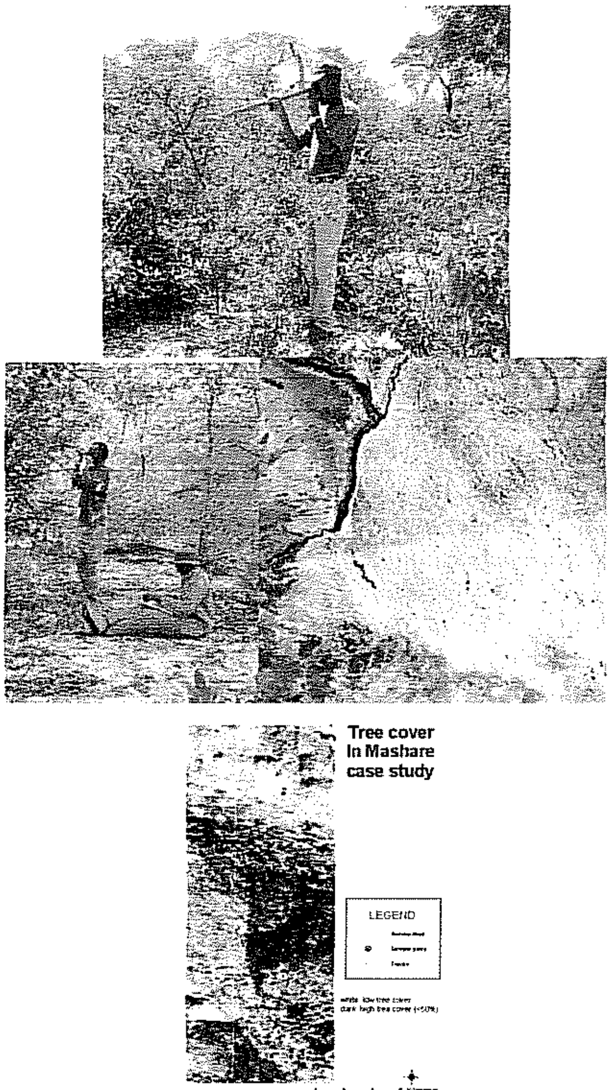
Ministry of Environment and Tourism

Directorate of Forestry

The role of remote sensing in monitoring woody vegetation resources in Northern Namibia.



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Windhoek
April 2002

The role of remote sensing in monitoring woody vegetation resources in Northern Namibia.

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Abstract

In 1995 a forest inventory covering Northern Namibia was initiated based on stratified systematic field sampling of plots with a radius of up to 30 m. In these plots detailed tree parameters were measured. Due to security problems the most important wooded parts of the area could not be covered completely, while the inventory method used was also very costly. The present study investigates if Landsat TM imagery can be used to estimate the necessary woody vegetation parameters in areas where only limited fieldwork is possible, based on similar data collected in other areas. Statistical tests between pixel values of different bands of the imagery with the tree parameters obtained by the existing field sampling method did not result in significant relationships useful for modeling woody vegetation parameters in three test areas. Two methods of different design were tested in one pilot area. Both resulted in statistically significant correlations (up to R= -0.74 for trees and R= +0.70 for shrubs) between % woody vegetation layer cover and pixel values of band 4 of Landsat TM. The increased size of the sample plots in both methods was likely to be the main reason of the improved correlations as the results of both the new methods tested were not significantly different from each other. Relationships between cover and other woody plant parameters like basal area and models for estimating woody resources in parts of Northern Namibia are discussed.
This paper also investigates the relationships between species presence/absence of several important timber species and remote sensing. Significant relationships using Generalized Linear Models were obtained for some species and these could be used to model species composition using Landsat TM.

Introduction

Information on woody vegetation parameters on large scales is often required by government agencies for strategic planning and management purposes. Countrywide inventories are used in many countries for these reasons (Danaher et al. 1998). Besides these purposes, deforestation and forest change are often monitored in national programmes, as information on changes in forest resources is used for political and management decisions (Apan, 1997). In Namibia, millions of hectares are reportedly affected by a process of bush thickening resulting in economic losses, while in other areas deforestation is considered important (Tokola et al. 1999; Erkkilä and Löfman, 1999). Processes of deforestation and bush thickening are important throughout southern Africa and in many other areas (Archer, 1995; Hudak and Wessman, 1998, Hudak, 1999, Hudak and Wessman, 2000). All this points to the importance of being able in Namibia to assess woody vegetation parameters on a large scale.

In Namibia a woody vegetation inventory based upon detailed field sampling of tree parameters was started in 1995 to obtain cover, basal density and volume estimates at species level for various regions of a total size of close to 17 million ha of mainly communal areas in northern Namibia. It was hoped that this approach would result in regional level inventories useful for strategic planning of the forest resources of the country. Suggestions were also made to use the methodology for monitoring woody resources on a long-term basis.

Due to sporadic guerilla warfare on the Namibia-Angolan border flaring up in the late 1990s, the most important wooded parts of the area could not be covered completely, while the inventory method used was also time consuming and very costly, causing concerns of sustainability. Remote sensing is often considered a more cost-effective alternative, reducing the amount of fieldwork, while it certainly is a potentially attractive alternative to intensive fieldwork in war zones.

This paper investigates to what extent Landsat TM imagery could be used 1) to reduce the inventory costs, 2) to model woody resources in areas not yet covered and 3) to monitor changes in woody resources over time.

Initially tests were conducted using the results of the original inventory method. This resulted in low correlations between TM waveband pixel values and various woody plant parameters.
Field observations suggested that plots with a maximum radius of 30 are not necessarily representative for the surrounding area, while geometric errors caused by using GPS referenced samples and errors in satellite image registration may also contribute to the lack of significant correlations. Therefore it was decided to change the field sampling method by increasing the size of the area covered in each sample. Two new methods were tested, one using estimates of tree parameters and one more time-consuming using measurements of location, diameter and canopy cover.

Material and Methods

Study Area

The area concerned here is located in Northern Namibia, between 14 deg E and 23 deg E and 17.2 S and 19 S (Figure 1.).

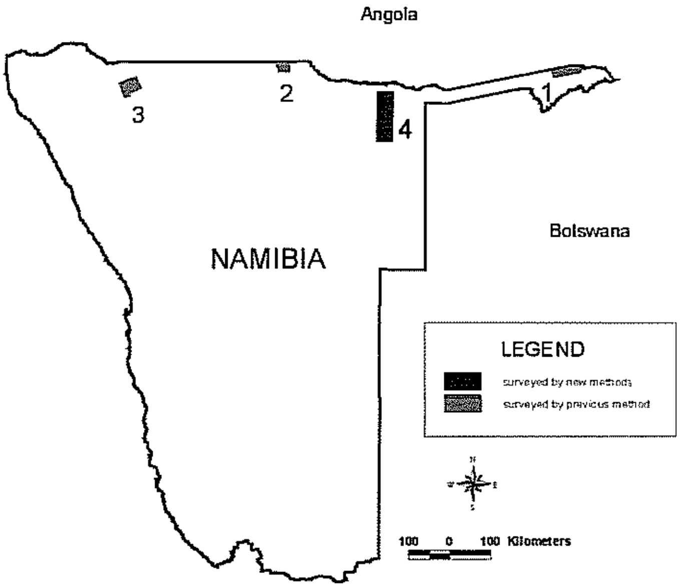


Figure 1 The location of the pilot areas in northern Namibia

The rainfall gradient is substantial: average 710 mm in the East and 350 mm in the West. In the West, the area is characterized by *Colophospermum mopane* Kirk. ex J. Leonard shrubland and in the East by open woodland with *Pterocarpus angolensis* DC., *Baikiaea africana* Harms., *Guibourtia coleosperma* (Benth.) J. Leonard, *Burkea africana* Hook.

Four test areas were selected for this study (Figure 1). All were the subject of a more intensified sampling resulting in a higher number of samples. Area 1 covers 136,000 ha, Area 2 72,000 ha, Area 3 163,000 ha and Area 4 460,000 ha. Area 3 was only partly covered as the inventory teams found unexploded explosives of previous warfare and aborted the inventory. Area 4 was added applying a new methodology as correlations tests with woody vegetation cover and image pixel values of corresponding locations with existing data did not give successful results for vegetation modeling purposes.

Field Sampling methods

Throughout the sampling, woody vegetation with diameter at breast height (1.3 m) (dbh) > 0.05 m is classified as trees. If dbh < 0.05 m, the woody vegetation is classified as shrubs. Diameters are measured with calipers. Other parameters measured on trees are height and crown diameter, both with a Vertex hypsometer.

Method 1

The original inventory has been designed to produce results for each political region in the country. It has been based on stratified systematic sampling of field plots. A field plot consists of three concentric circles with a radius of 10, 20 and 30 m for different sizes of trees. For small trees (0.05m <dbh <0.2m) the radius is 10 m, for medium sized trees (0.2m <dbh <0.45m) the radius is 20m and for big trees (dbh>0.45 m) the radius is 30m. In many cases two plots have been measured at a distance of 100 m to each other as a cluster to increase the size of the sampling unit. Averages of the two plots in a cluster were then used for the calculations. The location of each cluster has been predetermined with GIS software. and in the field the clusters have been located with a Global Positioning System (GPS).

Method 2

In order to test the hypothesis that a small plot size of maximum 30 m influenced the low correlations with the satellite imagery, 49 sites were visited as a part of a reconnaissance survey prior to a timber inventory in Area 4. In each site, a tract with three sides of 100 m length was used. Along the tract, a recording point was laid after every 20 m. At each recording point (a total of 15 points per tract) the woody vegetation cover was estimated separately for woody plants between 2 and 4 m height and for trees taller than 4 m. A densiometer (Lemmon, 1957) was used for estimating the woody plant cover in the two classes. 4 readings per recording point of both height classes were taken. In addition, woody plants lower than 2 m were estimated with a Bitterlich relascope (references) sweep with factor 5 in each recording point. Average values of cover for the three woody plant classes were calculated and used in the analysis.

Method 3

The third method was combined with a timber inventory. Using the data collected with method 2 and visual interpretation of three-band combination of a Landsat TM image, some large open areas were delineated and left out of the sampling. A systematic selection of sample units for the timber inventory was carried out. Every 12th sampling unit (or cluster) was established in the field with a new design (Figure 2).

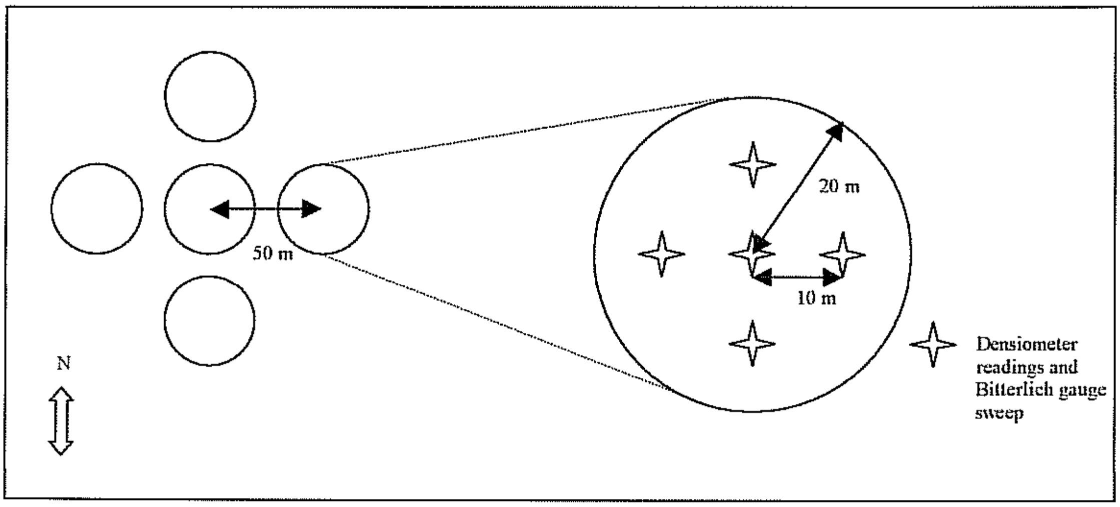


Figure 2. Cluster and plot design. On the left is the design for the cluster with five plots. On the right is the design of one plot: all trees with dbh > 5 cm are measured within radius of 20 metres. Densiometer

readings of trees in 4 directions and a Bitterlich gauge sweep of shrubs are taken at places with the star shaped symbol.

A cluster of five plots each with a radius of 20 m was used to cover a larger area than with method 1. On each plot, tall trees with a dbh > 0.05 m were measured (species, location, canopy diameter. The location of each tree from the central coordinate was obtained by taking the bearing with a compass and measuring the distance from the center to the tree with a Vertex distance measurer. Tree height and canopy diameter were measured as in method 1. The canopy diameter measurements in two directions were done for each tree separately without taking into account the possible overlap of adjoining crowns. Therefore the crown cover percentage of a plot includes a certain amount of overlap in dense stands. This overlap could be measured in a GIS by plotting all measured trees with their canopy diameters. This allowed to investigate the influence of canopy overlap on the relationships between cover and other tree parameters. Canopy overlap is defined as the difference between the measured crown cover and the projected canopy cover in each cluster.
Inside each plot, five recording points for estimating cover with the densiometer and the Bitterlich relascope (Friedel and Chewing, 1988) were selected. Tree cover of trees with a dbh > 0.05 m was estimated with the densiometer (four readings at each point). Woody plant cover with a dbh< 0.05 m was estimated with the Bitterlich relascope. This method allows the comparison of results obtained by measuring tree canopy parameters with results obtained by estimating these with the densiometer and the Bitterlich relascope. Using the densiometer is a much faster method to estimate canopy cover than measuring individual tree crown cover and therefore this method was tried to see if it could replace the time-consuming measurements.

Species presence/absence.

A large set of field observations obtained with method 1 over a 7 year period are available to estimate species frequency in and around the 4 study areas. These samples are considered to be counts of presence/absence and used in estimates of the probability of the presence of certain species at certain pixel values of the satellite imagery (references). As the samples of the established inventory method are small, these are to be considered as underestimates of species presence and therefore fairly low thresholds of probability of occurrence could be applied to derive species distribution maps from satellite images and obtained significant equations.
For these tests *Pterocarpus angolensis, Baikiaea plurijuga,Guibourtia coleosperma, Burkea africana, Terminalia sericea* Burch. ex DC. and *Terminalia prunioides* C. Lawson were selected in the samples of the four study areas. The three former species are the most important commercial species, while the latter are the most important timber species used locally for construction.

Remote Sensing

Four satellite images, three Landsat ETM+ and one TM 5 were examined. Of the TM5 scene only bands 1,2,3 and 4 were purchased, the others had the full waveband range.
All satellite images were selected primarily on having cloud-free data and on the same seasonal phase of the vegetation. The end of the wet season and the early dry season

are in Northern Namibia considered to be the optimal period for detecting woody plant vegetation (Erkkilä and Löfman, 1999, Tokola et al. 1999).
All four images used in the analysis had already been rectified by the supplier but had to be re-registered using the nearest neighbour method with co-ordinates obtained by GPS in the survey areas during field trips in areas 2,3 and 4. Only GPS data of 2001 and 2002 were used, as previous ones obtained were less accurate. The registration used in the analysis reduced geometrical errors to an RMSE of less than 30 m. Overlays with GPS tracks and points collected during field trips in three of the study areas confirmed position errors of less than 30 m. This does however not ensure that the pixel exactly corresponding with the central location of the field sample is used in the analysis of the first sampling method, as nearest neighbour resampling techniques were used in the registration of the images.

For the first and third method, using ARCVIEW GIS software (ESRI, 1999), a circular buffer with a 100m radius around the GPS coordinates of the central position of each sample was drawn. The resulting polygons were imported into IDRISI and converted to a Boolean raster image with the same registration as the corresponding Landsat TM image. This Boolean image was used to extract the pixel values of the different bands of the satellite image that fell within the 100 m radius. The average value of all pixel values with more than 50% of their areas falling within a 100 m radius of the central location of the sample was used for the statistical analysis. This ensures that the majority of the pixel values corresponding with the areas covered by the field samples are represented in the analysis.

For the second sampling method a square of 100x100m with the starting GPS coordinate on one corner of the square was drawn in ARCVIEW GIS software (ESRI, 1999) for each sample. This area represents the area covered by each sample in the field. The resulting polygons were imported into IDRISI software (Eastman, 2000) and converted to a Boolean raster image with exactly the same registration as the Landsat TM images. This Boolean image was used to extract the pixel values of the different bands of the satellite image that fell within the 100 x 100 m square. The average value of all pixel values with more than 50% of their areas falling within the 100x100m square was calculated with IDRISI and used for the statistical analysis. For the analysis bands1,2,3,4,5,7 are used. Bands 3 and 4 were used to calculate the Normalized Vegetation Index (NDVI):

$$NDVI = (Band\ 4 - Band\ 3)/(Band\ 4 + Band\ 3)$$

The NDVI is often used as it has been demonstrated in many cases to be correlated to green biomass in semi arid areas (Tucker, 1979, Danaher et al. 1992, Duncan et al. 1993, Verlinden & Masogo 1997), although Ringrose et al. (1994) found that green vegetation exhibited varying response curves in different climatic zones across all Landsat MSS wavebands and NDVI is therefore not always reliable.

Statistical Analysis

As not much is known about relationships between woody plant parameters and remote sensing in the study area, linear regression models were used for the relationships between woody cover and pixel values of individual bands. It has often been demonstrated that woody cover has the highest correlation with satellite imagery

(McCloy and Hall, 1991, Duncan et al. 1993, Hudak and Wesman, 2001). To meet the requirements of the forest inventory and woody resource monitoring, cover data need to be significantly correlated to basal area and volume. Regression analysis was used to test these requirements. Possible influences limiting high correlations between cover and stand basal area are: canopy diameter overlapand the use of densiometers to estimate tree cover

For the modeling of woody parameters basal area, crown cover, crown projections, volume, various commonly used models in forestry were used. For the prediction of stand basal area a linear model was used. For % overlap with measured crown cover an exponential model was used.

The NFI reports present data at *species level.* The correlations and regression equations presented so far dealt with *total* tree and shrub cover, without making distinctions between species.

The possibility of predicting the presence of important species with remote sensing by making use of Generalised Linear Models (GLM) (Smilauer 1992) was explored. A logit model of the form y = ln (1/1+x) on a dataset of Okongo Community forest to test this possibility, using a binomial distribution for the species and assuming a Gaussian distribution for the pixel values with the average value of all pixel values with more than 50% of their areas falling within a 100 m radius around the center of the samples

Results

Influence of Canopy Diameter Overlap

In the field work, the canopy diameter (in two directions) of each individual tree was measured. Because of overlapping canopies, the calculated cover percentage includes a certain overlap. This overlap was analysed with ArcView by plotting the tree crowns on the cluster on their exact locations and defining the projected coverage. The overlaps on each cluster have been illustrated in Figure 3.

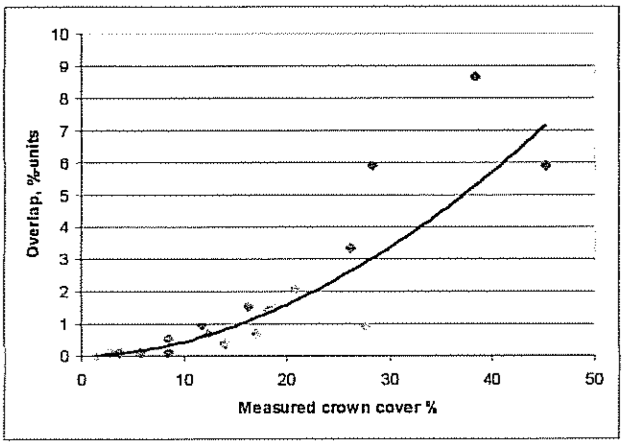


Figure 3. Overlap of tree crown cover. The overlap is expressed as the difference between the measured crown % and the projected crown % on each cluster.

The overlap is fairly low – less than 2 %-units – up to a measured cover of 20 %. With higher covers, the overlap increases rapidly.

Comparison between Tree crown cover % estimated by densiometer with measured samples

Both densiometer readings and the canopy measurements were obtained on 17 clusters (see Figure 4). On two clusters, the densiometer recordings on the form were lost. In principle, the densiometer estimates should be lower as there is no overlap in the readings. However, the figure shows that the densiometer in many cases gives an overestimate. Reason for this seems to be the problem of making the difference between trees and shrubs. In this data, shrubs were defined to have a dbh less than 5 cm. However, the height of a shrub can be even 4 meters and there is a high risk of including them in the densiometer counting.

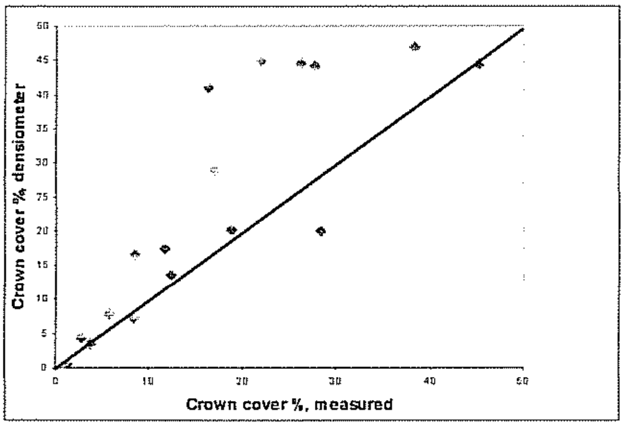


Figure 4. Tree cover %: canopy measurements vs. densiometer readings.

Prediction of stand basal area

The data of the 19 clusters (93 plots) was used to examine the relationship between the basal area of the trees and the crown cover per cent (see Figure 5). Two outlier observations (plots) were removed because of errors in the data recording in the field.

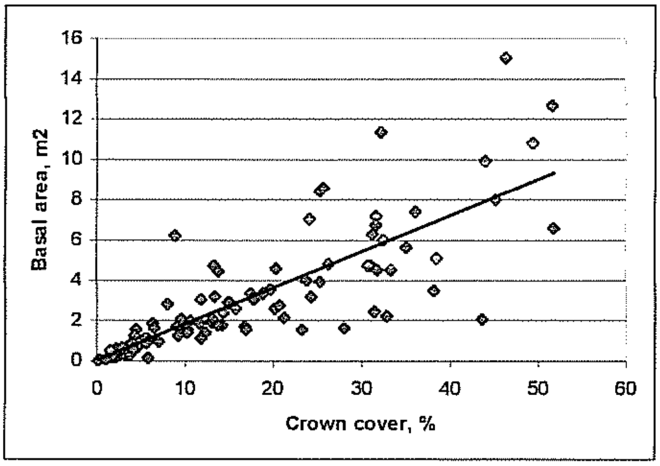


Figure 5. Field data: stand basal area (m2) against crown cover %.

Testing a linear model gave the following results:

Linear Fit: y=a+bx
y = predicted basal area in stand
x = observed crown cover
Coefficient Data:
a = -0.0547578
b = 0.18837192
Standard Error SE: 1.6841381
Correlation Coefficient R: 0.8348766

Visually the best fit can be obtained with a 4th degree polynomial function (SE = 1.6746040 and R = 0.8428021). The linear model gives too high basal areas for the middle part of the data set and too low basal areas for high crown covers compared with the measured data. However, looking at the data, the correlation in real life between crown cover and basal area is most likely linear.

Another set of data – 53 plots - from Okongo community forest inventory (Angombe et al. 2000) was analysed to verify the regression. In this inventory, all sized tree were measured on a plot with a radius of 10 meters. This data has values up to 80 % of crown cover plus two extreme values over 100 %. Visually the best fit could be obtained with an exponential association model:

Exponential Association: y=a(1-exp(-bx)
y = predicted basal area in stand
x = observed crown cover
Coefficient Data:
a = 9.6587382
b = 0.010283697
Standard Error SE: 1.1548750
Correlation Coefficient R: 0.8211210

Tree cover and shrub cover in three study areas covered with inventory field method 1

Spearman Rank correlation coefficients between Total tree cover and pixel values of the individual bands are presented in Table 1 for all areas. Only one of the correlation coefficients is significant in one area, indicating that shrubs in the West might be correlated with NDVI.

Tree cover and shrub cover in Area 4 covered with inventory method 2

Pearson correlation coefficients between Total tree cover, Shrub cover and pixel values of the individual bands are presented in Table 2.

Tree cover and shrub cover in Area 4 covered with inventory method 3

Pearson correlation coefficients between Total tree cover, Shrub cover and pixel values of the individual bands are presented in Table 3.

Table 1: Tree cover (T) and shrub cover (S) in three study areas covered with inventory field method 1: Spearman Rank correlations between Tree cover (T) and pixel value closest to the plot center (TM wavebands 1-5,7, including NDVI). Area 1: n=115, Area 2: n=60, Area 3: n=40
****: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed)**

Type	Area	R (T/S, b1)	R (T/S, b2)	R (T/S, b3)	R (T/S, b4)	R(T/S, b5)	R(T/S, b7)	R(T/S,NDVI)
Trees								
	1	0.02	0.01	0.01	-0.01	x	x	-0.03
	2	-0.08	-0.05	-0.05	-0.02	-0.08	-0.04	-0.06
	3	-0.10	-0.07	-0.12	0.07	-0.17	-0.13	0.21
Shrubs								
	1	-0.20*	0.04	-0.2*	-0.27**	x	x	-0.26**
	2	0.08	0.07	-0.07	0.34	0.04	-0.14	0.22
	3	-0.39*	- 0.21	-0.20	0.25	-0.32	-0.32	0.45**

Table 2: Tree cover (T) and shrub cover (S) Pearson Correlation Coefficients (R) with average pixel values of 6 TM wavebands and NDVI in a 100 m square around the central point of the sampling area. Area 4 covered with inventory method 2 (n=49). **: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed)

Type	R (T/S, b1)	R (T/S, b2)	R (T/S, b3)	R (T/S, b4)	R(T/S, b5)	R(T/S, b7)	R(T/S,NDVI)
Trees	-0.23	-0.25	-0.50**	-0.66**	-0.39*	0.25	0.14
Shrubs	-0.05	0.20	0.17	0.65**	0.27	-0.11	0.21

Table 3: Tree cover (T) and shrub cover (S) Pearson Correlation Coefficients (R) with average pixel values of 6 TM wavebands and NDVI in a 100 m radius around the central point of the sampling area. Area 4 covered with inventory method 3 (n=19). **: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed)

Type	R (T/S, b1)	R (T/S, b2)	R (T/S, b3)	R (T/S, b4)	R(T/S, b5)	R(T/S, b7)	R(T/S,NDVI)
Trees	-0.28	-0.40	-0.35	-0.74**	-0.41	0.25	0.14
Shrubs	-0.04	0.17	0.11	0.70**	0.11	-0.07	0.52*

Combined results for both methods in Area 4

Table 2 and 3 illustrate that the correlations between methods 2 and 3 are similar and the data are not significantly different from each other. This allowed grouping the samples of area 4 to calculate the regression equations for tree and shrub cover with the pixel values of band 4.

For trees the resulting model is (Figure 6):
Tree cover % = 126.99 – 1.166 band 4 (R=0.72. r^2_{adj}= 0.51, F_{64} = 55.8, P <0.001)

For shrubs the resulting model is (Figure 7):
Shrub cover% = -54.79 + 0.115 band 4 (R=0.69, r^2_{adj}=0.48, F_{64} = 43.5 P <0.001)

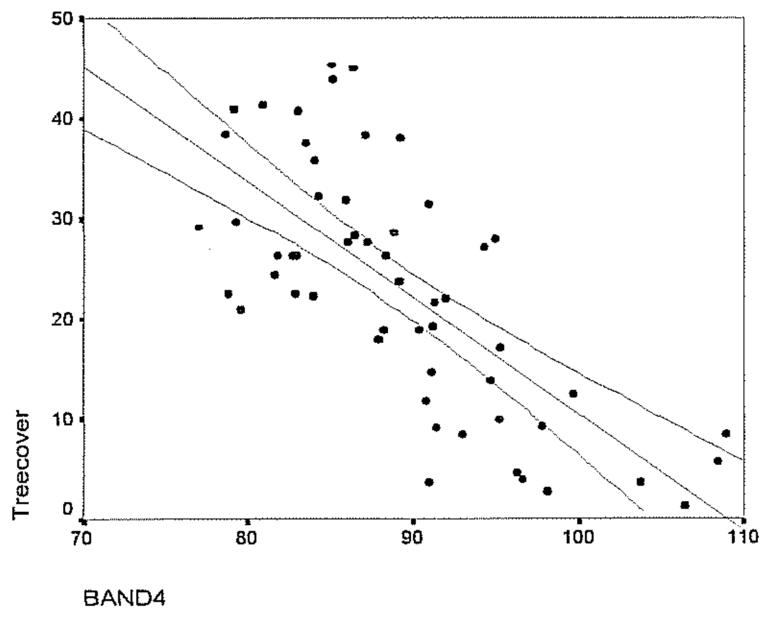


Figure 6: Relationship between Tree cover (%) and average pixel values of band 4 in a 100 m radius around the central point of measured clusters

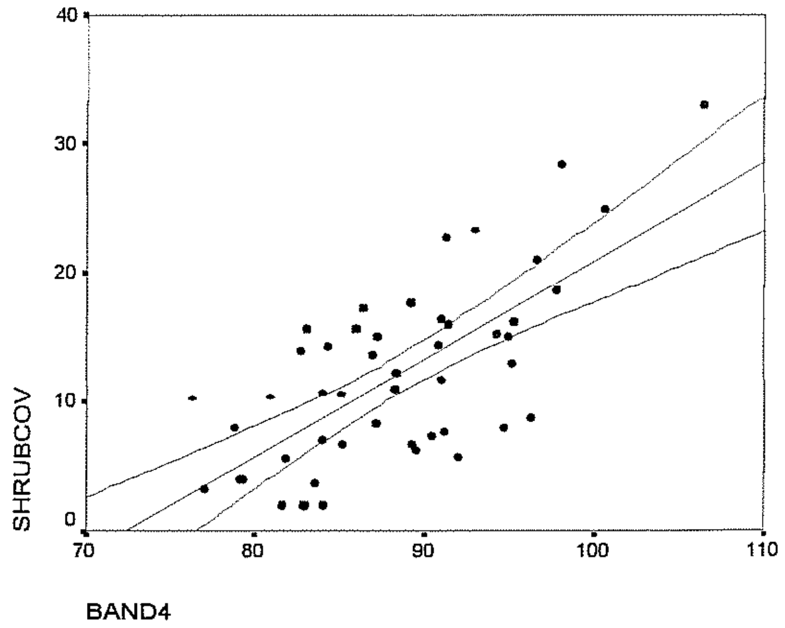


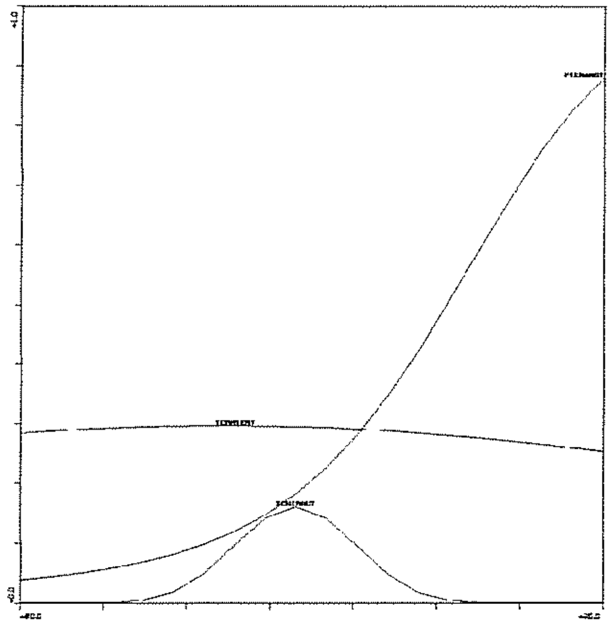
Figure 7: Relationship between Shrub cover (%) and average pixel values of band 4 in a 100 m radius around the central point of measured clusters

Relationships between species presence/absence and waveband values of Landsat TM.

For band 4 we found 3 species out of 8 tested significant. For band 2 we found 3 more species significant. Example: Okongo 69 samples (independent from the NFI survey carried out in 1999)

Figures 8, 9 and 10 show the models obtained for the species that were significantly related to a TM waveband ($p<0.05$). The graphs show the probability of presence when comparing counts of species with waveband pixel valued of Landsat TM with logit link models using Generalised Linear Models (GLM)

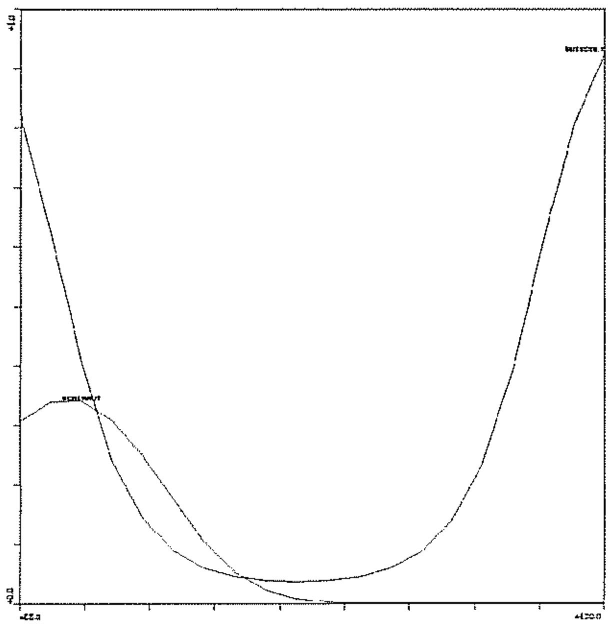
Probability



Band 4

Figure 8. Relationships of *Pterocarpus angolensis*, *Terminalia sericea* and *Schinziophyton rautanenii* with waveband 4 of Landsat TM (p<0.05)

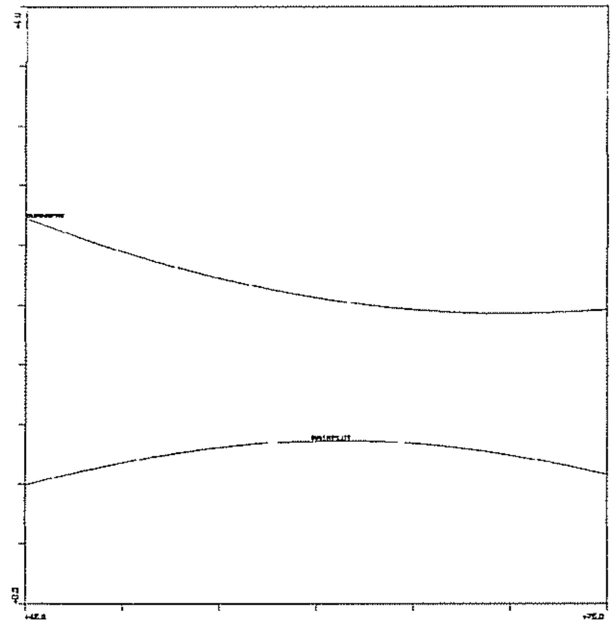
Probability



Band 2 (visual)

Figure 9: Relationships of *Guibourtia coleosperma* and *Shinziophyton rautanenii* with waveband 2 of Landsat TM (p<0.05)

Probability



Band 2 (visual)

Figure 10: Relationships between *Baikiaea plurijuga* and *Burkea africana* with waveband 2 of Landsat TM ($p<0.05$)

Discussion

Size of plots has an influence on correlation results between tree and shrub cover and TM wavebands. Plots with a maximum radius of 30 m used in method 1 are not necessarily representative for the immediate surroundings, while positioning errors with the GPS before 2000 and errors of satellite image registration possibly contribute to the low results obtained, although in three out of the four images the errors in the study area were less than 30 m. Small size of plots was apparently more influential for trees than shrubs, as correlations between shrub cover and TM wavebands were fairly high for shrubs with the small plots of method 1. With this method the correlations between tree cover and TM wavebands were not significant for the three study areas, while the significant correlations between shrub cover and TM wavebands were not consistent between the study areas.

In the predominantly shrubbed vegetation with *Colophospermum mopane* of Area 3 a significant positive relationship between shrub cover and NDVI in comparison with a negative relationship between shrub cover and NDVI in the more densely wooded study area 1 may be the result of the negative relationship between tree cover and shrub cover in the more wooded vegetation types characterized by *Burkea africana*, *Baikiaea plurijuga*, *Guibourtia coleosperma* and *Pterocarpus angolensis* as was demonstrated with the results obtained in area 4.

The different models obtained for trees and shrubs are suggested to be related to negative correlations between trees and shrubs in the study and this suggests that total woody vegetation cover is in the northern Namibian conditions not a useful parameter to monitor with remote sensing and that different woody layers have to be treated separately.

There were no significant changes between the results of methods 2 and 3, although method 3 performed better than method 2.
The relationships presented above can be used to monitor changes over time using images from previous dates. This requires image processing on the following topics:

- radiometric correction between the images (best method –histogram matching, correction with regression and others still to be researched)
- accurate registration of the images (minimal location differences between images)
- overlay of cover/basal area images to make difference images

Some degree of fieldwork will still be necessary to groundtruth the results. For example 'hot spots' with changes of 10 % cover or more over time.

Using Generalized Linear models to predict species distribution of certain important species was investigated in this paper with some success on a limited dataset. It is possible that multiple logistic regression, taking into account not only Landsat wavebands, but also other influential factors like soils, human occupation, waterpoint distances will result in useful equation for predicting the probability of presence of important species.

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FIELD WORK DESIGN FOR WOODY RESOURCES MONITORING: OKONGO PILOT AREA

1. Inventory design

Nineteen clusters for the woody monitoring system design were measured in Mashare area in Kavango in October-November 2001. Promising results have been achieved in the correlation tests with the field data and satellite data.

For the design of the system, another set of data is needed from an area which is covered by another satellite image. It is important to verify that there is a similar type of correlation on the other area too. Okongo community forest area was selected as the target area for this second field exercise for woody resource monitoring. A total of 26 clusters have been located on a satellite image. These clusters represent different levels of crown covers. The coordinates of these clusters have been predefined at the office (see Annex 3).

2. Cluster design

A sampling (a cluster) unit consists of 5 plots. Plot number 1 is a central plot (see figure 1.) Plot number 2 lies north from plot no 1. Plot no 3 lies east, plot no 4 lies south and plot no 5 lies west from plot no 1. The radius of each plot is 20 metres. The distance between the center of two plots is 50 metres.

Laying the plots is done out by locating the center of the plot 1 with predefined coordinates using gps. The tree and shrub measurement of this first plot will be then completed. Then, the center of the plot no 2 will be located by measuring a distance of 50 metres to the north with the help of a tape and a compass. Then the tree and shrub measurements will be completed on the second plot. Consequently, the plots no 3, 4 and 5 will be located the same way as plot no 2 and the measurements will be completed.

<u>Shifting the cluster</u>

If one or more of the plots within the cluster will fall on a field, the cluster should be shifted so that it will be completely on a wooded area. Shifting will be done by moving the central plot 50 metres into a direction vertically away from the field. If this is not enough and one of the plots still fall on a field, another moving of 50 metres is applied in the same direction. The new location of the center plot is recorded with gps and the coordinates written on the coordinate form in replacement of the original ones. If shifting does not solve the problem and some of the plots will fall on a field anyway, the cluster may be abandoned and one of the timber inventory plots changed into a woody monitoring cluster as a replacement.

3. Measurements

Vegetation type description, grass frequency counting, Bitterlich and densiometer measurements are recorded on the **SURVEY DATA SHEET FOR VEGETATION TYPE SAMPLING** (see further). The same form (slightly modified) is used as in the preliminary survey of Mashare area.

Vegetation type sampling

For each cluster, a survey data sheet for vegetation is filled in. This description must describe the whole area of the cluster that is the area covered by all 5 plots. Following parameters are assessed visually on the site: land form, surface layer, soil type, soil colour, intensity of grazing, damages and type of damage. Also, the vegetation layers are classified visually in three classes (open, medium, closed). The layers to be considered in this are the following: shrubland (all shrubs), woodland (all trees), low shrub layer (< 1m), shrub layer (1-2 m), low tree layer (2-4 m), medium tree layer (4-8 m) and high tree layer (> 8 m).

Grass cover estimate

Starting from the center of each plot, 20 steps in the direction of north are taken. Whenever the tip of the foot touches a grass, a YES is counted. And whenever the tip of the foot does not touch a grass, a NO is counted. This gives an estimate of the grass coverage. This counting of 20 steps is repeated on each 5 plots so that a total of 100 steps will be counted.

Densiometer measurements

On each plot, a densiometer measurement is done on five locations. The first measurement on a plot is made on the plot center. Then, four more locations are selected in north, east, south and west, each of these at 10 meters distance from the plot center. The distance from the plot center can be estimated by taking 10 steps of approximately 1 meter / step.

In each location inside a plot, four readings (north, east, south and west) with the densiometer are taken. Trees with dbh more than 5 cm are counted.

Shrub measurements

On each plot, five separate Bitterlich sweeps of shrubs are made. **In this inventory all shrubs and small trees which have a dbh less than 5 cm will be counted, that is, all those shrubs and trees which were not taken into account in the tree measurements.** All those shrubs/trees whose crowns extend beyond the tips of the Bitterlich gauge, are counted. One individual shrub/tree counted represents 5 % in crown coverage / hectare.

The first sweep on a plot is made on the plot center. Then, four more sweeps are made in north, east, south and west, each of these at 10 meters distance from the plot center. The distance can be estimated by taking 10 steps of approximately 1 meter / step. (This is the same arrangement as with the densiometer.)

Five Bitterlich sweeps are made on all five plots. In total, there will be 25 sweeps.

Shrub ranking

A ranking of shrubs/trees which were measured with Bitterlich gauge is to be marked on the first page of the **SURVEY DATA SHEET FOR VEGETATION TYPE SAMPLING**. This means that the most frequent species will get the ranking 1. The second most frequent will get a ranking of 2 and so on.

Tree measurements

Tree measurements are recoderd on the **TREE SAMPLING FORM** (see Annex 2).

All recordings of sample tree data are done using NFI codes (see Manual for woody resources inventory for detailed instructions).

On all plots: all trees with dbh more or equal than 5 cm are measured. Following parameters are measured and recorded (nr in parenthesis refers to the Sample tree form):

Tree number (1)
Tree species (2)
Diameter (3)
Status (4)
Bearing (5)
Distance (6)
*Timber quality (7)
*Reason for medium or poor timber quality (8)
*Length of sawlog (9)
*Length of deformed or decayed base (10)
Crown class (11)
Phenology (12) (mark an X at appropriate column) *Note: Only on plots 2 and 4*
Height (13) *Note: Only on plots 2 and 4*
Crown height (14) *Note: Only on plots 2 and 4*
Canopy diameters (15)

Parameters marked with * above are measured only for the following species: Baikiea plurijuga, Pterocarpus angolensis, Guibaurtia coleosperma, Burkea africana, Schinziophyton rautanenii.

Phenology, height and crown height are measured only on plots 2 and 4. Note also, that canopy diameters are measured on all plots.

SURVEY DATA SHEET FOR VEGETATION TYPE SAMPLING

Observer:	Cluster:	GPS reading
Date:	Locality:	S:
Region:		E:
		Accuracy:

Local land unit name if relevant :							
Land form:	Riverine	Plain	Plateau	Omuramba	Flood plain	Pan	Dune
Footslope	Midslope	Hill crest	Interdune street		Other:		
Soil type	clay	Silt	Loam	Sandy loam	Loamy sand	Sand	
Surface Layer : (0-3)	Rock outcrop (>60cm)		Stones (6-60cm)		Soil colour:		
	Pebbles (2-6cm)		Gravel (0.2-2cm)				

Vegetation layer		Remarks	Vegetation class:	
Herbaceous (G) 100 steps touch grass Y or N (grass counting, see other page)			Shrubland: open medium closed Woodland: open medium closed	
Low shrub layer (LS) <1mOpen/Medium/Closed			Cover of Shrubs to dbh 5 cm are measured with Bitterlich gauge	
Shrub layer (S) 1-2m Open/Medium/Closed				
Low tree layer (LT) 2-4m Open/Medium/Closed			Intensity of grazing: L/M/H	
Medium tree layer (MT) 4-8m Open/Medium/Closed			Damages: L/M/H	
High tree layer (HT) >8m Open/Medium/Closed			Type of damage: F/H/L/W	
Layer: Shrub	Botanical name	Rank	Vernacular name	Local use

1. 100 steps for the grass layer

Walk 20 steps on each plot (a total of 100 steps) and when the tip of your foot touches a grass base, note it under the column YES, if no grass is touched, note it under NO 100 points are required.

Plot	YES	NO
1		
2		
3		
4		
5		
	SUM	SUM

2. Bitterlich readings (Number of shrubs extending beyond the tips of the gauge)

Plot1		Plot 2		Plot 3		Plot 4		Plot 5	
Sample	Nr	Sample	Nr	Sample	Nr	Sample	Nr	Sample	Nr
1		1		1		1		1	
2		2		2		2		2	
3		3		3		3		3	
4		4		4		4		4	
5		5		5		5		5	

3. Densiometer readings (Include trees with dbh > 5 cm)

Plot 1				
Sample	N	E	S	W
1				
2				
3				
4				
5				

Plot 2	.			
Sample	N	E	S	W
1				
2				
3				
4				
5				

Plot 3	.			
Sample	N	E	S	W
1				
2				
3				
4				
5				

Plot 4				
Sample	N	E	S	W
1				
2				
3				
4				
5				

Plot 5				
Sample	N	E	S	W
1				
2				
3				

4				
5				

Figure 11. Field plot design for woody resource monitoring system, Mashare inventory