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# Human activities outcomes on the composition of woody plant species of Ngarama Southern Forest Reserve in Kilwa District, Tanzania

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**Abstract.** *Jilala ZJ, Mwakalukwa EE, Chamshama SAO. 2019. Human activities outcomes on the composition of woody plant species of Ngarama Southern Forest Reserve in Kilwa District, Tanzania. Asian J Ethnobiol 2: 108-118.* This study evaluated the effects of human activities on the composition of woody plant species of the Ngarama Southern Forest Reserve (NSFR) in Kilwa District, Tanzania. Vegetation research was conducted in 40 systematically arranged rectangular test plots, aligned in five transepts over 2,070 ha forest. Information recorded in each plot included: species name, diameter at breast height (DBH), the height of selected timber species with a diameter ≥ 5 cm, and various indicators of human disturbance. Landsat TM and ETM+ images from 1995, 2000, and 2011 were used to locate and quantify the land cover change in the NSFR over the past 20 years. Inventory data was analyzed using Microsoft Excel and R software, while Landsat images were analyzed using the academic software ILWIS 3.0. About 126 plant species belonging to 34 families have been identified. Trees contributed 63% (28 families), and shrubs 37% (17 families). The Shannon-Wiener index and Simpson's diversity indices were 3.95 and 0.03, respectively. In addition, a mean stem density of 667 ± 19 stems $ha^{-1}$ and a basal area of 13.11 ± 0.34 $m^2$ $ha^{-1}$ were obtained. Twenty-three stumps (7 ± 3 $ha^{-1}$ stems) with a mean baseline area of 0.24 ± 0.09 $m^2$ $ha^{-1}$ stumps were removed, indicating ongoing anthropogenic disturbances in the forest. Other indicators of disturbance recorded were damage from fire (50%), paths / roads (13%), silage (8%), lumber/planks/pile harvesting (8%), cultivation (5%) and logging ( 8%). Although NSFR has a decent species richness and is well-diversified, there has been a consistently negative change in forest cover concerning low trunk density, average tree height, average DBH, and basal area, indicative of anthropogenic disturbance. Conservation measures are recommended to improve governance and accountability regarding accountability for intensive forest resource management.

**Keywords:** Composition, human activities, Ngarama Southern Forest Reserve, woody plant

## INTRODUCTION

Tanzania has about 48.1 million hectares (ha) of forest cover, of which 93% is forest and only 7% is classified as forest (mangroves, coastal forests, montane rainforests, and plantations) (NAFORMA 2015). About 3.5% is coastal forest covering an area of 0-150 km along the Indian Ocean coastline, and 0.3% is mangrove covering the area along the Indian Ocean coastline (FAO 2007, 2012; IPPC 2011). Currently, statistics show that in Tanzania, there are at least 70 000 hectares of coastal forest scattered on the inland coastal strip from 0 to 150 km from the Indian Ocean (Burgess et al. 2003). Coastal forests are generally 0-50 m and 300-500 m above sea level, but other locations are more than double this upper limit, where they begin to transition to submontane forests (Burgess et al. 2003, 2011; Sumbi et al. 2003).

In Tanzania, along with these areas, more than 66 coastal forests come under different forms of protection (Kibet 2011). There is currently only one coastal forest in a national park and 41 forests managed by Tanzania Forest Services and the local government (Burgess and Clarke 2000; Dickinson et al. 2010). Two forests are under the game reserve, and three are under private land (Burgess and Muir 1994). There are 21 forests that do not have a formal status; although some have started to publish a participatory forest management program, their total number is not well known. (Howell and Msuya 2002).

Clarke et al. (2011) reported that pressure on fresh farmland, along with an ever-increasing demand for charcoal, stakes, firewood, and uncontrolled bushfires, pose a threat to the existence of these forests, particularly those in southeastern Tanzania and most of the remaining areas of the East African coastal forest as a whole. Consequently, these disturbances have contributed to the loss of biodiversity, as well as the emission of greenhouse gases such as carbon dioxide, which over time contribute to global climate imbalance and, ultimately, climate change (Paavola 2003; Dallu 2004; Dickinson et al. 2010; Godoy et al. 2011).

Efforts to conserve these forests have been hampered by the lack of reliable data on flora and fauna present in these areas. In addition, most biological surveys conducted in coastal forests have been highly uneven and selective. For example, in Tanzania, most of these surveys have been conducted on the country's northern coast, leaving much of the forest in southeastern Tanzania almost unsurveyed, despite the available evidence that these areas have levels of floristic endemism higher than any other. Along the coast (Prins and Clarke 2006). *Erythrina schliebenii* is a good example of endemism detected in the coastal forests of Tanzania. Formerly classified as extinct in 1998 (Lovett et al. 2006), it was rediscovered in 2001 and confirmed in

May 2011 in the Namatimbili forest in Kilwa, in the Lindi region of Southern Tanzania (Clarke et al. 2011).

The objectives of this research were (i) to determine the species richness and diversity of NSFR. (ii) Determination of NSFR vegetation structure in basal area and stem density. (iii) Assess the intensity and distribution of human activities within the NSFR. (iv) Assess land cover change in the NSFR over the past 20 years.

## MATERIALS AND METHODS

### Description of the study area

This study was conducted in the Ngarama Southern Forest Reserve (NSFR), located in the Kilwa District of the Lindi region of Southeastern Tanzania (Figure 1). The forest reserve was established with the Government Notice n. 300 of 12/09/1955. It is located between latitudes 9°3'S-9°33'S and 39°23'E-39°26'E with an area of 2,070 hectares (Prins and Clarke 2006; Howell et al. 2012). It borders the village of Kiranjeranje on the northeast side and the village of Makangaga on the southwest side (Burgess et al. 2011). The inhabitants of these villages belong to the Ngindo, Matumbi, Mwera, and immigrants like Sukuma and Nyasa. Most villagers are farmers who own plots of land ranging from two to five acres. The size of their families varies, with an average of six to seven members per family or even more. They mainly grow subsistence crops such as maize, coconut, sorghum, pigeon peas, and beans (Perkin et al. 2008b).

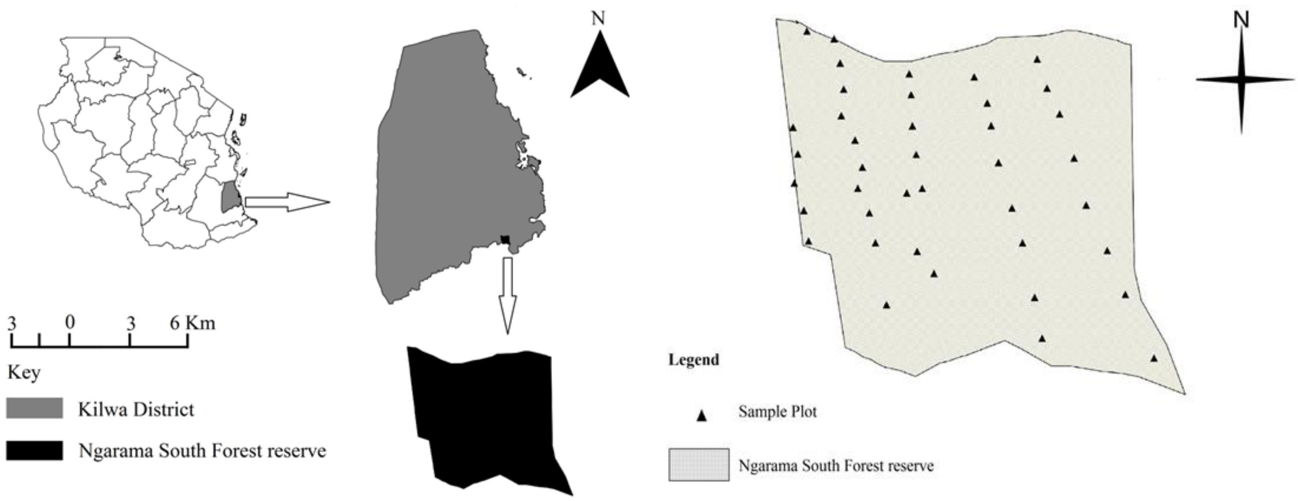
Kilwa District has a coastal, hot, and humid climate with an average temperature between 22ºC and 30ºC. Humidity is high, nearly 98-100%, during long rains (Dickinson et al. 2010). The district receives a total rainfall of 800-1400 mm $yr^{-1}$, and its distribution varies by location. The period of precipitation coincides with the start of each monsoon, with the long rains starting from mid-February to April and the short rains from late October to December.

### Data collection

*Vegetation survey*

The field study was conducted in November 2013. A systematic sample design was adopted as it increases the likelihood of including all vegetation types in the forest (Burgess and Muir 1994; Sutherland 2006). Five transects were established from the forest boundary, with the long axis running through the entire forest reserve, guided by a compass and a global positioning system (GPS). The start, endpoints, and textures were geotagged using GPS for mapping purposes.

With a sampling intensity of 0.15%, 40 rectangular test plots were set up along the transects. The distance between the plots in the same transept was 400 m and 1 km from one transept to another (Figure 1B). Rectangular plots were used because they are easy to identify, more accurate in area determination, and more than 10% of species can be recorded than square ones (Sutherland 2006; Jayakumar et al. 2011). This type of plot is also compared to previous studies in this forest. Therefore, three-level test plots (nested plots) adopted by Kibet (2011) and Howell et al. (2012) were used, including plots of 20 m x 40 m (0.08 ha) for woody plant species with a diameter of 10 cm, 10 m x 20 m (0.02 ha parcels) nested in 0.08 ha parcels for plants with a diameter of 10> DBH ≥ 5 cm and 1 m x 2 m (0.002 ha parcels) nested in parcels of 0.02 ha for regenerants and all trees/shrubs with 5> DBH ≥ 1 (Figure 2).




A B

**Figure 1.** A. Map of Kilwa District showing the location of Ngarama Southern Forest Reserve (NSFR) in Tanzania. B. Sketch map of NSFR showing the distribution of the sample plots

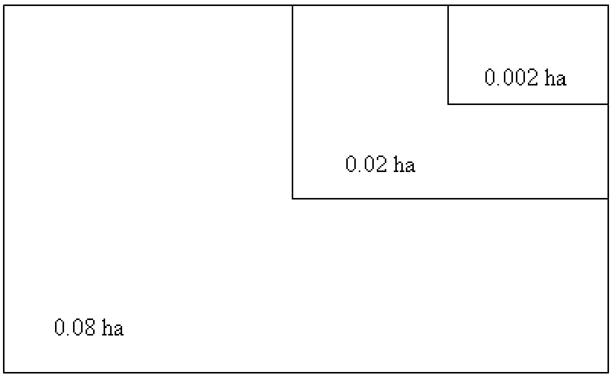



**Figure 2.** Three-level rectangular sample plots (nested plot) used in this study

The information recorded from each sample plot included: the name of all trees/shrubs measured (local and scientific names), diameter at breast height (DBH) for trees/shrubs 5 cm in diameter and above, and the height of selected sample trees (small, medium, large) and location of property based on GPS measurements. In addition, trees and shrubs were identified in the field to the species level. For those difficult to identify in the field, samples were collected and identified by a botanist from the Tanzania Forestry Research Institute (TAFORI) in Morogoro. The assistant researcher, who was local and knowledgeable in plant identification, provided local names.

*Intensity and distribution of human disturbance*

The intensity and distribution of human disturbance were recorded, according to Doggart (2006). The degree of disturbance was assessed based on the number of accidents within a test plot of 0.08 ha. In this study, felled trees and poles were described as "old felled" if there was any sign of blackening the stump and as "just felled" otherwise. All strains were measured by strain diameter and identified to the species level. Other indicators of human disturbance considered were areas highlighted by the presence of burned trees and ground vegetation. These areas were called "fire damage ."Another type of disturbance was areas cleared for pit sawing operations, with a pit sawing platform in the area or remnants of such parts. These areas were called "Pitsaw ."Sawn lumber, sawn planks, or poles that lay on the ground ready for transport have been described as "wood/planks/poles."Animal traps of any kind, whether adjustable or spring-loaded, were called "trapping ."Evidence of agriculture (past or present) has been referred to as "development," all paths used by humans as "trails" and, as a result of human intervention, well-established clearings in the forest (mostly short grasslands, possibly older stands) have been referred to as "cleansing". Once found in each plot, those types of ailments were recorded and counted.

*Land cover changes in Ngarama Southern Forest Reserve*

Mapping was done using forest cover images available on the Internet (Table 1). The objective was to obtain the current images taken during the dry season (June-October) and with minimal cloud cover. Therefore, three images from 1995, 2000, and 2011 were used to achieve the purpose of the study. Current images, i. H beyond 2011, however, was not available.

In addition, ground-truthing was performed to verify and modify land cover during preliminary imagery interpretation. GPS was used to locate samples of land cover observations, while digital cameras recorded photos of features such as water bodies, infrastructure, habitats, and forest use. All scanned GPS points were recorded as waypoints on reservation paper and numbered with a photo. Information is used to increase the accuracy of the satellite imagery interpretation and mapping process. Local people have also been involved with the team to provide information on boundaries, land cover history, and land use, particularly over the past 20 years. Drilling was performed during the dry season (November 2013) to access all areas that may be inaccessible during the rainy season.

**Data analysis**

*Vegetation survey data*

The following measurements were analyzed using the Microsoft Excel program and Biodiversity R software for statistical and quantitative analysis. First, species composition was expressed by species richness, diversity, and importance value index (IVI). Second, forest density was expressed by mean tree diameter, mean tree height, mean trunk density, and basal area for all trees with the following diameter classes (5 DBH <20 cm, 20 cm ≤ DBH <50 cm, and ≥ 50 cm). Third, IVI's were calculated as the mean of the relative basal area, density, and frequency (Malimbwi 2009; Tavankar and Bonyad 2015). Ecologically, the density and frequency of a species measure the distribution of a species within the population, while the basal area measures the area occupied by tree stems.

**Table 1.** Landsat images used in the analysis of land cover changes of NSFR

| Image | Path/row | Acquisition date | Season | % Cloud |
|---|---|---|---|---|
| LANDSAT 5 | 165 / 067 | 02-June-1995 | Dry | 0 |
| LANDSAT 7 | 165 / 067 | 22-June-2000 | Dry | 0 |
| LANDSAT 5 | 165 / 067 | 17-Aug-2011 | Dry | 0 |

Species diversity was calculated using the Shannon-Wiener and Simpson diversity indices. The Shannon-Wiener diversity index was calculated as (H' = SPi*ln Pi), where H' is the diversity index and Pi is the importance value of a species relative to all species. Simpson's diversity index was calculated as C = SP2i, where C is the index number and Pi is defined above (Sutherland 2006; Rands et al. 2010). Knowledge of species diversity is useful in determining the influence of the biotic disturbance and the state of succession and stability in the environment. This biodiversity index increases with the number of species in the community (Armstrong et al. 2011). In addition, data on human disorders were organized using Microsoft Excel software using simple descriptive statistics, listed, tabulated, and ordered by their number of occurrences.

*Land cover change in Ngarama Southern Forest Reserve*

Methods for image analysis combined both visual and digital image processing (ILWIS 2001). Before image processing, image layers/bands were rectified, georeferenced, and enhanced using the GPS reading obtained from the field. Then the image layers/bands were stretched and filtered. All image processing and subsequent image analysis using Quantum GIS Desktop (1.8.0) and ILWIS Academic software Version 3.3. Often, image files contain areas much larger than a particular study area. Therefore, the image file was reduced to include only the area of interest (AOI). This eliminates the extraneous data in the file and speeds up processing due to the smaller amount of data to process (ILWIS 2001; Kashaigili et al. 2006).

The supervised classification process involved selecting training sites on the image, which represented specific land classes to be mapped. Training sites are sites of pixels that represent specific land classes to be mapped (Kashaigili and Majaliwa 2010). They are pixels representing what we're recognized as a potential land cover class during ground-truthing. The training sites were generated by on-screen digitizing selected areas for each land cover class identified on color composite. Training is an iterative process; basically, it is a visual tool that gives an overview of where the classes will be assigned in the image and whether additional classes are required (Kashaigili and Majaliwa 2010).

Training samples were refined until satisfactory results were obtained based on the inspection of results. The objective was to produce thematic classes that resemble or can be related to actual land cover types on the earth's surface. The advantage of digital image classification is that it can provide efficient, consistent, and repeatable routines for mapping large areas (Kashaigili and Majaliwa 2010). Classified images were recorded to respective classes (i.e., forest, woodland, and grassland). Following the recording, images were filtered using a 3 x 3 majority-neighborhood filter to eliminate patches smaller than a specified value and replace them with the most common value among the neighboring pixels. A mosaic operation was performed on multiple classified images to produce one map for the entire study area. Change detection is a very common and powerful application of satellite-based remote sensing. Change detection analysis entails findings on the type, amount, and location of land-use changes that are taking place (Kashaigili and Majaliwa 2010). This study used a post classification comparison method to assess land use and cover changes. The advantage of post-classification comparison is that it bypasses the difficulties associated with analyzing images acquired at different times of the year and by different sensors (Kashaigili et al. 2006). The method is the most suitable for detecting land cover changes as this enables estimation of the amount, location, and nature of change. The estimation for the rate of change for the different covers was computed based on the following formulae.

Percentage Cover change $= \frac{\text{Area}_{i\ \text{year}\ x} - \text{Area}_{i\ \text{year}\ x+1}}{\sum_{i=1}^{n} \text{Area}_{i\ \text{year}\ x}} \text{ x } 100\%.$

The annual rate of change $= \frac{\text{Area}_{i\ \text{year}\ x} - \text{Area}_{i\ \text{year}\ x+1}}{t_{\text{years}}}$

Percentage Annual rate of change $= \frac{\text{Area}_{i\ \text{year}\ x} - \text{Area}_{i\text{year}x+1}}{\text{Area}_{i\ \text{year}\ x} x t_{\text{years}}} \text{x}100\%.$

Where;
Area $_{i\ year\ x}$ = area of cover i at the first date.
The area $_{i\ year\ x+1}$ = area of cover i at the second date.
$\sum_{i=1}^{n} \text{Area}_{i\ \text{year}\ x}$ = total cover area at the first date.
$t_{years}$ = years between the first and second scene acquisition dates.

## RESULTS AND DISCUSSION

### Species richness

This study identified 126 plant species with 79 tree species and 47 shrub species from 34 families in the NSFR (Tables 2, 3). Trees contributed 63% (28 families), and shrubs 37% (17 families). Plant species of the Fabaceae family contributed the most (26%) to the total number of species, followed by those of the Combretaceae (9%), Euphorbiaceae (8%), Rubiaceae (6%), and the Tiliaceae (5%) families. The families with the highest number of tree species in descending order were Fabaceae (27), followed by Euphorbiaceae (6), Combretaceae (6), and Malvaceae (4). Among shrub species, the most dominant families were Tiliaceae (6), Fabaceae (6), Rubiaceae (6), Combretaceae (5), and Euphorbiaceae (4) (data not shown).

The species accumulation curve (Figure 3) shows that the graph increases at a high rate, and as the number of plots increases, the increase becomes smaller and smaller. At 40 plots, the graph has not yet reached its asymptotic level but is beginning to converge, implying that any further increase in sample size should include other rare species.

**Table 2.** Average stem density (stem ha$^{-1}$) of tree and shrub species recorded in NSFR

| Trees species | Density (Stem/ha) |
|---|---|
| *Hymenocardia ulmoides* Oliv | 58 |
| *Spirostachys africana* Sond | 53 |
| *Markhamia lutea* (Benth.) K. Schum | 33 |
| *Isoberlinia globiflora* (Benth.) Hutch. ex Greenway | 32 |
| *Pseudolachnostylis maprouneifolia* Pax | 24 |
| *Combretum molle* (Klotzsch) Engl. & Diels | 24 |
| *Terminalia mollis* M. A. Lawson | 20 |
| *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth. | 18 |
| *Diplorhynchus mossambicensis* Benth. ex Oliv. | 16 |
| *Pteleopsis myrtifolia* (M. A. Lawson) Engl. & Diels | 16 |
| *Combretum collinum* Fresen | 15 |
| *Brachystegia boehmii* Taub | 12 |
| *Dalbergia melanoxylon* Guill. & Perr | 10 |
| *Hymenocardia mollis* Pax | 10 |
| *Tamarindus indica* L | 9 |
| *Lannea stuhlmannii* (Engl.) Engl | 9 |
| *Acacia robusta* Burch | 8 |
| *Stereospermum kunthianum* Cham | 8 |
| *Terminalia sambesiaca* Engl. & Diels | 8 |
| *Combretum zeyheri* Sond | 8 |
| *Acacia nigrescens* Oliv. | 7 |
| *Carpodiptera africana* Mast | 7 |
| *Ochna holstii* Engl | 7 |
| *Bridelia cathartica* Bertol | 7 |
| *Xeroderris stuhlmannii* (Taub.) Mendonça & E. C. Sousa | 5 |
| *Lonchocarpus capassa* Rolfe | 5 |
| *Diospyros kirkii* Hiern | 4 |
| *Albizia harveyi* E. Fourn. | 4 |
| *Oxystigma msoo* Harms | 4 |
| *Diospyros mespiliformis* Hochst. ex A. DC. | 4 |
| *Commiphora eminii* Engl. | 4 |
| *Bombax rhodognaphalon* K. Schum | 4 |
| *Lonchocarpus eriocalyx* Harms | 3 |
| *Afzelia quanzensis* Welw. | 3 |
| *Dombeya acutangula* Cav | 3 |
| *Cylicomorpha parviflora* Urb. | 3 |
| *Erythroxylum emarginatum* Thonn. | 3 |
| *Lecaniodiscus fraxinifolius* Baker | 2 |
| *Dobera loranthifolia* (Warb.) Harms | 2 |
| *Lonchocarpus bussei* Harms | 2 |
| *Balanites aegyptiaca* (L.) Delile | 2 |
| *Diospyros abyssinica* (Hiern) F. White | 2 |
| *Terminalia sericea* Burch. ex DC. | 2 |
| *Julbernardia globiflora* (Benth.) Troupin | 2 |
| *Dalbergia nitidula* Baker | 2 |
| *Deinbollia borbonica* f. glabrata Radlk. | 2 |
| *Dombeya rotundifolia* (Hochst.) Planch | 2 |
| *Euphorbia candelabrum* Trémaux ex Kotschy | 1 |
| *Pterocarpus rotundifolius* (Sond.) Druce | 1 |
| *Dalbergia boehmii* Taub | 1 |
| *Boscia salicifolia* Oliv | 1 |
| *Ehretia silvatica* Gürke | 1 |
| *Sclerocarya birrea* (A. Rich.) Hochst. | 1 |
| *Pterocarpus chrysothrix* Taub | 1 |
| *Haplocoelum inoploeum* Radlk | 1 |
| *Albizia lebbeck* (L.) Benth | 1 |
| *Acacia goetzei* Harms | 1 |
| *Sterculia quinqueloba* (Garcke) K. Schum | 1 |
| *Ricinodendron gracilius* Mildbr | 1 |
| *Schrebera alata* (Hochst.) Welw | 1 |
| *Adansonia digitata* L | 1 |
| *Pterocarpus angolensis* DC. | 1 |
| *Cassine aethiopica* Thunb | 1 |
| *Markhamia obtusifolia* (Baker) Sprague | 1 |
| *Lannea fulva* (Engl.) Engl. | 1 |
| *Piliostigma thonningii* (Schumach.) Milne-Redh | 1 |
| *Milicia excelsa* (Welw.) C.C. Berg | 1 |
| **Shrubs species** | |
| *Strychnos spinosa* Lam. | 22 |
| *Diospyros kabuyeana* F. White | 13 |
| *Grewia bicolor* Juss | 11 |
| *Commiphora africana (*A. Rich.) Engl | 11 |
| *Combretum adenogonium* Steud. ex A. Rich | 9 |
| *Bauhinia petersiana* Bolle | 7 |
| *Dichrostachys cinerea (L.)* Wight & Arn | 7 |
| *Catunaregam spinosa* (Thunb.) Tirveng | 6 |
| *Millettia dura* Dunn | 5 |
| *Allophylus rubifolius* (Hochst. ex A. Rich.) Engl | 5 |
| *Uvaria welwitschii* (Hiern) Engl. & Diels | 5 |
| *Ehretia stuhlmannii* Gürke | 5 |
| *Canthium oligocarpum* Hiern | 4 |
| *Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don | 3 |
| *Ehretia amoena* Klotzsch | 3 |
| *Grewia platyclada* K. Schum | 3 |
| *Spermacoce assurgens* Ruiz & Pav. | 3 |
| *Acacia hockii* De Wild | 3 |
| *Grewia similis* K. Schum | 2 |
| *Ptaeroxylon obliquum* (Thunb.) Radlk | 2 |
| *Manilkara mochisia* (Baker) Dubard | 2 |
| *Maytenus lancifolia* (Thonn.) Loes. | 2 |
| *Lannea humilis* (Oliv.) Engl. | 2 |
| *Strychnos innocua* Delile | 2 |
| *Margaritaria discoidea* (Baill.) G.L. Webster | 2 |
| *Diospyros fischeri* Gürke | 1 |
| *Ziziphus mucronata* Willd. | 1 |
| *Rytigynia uhligii* (K. Schum. & K. Krause) Verdc | 1 |
| *Antidesma venosum* E. Mey. ex Tul. | 1 |
| *Combretum schumannii* Engl | 1 |
| *Grewia holstii* Burret | 1 |
| *Suregada zanzibariensis* Baill | 1 |
| *Combretum padoides* Engl. & Diels | 1 |
| *Grewia trichocarpa* Hochst. ex A. Rich | 1 |
| *Zanthoxylum chalybeum* Engl | 1 |
| *Sericanthe odoratissima* (K. Schum.) Robbr | 1 |
| *Erythrococca kirkii* (Müll. Arg.) Prain | 1 |
| *Grewia monticola* Sond | 1 |
| *Rotheca myricoides* (Hochst.) Steane & Mabb | 1 |

**Table 3.** Richness, diversity, and stem density of woody plant species in NSFR

| Parameter | Values |
|---|---|
| Sample size (n) | 40 |
| Richness (total number of species) | 126 |
| Mean tree height (m) | 8.7 |
| Mean tree diameter (cm) | 13.1 |
| Mean stem density (stems ha$^{-1}$) | 667±19 |
| Basal area (m$^2$ ha$^{-1}$) | 12.78±0.34 |
| Shannon's index | 3.95 |
| Simpson's index | 0.03 |

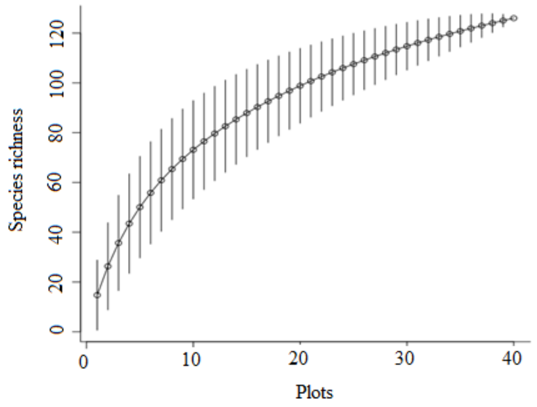



**Figure 3.** Species accumulation curve of trees/shrubs sampled in NSFR

## Species diversity

Species diversity according to the Shannon-Wiener and Simpson indices in the NSFR is shown in Table 3 and Figure 4. Species that contributed to the high species diversity according to the Shannon-Wiener index included *Spirostachys africana* (0.185), *Pseudolachnostylis maprouneifolia* (0.163), *Isoberlinia globiflora* (0.162), *Crossopteryx febrifuga* (0.151) and *Terminalia mollis* (0.150). In terms of frequency of occurrence of individual trees and shrubs, *Hymenocardia ulmoides* was the most common species, with 9% of the 126 species, followed by *S. africana* (8%), *Markhamia lutea* (5%), and *I. globiflora* (5%). ). According to the IVI, *S. africana* (2.78) was the most dominant species, followed by *P. maprouneifolia* (2.28), *I. globiflora* (2.25), *C. febrifuga* (2.02), *T. mollis* (2) and *Combretum molle* (1.47). *Brachystegia spiciformis* and *Diospyros squarrosa* were the least important species because they had a small IVI (Figure 4).

## Vegetation structure

The average stem density in the NSFR was 667 ± 19 stems $ha^{-1}$, with the stem density for shrubs being 165 ± 8 stems $ha^{-1}$ and the stem density for trees being 503 ± 11 stems $ha^{-1}$ (Tables 2 and 3). Among trees, the most common tree species was *H. ulmoides* (11% of 503 stems $ha^{-1}$), followed by *S. africana* (11%), *Pteleopsis myrtifolia* (10%), *M. lutea* (7%), *I. globiflora* (6%) and *P. maprouneifolia* (5%). Among shrubs, the most abundant shrub species were *Strychnos spinosa* (13% of 165 stems $ha^{-1}$), followed by *Diospyros kabuyeana* (8%), *Grewia bicolor* (7%), and *Commiphora africana* (6%). The stem density of trees/shrubs with a diameter of 5-20 cm was 565 ± 18 stems $ha^{-1}$, while those with a diameter of 20-50 cm were 99 ± 3 stems-$ha^{-1}$, and those with a diameter > 50 cm 3 ± 0 were strain $ha^{-1}$ (Figure 5).

The total basal area of the NSFR was 12.78 ± 0.34 m² $ha^{-1}$, the basal area of shrubs was 2.7 ± 0.21 m² $ha^{-1}$, and that of trees was 10.4 ± 0.18 m² $ha^{-1}$ (Table 3, Figure 6). *S. spinosa* (26%), followed by *C. africana* (11%), *G. bicolor* (5%), and *Spermacoce assurgens* (4%) were the shrub species that contributed the most to the footprint. The species that contributed most to the basal area for tree species were *S. africana* (8%), *I. globiflora* (6%), *Dalbergia melanoxylon* (6%), *P. maprouneifolia* (5%) and *H. ulmoides* (4%). The base area of trees/shrubs with a diameter of 5-20 cm was 5.3 ± 0.15 m² $ha^{-1}$, while those with a diameter of 20-50 cm were 6.1 ± 0.17 m² $ha^{-1}$ and those with a diameter> 50 cm 1.7 ± 0.23 m² $ha^{-1}$ (Figure 6).

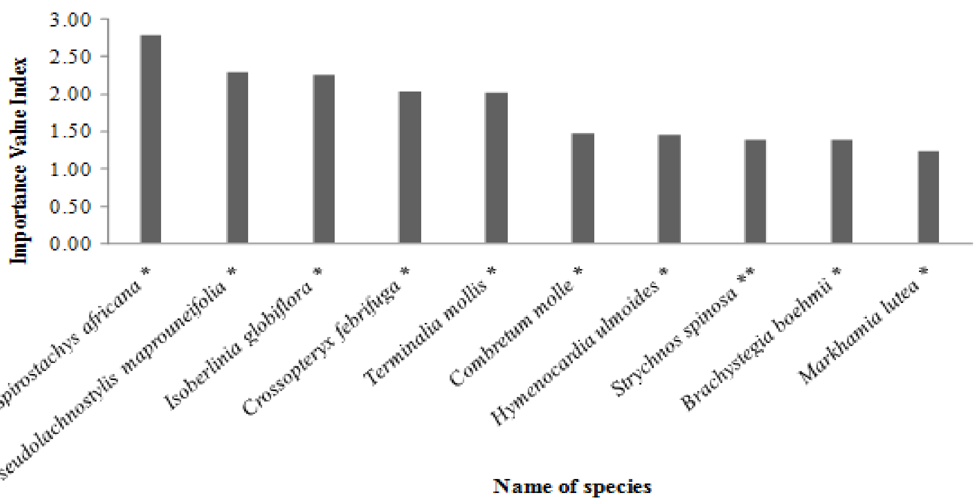



**Figure 4.** Species diversity according to Importance Value Index (IVI) in NSFR. ** = shrubs and * = trees)

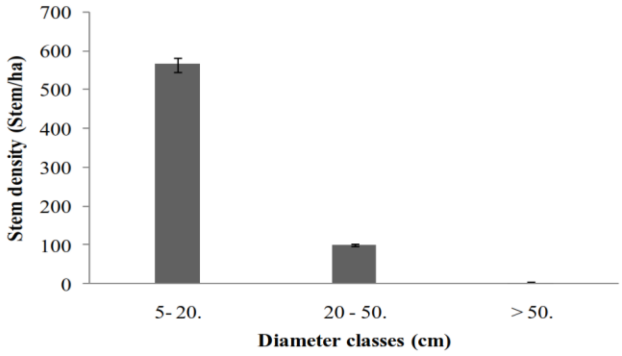



**Figure 5.** Stem density of woody plant species in NSFR, Tanzania

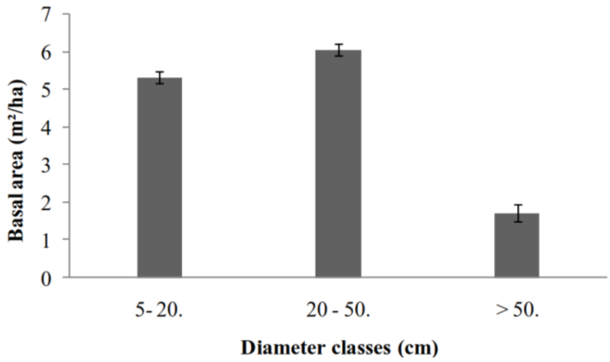



**Figure 6.** Basal area of woody plant species in NSFR, Tanzania

**Intensity and distribution of human disturbance**

The number of strains recorded in the NSFR was 23, corresponding to 7 ± 3 strains $ha^{-1}$, with an average footprint of 0.24 ± 0.09 $m^2$ $ha^{-1}$ (Figure 7). New sections were 78%, and 22% were old sections. In terms of frequency, *S. africana* seems to be harvested most frequently, accounting for 56% of all strains, followed by *Allophylus rubifolius* (17%), *Grewia platyclada* (09%), *D. melanoxylon* (09%) and the rest (09%). *Terminalia sambesiaca* and *Carpodiptera africana*. All other forms of anthropogenic disturbance in the sample plots were observed in this study, with 51% being fire damage, 13% being paths or roads, 8% being hole saws, 8% being wood/planks/piles, and 5% being trapping sites, 5% was cultivation and 8% deforestation (Figure 8).

**Land cover change in Ngarama Southern Forest Reserve**

Land cover maps for 1995, 2000, and 2011 are shown in Figure 9. The figure shows the variation in forest cover between the three periods considered. The coverage of each land cover/use class in 1995, 2000, and 2011, including area and percent change in the area between the three periods for the NSFR, is shown in Tables 4 and 5. 1995 to 2000, forest and forest cover classes increased by +15.9 ha $yr^{-1}$ (+1% $yr^{-1}$) and +12.6 ha $yr^{-1}$ (+3% $yr^{-1}$), respectively, while grass cover decreased at a rate of -28.5 ha $yr^{-1}$ (-7% $yr^{-1}$). From 2000 to 2011, the area of grassland and forest increased at a rate of +32.1 ha $yr^{-1}$ (+13% $yr^{-1}$) and +43.2 ha $yr^{-1}$ (+8% $yr^{-1}$ ), respectively, while forest area increased and decreased at a rate of -75.4 ha $yr^{-1}$ (-4% $yr^{-1}$). In general, the NSFR experienced notable changes in land cover during the years 1995-2000 and 2000-2011, during which forest cover areas were severely degraded from 68% (1995) to 39% (2011), and forest and grass cover was noted. continuously increased from 15% or 17% (1995) to 23% or 38% (2011).

**Discussion**

*Floristic composition*

Defining an optimal sample size is based on the idea that the larger the sample size, the larger the number of species in the sample, but the rate of increase becomes smaller and smaller, so the curve tends to be a flat line (Rands et al. 2010). The point at which the curve becomes horizontal is the minimum area representing the plant community (Sutherland 2006). This concept assumes that the plant community is a spatially discrete entity with a fixed species composition. It is particularly difficult to identify community boundaries in tropical forests, and due to their high species richness, species accumulation curves do not flatten even with large samples (Sutherland 2006; Rands et al. 2010). Thus, the species accumulation curve shows that at 40 plots, the graph has not yet reached its asymptotic level, but it is beginning to converge. This implies that 40 sites/plots used in this study were sufficient to cover much of the variation and species diversity of the study area. Any further increase in sample size would likely result in the inclusion of additional rare species.

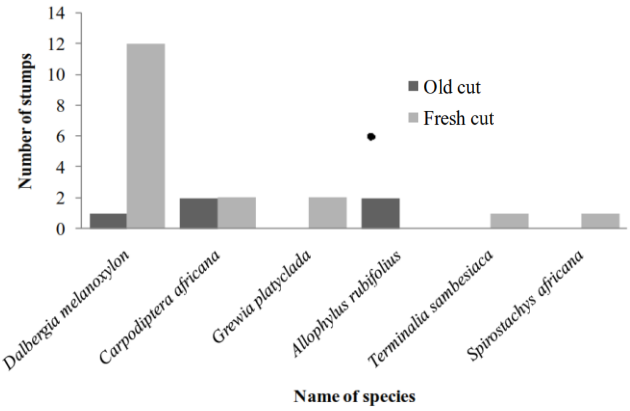



**Figure 7.** Quantity of old cut and fresh-cut stumps recorded in NSFR

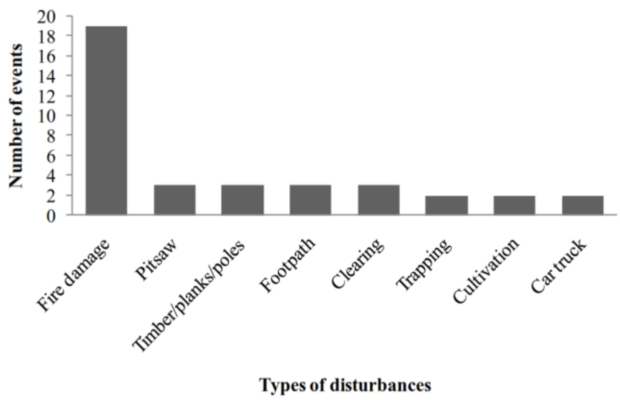



**Figure 8.** Types of disturbance observed in NSFR

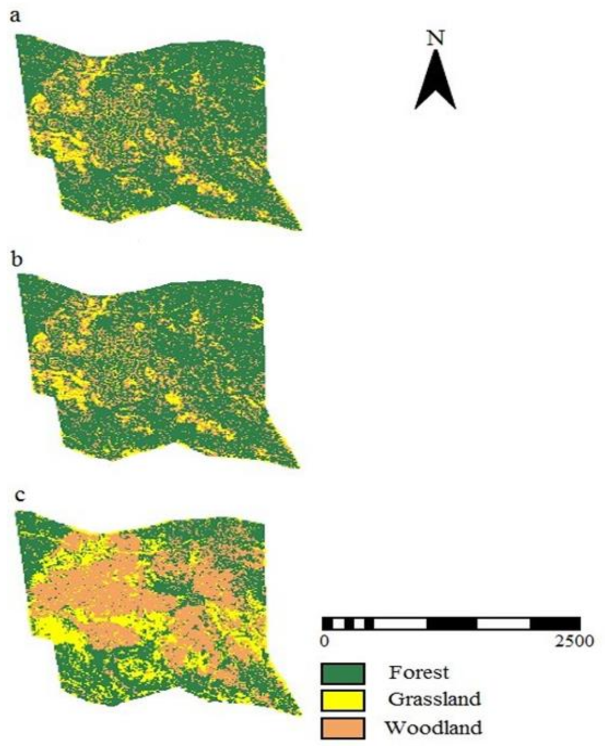



**Figure 9.** Classified land cover map of (a) 1995, (b) 2000, and (c) 2011 of NSFR

The species composition found in the NSFR, based on the predominance of species of the Euphorbiaceae and Fabaceae families, agrees well with previous descriptions of coastal forests belonging to the mixed scrub type of the coastal forest community. Characterized by the rare dominance of a species and with the most common species such as *H. ulmoides*, *P. myrtifolia*, *Bombax rhodognaphalon*, *Afzelia quanzensis*, and genera such as *Albizia*, *Combretum*, *Diospyros*, *Grewia*, and *Strychnos* found well in the forest composition of NSFR and Clarke Burgess (Burgess et al. 2003, 2011; Godoy et al. 2011). The high species richness in the study area is probably attributed to the presence of riparian forests along the Mbwemkulu River, which contributes to the growth of many species (Burgess et al. 2003). The Shannon-Wiener (H') diversity index indicates species richness and evenness, where the higher the H' value, the greater the species diversity and vice versa (Rands et al. 2010 ). An ecosystem with an H' value greater than 2 is considered species-rich (Rands et al. 2010). Thus, with a Shannon-Wiener diversity index (H') of 3.95, NSFR exhibits high species diversity. Munishi et al. (2011) reported that the higher the Simpson's Index value, the lower the species diversity and vice versa, from 0 to 1. The Simpson's Index value of 0.03 (Table 3) in the NSFR implies that the probability of selecting two individuals belonging to the same species is very low or the probability that a species encountered by chance is a different species (Prins and Clarke 2006; Dickinson et al. 2010 ). So having that index shows that the plant species found in NSFR are more equally diverse.

*Forest structure*

Forest structure usually refers to tree characteristics distributed within a forest ecosystem (Sutherland 2006; Rands et al. 2010). The forest structure results from natural processes, such as growth, mortality, recruitment of plant species, and natural disturbances, such as damage from fire, wind, or snow (Godoy et al. 2011). However, the state of most coastal forest ecosystems today is the result of human interventions such as clearcutting, deforestation, and fire damage, which often results in altered ecosystems with novel species compositions and structures (Burgess et al. 2011; Godoy et al. 2011). Characterized by various structural characteristics such as low trunk density, small basal area, low average shaft height, and small average shaft diameter. To explain this, Burgess and Clarke (2000) described some forests affected by a range of human ailments, the most common of which in terms of the affected area were fire damage, pile-up, logging, and burning of the coal (Table 6).

**Table 4.** Cover area, changing area, and the rate of change between 1995 and 2000

| Cover class | 1995 | | 2000 | | Change area (ha) | % Change | Annual rate of change (ha $yr^{-1}$) | % Annual rate of change (% $yr^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | Cover area (ha) | % Cover coverage | Cover area (ha) | % Cover coverage | | | | |
| Forest | 1,770.84 | 68% | 1,850.31 | 71% | 79.47 | 3% | 15.894 | 1% |
| Grassland | 380.61 | 15% | 238.32 | 9% | -142.29 | -5% | -28.458 | -7% |
| Woodland | 453.96 | 17% | 516.78 | 20% | 62.82 | 2% | 12.564 | 3% |
| | 2,605.41 | 100% | 2,605.41 | 100% | | | | |

**Table 5.** Cover area, changing area, and the rate of change between 2000 and 2011

| Cover class | 2000 | | 2011 | | Change area (ha) | % Change | Annual rate of change (ha $yr^{-1}$) | % Annual rate of change (% $yr^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | Cover area (ha) | % Cover coverage | Cover area (ha) | % Cover coverage | | | | |
| Forest | 1,850.31 | 71% | 1,021.41 | 39% | -828.9 | -32% | -75.35 | -4% |
| Grassland | 238.32 | 9% | 591.66 | 23% | 353.34 | 14% | 32.12 | 13% |
| Woodland | 516.78 | 20% | 992.34 | 38% | 475.56 | 18% | 43.23 | 8% |
| | 2,605.41 | 100% | 2,605.41 | 100% | | | | |

**Table 6.** Structural parameters of the forest sites with a known history of disturbance

| Site | Plot area (ha) | Sample size (n) | Mean tree height (m) | Mean tree DBH (m) | Mean stem density (trees/ha) | Stem density/ha by DBH class | | | Basal area ($m^2$/ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 10 - 20 (cm) | 20 - 50 (cm) | > 50 (cm) | |
| Gendagenda B* | 0.03 | 15 | 14 | 0.277 | 500 | 267 | 200 | 33 | 30.1 |
| Namakutwa 1* | 0.16 | 88 | 15.2 | 0.226 | 550 | 331 | 181 | 38 | 22 |
| Kazimzumbwi 4* | 0.025 | 11 | 13.5 | 0.248 | 440 | 280 | 80 | 80 | 21.3 |
| Kazimzumbwi 2* | 0.075 | 40 | 9.9 | 0.204 | 533 | 373 | 133 | 27 | 16.4 |
| Kazimzumbwi 3* | 0.25 | 148 | 11.4 | 0.169 | 592 | 444 | 144 | 4 | 13.3 |
| Namakutwa 2* | 0.16 | 95 | 12.7 | 0.162 | 594 | 456 | 138 | 0 | 12.2 |
| Ruvu North* | 0.16 | 47 | 14.1 | 0.222 | 294 | 70 | 212 | 12 | 11.4 |
| Litipo 1* | 0.16 | 49 | 14.6 | 0.21 | 306 | 156 | 125 | 25 | 10.7 |
| Kilulu C* | 0.03 | 13 | 10.1 | 0.173 | 433 | 300 | 133 | 0 | 10.2 |
| Litipo 2* | 0.16 | 62 | 12.1 | 0.178 | 387 | 244 | 143 | 0 | 9.7 |
| Rondo Plantation* | 0.16 | 48 | 13.4 | 0.189 | 300 | 238 | 50 | 12 | 8.4 |
| Kazimzumbwi 1* | 0.25 | 93 | 9.9 | 0.167 | 372 | 300 | 24 | 48 | 8.2 |
| Namburika Hill* | 0.16 | 22 | 12.3 | 0.259 | 138 | 68 | 56 | 12 | 7.3 |
| Gendagenda C* | 0.03 | 10 | 10.3 | 0.16 | 333 | 267 | 67 | 0 | 6.6 |
| NSFR** | 0.08 | 40 | 8.7 | 0.131 | 667 | 565 | 99 | 3 | 13.1 |

Note: * Adopted from Burgess and Clarke (2000); **This study, 2013

To varying degrees, all forests affected by anthropogenic disturbance appeared to have a consistently significant impact on the forest structure of many coastal forest areas, such as relatively low trunk density and low average tree height and diameter. It is clear that anthropogenic disturbance causes a disturbance to the forest structure and changes the community composition of the forest (Godoy et al. 2011; Kibet 2011; Munishi et al. 2011). Based on the forest structure, the results in NSFR (Table 6 and Figure 6) with a significant number of strains and number of events from other forms of anthropogenic disturbance (Figures 7 and 8). This indicates that the large human disturbance is likely to affect the vegetation structure of NSFR and these disturbances remain detectable in the resulting forest physiognomy of NSFR.

Besides the relatively low trunk density, basal area, and few large-diameter trees, likely due to human encroachment, the trunk density distribution still reflects an inverted J shape common to natural forests with regeneration and active recruitment (Munishi et al. 2011). Accordingly, active regeneration and recruitment in the NSFR coastal forest, as presented in this study, bodes well for the sustainability of the forest stand, which is only likely to provide a sustainable supply of products and services if not subject to greater anthropogenic disturbance (Ahrends 2005; Dickinson et al. 2010; Giliba et al. 2011).

**Forest condition**

The results for the cover classes over an average period of 5 years (i.e., 1995 and 2000) (Tables 4, 5) show that two classes of forest and wooded cover at a rate of +15.9 ha $yr^{-1}$ (+1% $yr^{-1}$) and +12.6 ha $yr^{-1}$ (+3% $yr^{-1}$), with grass cover decreasing at the rate of -28.5 ha $yr^{-1}$ (-7% $yr^{-1}$). It is possible that the increase in forest cover is due to a reduction in forest disturbance due to poor infrastructure before the opening of the Mkapa Bridge over the Rufiji River in 2003 (Burgess and Clarke 2000). Furthermore, the limited technical capacity and a small population in the villages surrounding the study area had little impact on the forest and, therefore, a much lower impact on the condition of the forest reserve compared to other factors such as elephant damage and climate change impacts (Howell and Msuya 2002; Perkin et al. 2008b). The effects were also noted by Howell et al. (2012) described in their study when they found that the increase in forest cover was due to earlier exploration of gypsum mining activities in Makangaga village. Where mining machinery in the area destroyed vegetation by removing underground rock deposits in the southern part of the NSFR and nearby areas (Howell and Msuya, 2002). Fire is a major threat to coastal forests, including NSFR, as shown in Figure 8. Although forests are generally tolerant to low-temperature fires, most forest species are sensitive to and easily destroyed by fire (Maliondo et al. 2000; Howell et al. 2012). The fire intrusion opens the forest to widespread forest species, reducing habitats and their biodiversity values, both in terms of species diversity and strongly impacting species with restricted distribution patterns (Edwin 2004; Munishi et al. 2011). This may be the reason for the increase in forest cover, as shown in Table 4.

From 2000 to 2011 (Table 4), grassland and forest areas increased respectively by +32.1 ha $yr^{-1}$ (+13% $yr^{-1}$) and +43.2 ha $yr^{-1}$ (+8% $year^{-1}$ ), at Forest cover decreased at a rate of -75.4 ha $yr^{-1}$ (-4% $yr^{-1}$). This decline in forest cover is attributed to increased forest disturbance after the opening of the Mkapa Bridge and improved infrastructure, which has increased the pressure and risk of forest destruction and overexploitation in southern coastal areas of Tanzania (Ahrends 2005). Howell et al. (2012) and Mhache (2014) also pointed out that rapid population growth has led to strong demand for timber and non-timber products in Dar es Salaam, Zanzibar, Tanga, and the areas around NSFR. This results in a loss of forests due to the direct effects of human activities such as habitat destruction (deforestation), land-use change, invasive species, overexploitation, and indirect effects of human activities such as climate change (Howell et al. 2012). This observation is consistent with the findings of this NSFR study that fires, sawing, logging, and logging (Figure 8) were activities that likely led to a decrease in forest cover and an increase in forest and meadow cover over the past 20 years in this forest.

## Conclusion

The main objectives of this study were to assess the floristic composition, stand, and the impact of anthropogenic activities on the forest condition of the NSFR and to provide data that constitute a basis for the definition of appropriate protection strategies and monitoring in the forest. The NSFR coastal forest was found to have reasonably good tree/shrub composition and species richness. Additionally, the tree/shrub species identified as dominant and high-diversity fit quite well into the general definition of coastal forests, which belong to the mixed scrub forest community. On the other hand, the vegetation structure of NSFR is characterized by relatively low trunk density, low average tree height, low average tree diameter, small basal area, and a lack of large-diameter trees, suggesting that the forest is subject to anthropogenic disturbance and reckless use of the forest as a resource.

Moreover, the anthropogenic disturbance indicators observed in the forest suggest that human disturbances were the main factors affecting the vegetation structure of the forest. The study also showed that the NSFR had experienced notable changes in land cover over the past 20 years (1995-2011). If we compare the two periods (1995-2000 and 2000-2011), in the period 2000-2011, there have been greater variations in the coverage areas. Forest cover is severely affected; in particular, forest and grassland areas have been shown to continuously increase, indicating poor forest performance and the need to improve overall forest resources by controlling human disturbances and avoiding reckless use of forest resource boundaries to protect the integrity of the forest.

## REFERENCES


Ahrends A. 2005. Patterns of Degradation in Lowland Coastal Forests in Coast Region, Tanzania. [Dissertation]. University of Greifswald, German.

Armstrong AH, Shugart HH, Temilola E. 2011. Characterization of community composition and forest structure in a Madagascar lowland rainforest. Trop Conserv Sci 4 (4): 428-444. DOI: 10.1177/194008291100400406.

Burgess ND, Clarke GP. 2000. Coastal Forest of Eastern Africa. IUCN, Gland, Switzerland and Cambridge, UK.

Burgess ND, Harrison P, Sumbi P, Laizer J, Kijazi A, Salehe J, Malugu I, Komba R, Kinyau N, Kashindye A. 2011. Synthesis Document of Available Baseline Information on the Coastal Forests Protected Area Sub- system. WWF, Tanzania.

Burgess ND, Muir C. 1994. Coastal forest of Eastern Africa: Biodiversity and conservation. Proceedings of the Coastal Forests of Eastern Africa Workshop. University of Dar es Salaam, Tanzania, 9-11 August 1993.

Burgess ND, Doggart N, Doody K, Negussie G, Sumbi P, Perkin A. 2003. New information on the lowland coastal forests of eastern Africa. Oryx 37: 280-281.

Clarke GP, Burgess ND, Mbago FM, Mligo C, Mackinder B, Gereau RE, Hermitage T. 2011. Two “Extinct” trees rediscovered near Kilwa, Tanzania. J East Afr Nat Hist 100 (1-2): 133-140. DOI: 10.2982/028.100.0109.

Dallu A. 2004. A National Synthesis Report for the Preparation of EACFE Programme. The Coastal Forests of Tanzania. WWF, Tanzania.

Dickinson A, Burgess ND, Clarke GP. 2010. Tanzania Coastal Forest: Status and Biological Diversity. Frontier-Tanzania Coastal Forest Programme, Tanzania.

Doggart N. 2006. Filling the Knowledge Gap: Methods Manual. Tanzania Forests Conservation Group/ Museo Tridentino di Scienze Naturali. Dar es Salaam, Tanzania.

Edwin N. 2004. Fire in miombo woodlands: A case study of Bukombe District, Shinyanga, Tanzania. Community in Flames.

FAO. 2007. State of the World’s Forests 2007. Rome, Italy.

FAO. 2012. Building resilience for adaptation to climate change in the agriculture sector. In: Proceedings of a Joint FAO/OECD Workshop. Rome, Italy, 23-24 April 2012.

Giliba RA, Boon EK, Kayombo CJ, Musamba EB, Kashindye AM, Shayo PF. 2011. Species composition, richness and diversity in Miombo woodland of Bereku Forest Reserve, Tanzania. Biodivers J 2 (1): 1-7. DOI: 10.1080/09766901.2011.11884724.

Godoy FL, Tabor K, Burgess ND, Mbilinyi BP, Kashaigili JJ, Steininger MK. 2011. Deforestation and $CO_2$ emissions in coastal Tanzania from 1990 to 2007. Environ Conserv J 39 (1): 62-71. DOI: 10.1017/S037689291100035X.

Howell KM, Msuya CA, Mligo C, Werema C. 2012. Biodiversity Surveys of Poorly Known Coastal Forests of South-eastern Tanzania and Zanzibar. WWF, Tanzania.

Howell KM, Msuya CA. 2002. UTUMI Biodiversity Surveys Tanzania: Consultancy Report to Ornis Consult Based on Fieldwork Conducted in Southeastern Tanzania. DANIDA, Tanzania.

ILWIS. 2001. ILWIS 3.0 Academic: User's Guide. International Institute for Aerospace Survey and Earth Sciences (ITC), Netherlands.

IPPC. 2011. International Standards for Phytosanitary Measures ISPM 12: Phytosanitary Certificates. FAO, Italy.

Jayakumar S, Kim SS, Heo J. 2011. Floristic inventory and diversity assessment - a critical review. Proc Intl Acad Ecol Environ Sci 1 (3-4): 151-168.

Kashaigili JJ, Majaliwa AM. 2010. Integrated assessment of land use and cover changes in the Malagarasi river catchment in Tanzania. Phys Chem Earth 35: 730-741. DOI: 10.1016/j.pce.2010.07.030.

Kashaigili JJ, Mbilinyi BP, Mccartney M, Mwanuzi FL. 2006. Dynamics of Usangu plains wetlands: Use of remote sensing and GIS as management decision tools. Phys Chem Earth 31: 967-975. DOI: 10.1016/j.pce.2006.08.007.

Kibet S. 2011. Plant communities, species diversity, richness, and regeneration of a traditionally managed coastal forest, Kenya. For Ecol Manag 261: 949-957. DOI: 10.1016/j.foreco.2010.11.027.

Lovett JC, Marshall AR, Carr J. 2006. Changes in tropical forest vegetation along an altitudinal gradient in the Udzungwa Mountains National Park, Tanzania. Afr J Ecol 44 (4): 478-490. DOI: 10.1111/j.1365-2028.2006.00660.x.

Malimbwi RE. 2009. Kitulangalo Territorial forest reserve: An overview. In: Proceedings of the MITIMIOMBO Project Planning Workshop. Morogoro, Tanzania, , 6- 13 February 2007.

Maliondo SMS, Malimbwi RE, Temu RPC, Constantine E, Zahabu E. 2000. Fire impact on population structure and diversity of tree species in West Usambara Camphor zone forests. J Trop For Sci 12 (3): 472-481.

Mhache EP. 2014. Anthropogenic impacts on coastal forests: A case study of Kazimzumbwi and Pugu forests, Tanzania. J Geogr 1 (2): 1-12.

Munishi PKT, Temu RPC, Soka G. 2011. Plant communities and tree species associations in a Miombo ecosystem in the Lake Rukwa basin, Southern Tanzania: Implications for conservation. J Ecol Nat Environ 3 (2): 63-71.

NAFORMA. 2015. National Forest Resources Monitoring and Assessment of Tanzania Mainland, Main Results. MNRT(TFS), Tanzania.

Paavola J. 2003. Vulnerability to climate change in Tanzania: Sources, Substance and Solutions. A Paper Presented at the Inaugural Workshop of Southern Africa Vulnerability Initiative. Maputo, Mozambique, . 19-21 June 2003.

Perkin BA, Leonard C, Doggart N. 2008a. Landscape profile of Rondo/Noto. Document Prepared as an Input to the GEF PPG Process to Develop a Full Sized Proposal for the Tanzanian Coastal Forests. Tanzania Forest Conservation Group, Tanzania.

Perkin BA, Leonard C, Doggart N. 2008b. Landscape profile of Kilwa. Document Prepared as an Input to the GEF PPG Process to Develop a

Full Sized Proposal for the Tanzanian Coastal Forests. Tanzania Forest Conservation Group, Tanzania.
Prins E, Clarke GP. 2006. Discovery and enumeration of Swahilian Coastal Forests in Lindi region, Tanzania. Biodivers Conserv 16: 1551-1565. DOI: 10.1007/s10531-006-9047-4.
Rands MRW, Adams WM, Bennun L, Butchart SHM, Clements A, Coomes D, Vira B. 2010. Biodiversity conservation: Challenges beyond 2010. Science 329 (5997): 1298-1303. DOI: 10.1126/science.1189138.
Sumbi P, Watkin J, David H, Kim H. 2003. Ecosystem Profile Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya Biodiversity Hotspot. WWF, Tanzania.
Sutherland WJ. 2006. Ecological Census Techniques. Cambridge University Press, New York, United States of America. DOI: 10.1017/CBO9780511790508.
Tavankar F, Bonyad AE. 2015. Effects of timber harvest on structural diversity and species composition in hardwood forests. Biodiversitas 16: 1-9. DOI: 10.13057/biodiv/d160101.