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Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 19, No. 5, p. 50-64, 2021
http://www.innspub.net

RESEARCH PAPER | OPEN ACCESS

Tree species diversity, composition and structure across human impacted and non-impacted areas in upgraded Marang' Forest, Northern Tanzania

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Article published on November 26, 2021

Key words: Protected forest, Protection status, Human impact, Anthropogenic activities, Sustainability

Abstract

Globally, forests' capacity to provide ecological services and support human life is rapidly declining due to the lack of deployment of proper resource management approaches. Countries adopt a wide range of management regimes that vary in degree of effectiveness in controlling unstainable human activities. This study aimed at understanding the impacts of upgrading the protection status of forested areas to a higher International Union for Conservation of Nature (IUCN) categories on tree species diversity, composition, and structure. The study explored Marang' Forest (MF), annexed into Lake Manyara National Park a decade ago after being strongly impacted by mining and other human activities. It uses concentric circular plots to identify tree species, count stems, measure tree diameter at breast height, and assess indicators of disturbances in human-impacted and non-impacted areas. Results show a lower degree of human disturbances, including wood extraction, mining, livestock grazing, and trespassing has deterred in the forest. Tree species richness was about one third, and the Shannon's diversity index was 17% higher, in impacted than non-impacted areas ($t = 5.03$, $df = 34$, $P < 0.001$ and $t = 4.98$, $df = 34$, $P < 0.001$, respectively). The average number of tree stems ha^{-1} was 640 ± 26 significantly higher in impacted areas than non-impacted areas (524 ± 22; $t = 3.46$, $df = 34$, $P = 0.01$). It shows that lowering human disturbances by upgrading forests reserve to higher protected status enhance forest recovery and improve tree species diversity, composition, and structure.

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Introduction

Protected forest reserves are important for biodiversity conservation (Riggio *et al.,* 2019, Rosa *et al.,* 2018), since they minimize anthropogenic activities that are destructive to species and their habitats (Gizachew *et al.,* 2020). Protected forest reserves are often established for multiple purposes, including extractive utilization such as timber production and firewood collection (Riggio *et al.,* 2019). They are therefore more prone to anthropogenic threats compared to national parks which are strictly conservation areas (Pfeifer *et al.,* 2012, Riggio *et al.,* 2019). According to Gizachew *et al.* (2020), extractive utilization and other anthropogenic activities such as agriculture are the major drivers of deforestation and degradation of forests in both protected and non-protected areas. Tree species distribution and diversity are highly affected by extractive utilization (Riggio *et al.,* 2019), and the gaps left after the removal of preferred species are easily colonized by other fast-growing, often invasive pioneer tree species (Abdo *et al.,* 2017).

However, most of the protected forest reserves globally remain excluded from a list of globally protected areas under the International Union for Conservation of Nature (IUCN) categories (Burgess *et al.,* 2017, IUCN 2020). The IUCN categories set the level of access and exclusion of human activities to protect the resources depending on the importance of a particular area to global biodiversity. Tanzania is one of the Sub-Sahara African countries that code its protected areas based on IUCN categories (UNEP-WCMC and IUCN 2016, URT 2014) (Table 1). Yet, most of the protected areas in Tanzania coded under IUCN categories focus more on wildlife conservation (Burgess *et al.,* 2017).

Table 1. Protected areas of Tanzania coded based on IUCN categories.

IUCN category	Purpose	Protected area type	Number	Total area (ha)
Ia	Conserved for science or wilderness protection			
Ib	Conserved for wilderness protection	Forest Nature Reserve	12	30617100
II	Conserved for ecosystem protection and recreation	National Parks Ngorongoro Conservation Area Marine Reserve	22 1 15	12882718 829200 135100
III	Conserved for conservation of specific natural features			
IV	Conserved for conservation through management intervention	Game Reserve Game controlled area	17 42	4954690 58556502
V	Conserved for landscape/seascape protection or recreation			
VI	Conserved for the sustainable use of natural resources	Marine Parks	3	82200

Source: Dudley and Phillips (2006) and URT (2014)

The protected forests reserves management category is less effective in protecting forest resources and biodiversity from threats emanating from human activities, and it is more likely to be converted into other competing land uses as they are not linked to the IUCN category under global watch (Burgess *et al.,* 2017). Thus, in an attempt to improve the protection of forest resources conservation agencies push governments in the countries of the global south to adopt IUCN categories, which are considered to be a more efficient way of protecting global biodiversity (Gizachew *et al.,* 2020, Pringle 2017). The IUCN categories facilitate countries to adopt globally acceptable conservation approaches and benefit from conservation efforts supported by IUCN (2020). This means forest protection status and its management regimes are important in determining the effectiveness of biodiversity protection (Gizachew *et al.,* 2020). Thus, re-categorization and upgrading of protected forests to higher-ranked conservation status have recently become an important conservation tool for forest resources (Akida and Blomley 2008, Pringle 2017, UNEP-WCMC and IUCN 2016).

In Tanzania most of the protected forest areas are managed as national forest reserves, catchment forests, district local authority forests reserves, private forests, and village forest reserves (Santos 2017, URT 2002), which are not under IUCN categories. These forests are not linked to IUCN categories because they are mainly established for watershed protection and extractive uses, and are less focused on biodiversity conservation (Heino *et al.,* 2015, MNRT 2006), weakening its protection (Burgess *et al.,* 2017). Thus, in an attempt to halt the rapid deforestation and forest degradation, Tanzania has entered into sector restructuring by establishing Tanzania Forest Service Agency (TFS), a country forestry agency, to strengthen the implementation of forest management and enforcement of forest conservation laws, adopted the paramilitary forest management strategies, and have upgraded protected forest reserves into nature reserves or annexed them into National Parks (MNRT 2020, Santos 2017). The upgraded forest reserves are managed under IUCN categories (Santos 2017), however, the effect of stricter protection on forest tree species diversity, structure, and composition has rarely been systematically quantified and documented, given the large size and number of protected forests reserves present in Tanzania (Gizachew *et al.,* 2020). Also, Tanzania continues to upgrade protected forests into higher IUCN categories without empirical evidence on its impacts to improve forest condition including tree species diversity, structure, and composition.

Tree species diversity is an essential attribute of forest biodiversity and an indicator of good sustainable management practices (Khaine *et al.,* 2017). On the other hand, Tree species richness, composition, and structure are important indicators for disturbances, and for defining the forest recovery status from previous disturbances (Zilliox and Gosselin 2014). The information is also important for forecasting future trends of forest resource stabilization since the presence of species such as *Croton macrostachyus* (Hochst. Ex Delile)*, Macaranga capensis* (Bail) Benth*, Clausena anisate* (Wild) Hook*, Celtis africana* (Burm.f)*, Dovyallis abyssinica* (A.Rich) Warb*, Albzia gummifera* (J.F.Gmel) C.A.Sm*,* and *Neoboutonia macrocalyx* (Pax) are known to be a good indicator of stages of forest recovery and habitat suitability for other species such as large herbivores (Mwakosya and Mligo 2014, Ndangalasi *et al.,* 2014).

This article, therefore, assesses the biological diversity in an upgraded Marang' Forest (MF) in Manyara Region, Tanzania. The Marang' Forest was designated as a national forest reserve in 1938 and annexed to Lake Manyara National Park (LMNP) in 2009 to conserve tree species, protect crucial habitat for large herbivores, and maintain watershed and catchment functions for lake Manyara (TANAPA 2014). However, there is little information about the forest's tree species diversity, composition, distribution, and population dynamics (URT 2014). Moreover, although human activities are still threatening the forest, these have never been systematically assessed and quantified. The inadequate availability of information is likely to impede conservation authorities from achieving conservation objectives (UNEP-WCMC and IUCN 2016) and monitoring the impact of upgrading the forest's protection status. The present study was conducted to assess the tree species diversity, composition, and structure in impacted and non-human impacted areas of MF to assess the impact of human activities in the forest. We selected areas with anthropogenic disturbances and nearby areas with similar vegetation as control sites to explain the possible causes of variations in tree species diversity, composition and structure. We unveil the effectiveness of upgrading forests to higher ranks of conservation status on tree species diversity, composition, and structure. This study thus contributes to the ongoing debates of finding better ways to manage forest resources in Tanzania and beyond.

Material and methods

Study area

This study was conducted in MF, in Manyara Region, Tanzania. MF has a total area of 230 km², making one-third of Lake Manyara National Park after being annexed in 2009 (Fig. 1). Lake Manyara National

Park is located within longitudes 35° 44' and 35° 51' E and latitudes 03° 21' and 03° 34' S in northern Tanzania (TANAPA 2014), and the greater part of the forest reserve lies between 1,500 and 2,000 meters above sea level (TANAPA 2014). MF lies in the Great Rift Valley covering the plateau and escarpment on the western side of Lake Manyara. The area experiences a bimodal rainfall pattern, with rains between November - December, and March-May, with an average annual rainfall of 1,200-1,500 mm (AWF 2003).

The average temperature ranges from 19°C in March to 15°C in July (Kiffner *et al.,* 2017). The MF is a montane forest dominated by *Casearia battiscombei* (R.E.Fr), *Cassipourea malosana* (Baker) Alston, *Ekebergia capensis* (Sparwm), *Tabernaemontana ventricose* (Hochst.ex.A.DC), *and Teclea nobilis* (Hook.f.), tree species. The large mammalian herbivores within the forest include African elephants (*Loxodonta africana)* and buffaloes (*Cyncerus caffer*), which utilize the area during the dry season (TANAPA 2014).

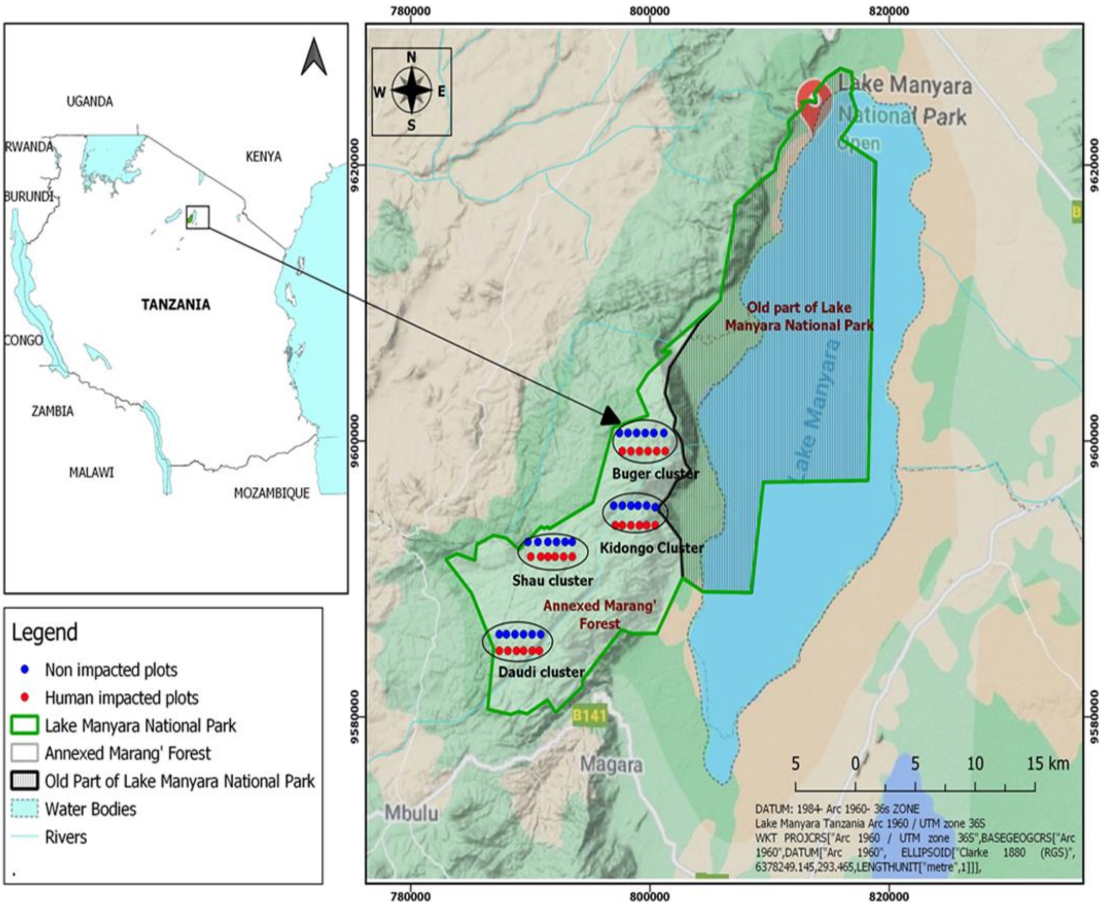

Fig. 1. The map of Lake Manyara National Park including the annexed MF showing sampling plots across human-impacted (red dots) and non-impacted (blue dots) areas.

Data Collection

We used stratified cluster sampling based on the topography and history of human disturbances in the area (Mandallaz 2008). Based on Cochran and William (1977), we established 24 plots in the human-impacted areas and replicated them in control areas, the non-impacted areas, with similar vegetation features (Fig. 1). We used systematic random sampling to establish plots within the clusters, whereby the first plot was laid randomly at a distance of at least 50 m from the edge of the disturbed area, and the subsequent plots were established systematically at intervals of 100 m along a line transect. The distance between the plots was calculated using Equation 1 following by Kashaigili *et al.,* 2013 with slight modifications.

$$PI = \sqrt{\frac{TA}{n}} \quad (1)$$

where PI is plot interval, *TA* = total area of the forest, and *n* = number of plots.

Concentric circular plots, modified from the National Forestry Resource Monitoring and Assessment approach (Vesa *et al.,* 2010), with subplots of 2 m radius and 15 m radius were established. Within the 2 m radius, all seedlings (a tree with a height of ≤ 1 m tall) and saplings (a tree with height > 1 m and diameter at the breast (DBH) < 2 cm-5cm) were counted and identified, while the stems of all trees with a DBH $\geq 5-20$cm (sub-mature) and ≥ 20 cm (mature tree) (Lejju 2004, Luoga *et al.,* 2004) were counted, identified for their scientific names and measured for their diameter at 1.3 m from the ground by using caliper and diameter tape (West 2015). Flora of Tropical East Africa (Kokwaro 1986); Graham (1960), and the botanical field guide book of Trees and Shrubs of East Africa (Dharani 2011) were used to identify the tree species encountered in the study area. Plant samples were also collected for further identification using more Flora of Tropical East Africa (FTEA). The identification of sterile materials of young trees (seedlings, saplings, and sub mature trees) was possible through the use of mature trees of the same species with fertile materials (Rejmánek and Brewer 2001).

Human disturbance indicators such as livestock dung, grazing signs, tree stumps, tree debarking, cleared and excavated areas, soil heaps, and footpath trespassing were recorded along the transect lines and in each plot. The severity of human disturbance was visually estimated and quantified using the Likert scale of 0 to 4, where; 0 = absence of disturbance, 1 = low disturbance, 2 = moderate disturbance, 3 = high disturbance, and 4 = severe disturbance (Makero and Kashaigili 2016) (Table 2).

Table 2. Semi-quantitative indicators of human disturbance and their severity indices in Marang' Forest based on Linkert scale

Disturbance	Severity category	Severity description	Likert scale
0%	0	Absent	0
25%	25	Low	1
66%	50	Moderate	2
99%	75	High	3
100%	> 75	Severe	4

Disturbance =% of plot covered by a disturbance (based on visual estimates).

Data analysis

We applied the Shannon Wiener diversity index (H') formula ($\boldsymbol{H' = -\sum_{i=1}^{s} P_i lnP_i}$) (Kent and Coker 1992) and Simpson's Index of Dominance ($\boldsymbol{ID = \sum\left(\frac{n_i}{N}\right)^2}$) (Simpson 1949) to compute tree species diversity indices. The composition and structure of the tree species within the forest were expressed in terms of stem density (ha^{-1}) and within different growth stages and diameter size classes. We analyzed and expressed the frequency of occurrence of each human disturbance indicator in the surveyed areas as a percentage, and the severity of each disturbance was calculated using equation 2 as proposed by Makero and Kashaigili (2016):

$$\text{Severity}= \frac{\sum \text{occurrence of individual human disturbance}}{\text{Total severity scaled in all sampled plots}} \quad (2)$$

We performed inferential statistics in Jamovi (V. 1.1.9.0), tested for normality using the QQ plot and Shapiro-Wilk test, and conducted a student's t-test to compare average tree species diversity indices, composition, and structure between impacted and non-impacted areas. Chi-square tests investigated whether human disturbance differed significantly within the surveyed areas (Makero and Kashaigili 2016).

Results

Tree species diversity in Marang' Forest

We found a total of 58 tree species across the human-impacted and non-impacted areas of the forest. Among these, 15 and 9 tree species occurred only in the impacted and non-impacted areas respectively, while 34 tree species occurred in both areas.

The unique tree species in the impacted areas that contributed to the high diversity were *Nuxia congesta* (R.Br. ex Fresen.), *Senna didymobotrya* ((Fresen.) H.S.Irwin & Barneby)), *Solanicio mannii* ((Hook. f.) C. Jeffrey.)), *Vernonia myriantha* (Hook.f), *Brucea antidysentrica* (J. Miller), *Canthium oligocarpum* (Hiern), *C. anisate*, *Ehretia cymose* (Thonn) and *Abutilon longicuspe* (Hochst. ex A. Rich.).

The most dominant tree species in the non-impacted areas were *Xymalos monosphora* ((Harv.) Baill)), *T. ventricosa (Hochst. ex A.DC.)*, *C. battiscombei* (R.E. Fr), *Vepris simplicifolia* ((Engl.) Verdoon)), *T. nobilis* (Hook.f.), *B. abyssinica* (Fresen), *Olea capensis* L, and *Prunus africana* (Hook.f.) Kalkman, (Appendix A).

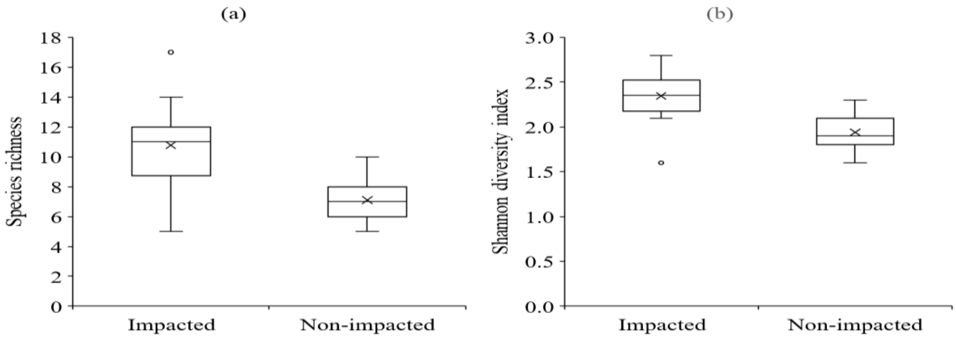

Fig. 2. Tree species richness and diversity indices in the impacted and non-impacted areas of Marang' Forest. (a) Tree species richness, (b) Shannon's index. The boxes represent the inter-quartile range, circles represent outliers, the median represented by a line, and the whiskers represent the variation range

The tree species richness was higher in impacted areas (t = 5.03, df = 34, P < 0.001) than in non-impacted areas by about one third. Both ID and H' indices were higher in the impacted areas than the non-impacted areas by about 2% and 17% respectively (t = 4.54, df = 34, P < 0.001; t = 4.98, df = 34, P < 0.001, respectively) (Fig. 2).

However, the Index of Dominance (ID) was generally lower, reflecting the small number of stems per individual tree species, and differed slightly but significantly between the human-impacted (ID = 0.10 ± 0.01) and non-impacted areas (ID = 0.15 ± 0.00; t = 4.5, df = 34, P < 0.001). The two most dominant tree species in both areas were *T. ventricosa* and *X. monosphora*, occurring at a frequency of about 8% and 11%, respectively in the impacted areas, and 6% and 7%, respectively in the non-impacted areas. Additionally, these two tree species had the highest number of stems ha^{-1} and appeared to have more stems ha^{-1} in the impacted areas than the non-impacted ones (Fig. 3).

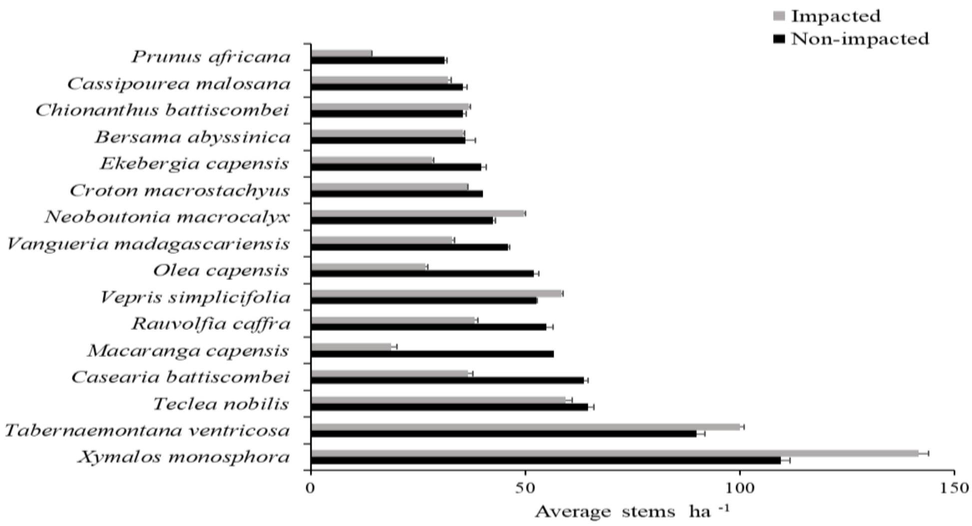

Fig. 3. The average stem density ± SE for the most frequently-occurring tree species in the impacted and non-impacted areas of Marang' Forest.

Tree species composition and structure in Marang' Forest

Most of the stems in the impacted area had a diameter of 10 - 30 cm while only a few species such as *Ekebergia capensis* (Sparwm), *Albizia gummifera,* and *Ficus thonningii* (Blume) had stems with > 50 cm. In contrast, the non-impacted areas had more stems of tree species with larger diameters (> 50 cm), including the endangered tree species *P. africana* (Fig. 4).

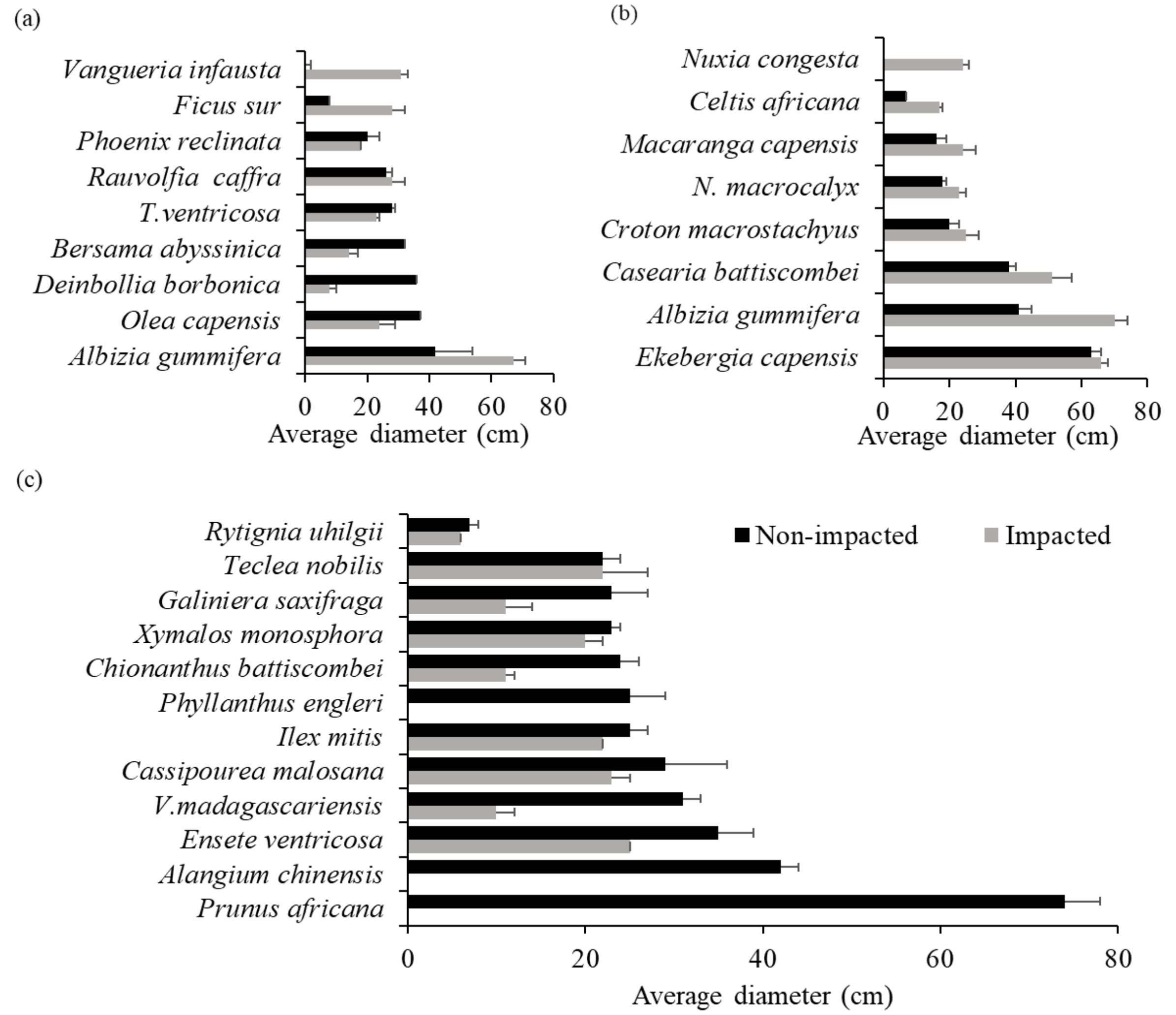

Fig. 4. Average ± SE stem diameter stem diameter of the mature tree species with a diameter greater than 30cm at breast height in the impacted and non-impacted area in Marang' Forest.
(a) Opportunistic tree species, (b) Pioneer species (c) Tree species which are intolerant to disturbance

The average number of tree stems ha^{-1} was significantly higher in the human-impacted areas than the non-impacted areas by about 10% (t = 3.46, df = 34, P = 0.01). The high stem density in the human-impacted areas was largely contributed to by seedlings and saplings which were higher in these areas than the non-impacted areas by about 62% and 38% respectively (t = 7.21, P < 0.001 and t = 10.56, P < 0.001, respectively). Similar patterns were observed for sub-mature tree stem density which was also higher in the impacted areas than the non-impacted areas by about 26% (t = 5.18, P < 0.001). In contrast, the mature tree density was higher in non-impacted areas than impacted areas by about 40% (t = 10.37, P < 0.001) (Fig. 5).

Besides, the tree stem density differed significantly among growth stages, with seedlings and saplings being more abundant than sub-mature and mature trees (F= 16.8, df = 3, P <0.001; Fig. 5).

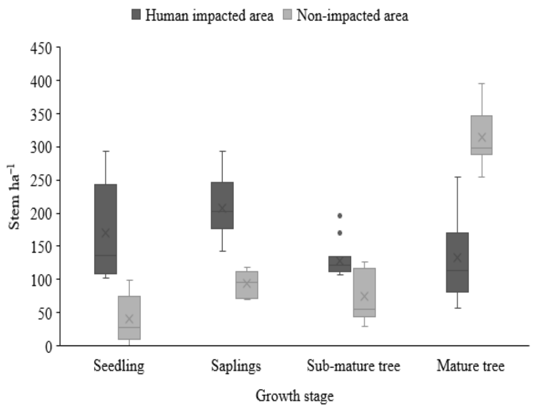

Fig. 5. The number of tree stems ha^{-1} across different growth stages in impacted and non-impacted areas in Marang' Forest within Lake Manyara National Park, Tanzania. Boxes represent the inter-quartile range, mean represented by x, grey circles represent outliers, median represented by a line in the boxes, and whiskers represent the range of variation.

Tree population structure and composition in Marang' Forest

Out of the 58 tree species identified in MF, only 36 had seedlings. Most of these seedlings and saplings were dominated by species of *S. didymobotrya, C. anisate, C. macrostachyus,* and *A. longicuspe*. We also observed the presence of some seedlings of the endangered tree species; *P. africana* in the impacted areas (Appendix A). Other tree species such as *Ensete ventricosa* ((Welw.) Cheesman)), *Galiniera saxifrage* ((Hochst.) Bridson)), *Ritchiea albersii* (Gilg.), and *Rothmania fischeri* ((K. Schum.) Bullock)) showed no seedlings and were only recorded in sub-mature and mature stages in both impacted and non-impacted areas (Appendix A).

Human disturbances in Marang' Forest

The types of human disturbance differed significantly in their frequencies. About one-third of the signs of human disturbance was wood extraction, followed by mining, and livestock grazing, associated with trespassing ($\chi^2 = 9.24$, $df = 3$, $p = 0.026$) (Table 2). The percentage of human disturbances was calculated as the total frequency of the indicators for each disturbance over the total frequency of all indicators across all sampled plots (Table 3).

Table 3. The frequency of human disturbance signs observed in Marang' Forest.

Observed indicator	Wood extraction	Grazing	Trespassing	Mining	Total	Percent (%)
Stump	38	0	0	5	43	31.6
Sawing platform	1	0	0	0	1	0.7
Log beehive	1	0	0	0	1	0.7
Excavated area	0	0	0	24	24	17.8
Siltation	0	0	0	7	7	5.1
Uprooted tree	1	0	0	7	8	5.9
Plastic materials	0	0	0	1	1	0.7
Cow dung pile	0	20	0	0	20	14.7
Cow footprint	0	5	0	0	5	3.7
Goat pellets	0	1	0	0	1	0.7
Cattle present	0	1	0	0	1	0.7
Browsing signs	0	1	0	0	1	0.7
Fodder collection	0	1	0	0	1	0.7
Footpaths	0	0	22	0	22	16.2
Total	41	29	22	44	136	100.0
Human disturbance (%)	30.1	21.3	16.2	32.4	100	
Chi- square test		$\chi^2 = 9.24$	df = 3	p = 0.026		

The Chi-Square test was conducted to compare whether human disturbances differed significantly within the impacted area

We classified mining and grazing as the most severe human disturbance within the forest based on their estimated percentage of occurrence in the sampled plots, with an average severity of 63.1% ± 3.2 and 55.2% ± 3.8 per sampled plot. Most signs of livestock grazing (97%) were < 7 days old, while about 33% of signs of mining were < 1 year old and a few signs of mining (5%) were > 8 years old (Table 4). The severity of the disturbance was calculated as the total occurrence of individual human disturbance over the total estimated severity of a particular disturbance in all sampled plots (Makero and Kashaigili 2016).

Table 4. The average severity (± SE) of human disturbance and estimated time since disturbance as observed in Marang' Forest

Human disturbance	Average severity ± SE (%)	Estimated time since disturbance	Frequency	Percent (%)
Grazing	55.2 ± 3.8	Total	29	100
		< 7 days	28	97
		< 1 day	1	3
Mining	63.1 ± 3.2	Total	42	100
		< 1 year	14	33
		< 3 years	7	17
		< 5 years	19	45
		< 8 years	2	5
Trespassing	50.2 ± 2.9	Total	22	100
		< 1 year	6	27
		< 7 days	16	73
Wood extraction	37.8 ± 2.3	Total	43	100
		< 1 year	5	12
		< 5 years	13	30
		< 8 years	7	16
		< 10 years	18	42

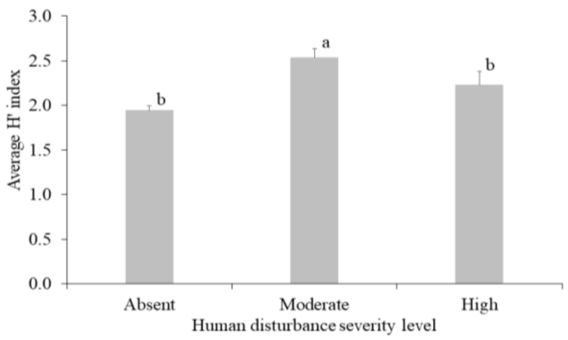

Fig. 6. Average ± SE Shannon diversity index (H') for tree species across different levels of human disturbance severity in Marang' Forest.

We also found that the areas with signs of mining had significantly lower tree species diversity compared to areas with signs of fresh livestock grazing and wood extraction (Fig. 6). The H' values also differed slightly within the sampled plots but significantly between the moderately disturbed (H' = 2.5 ± 0.1), highly disturbed (H' = 2.2 ± 0.2) and areas with zero disturbance (H' = 1.9 ± 0.1; $F = 12$, $df = 2$, $p < 0.001$).

Discussion

Tree species diversity in Marang' Forest

The present study reveals that most tree species in MF were common in both human and non-human impacted areas while a few were unique to either of the two areas. The study shows that the high tree species diversity in the impacted areas was mostly contributed by pioneer and opportunistic tree species. Our observations are similar to studies by Mwakosya and Mligo (2014), and Abdo *et al.* (2017) who also noted higher numbers of pioneer and opportunistic tree species in disturbed areas of forests. The H' ranged within 1.9 and 2.3 in the impacted areas, which is within the range reported in other protected forests in eastern Africa (Gizachew *et al.,* 2020, Wekesa *et al.,* 2019). Our findings highlight the importance of deterring human disturbances by upgrading the status of MF to full protection.

Other studies in forests with interventions in management regimes have also highlighted that high tree species diversity is partly caused by minimum previous human disturbance (Calle and Holl 2019, Wekesa *et al.,* 2019). The studies by Chazdon (2003) and Chazdon and Guariguata (2016) show that natural recovery of forest species diversity occurs gradually and depends on the severity of the prevailing disturbance.

In this study, we also observed that the first stages of recovery in MF occurred after the forest received full protection in the year 2009 (TANAPA 2014). Studies by Calle and Holl (2019) and Chowdhury *et al.* (2019) also show that upgrading forest reserves to higher conservation status allows forest diversity to recover. There is also little dominance among tree species. This shows that most tree species contributed to the forest's diversity relatively evenly (Chowdhury *et al.,* 2019). The index of dominance values obtained in our study is comparable to other protected forests of the Eastern Arc and Great Rift valley mountains forests within Tanzania and Kenya (Wekesa *et al.,* 2019).

Tree species composition and structure in Marang' Forest

Our results show that tree species communities within the human-impacted areas in MF are not evenly distributed within different growth stages. This highlights the impact of selective wood extraction, clearance during mining activities, and livestock grazing on different stages of tree growth (Gebeyehu *et al.,* 2019). These observations are similar to those of Chhetri and Shrestha (2019) who assert that the removal of forest biomass through human disturbances such as grazing or tree harvesting affects the forest succession process. Most tree species in the human-impacted areas were in the seedling, sapling, and sub-mature growth stages, with diameters ranging between 10 and 30 cm. Only a few species such as *E. capensis, A. gummifera,* and *F. thonningii,* had larger diameters, which indicates that these species can quickly regrow (Gebeyehu *et al.,* 2019, Mwakosya and Mligo 2014). However, the existence of many small trees also shows the potential recovery of forests, resulting in secondary forests (Chazdon and Guariguata 2016). Further, our results also revealed the recovery of most extracted valuable tree species such as *Olea capensis,* which is a commercially important timber plant internationally, and *P. africana,* a species used for medicine and timber both locally and internationally (Lukumbuzya and Sianga 2017). Although these valuable tree species had seedlings and saplings, they had no mature individuals in the impacted areas. Our findings are in line with other studies conducted in protected forests in Africa including in Cameroon, Ethiopia, and Zimbabwe which show that most of the exploited tree species had more stems in lower classes comprising seedlings and saplings (Kabede *et al.,* 2014). *Prunus africana* is presently added as a vulnerable tree species to the IUCN red list of threatened tree species (World Conservation Monitoring Centre 1998). This signifies the effect posed by selective wood extraction on species in MF. According to Pfeifer *et al.* (2012), the protection strategies in the forest reserves in East Africa are still not sufficient, and human disturbances continue to threaten many tree species within the reserves, particularly those which have commercial values. However, *X. monosphora* and *T. ventricosa* were the most abundant species, both in the impacted and non-impacted areas, showing that they are less exploited by the local community (Dharani 2011).

Tree population structure and composition in Marang' Forest

The overall higher number of seedlings, saplings, and sub-mature trees in the impacted sites show the recovery stage (Chazdon and Guariguata 2016). Our findings are also in line with those of AWF (2003) and Ndembwike (2010) who revealed that MF has been under constant threat from different human activities such as mining since the 1970s. Apart from mining activities, MF is also threatened by other human activities such as firewood collection, tree cutting for building materials, domestic animal grazing, and collection of non-timber forest products (AWF 2003). The human disturbances, also confirmed by the present study, open up gaps that allow for the penetration of light and fast-growing tree species to take over and colonize an area (Mligo 2018). The presence of many sub-mature trees of pioneer species such as *M. capensis, C. macrostachyus, C. malosana,* and *C. africana* in MF is an indication of forest recovery from the previous disturbances after the conservation intervention by TANAPA (Riggio *et al.,* 2019, Rosa *et al.,* 2018).

Also, the presence of seedlings and saplings of tree species that are sensitive to disturbance (Mwakosya and Mligo 2014) such as *B. antidysentrica, C. malosana C. africana, Chionanthus battiscombei, Ilex mitis, Lepidotrichilia volkensii, Ochna holstii, P. africana, Psychotria riparia* ((K.Schum & K.Krause) E.M.A.Petit)), *Rytignia uhilgii* ((K.Schum.) & K. Krause) Verdc.)), *Trimeria grandifolia* ((Hochst.) Warb.)), *V. infausta* (Burch.), *and V. madagascariensis* (J.F.Gmelin) indicates the recovery of the forest, which leads to an overall stable forest tree community (Gebeyehu *et al.,* 2019). The presence of many seedlings and saplings of *S. didymobotrya* and *A. longicuspe* in MF further confirm that it has previously been disturbed by human activities (Chazdon and Guariguata 2016). However, other tree species seedlings and saplings that regenerated in disturbed areas such as *P. africana, C. africana, V. infausta,* and *C. anisata* imply a recovery and potential stabilization of the forest ecosystem, though with secondary forest growth (Chazdon 2003).

The regeneration of seedlings and saplings of species intolerant to disturbances such as *P. africana* signifies that MF has a high capacity for recovering. However, without strong protection through the upgrading of the forest to higher conservation status that restricts human activities, the number of seedlings can easily be destroyed by livestock grazing, particularly within areas near grassland patches within the forest (Kikoti and Mligo 2015).

Human disturbances in Marang' Forest

Illegal grazing within MF still occurs regularly, probably due to the availability of palatable grass within the grassland patches. Mining activities were also still frequently encountered during our study, probably because people had been used to legally mining in the forest and were still aware of the mineral potential of the area. These incidences of illegal activities within the forest were largely due to irregular patrols in the interior part of the forest (Mwakosya and Mligo 2014). Most human disturbances, either legal or illegal, involve removing and damaging tree species (Garcin *et al.,* 2018). Livestock browsing damages leaves and tender twigs of seedlings and saplings, and subsequently allows areas to be dominated by unpalatable shrub species rather than trees (Kikoti and Mligo 2015). This could explain why *Sida massaica* (Vollesen), was dominant in the patches of grassland within MF. According to Kikoti and Mligo (2015), *Sida massaica,* is a shrub, thus, its presence in the forest indicates frequent grazing in an area. These authors also revealed the increase of shrubs in areas affected by livestock grazing within the Kilimanjaro montane forest. However, the presence of tree species such as *B. abyssinica* and *C. malosana* indicates that the disturbance within the forest is declining as these tree species are indicators of low disturbance in montane forest ecosystems (Kikoti and Mligo 2015, Mwakosya and Mligo 2014). This implies that upgrading forests to a higher conservation standard reduce human disturbances and improve forest condition.

Conclusion

This study shows that the differences in diversity indices, composition, and structure of forest tree species are strongly influenced by human disturbances that prevailed. The presence of seedlings and saplings of pioneer tree species favored by disturbance, such as *A. longicuspe, C. macrostachyus,* and *S. didymobotrya*, and disturbance-intolerant tree species such as *C. malosana C. africana, C. battiscombei,* and vulnerable tree species, *P. africana* elucidate forest recovery and stabilization. It also means upgrading forest areas to a higher conservation status can reduce human disturbances and improve forest conditions. This calls for conservation agencies to reinforce conservation activities through the use of globally acceptable approaches to guarantee the long-term persistence of native, endangered, and highly valued tree species communities.

Acknowledgments

The authors also are grateful to Dr. Canisus Kayombo and Richard Giliba for their assistance in the identification of trees in the field and the Tanzania National Park Authority for consenting to the conduction of this study within the area of their jurisdiction.

Funding

This work was supported by the This work was supported by the Centre for Research, Agricultural advancement, Teaching Excellence and Sustainability in Food and Nutritional Security (CREATES) of the Nelson Mandela African Institution of Science and Technology, with generous funding from the World Bank. The funders had no role whatsoever in the study design, data collection, data interpretation, nor in the writing and the decision to send this article for publication.

Declaration of interest

The authors declare no conflict of interest

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Appendix A.

The list of tree species identified within impacted and non-impacted areas in Marang' Forest and their distribution within different growth stages

Botanical name	PS	OS	ID	ITD	Impacted area	Non-impacted area	Seedling	Sapling	Sub-mature	Mature
Abutilon longicuspe	X	X	√	X	√	X	√	X	X	X
Alangium chinense (Lour.) Harms	X	X	X	√	X	√	X	X	X	√
Albizia gummifera	√	√	X	X	√	√	√	X	X	√
Bersama abyssinica	X	√	X	X	√	√	√	√	√	√
Brucea antidysentarica	X	√	X	√	√	X	√	X	X	X
Canthium oligocarpum	X	√	X	X	√	X	X	X	√	√
Casearia battiscombei	√	X	X	X	√	√	√	√	√	√
Cassipourea malosana	X	X	X	√	√	√	√	√	√	√
Celtis Africana	√	X	X	X	√	√	X	√	√	X
Chionanthus battiscombei (Hutch.) Stearn	X	X	X	√	√	√	√	√	√	√
Clausena anisate	X	√	X	X	√	X	√	X	X	X
Croton macrostachyus	√	X	X	X	√	√	√	√	√	√
Deinbollia borbonica (Scheff.)	X	√	X	X	√	√	√	√	√	√
Dovyalis abyssinica	√	X	X	X	√	√	√	X	X	√
Dracaena steudneri ((Engl. (M))	X	√	X	X	X	√	X	X	X	√
Ehretia cymose	X	√	X	X	√	X	√	X	X	X
Ekebergia capensis	√	X	X	X	√	√	X	X	√	√
Ensete ventricosum	X	X	X	√	X	√	X	X	X	√
Erythrococca fischeri (Pax)	X	√	X	X	√	√	√	√	√	√
Eucalyptus camaldulensis (Dehnh)	X	X	√	X	√	X	X	X	√	√
Eucalyptus saligna (Sm.)	X	X	√	X	√	X	X	X	√	√
Euclea divinorum (Hiern)	X	√	X	X	√	√	X	X	√	√
Ficus sur (Forssk.)	X	√	X	X	√	√	√	√	√	√

Ficus thonningii	X	√	X	X	√	X	X	√	√	X
Galiniera saxifrage	X		X	√	√	√	X	X	√	X
Ilex mitis (L.) Radlk.	X	X	X	√	√	√	√	√	√	√
Lepidotrichilia volkensii (Gürke) J.-F.Leroy)	X	X	X	√	√	X	√	X	X	X
Macaranga capensis	√	X	X	X	√	√	√	X	√	√
Maytenus heteropylla (Eckl. and Zeyh.) N.K. B	√	X	X	X	√	√	√	X	X	X
Mystoxylon aethiopicum (Thunb.) Loes.	X	√	X	X	√	√	X	√	X	√
Neoboutonia macrocalyx	√	X	X	X	√	√	√	X	X	√
Nuxia congesta	√	X	X	X	√	X	X	X	X	√
Ochna holstii (Engl.)	X	X	X	√	√	√	√	X	X	X
Olea capensis	X	√	X	X	√	√	X	√	X	X
Oncoba spinosa (Forssk.)	X	√	X	X	X	√	X	√	X	X
Pavetta abyssinica (Bridson)	X	X	X	√	X	√	X	√	√	X
Phoenix reclinata (Jacq.)	X	√	X	X	√	√	X	X	X	√
Phyllanthus engleri (Pax)	X	X	X	√	X	√	X	X	√	√
Prunus africana	X	X	X	√	√	√	√	X	X	√
Psychotria riparia	X	X	X	√	√	√	√	X	X	X
Rauvolfia caffra (Sond.)	X	√	X	X	√	√	√	√	√	√
Ritchiea albersii	X	X	X	√	X	√	X	√	X	X
Rothmania fischeri	X	X	X	√	X	√	X	√	X	X
Rytignia uhilgii	X	X	X	√	√	√	√	√	X	X
Senna didymobotrya	√	X	√	X	√	X	√	√	X	X
Sida massaica	X	X	√	X	√	X	X	X	X	X
Solanecio mannii	√	X	√	X	√	X	√	X	X	X
Strombosia scheffleri (Engl.)	X	X	X	X	√	√	X	√	√	X
Syzygium guineense (Willd.) DC	X	√	X	X	√	√	X	√	√	X
Tabernaemontana ventricosa	X	√	X	X	√	√	√	√	√	√
Teclea nobilis	X	X	X	√	√	√	X	√	√	√
Trimeria grandifolia	X	X	X	√	X	√	√	X	X	X
Vangueria infausta	X	√	X	X	√	√	√	X	X	X
Vangueria madagascariensis	X	X	X	√	√	√	√	√	√	√
Vepris simplicifolia	X	X	√	X	√	√	√	√	√	√
Vernonia myriantha	√	X	√	X	√	X	√	X	X	X
Xymalos monospora	X	X	X	√	√	√	√	√	√	√

Whereby there are pioneer species (PS), Opportunistic species (OP), Indicator species of disturbance (ID) and Intolerant species to disturbance (ITD); X = Absent, √ = Present