Bamboo: A Potential Resource for Contribution to Industrial Development of Tanzania

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Abstract

Bamboo is an important non-timber forest product and a major wood substitute. Itcan be processed and fabricated into different products as a substitute for wood products at an industrial scale. However, the available information on bamboo resources availability, its properties and potential for contribution towards Sustainable Development Goals is limited. Therefore, this study aimed at determining the potentials of bamboo resources for sustainable industrial development in Tanzania. Specifically, the study aimed at exploringavailable bamboo resources, unique propertiesand its potential for contribution to Sustainable Development Goals in Tanzania. We conducted a comprehensive literature review in Tanzania mainland, supported by field visits to validate the National Forest inventory bamboo data. We used meta-analysis to generate descriptive statistics of the variables of interest. Results show that bamboo covers about 1,025,033 ha in Tanzania mainland, dominated by Yushania alpina, Bambusa vulgaris, Bambusa bambos and Oxytenanthera abyssinica. Bamboo has unique physical, chemical, and mechanical properties compared to wood, steel, cements and plastics, ithas many unique properties related to strength, elasticity and lightness, which could be used to contribute towards Tanzania industrial development ambitions.Use of bamboo resources can contribute to achievement ofsix of the 17 Sustainable Development Goals.

Keywords: Bamboo, Sustainable Development Goals, Tanzania, Potential Resource

Introduction

Bamboo is a fast-growing woody grass in the family Poaceae. Itcomprises of over 1642 species belongingto 91 genera worldwide (FAO 2007; Vorontsova*et al.*, 2017). Some of its members are giants, forming by far the largest members of the grass family. It is naturally distributed in the tropical and subtropical belt between approximately 46° north and 47° south latitude, and is commonly found in Africa, Asia and Central and South America. Some species may also grow successfully in mild temperate zones in Europe and North America. Bamboo grows naturally on the major mountains and highland ranges of Tanzania and other East African countries. Itis an extremely diverse plant, which easily adapts to different climatic and soil conditions (FAO, 2005; 2007; Chihongo*et al.*, 2000).

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Bamboo has proven to be a potential resource for industrialization and sustainable development in various countries (INBAR, 2015). It is an environmentally friendly building material, presentingadvantages such as physical properties comparable withsteel, high renewability with a rate of CO_2 absorptiongreater than wood and thus a closed life cycle materialfor buildings; besides its social benefits (Losada, 1993; Janssen, 2000).Resource management and technical improvements can convert this fast-growing grass into a durable raw material for construction purposes and a wide range of semi-industrialised products (Li *et al*. 2004).

FAO (2007) estimated that bamboo forest coversmore than 36 million hectares(ha) worldwide. It is most abundant in the monsoon area of East Asia, especially in India with 11.4 million ha and China with 5.4 million ha. Over the last 15 years, the bamboo area in Asia has increased by 10 percent, primarily due to large-scale planting in China and India (Lobovikov *et al*., 2007). In Africa, Ethiopia, Kenya and Uganda possess most of the bamboo resources, according to the world bamboo resources assessment report (Lobovikov*et al*., 2007). Among the three countries, 86% of the African bamboo resource is distributed in Ethiopia (Kelbessa*et al*., 2000). Two indigenous bamboo species Yushania alpina (highland bamboo) and Oxytenanthera abyssinica (lowland bamboo) are commonly found in East Africa.

Bamboo is a long stick like non-wood forestproduct and sometimes used as wood substitute. Itis found any regions of the world and plays an importanteconomic role. Even though it is used for housing, crafts, pulp and paper, panels, boards, veneer, flooring, roofing, fabrics andvegetable (the bamboo shoot). The shoot of young bamboo grass can be processed into various delicious healthy foods and sometimes used as medicines. Young bamboo shoot is usually consumed as vegetable in curry and also as pickle. The nutritional value of bamboo shoots varies from species to species, harvesting procedure and growing environment (FAO 2007; Vorontsova*et al*., 2017). Generally, it is reported that bamboo has more than 1,500 documented uses andover 1,000 million people live in houses made of bamboo or with bamboo as the key structural, cladding or roofing element (Baksy, 2013; Khan *et al*, 2007).Products of bamboos are usingeverywhere and bamboo industries are now thriving in Asia andare quickly expanding across the continents to Africa andAmerica (FAO 2007).

There are four major bamboo species occurring naturally in Tanzania namelyYushaniaalpina, Oreobambosbuchewaldii, Hickelia sp. aff. madagascariensis and O.abyssinica (syn. Oxytenantherabraunii) (URT, 2008). Also, there are several introduced bamboo species in Tanzania namely Dendrocalamusasper, Bambusavurgaris var. Striata, Bambusa multiplex, Bambusa nutans, and Bambusa bambos exist (Kigomo, 1988; Chihongo*et al*., 2000). The dominant spp are Y. alpina, O. buchwaldii, and O. absyssinica (Chihongo*et al*., 2000).

In spite of the importance of bamboo, very little is known about bamboo resources availability, its properties and potential for contribution towards Sustainable Development Goals in Tanzania.As a non-timber forest product, bamboo is not routinely included in forest inventories. According to the FAO (2001), statistical data on bamboo are available for the period 1954 to 2005 only. Currently, very few countries monitor bamboo supply and utilization at the national level. This might be due to difficultness of assessing bamboo resources and their use arises from: uncertainty associated with their taxonomy; the large number of, and wide variation in their uses at local, national and international levels; the fact that many bamboo products are used or marketed outside traditional economic structures; it lacks of common terminology and units of measurement (FAO 2001). It is evident from National Forest Monitoring and Assessment (NAFORMA) of Tanzania where bamboo resources were not reported.

Inadequacy of comprehensive and updated information onbamboo resources, its properties and potential for contribution towards Sustainable Development Goals in Tanzania hampers itsutilization and limits its potential to contribute to sustainable industrial development of Tanzania. Additionally, literature on the potential uses of bamboo resources to sustainable development of Tanzania is scarce. Therefore, this study aimed to explore the potential of bamboo resources for sustainable industrial development of Tanzania. Specifically, the study the study aimed determine the available bamboo resources, unique properties and its potential for contribution to Sustainable Development Goals in Tanzania.

Materials and methods

Study Area

Tanzania is located between 1° 00' S and 12° 00' S and between 30° 00' E and 41°00'E at an altitude between 358 m a.s.l. and 5,950 m a.s.l. Mainland Tanzania ischaracterized by tropical climate, which can be divided into four distinct climaticzones, namely, the hot humid coastal plain, the semi-arid zone of the central plateau,the high-moist lake regions, and the temperate highland areas. The country hasmean maximum day-time temperatures ranging from 10°C to 31°C and a meanannual rainfall ranging from 500 to 2,500 mm across the four zones (URT, 2017).The study was conducted on forestland in Tanzania Mainland which covers an estimated area of 48.1 million ha (MNRT, 2015).

Sampling design

Sampling design and data collected by National Forest Resources Monitoring Assessment (NAFORMA) (MNRT, 2015) were used in this study. The NAFORMA inventory adopteda two-phase stratified systematic cluster design with double sampling for stratification which was designed based on a simulation study described by Tomppo *et al*. (2014).The first-phase sample consists of clusters of plots on a 5 × 5 km grid over mainland Tanzania based on predicted growing stock, terrain of the area and time for cluster measurements, and results into 18 strata. The clusters in the first-phase contain a range of 6 to 10 plots, but the number of plots in cluster of the same stratum is the same.

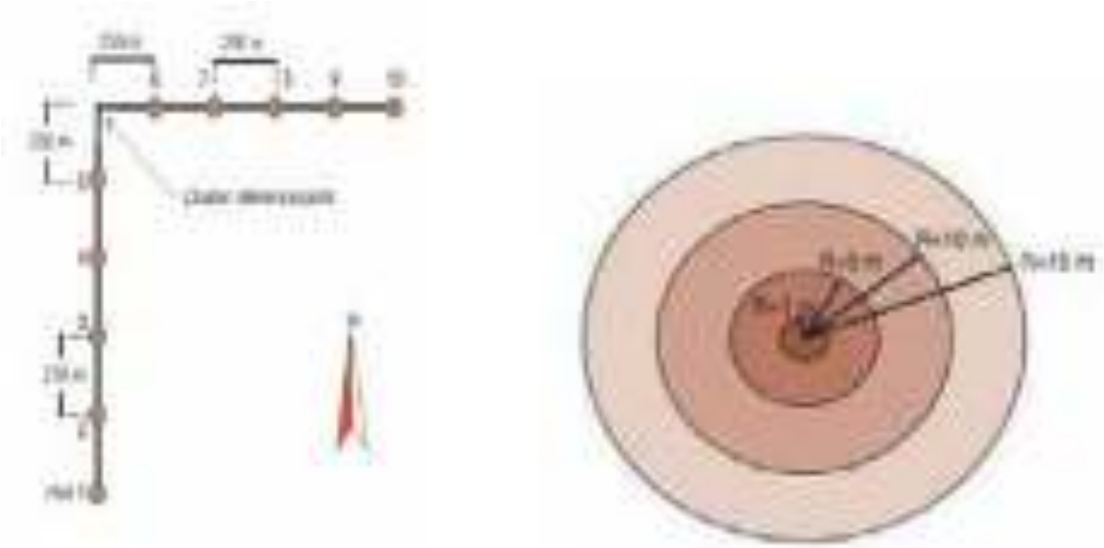

Figure 1:Cluster design used byNational Forest Resources Monitoring Assessment

The second-phase samples were systematically selected from the first phase sample, with different sampling intensities in each of the 18 strata following an optimal allocation procedure and with cost functions designed for each stratum. Greater sampling intensity was allocated to strata with large predicted growing stock and smaller sampling intensity to strata with small predicted growing stock. Thus, the second phase which is a sub-sample of the first phase were measured in the field.The distance between field plots within a cluster was 250 m, while the distance between clusters varied from 5 km to 45 km (Tomppo *et al*., 2014).

Data collection

Circular plots of 15 m radiuswere laid out. Bamboos present in the plots were identified, followed by measurements ofaverage diameter at breast height (Dbh), average height, and number of culm/stems in the plot. Also, vegetation type, land use, ownership, land cover, altitude, plot centre coordinates and coverwere recorded for the plots.

Additionally, we conducted comprehensive literature review on the properties of bamboo and how it can beused to achieve sustainable development goals in Tanzania.

Data extraction

Data was extracted from the NAFORMA database server located atSokoine University of Agriculture. The whole NAFORMA data set was imported to R software for the extraction of bamboo data and their related cluster and plot information. The extraction of the data was then done by performing Structured Query Language (SQL) queries within R software using sqldf package. After extraction, the data were subjected to validation, cleaning (removal of noisy data and data cleansing) and outliers' analysis (Son, 2011).

Data Analysis

Aspatial distribution map was generated from the plot center Global Positioning System (GPS) coordinate points. QGIS version 2.16.3 was used for mapping the spatial distribution of bamboo species across the country.The distribution was assessed by presence data of the bamboo species along the altitudinal gradient, across vegetation types and land uses(Whittaker, 1972).The altitudinal band of the 200 m band was adopted for this study. Samples within each altitudinal band were pooled and the number of species observed in each band was regarded as richness (Whittaker, 1972; Shimada and Wilson, 1985).

A relative abundance of bamboo species in various vegetation types was calculated as the ratio of the number of species found in each vegetation type and the total number of species recorded in all study vegetation types which according to May (1975), as cited by Magurran (1988) is:

$$n_i = \frac{N_T}{S}\sum_{n=1}^{S} 1/x$$

Where:ni the abundance of the ith species,NT is the total number of individuals, andS is the total number of species.

Stand density (culms/ha) was determined based onthe formula of Philip (2004).

$$N = \frac{\sum\left[\frac{n_i}{a_i}\right]}{n}$$

Whereby; N is the number of stems per ha, nicounts in ith plots, aiis the area of the of ith plots in ha and n is the total number of sample plots.

Land area estimation equation developed by NAFORMA was adopted to estimate area occupied by bamboo species.

$$A_{ah} = A \times \left(\frac{n_{ah}}{n_{sa}}\right)$$

Where:A_{ah} is area estimates of the land category

n_{ah} is the number of plots in the second phase sample on the land category n_h, l

n_{sa} is the total number of plots in the second phase sample on land on stratum h, n_h

A is estimated land area of the stratum from the first phase sample

Results

Distribution and coverage of bamboo resources

Bamboo covers about 1,025,033 ha in Mainland Tanzania. About 62% (636,545 Ha) of bamboos are found in the Southern zone (Lindi, Mtwara and Ruvuma) of Tanzania

(Table 1).Bamboo resources are distributed in eleven administrative regions of Arusha, Tanga, Morogoro, Lindi, Mtwara, Ruvuma, Njombe, Iringa, Mbeya, Katavi and Kigoma (Figure2). Bamboo were most abundant in Lindi, Ruvuma, Mtwara, Iringa and Njombe with 75.2% of total population. Less abundance of bamboos observed in Arusha, Mbeya, Katavi and Tanga that constitute to 7.9% of the total population. Most bamboo species were distributed in low altitudes compared to high altitude, and about 85.2% of bamboos distributed below 1500 m.a.s.l. (Figure3).

Bamboo has been distributed in all land use types (Figure4). They are widely distributed in production forest, protection forest and Wildlife protected areas, which all together forms the public forests and contributes about 65% of the total distribution of bamboo across different land use(Table 2).

Additionally, bamboo species were observed to be distributed across all vegetation types in Tanzania (Figure5). The highest proportion of occurrence is in woodland, cultivated land, and forest, with 66% 12% and 10% respectively. Most of the bamboo species area distributed on woodland, especially in open woodland with 10-40% of the canopy cover. Despite bamboo species being distributed across all types of land use, though species richness found at each land use tends to vary.More bamboo stems were observed in lower Dbh class (<4cm) as shown in diameter distribution (Figure 6). Bamboo forest is composed of many small diameter culms and very few large diameter culms, thus making an inverse J structure.

Table 1: Coverage of bamboo species across zones/regions of Tanzania

Zone	Regions	Coverage (Ha)
Southern zone	Lindi, Mtwara and Ruvuma	636545
Southern highland zone	Iringa, Njombe and Mbeya	165030
Western zone	Kigoma and Katavi	128129
Eastern zone	Morogoro	77903
Northern zone	Arusha	17426
Total area		1025033

Table 2: The coverage of bamboo species across land use types in Tanzania

S/n	Land use type	Coverage (ha) (000)
1.	Production forest	458.189
2.	Protection forest	98.403
3.	Wildlife protected areas	118.903
4.	Shifting cultivation	116.854
5.	Agriculture	199.881
6.	Grazing land	3.075
7.	Built up areas	16.401
8.	Water body/wetland	4.1
9.	Others	9.227
Total		1025.033

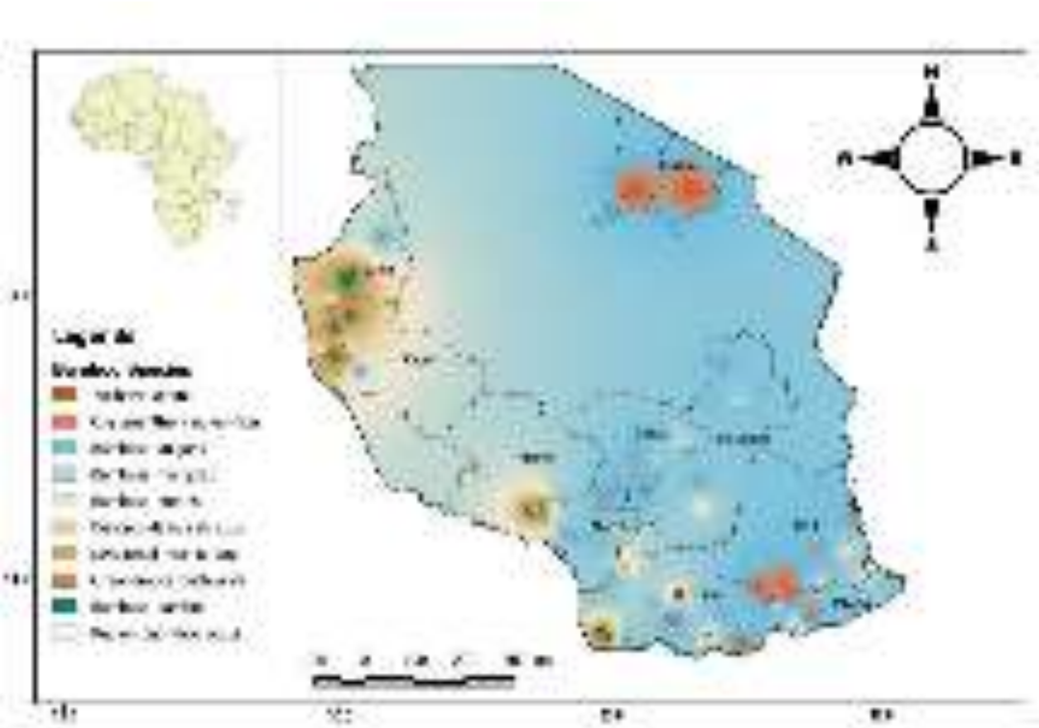

Figure 2: A map of bamboo species distribution in Tanzania

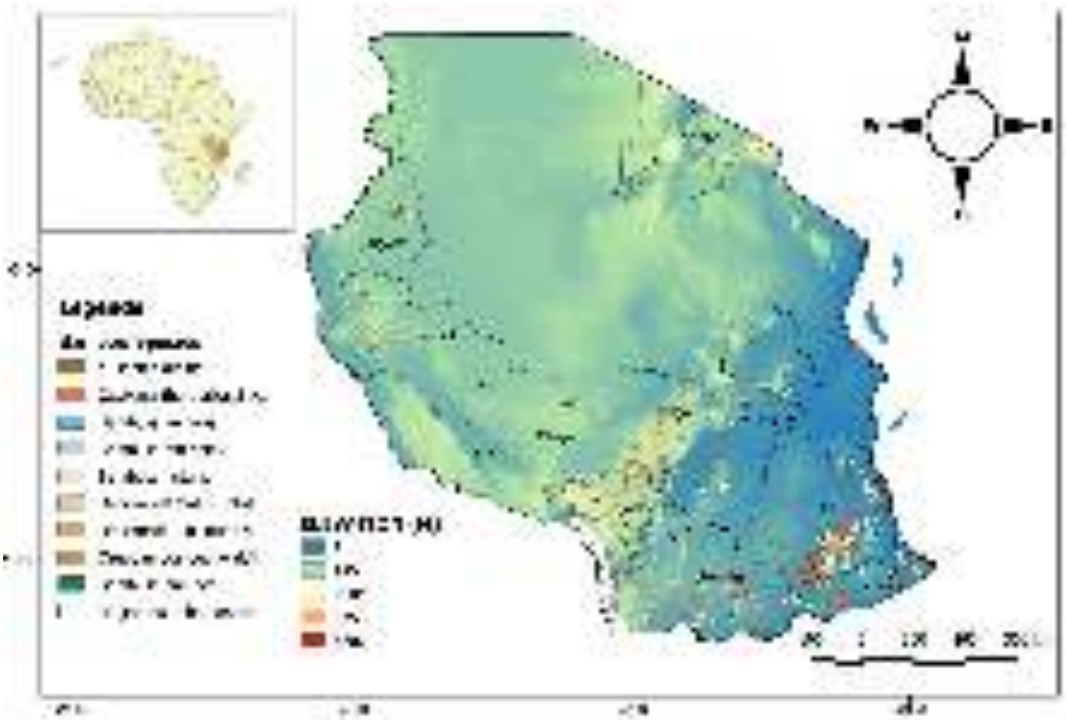

Figure 3: A map of bamboo species distribution along elevation gradients in Tanzania

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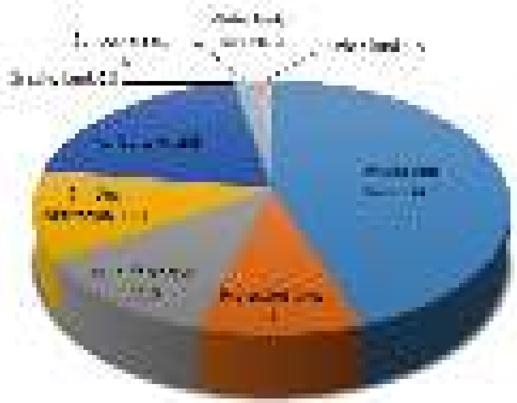

Figure 4: Distribution of bamboo species across land use types in Tanzania

Figure 5: The distribution of bamboo species across vegetation types

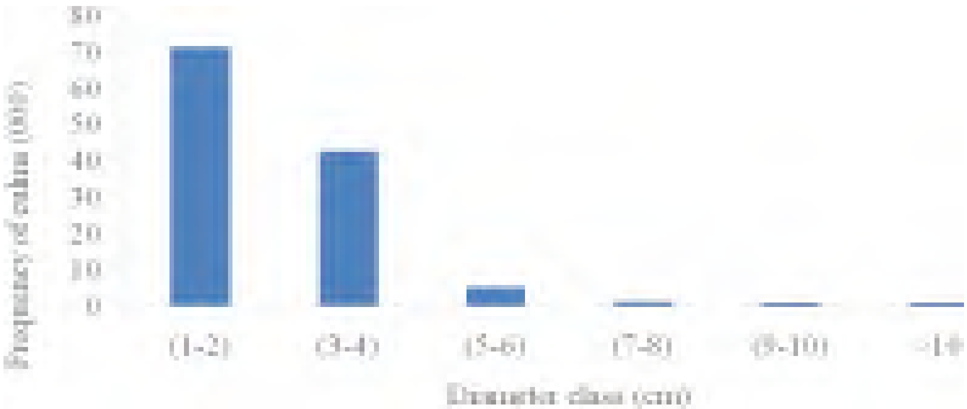

Figure 6: Diameter class distribution of bamboo species in Tanzania

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Bamboo species composition and richness in Tanzania

A total of 11 bamboo species were identified and recorded in Tanzania (Table 3). These bamboo species are distributed in 5 genera within two tribes of Arundinarieae and Bambuseae, both of which are woody bamboo. The identified bamboo species include three indigenous species and eight exotic species.

Table 3: A list of bamboo species identified in Tanzania

s/n	Species name	Genera	Status
1.	*Yushania alpina*	Arundinarieae	Indigenous
2.	Bamboo spp.	-	-
3.	*Bambusa bambos*	Bambusa	Exotic and Naturalized
4.	*Bambusa multiplex*	Bambusa	Exotic
5.	*Bambusa nutans*	Bambusa	Exotic
6.	*Bambusa spp.*	Bambusa	Exotic
7.	*Bambusa vulgaris*	Bambusa	Exoticand Naturalized
8.	*Dendrocalamusstrictus*	Dendrocalamus	Exotic
9.	*Dendrocalamusnutans*	Dendrocalamus	Exotic
10.	*Oreobambosbuchwaldii*	Oreobambos	Indigenous
11.	*Oxytenanthera abyssinica*	Oxytenanthera	Indigenous

Production forest had the highest richness of bamboo species observed with eleven species, among which the most abundant are Y. alpina, O. abyssinica, B.bambos and B. species (Table 4). Protection forests and shifting cultivation land use type have also high bamboo species richness with eight bamboo species. Bamboo richness of agriculture land use type is seven species, while the most abundant specie is O. abyssinica. Wildlife protected areas land use type is six species withY.alpina being the most abundant. Lowest species richness wasobserved in grazing, built-up area, water and swamp area and other land use types.

Table 4: The richness of bamboo species across land use types in Tanzania

S/n	Land use type	Number of bamboo species
1.	Production forest	11
2.	Protection forest	7
3.	Wildlife protected areas	4
4.	Shifting cultivation	6
5.	Agriculture	6
6.	Grazing land	2
7.	Built up areas	1
8.	Water body/wetland	1
9.	Others	3
Total		11

The richness of bamboo species along the altitudinal gradient differs (Figure 7). There is an increasing trend in total species richness from 76 m.a.s.l to 500 m. a. s. l., then followed by decrease in richness from 500 m.a.s.l to 2600 m.a.s.l. Thus, the high bamboo species richness in Tanzania is between 400 m.a.s.l and 800 m.a.s.l with a maximum value at 500 m.a.s.l (Figure 7). This falls within the general pattern of an initial increase in species richness with altitude followed by a peak and then a decline with further increased altitude.

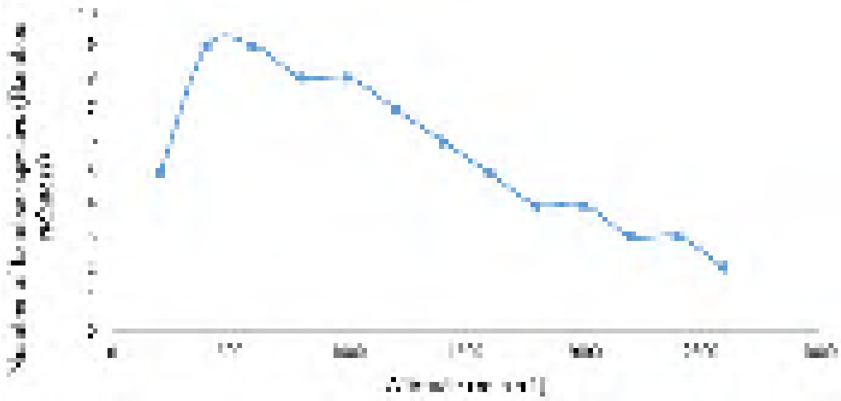

Figure 7: Bamboo species richness along altitudinal gradient in Tanzania

Abundance and Density of Bamboo in Tanzania

The most abundant bamboo species were Y. alpina, B. vulgaris, B. bambos and O. abyssinicawhich altogether constituted to 73.2% (Table 5) of the total bamboo abundance in the country.Results from the study show that the mean stand density of bamboo was 2660.18 culms/ha (Table 6). There is a great variation in culm density for different bamboo species that ranges from 1247 culms/ha for Bambusa vulgaris to 3622 culms/ha for Bamboo spp.

Table 5: The relative abundance of bamboo species in Tanzania

S/n	Scientific name	Relative abundance	Percentage (%)	Ranking
1	*Yushania alpine*	0.213	21.3	1
2	*Bambusa vulgaris*	0.207	20.7	2
3	*Bambusa bambos*	0.165	16.5	3
4	*Oxytenanthera abyssinica*	0.147	14.7	4
5	*Bambusa spp.*	0.109	10.9	5
6	Bamboo spp.	0.069	6.9	6
7	*Dendrocalamusnutans*	0.027	2.7	7
8	*Dendrocalamusstrictus*	0.019	1.9	8
9	*Bambusa nutans*	0.017	1.7	9
10	*Bambusa multiplex*	0.016	1.6	10
11	*Oreobambosbuchwaldii*	0.011	1.1	11

Table 6: The stand (culm) density of bamboo species in Tanzania

S/n	Species name	Stand density (culms/ha)	Ranking
1	*Bamboo spp.*	3622	1
2	*Bambusa nutans*	3211	2
3	*Bambusa multiplex*	3029	3
4	*Oreobambos buchwaldii*	2972	4
5	*Bambusa spp.*	2852	5
6	*Oxytenanthera abyssinica*	2790	6
7	*Yushania alpine*	2656	7
8	*Dendrocalamus strictus*	2519	8
9	*Bambusa bambos*	2368	9
10	*Dendrocalamus nutans*	1996	10
11	*Bambusa vulgaris*	1247	11
Average		2660.18	

Bamboo properties

Bamboo has unique physical,chemical, and mechanical properties

Physical properties

Specific gravity, moisture content and dry shrinkage

The specific gravity of bamboo ranges between 0.5 and 0.8 g/cm3 (oven-dry weight). This value increases from the central parts to the peripheral parts of the culm and from the bottom to the top (Liese 1985).

Moisture content influences the utilization of bamboo in a similar way like that of wood. The moisture content of bamboo depends on: 1. Bamboo species: the different species have a different amount of parenchyma cells which correlate to the water holding capacity (Liese and Grover, 1961). 2. Culm zones: the base has a higher value than the top. The inner part of the culm cross section has a higher value than the outer part. 3. Nodes or internodes: the nodes have a lower value than internodes (up to 25%). 4. Seasons: at the end of the rainy season it is much higher than at the end of the dry season; 5. Age of the cane: the young culm has a higher and more uniform moisture content than the mature one (Dunkelberg, 1985). After the harvesting the moisture of bamboos can be influenced by the humidity and dryness of the environment.

Chemical properties

The chemical properties influence the growth and the mechanical properties of bamboos. Through the chemical analysis more information on the taxonomical identification and propagation can be obtained. The chemical composition of bamboos also has an influence on deciding what kinds of bamboos with which kind of material in combination is suitable for the utilizations. Bamboo consists mainly of cellulose, lignin and hemicellulose which are not different to that of trees (Table7). The difference lies in the percentages of each component and their micro structures. Some minor chemical components are resins, tannins, waxes and inorganic salts. This chemical composition changes according to the species, the age and the parts of bamboo. The variation of bamboo's chemical composition has a big influence on the physical and mechanical properties of bamboos and therefore the treatment and utilization of bamboos (Liese, 1985).

Table 7: Chemical compositions of bamboo and softwood (Source: Janssen, 1981)

Material	Cellulose (%)	Lignin (%)	Hemicellulose (%)
bamboo	55	25	20
softwood	50	25	25

Mechanical properties

The studies on bamboo mechanical properties are commonly based on laboratory tests of the strength of bamboo (tensile strength, bending strength, compression strength, shear strength and modulus of elasticity) (Atrops, 1969; Janssen, 1981; Dunkelberg, 1985). These tests show remarkable differing values when changing species, ages, moisture content, locations, soil and climatic conditions. The variation of mechanical properties is similar to wood, but even more remarkable (Table 8).

Table 8: Material mechanical properties concrete, steel, wood and bamboo (Janssen, 1981)

Material	Working stressσ (N/mm2)	E (N/mm2) Modulus of lasticity	Working strain ε(10-6)	Strain energy stored	
				J/m3	J/kg
concrete	8	25000	300	1200	0.5
steel	160	210000	800	64000	8.2
wood	7.5	11000	700	2600	4.3
bamboo	10.7	20000	500	2500	4.2

The research by Janssen (1981) shows that compared to concrete, steel and wood bamboo has excellent mechanical properties with reference to material efficiency for strength (working stress per volume unit) and stiffness (E modulus per volume unit) (Table 9).

Table 9: Material efficiency for strength and stiffness (Janssen, 1981)

Material	Working stress/Weight by volume	E/Weight by volume
concrete	8/2400 = 0.003	25000/2400 = 10
steel	160/7800 = 0.02	210000/7800 = 27
wood	7.5/600 = 0.013	11000/600 = 18
bamboo	10/600 = 0.017	20000/600 = 33

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Bamboo and Sustainable development goals

Bamboo is among unique resource which can be used to address Sustainable Development Goals (SDGs). This study found six of the 17 SDGs can be achieved through sustainable use of bamboo resources in Tanzania (Table 10). Thought sustainable use of bamboo, several targets can be achieve including poverty reduction; energy; housing and urban development; sustainable energy production and consumption; climate change and land degradation.

Table 10: Sustainable Development Goal can be contributed through using bamboo resources

S/No	Sustainable Development Goal (SDG)
1	SDG 1 (End poverty in all its forms everywhere)
2	SDG 7 (Ensure access to affordable, reliable, sustainable and modern energy for all)
3	SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable)
4	SDG 12 (Ensure sustainable consumption and production patterns)
5	SDG 13 (Take urgent action to combat climate change and its impacts)
6	SDG 15 (Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss)

Discussion

Distribution and coverage of bamboo resources

The found distribution and coverage of bamboo resources in this study contradict with the study by Kigomo (1988) and Chihongo*et al*. (2000) who reported that bamboo species distributed in Arusha, Tanga, Morogoro, Iringa, Mbeya, Lindi, Ruvuma, Kigoma, Kilimanjaro, Coastal and Kagera regions, though the proportional of distribution differs completely. The study reveals that there is no longer existence of bamboo in Coastal and Kagera regions which previously reported to exist. Also, there is occurrence of bamboo in Katavi and Mtwara regions which previously were not reported. The difference could be attributed by introduction of bamboo species in different areas after previous studies, the reported over-exploitation of bamboo resources in the country that cause depletion of bamboo (Chihongo*et al*., 2000). Also, the difference attributed by methodological approach. Previous researches were based on remote sensing (FAO, 2007). According to FAO (2007) reported that remote sensing technology that does not recognize bamboo as a separate class. Also, there is a contradiction in differentiating the refractive index of bamboo and other species like sugarcane (Chihongo*et al*., 2000; FAO, 2007; Liese and Köhl, 2015) that may cause bamboo not recorded its occurrence. On other hand, the findings of this study on distribution of bamboo across different land use agree with the study by Chihongo*et al*. (2000) reported that bamboo species are widely distributed in public forests.

Bamboo species composition and richness in Tanzania

The identified 11 bamboo species include three indigenous species and eight exotic species contradict with the study by Kigomo (1988); Chihongo*et al*. (2000); Bystriakova *et al*. (2004); FAO (2007) and Oyen (2011) reported that, four indigenous bamboo species exist in Tanzania, namely *Yushaniaalpina*, *Oxytenanthera abyssinica*, *Oreobambos buchwaldii* and *Hickelia africana*, and five exotic bamboo species namely *Bambusa bambos, Bambusa vulgaris, Bambusa multiplex,Chimonobambus ahookeriana and Bambusa nutans*. The difference in the species richness could be attributed by the intensity of the survey, since NAFORMA was the first compressive and most detailed survey conducted in Tanzania that included bamboo (MNRT, 2015) and previously bamboos were not included in the National Forest Inventories. Also, the difference might be contributed by the fact that other species were introduced. According to IUCN (2013) reported that *Hickelia africana* is under risk of extinction, its absence in this survey might mean that the species is very rare and would need a special survey to assess its status.

Three bamboo species that exist in Tanzania namely *Bambusa bambos*, *Bambusa vulgaris* and *Dendrocalamus strictus* fall under prioritized bamboo species for sustainable development and potential materials for industry. The group consists of twenty bamboo species considered as bamboo of high value globally (Rao *et al*., 1998). Other bamboo species existing in Tanzania like Yushaniaalpina, OxytenantheraabyssinicaandBambusa nutans falls under the category of proposed high value taxa of bamboo. This group constitutes a total of 21 bamboo species (Rao *et al*., 1998). Therefore, six bamboo species among eleven bamboo species exists in Tanzania are bamboo of high value globally.

The found richness of bamboo in this study contradicts with the study by Kigomo (1988) and Chihongo*et al*. (2000) who reported that the maximum richness of 8 bamboo species occurred in Tanga mostly confined to Amani arboretum. Other regions of Arusha, Iringa, Morogoro, Lindi, Kagera, Mbeya, Kigoma and Coast had a richness of 1, 2, 4, 1, 1, 2, 1, and 2 respectively (Chihongo*et al*., 2000). The differences could be attributed by difference in methodological approach. Also, the difference might be contributed by the fact that other species were introduced in other areas after the two studies. Most bamboo species were distributed in low altitudes compared to high altitude, and about 85.2% of bamboos are distributed below 1500 m.a.s.l. This agrees well with other studies as most of bamboos found in Tanzania were under tribe Bambuseae, genera Bambusa that prefer altitude below 1500 m.a.s.l. (Seethalakshmi and Kumar, 1998; Judziewicz*et al*., 1999; BPG, 2012). Therefore, altitude should be considered as an important factor for the selection of exotic bamboo species for the establishment of bamboo plantation in Tanzania.There is an increasing trend in total species richness from 76 m.a.s.l to 500 m. a. s. l., then followed by decrease in richness from 500 m.a.s.l to 2600 m.a.s.l. Thus, the high bamboo species richness in Tanzania is between 400 m.a.s.l and 800 m.a.s.l with a maximum value at 500 m.a.s.l. This falls within the general pattern of an initial increase in species richness with altitude followed by a peak and then a decline with further increased altitude. This, observed hump -shaped species richness patterns of bamboo species are in accordance with the hypothesis of productivity and optimum resource combination in the intermediate portion of the altitudinal gradient (Lomolino, 2001; Gerytnes and Vetaas, 2002). The indicated inverse J shaped showed that culms frequencies decreasing with an increase in DBH. This implies that bamboos are developing and regeneration is taking place. This situation also indicates that there is severe disturbance which is characterized by presence of smaller diameter culms (Smiet, 1992).

Abundance and Density of Bamboo in Tanzania

The found abundance of bamboo in this study differ from study by Chihongo *et al*. (2000) which found that the relative of *Yushania alpina, Oxytenanthera abyssinica, Oreobambos buchwaldii, Bambusa vulgaris* and other bamboo species were 0.497, 0.348, 0.149, 0.006 and 0.0002 respectively. The difference in abundance might be attributed by the reported over-exploitation, gregarious flowering of bamboos which lead to mass death and the introduction of more bamboo species in different areas. Also, the difference in abundance could be attributed by the research methodologies between studies, since Chihongo *et al*. (2000) estimate bamboo resources by the use of remote sensing data. According to FAO (2007) remote sensing does not recognize bamboo as a separate class since most of bamboo exists as understory, thus recommend for a more detailed ground survey. Specifically, the difference in abundance for *Oxytenanthera abyssinica* especially on public land could be attributed by over-exploitation of the species as it is more preferred by the community for different uses (Chihongo*et al*., 2000). Moreover, for Yushania alpina the difference in abundance especially the increase is due to the fact that the species mostly distributed in protected areas where there is intensive management hence little disturbance.

Furthermore, the study reveals that indigenous bamboo species were more abundant with a total of 62.9%, while the exotic bamboo species constituted to 37.1 % of the total bamboo abundance in Tanzania. These findings concur with the findings by Chihongo *et al*. (2000) reported indigenous bamboo species are the most abundant, though the level of abundance for the two studies differ. The difference of the percent which is 99.4% of the study by Chihongo *et al*. (2000) and 62.9% in this study the difference relies on methodological approach, the introduction of other exotic bamboo species over-exploitation of indigenous bamboo species especially from public land. This informs decision makers to intensify the management of bamboo resources.

The results showed that there is a great variation in culm density for different bamboo species that ranges from 1247 culms/ha for *Bambusa vulgaris* to 3622 culms/ha for *Bamboo* spp. The low stocking of bamboos attributed by the fact that bamboos are mixed with other tree species, difference in preference for different species and variation in management efforts to different area where species found. Also, bamboos are under severe pressure from over-exploitation, grazing, wild fire, expansion of agricultural activities and other human disturbances cultivation (MNRT, 1998; Chihongo *et al*., 2000; MNRT, 2015). This overemphasize the need for conservation efforts on bamboo to meet the demand in Tanzania and global as the whole.

Properties of Bamboo

The study found bamboo has many advantages like strength, elasticity and lightness compared to wood, steel, cements and plastics (Yu, 2007). The material properties of bamboo are the sum of the substances plus the structure of the substances. As material bamboo means mostly the culm, when the material properties of bamboos are discussed it mostly means the properties of the culm. The material properties will explain how the bamboo plant changes to bamboo material (Li *et al*. 2004).

Cellulose: Cellulose $(C_6H_{10}O_5)_n$ is a carbohydrate. It forms the primary structural component of green plants. For the plants the primary cell wall is made of cellulose and the second cell wall is made of cellulose with a varying amount of lignin. Cellulose is also the most abundant form of living terrestrial biomass in the world, which in combination with lignin and hemicellulose can be found in all the plants (Crawford, 1981). It is also the major constituent of paper and for the synthesis of the plastics celluloid (Li *et al*. 2004).

Lignin: Lignin is an integral part of the cell walls of plants, especially in tracheids, xylem fibers and sclereids. It is the second most abundant organic compound on earth after cellulose. Lignin makes up about one-quarter to one-third of the dry mass of wood. The lignin fills the cell wall of the plant in the space among the cellulose, hemicellulose and pectin components. It confers mechanical strength to the cell walls and thus the whole plant. It is important in conducting water in culms. Because it is difficult to degrade it helps to build a barrier to defend the plant against the invasion of pathogens and enhances the durability of the plant. The high lignified wood is durable and yields more energies than cellulose. But it is a detrimental for paper making and therefore should be removed by pulping (Li *et al*. 2004).

Hemicellulose: Hemicellulose is similar to cellulose but is less complex. Hemicelluloses bind with pectin to cellulose to form a network of cross-linked fibers in plants. The hemicellulose in bamboo has its main component xylan between that of the hardwood and softwood (Li *et al*. 2004).

Unlike wood, bamboo begins to shrink from the beginning of drying (Liese and Grover 1961). The process is not regular and will stop at about 40% moisture content. After the bamboo is cut, its moisture content decreases and the shrinkage begins. The shrinkage varies in different directions. It is reported the dry shrinkage of phyllostachyspubescens, when the moisture lost is 1%, the average shrinkage rate is: lengthwise 0.024%, tangential 0.1822%, radial 0.1890% (on node parts 0.2726%, on inter node part 0.1521%) (Zhang *et al*., 2002). The dry shrinkage also increases from inner to outer parts. The dry shrinkage of the outer part of bamboo in length direction can be neglected, but the crosswise shrinkage is large (Li *et al*. 2004).

Some researchers triedto analyze and calculate bamboo's mechanical properties by studying its molecularstructure. Janssen (1981)developed a mathematical model of cells of bamboo culm to calculate the mechanical properties, whose principle has been used in the research on mechanical properties of cell walls in wood. Ye (1995) studied the different mechanical properties in the outer, middle and inner parts of the bamboo culm by studying the distributions of vascular bundles in these areas. These studies reveal arelationship between the micro structure of bamboo and its properties and help to form a better understanding of the mechanical properties of bamboo (Li *et al*. 2004).

Bamboo and Sustainable Development Goals (SDG) in Tanzania

SDG 1 (End poverty in all its forms everywhere)

Bamboo exploitation and utilization have yielded direct and immediate micro level benefits to economically disadvantages of rural communities in many Asian, South and East African countries. In Tanzania, Bamboo has been employed as a veritable poverty fighter, replacing timber wood, iron, plastics, increasing wealth in rural livelihoods and even for exports, and most particularly contributing to decrease environmental footprints in carbon sequestration. It also plays a vital role of build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental disasters.The planting and cultivation of bamboo, it will help to achieve poverty reduction; energy; housing and urban development; sustainable energy production and consumption; climate change and land degradation and SDG1. Bamboos can be grown on marginal land, which may not be under cultivation, and may not have existing land tenure. Promoting the cultivation of bamboo therefore helps to provide the poor with natural resources that they have access to and ownership over (INBAR, 2013).

SDG 7 (Ensure access to affordable, reliable, sustainable and modern energy for all)

Bamboo provides energy when it is burned as firewood, processed into chips or pellets, or carbonized as charcoal. Recent studies in China, Ethiopia and Ghana reveal that the calorific value of bamboo charcoal is similar to that of the most suitable woods used for charcoal. At an industrial scale, bamboo can be used to fire generators and power stations, and research is progressing in Indonesia, Japan and Spain to study how to establish large-scale power generation based on bamboo plantations. Bamboo can also be the raw material for biogas systems, and research is now starting to define the properties for bioethanol and biodiesel. The starting point for this value chain is that managed bamboo stands give a long-term, sustainable source of raw material for bio-energy that helps to avoid deforestation (INBAR, 2015).

SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable)

For affordable housing and dwellings that can be rapidly erected to respond to floods or other natural disasters, bamboo is emerging as a flexible construction material of choice for many uses. A number of documented cases testify how bamboo structures better withstand natural disasters than concrete housing, which is largely destroyed. Bamboo's unique properties of being sustainable and with high tensile strength, point to a revolution that is waiting to happen. In the world of high design, more top architects and designers are specifying bamboo for their creations in urban development (INBAR, 2015).

SDG 12 (Ensure sustainable consumption and production patterns)

Bamboo is a "woody grass", not a tree and is selectively harvested without harming the ecosystem, or contributing to deforestation. Bamboo poles, fibre and engineered bamboo can be used for most purposes where timber is used today, and in some cases offers better performance than some timber products. In its cultivation and production life cycle, no part of the bamboo plant is wasted. Shoots are harvested for food; branches for poles used for many applications; the main bamboo pole for fibres for pulp or charcoal production and the lower trunk for construction uses or flooring and engineered bamboo products (INBAR, 2015).

SDG 13 (Take urgent action to combat climate change and its impacts)

Bamboo like other plants, also absorb CO2, and research in China has shown that a managed bamboo Moso bamboo forest absorbs more CO2 than an equivalent woodlot of Chinese fir. Unlike trees, bamboo is harvested selectively (in the case of Moso, only >3-4 years old culms are cut) and continues to store carbon for a longer term. Once products are made from bamboo, the carbon is locked up and is prevented from escaping into the atmosphere for the product lifetime. Bamboo therefore provides a secure carbon sink (INBAR, 2013; 2015).

Bamboo can help rural communities become less vulnerable as the plant's rapid growth allows frequent harvesting. Bamboo's excellent adaptability and resilience to natural disasters, allows farmers to adapt their landscape management practices, using bamboo, to respond to the changing weather patterns. At the same time. Bamboo can help to build resilience against changes in climate and related loss of livelihood options (INBAR, 2015).

SDG 15 (Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss)

This SDG is particularly relevant for bamboo as it includes targets related to the conservation, restoration and sustainable use of terrestrial ecosystems and their services; the implementation of sustainable management of all types of forests, restoring degraded forests and substantially increasing afforestation and reforestation globally; restoration of degraded land and soil; reducing the degradation of natural habitats; and integrating ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.

SDG 15 also introduces measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species. In some cases, often inadvertently bamboo has been labelled an 'invasive species. It is important to clarify the invasiveness character of bamboo and identify which species carry a risk and which species are harmless in this respect.

Bamboo is used to rapidly restore severely degraded landscapes in Mbeya, Tanzania. With its over 1642 species, bamboo offers a range of characteristics for different uses and survival from wet to dry seasons of Tanzania suitable for a range of restoration and land use planning needs. Bamboo grows rapidly, regenerates annually through an extensive root system and very good adoption to poor soil or climate conditions, and helps bind soil. These properties make it a unique and effective tool to control erosion and slope stability. Several countries use bamboos along river banks to maintain slope stability and restrain erosion. Additionally, to the soil conservation and climate change mitigation opportunities, ecosystem services provided by bamboo include biodiversity conservation, recreation and green spaces for wellbeing. However, the values of these various natural services are not well understood, and in most cases not reported (INBAR, 2015).

Conclusion

The study found 11 bamboo species that include three indigenous and eight exotic species exists in the country. Production forest had the highest richness of bamboo species observed with eleven species, among which the most abundant are *Y. alpina, O. abyssinica, B. bambos* and B. species. Results from the study show that the mean stand density of bamboo was 2660.18 culms/ha in Tanzania.The abundance and stocking of bamboo species is relatively low, since most of the bamboos in Tanzania are distributed in woodland, especially open woodland that follows under category of production forests which are under severe pressure from over-exploitation, wildfire and livestock grazing. Therefore, proper management intervention is required for the sustainability of bamboo resources in the country.

Bamboo species are distributed in eleven administrative regions of Arusha, Tanga, Morogoro, Lindi, Mtwara, Ruvuma, Njombe, Iringa, Mbeya, Katavi and Kigoma. Bamboo were most abundant in Lindi, Ruvuma, Mtwara, Iringa and Njombe with 75.2% of total coverage.

Bamboo has been distributed in all land use and vegetation types. They are widely distributed in production forests, protection forests and wildlife protected areas. More bamboo stems were observed in lower DBH class (<4cm) and very few large diameter culms, thus making an inverse J structure.

This study found bamboo has unique physical, chemical, and mechanical properties compared to wood, steel, cements and plastics, ithas many unique properties related to strength, elasticity and lightness, which could be used to contribute towards Tanzania industrial development ambitions.Use of bamboo resources can contribute to achievement of six of the 17 Sustainable Development Goals. Through sustainable use of bamboo, several targets can be achieved including poverty reduction; energy; housing and urban development; sustainable production and consumption; climate change and land degradation. Bamboo can make a positive contribution to addressing food security, women's empowerment, economic growth and technology.

Bamboos should be considered as a resource with great potential for sustainable industrial development of Tanzania. There is a need of more effort to create awareness about the available bamboo resources and its potential uses in Tanzania. Therefore, bamboos should regularly be included in the national forest inventory (NFI) in order to update information and monitor trends on the richness, coverage, abundance, density,

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distribution and its role to address national concerns in the country.

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