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Multi-temporal assessment of forest cover, stocking parameters and above-ground tree biomass dynamics in Miombo Woodlands of Tanzania

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Miombo woodlands form the widespread ecosystem in Tanzania. The ecosystem of these woodlands serves as a carbon sink and source containing majority of the above-ground terrestrial organic carbon. The study assessed forest cover, stocking parameters and above-ground tree biomass dynamics in the Miombo woodlands of Bereku and Duru Haitemba in Tanzania. The data were obtained from conventional forest inventory and remote sensing and GIS techniques. Results show that forest cover has increased for the two consecutive assessment period of 1988 to 2000 and 2000 to 2009, mostly by higher canopy cover of 6.82 and 0.79%, respectively. Stocking parameters: stand density (N) stand volume (V) and stand basal area (G) were found to be 1909.5 ± 9.4 stem/ha, 12.3 ± 0.6 m^2ha^{-1} and 71.0 ± 6.8 m^3ha^{-1}, respectively. Vegetation indices (NDVI, ARVI and ND54) were then combined with forest inventory data for computation of average above ground biomass which was found to increase from 64 ± 6.53, 67.8 ± 5.42 to 79.218 ± 2.75 t/ha for 1988, 2000 and 2009, respectively. The results suggest that, the Miombo woodland resources have been consistently improving over the years of assessment. This could be attributed to reduction in negative anthropogenic factors that are known to be the major cause of resources degradation in Miombo woodlands. However, this improvement may be partial as plot level information revealed higher exploitation of the dbh class of 4 to 5 cm. Increase of management effectiveness through involvement of local people under participatory forest management, strengthened bylaws and provision of other incentives might have contributed greatly to the improvement of the forest resources.

Key words: Forest resources management, forest inventory, remote sensing, aboveground biomass stock.

INTRODUCTION

Forests and woodlands have been highly affected by land use changes across sub-Saharan Africa. This has caused change in vegetation cover especially conversion from forests and woodlands to other land uses like cropland and grazing land (Bukombe, 2007; Madulu, 2004). In the extreme cases, land use and land cover changes have been cited as one of the factors contributing to global climate change as well (Gong and Howarth, 1990). Miombo woodlands which are found in the Eastern and Southern Africa are one of vegetation types that have suffered due to land use changes. They cover approximately 320 million hectares. They are tro-

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pical seasonal woodlands and dry forest formation of African forests, most widespread fire-adapted and closed-canopy (Shackleton and Clarke, 2007). They occur in altitude from near sea level to 1600 m.a.s.l. with annual rainfall ranging from 500 to 1200 mm (Jeffers and Boaler 1966; Nshubemuki and Mbwambo, 2007).

In Tanzania, Miombo woodlands constitutes the largest single vegetation type, covering an area of about 30.93 million ha, forming nearly 90% of the total forest land or 13% of the entirely land (URT, 1998).

The physiognomy of Miombo woodlands in Tanzania consists of three layers: the tree canopy, under-wood layer of smaller trees and ground layer mainly shrubs and herbs (Nshubemuki and Mbwambo, 2007). With over 80% of population living in rural areas exploiting forest resources, Tanzania is witnessing rapid decline of forests and woodlands estimated at 97,260 hectares per year (URT, 2002; NBS, 2002). Clarke et al. (1996) reported that Miombo ecosystem supplies plenty of products and services that are essential to the wellbeing of rural communities. Miombo's woody products are normally extracted for fuelwood, poles, timber, carving, medicine, withies, food, ropes, live fences, ritual items and charcoal (Luoga et al., 2002; Abdallah and Monela, 2007).

In late 1980s, up to mid-1990s Tanzania engaged in introducing participatory forest management, which was a total shift from long standing paradigm of state control of forest resources (Kajembe et al., 2008). Soon, the promotion and adoption of the decentralisation model which was termed as Participatory Forest Management (PFM) practiced either as joint forest management or community-based forest management were accelerated country-wide and supported by National Forest Policy of 1998 (URT, 1998). However, the decentralization in a broader sense were in terms of forestland tenure changes and access to forest resources, witnessing some forests changing from general lands to village land forests reserves (VLFR) and others changing from private ownership to central government under the joint forest management (Mpanda et al., 2011).

It should be noted that in Tanzania there are two land acts (the Land act 1999 and the Village land act 1999). In the Land Act, the legal framework for the two land categories is defined, namely General Land and Reserved Land. Reserved Land, is that land set aside for specific purposes, under different legislation, it includes forest reserves, national parks and game reserves, etc, where as the General Land is a residual category, which includes all land that is not Reserved Land or Village Land, the Village land on the other hand is that land which is vested in the Village Assembly, and that the Village Council administers the land through the authority of the Village Assembly (Sundet, 2005)

In order to assess impact of these changes of forestland tenure and management arrangement that was spearheaded two decades ago, and taking into consideration new emerging ideas on REDD+, this study attempted to evaluate the status of forest resources in Bereku Forest Reserve (FR) and Duru-Haitemba Village Forest Reserves (VLFR) in the northern Tanzania. Forest biomass estimation have been estimated based on field inventory data which are normally labour intensive, time consuming, difficult to implement on vast areas and sometime they become destructive in cases where it is necessary to fell sample trees (Deo, 2008; Lu et al., 2005).

Remote sensing techniques have primarily been used in forest mapping, a real extent estimation and determination of deforestation rate (Mayaux and Lambin, 1995). The difficulty associated with traditional techniques of estimating forest biomass as expressed above has opened a door for the use of remote sensing techniques uses in biomass estimation. Remote sensing has been employed in many studies related to biomass estimations. For example, Solicha (2007) used remotely-sensed images in estimating aboveground biomass by employing three different ways based on classification of vegetation cover and generation of a vegetation type map. Indirect estimation of biomass through some form of quantitative relationship and partition the spatial variability of vegetation cover into relatively uniform patches.

A study conducted by Gibbs et al. (2007) showed that above ground biomass can be evaluated using remote sensing techniques supplemented by ground based data (inventory data). This approach has an advantage of providing wall to wall observation of carbon stock proxies. However, it should be noted that remote sensing does not measure biomass directly, but rather it measures other forest characteristics (spectral reflectance of trees), therefore it is necessary to supplement field measurement data with remote sensing data in estimating above ground biomass to develop statistical relationships between ground based measurements and satellite-observed vegetation indices (Gibbs et al., 2007).

Specifically, the study had three objectives including; i) understanding the forest vegetation cover changes at a landscape level, ii) determining stocking parameters at plot level depicting state of the forest resources, and iii) estimating temporal changes of total above ground biomass. The study employed remote sensing and GIS techniques (Abd El-Kawya et al., 2011; Kashaigili and Majaliwa, 2010) and thus complemented the standard forest inventory (Luoga et al., 2002). Combination of the two methods can provide more useful insights of the ecosystem at landscape scale (Mpanda et al., 2011), especially in assessing above ground biomass dynamics (Baccini et al., 2008).

MATERIALS AND METHODS

Study site

The study was conducted in Bereku Forest Reserve (6,111 ha) and Duru-Haitemba Village Forest Reserve (9,000 ha) located between

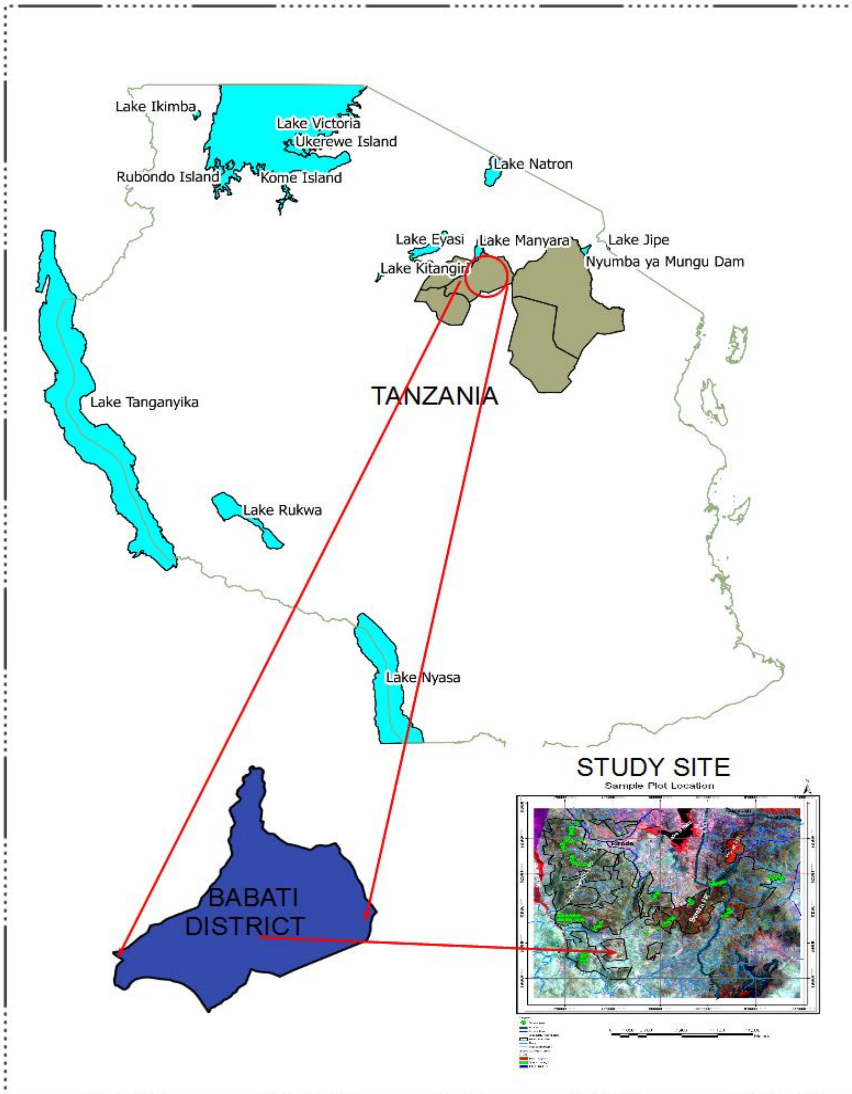

Figure 1. Location of sample plots in Bereku and Duru- Haitemba forests.

4°19' to 4°23' S and 35°43' to 35°51' E, respectively (Figure 1). The two forests cover the Bereku ridge and Gedabosh Mountain in Babati district, Manyara region, Tanzania (Lovett and Pócs, 1993). Population for the entire district stands at 303,013, with growth rate of 3.8% per annum and a density of 54 people per km^2 (NBS, 2002). The forests lie between altitudes of 1,000 and 2,500 m above sea level. Rainfall in the area is characterised by bi-modal and irregular rains ranging from 300 to 1,200 mm per year (Lovett and Pócs, 1993; Kajembe et al., 2003), and temperature ranges from 18 to 28°C (Lovett and Pócs, 1993). The soil is mostly loamy with good drainage and vegetation is mostly dry Miombo (Lovett and Pócs, 1993).

The two reserves are covered by woodland dominated by *Brachystegia microphylla.* The woodland consists of a continuous light canopy of 8 to 10 m tall grassland. The trees include: *Acacia* spp., *Albizia versicolor, Brachystegia microphylla, Brachystegia spiciformis, Cussonia arborea, Markhamia obtusifolia, Parinari curatellifolia, Strychnos* sp., *Syzygium guineense* subsp. *guineense, Vitex* sp. Bamboo is reported from the upper valleys of the Kikore and Madege rivers. Seasonally waterlogged grassland are associated with small tract of riverine forest which is mainly covered by *Bridelia micrantha* and *Syzygium cordatum* along the many undulating valleys.

Methods

The forests in Bereku Forest Reserve and Duru-Haitemba Village Forest Reserve were stratified into relatively small homogenous stands through visual interpretation of the geo-referenced satellite imageries at a scale of 1:50000 with the help of standard sheets of topographical maps of scale 1:50000 and Land Cover and Land Use map of Singida of scale 1:250,000 which shows the distribution of land cover and land use in Singida that includes some parts of Babati district.

In each stratum, sample plots were systematically laid out along transects at an interval of 250 m with an allowable error of 10%. Transect orientation was based on spatial distribution on road network passing through the reserves. The first sample plot was randomly determined; to minimize the edge effect, the plot centre for the first plots was half the prescribed plot interval from the road edge. Each sample plot was set out on the ground and its corresponding coordinate were recorded using a hand held GPS (Garmin GPS map etrex 60 CSx) receiver of a precision of ±3.

A total of 80 concentric sample plots of 0.07 ha or (700 m^2) was used, with 2, 5, 10 and 15 m radii respectively, measurement in the first concentric were taken on all trees with diameter at breast height (Dbh) ranging from 1 to 5 cm, in the second concentric it was 6 to 10 cm, in the third 11 to 20 cm and in the last concentric it was ≥ 20 cm (Figure 1), with the maximum radius of the plot of 15 m which is comparable with the spatial resolution of Landsat TM and ETM+. In each sample plot, all trees were identified by local people and a botanist. Additionally, two trees nearest (fattest and the small sized tree which were easily to be determined and time saving) to the plot centre were identified, dbh and height measured for establishing equations were used to estimate height of the rest of trees. Three satellite imageries were used including Landsat TM of 1988 and 2009 and Landsat ETM+ for 2000.

Standard forest inventory analyses were applied as used by Mpanda et al. (2011), where number of trees per plot was summarized and extrapolated into per hectare values (N). Basal areas for individual trees (g) were calculated according to DBH, summarized and transformed into per hectare values for the plot (G). A height-dbh equation developed by Malimbwi (2003) was used to estimate height of unmeasured trees as shown in Equation 1:

$$Ht = Exp\ (0.58048 + 0.602965 \times Ln(Dbh)) \quad (1)$$

with R^2= 83, SE = 1.32,

Where: Ht is total tree height in meters; Dbh = is tree diameter at breast height; Ln is the natural logarithm; SE is the standard error of estimate; the volume of individual tree was calculated using the following equation:

$$v = g \times Ht \times f \quad (2)$$

where v = tree volume, g = tree basal area, Ht = estimated tree height and f = form factor with value 0.5.

A form factor of 0.5 has traditionally been used for Miombo forests in Tanzania (Chamshama et al., 2004; Luoga et al., 2002). The volume of individual trees was summarized within plots and transformed into per hectare values (V). Biomass was calculated using the adopted equation from (3), which is given as:

$$y = 0.0625Dbh^{2.553} \quad (3)$$

With R^2 = 97, SE = 1.79, where, y = biomass ($kgha^{-1}$).

Landsat TM (1988 and 2009) and Landsat ETM+ (2000) of path/row 168/63 and 169/63 were geometrically corrected so as to transform from WGS84 UTM coordinate system to Tanzania UTM coordinate system (Clarke 1880 ellipsoid and Arc 1960 Datum) in UTM zone 36 South. The first order polynomial transformation for the geometric correction and resampling all images to pixel size 30 x 30 m using the nearest neighbour method was carried out. The images were also radiometrically corrected to remove any bias due to sensor parameters. The digital numbers (DN) were converted into radiance value and then to the surface reflectance in order to calculate the spectral vegetation indices.

Supervised classification was used to process the imageries using information collected at plot level using hand held GPS. Sample plot data (ground truth data) were used to train the computer to recognize patterns in the data by selecting pixels that represents pattern or recognizable land cover features. Normally in supervised classification, the analyst has a prior knowledge of some land cover types, then identifies and locates these features through a combination of field work, map analysis and personal experience. The resulting signature file created was used in the classification process, where by each pixel is categorized into the land cover class it mostly belongs to. The land cover classes developed were based on the predetermined classification scheme which adheres to the principle that the classification scheme for land use and land cover should be mutually exclusive, exhaustive and hierarchical (Jensen, 2007). Ten land cover class/category were developed namely as waterbodies, open grassland, grassland with scattered crop lands, woodlands with scattered cropland, closed woodland, open woodland, bushed grassland, Marshaland, cropland with scattered trees and bushland with scattered cropland.

Land cover maps for the years 1988, 2000 and 2009 were developed, and later used in change detection using image differencing (Singh, 1989; Coppin and Bauer, 1996; Lillesand et al., 2004; Jensen, 2007). In this study, image differencing was used as a method of choice for change detection where by the thematic classified images were differenced. This algorithm involves subtracting one epoch of the classified imagery from a second epoch of classified imagery that has been precisely registered to the first. It normally results into positive and negative values representing areas of change and zero values representing no change.

Regression analysis of Biomass and Spectral Indices was performed involving various vegetation indices to tested the correlation of field estimated biomass with spectral data for all three scenes. The regression equation developed was based on Vegetation Indices (VI) which relates to optical measures of vegetation canopy 'greenness' resulting from the composite property of total leaf chlorophyll, leaf area, canopy cover, and structure. Three VIs were tested i.e. Atmospherically Resistance Vegetation Index (ARVI), Normalized Difference Vegetation Indices (NDVI) and Normalized Different Vegetation index that use band 5 and 4 instead of band 1 and 2 (ND54) were tested to relationship between biomass and spectral data.

Vegetation Indices (VIs) were computed for each scene after the application of geometric and radiometric correction of the images. Forest inventory data were then integrated with satellite data (VIs). These values were then linked with field measured biomass data using empirical analysis employing the ordinary least square (OLS) regression to study the relationship between per plot above ground biomass and Vegetation indices, using the following modified equation;

$$AGB = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon i \quad (4)$$

Where, AGB = Above-ground biomass, β_0 = Intercept, β_1…….. β_4 = slopes of respective explanatory variables, ε_i = error term, X_1 = NDVI, X_2 = ND54 (Normalized Different Vegetation Index that use band 5 and 4 instead of band 1 and 2) and X_3 = ARVI

The resulting regression equation from the analysis was used to predict Total Above-ground Tree Biomass (TAGB) for the entire study area as shown in Table 1.

RESULTS

Forest cover changes

Results of forest cover changes using post-classification change detection techniques over a period of 21 years from 1988 to 2009 at Bereku Forest Reserve and Duru-Haitemba Village Forest Reserve (Tables 1 and 2; Figure 2a and b) shows positive increment for the Closed woodland. The second highest cover class Open wood-land has been unstable as some of its cover im proved

Table 1. Above-ground biomass estimation models.

Variable	Scene	Model	R^2 (%)
	1988	$- 10.28X_1 + 20.33X_2 + 22.58X_3 + 30.81$	59.48
Spectral indices	2000	$- 0.581X_1 + 20.484X_2 + 28.842X_3 + 68.73$	35.52
	2009	$4.752X_1 - 25.2X_2 - 12X_3 + 59.5$	51.9

Table 2. Areas of land cover changed forest cover changes from 1988 to 2009.

Class Name	1988	2000	2009	1988-2000	2000 -2009	Change (%) (1988 - 2000)	Change (%) (2000- 2009)
	Area of respective land cover classes in hectares						
Closed woodland	4690.93	6555.15	6970.77	2886.12	415.62	6.82	0.79
Open woodland	16208.59	11626.8	11721.9	2739.28	95.1	-6.47	0.18
Bushed grassland	4997.31	4720.59	6441.84	35.97	1721.25	-0.08	3.29
Unclassified	0	0	225.18	0	225.18	0.00	0.43
Total	25896.83	22902.5	25359.7	-	-	-	-

to a closed woodland while others deteriorated to a bushed grassland.

Forest stocking parameters

Results for the stocking parameters are shown in Tables 2 and 3. A total of 77 species were recorded of which the dominant species were *Braschytegia* species, *Jubernadia globiflora* and *Combretum molle.* The distribution of stand biomass and volume by diameter class indicates a J-shaped curve which implies that larger sized tree has more biomass as compared to small trees, where as that of stand stocking density indicated and inverted J-shaped curve, which implies the distribution trend is more dominated by small trees; which is a normal tendency for naturally growing forests. Furthermore, this study observed irregular regeneration and over-exploitation of certain preferred diameter classes (4 to 5 cm).

Above ground biomass estimation

Forest parameters delivered from inventory data were integrated with vegetation indices (satellite data). A window of 3 by 3 was used to extract pixels corresponding to plots using the shape file of the plots, and then the mean value at the centre of the pixel where the coordinates of the sample were located was determined. These values werethen linked with field measured biomass data using empirical analysis employing the ordinary least square (OLS) regression to study the relationship between per plot above ground biomass and vegetation indices.

The OLS regression is an empirical approach used in modeling the relationship between two observed variables, X and Y (Cohen et al., 2003). The OLS regression is in form of:

$$Y=\beta_0+\beta_1X+\varepsilon_i \quad (5)$$

Where, Y = variable to be predicted (dependent variable); X= the variable to be predicted from explanatory or independent variable; β_0 = intercept; β_1 = slope of explanatory variables; ε_i = error term.

Cohen et al. (2003) suggested that data for the analysis in OLS regression should be supplied from paired observation of the two variables (dependent and explanatory variable). Commonly, one variable is difficult or costly to measure (forest or vegetation parameters from field sampling) and the other is relatively easy or inexpensive to observe (vegetation indices).

The regression analysis for both TM and ETM+ tested revealed a high correlation of spectral indices (ARVI, NDVI and ND54) with above-ground biomass (fAGB). The model for 1988 scene (Equations 5 and 6) (Table 1) was selected for use in computing TAGB for the entire study area since it has a relatively higher coefficient of determination (r^2):

$$-10.28X_1+20.33X_2+22.58X_3+30.81 (r^2R^2=0.59) \quad (6)$$

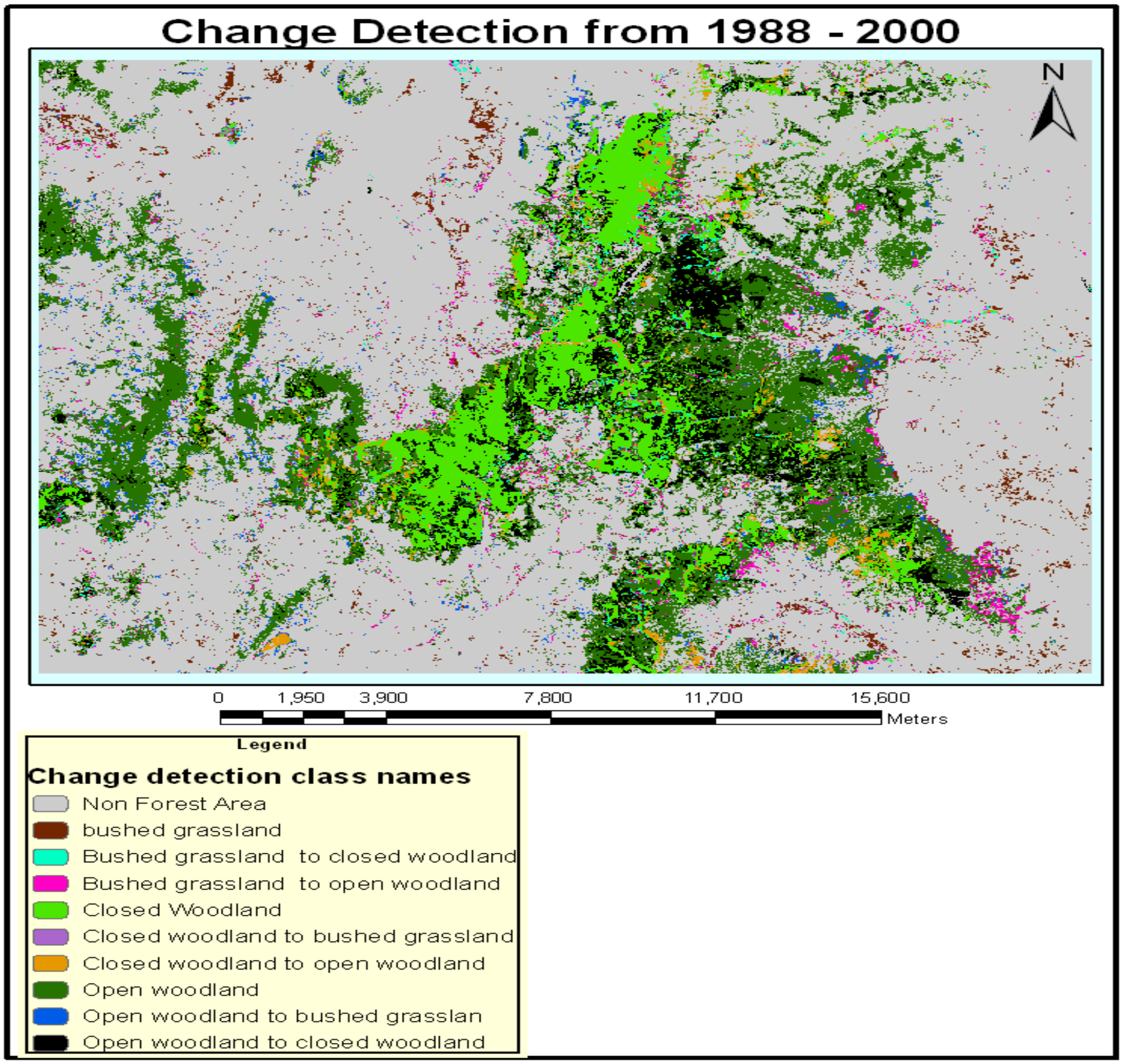

Figure 2a. Forest cover change detection map for the period of 1988 to 2000.

Where; x_1 =ARVI, x_2 =NDVI, and x_3 = ND54.

The biomass values obtained from stocking parameters and vegetation indices were used to prepare biomass maps using ArcGIS (Figure 3a, b, c and d), and further computing biomass of the entire area. The average biomass of all trees ≥ 1cm of the entire area has increased from 64 ± 6.53 t/ha in 1988) to 67.8 ±5.42 t/ha in 2000 and 79.218±2.75 t/ha in 2009.

DISCUSSION

Forest cover changes

Miombo woodlands in the Eastern and Central Africa have been observed to have dynamic systems whose multiple states are driven by disturbances, environmental variability and feedbacks (Forst, 1996). This study unveiled a similar situation where various cover types have been changing from 1988 to 2009 in both Duru Haitemba VFR and Bereku FR.

This study unveils changes in forest cover types and biomass from 1988 to 2009 in both Duru Haitemba VFR and Bereku FR, expressing the dynamic nature of the Miombo ecosystem. Similar observation was made by Forst (1996) resulting from multiple drivers including disturbances, environmental variability and feedbacks.

This study unveils changes in forest cover types and biomass from 1988 to 2009 in both Duru Haitemba VFR and Bereku FR, expressing the dynamic nature of the Miombo ecosystem. Similar observation was made by Frost (1996) resulting from multiple drivers including disturbances, environmental variability and feedbacks. Of the four cover classes, closed woodland which was the highest has been shown to increase, first at higher mag-

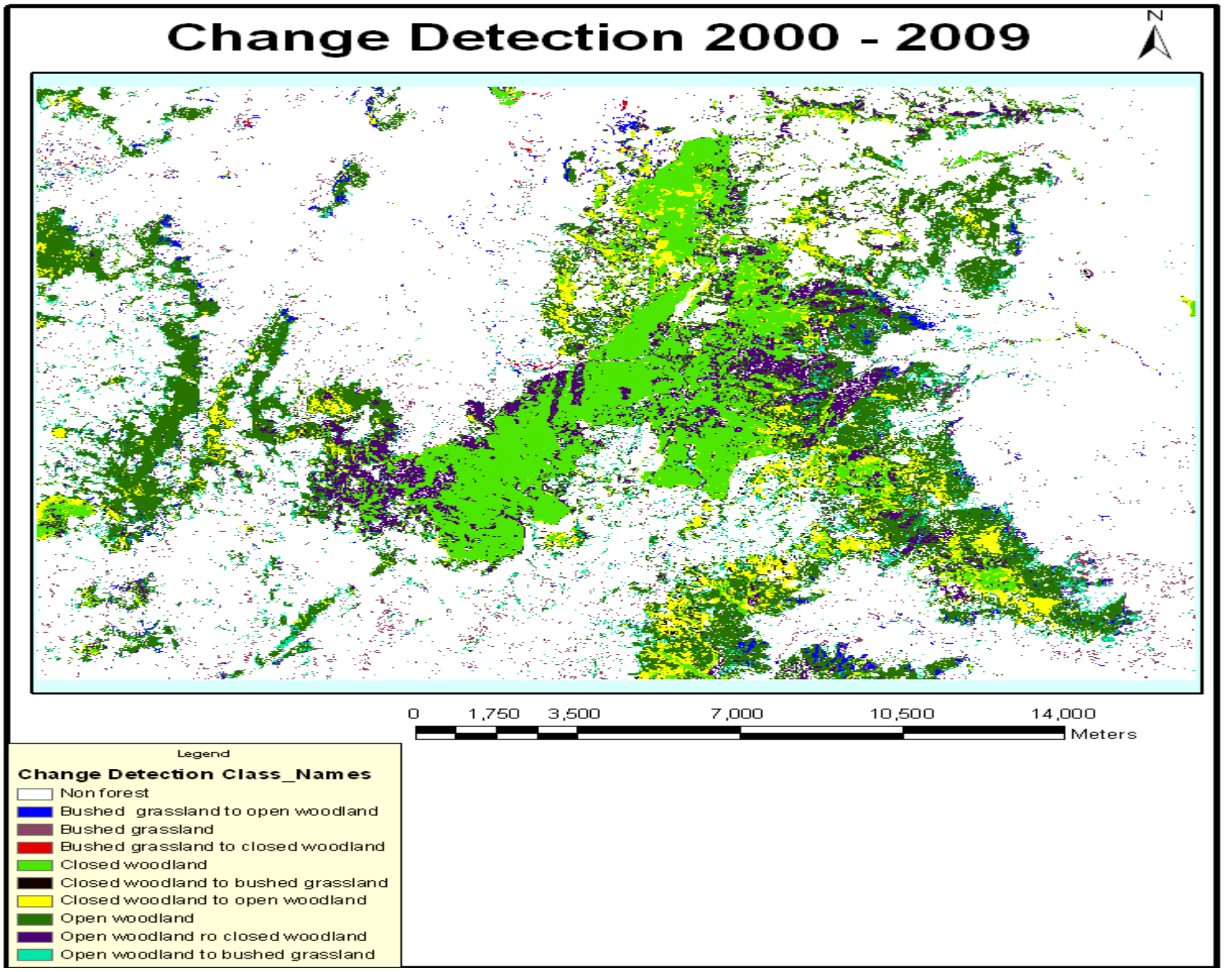

Figure 2b. Forest cover change detection map for the period of 2000 to 2009.

Table 3. Stocking parameter as per dbh classes in Bereku and Duru-Haitemba forests in 2010.

Stocking parameter (n=80)	Diameter class (in cm)						Mean*
	1 -4.9	5-9	10-19	20-29	30-39	≥40	
	1 -4.9	5-10	10-20	20-30	30-40	≥40.1	
N (no. ha^{-1})	1497.3	41126.1	50455.6	38360.3	13832.8	7487.6	1909.5 (9.4)
G (m^2ha^{-1})	0.28	29.3	178.1	301.1	212.6	262.7	12.3 (0.6)
V (m^3ha^{-1})	0.68	133.3	1300.4	2813.1	2297.1	3375.2	71.0 (6.8)
fAGB ($tonha^{-1}$)	0.40	80.1	790.8	1718.4	1406.0	2067.9	75.7 (2.4)

*Mean with standard error (in parenthesis) of the stocking parameters of all trees ≥ 1cm. Where: N = stocking per hectare, G = basal area per hectare, V = volume per hectare and fAGB = aboveground biomass in tonnes per hectare.

magnitude (between 1988 and 2000) and later at a low extent (between 2000 and 2009). This positive change especially that occurred between 1988 and 2000 can be attributed to improvement in management regime, which minimized human disturbances. In early 1990s, Tanzania witnessed a paradigm shift in forestry resource management where decentralized model was introduced in the name of participatory forest management (PFM) (Zahabu, 2008). This has empowered local communities living adjacent to forests and woodlands to either enter into Joint Forest Management (Bereku FR) or establish their own Community-Based Forest (Duru- Haitemba) (Kajembe et al., 2008; Mpanda et al., 2011). A number of studies have reported halting of deforestation and forest degradation in most areas of the country as result of PFM implementation.

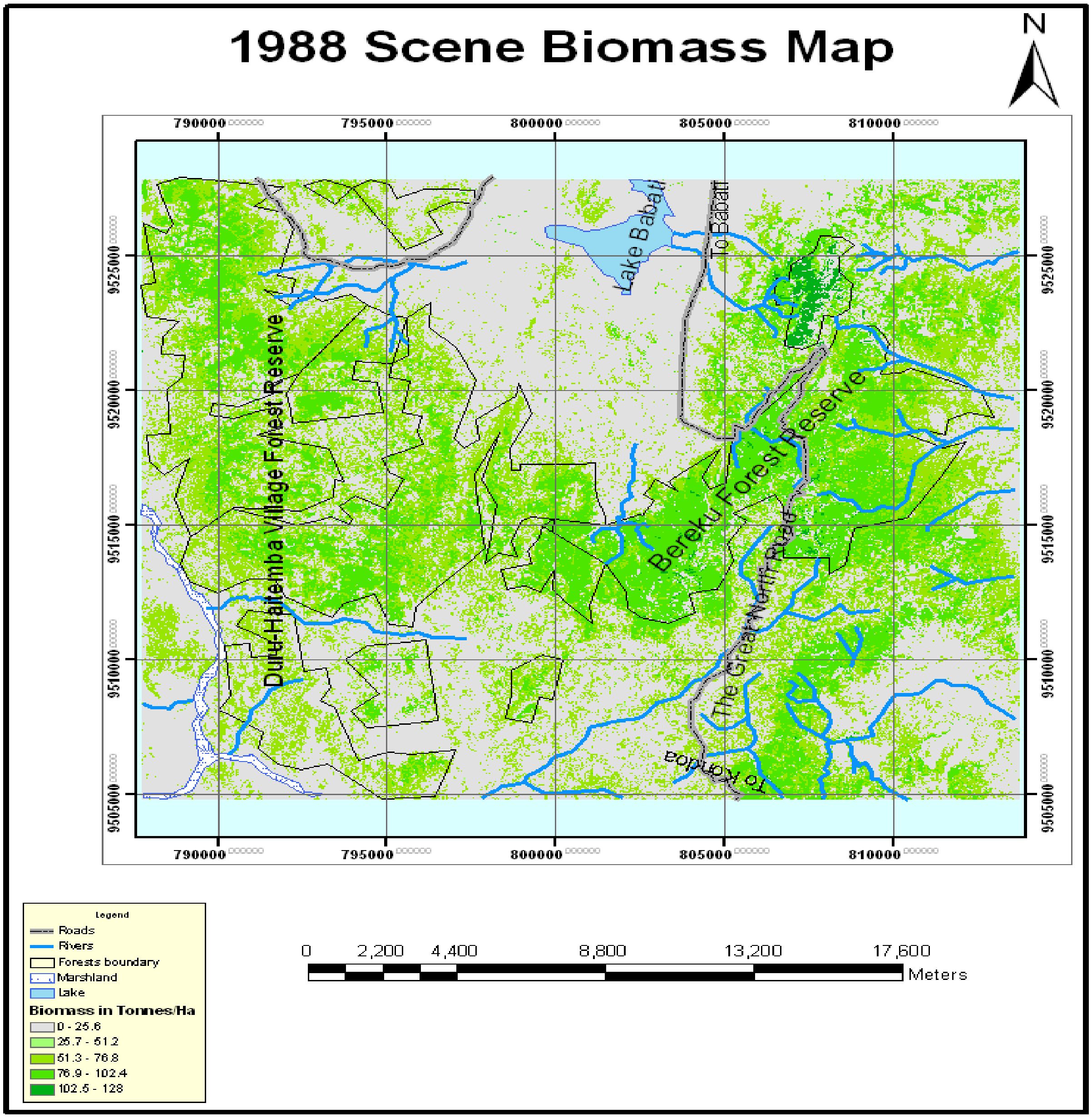

Figure 3a. Above-ground biomass distribution map for the 1988 scene for both path 168, row 63 and 169 row 63.

Support from bilateral and multi-lateral agrees with the government of Tanzania to support Participatory Forest Management ensured availability of finances and human resources to better manage the forests, mostly from Norway, Denmark, the World Bank, Germany and Finland (URT, 2003). It is important to note that one village named Ayasanda bordered the two forests (Bereku and Duru Haitemba) in the study area and hence benefited from both JFM and CBFM.

Results from the study further indicates that bushed grassland which is among the lower cover classes has increased in the period of 2000 to 2009, this is opposed to slight decrease in period of 1988 to 2000. This recent increase which translates to deforestation is probably attributed to local people's harvesting pressure on these forests. As both JFM and CBFM do not advocate total exclusion but rather rational use of the forest resources, it is probably this factor with minimum supervision that led to the decline of forest cover. A balance between utilization and protection need to be stricken otherwise deterioration of forest resource can result. Kajembe et al. (2008) and Vihemäki (2009) have argued that a complex situation exists between decentralization and local livelihoods, where in some cases instead of decentraliza-

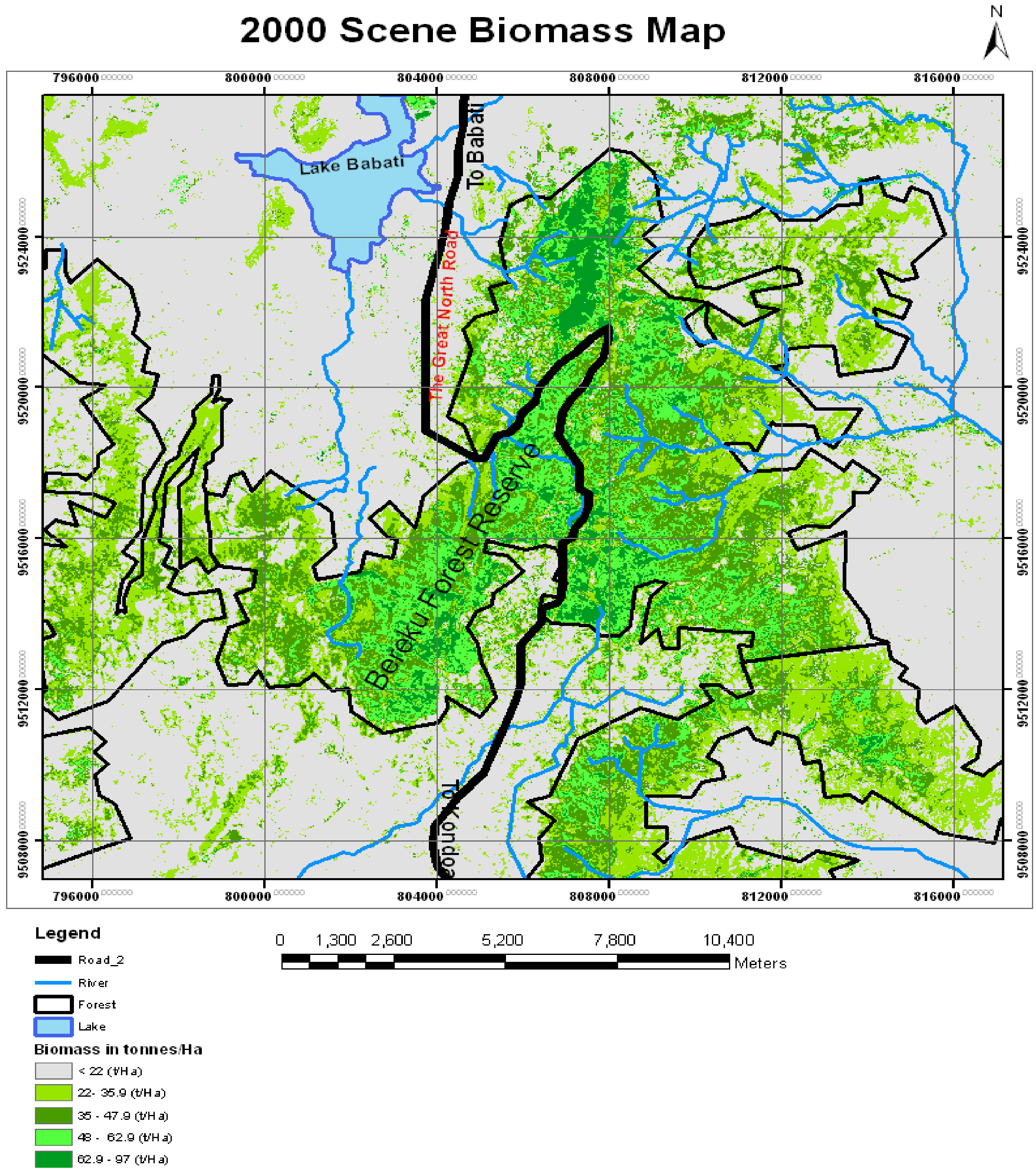

Figure 3b. Above-ground biomass distribution map for the 2000 scene path 168 row 63.

lization the situation becomes further exclusion which in turn deterioration of livelihood and forest resources can be witnessed.

Forest stocking

Average stocking parameters in Bereku FR and Duru Haitemba VFR found in this study are within the range reported by other researchers in various areas of Miombo woodlands (Malimbwi, 2003; Mugarura, 2007; Isango, 2007; Mwase et al., 2007; Zolho, 2005). Number of stems per hectare of tree species at diameter class 1 to 4.9 cm was lower than expected. This is probably due to excessive exploitation of that particular class. It was expected

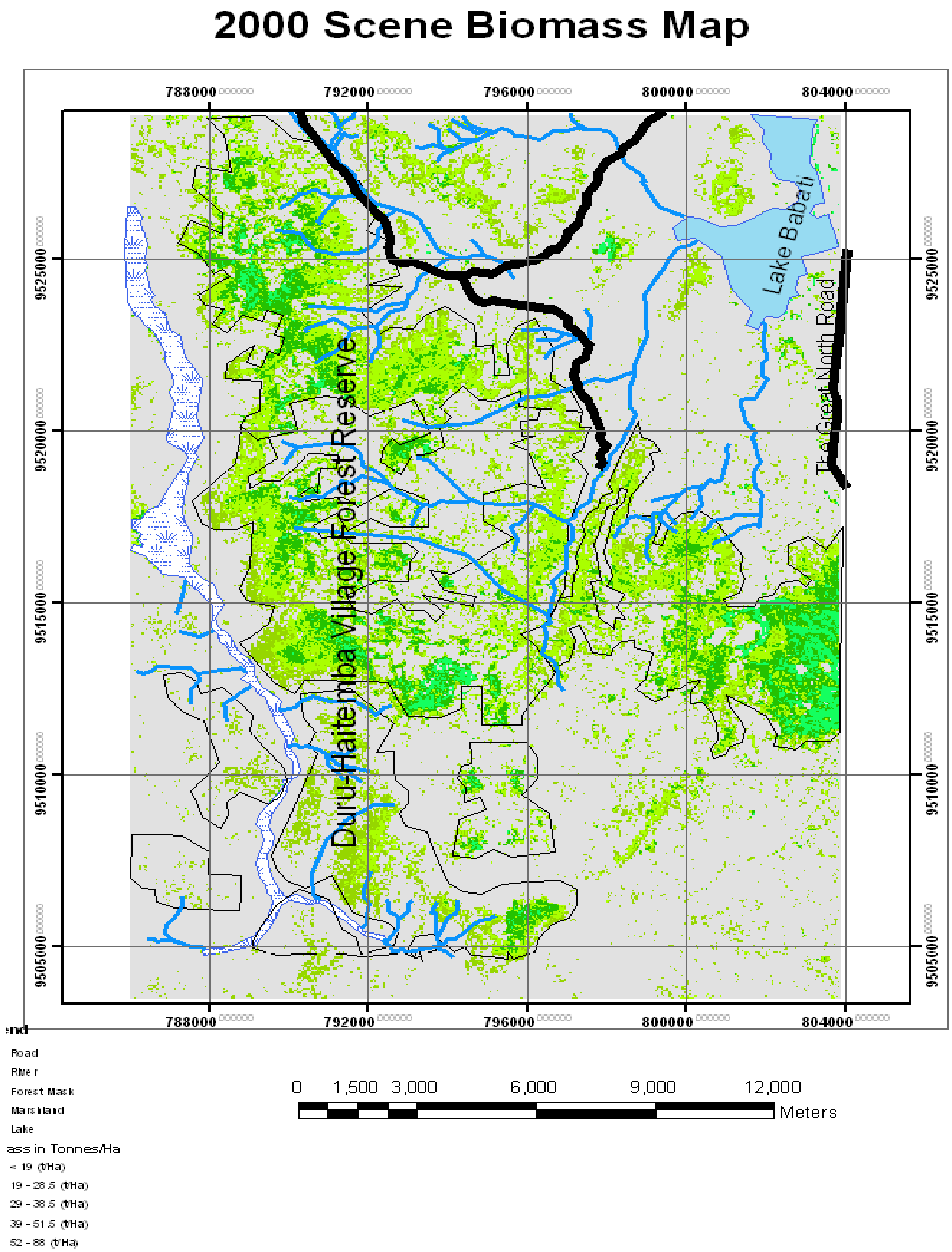

Figure 3c. Above-ground forest biomass distribution map for the 2000 scene path 169 row 63.

that the diameter classes at this dbh class would have similar trend with their nearby classes, as Chidumayo (1997) noted that there is positive correlation between age and wood annual increment in Miombo woodlands at least for the first ten years. Signs of excessive removals were observed for this diameter class, and their corresponding uses were identified in the surrounding villages. Withies are highly used in construc-tion of shelters and household compound fences in the study area, prompting extraction of this diameter class. Furthermore, they are used for baking bricks and as poles for construction of houses.

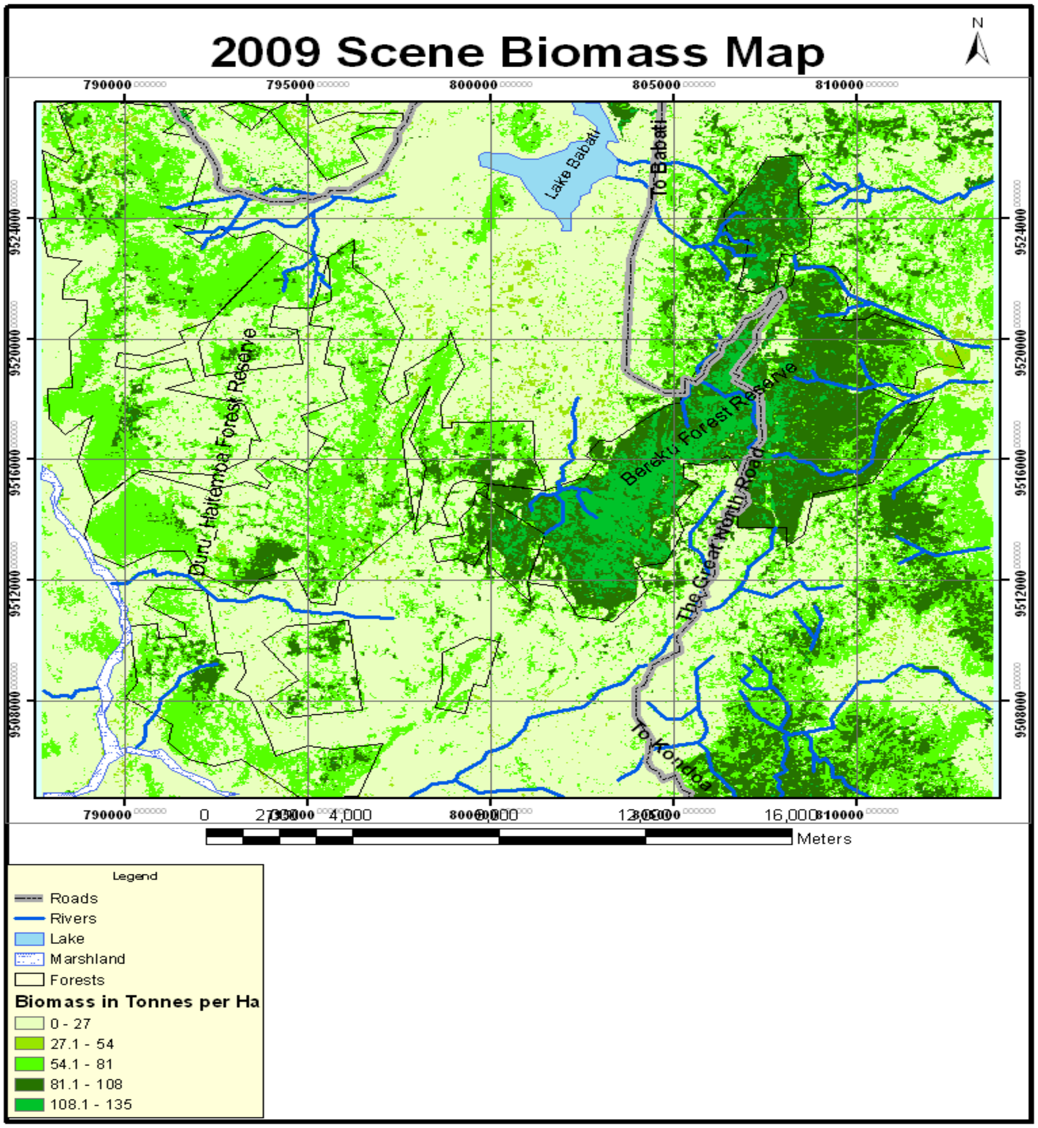

Figure 3d. Above-ground biomass distribution map for the 2009 scene for both path 168, row 63 and 169 row 63.

Ecologically, Miombo woodlands co-exist with fire but seedling shoots undergo a series of death and re-sprouting until they reach a threshold height and diameter to escape fire (Frost, 1996; Zolho, 2005). This may be one of the factors undermining the seedling layer at diameter class of 1 to 4.9 cm in terms of both survival and early growth as is still under the recruitment stage before escaping to sapling stage. Furthermore, as noted by Akinnifesi et al. (2008) early growth of Miombo vegetation differs with species. Frost (1996) reported that the mean biomass in Miombo woodlands tends to increase with increasing mean annual rainfall of a site. However, for this study area there were no significant spatial climatic differences which could have resulted into biomass differences. What is therefore observed in the study site could be a result of direct forest management and application of local forest governance.

Above ground biomass

Total biomass of the study area has been found to increase consistently from 1988, 2000 to 2009. This trend suggests that the forests (Bereku and Duru-Haitemba) are still undergoing growth and have not reached climax stage. As noted earlier, at one point during firm state control without Participatory Forest Management, these forests were overexploited. For instance, Duru-Haitemba was previously managed under traditional customs and taboos, with sometimes punishment less that damage sustained. As a result, the harvesting of the forest products intensified in the late 1970s and early 1980s and thus forests were highly degraded. The state intervened and gazetted the forests under state ownership between 1987 and 1994, and signified some improvement, and furthermore it was later in 1994 that Village Forest Reserve was made to exercise full decentralization (Zahabu, 2008).

Another factor that could have also contributed to this observation is perhaps the forest ecosystem succession, whereby the degraded parts in the forest recovered upon decrease of anthropogenic factors that were undermining the forest cover. Miombo woodlands have high coppicing and re-sprouting ability which make it cope with fire and other detrimental regimes. Luoga et al. (2002) reported that 83% of the 30 harvested species in Kitulangalo forest reserve (Morogoro, east-central Tanzania) were re-sprouting; with the average stump height for all preferred species at 40.6 cm. This means with cessation of excessive human pressure, the Miombo woodlands rapidly regenerates to recover its healthy state.

Conclusion

There was consistently positive change in forest resources from results of forest cover, stocking parameters and above ground biomass. This general trend signifies the improvement in favourable conditions which had positive effect on the state of the forests. Some dynamics in forest condition has also been observed, indicating that there is still a room for improvement of the overall forest resources by restricting unwise use. Increase of management effectiveness through involvement of local people under both joint forest management and community based forest management, strengthened bylaws and provision of other incentives might have contributed greatly to the improvement of the forest resources.

The methodological approach presented in this study offers a simple and fast way to estimate the temporal and spatial dynamics of aboveground biomass and assessment of forest cover changes especially when the ancillary data are unavailable. These findings are therefore an important baseline data source for future scientific research and knowledge in the area of geosciences and forestry biometrics in Tanzania.

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