Towards estimation of growing stock for the timber tree Pterocarpus angolensis in Namibia

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Towards estimation of growing stock for the timber tree *Pterocarpus angolensis* in Namibia

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Abstract

The open woodlands in the north-east of Namibia are at the southern edge of the Miombo ecoregion. They are characterised by a few canopy species of which *Pterocarpus angolensis* is considered the most valuable timber wood in the country. Despite its economic importance, there are no estimations for the growing stock of the species on a national level. It is therefore hard to demonstrate that there is not enough wood to sustain a timber economy and that the species is threatened by global climate change or by high fire frequency. There are forest inventory data and wood volume equations available on a regional and local level that allow to give rough estimates of the growing stock of Kiaat. An overview is made of the regional wood volume data for all species and for *P. angolensis* for the year 2000. The inventory area used for the estimate is four times higher than that used in forest resources assessments used in Namibia since 2000, and the mean wood volume for Namibia's forested areas decreased from 24.1 to 21.2 m^3/ha. Mean wood volume of *P. angolensis* for all forested areas in Namibia, including regions where the species is not found, is about 1 m^3/ha. Available wood volume equations are compared for *P. angolensis* with historical and recent data of the Kavango regions. Values vary between 11 and 19 m^3/ha for the recent total wood volume per hectare. More data is needed to improve the estimates and to monitor changes, especially because the standard error of the mean volume estimates are high for *P. angolensis*. Assessing tree cover accurately and on a regular basis is one of the main challenges for the future. Forest cover in Namibia according to FAO is now about 8% but is based on linear extrapolations of data of 1993. An integrated method using field inventories with a national cluster-wise systematic grid in combination with remote sensing and other data appear the most efficient approach for future forest assessments.

1. Introduction - background

Namibia is mainly covered by deserts and thorn bush savannah, however it has a considerable area of woodlands in the north east (figure 1). The woodlands are open *Burkea* forests, also named Zambesian *Baikiaea* forests and considered part of the Miombo Ecoregion of the WWF classification (Burke, 2002; Olson et al., 2001; Timberlake & Chidumayo, 2011). More southwards, the woodlands get intermingled with *Acacia* species. Little is known about the woodlands, especially their exact extent, sustainable harvest rates and wood production potential (Graz, 2004; Strohbach, 2013).

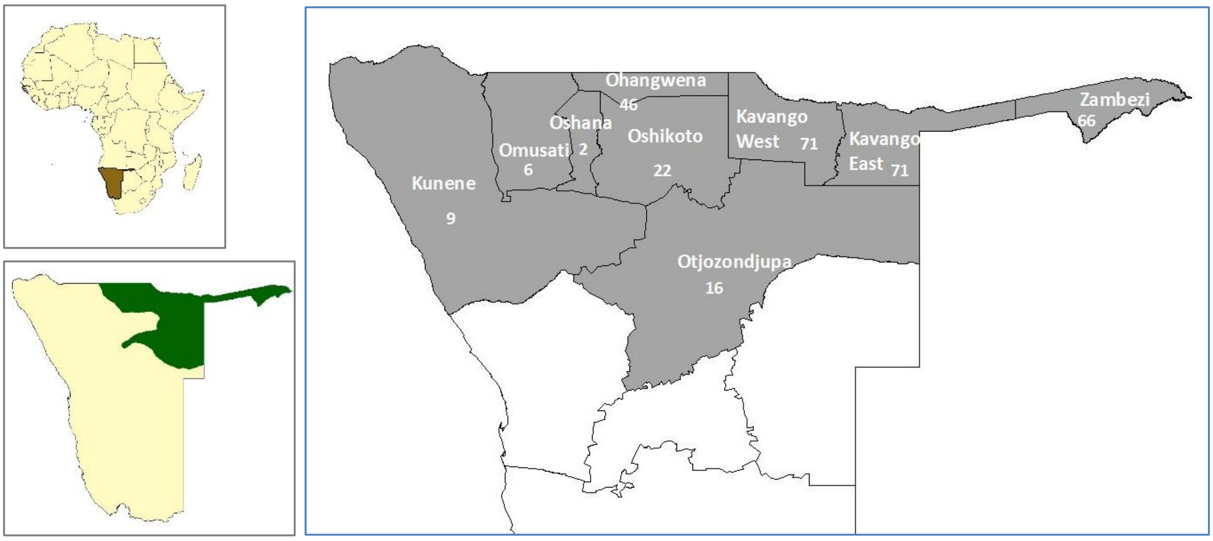

Figure 1. *Woodlands in Namibia. Top left: location of Namibia within Africa. Bottom left: Forest savannah and woodland in Namibia according to Giess (1998). Right: Forest coverage per region in 1993 (Directorate of Forestry, 1995; FAO, 2014; Mendelsohn, Jarvis, Roberts, & Robertson, 2002).*

The woodlands are characterised by a few canopy species, mainly *Burkea africana*, *Baikiaea plurijuga* and *Pterocarpus angolensis*. *P. angolensis* is considered the most valuable timber species in Namibia and its wood is known as, amongst others, Kiaat or Blood wood. It is a deciduous tree, reaching a height of 10 to 18 m in Namibia and growing in mixed stands of open forest (figure 2). The wood is sought after for furniture and decking because of its beautiful grain, colour and good stability; its density is about 440 to 680 kg/m^3 (air dry) (Vermeulen, 1990). The species is only commercially interesting when the bole is large enough to saw planks of the dark heartwood. Despite its economic importance, there are no estimations for the growing stock of the species on a national level (FAO, 2010a).

Claims that there is not enough wood to sustain a timber economy and that the species is threatened by global climate change or by high fire frequency, are therefore hard to proof. There are forest inventory data available on a regional and local level that would allow to give rough estimates of the growing stock of Kiaat. Most of these data were collected before 2010 and would allow establishing a reference against which changes in future growing stock can be assessed. This article aims to give an overview of the information available to determine growing stock for Namibia. It includes a comparison of available wood volume equations for *P. angolensis*. Possibilities for future inventories are discussed.

Figure 2. *Pterocarpus angolensis tree in Kavango East, Namibia (Photo: V. De Cauwer)*

2. Forested area

The first step towards establishing growing stock is determining the forested area. Forest is internationally defined as "*land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ*" (FAO, 2014). The forested area reported for Namibia for the current year is 8.4%, down from 8.8% in 2010 and considerably less than the 15% reported in 1990 (FAO, 1990, 2010a, 2014). The current estimate is not very accurate and is based on linear extrapolations of older data. The main source is a vegetation map derived from SPOT images of 1993 that used another definition for forest than FAO (Directorate of Forestry, 1995). This causes some difficulties, for example, the vegetation map includes savannah classes defined as areas with more than 10% bush cover and trees of 2m to 5m in height. In the FAO reports for Namibia, 35% of these classes is converted to forest without indicating the reason.

Figure 1 shows the forested area per region based on the data of 1993 as reported to FAO. The regional boundaries changed in 1998 and areas of the new regions (listed in table 1) were used to calculate forest cover per region. No information on the regional areas before the changes was available, with exception of the Kavango and Caprivi regions for which the areas were corrected to the situation before 1998 because of the large impact on mean values.

Namibian forest inventories report the forested areas per vegetation type according to Edwards (1983), another classification with a different forest definition than FAO. The vegetation map of 1993 is combined with the information gathered in the field to determine the classes, which provide input in FAO's Global Forest Resources Assessment (FRA) (FAO, 2014; Korhonen, Juola, & Chakanga, 1997a). An accurate forest assessment according to FAO definitions still has to be done (Mendelsohn & Obeid, 2005) and is urgently needed, especially considering ongoing deforestation and degradation.

3. Growing stock

The forested areas are multiplied with the mean growing stock in forested areas to determine total growing stock. According to FAO, the growing stock is the "*volume over bark of all living trees more than X cm in diameter at breast height (DBH)*". This includes the stem from ground level or stump height up to a top diameter of Y cm, and may also include branches up to a minimum diameter of W cm. Each country defines their X, Y and W values. In Namibia, the growing stock is calculated with volume equations for all trees of more than 5 cm in DBH and includes all branches (Burke, Juola, Korhonen, Selaniemmi, & Chakanga, 2001; Chakanga, Juola, & Korhonen, 1996). The equations were established as part of the Namibia – Finland Forestry programme and are based on trees felled in four regions.

3.1 Mean growing stock in Namibia

The most comprehensive datasets for Namibia are the regional forest inventories carried out in the period 1997 – 2002. They were done for most of Namibia's northern regions, with exception of Ohangwena and Kavango because of guerrilla activity and landmines (Angombe, 2004; Julin, 2002). However in the FRA's for Namibia, only data of three regions is being used to determine mean growing stock on a national level (Angombe & Laamanen, 2002; Chakanga, Korhonen, & Selaniemmi, 1998; FAO, 2014; Selanniemi, Chakanga, & Angombe, 2000a, 2000b). It concerns Omusati, Oshana and Oshikoto, which were reported to have a mean growing stock of 24.07 m^3/ha in 2000 (FAO, 2014). Hence, the mean wood volume used to calculate total growing stock in Namibia since 2000 is based on inventories representing only a fraction of the forested regions of Namibia (figure 1).

Table 1 gives an overview of forest inventory information available on a regional level for the reference year 2000. The inventories report total wood volume on a species level and the information for *P. angolensis* was included in the table. The reports of the 1997 and 1998 inventories (Chakanga et al., 1998; Korhonen et al., 1997a; Korhonen, Juola, & Chakanga, 1997b) do not give wood volume for the forested area but for the complete inventory area, thus including not only forest but also other shrub and woodland. The wood volumes were therefore corrected by removing the total wood volumes of species typical for very open woodland or for shrub land, such as *Boscia spp.*, *Acacia recifiens*, the bush encroachers *A. mellifera* and *Dichrostachys cinerea*, and *Colophospermum mopane*. For the two regions without regional inventories, Kavango and Ohangwena, inventory reports of communal forests were used, which resulted in a much smaller inventory area (Angombe, Selaniemmi, & Chakanga, 2000; J. M. Kamwi, 2003; Kanime, 2003a, 2003b). The reports did not mention the forested area and this was derived from a tree coverage map for the Kavango regions created by Verlinden and Laamanen (2006) (see more information in 4.).

Table 1. *Wood volume in Namibia as determined by forest inventories on regional level for 2000. Mean wood volume is determined for the forested areas. Regional areas are from Mendelsohn et al. (2002).*

Regions	Date	Area (ha)			% forest	Wood volume all species		Wood volume Pterocarpus angolensis	
(*)		Region	Inventory	Forested (**)		Total (m3)	Mean (m3/ha)	Total (m3)	Mean (m3/ha)
Omusati	2000	2655800	1383924	152394	11,0	1079400	7,1	0	0
Oshana	2000	868200	514163	7683	1,5	21000	2,7	0	0
Oshikoto	2002	3866900	1646401	588478	35,7	16690700	28,4	896500	1,5
Otjozondjupa west	1997	10533400	607949	341212	56,1	10756240	31,5	968200	2,8
Otjozondjupa east	1997		8212447	1757037	21,4	17449990	9,9	14880	0,0
Caprivi	1998	1446700	2007764	891671	44,4	31029700	34,8	968200	1,1
Kavango	2003	4848300	43299	38369	88,6	1578082	41,1	236138	6,2
Ohangwena	2000	1069400	55918	44509	79,6	2338800	52,5	457400	10,3
TOTAL		25288700	14471865	3821353	26,4	80943912	21,2	3541318	0,9

(*) Otjiozondjupa east also includes a small part of Omahake (north)
(**) The forested area for Omusati is slightly different from that in the FAO reports but is based on the values indicated in the forest inventory report (FAO, 2014; Selanniemi et al., 2000a).

The table shows that the inventory area used to calculate the mean wood volume is four times the area used in the FAO country reports for Namibia. The resulting mean wood volume is slightly lower with 21.2 m^3/ha. This is mainly caused by the large forested area of eastern Otjozondjupa with low mean wood volume. Increasing the inventory size for Kavango would raise the mean wood volume.

3.2 Comparison of wood volume equations

Next to the equations established as part of the Namibia-Finland programme, other authors have established allometric relations for Namibia and some of those available for *P. angolensis* are compared by applying them to tree inventory data of Kavango (table 2). The equations for total wood volume including branches are based on the same dataset of trees felled during the Namibia-Finland programme (Angombe et al., 2000; Julin, 2002; Kanime & Laamanen, 2002). The inventory data consisted of three datasets: 1) research data: own data collected during the period 2011 – 2014 along transects representing an increasing distance from human settlements and rivers (Vera De Cauwer, 2013); 2) forestry data: data of the Namibian Directorate of Forestry collected by systematic grid sampling in community and state forests in the period 1998 – 2014 with the aim to assess forest resources (Chakanga & Selanniemi, 1998; J. M. Kamwi, 2003; Kanime, 2003a; Mukoya & Kamwi, 2014); and 3) historical data of the Department of Forestry of South-Africa, then in charge of forestry in Namibia, collected in a systematic grid design in the Kavango region over the period 1972 – 1974 (Geldenhuys, 1992). The oldest dataset is based on a minimum

DBH of 10 cm while the others use a minimum DBH of 5 cm, which explains the smaller number of stems for the older data. All variables, except mean DBH, show a high standard error of about 80 to 110% indicating the high variability of Kiaat wood volume and the need for more data. Of the historical growing stock, 0.45 m^3/ha concerned Kiaat trees with harvestable sizes, a minimum DBH of 45 cm (Geldenhuys, 1992). The total wood volumes show large differences and the suitability of the equations should be explored in further detail and compared with amongst others the volume equation of Moses (2013).

Table 2. *Wood volume of Pterocarpus angolensis for different datasets of the Kavango regions and calculated with different equations: total wood volume is based on 1) (Kanime & Laamanen, 2002), 2) (Angombe, 2004), site III, and 3) (Julin, 2002). Saw log volume is that of 1) the volume of a cylinder with measured bole length and 2) (De Ruytter, 2015)*

Dataset	Historical	Forestry	Research	Grand Total
Total number of plots	492	462	185	**1139**
Number of plots with Kiaat	407	276	105	**788**
Period	1972 - 1974	1998 - 2014	2011 - 2014	**1972 - 2014**
Stems/ha	19 (16)	35 (42)	39 (35)	
Mean DBH (cm)	23,3 (8,5)	27,2 (11,3)	24,6 (12,1)	**24,8 (10,2)**
Basal area (m^2/ha)	0,9 (0,8)	1,5 (1,2)	1,6 (1,5)	**1,2 (1,1)**
Total wood volume 1 (m^3/ha)	7,3 (7,1)	12,6 (11,1)	14,4 (14,6)	**10,1 (10,3)**
Total wood volume 2 (m^3/ha)	9,8 (9,1)	16,7 (14,2)	18,8 (18,0)	**13,4 (13,1)**
Total wood volume 3 (m^3/ha)	6,4 (6,1)	11,0 (9,6)	12,9 (13,5)	**8,9 (9,1)**
Sawlog volume 1 (m^3/ha)			5,4 (5,5)	
Sawlog volume 2 (m^3/ha)	3,3 (3,1)	5,5 (4,6)	6,1 (6,0)	**4,4 (4,3)**

Table 2 shows larger amounts of *P. angolensis* wood available per hectare for Kavango than the 6.2m^3/ha of table 1. The inventories used for the forestry dataset in table 2 are almost the same as those for Kavango in table 1, with the inventory of Hamoye state forest added to table 2. The main difference is that results of inventory reports were used for table 1 and original inventory data for table 2.

4. Future inventories

FAO has assisted several countries, such as Angola, in establishing forest inventories with a new inventory method, the National Forest Monitoring and Assessment (NFMA) (FAO, 2008). Tomppo and Katila (2008) showed that the FAO NFMA design is inefficient when compared to cluster-wise design with sampling density adapted to the variability of forests. Considering the simple and straightforward approach of a cluster design compared to the NFMA method, and considering the fact that the use of clusters has already been applied in some of the grid sampling designs used for the forest inventories in Namibia, it seems advisable to stick to systematic grid sampling with clusters. A national forest inventory grid is however needed, preferably one that incorporates some of the previous inventory plots. The correct distance between clusters may be derived from other countries that include areas with similar mean wood volumes and from the sampling errors found in the previous inventories done in Namibia.

Collecting all forest inventory information with field based measurements is however hardly feasible on a 5 to 10 yearly basis because of the cost and intensive labour involved. Moreover, Namibia has a serious lack of manpower and skills in the forestry sector (FAO, 2010a). While part of the problem can be solved by involving post-graduate students from Namibia and abroad in the inventory, other methods are needed to complement the field measurements. Most countries use a combination of field measurements and remote sensing to reduce the cost involved in forest assessments (Gallaun et al., 2010). In Namibia, attempts have been made to combine inventory data with information extracted through remote sensing. Verlinden and Laamanen (2006) tested the use of Landsat TM data to determine forest cover. Kamwi and Kätsch (2009) explored high-resolution images to derive stand volume, stand density and diameter distribution. Their stand density model performed best, explaining 81% of the model.

The most frequently and urgently needed forest measurement, forested area, is based on tree cover. This is also the forest parameter that is the easiest to determine from satellite images (Verlinden & Laamanen, 2006). There are however a range of factors making it difficult to determine tree cover with high accuracy for Namibia. The classification of satellite images is affected by firescars; Namibia is among the countries with the largest areas burnt (FAO, 2010b). A second factor is the open canopy resulting in a remote sensing signal that is the combination of both tree and shrub layer reflectance. Finally, there is the high variability in rainfall causing big differences between vegetation indexes from year to year (Ganzin, Coetzee, Rothauge, & Fotsing, 2005). Hence, global or continental tree cover maps such as the SAFARI2000 tree cover dataset (DeFries, Hansen, Townshend, Janetos, & Loveland, 1999) and FRA 2000 (FAO & EDC, 2000), detect as good as no areas with forest cover of more than 10% in Namibia.

Verlinden and Laamanen (2006) did however establish a linear relation between tree cover and Landsat TM band 4 (R=0.72) for images acquired in 2000. Tree cover maps for most northern regions of Namibia were established with this equation, after the map was resampled to a pixel size of approximately 0.5 ha and a threshold of 10% tree cover was applied. The maps are not indicated as a source in any of the FRA's of Namibia. When the maps were used to derive forest cover for the research dataset of the Kavango regions, there was a very low correlation (0.25) with the field based tree cover (figure 3). Forest cover from the tree cover maps were often underestimations from the field situation. Verlinden and Laamanen (2006) did indicate that a field design covering a larger area than most Namibian forest inventory plots was required to establish the relation. The research inventory dataset used the typical circular plots with a radius of 30m (Burke et al., 2001).

The bad correlation can also be explained by the fact that only remote sensing data of one season was used, and this for a year with more than average rainfall in Namibia. Hüttich et al. (2009) obtained much better results for mapping vegetation types in Namibia with the use of longer time series of satellite images compared to using data of one year. They also found that remote sensing data of the driest rainfall seasons gave better results. The research dataset of the Kavango regions was compared with parameters derived from multi-temporal data of MODIS (Stellmes, Frantz, Finckh, & Revermann, 2013). Correlation with the mean of enhanced vegetation index (EVI) values derived from time series of the period 2000 – 2006 was 0.43, better than the mean EVI for the period 2007-2013 (0.33*)*. The best correlation obtained was with the total integral, a phenology descriptor that represents total biomass (Mader, 2012), for the period 2000 - 2013 (0.48). Using time series of satellite images is more appropriate for the rainfall dependent vegetation of Namibia (Ganzin et al., 2005).

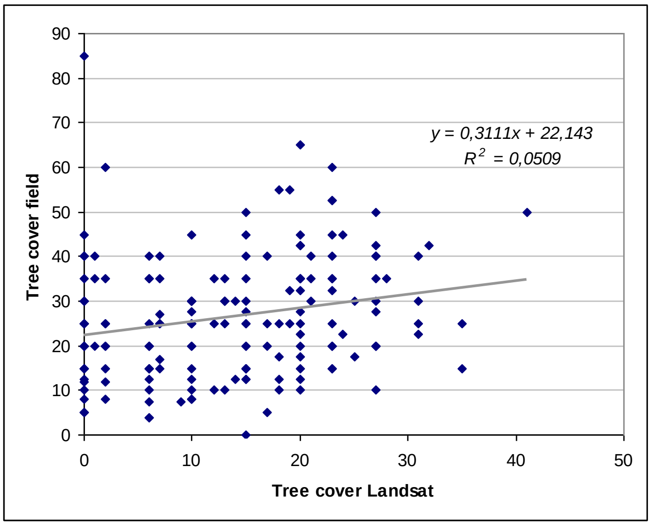

Figure 3. *Relation between tree cover derived from Landsat TM and tree cover measured in the field. Spearman correlation was 0.25.*

The most cost-efficient method to derive vegetation related information for dry land forests is a method that integrates several ways of data collection (Hüttich et al., 2009; Kamwi & Kätsch, 2009). Modelling allows to integrate remote sensing and climatic variables for relevant forest measures, such as species or tree community occurrence but also basal area or wood volume. Revermann et al. (2015) modelled the distribution of canopy tree species in the Okavango basin with environmental variables and MODIS derived parameters. De Cauwer (2015) used a boosted regression model to model the contribution of *P. angolensis* to the total basal area in a plot with MODIS (derived by (Stellmes et al., 2013)) and environmental data (*rho* = 0.53). The variables contributing most were start and end of the green season, aspect, land cover, tree cover, slope, cattle density, distance to main roads and dry season EVI for 2007 – 2013. Similar models should be tested for larger forest inventory datasets available for Namibia.

5. Conclusions

Namibian forest assessments are mainly based on forested area as determined in 1993 and on forest inventories made in 2000 for some of the woodland regions. Using all regional forest inventory data available results in an inventory area that is four times larger than that used in forest resources assessments used in Namibia since 2000. The resulting mean wood volume for Namibia's forested areas decreased from 24.1 to 21.2 m^3/ha. This estimate can be improved if more inventory data would be available for the most forested regions of Namibia, the Kavango regions. Mean wood volume of *P. angolensis* for all forested areas in Namibia, including regions where the species is not found, is about 1 m^3/ha. There are several equations for total wood volume of *P. angolensis* available for Namibia which give large differences in total wood volumes, varying between 11 and 19 m^3/ha when applied on inventory data of the Kavango regions. The suitability of the equations should be explored in further and preferably updated with more data. Regulary updated information on forest cover in Namibia will allow to determine the forested area according to FAO definitions for past and future forest assessments. It will improve the estimate of mean and total growing stock on a national and regional level. A national methodology for future assessments is needed, preferably based on both remote sensing and field measurements. Remote sensing measurements can be combined with climatic and other environmental variables through modelling to reduce the need of collecting and analysing large image datasets and to assist with remote sensing problems such as fire scars, rainfall variability and low canopy cover.

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