NGAMO-SIKUMI REDD+ PILOT PROJECT

BIOMASS ASSESSMENT REPORT

Version 1.1

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ABBREVIATIONS

DBH	Diameter at breast height
FRA	Forest Resources Assessment
FREL	Forest Reference Emission Level
GIS	Geographical Information System
GPS	Global Positioning System
Ha	Hectare
HSBCP	Hwange Sanyati Biological Corridor Project
KS	Kalahari Sands
MODIS	Moderate Resolution Imaging Spectroradiometer
REDD+	Reducing Emissions from Deforestation and Forest Degradation
UN	United Nations
UTM	Universal Transverse Mercator

ABSTRACT

A biomass assessment survey was carried out to quantify the carbon stock baseline for Ngamo and Sikumi Forest Reserves. The two gazetted forests are earmarked for the REDD+ carbon trading process under the Hwange Sanyati Biological Corridor Project (HSBCP). Using both remotely sensed data and in-situ field based measurements two carbon pools were measured *i.e* the above ground woody biomass carbon pool and the deadwood carbon pool. A total of 228 plots were established across all vegetation cover classes in both forests. The following parameters were then recorded per plot: tree height, dbh and tree health status. 52 different tree species were recorded in Ngamo whilst 62 tree species were recorded in Sikumi with *Baikiaea plurijuga* being dominant in both forests. Sikumi had an average above ground carbon stock of 19.4 tonnes per ha whilst Ngamo had 18.2 tonnes per ha. However Ngamo had the highest total carbon stock value of 1.68 million tonnes due to its vast nature whilst Sikumi had a total carbon stock value of 867 000 tonnes. Combined the two forests have a total above ground carbon pool of 2.6 million tonnes.

Using field based measurements for model calibration a linear regression model was also developed to predict the spatial distribution of above ground carbon in the two forests. From a host of satellite derived vegetation indices NDVI showed the strongest relationship with field based carbon measurements thus it was used as a proxy for mapping the spatial distribution of above ground carbon in the two forests. It is highly recommended that forest management activities be enhanced in the two forests to ensure reducing emissions from forest degradation and deforestation. Of major concern are the frequent fires that occur every year posing a major threat to achieving the goal of contributing to climate change mitigation.

ACKNOWLEDGEMENTS

Our sincere gratitude goes to the World Bank and the World Wide Fund for Nature (WWF) for the financial and material support. Special thanks also go to the Government of Zimbabwe and the Forestry Commission management particularly the Project Coordinator and Project Manager for steering the ship and ensuring successful implementation of the project.

1.0 BACKGROUND

Ngamo and Sikumi Forest Reserves have been earmarked for the carbon trading process under the Hwange Sanyati Biological Corridor Project (HSBCP). One of the requirements to enter the carbon market is being able to establish the Forest Reference Emission Level (FREL) by quantify the existing carbon stocks. With this in mind a biomass assessment exercise was carried out to quantify the carbon stock thus establishing the Forest Reference Emission Level of the two forest areas. The FREL will serve as the baseline for measuring emissions reduction from the implementation of activities targeted at reducing emissions from deforestation and forest degradation.

Currently the management activities within the two gazetted forests include protection from fire, research on various aspects of the forests, wildlife management, control of forest occupants and anti-poaching activities. In spite of these management activities; the two forests share common problems *i.e* wildfires and timber and wildlife poaching; additionally Ngamo forest has witnessed encroachment by settlers over the years. These problems pose a threat to future survival, function and development of these forests. The aforementioned threats are the most probable drivers of deforestation and degradation thus implementation of the REDD+ initiative within the study area would ensure enhancement of management activities so as to achieve the main goal of climate change mitigation by reducing emissions resulting from forest degradation and deforestation.

Using both remotely sensed data and in-situ field based measurements two carbon pools were measured *i.e* the above ground woody biomass carbon pool and the deadwood carbon pool. A forest inventory manual was developed and field officers were trained prior to the biomass assessment field work.

1.1 Objectives

i) To quantify the above ground carbon pool of Ngamo and Sikumi forest reserves
ii) To show the spatial distribution of carbon within the two study sites.

2.0 STUDY AREA

2.1 Location, Climate, Soils and Vegetation

2.1.1 Location

Ngamo and Sikumi forest reserves cover approximately 157 300 hectares (1 573km^2) within the Hwange Sanyati Biological Corridor (HSBC) which forms part of the Kavango-Zambezi Trans-frontier Conservation Area (KAZA TFCA) on the Zimbabwean side. The forests are located in Matabeleland North Province between latitude 18^0 45'S and 18^0 58'S and longitude 27^0 07'E and 27^0 31'E. The two forests share a common boundary and they straddle two districts, i.e. Hwange and Lupane districts (Fig 1).

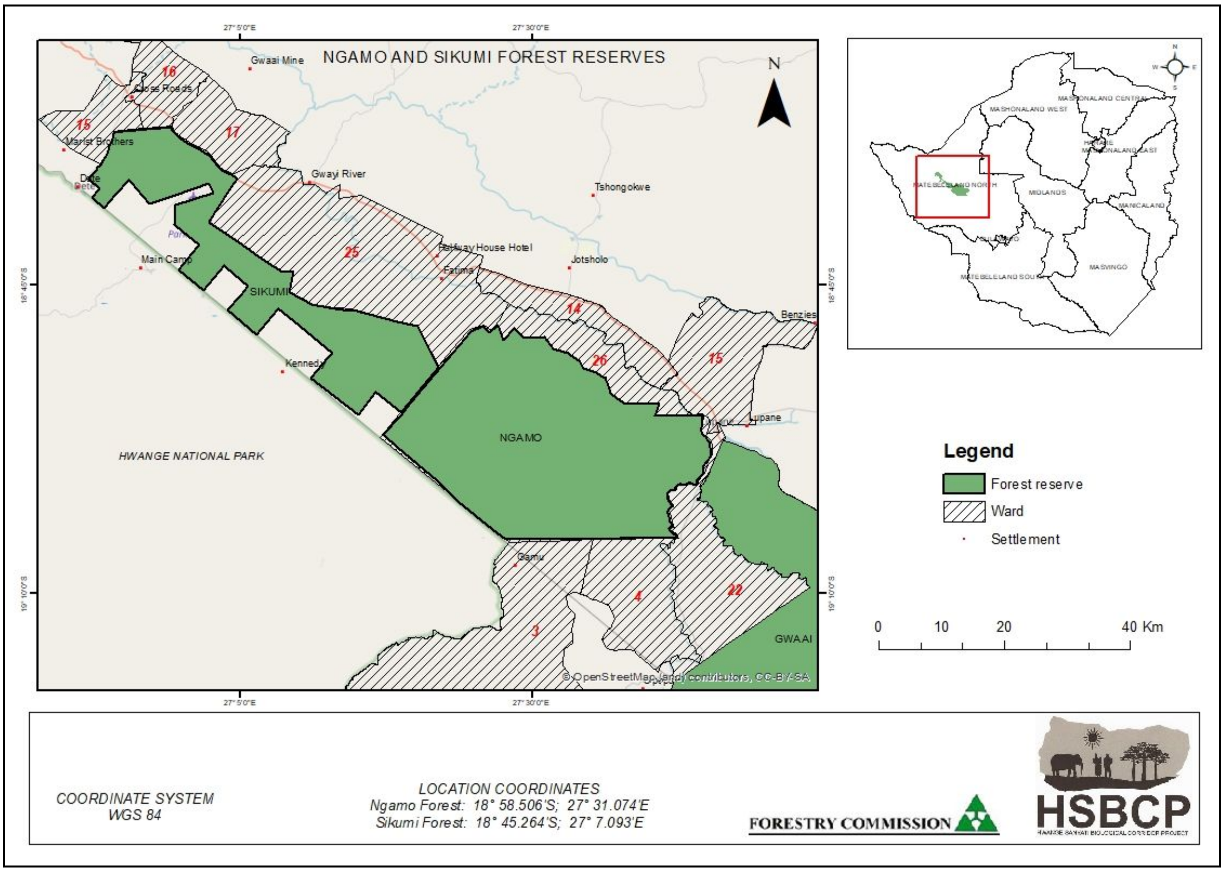


Figure 1: Location of Ngamo and Sikumi Forests, Matabeleland North, Zimbabwe

Table 1: Gazetted Forest area

Forest	Area (ha)
Ngamo	102 900
Sikumi	54 400
TOTAL	157 300

2.1.2 Climate

The two forests are typical Kalahari Sands teak forests thus climatic conditions are mainly characterized by a short and erratic rainfall season from mid-November to mid-March. The dry season ranges from April/May to October/November. Average annual rainfall is between 450-600 mm and the mean monthly temperatures in the hot and cold months are about 30 C and 17 0 C, respectively. In terms of agro-climatic classification the forests generally fall within Natural Region IV.

Table 2: Climatic Conditions

	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Avg. Temperature (°C)	25.7	25.5	25.4	24.3	21.2	18.2	18.4	21	25.4	28.7	27.8	26.2
Min. Temperature (°C)	20	19.9	19.2	16.9	12.5	9.6	9.5	12.1	16.9	21.1	20.9	20.2
Max. Temperature (°C)	31.5	31.2	31.6	31.8	30	26.9	27.3	29.9	33.9	36.4	34.8	32.3
Avg. Temperature (°F)	78.3	77.9	77.7	75.7	70.2	64.8	65.1	69.8	77.7	83.7	82.0	79.2
Min. Temperature (°F)	68.0	67.8	66.6	62.4	54.5	49.3	49.1	53.8	62.4	70.0	69.6	68.4
Max. Temperature (°F)	88.7	88.2	88.9	89.2	86.0	80.4	81.1	85.8	93.0	97.5	94.6	90.1
Precipitation / Rainfall (mm)	154	132	64	17	3	0	0	0	1	16	58	131

2.1.3 Geology and soils

Kalahari sands cover the greater part of the forests. The Kalahari sands comprise of deep, unconsolidated and well-drained tertiary sands of Aeolian origin. The underlying geology is of sedimentary rocks overlying Karoo basalt and sedimentary deposits. These underlying formations are only exposed along Gwaai River (Ngamo forest eastern boundary) where the sands have been eroded. The dominant KS soils are uniform physically and chemically (Anderson et al., 1993; Nyamapfene, 1991). The extremely low occurrence of silt and clay particles (< 10percent) is due to the absence of any weather resistant minerals (Lockett, 1979). The soils are also highly infertile. Permeability is rapid and there is very little runoff.

2.1.4 Vegetation

Prior to carrying out the carbon quantification exercise a thorough vegetation assessment of the study area was carried out. The identified vegetation types are summarized below:

Table 3: Vegetation cover types in the study area

Vegetation cover type	Species composition
Baikiaea woodland	Covering almost 70% of study area *Baikiaea plurijuga* is the principal upper storey species for this woodland type. Other species include *Pterocarpus angolensis, Guibourtia coleosperma, Afzelia quanzensis,* and *Erythrophleum africanum.* The understorey species are dominated by *Bauhinia petersiana*, *Baphia massaiensis, Grewia flavescens, Grewia monticola, Dichrostachys cinerea, Ochna pulchra* and *Commiphora* species.
Miombo woodland	Mainly found in Sikumi's block I and Ngamo's block B this woodland type is dominated by *Brachystegia spiciformis.* Species composition in the upperstorey comprises *Brachystegia spiciformis*, *Julbernardia globiflora and Brachystegia boehmii.*

Terminalia-Combretum woodland (Combretaceae)	Terminalia-Combretum woodlands are characterized by *Terminalia sericea* and *Peltophorum africanum* species. Other species include *Combretum* spp, *Lannea discolor*, *Sclerocarya birrea* and *Kirkia acuminata.*In Ngamo forest *Terminalia sericea* mainly occurs in association with *Burkea africana*, with *Burkea africana* forming the upperstorey. Terminalia species are prone to elephant damage and this is quite prominent in Sikumi forest.
Acacia woodland	The dominant Acacia species in the study area is *Acacia erioloba*.
Mopane woodland	Mopane woodland niche is mainly found in Ngamo forest with *Colophospermum mopane* being the principal upper canopy species on black clayey soils and abandoned fields closer to Masungamhala area.
Burkea africana woodland	*Burkea africana* is the principal upper storey species for this woodland type and in Ngamo it occurs in association with *Terminalia sericea* especially in areas were fire occurrence is prominent.
Grasslands	The most common grasslands within the study area are the ones associated with the vlei depression system. The common grassland areas are found along the Dete vlei in Sikumi and Masungamhala vlei in Ngamo.

3.0 FOREST INVENTORY DESIGN

3.1 Sampling design

A stratified random sampling approach was adopted. Vegetation cover was used as the basis for stratification since the study area is made up different vegetation cover types. The assumption is different woody vegetation cover types *i.e* Miombo, Baikiaea, Terminalia, Mopane *etc* have different carbon sequestration and storage potential for instance Terminalia and Mopane *spp* are prone to elephant damage thus their carbon storage capabilities are compromised. In light of that stratifying the area into different vegetation strata was vital so as to capture all vegetation cover types.

3.1.1 Vegetation cover stratification and mapping

Using a handheld GPS, a total of 75 test sites were collected within the study area and these were used as training sites for the vegetation cover mapping. The test sites were overlaid on Sentinel Satellite imagery of 2018 (Fig 2). Using GIS software (TNT Mips) the different vegetation cover types were manually traced /digitized. The manual classification method was selected over the automatic pixel based classification method to avoid misclassification between vegetation types with similar tints/reflectance as is often the case with Miombo species and *Baikiea plurijuga*. Sentinel was chosen over other free satellites because it provided better spatial resolution (10m resolution) compared to other open source satellite images *i.e* MODIS (1km resolution) and Landsat (30m resolution). Table 4 below highlights the Sentinel scenes that were utilized for the vegetation cover mapping exercise.

Table 4: Sentinel Satellite scenes used for vegetation cover stratification and mapping

Sentinel Sensor	Sentinel Scene	Spatial resolution	Spectral Bands	Sensing/Acquisition date
2A	35 KMV	10m	8;4;3	12/06/2018
2B	35 KNU	10m	8;4;3	24/06/2018
2A	35 KNV	10m	8;4;3	29/06/2018

Sentinel satellite data downloaded from https://scihub.copernicus.eu

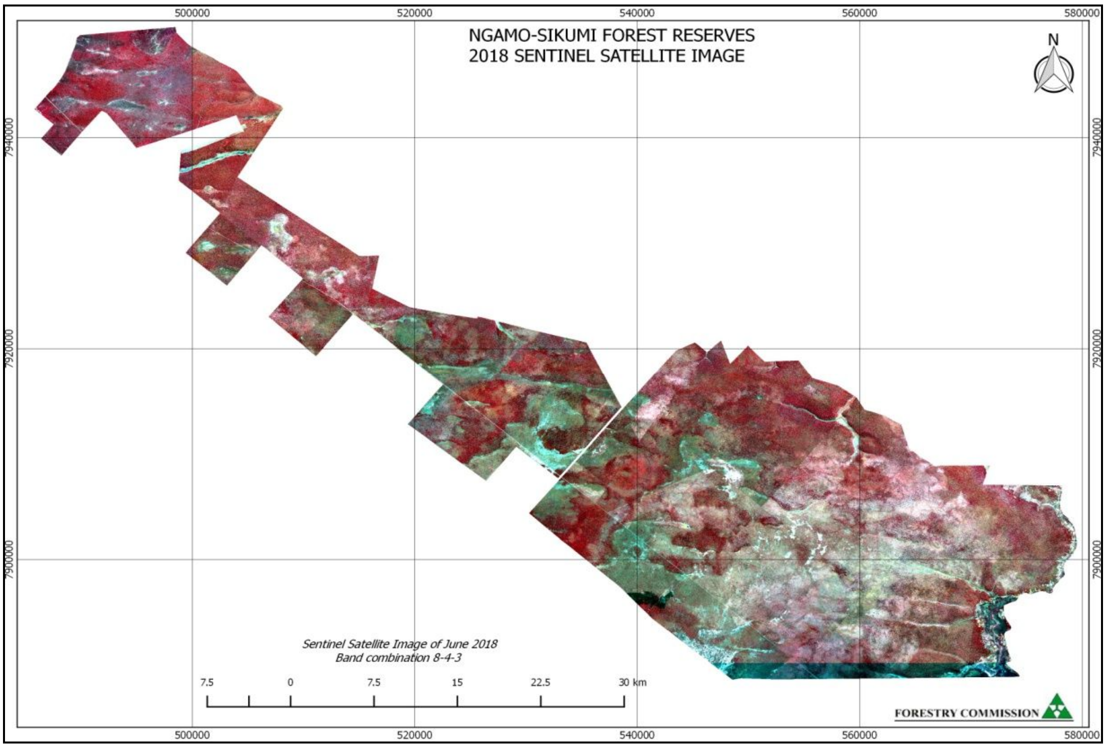


Figure 2: Sentinel satellite image of the study area (Image of June 2018 -Band combination 8-4-3)

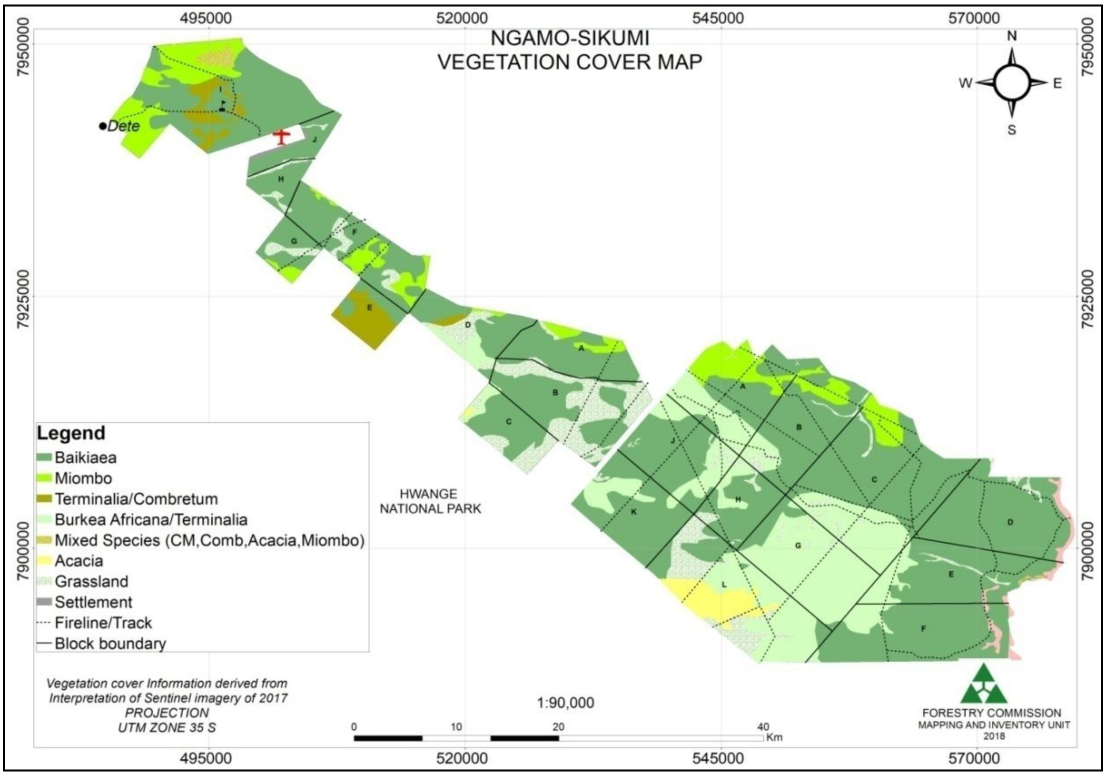


Figure 3: Vegetation cover of the study area

Table 5: Woody vegetation cover statistics

Vegetation cover type	Ngamo (ha)	Sikumi (ha)
Baikiaea	60 539.3	33 468.8
Miombo	4 497.9	6 793.7
Burkea africana	29 124.4	1 278.1
Terminalia/Combretacea	*Occurs in association with Burkea africana*	3 550.6
Acacia	2 593.3	60.1
Mopane	61.3	-
Mixed Species (Acacia,Mopane,Miombo,Terminalia etc)	-	506.5
**Grassland*	*4 880.5*	*7 856.3*
**Cultivation*	*1 203.3*	-
**Settlement*	-	*183.29*

NB: Classes in italics are non-woody classes thus they were deemed non productive in above ground woody carbon sequestration.*

The number of plots per vegetation strata was then derived using the formula below:

$$n = \frac{(\sum_{h=1}^{L} N_h \times s_h)^2}{\frac{N^2 \times E^2}{t^2} + (\sum_{h=1}^{L} N_h \times s_h{}^2)}$$

Where:

E = allowable error or the desired half-width of the confidence interval.

Calculated by multiplying the mean carbon stock by the desired precision (that is, mean carbon stock x 0.1, for 10% precision, or 0.2 for 20% precision),

t = the sample statistic from the t-distribution for the 95% confidence level. t is usually set at 2 as sample size is unknown at this stage,

Nh = number of sampling units for stratum h (= area of stratum in hectares or area of the plot in hectares),

n = number of sampling units in the population

sh = standard deviation of stratum h.

A total of 228 plots were then established in the two forests with Ngamo having 153 plots whilst Sikumi had 75 (Table 6). The distribution of plots, in form of clusters was done randomly per woody vegetation strata. Each cluster was made up 3 plots thus a total of 76 clusters were established. Clusters that fell on roads, forest boundaries or on the wrong vegetation strata were manually shifted.

Table 6: Cluster (plots) allocation per vegetation strata

Woody vegetation strata	Ngamo	Sikumi
Baikiaea	28 (84)	11 (33)
Miombo	5 (15)	5 (15)
Burkea africana-Terminalia mixture	14 (42)	-
Terminalia/Combretacea	-	3 (9)
Acacia	2 (6)	1 (3)
Mopane	2 (6)	-
Mixed Species	-	1 (3)
Burkea africana	-	4 (12)

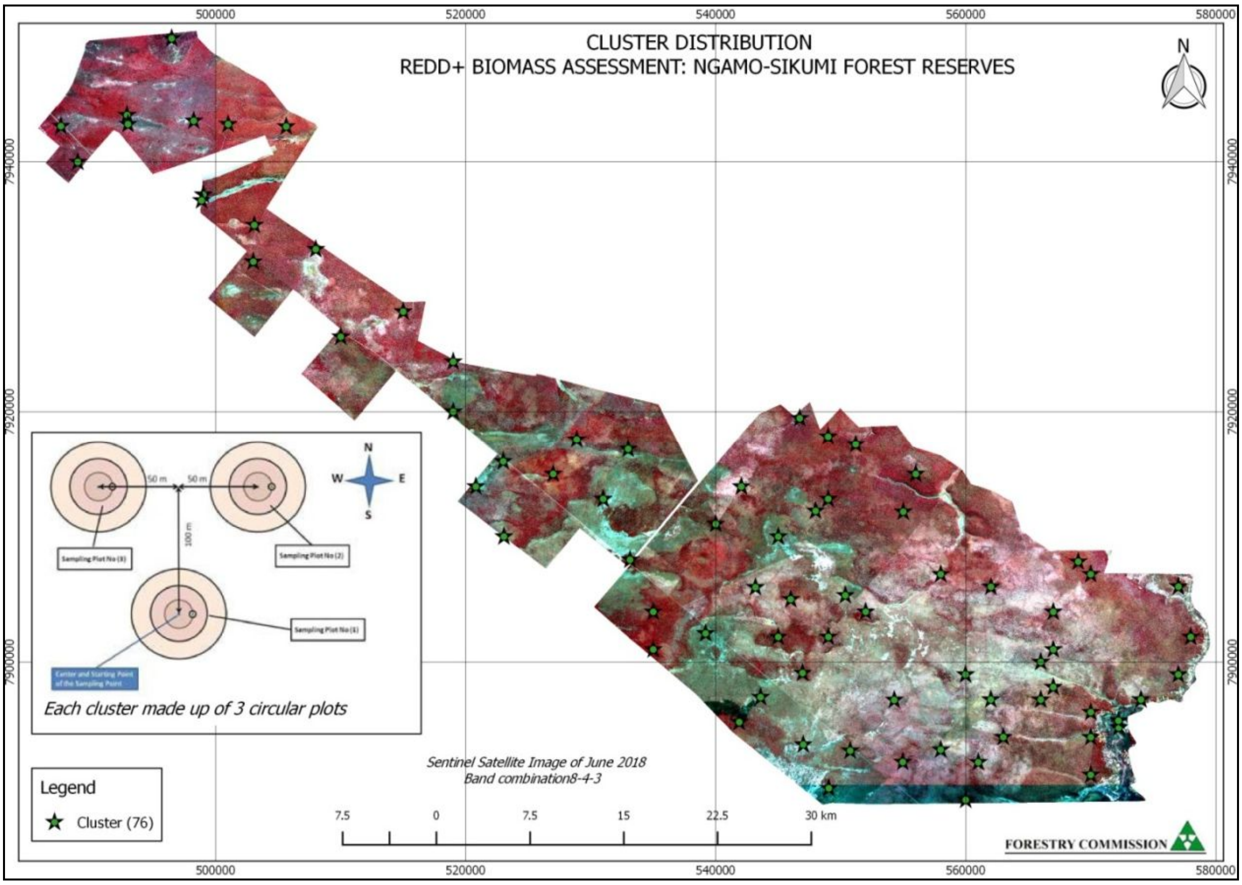


Figure 4: Distribution of sampling units-Clusters (Sentinel image of June 2018- Band combination 8-4-3)

3.2 Locating sampling units in the field

The location of the sampling units *i.e.* clusters was determined by UTM coordinates, which were entered on a handheld GPS instrument. The sampling unit was a cluster made up of 3 sampling plots (nested concentric circles) (Fig 5), where the centre of the first point (southern most point) was the determination point for the location of the cluster. This point was located using coordinates allocated to the sampling unit on the map.

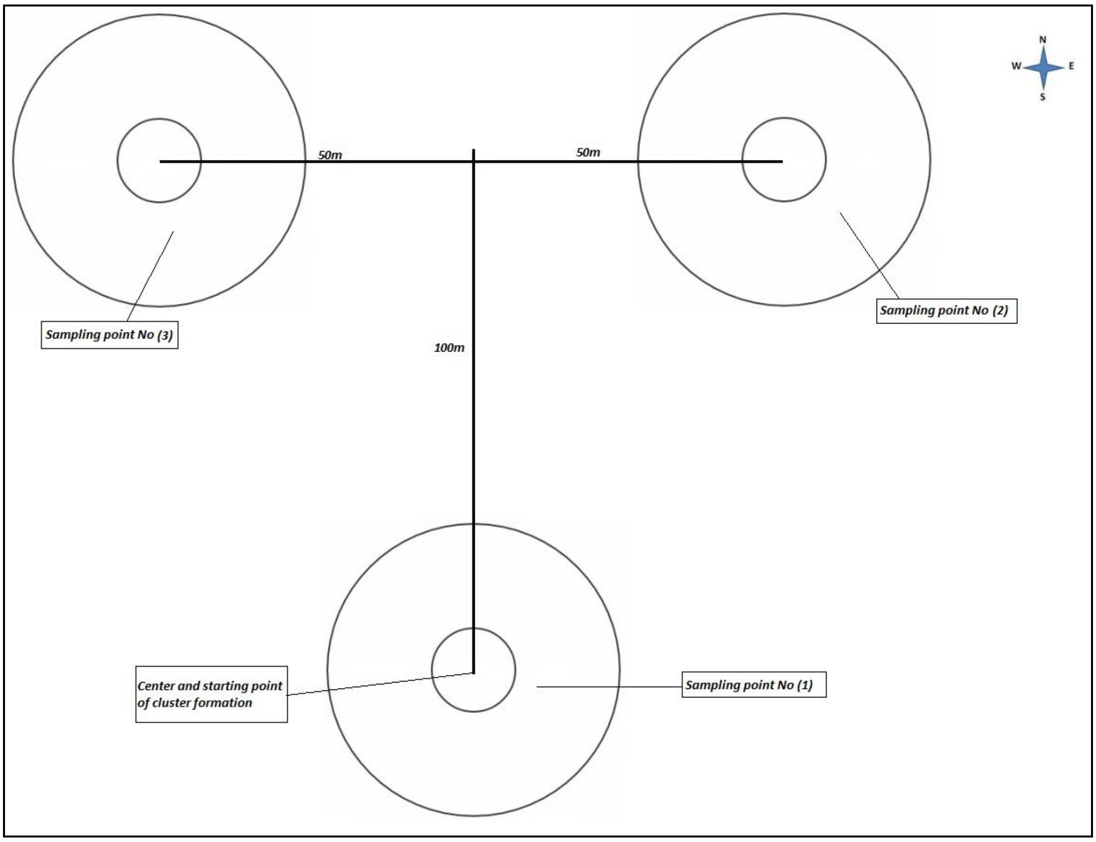


Figure 5: Sampling Cluster Design

The GPS instrument was used in navigation mode to guide the team to the sampling unit centre. In order to get to the exact sampling point the last 10 meters were accessed with a handheld compass and distance tape.

3.2.1 Demarcation of sampling units

Once at the sampling point, plots were marked at the centre with a metal peg. Coordinates and pictures of 2 trees next to the centre of the point were also recorded as references. Placement of the metal peg was meant to make it easier to locate the plot centre during quality control.

Figure 6: Metal peg placed at the centre of each plot

3.2.2 Data recording on sampling unit

The following information was recorded per plot prior to tree measurements:

i) Cluster and plot number: For identification the cluster number was filled on all pages of the sampling point data recording sheets. The plot number, which could only be 1 to 3, was also recorded.

ii) Date and Team: For identification purposes and in case of any questions regarding the sampling point- the date of assessment, the team members and the team leader name was noted.

iii) GPS Records: To make relocation and quality reconfirmation possible the GPS coordinates of each sampling point were recorded. The actual reading of the GPS at the centre of each plot was recorded.

3.3 Tree related measurements

Nested Circular plots with a radius of 20m (Fig 7) were used in tree assessment. The assessment of trees including regeneration was carried out in a full count. Trees of different sizes were assessed in different concentric circles/plot radius. Trees with dbh between 5 cm to 9.9 cm (small trees) were measured in the 6m radius whilst trees with dbh ≥ 10 cm (big trees) were measured in the 20m radius (Table 7).

Table 7: Sampling Plot Sizes for Different Tree Sizes

DBH and size	Plot Radius
height 20 cm – 50 cm (regeneration)	2m
height 50 cm – 129 cm (regeneration)	2m
height 130 cm – DBH 4,9 cm (regeneration)	2m
DBH 5 cm – 9.9cm (small trees)	6m
DBH ≥ 10 cm 20 m (big trees)	20m

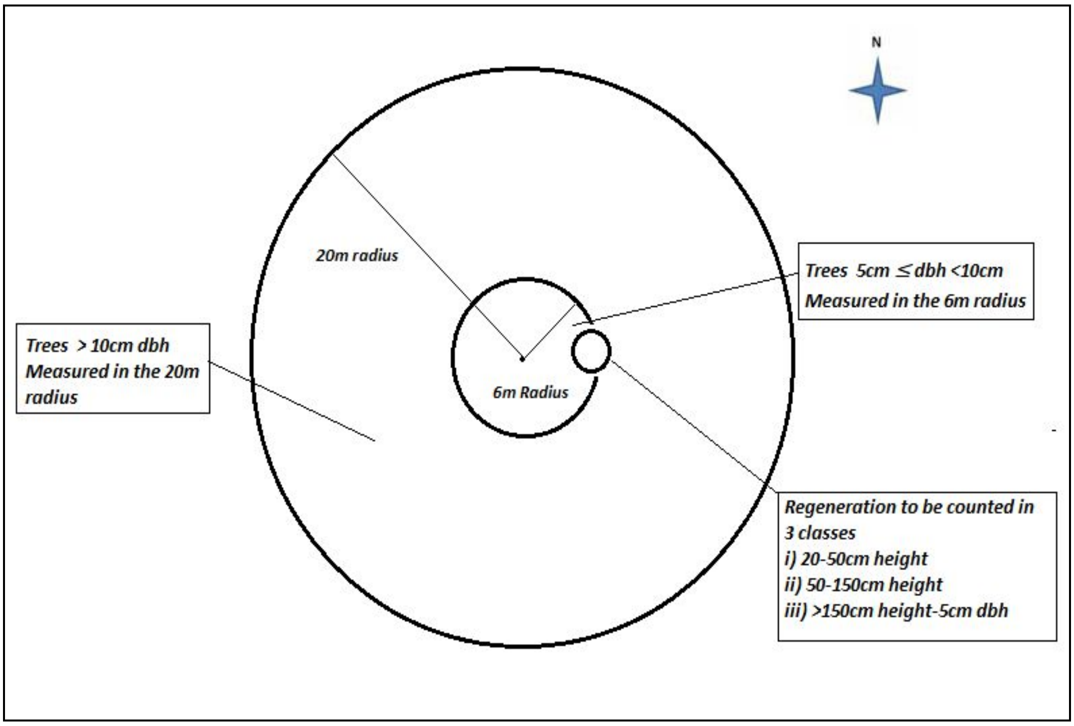


Figure 7: Sampling Plot Design – Nested Circular Plots

3.3.1 Regeneration

To avoid disturbance of the regeneration count by the establishment of the plot centre the regeneration plot centre was located at 6 m distance to the east (90°) from the assessment point centre. The regeneration of trees, including the important bush and shrub species was counted per species in 3 height classes (Table 7). Coppices from coppice trees were also recorded under regeneration, in the respective size class.

3.3.2 Trees

Trees were measured per respective dbh class and the following was recorded per tree:

i) The tree species name: these were recorded with code and name, as provided from the tree species list.

ii) The dbh: diameter measurements were done using a diameter tape and were taken at 1.3 meters above the ground. In cases of uncertainty of the measuring point reference was made to the graph below:

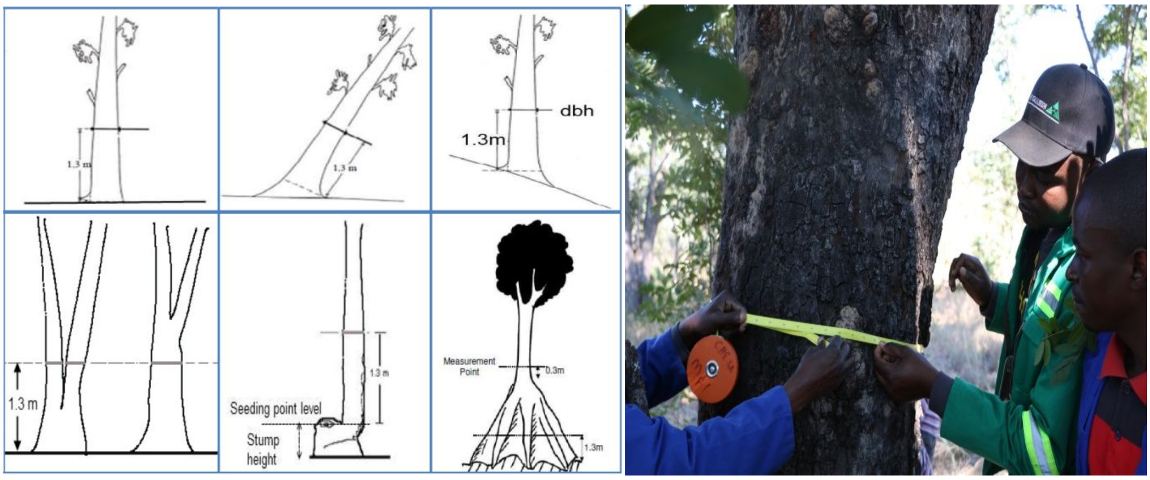


Figure 8: Measuring points for diameter and diameter measurement in the field

iii) Tree height: Tree height was measured with the clinometer based instrument Vertex.

iv) Tree health status: tree health status, causative agent and damage severity was assessed by expert's assessment using the damage classification list.

v) Tree utility/use *i.e* timber, firewood, poles, medicinal etc was also recorded per tree.

vi) Bearing and distance from plot centre to each tree: this was measured and recorded to facilitate quality control and re-measurement. The bearing was measured using a handheld campus whilst distance from the centre to each tree was done using either a vertex or a rangefinder.

Figure 9: A- Bearing measurement using a handheld Compass. B- Distance measurement using a Rangefinder.

3.4 Deadwood

The lying dead wood in the entire plot was measured. The lower and top diameters were measured as well as the length that fell within the plot. Dead wood logs that lay across the circle boundary were only measured with the part that was inside the circle. Decay percentage per log was also recorded and the decay of the log was estimated in percent by expert judgment.

3.5 Execution

The inventory field work was carried out during the period 18 June to 20 August 2018 with breaks in between. Two teams were formed during the exercise. Each inventory team was made up of 8 members plus members of the Forest Protection Unit. In the total, 42 days were taken to complete the survey.

3.6 Data cleaning, capturing and analysis

The inventory field forms were checked in the office, especially for species codes and data recording typo errors. The data was then captured in Microsoft ACCESS database software, which was also used to produce the final inventory results.

The following equation was used to derive the Biomass in tonnes per ha

$$Biomass = 0.1936 * (DBH^2 * 3.141592654 / 4)^{1.1654}$$

The equation was adopted from the "GIZ- Development of IPCC Compliant MRV Systems Manual for Southern Africa, 2012". The conversion from Biomass to Carbon was then done by multiplying the Biomass value by 0.47 since 47% of Biomass is Carbon (IPCC; 2003). This ratio considers that 45-55% of forest aboveground biomass is carbon (Rahman et al. 2008; Schlesinger; 1991)

Figure 10: Data cleaning and capturing

4.0 RESULTS

4.1 Basic parameters

The following results were obtained from a total of 76 clusters established in the two forest areas. Tables 8 and 9 below summarize results for the top 5 species (in terms of carbon content) and other species. Detailed results are attached in the appendix.

Table 8: Summary of results per species in Ngamo Forest

Species	Regeneration (saplings/ha)	Stocking (trees/ha)	Average dbh	Average height	Volume (m^3/ha)	Biomass (t/ha)	Carbon (t/ha)
Baikiaea plurijuga	3828.1	99.1	20.7	9.3	17	17.2	8.1
Guibourtia coleosperma	1331.5	31	21.7	8.7	8.4	7.3	3.4
Burkea africana	2668.3	41	18.3	8.8	2.6	3.5	1.6
Brachystegia spiciformis	119.6	12	23	13	2.3	2.5	1.2
Erythrophleum africanum	2033.8	19	14.9	7.9	0.8	1.3	0.6
Sub-total other tree species	35040.2	168	-	-	5.1	6.9	3.2
TOTAL (N=51)	***45021.5***	***369.8***	***19.5***	***8.5***	***36.2***	***38.7***	***18.2***
Coefficient of variation (%)	-	-	-	-	**±78**	**±67.5**	
Sampling error	-	-	-	-	**3.9 m^3/ha**	**3.4 t/ha**	**1.6 t/ha**
Standard deviation	-	-	-	-	**28.5 m^3/ha**	**24.6 t/ha**	**11.6 t/ha**

Table 9: Basic parameters per species in Sikumi Forest

Species	Regeneration (saplings/ha)	Stocking (trees/ha)	Average dbh	Average height	Volume (m^3/ha)	Biomass (t/ha)	Carbon (t/ha)
Baikiaea plurijuga	1740.1	111	19.9	9.3	13.1	13.9	6.5
Brachystegia spiciformis	1039.8	91	16.3	9.1	4.3	5.4	2.5
Guibourtia coleosperma	742.7	29	20.9	8.6	5.8	5.1	2.4
Acacia erioloba	0	2	61.2	15.7	7.8	5	2.4
Burkea africana	986.8	46	17.8	9.3	2.8	4.1	1.9
Sub-total other tree species	32393.8	199	-	-	5.1	7.8	3.7
TOTAL (N=25)	***36903.2***	***477.4***	***19.5***	***8.5***	***38.9***	***41.3***	***19.4***
Coefficient of variation (%)	-	-	-	-	**±100**	**±73.6**	
Sampling error	-	-	-	-	**8.3 m^3/ha**	**5.8 t/ha**	**2.7 t/ha**
Standard deviation	-	-	-	-	**41.5 m^3/ha**	**28.8 t/ha**	**13.5 t/ha**

52 different tree species were recorded in Ngamo whilst 62 were recorded in Sikumi. From the basic parameters it is quite evident that *Baikiaea plurijuga* is dominant in both forests; having a stocking rate of 99 trees/ha in Ngamo and 111 trees/ha in Sikumi. Overall Sikumi is more stocked (199 trees/ha) than Ngamo Forest (168 trees/ha). This is probably because of frequent fires that occur in Ngamo almost every fire season.

4.1 Above Ground Carbon stock

In determining the above ground carbon stock the following non-woody land-cover classes were deemed unproductive *i.e* grasslands, settlements and cultivated lands thus they were subtracted from the total forest area.

Table 10: Carbon distribution per vegetation strata in Ngamo Forest

Woody Vegetation cover strata	Area (ha)	Biomass (t/ha)	Carbon (t/ha)	Total Carbon (tonnes)
Baikiaea	60,539.3	48.7	22.9	**1,386,349.97**
Miombo	4,497.9	47.1	22.1	**99,403.59**
Burkea africana-Terminalia	29,124.4	15.6	7.3	**212,608.12**
Acacia	2,593.3	48.2	22.7	**58,867.91**
Mopane	61.3	33.8	15.9	**974.67**
TOTAL				**1,758,204.26**

Table 11: Carbon distribution per vegetation strata in Sikumi Forest

Woody Vegetation cover strata	Area (ha)	Biomass (t/ha)	Carbon (t/ha)	Total Carbon (tonnes)
Baikiaea	33,468.8	44.4	20.9	**699,497.92**
Miombo	6,793.7	33.8	15.9	**108,019.83**
Burkea africana	1,278.1	39.8	18.7	**23,900.47**
Terminalia/Combretacea	3,550.6	16.4	7.7	**27,339.62**
Acacia	60.1	87.3	41.0	**2,464.10**
Mixed Species	506.5	26.2	12.3	**6,229.95**
TOTAL				**867,451.89**

Sikumi has an average above ground carbon stock of 19.4 tonnes per ha whilst Ngamo has 18.2 tonnes per ha. However Ngamo has the highest total carbon stock value (1.76 million tonnes) due to its vast nature. Sikumi has a total above ground carbon stock value of 867 000 tonnes. Combined the two forests have a total above ground carbon pool of 2.6 million tonnes.

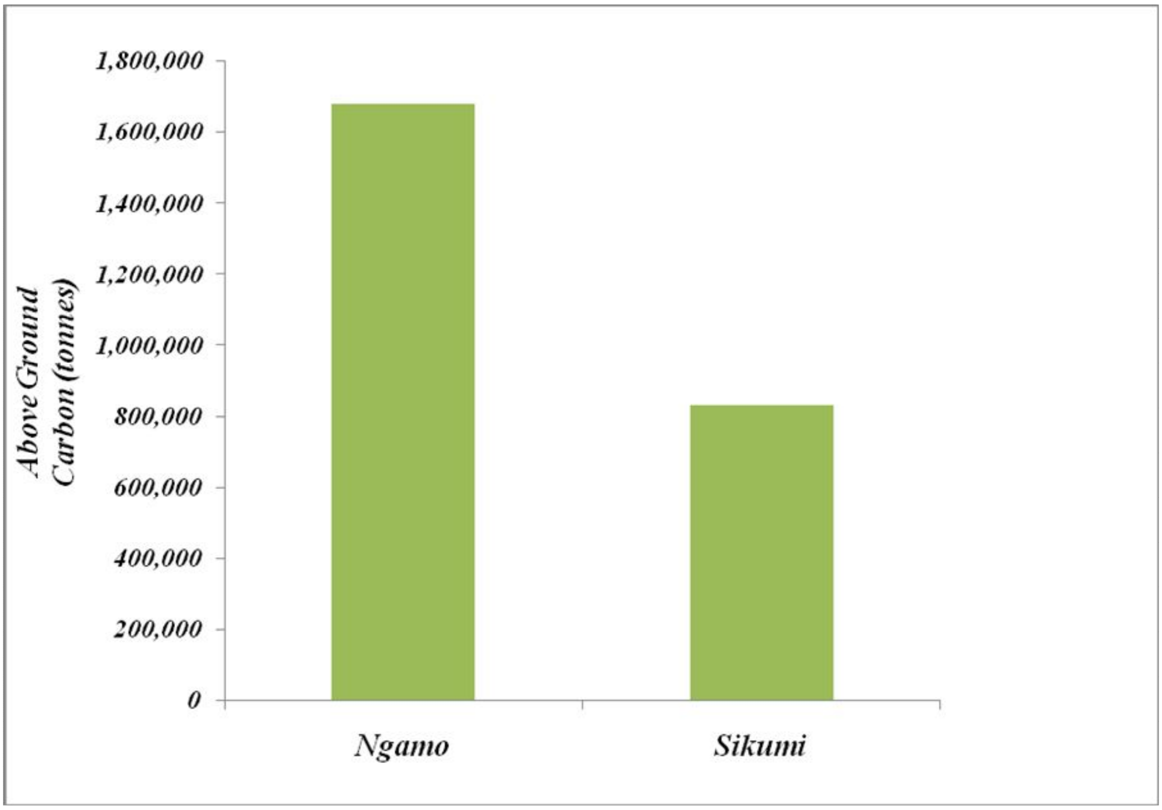


Figure 11: Carbon stock for the two forests

4.2 Spatial distribution of above ground carbon

Using data from 120 plots from Ngamo forest a linear regression model was developed to predict the spatial distribution of above ground carbon in the two forests. Correlation and regression analysis were used to quantify the relationship between field based carbon measurements, satellite bands reflectance and remotely sensed vegetation indices. The following vegetation indices were computed from Sentinel satellite data: Difference Vegetation Index (DVI), Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI) and the Soil Adjusted Vegetation Index (SAVI). Reflectance values from single bands 3 (Green), 4 (Red) and 8 (Near Infra-red) of Sentinel were also correlated to the field based carbon measurements. Out of the 7 satellite derived variables *i.e* DVI, RVI, NDVI, SAVI and Bands 3, 4 and 8; **NDVI** had the most significant positive relationship with field based carbon measurements (r^2=0.72; $p < 0.05$) (Table 12).

Table 12: Relationship between Satellite data and Above Ground Carbon

Satellite derived variable	N	Pearson's r	r^2
NDVI	120	0.85	0.72
RVI	120	0.81	0.66
SAVI	120	0.65	0.43
DVI	120	0.46	0.21
Band 3 (Green)	120	0.72	0.52
Band 4 (Red)	120	0.79	0.62
Band 8 (Near-infrared)	120	0.25	0.063

Based on the significant positive relationship between NDVI and field based carbon measurements (Fig 12), NDVI was used as a predictor for carbon distribution in the two forests. The regression equation $\boldsymbol{y = 35.65x\text{-}12.43}$ where $\boldsymbol{x}$ is the NDVI and $\boldsymbol{y}$ is the Above Ground Carbon was inputted in a GIS to produce the carbon distribution maps (Fig 13 and Appendix 1)

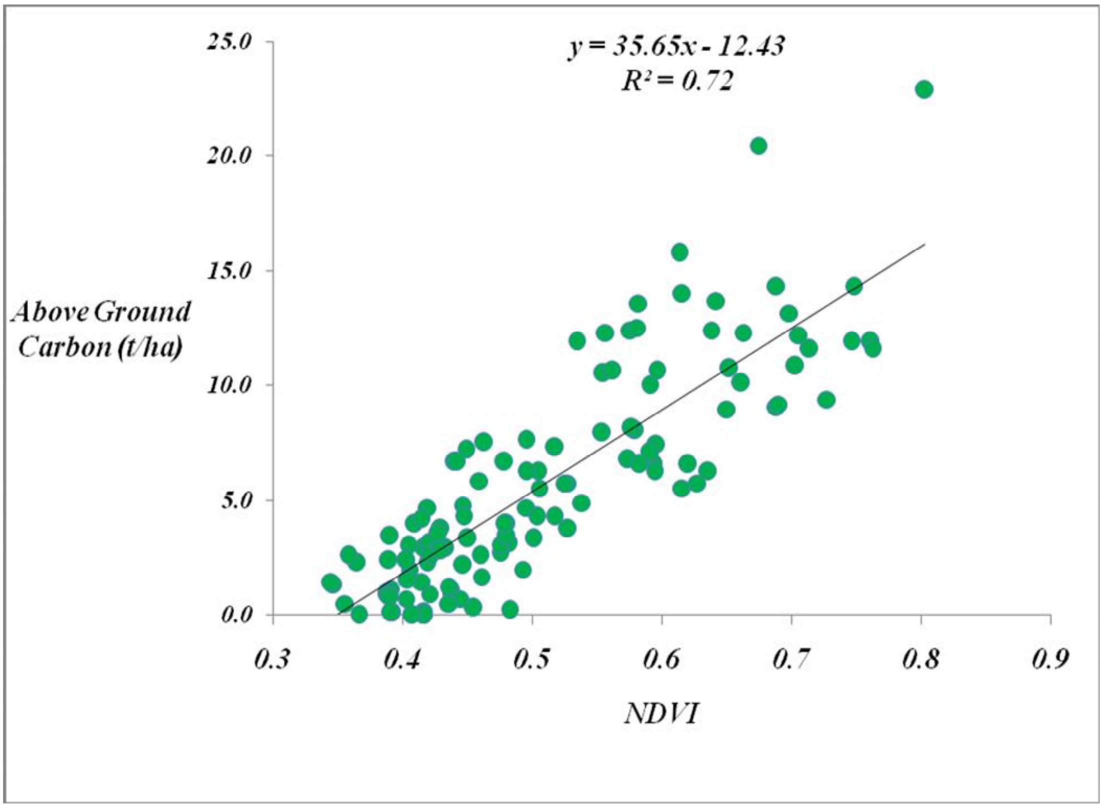


Figure 12: Relationship between Above Ground Carbon and NDVI

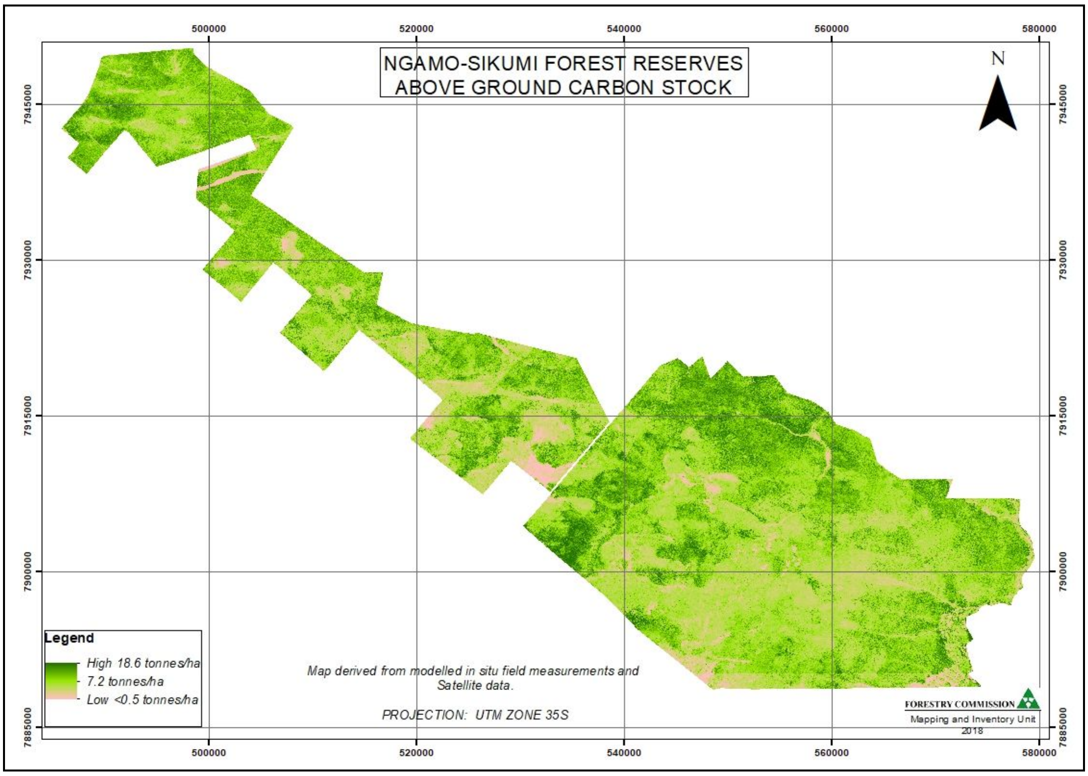


Figure 13: Satellite derived Above Ground Carbon distribution map of Ngamo and Sikumi forest

Figure 14: Modelled Carbon distribution Map vs Real Life Imagery showing Hwange National Park Airport and Dete Vlei (Sikumi Forest) having very low carbon. On the other hand forested lands show high levels of carbon.

4.2 Deadwood Carbon

Deadwood quantities per forest area were first derived as volume/ ha then converted to biomass/carbon. Conversion from Volume to Biomass was done using the equation below:

Biomass = Volume x Wood Density x Biomass Expansion Factor

Where: Wood Density = 0.58 (Brown, 1997)

Biomass Expansion Factor = 1.2 (average for tropical broadleaved) (IPCC, 2003)

Table 13: Deadwood carbon

Forest	Deadwood volume (m^3/ha)	Deadwood Biomass (t/ha)	Deadwood Carbon (t/ha)
Ngamo	7.5	5.2	2.4
Sikumi	5.6	3.9	1.8

Conversion to Carbon was done by multiplying Biomass by 0.47

5.0 CARBON MONITORING PLAN

5.1 Establishment of permanent forest carbon monitoring plots

Following establishment of the forest carbon baseline, permanent Forest Carbon monitoring plots were established. The plots were established for the purpose of monitoring forest carbon emissions and sequestration over the entire duration of the REDD+ project. 5 plots were established in Sikumi whilst 6 were established in Ngamo. The plots were distributed in different vegetation cover types within the forest areas and each plot measured 50m x 25m (Fig 15)

The following activities were carried out per plot: Sign post installation, tree identification, distinctive tree tagging; height and dbh measurements; coordinates collection per tree and ring painting each tree at 1.3m above ground (Picture collage on the next page shows these activities). The above mentioned activities were done to minimize errors during subsequent measurements which will be carried out at 3-5 year intervals. Monitoring of these plots will be done using both remote sensing technology and field visits. Appendix 2 shows the distribution of the monitoring plots in the two forests. It is also important to note that depending on the availability of funds more monitoring plots would be established.

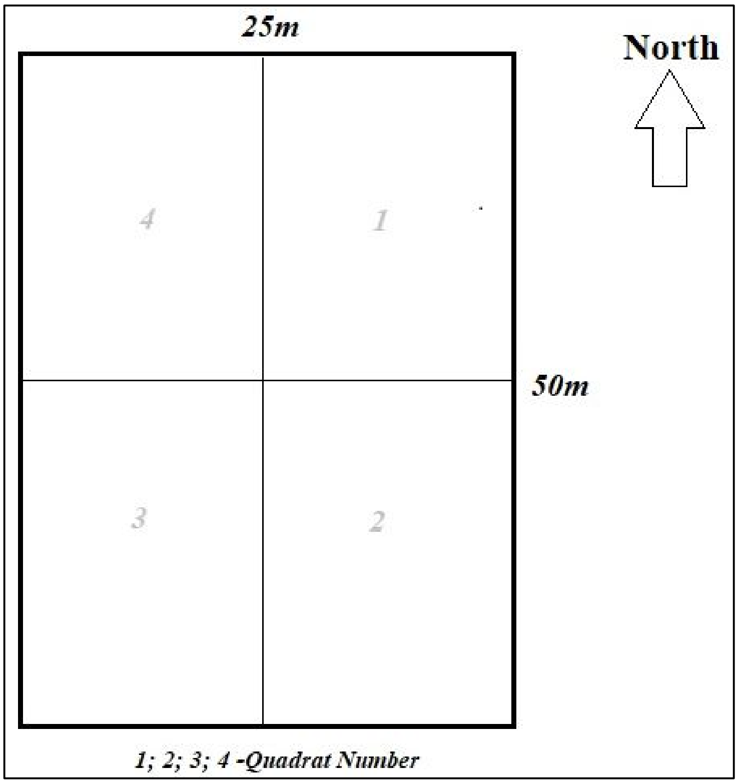


Figure 15: Permanent Forest Carbon Plot design

Figure 16: Picture Collage showing Forest Carbon Monitoring plots establishment

6.0 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

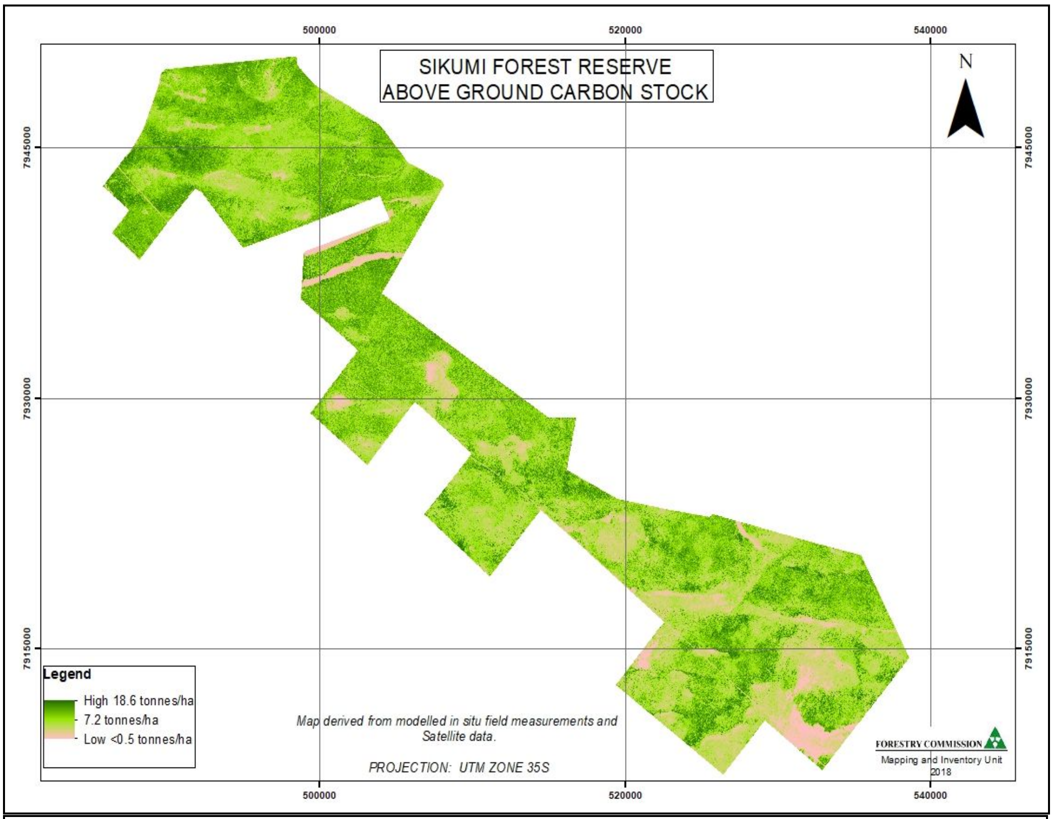
Ngamo and Sikumi forests are endowed with vast carbon stocks as witnessed by the high total carbon pool of 2.6 million tonnes. The average carbon stock of 18.2 t/ha for Ngamo and 19.4 t/ha for Sikumi is consistent and within range of the national carbon stock estimate for Zimbabwe. Recent results from the Zimbabwe Global Forest Survey (GFS) of 2017 show that Zimbabwe has an average of 19.5 t/ha of above ground carbon per ha whilst a similar survey carried out in 2005 gave an estimate of 15.7 t/ha of above ground carbon. The GFS study of 2017 also gave an estimate of 2.3 t/ha of deadwood carbon and similarly this is also consistent with values obtained from this study. Ngamo had 2.4 t/ha of deadwood carbon whilst Sikumi had 1.8 t/ha of deadwood carbon. However there is need for the country to come up with local country specific biomass equations. This will ensure improved accuracy in carbon estimates.

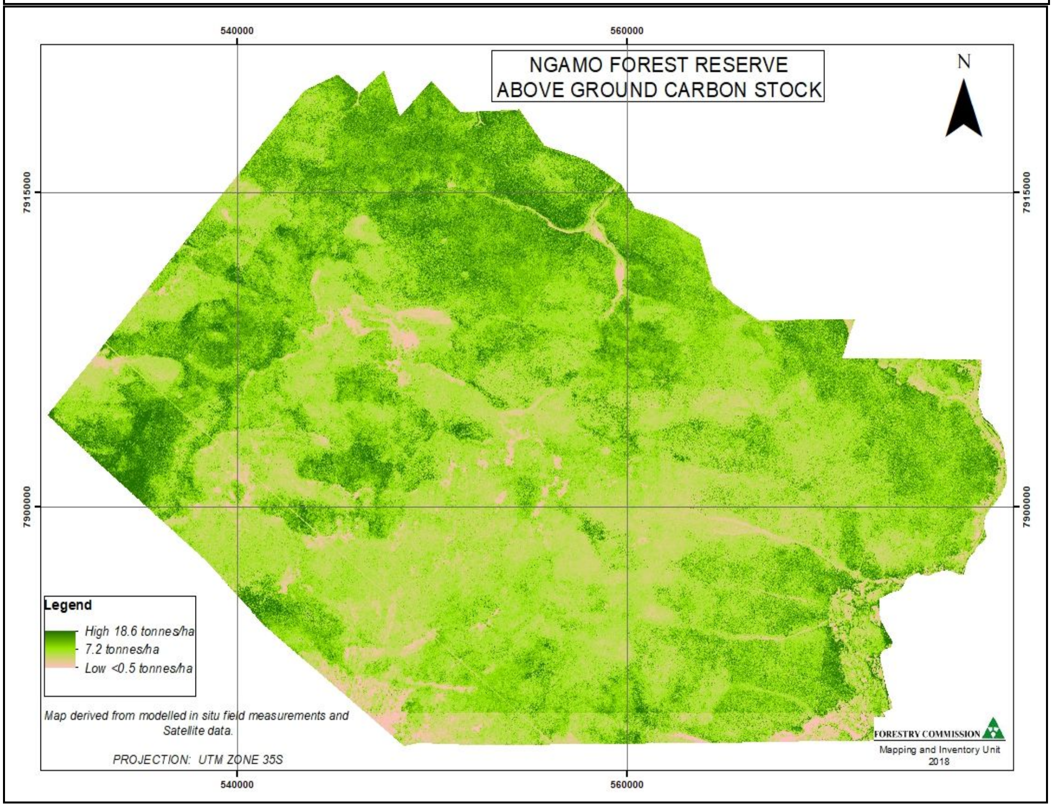
Furthermore the significant relationship between field based carbon measurements and satellite data shows that satellite data can be used as a proxy for above ground carbon estimation. This finding underscores the potential and significance of remote sensing data particularly Sentinel in understanding and quantifying carbon stocks in Zimbabwe's dry indigenous forests. However the relationship can further be up-scaled by using high resolution satellite imagery and Unmanned Aerial Vehicles (Drones).

In light of the vast carbon pool in Ngamo and Sikumi forests the following is recommended:

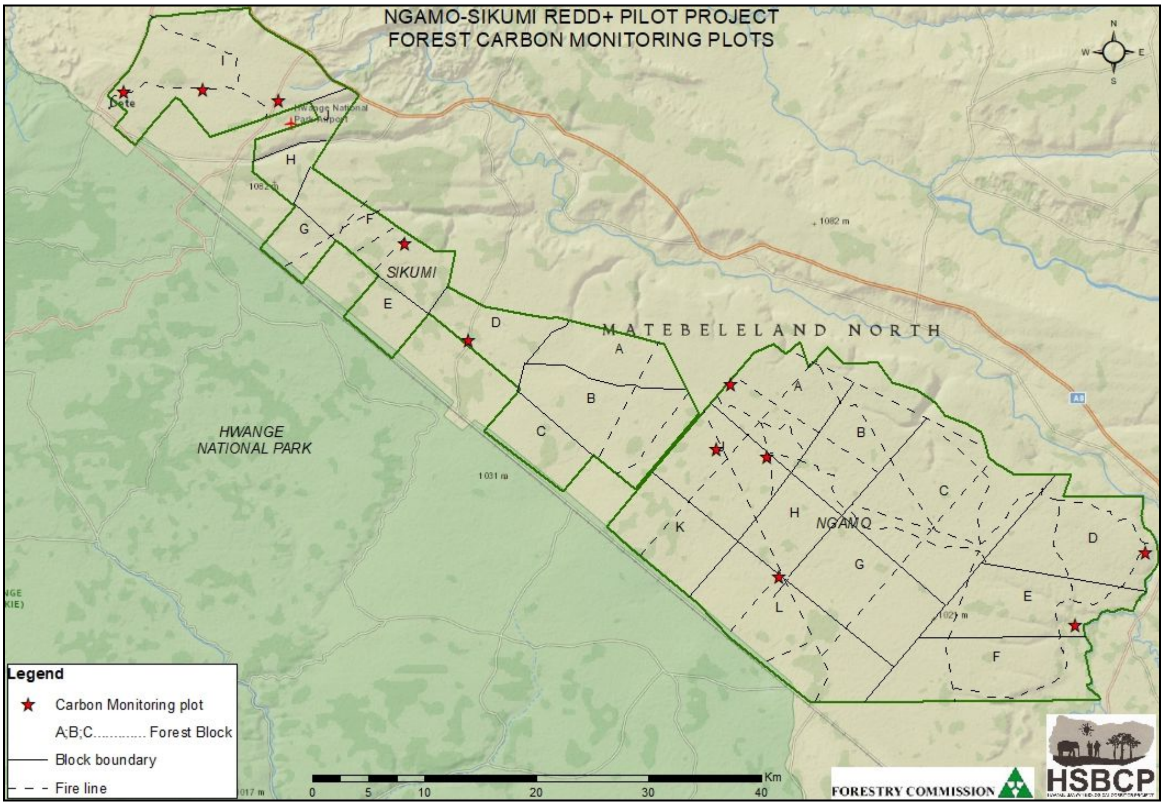
i) Enhancement of the total carbon pool should be a priority and this can be achieved by monitoring forest disturbances and taking practical remedial measures.
ii) Measures should be put in place to ensure surrounding communities (possible leakage zones) are made aware of the need to conserve forests.

APPENDIX 1: CARBON DISTRIBUTION MAPS





APPENDIX 2 : CARBON MONITORING PLOTS DISTRIBUTION MAP



APPENDIX 3: FIELD ACTIVITIES PICTURE COLLAGE

APPENDIX 4: RESULTS PER SPECIES: NGAMO

Species	Regen/ha	Stocking/ha	AVG DBH	AVG Height	Volume/ ha	Biomass t/ha	Carbon t/ha
Baikiaea plurijuga	3828.1	99.1	20.7	9.3	17	17.2	7.74
Guibourtia coleosperma	1331.5	31.1	21.7	8.7	8.4	7.3	3.285
Burkea africana	2668.3	41	18.3	8.8	2.6	3.5	1.575
Brachystegia spiciformis	119.6	11.7	23	13	2.3	2.5	1.125
Erythrophleum africanum	2033.8	19.2	14.9	7.9	0.8	1.3	0.585
Acacia erioloba	0	2.7	26.7	8.6	1.2	1.2	0.54
Combretum collinum	665.8	22.3	15	7.5	0.8	1.1	0.495
Colophospermum mopane	306.9	35.1	12	6.8	0.5	1	0.45
Pterocarpus angolensis	156	7.1	19.3	7.8	0.8	0.7	0.315
Terminalia sericia	1690.4	25.2	12.7	6	0.4	0.7	0.315
Combretum molle	2049.3	22.9	9.1	5.1	0.1	0.4	0.18
Ochna pulchra	4124.6	6.4	13.7	5.9	0.1	0.3	0.135
Combretum hereroense	72.8	7.3	14.8	7.6	0.2	0.3	0.135
Pseudolachnostylis maprouneiflora	457.7	7.7	11.3	5.4	0.1	0.2	0.09
Combretum imberbe	0	2.7	15.4	6.5	0.2	0.2	0.09
Diospyros mespiliformis		0.1	77.6	9.7	0.3	0.2	0.09
Other	10.4	0.1	55	15.9	0.2	0.2	0.09
Baphia massaiensis	2730.7	10.8	8.2	5.2	0.1	0.2	0.09
Diplorynchus condylocarpon	3058.3	6.4	10.4	5.1	0	0.1	0.045
Albizia amara		0.1	39	11.3	0.1	0.1	0.045
Lonchocarpus capassa		0.2	13.8	5.2	0	0	0
Peltophorum africanum		0.4	15.3	4.4	0	0	0
Croton gratissimus	140.4	1.9	7.8	5.2	0	0	0
Dalbergia melanoxylon	150.8						0
Dichrostachys cineria	15.6						0
Strychnos pungens	145.6	0.6	7.2	3.4	0	0	0
Strychnos spinosa	88.4						0
Ziziphus mucronata	15.6	0.1	11.5	6.2	0	0	0
Combretum apiculatum	26	0.2	12.9	5.3	0	0	0
Grewia flava	171.6						0
Grewia monticola	322.5						0

Pterocarpus rotundifolius	686.6						0
Vangueriopsis lanciflora	31.2						0
Vangueria infaustia	166.5						0
Vitex mombassae	197.6						0
Acacia nilotica	0	1.4	10.9	5.2	0	0	0
Acacia polyacantha	0	0.6	7	2.2	0	0	0
Combretum spp	10.4						0
Strychnos cocculoides	31.2	0.6	5.2	2.9	0	0	0
Commiphora matebelensis	5757.7	2.9	8.8	5.6	0	0	0
Bauhinia thonningii		0.2	15.5	2.6	0	0	0
Xeromphsis obovata	5601.6						0
Ximenia americana	182						0
Terminalia stenostachya		0.2	15.6	6.8	0	0	0
Securidaca longipedunculata	114.4	0.6	9.2	6	0	0	0
Bauhinia petersiana	4306.5						0
Maytenus heterophylla	88.4						0
Tarenna neurophylla	1367.9						0
Commiphora schimperi	57.2						0
Bolusanthus speciosus	0	0.7	12.3	5.8	0	0	0
Commiphora mossambicensis	41.6	0.1	16	7.5	0	0	0
Commiphora marlothii		0.1	10	4.4	0	0	0

APPENDIX 5: RESULTS PER SPECIES: SIKUMI

Species	Regen/ ha	Stocking/ ha	AVG_DBH	AVG_height	V_ha	Biomass/ ha	Carbon/ha
Baikiaea plurijuga	1740.1	110.5	19.9	9.3	13.1	13.9	6.255
Brachystegia spiciformis	1039.8	90.8	16.3	9.1	4.3	5.4	2.43
Guibourtia coleosperma	742.7	28.8	20.9	8.6	5.8	5.1	2.295
Acacia erioloba	0	1.9	61.2	15.7	7.8	5	2.25
Burkea africana	986.8	46.2	17.8	9.3	2.8	4.1	1.845
Erythrophleum africanum	1135.4	39.2	14.7	7.9	1.3	1.9	0.855
Combretum imberbe		1.5	26	8.3	0.8	0.7	0.315
Combretum celastroides	74.3	22.2	11.8	6.6	0.3	0.6	0.27
Ochna pulchra	3140.7	24.7	11.2	4.9	0.2	0.5	0.225
Terminalia sericia	456.3	25.6	10.9	4.9	0.2	0.5	0.225
Combretum molle	2578.1	18.7	12.4	6.1	0.2	0.5	0.225
Colophospermum mopane	742.8	9	13.9	3.9	0.2	0.4	0.18
Julbernardia globiflora	95.5	5.9	19	7.9	0.3	0.4	0.18
Amblygonocarpus andongensis	42.4	4.1	17.4	5.8	0.3	0.3	0.135
Kirkia acuminata	10.6	0.4	23.8	9.3	0.2	0.2	0.09
Pterocarpus angolensis	233.5	0.4	28.4	9.8	0.2	0.2	0.09
Combretum collinum	350.2	3.9	15.1	8.1	0.1	0.2	0.09
Pseudolachnostylis maprouneiflora	573	8.3	11.2	4.6	0.1	0.2	0.09
Combretum apiculatum	169.8	6	13	6.5	0.1	0.2	0.09
Terminalia prunoides		1.3	17.8	5.6	0.1	0.2	0.09
Diospyros quiloensis	0	3.5	14	6.5	0.1	0.2	0.09
Hyphaene petersiana	413.8	0.2	31.6	18.1	0.1	0.1	0.045
Bolusanthus speciosus		0.5	20.8	8.5	0.1	0.1	0.045
Brachystegia boehmii	392.6	0.3	27	12.4	0.1	0.1	0.045
Lonchocarpus capassa	63.7	5.9	6.7	3.8	0	0.1	0.045
Combretum hereroense	116.7	3.9	11.5	6.2	0	0.1	0.045
Baphia massaiensis	4191.1	4.8	7.1	5.2	0	0.1	0.045
Erythroxylum zambesiacum		0.1	15.8	7.4	0	0	0
Commiphora mossambicensis	42.4	0.6	15.1	6.6	0.1	0	0
Acacia ataxacantha		0.2	12.8	5.4	0	0	0
Croton gratissimus	21.2	1.2	6.4	3	0	0	0

Dalbergia melanoxylon	180.4	0.1	10.7	7.2	0	0	0
Diplorynchus condylocarpon	5315.8	0.5	12	3.8	0	0	0
Ziziphus mucronata	42.4	0.2	13.1	5.6	0	0	0
Commiphora caribensis		0.1	12.5	6.7	0	0	0
Parinari cyratellifolia		0.3	11.9	2.3	0	0	0
Diospyros mespiliformis	116.7	1.3	11.7	2.7	0	0	0
Strychnos potatorum	106.1	0.2	13.4	5.6	0	0	0
Strychnos cocculoides	191	0.1	10	2.7	0	0	0
Other	212.2	2.7	9	6.1	0	0	0
Diospyros spp	286.5	0.1	10.5	3.5	0	0	0
Bauhinia petersiana	4806.6	1.2	6.4	2.5	0	0	0
Maytenus senegalensis	594.2						
Euclea undulata	445.6						
Rhus dentata	95.5						
Dichrostachys cineria	31.8						
Strychnos pungens	244						
Strychnos spinosa	106.1						
Grewia flava	201.6						
Grewia monticola	350.2						
Friesodielsia obovata	63.7						
Pterocarpus rotundifolius	42.4						
Vitex payos	74.3						
Vangueria infaustia	1485.5						
Rhus dentata	95.5						
Commiphora matebelensis	10.6						
Xeromphsis obovata	1347.6						
Cantihium huillense	74.3						
Hexalobus monopetalus	63.6						
Tinnea spp	31.8						
Maytenus heterophyll	827.6						
Tarenna neurophylla	106.1						

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