	1.4
50-55	4.0	1.9	1.0	1.3	0.5	0.3
55-60	2.7	1.0	0.5	0.7	0.3	0.1
65-70	3.0	0.7	0.4	1.2	0.3	0.1
70-75				1.7	0.3	0.1
95-100				5.0	0.3	0.1
Total	**96.5**	**198.8**	**100.0**	**71.7**	**202.8**	**100.0**

Figure 1a. Diameter distributions of P. Angolensis and B. Plurijuga.

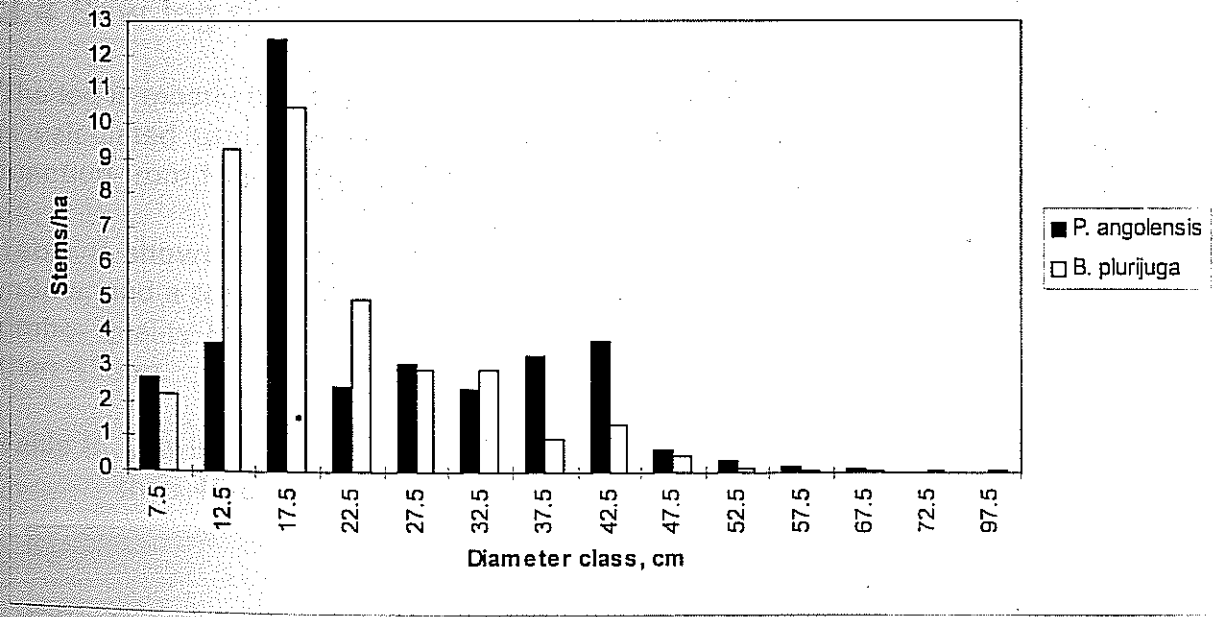
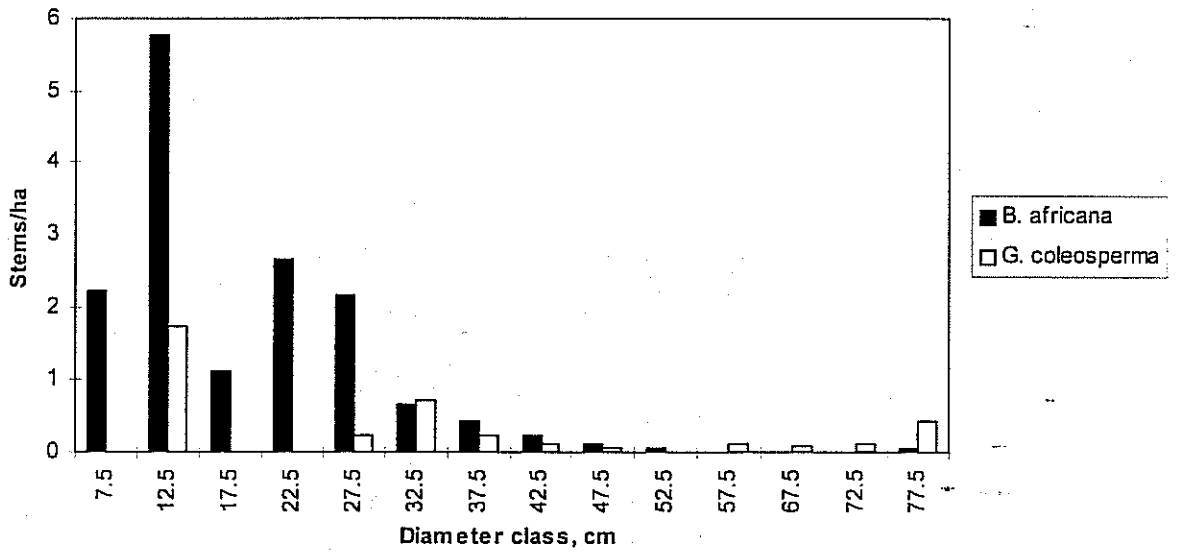


Figure 1b. Diameter distributions of B. Africana and G. Coleosperma.



3.4 Saw log timber volume and number of logs

The log is mostly the trunk of the tree below the first branching. The saw log volume is calculated using the formula for the volume of a cylinder. There is no volume function from felled trees involved here.

Table 8 shows the mean saw log volume of Pterocarpus angolensis trees, 0.53 m3/ha, and a total saw log volume of 2 980 m3 for the whole area. There are 6 650 timber quality Pterocarpus angolensis trees with breast height diameter (dbh) larger than 45 cm.

Table 8. Distribution by quality classes of P. Angolensis and B. Plurijuga trees larger than 45 cm.

Species	Quality	Stems/ha	No. of stems, 1000	Timber volume, 1000	Mean timber volume, m3/ha
	Good quality	0.66	3.74	2.15	0.38
P. angolensis	Medium quality	0.17	0.97	0.73	0.13
	Poor quality	0.34	1.95	0.10	0.02
Total		**1.18**	**6.65**	**2.98**	**0.53**
	Good quality	0.11	0.61	0.27	0.05
B. plurijuga	Medium quality	0.10	0.55	0.00	0.00
	Poor quality	0.19	1.09	0.11	0.02
	Not sawable	0.29	1.64	0.20	0.04
Total		**0.69**	**3.89**	**0.58**	**0.10**

The quality classes in Table 8 mean:

Good quality = At least 2 m long straight stem without damages.
Medium quality = Stem slightly curving or sweeping or having other damages but still having at least 2 m sawable log.
Poor quality = It is possible to find only 1.2-2.2 m long stem meeting minimum timber requirement.

Table 9 shows the log length distribution of sawable P. angolensis and B. Plurijuga trees larger than 45 cm DBH. It is assumed that a tree is regarded as sawable if it is possible to obtain at least a 1.2 m long log. Table 9 shows that the sawable part of Pterocarpus angolensis trees is about 3.2 m long for more than 50% of the trees. Therefore, about 4 710 logs (Table 9) out of the 6 650 logs (Table 8) are sawable. This is about 2 880 m3 (Table 8, Good and Medium quality logs).

Table 9. Log length distribution of sawable P. angolensis and B. Plurijuga trees larger than 45 cm DBH.

Species	Log Length, m	Stems, 1000	%
P. angolensis	1.2-2.2	1.25	26.4
	2.2-3.2		
	3.2-4.2	2.49	52.9
	4.2-5.2	0.97	20.7
Total		4.71	100.0
B. plurijuga	1.2-2.2	1.09	64.0
	2.2-3.2	0.61	36.0
Total		1.70	100.0

3.5 Damages

Damages were recorded both at cluster level (for the sampled vegetation unit) and at tree level (for the measured sample trees). At tree level 54.8% of P. Angolensis have no damage while 45.2% of the damages were mild causing only noticeable but not serious damages to the trees.

Table 10. Distribution by damage class of Pterocarpus angolensis and B. Plurijuga trees.

Degree of damage	B. plurijuga % of trees	P. angolensis % of trees
No damage	100	54.8
Mild, no harm for the tree		45.2
Total	100	100.0

3.6 P. angolensis and B. Plurijuga woodlands

From forestry point of view, woodlands dominated by Pterocarpus angolensis and Baikieae plurijuga are most important because of their economic value. Table 4 shows that these two species are often found together. The estimated area of woodlands where P. angolensis or B. Plurijuga is the first or second dominant species is 5 412 ha or 96% of area number 1 (when open and low woodlands and thickets are excluded i.e. crown coverage must be more than 10 % and mean height more than 5 m).

The stem size distribution of P. angolensis and B. Plurijuga trees on these 'P. angolensis and B. Plurijuga woodlands' is shown in Figure 2. The average stem number per hectare for the P. angolensis and B. Plurijuga woodlands is the same as the diameter distribution of these species in Figure 1a for the whole area because almost the entire area number 1 (96%) is dominated by P. Angolensis and B. Plurijuga. But, there is a slight increase in the 17.5 cm class. The class midpoint of 5 cm DBH classes are on the x-axis. In addition, excluding the savanna and woodlands dominated by other species did not affect the shape of the diameter distribution.

Figure 2: Diameter Distribution of P. Angolensis and B. Plurijuga on P. Angolensis and B. Plurijuga woodlands.

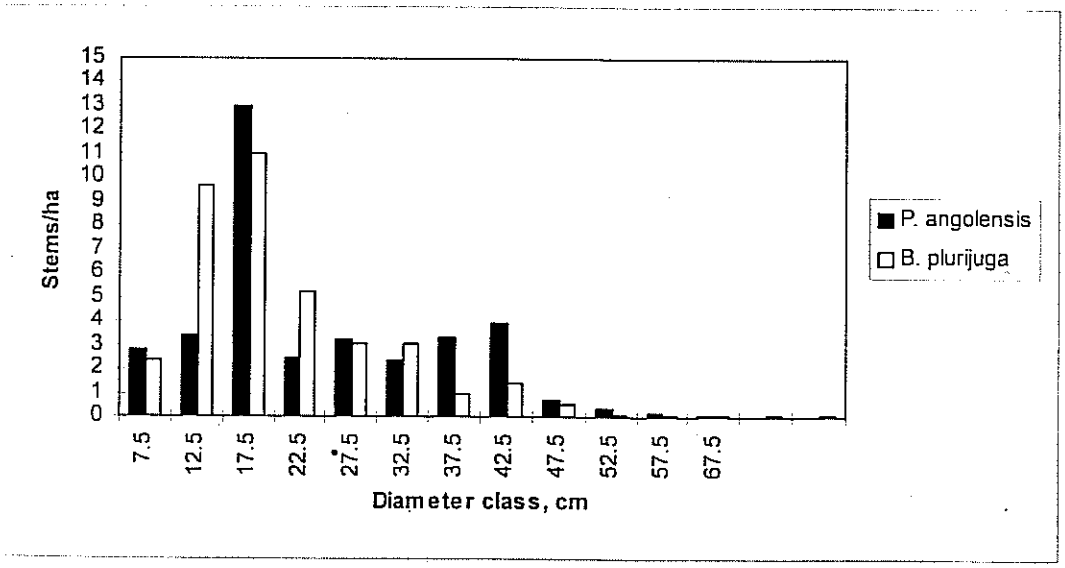


Table 11 shows the number of seedlings per hectare by height classes for P. angolensis and B. Plurijuga. There are 35.7 P. angolensis and 457.1 B. Plurijuga seedlings per hectare. The area is rich in B. Plurijuga seedlings. Most of the P. angolensis seedlings are between 51-100 cm high. It should be noted that Table 11 includes only seedlings less than 5 cm in diameter - larger stems were measured as trees.

Table 11. Number of P. angolensis and B. Plurijuga seedlings per hectare by height classes.

Height class, cm	P. angolensis, 1/ha	B. plurijuga, 1/ha
0 -25	0.0	14.3
26 - 50	0.0	385.7
51 - 100	14.3	35.7
101 - 150	7.1	21.4
151 - 200	7.1	0.0
201 - 250	0.0	0.0
251 - 300	7.1	0.0
> 300	0.0	0.0
Total	35.7	457.1

3.7 Species diversity

Table 6 gives a figure on the frequency of different species on the inventory area number 1. Tables 3 and 4 describe the occurrence of dominant species and also give an idea about the mixture of species.

Another measure of species diversity is the number of clusters where each species was found. Table 12 shows this result for both trees less than 5 cm in diameter (including shrubs) and trees larger than 5 cm DBH. Seventeen (17) different species were recorded on the tree field form and 21 species on the regeneration and shrub field form. Pterocarpus angolensis and Baikieae plurijuga were recorded on 15 and 10 clusters respectively.

Some species, like Combretum angleri, Strychnos cocculoides, and Grewia bicolor were found only on 1 cluster each.

Table 12. Number of clusters where each species was found.

Species	Number of clusters dbh < 5 cm	Number of clusters dbh > 5 cm
Baikea plurijuga	4	10
Baissea wulfhorstii	1	
Baphia massaiensis	6	
Bauhia petersiana	8	
Burkea africana	8	11
Combretum collinum	7	7
Combretum engleri		1
Combretum psidioides (dinteri)	4	4
Combretum psidioides		2
Combretum zeyheri	6	1
Commiphora angolensis	2	
Croton gratissimus	3	
Dialium engleranum	2	1
Guibourtia coleosperma		9
Grewia bicolor	1	
Grewia retinervis	4	
Lonchocarpus nelsii	1	2
Ochna pulchra	8	6
Ozoroa paniculosa	3	
Ozoroa schinzii	5	3
Pterocarpus angolensis	4	15
Schinziophyton rautanenii	1	4
Strychnos cocculoides		1
Strychnos pungens	3	3
Terminalia sericea	8	6

3.8. Standard error and confidence limits

Table 13 shows the average volume per hectare estimated from each cluster for all species and for P. angolensis sawlogs with DBH > 45 cm. Table 14 shows the sampling error and 68% confidence limits.

Table 13. Average volume per hectare estimated from each cluster.

Cluster	Total tree volume, m3/ha for all species		Sawlog volume, m3/ha for P. angolensis, DBH > 45 cm
1	20.24		0.00
2	22.89		0.00
3	36.05		0.96
4	56.18		0.00
5	60.39		0.69
6	89.96		0.44
7	93.32		0.00
8	20.08		0.93
9	30.16		0.75
10	56.60		0.42
11	50.24		0.00
12	41.00		0.00
13	30.71		0.00
14	62.01		2.04
15	41.12		1.91

For the average volume estimate of all species the sampling error was 7.09 m^3/ha (i.e. 14.8%). For the average volume of Pterocarpus angolensis saw logs (DBH > 45 cm) the sampling error was 0.14 m^3/ha (26.4%).

This means that the true average total tree volume for all species is between 40.88 and 56.06 m^3/ha with 68% probability. Correspondingly, the average volume of P. angolensis saw logs (DBH > 45 cm) is between 0.39 and 0.67 m^3/ha with the probability of 68%.

Since no sampling error is related to the area estimates of the two sampling strata, the total volume estimates have the relative sampling errors of 14.8% and 26.4% for the total tree volume of all species and P. angolensis saw logs, DBH > 45 cm, respectively.

Table 14. Standard error and 68% confidence limits

Item	Sampling variance	Standard error, m3/ha	Average volume, m3/ha	Lower confidence limit, m3/ha	Upper confidence limit, m3/ha	Confidence level, %
Total tree volume, all species	50.24	7.09	47.97	40.88	55.06	68
Saw log volume, P. angolensis, DBH > 45 cm	0.02	0.14	0.53	0.39	0.67	68

The sampling error for P. Angolensis saw logs (DBH > 45 cm) seems high, 26.4%, because from Table 13, 7 out of the 15 clusters, or 46.7% of the clusters, did not have logs with DBH > 45 cm. As a comparison, the standard error for P. Angolensis saw logs (DBH > 45 cm) for West Tsumke was 0.05 m3/ha with an average of 0.31 m3/ha. Hence, the sampling error was 16%.

SECTION 2

Area Number 2

4.0 FOREST INVENTORY RESULTS FOR AREA II

4.1 Measured data

A total of 78 plots on 26 clusters were measured. After post-stratification on the vegetation maps, 54 of the plots were on the stratum Fm-Mx and 24 on the stratum Fv-Mx. Thus, each plot in the Fm-Mx stratum represented 159.11 ha and each plot in the Fv-Mx stratum represented 149.13 ha.

A total of 586 trees with diameter at least 5 cm were measured on the plots. Out of these, 146 were sample trees. Table 1 shows the number of measured trees by species. Note that the number of measured trees includes the sample trees.

Table 1. Number of measured trees and sample trees by species.

Species	No. of measured trees	% of measured trees	No. of sample trees	% of sample trees
Baikea plurijuga	255	43.5	59	40.4
Burkea africana	62	10.6	17	11.6
Combretum collinum	37	6.3	10	6.8
Combretum psidioides (psidioides)	2	0.3		
Combretum zeyheri	7	1.2	4	2.7
Commiphora angolensis	6	1.0		
Guibourtia coleosperma	8	1.4		
Lonchocarpus nelsii	7	1.2	5	3.4
Ochna pulchra	8	1.4	1	0.7
Pterocarpus angolensis	112	19.1	25	17.1
Schinziophyton rautanenii	59	10.1	17	11.6
Strychnos pungens	2	0.3		
Terminalia sericea	21	3.6	8	5.5
Total	586	100.0	146	100.0

4.2 Area estimates

The Vegetation Structural Type were derived for each vegetation unit with data from measured sample plots. The derivation of the Vegetation Structural Type is based on measured height of tree, shrub and grass cover and on measured coverage of each of these layers (Edwards 1983).

Table 2 shows the area and percentage of the different Vegetation Structural Types. Woodlands (definition: tree cover > 0.1 % and shrub cover < 10 % if shrub height more than 1 m) cover 88 % of the area. The woodlands are mostly in the category Short Closed Woodland (definition: tree cover 11-75 % and tree height 5-10 m). Most of the area, 45.6% is Tall, Short and Low closed woodland and 42.6 % is short thicket.

Table 2. Area by Vegetation Structural Types.

Vegetation Structural Type	Area in ha	Area in %
Tall Closed Woodland	924.7	7.6
Short Closed Woodland	4176.2	34.3
Low Closed Woodland	447.4	3.7
Short Thicket	5190.7	42.6
Low Thicket	477.3	3.9
No trees	954.7	7.8
Total	**12171.1**	**100.0**

The crown coverage of each species was calculated for each cluster. The dominant and second dominant species were derived from these crown coverage estimates. Table 3 shows the areas and percentages of dominant species. Baikieae plurijuga is the most common dominant species on 6 175.3 ha or 50.7% of the area followed by Schinziophyton rautanenii as the second most common species on 2 714.3 ha or 22.3% of the area, and P. Angolensis on 1 372.1 ha or 11.3% of the area.

Table 3. Area in hectares and percent by dominant species.

Species	Area in ha	% of total area
Baikea plurijuga	6175.3	50.7
Burkea africana	477.3	3.9
Guibourtia coleosperma	477.3	3.9
No trees	954.7	7.8
Pterocarpus angolensis	1372.1	11.3
Schinziophyton rautanenii	2714.3	22.3
Total	**12171.1**	**100.0**

Table 4 shows the occurrence of second dominant species for each dominant species in area number 2. For example, if B. Plurijuga is the dominant species most often the second dominant species is P. Angolensis and vice versa. When B. Plurijuga is the dominant species then P. Angolensis is the second dominant species in 32.8% of the B. Plurijuga dominated forest and savanna. When P. Angolensis is the dominant species then B. plurijuga is the dominant species in 100% of cases.Again, as in area 1 B. Plurijuga and P. Angolensis occur together.

Table 4. Occurrence of dominant and second dominant species.
(Numbers in the table are percentages of the area of the first dominant species covered by the second dominant species).

	Second Dominant Species							
First Dominant Species	Baikeae plurijuga	Burkea africana	Ccombretum collinum	Commiphora angolensis	No trees	Ochna pulchra	Pterocarpus angolensis	Total area, in %, of first dominant species
Baikea plurijuga		7.7	30.9	15.5		7.7	38.2	100
Burkea africana	100.0							100
Guibourtia coleosperma		100.0						100
No trees					100.0			100
Pterocarpus angolensis	100.0							100
Schinziophyton rautanenii	33.0						67.0	100

Table 5 shows the distribution of crown cover classes by dominant species. Pterocarpus dominated areas are most often in the cover classes 15-20% and 20-25%. Most of the Baikieae dominated areas are also in cover classes 15-20% and 20-25%.

Table 5. Percentage of crown cover classes by dominant species.
The numbers in the table are percentages of the area of the dominant species in the table.

Species	0-5	10-15	15-20	20-25	25-30	35-40	40-45	45-50	55-60	60-65
Baikea plurijuga		7.7	38.2	38.6		7.7			7.7	
Burkea africana			100.0							
Guibourtia coleosperma						100.0				
No trees	100.0									
Pterocarpus angolensis			65.2	34.8						
Schinziophyton rautanenii				17.6	16.5	16.5	16.5	16.5		16.5

4.3 Total tree volume and number of stems

Tree volume here means the volume of the trunk and branches. Table 6 shows the total tree volumes, mean tree volumes, total number of stems and average number of stems per hectare for the whole area by species. Only living trees are included in the table. The most common species is B. Plurijuga (on average 37.54 stems per ha) followed by P. Angolensis (15.49 stems per ha), C. Collinum (11.44 stems per ha) and B. Africana (10.72 stems per ha).

This area too is rich in Pterocarpus Angolensis and Baikieae Plurijuga. But, contrary to area 1, B. Plurijuga has the highest mean and total tree volume, 14.87 m3/ha with 180 960 m3. The second highest mean tree volume is for Pterocarpus angolensis, 7.88 m3/ha, followed by Burkea africana, 3.93 m3/ha. There are about 1 244 390 trees in the inventory area number 2 of which about 456 000 and 188 000 thousand are B. Plurijuga and P. Angolensis respectively.

Table 6. Number of stems and tree volume per hectare and for the whole area by species.

Species	No. of stems, 1000	Stems/ha	% of total Stems/ha	Total tree volume, 1000 m3	Average tree volume, m3/ha	% of total m3/ha
Baikea plurijuga	456.95	37.54	36.72	180.96	14.87	44.53
Burkea africana	130.53	10.72	10.49	47.85	3.93	11.78
Combretum collinum	139.19	11.44	11.19	13.26	1.09	3.26
Combretum psidioides (psidioides)	9.49	0.78	0.76	0.20	0.02	0.05
Combretum zeyheri	31.65	2.60	2.54	1.14	0.09	0.28
Commiphora angolensis	26.59	2.18	2.14	1.98	0.16	0.49
Guibourtia coleosperma	28.34	2.33	2.28	7.22	0.59	1.78
Lonchocarpus nelsii	14.80	1.22	1.19	3.14	0.26	0.77
Ochna pulchra	34.43	2.83	2.77	6.17	0.51	1.52
Pterocarpus angolensis	188.53	15.49	15.15	95.94	7.88	23.61
Schinziophyton rautanenii	83.62	6.87	6.72	43.28	3.56	10.65
Strychnos pungens	10.13	0.83	0.81	0.31	0.03	0.08
Terminalia sericea	90.14	7.41	7.24	4.88	0.40	1.20
Total	**1244.39**	**102.24**	**100.00**	**406.34**	**33.39**	**100.00**

Figure 1 shows the diameter distribution of the total number of stems and stems per hectare in area 2 for all species.

Table 7 shows the total tree volumes and total number of stems by diameter classes for Pterocarpus angolensis and Baikieae plurijuga in the inventory area number 2. The diameter distribution for dominant species is also shown in graphical form in Figure 2. The DBH is in 5 cm classes and the class midpoints are indicated on the x-axis.

Figure 1. Diameter distribution of all species

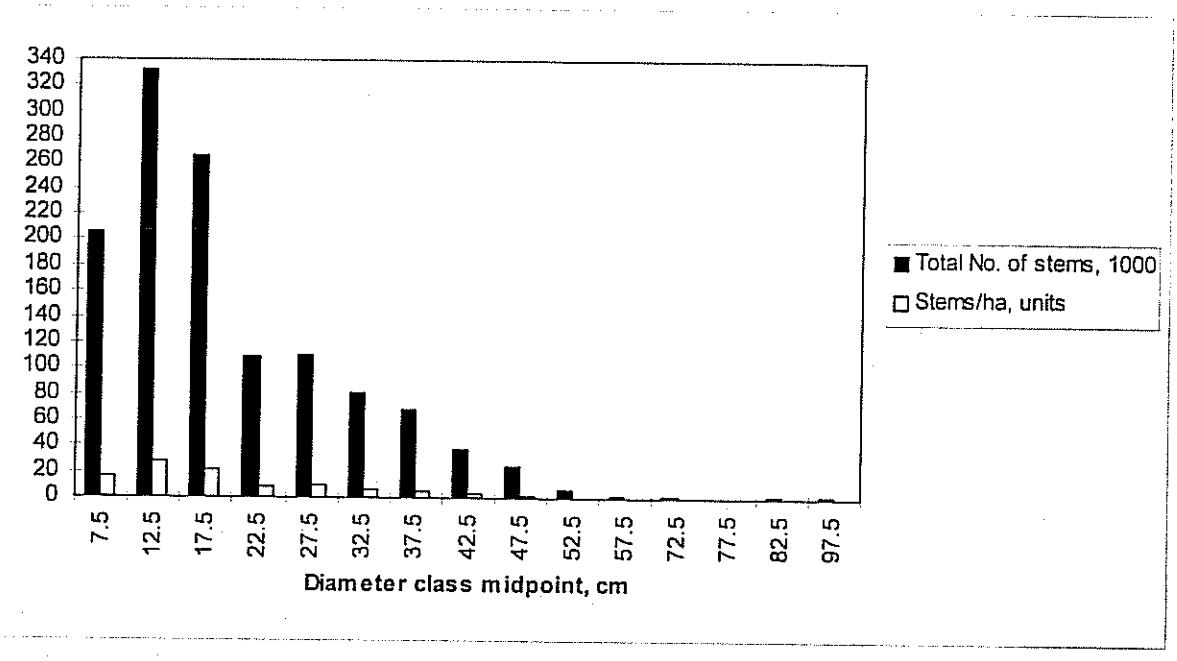


Table 7. Total tree volume and number of stems by diameter classes for P. angolensis and B. Plurijuga.

	P. angolensis				B. plurijuga			
Diameter class, cm	Volume, 1000 m3	Number of stems, 1000	% of stems		Diameter class, cm	Volume, 1000 m3	Number of stems, 1000	% of stems
5-10	0.8	20.2	10.7		5-10	2.4	65.5	14.3
10-15	4.5	49.9	26.5		10-15	7.0	78.7	17.2
15-20	6.5	33.9	18.0		15-20	15.4	86.4	18.9
20-25	3.7	12.4	6.6		20-25	14.0	49.5	10.8
25-30	10.2	23.3	12.3		25-30	23.8	53.1	11.6
30-35	8.3	12.3	6.5		30-35	26.3	41.3	9.0
35-40	11.7	12.7	6.7		35-40	38.2	42.9	9.4
40-45	9.7	7.4	3.9		40-45	31.4	26.5	5.8
45-50	17.0	10.5	5.6		45-50	17.3	10.8	2.4
50-55	7.5	3.3	1.8		50-55	3.7	1.7	0.4
55-60	4.5	1.6	0.9		55-60	1.5	0.6	0.1
70-75	2.9	0.5	0.3					
95-100	8.6	0.5	0.3					
Total	95.9	188.5	100.0			181.0	457.0	100.0

Figure 2a. Diameter distributions of P. Angolensis and B. Plurijuga.

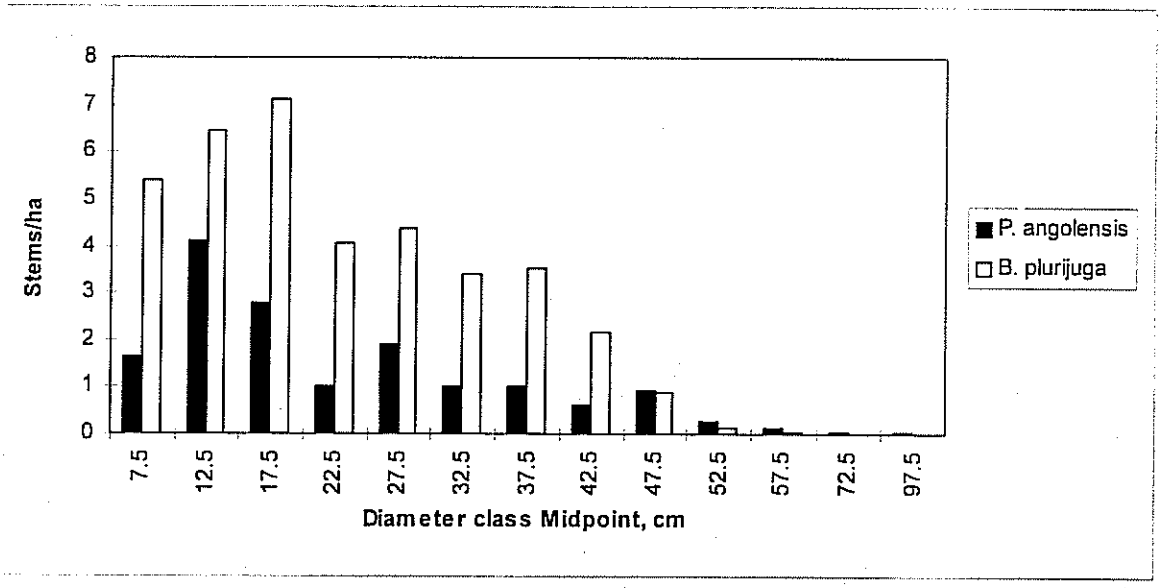
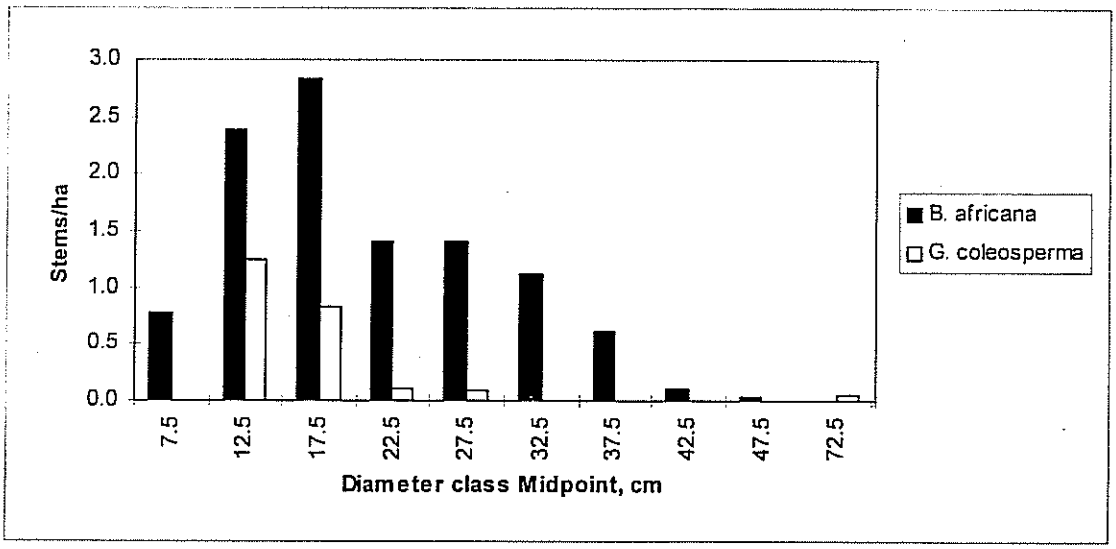


Figure 2b. Diameter distributions of B. Africana and G. Coleosperma.



4.4 Saw log timber volume and number of logs

The log is mostly the trunk of the tree below the first branching. The saw log volume is calculated using the formula for the volume of a cylinder. There is no volume function from felled trees involved here.

Table 8 shows the mean saw log volume of Pterocarpus angolensis trees, 0.71 m3/ha, and a total saw log volume of 8 610 m3 for the whole area. There are 13 500 timber quality Pterocarpus angolensis trees with breast height diameter (dbh) larger than 45 cm.

Table 8. Distribution by quality classes of P. Angolensis and B. Plurijuga trees larger than 45 cm.

Species	Quality	Stems/ha	No. of stems, 1000	Timber volume, 1000	Average timber volume, m3/ha
	Good quality	0.44	5.38	3.74	0.31
P. angolensis	Medium quality	0.49	5.98	3.99	0.33
	Poor quality	0.13	1.62	0.78	0.06
	Not sawable	0.04	0.53	0.10	0.01
Total		1.11	13.50	8.61	0.71
	Medium quality	0.27	3.34	1.44	0.12
B. plurijuga	Poor quality	0.41	4.99	2.44	0.20
	Not sawable	0.18	2.25	0.61	0.05
Total		**0.87**	**10.59**	**4.49**	**0.37**

The quality classes in Table 8 mean:

Good quality = At least 2 m long straight stem without damages.

Medium quality = Stem slightly curving or sweeping or having other damages but still having at least 2 m sawable log.

Poor quality = It is possible to find only 1.2-2.2 m long stem meeting minimum timber requirement.

Not sawable = The stem is not sawable and will probably never develop into a sawable log.

Table 9 shows the log length distribution of sawable P. angolensis and B. Plurijuga trees larger than 45 cm DBH. It is assumed that a tree is regarded as sawable if it is possible to obtain at least a 1.2 m long log. Table 9 shows that the sawable part of Pterocarpus angolensis trees is between 2.2-3.2 and 4.2-5.2 m long for more than 70% of the trees. About 9 670 logs (in, this case logs >1.2 m and excluding Poor and Not Sawable quality) out of the 13 500 logs in Table 8 are sawable. This is about 7 730 m3.

Table 9. Log length distribution of sawable P. angolensis and B. Plurijuga trees larger than 45 cm DBH.

Species	Log length class, cm	No. of stems, 1000	% of stems
P. angolensis	1.2 - 2.2	1.09	9.7
	2.2 - 3.2	3.20	28.3
	3.2 - 4.2	1.09	9.7
	4.2 - 5.2	4.82	42.7
	5.2 - 6.2	1.09	9.7
Total		11.29	100.0
B. plurijuga	1.2 - 2.2	4.47	47.2
	2.2 - 3.2	2.78	29.4
	3.2 - 4.2	1.09	11.5
	4.2 - 5.2	1.13	11.9
Total		9.46	100.0

4.5 Damages

Damages were recorded both at cluster level (for the sampled vegetation unit) and at tree level (for the measured sample trees). At tree level 51.3% of P. Angolensis have no damage while 48.7% of the damages were mild causing only noticeable but not serious damages to the trees. It is interesting to note that as in area 1, there is no fire damage recorded in area 2.

Table 10. Distribution by damage class of Pterocarpus angolensis and B. Plurijuga trees.

Degree of damage	B. plurijuga	P. angolensis
No damage	99.9	51.3
Mild, no harm to the tree	0.1	48.7
Total	100.0	100.0

4.6 P. angolensis and B. Plurijuga woodlands

From forestry point of view, woodlands dominated by Pterocarpus angolensis and Baikieae plurijuga are most important because of their economic value. Table 4 shows that these two species are often found together. The estimated area of woodlands where P. angolensis or B. Plurijuga is the first or second dominant species is 10 739 ha or 88% of area number 2 (when open and low woodlands and thickets are excluded i.e. crown coverage must be more than 10 % and mean height more than 5 m).

The stem size distribution of P. angolensis and B. Plurijuga trees on these 'P. angolensis and B. Plurijuga woodlands' is shown in Figure 3. The average stem number per hectare for the P. angolensis and B. Plurijuga woodlands is the same as the diameter distribution of these species in Figure 2a for the whole area because almost the entire area number 2 (88%) is dominated by P. Angolensis and B. Plurijuga. However, there is a slight increase in the 17.5 cm class. The class midpoint of 5 cm DBH classes are on the x-axis. In addition, excluding the savanna and woodlands dominated by other species did not affect the shape of the diameter distribution.

Figure 3: Diameter Distribution of P. Angolensis and B. Plurijuga on P. Angolensis and B. Plurijuga woodlands.

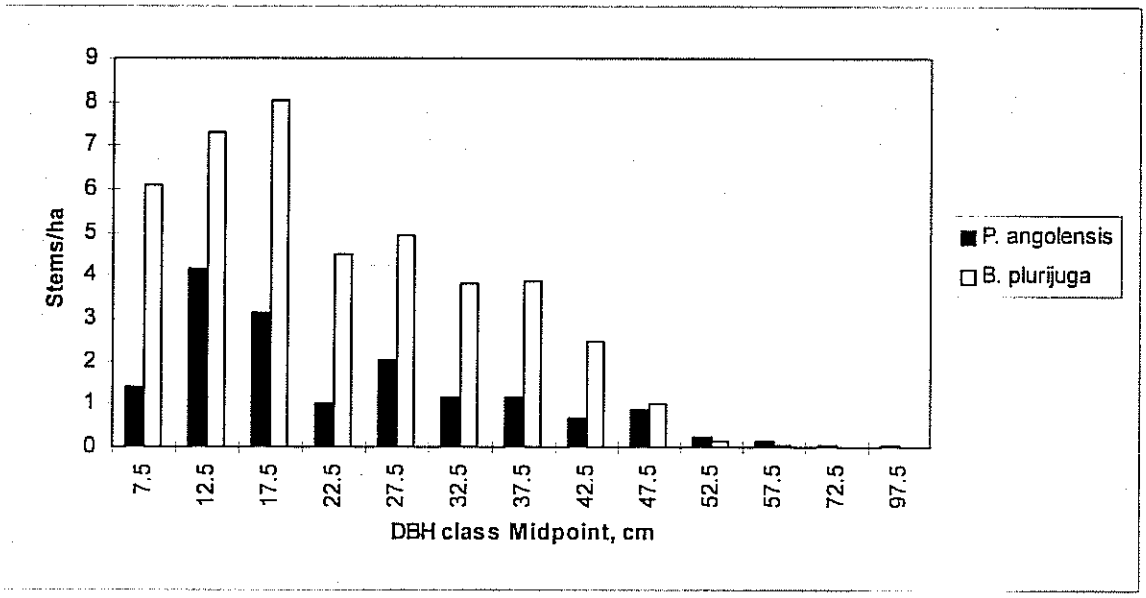


Table 11 shows the number of seedlings per hectare by height classes for P. angolensis and B. Plurijuga. There are 4.3 P. angolensis and 178.3 B. Plurijuga seedlings per hectare. The area is low in B. Plurijuga seedlings compared to area 2. The P. angolensis seedlings are between 151-100 cm high. It should be noted that Table 11 includes only seedlings less than 5 cm in diameter - larger stems were measured as trees.

Table 11. Number of P. angolensis and B. Plurijuga seedlings per hectare by height classes.

Height class, cm	P. angolensis, 1/ha	B. plurijuga, 1/ha
0 - 25	0.0	0.0
26 - 50	0.0	0.0
51 - 100	0.0	82.6
101 - 150	0.0	65.2
151 - 200	4.3	0.0
201 - 250	0.0	0.0
251 - 300	0.0	26.1
>300	0.0	4.3
Total	4.3	178.3

4.7 Species diversity

Table 6 gives a figure on the frequency of different species on the inventory area number 2. Tables 3 and 4 describe the occurrence of dominant species and also give an idea about the mixture of species.

Another measure of species diversity is the number of clusters where each species was found. Table 12 shows this result for both trees less than 5 cm in diameter (including shrubs) and trees larger than 5 cm DBH. Thirteen (13) different species were recorded on the tree field form and 23 species on the regeneration and shrub field form. Pterocarpus angolensis and Baikieae plurijuga were recorded on 20 and 24 clusters respectively.

Some species, like Combretum engleri, Strychnos pungens, and Ozoroa schinzi were found only on 1 cluster each.

Table 12. Number of clusters where each species was found.

Species	Number of clusters, dbh <5 cm	Number of clusters, dbh >5 cm
Acacia ataxacantha	7	
Acacia fleckii	2	
Baikea plurijuga	9	24
Baphia massaiensis	19	
Bauhia petersiana	15	
Burkea africana	3	11
Combretum collinum	7	13
Combretum engleri	1	
Combretum psidioides (dinteri)	1	1
Combretum zeyheri	4	5
Commiphora angolensis	4	3
Croton gratissimus	10	
Dichrostachys cinerea	2	
Grewia retinervis	11	
Guibourtia coleosperma	2	3
Lonchocarpus nelsii	5	5
Ochna pulchra	11	4
Ozoroa schinzii	1	
Pterocarpus angolensis	1	20
Schinziophyton rautanenii		12
Rhigoszum brevispinosum	1	
Rhus tenuinervis	2	
Strychnos pungens	1	1
Terminalia sericea	15	11

4.8. Standard error and confidence limits

Table 13 shows the average volume per hectare estimated from each cluster for all species and for P. angolensis sawlogs with DBH > 45 cm. Table 14 shows the sampling error and 68% confidence limits.

Table 13. Average volume per hectare estimated from each cluster.

Cluster	Total tree volume, m3/ha for all species	Sawlog volume, m3/ha for P. angolensis, DBH > 45 cm
16	27.65	0.49
17	45.41	0.59
18	47.57	1.04
19	43.64	0.00
20	19.02	0.61
21	44.40	1.19
22	46.19	0.00
23	34.29	2.33
24	40.19	4.27
25	33.80	1.07
26	26.62	0.00
27	21.30	0.00
28	37.54	0.00
29	45.30	0.00
30	69.45	5.08
31	27.95	0.00
32	42.14	0.00
33	36.29	0.00
34	0.00	0.00
35	28.59	0.00
36	0.00	0.00
37	38.77	0.00
38	30.07	0.00
39	34.08	2.23
40	20.08	0.00
41	32.78	0.00

For the average volume estimate of all species the sampling error was 2.58 m^3/ha (i.e. 7.7%). For the average volume of Pterocarpus angolensis saw logs (DBH > 45 cm) the sampling error was 0.23 m^3/ha (32.4%).

This means that the true average total tree volume for all species is between 30.81 and 35.97 m^3/ha with 68% probability. Correspondingly, the average volume of P. angolensis saw logs (DBH > 45 cm) is between 0.48 and 0.97 m^3/ha with the probability of 68%.

Since no sampling error is related to the area estimates of the two sampling strata, the total volume estimates have the relative sampling errors of 7.7% and 32.4% for the total tree volume of all species and P. angolensis saw logs, DBH > 45 cm, respectively.

Table 14. Standard error and 68% confidence limits

Item	Sampling varriance	Standard error, m3/ha	Average volume, m3/ha	Lower confidence limit	Upper confidence limit	Confidence level, %
Total tree volume, all species	6.63	2.58	33.39	30.81	35.97	68
Sawlog volume, P. angolensis, DBH > 45 cm	0.05	0.23	0.71	0.48	0.94	68

The sampling error for P. Angolensis saw logs (DBH > 45 cm) seems high, 32.4%, because from Table 13, 16 out of the 26 clusters, or 61.5% of the clusters, did not have logs with DBH > 45 cm.

5.0 RELIABILITY OF THE RESULTS

The following error sources are always present in sampling based forest inventories: sampling error, measurement error including coding error, size of area error, errors in data processing and errors in models used for e.g. volume estimation.

The National Forest inventory field personnel were trained for measurements and plant identification to guarantee good quality of the field data. The inventory team had carried out similar work in West Tsumkwe, Okakarara/Otjinene area and Caprivi Region. Data processing programs used in West Tsumkwe were applied here.

The applied volume functions are probably the main source of errors. The functions are for the West Tsumkwe area. B. plurijuga did not occur in West Tsumkwe and its volume is estimated using the volume model for P. angolensis. On the other hand, the saw log volumes were estimated simply by multiplying the log height with the log basal area at breast height. These error sources have an effect on the volume estimates but not, for example, on the estimates of stem numbers and size class distributions.

The magnitude of sampling error was estimated with the formula of stratified random sampling using clusters (not sample plots) as sampling units. The applied sampling method was not random but the formula is, statistically, more or less valid. The sampling errors and 68% confidence limits for area 1 and 2 and shown in items 3.8 and 4.8 respectively. The standard errors and confidence intervals obtained give an idea of the volume averages to be expected in repeated sampling of the area, assuming that no major forest harvesting takes place in the area.

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Appendices

Appendix 2. Biomass and volume functions.

Function (1) was found to describe well the relation between volume and diameter for Burkea africana and Terminalia sericea. For Combretum, Lonchocarpus and Pterocarpus, Function 2 was applied.

$$v = e\,(a_0 + a_1/d) \quad (1)$$

$$v/d2 = a_0 + a_1 * d + a_2 * d^2 \quad (2)$$

where v = volume, dm^3
d = diameter at breast height, cm

The parameter estimates for the volume functions are as follows

Species	a_0	a_1	a_2
Burkea africana	8.607856	-58.71163	-
Combretum collinum	0.131382	0.0180767	-0.0000905
Lonchocarpus nelsii	0.396588	0.0077865	-
Pterocarpus angolensis	0.667061	-0.008408	0.0002143
Terminalia sericea	7.158742	-39.232256	-

The volume is converted to biomass by multiplying with the basic density. The measured basic densities varied according to tree species and stem diameter as follows.

Species	Basic density, kg/dm3	Basic density,kg/dm3
Burkea africana	0.805, if d < 30 cm,	0.770, otherwise
Combretum collinum	0.881, if d < 25 cm,	0.770, otherwise
Lonchocarpus nelsii	0.977, if d < 25 cm,	0.854, otherwise
Pterocarpus angolensis	0.598, if d < 30 cm,	0.525, otherwise
Terminalia sericea	0.754, if d < 20 cm,	0.616, otherwise

The biomass of branches is estimated with Function (3).

$$B5/B = a_0 + a_1/d \quad (3)$$

where B5 = biomass of branches less than 5 cm in diameter
B = total biomass
d = breast height diameter of the tree, cm

The parameter estimates are as follows.

Species	a_0	a_1
B. africana	0.0468932	2.9833058
C. collinum	0.0956231	1.3644359
L. nelsii	0.0713440	3.5334357
P. angolensis	0.0344962	2.9576978
T. sericea	0.1000000	4.5794900

The biomass of branches can be converted to volume by dividing it with following averaged basic densities of branches.

Species	Conversion factor
B. africana	0.7881
C. collinum	0.8366
L. nelsii	0.9229
P. angolensis	0.6141
T. sericea	0.6627

Appendix 3. Vegetational Structural Types (Edwards 1983).

1a Tree cover > 0.1%	
2a shrub cover < 10%, if > 1m high	forest and woodland
3a tree cover > 75%	forest
4a tree height > 20m	high forest
4b tree height 11-20m	tall forest
4c tree height 5-10m	short forest
4d tree height < 5m	low forest
3b tree cover 11 - 75%	closed woodland
5a tree height > 20m	high closed woodland
5b tree height 11-20m	tall closed woodland
5c tree height 5-10m	short closed woodland
5d tree height < 5m	low closed woodland
3c tree cover 1 - 10%	open woodland
6a tree height > 20m	high open woodland
6b tree height 11-20m	tall open woodland
6c tree height 5-10m	short open woodland
6d tree height < 5m	low open woodland
3d tree cover < 1%	sparse woodland
5a tree height > 20m	high sparse woodland
5b tree height 11-20m	tall sparse woodland
5c tree height 5-10m	short sparse woodland
5d tree height < 5m	low sparse woodland
2b shrub cover > 10% and > 1 m high	thicket and bushland
8a tree cover > 10%	thicket
9a tree height > 5m	short thicket
9b tree height < 5m	low thicket
8b tree cover < 10%	bushland
10a tree height > 5m	short bushland
10b tree height < 5m	low bushland
1b Tree cover < 0.1%	
11a shrub cover >0.1%	shrubland
12a shrub cover > 10%	closed shrubland
13a shrub height > 2m	high closed shrubland
13b shrub height 1-2m	tall closed shrubland
13c shrub height < 1m	low closed shrubland
12b shrub cover 1 - 10%	open shrubland
14a shrub height > 2m	high open shrubland
14b shrub height 1-2m	tall open shrubland
14c shrub height < 1m	low open shrubland
12c shrub cover < 1%	open shrubland
15a shrub height > 2m	high sparse shrubland
15b shrub height 1-2m	tall sparse shrubland
15c shrub height < 1m	low sparse shrubland
11b shrub cover < 0.1 %	grassland and herbland

Appendix 3. Vegetational Structural Types (Edwards 1983).

1a Tree cover > 0.1%	
2a shrub cover < 10%, if > 1m high	forest and woodland
3a tree cover > 75%	forest
4a tree height > 20m	high forest
4b tree height 11-20m	tall forest
4c tree height 5-10m	short forest
4d tree height < 5m	low forest
3b tree cover 11 - 75%	closed woodland
5a tree height > 20m	high closed woodland
5b tree height 11-20m	tall closed woodland
5c tree height 5-10m	short closed woodland
5d tree height < 5m	low closed woodland
3c tree cover 1 - 10%	open woodland
6a tree height > 20m	high open woodland
6b tree height 11-20m	tall open woodland
6c tree height 5-10m	short open woodland
6d tree height < 5m	low open woodland
3d tree cover < 1%	sparse woodland
5a tree height > 20m	high sparse woodland
5b tree height 11-20m	tall sparse woodland
5c tree height 5-10m	short sparse woodland
5d tree height < 5m	low sparse woodland
2b shrub cover > 10% and > 1 m high	thicket and bushland
8a tree cover > 10%	thicket
9a tree height > 5m	short thicket
9b tree height < 5m	low thicket
8b tree cover < 10%	bushland
10a tree height > 5m	short bushland
10b tree height < 5m	low bushland
1b Tree cover < 0.1%	
11a shrub cover >0.1%	shrubland
12a shrub cover > 10%	closed shrubland
13a shrub height > 2m	high closed shrubland
13b shrub height 1-2m	tall closed shrubland
13c shrub height < 1m	low closed shrubland
12b shrub cover 1 - 10%	open shrubland
14a shrub height > 2m	high open shrubland
14b shrub height 1-2m	tall open shrubland
14c shrub height < 1m	low open shrubland
12c shrub cover < 1%	open shrubland
15a shrub height > 2m	high sparse shrubland
15b shrub height 1-2m	tall sparse shrubland
15c shrub height < 1m	low sparse shrubland
11b shrub cover < 0.1 %	grassland and herbland

Appendix 3: Acknowledgements

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Directorate of Forestry

Moses Chakanga	Project Manager
Dennis Sikabongo	Field Team Leader
Immanuel Pieters	Field team Leader
Nickey Orub	Field Team Leader
Eunice Ndaudonya	
Ndapanda Kanime	
Thomas Shilunga	
Philip Shipa	
Kunombara Mbai	
Gerhardt Boois	
Clints Mwilima	
Mervin Kasume	
Ferdinand Kaveta	

Government of Finland

Thomas Selänniemi	Forest Inventory Field Officer

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