

Native Tree Species Regeneration and Diversity in the Mountain Cloud Forests of East Africa

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1. Introduction

Biodiversity is defined by the Convention on Biological Diversity ¹ as “the variability among living organisms from all sources including *inter alia*, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. Thus in this definition diversity can also be described by listing of species even though such lists may not show the quality of diversity being described. For plants, assessments of biodiversities are complex because of the magnitude of numbers of species compositions in a setting. In the tropics alone, it has been reported that there are more than 200,000 species of flowering plants, which also include many tree species². Furthermore, variations in species compositions between different geographical areas make biodiversity assessment even more complicated. In tropical African forests for example it has been observed that in an area of about 10⁶ km², there can be between 30,000 and 120,000 of flowering plant species alone; and in smaller areas such as plots of about 0.1 and 1 hectares this variation has been found to be between 30 and 300 of tree species³. Nevertheless, it is acknowledged that patterns and processes of diversity analyses have improved as per FAO forest resource assessments ^{4,5}. With regard to habitats, it is noted that there is a lack of detailed survey information on habitat types, species or genetic diversity in many forests in the tropics⁶. In addition, the complexity in assessments is exacerbated in the tropics because of the introductions of exotic plant species such as was the case in most of the East African highlands during the last century⁷.

The interest in forest biodiversity has increased lately due to the many threats forest ecosystems face in many regions of the world. These threats not only affect the ecosystem co-benefits such as biodiversity; and cultural and aesthetic values but also the service provisions and regulatory functions of the forests. In Kenya, there are nineteen habitats and ecosystems which exclude agricultural and barren lands that are valued for their high biodiversity. One such is the highland moist forests ecosystem which occupies 2% of the land area of the country⁸ and occurs in altitudinal ranges of 1400-2000m. Similarly at the global level, the mountain cloud forests have received considerable attention because of their ecological values and threatened stability⁹. The Taita Hills forest ecosystem occurs within the highland moist ecosystems. These forests belong to the only existing mountain cloud forests in East Africa and form a part of the Eastern Arc Mountains which stretch from Tanzania to south-west Kenya. These forests form the northern most parts of these Mountains. The Taita Hills rise from 1400m in the southeastern slopes to above 1700 m altitude

in the northwestern slopes¹⁰, and as it is typical with most cloud mountain forests; these forests are the home to a variety of native tree and animal species. The forests host some endemic plant species such as the wild coffee, *Coffea fadenii* Bridson. In all, the plants they host are categorized as follows: 40% of the plant species, 2% of the genera and 13 taxa that are endemic to Taita Hills forests, and additional 22 plants that are endemic only to Kenya and Tanzania^{11,12,13}. Due to these diversities, the forests are ranked among the 34 biodiversity hotspots of the world with respect to high ratios of endemic plants and vertebrate species per area^{14,15}. Presently, there are only four out of twelve fragments of that are of appreciable coverage in area remaining in these hills and these are: Ngangao (120 ha), Chawia (86 ha), Mbololo (185 ha) and Irizi (47 ha), the largest of the three were investigated (Fig.1).

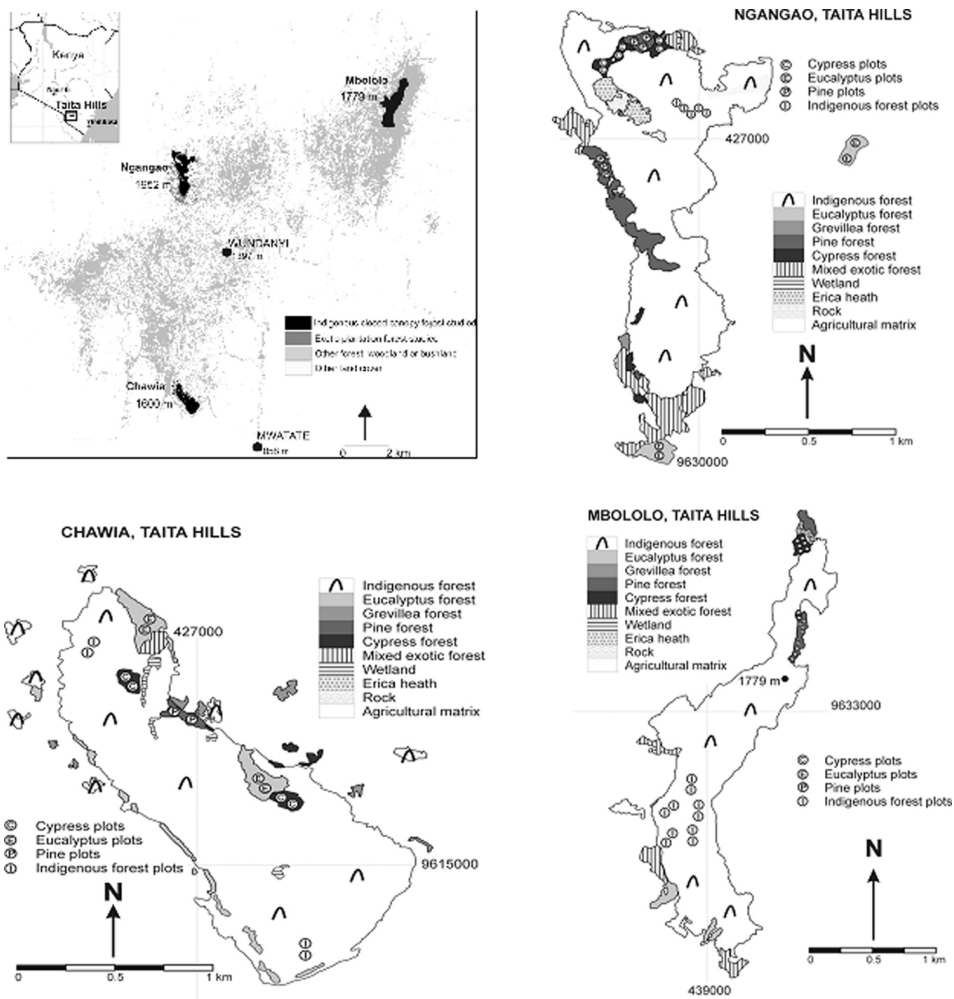


Fig. 1. The location of Taita Hills in Kenya and the three forests studied. (Source; Omoro et al., 2010)

In this chapter, the observation from research work conducted in three out of the 12 forest fragments considered larger in sizes are discussed. The study sought to assess the diversity of native tree species regenerated within the native and exotic forest plantations. The study assessed this biodiversity by evaluating the species diversity, richness and similarity of the regenerated species between the exotic plantations of pine, eucalyptus and cypress; as well as between native and exotic forests. Other factors such as levels of disturbance were established as not only affecting the ecological functions of these forests but also the loss in some of the species vital for use for medicinal purposes. The perceptions of the communities on how the species composition has affected the ecological functions of the forests was reported as effect on water yield into the streams. Finally, potential management activities that can be instituted to restore the biodiversity are suggested.

1.1 Causes for biodiversity loss

Globally, biodiversity hotspots previously covered an area of 15.7% of the global land surface¹⁴ but currently cover only 2.3%¹⁶ and they are still experiencing different forms of disturbances which constantly threaten their existences. In most cases, these disturbances are due to changes in land use, overexploitation of resources and introductions of exotic species. In addition, ineffective implementation of policies by national institutions exacerbates the losses of biodiversity in many countries, because less attention is given to ensuring that regulations that are in place for the management of these forests are implemented. The Taita Hills forests also faced similar threats until, the 1990s when their conservation was taken seriously. As a result, the disturbances they suffered not only impacted on the biodiversity loss but also on other functions and services of the forests. Farmers in Chawia, for instance, during a Participatory Rural Appraisal exercise by Lekasi¹⁶ recalled that water availability and soil fertility had been reduced from the 1920s to 2005 due to what they perceived as the destruction of forests and the introduction of unsuitable exotic tree species; and that they are presently conserving the forest to improve water yield through reforestation with native species¹⁷.

The sources of disturbances to these forests were anthropogenic and caused mainly by the demographic dynamics. In particular, population growth without corresponding increase in farm holding sizes prompted people to encroach into the forests. As a result, forests were cleared for agricultural production. In addition, other activities such as: firewood collection, charcoal production and grazing^{18,19} occurred, which rapidly contributed to the degradation of the forests to the extent that 90% of forest cover loss is estimated to have occurred during the last 200 years¹¹. These forests are also red listed by IUCN²⁰ because 236 of their plants are classified as either endangered or vulnerable. Furthermore, the exotic plantations of pine (*Pinus patula*, Schiede ex Schlecht. & Cham), eucalyptus (*Eucalyptus saligna* R. Baker) and cypress (*Cupressus lusitanica* Miller) that were established between the 1960s and 1980s as forest stands within the native forests and as individual trees for enrichment planting²² have further led to changes in species composition. These were part of management plans to provide softwood production, protection of the native forests and to mitigate against soil erosion. All these activities inadvertently exacerbated the threats to the biodiversity in these forests²³. Another reason for the loss in forest cover was the ineffective implementation of the forest policies in place. For instance, despite a national policy in 1977 which banned the logging of the native forests without licence¹⁹, the people continued to encroach and log from these forests; as a result of unsustainable use of forest resources akin to property of the commons²⁴ and without a well defined forest management strategy, the forests lost much of

their ecosystem functions. A study by Himberg¹⁷ shows how the communities living around these forests decry the losses of the services such as reliable water flow and some of the medicinal plants.

1.2 Forest disturbance and its consequences on biodiversity

Several forest degradation types have been documented, at the global level^{25,26,27} as well as at the local level²⁸, and most severe one consists of a total loss of forest cover due to disturbances. The consequences of this loss not only effects the biodiversity but also ecosystem functions²⁸, including pest control and pollination in agricultural crops²⁹, seed dispersal³⁰, and the regulation of water resources^{29,31}. While in many instances losses in forest cover have negative impacts, in other circumstances, positive impacts have been noted in which there have been increases in plant species diversity. Such improvement in species diversity has been attributed to resilience which allow the certain plants to regenerate profusely after disturbance or to changed forest conditions such as increased light to forest floor³² which favour the establishment of pioneer and early successional species whose seeds may have been stored in the soil seed bank. In the Taita Hills, the consequences of the disturbances documented have shown marked changes in tree species compositions^{25,33}. The most disturbed forest fragment had a higher degree of changes in tree species composition in which 58 different tree species regenerated with stem densities varying between 10 and 2000 trees per hectare³³. Differences in species composition occurred between the forest stand types, with native forests showing higher species diversities than the exotic plantations. The loss of biodiversity had also affected the animal species composition³⁴.

2. Biodiversity assessment

2.1 Sampling of vegetation

Generally for biodiversity assessments vegetation is sampled in designated plots whose designs vary. In the Eastern Arc Mountains, a Y design developed by USDA³⁵ (Fig.2) and modified for Forest Health Monitoring (FHM) in the Eastern Arc Mountains of Kenya and Tanzania^{36,37} have been used. Once the study plots are identified, sampling for vegetation entails enumerating the individual tree found in each plot by species. In order to assess the regeneration dynamics, it is important that during sampling, seedlings and saplings are enumerates as well. In this study, all live juvenile trees of > 5cm in diameter at breast height (dbh) were identified and recorded from each of the two randomly selected subplots. The seedlings were categorised based on height up to 1.3 m in height while sapling were categorized to be higher than 1.3m and with diameters less than 5cm dbh

2.2 Diversity calculations

There are several methods for analyzing plant diversity and its elements^{38,39}, and these methods provide indices which provide bases for comparison. Lou⁴⁰ has gone a step further by deriving Effective Numbers from these indices. These are whole numbers which make comparisons between different diversities easier since the numbers show the magnitude of the differences which makes it easy to perceive. Once the data collected for the diversity analysis is sorted, the diversities can be derived based on several formulae depending on which index is selected. An example is shown for Shannon-Weaver index that has been used in this analysis as Box 1. For practical use however, a Biodiversity Calculator software³⁹

and can be used for the calculations. This calculator is freely available online (<http://www.columbia.edu/itc/cerc/dunoffburg/MBD/LIMK.html>). In this software, values for species derived from the data are fed in the calculator which then provides a range of diversity indices (e.g. Shannon-Weaver, Simpson and Broken stick) which one can select to use. In many cases such as in the Eastern Arc Mountain forest, the Shannon-Weaver index (H') has been commonly used for these calculations^{25,33}. This is because it provides an account of both the abundance and evenness³⁸ and does not disproportionately favour any species as it counts all the species according to their frequency^{39,40} unlike indices such as Simpson's which disproportionately highlights common species (in terms of abundance) instead of showing their frequencies (richness) in samples. One documented disadvantage of the Shannon-Weaver index is however, that it requires a large sample size in order to minimize biases⁴¹. Shannon-Weaver's indices ranges are typically from 1.5 to 3.5 and rarely reach 4.5⁴². Other parameters such as species richness (S) and species evenness ($H'E$) are also generated from the same calculator.

Box 1. Shannon-Weaver biodiversity Index

Shannon's index, (H') is defined by

$$H' = -\sum_{i=1}^S p_i \ln p_i \quad (1)$$

Where i , is the proportion of the species relative to the total number of species (p_i) multiplied by the natural logarithm of this proportion ($\ln p_i$) and the final product multiplied by -1.

Species richness, the number of species present in an ecosystem (S) was defined by

$$S = \sum n \quad (2)$$

Where n is number of species in a community.

Species evenness, the proportion of individuals among species in an ecosystem is often assessed by Shannon's equitability index ($H'E$) which is calculated by

$$H'E = H' / H_{\max} \quad (3)$$

Where H_{\max} is defined as $\ln S$. $H'E$ values range from 0 to 1 and 1 indicates complete evenness.

The Shannon-Weaver's indices obtained in the study were converted to *effective numbers* using a method by Lou⁴⁰; this can be done to obtain values that can be used to compare the differences in species diversities. The *effective numbers* are calculated as an exponential of the Shannon's index as:

$$N_{\text{Effect of species}} (p_i) = \exp\left(-\sum_{i=1}^S p_i \ln p_i\right) \quad (4)$$

To obtain similarities in species composition between forest fragments and forest stands, the Jaccard's index⁴³ was used. Jaccard's index (C_j) is defined by

$$C_j = a/a+b+c \quad (5)$$

where a, is the number of species present in both forest types or locations compared, b is the number of species in only one forest type or location; and c is the number of species present in the other forest type or location.

When establishing diversities and studying the regeneration dynamics, densities of native tree species in the study sites and forest stands (e.g., in exotic and native forests) have to be calculated on per area basis as well. In order to show the differences both in diversity and regeneration levels, further statistical analyses have to be done for the indices and diversities derived. There are several statistical methods (SAS, STATA, SPSS) which can be used to assess such data sets. In the case of Taita hills, a one way ANOVA was used and SPSS 15 for windows software method adopted for the statistical analyses. The means were separated by applying Tukey's test to test the differences in the diversities and densities between the forest sites and types.

3. Regeneration and species diversities

3.1 General structure of exotic and native forests

A description of the existing trees, seedlings and saplings in all the three exotic and native forests studied in the Mountain cloud forests of Taita Hills is shown in Table 1. Significantly higher tree stem densities were found in the native forests than in the exotic forests. Similarly, the native forests had higher numbers of seedlings and saplings although not significantly different from those in Eucalyptus forests. The numbers of seedlings were not different between the pine and eucalyptus forests.

Forest type	Stand density (tree/ha)	Seedling species (#/ha)	Seedling density (#/ha)	Sapling species (#/ha)	Species richness (S)	Species diversity (H')	Species Evenness (H'E)	Abundance (N)
Cypress	765 ^b	1.2 ^b	412 ^b	1.5 ^b	0.85 ^b	0.56 ^b	4.17 ^b	3852
Eucalyptus	897 ^b	2.2 ^{ab}	962 ^{ab}	1.7 ^b	0.99 ^b	0.64 ^{ab}	4.00 ^b	3911
Pine	829 ^b	1.7 ^a	312 ^b	2.8 ^{ab}	1.14 ^b	0.75 ^{abc}	5.75 ^b	1667
Native	1016 ^a	6.9 ^a	2575 ^a	4.3 ^a	1.82 ^a	0.78 ^a	11.42 ^a	11015
p-value	≤0.05	≤0.05	≤0.05	≤0.05	≤0.05	0.031	≤0.05	NS

The p-value shows significance levels of a one way ANOVA test for differences between forest types. Values followed by the different letter superscripts are significantly different. Seedlings refer to young trees of < 1.3m height; Saplings ≥1.3.m high and ≤5cm dbh.

Table 1. Characteristics of the native tree species regenerated among the four forest types in the Taita Hills

3.2 A typical regeneration and diversity of native species within the exotic and native forests in the three forest fragments in the Taita Hills

In general, the diversity and densities of regenerated native species were higher in the native forests than in the exotic plots forests. The typical native species in cypress plantations were *Macaranga conglomerata*, *Rapanea melanophloesos*, *Rytigynia uhligii* *Tabernaemontana stapfiana* and *Syzgium guineese*; in the eucalyptus plantations were:

Species	<i>Cupressus lusitanica</i>			<i>Eucalyptus saligna</i>			<i>Pinus patula</i>			Native Stands		
	Nga	Cha	Mbo	Nga	Cha	Mbo	Nga	Cha	Mbo	Nga	Cha	Mbo
* <i>Acacia mearnsii</i> De wild	1304	15	7	1529		309	29					
<i>Albizia gummifera</i> J.F.Gmel		44	81	0	74		69	88			132	
* <i>Cupressus lusitanica</i> Miller	637	956	684	574		44						
* <i>Eucalyptus saligna</i> R. Baker			7	2000	706	1103						
<i>Macaranga conglomerata</i> Brenan	10	103	15				147	29	15	153		47
<i>Maesa lanceolata</i> Engl.	10		7		29					24		
<i>Newtonia buchananii</i> G.C.C.Gilbert & Boutique		29						294		35		512
<i>Oxyanthus speciosus</i> DC				118			29			82		6
<i>Polyscias fulva</i> Harms	10	29			15					24		18
<i>Phoenix reclinata</i> Jacq		44		15					15		221	
* <i>Phoenix patula</i> Schiede ex Schlecht.& Cham							29	843	235	485		
<i>Pleiocarpa pycnatha</i> K Schum					29			147	15		44	676
<i>Podocarpus latifolius</i> R.Br. ex Mirb	39	29							15	12		47
<i>Rapanea melanophloeos</i> L. Mez	88	74					10				59	24
<i>Rytigynia uhligii</i> K.schum.& K.Krause	78	235					353	265				82
<i>T.abernamontana stapfiana</i> Britten		309			338			1088		118	176	76
<i>Vangueria volkensii</i> K:Schum	10	15					137	59		24		
<i>Xymalos monospora</i> (Harv.)Baill.		44			29						29	41
<i>Sysygium guineense</i> Willd	108	118			103			88	74	71	15	671

*Denotes exotic species and the woody species include tree, saplings and seedlings regenerated combined

Table 2. Densities all native woody (#/ha) species occurring in at least three plots at each of the three forests fragments of Ngangao (Nga), Chawia (Cha) and Mbololo (Mbo).

Albizia gummifera, *Oxyanthus speciosus*, *T. stapfiana* and *S. guineese*; and the pine plantations were *A. gummifera*, *M. conglomerate*, *Newtonia buchananii*, *Pleiocarpa pycnatha*, *R. uhligii* *T. stapfiana*, *Vangueria volkensii* and *S. guineese*. The exotic plantations of Chawia hosted the highest number of native species among all the exotic forests, while cypress and pine forests had more native species than eucalyptus forest.

3.3 Variation in species regenerations and diversity among forest types

The species found naturally regenerated and their diversities are shown in Table 3. With regard to species diversity (H'), richness (S), Evenness ($H'E$) and abundance (N) of the native species regenerated in the different forests, the native forest had higher average totals than the exotic forests. However, some of the values in native forests were not significantly different from those found in some of the exotic plantations (e.g. H' in native, pine or eucalyptus forests).

Forest Area	Forest type	S	N	H'	$H'E$	EF
Ngangao	Cypress	4 (2)	2088 (2108)	0.88 (0.22)	0.64 (0.07)	2
	Eucalyptus	3 (1)	9044 (7637)	0.82 (0.89)	0.80(0.099)	2
	Pine	5 (3)	1588 (733)	0.89 (0.26)	0.51 (0.136)	2
	Native	9 (2)	1365 (147)	1.97 (0.16)	0.89 (0.02)	7
Chawia	Cypress	7 (3)	1485 (457)	1.53(0.26)	0.78 (0.216)	5
	Eucalyptus	6 (1)	1176 (825)	1.31 (0.08)	0.78 (0.071)	4
	Pine	11 (1)	2794 (1123)	1.73 (0.15)	0.72 (0.032)	6
	Native	5 (3)	794 (573)	1.07 (0.36)	0.63 (0.056)	3
Mbololo	Cypress	3 (1)	6358 (15609)	0.48 (0.13)	0.39 (0.062)	2
	Eucalyptus	4 (1)	1515 (391)	0.83(0.12)	0.68 (0.041)	2
	Pine	4 (1)	1221 (194)	1.22 (0.16)	0.81 (0.098)	3
	Native	15 (3)	19928 (39748)	2.05 (0.13)	0.78 (0.035)	8

Standard error is shown in the parenthesis for Shannon's index (H') and Shannon's evenness index ($H'E$); while for the individual species (N) and species richness (S), the value in parenthesis denotes standard deviation.

Table 3. Number of individual species (N), species richness (S), Shannon's index (H'), Shannon's evenness index ($H'E$) and effective numbers (EF) observed in four forest types in three forest fragments of the Taita Hills (n=65 plots)

The native forests had a higher species diversity than the exotic plantations. Other studies in East Africa⁷ have shown the same trend. The study under discussion however, showed that, the highly disturbed forest site of Chawia had higher tree species diversity in the exotic forests than in the native forests. The reason for this is probably attributed to the fact that native forest land had been cleared for the establishment of the exotic forests instead of bare land. Moreover, some of these exotic plantations were established around the native forests as buffers. Therefore, the high levels of anthropogenic activities at this site^{45,46} and a possible presence of soil seed bank⁴⁷ associated with the initial clearance of the native forests may explain the high levels of regenerated native species. These results also compare well with those established by Yirdaw and Luukkanen⁴⁷ in eucalyptus plantations surrounding a native forest in Ethiopia; in their study, higher species diversity was found close to the native forests as compared to stands that were planted further away.

An analysis of variance showed a significantly higher species richness in the native forests than the exotic plantations ($p=0.000$). A comparison between the three forest fragments, showed a significant difference in species richness only between the least and intermediately disturbed sites of Mbololo and Ngangao respectively ($p=0.002$). In general no statistical differences were detected in species abundance (N) between the native and exotic forests types; and between the three fragments. Nevertheless, the native forests in the least disturbed site (Mbololo) had a higher abundance (N) and number of species (S) than the exotic forests at the same fragment. The regenerated species showed higher abundance at this fragment than in

either the intermediately disturbed fragment (Ngangao) or the highly disturbed one (Chawia). Among the exotic forests, pine plantations in Chawia had higher species richness than the rest of the exotic forests. A comparison within each fragment showed that in Ngangao the regeneration of trees within the native forest was higher than within the exotic forests (Shannon-Weaver's index 7 and Effective number 7). In contrast, Shannon-Weaver's indices and Effective numbers in the three forest fragments were almost similar. In Chawia, the Shannon-Weaver's indices were higher for the exotic forests than for the native forest. The highest one was that for the pine forest; with a Shannon-Weaver's index of 1.73 and Effective number 6, followed by cypress and eucalyptus forests respectively. Similarly, the pine forest had the highest number of species as well as total density of species regenerated. In Mbololo, the Shannon-Weaver's indices for the regenerated native species were rather similar for all forest types except in the native forest which indicated somewhat higher values. Comparatively, the native species that regenerated in the different forest types in both Ngangao and Mbololo appeared similar again with the exception of those in the native forests where the values were higher. As mentioned above, in Chawia, the regeneration was more pronounced in the exotic forests than in the native forest.

The Shannon-Weaver's diversity indices (H') were higher in the native forests than in the exotic plantations in Ngangao and Mbololo whereas in Chawia this index was lowest in the native forests. A one-way analysis of variance using Tukey's test indicated differences in diversity indices between the native forests and all types of exotic forests. In particular, these were highly significant between the native forests and the cypress or eucalyptus forests ($p=0.000$) and between the native forests and pine forests ($p=0.001$). No significant differences were found between exotic forests. All the exotic forests in Ngangao had almost similar diversities with very slight differences in the regeneration pattern, possibly because the exotic plantations here were established in barren areas²² which provided fewer opportunities for the regeneration of native species. The differences in regenerations patterns observed between the exotics forests in Mbololo on the other hand and the more at the Chawia and Ngangao fragments were most likely due to a lower level of disturbance Mbololo fragment experienced. This observation is corroborated by the high Shannon-Weaver's indices and effective numbers in the native forests and the presence of few secondary species that are indicators of disturbance (e.g. *P. reclinata*, *M. lanceolata* and *T. stapfiana*). Ngangao, on the other hand, had more species associated with disturbance such as *M. conglomerata*, *R. uhligii* and *M. lanceolata* also confirming the earlier observations by Bytebier⁴⁸.

The application of effective numbers facilitated distinction of differences in diversity among the exotic forest types. The effective numbers were also consistent with the Shannon-Weaver's indices. The effective numbers were higher in exotic forests in Chawia than in native forests and in all the exotic forests both in Ngangao and Mbololo. The effective numbers were also high in the native forests at Mbololo and Ngangao fragments. The Shannon-Weaver's evenness index ($H'E$) reached its highest value in the native forests of Ngangao site (0.89) and in pine plantation at Mbololo fragment (0.81). The most uneven forest in terms of diversity was the cypress plantation at Mbololo fragment (0.39). A one way ANOVA for Shannon-Weaver's evenness showed that there was a significant difference between the exotic forests and the native forests in general and also a significant difference in the species evenness between the cypress forest and the native forest (0.031). With respect to the abundance of regenerated individuals at each fragment, the native forest plots in Chawia had the lowest number (794) compared to the other native plots of Ngangao (1365) or Mbololo (19928).

3.4 Similarities of species regenerated at the three sites

Table 4 shows the similarities in species composition between the different forest types and fragments. The highest similarity (77 %) was found between the cypress and pine forests in Chawia; the pine and cypress forests in Ngangao also showed a high species similarity (64%), which almost corresponded with the species diversity values found (11 and 13 species respectively). In Mbololo, the highest species similarity was 59% between the exotic forests of pine and cypress. The cypress forests in Mbololo were twice as diverse with 13 species as the eucalyptus forest and yet they shared a similarity of 50% species, the same as for these exotic forests in Chawia. The majority of the forests studied however, shared less than 30% of the species, while the forests which did not share any species were the eucalyptus forests in Mbololo and the native forests in Ngangao, as well as the eucalyptus and native forests in Mbololo.

		Ngangao			Chawia				Mbololo				
		C	E	P	N	C	E	P	N	C	E	P	N
Nga	C	40	64	33	40	32	52	18	42	22	24	26	
	E		22	7	11	11	25	0	35	36	11	6	
	P			26	29	21	38	24	44	29	50	29	
	N				31	36	43	17	16	0	26	53	
Cha	C					50	77	40	30	29	29	29	
	E						54	48	37	10	29	29	
	P							35	32	21	38	35	
	N								25	11	32	21	
Mbo	C									50	59	15	
	E										19	0	
	P											39	
	N												

Table 4. Similarities(%) of species regenerated in four forest types (C=Cypress, E=Eucalyptus, P-Pine and N= Native) from the three forest fragments. Values in bold similarities from 50%

Highest species similarities in the undergrowth of pine and cypress forests in Chawia and Ngangao observed were possibly because these forests were located close to each other. Thus, there were either similar seed dispersal mechanisms or the forests could have had similar soil seed banks. The complete absence of similar species in eucalyptus and native forests in Mbololo and Ngangao implies that the eucalyptus plantations cannot support similar regeneration of species as the native forests, especially if the stem density is high as indeed was the case in these eucalyptus forests. In general, the native forests in Mbololo shared a low species similarity with other forests. A possible explanation is the low level of disturbances in this forest which provided few opportunities for seedling recruitment except through dispersal and gap dynamics. *Ocotea usambarensis* which is extinct in some regions in East Africa⁴⁹ and under threat in Tanzania⁵⁰, was observed in the native forests of Mbololo with 94 stems, although it is also known to be present in Ngangao. *Coffea fadenii*, a wild coffee species, was only found in Ngangao, indicating the relatively low levels of disturbances experienced by these two sites. In Mbololo, the pine forest had a higher effective number and Shannon-Weaver's index than the eucalyptus and cypress forests plots possibly because the pine forest was located in the middle of the native forest, while cypress and eucalyptus had been planted at the edges.

4. Strategies for diversity restoration

4.1 Stakeholder involvement

Since the advent of the biological diversity convention of 1992, many countries have, as part of their global commitment to sustainable development, paid great attention to ecosystem conservation. Moreover, the realization that some vital biological resources are on the brink of extinction and yet they are vital for social and economic development reinforces the urgency for conservation. Similarly, due to the apparent loss of biodiversity and ecological functions in the forests of the Taita Hills and in many other forests in Kenya, a newly promulgated Forest Act⁵¹ provides several options for managing the forests, including those under threat such as the Taita Hills forests. These options include opportunities for stakeholders, particularly the local communities residing around these forests to participate in their management. As a result, Community Forest Associations have been formed for the different forest fragments in Taita Hills in preparation for their participatory management. Community involvement in management has already entailed participation in forest reforestation activities such as replanting with seedlings of native tree species in order to enhance the replacement of the exotic species. In areas outside the forests and on farms tree planting is being carried out so as to ease pressure off the forest. Scientific approach has been applied to facilitate the restoration by identifying suitable sites for planting. In particular, a GIS-based, least-cost modelling technique has been used to identify such sites⁵² and after integrating biological and socio-economic data within the forest corridors⁴⁶, a set of exotic plantations with highest priority for restoration activities have been identified by both the government and Non Governmental organizations that are active in the area. The choice of species planted is based on their potential to increase landscape connectivity or on their importance for conservation of critically endangered taxa, although with regard to soil characteristics of the forest fragments, any of the native species is suitable and can be used for restoration exercise⁵³.

Box 2. Community activities for restoration of forest biodiversity between two fragments

Ngangao and Chawia forest fragments are being linked through a three-step reforestation plan. This includes forest enrichment, agricultural matrix enrichment through on-farm tree planting and conversion of exotic plantations to native forest. As native forest enrichment is being done, it is accompanied by gradual removal of exotic species from the canopy level to increase the light availability for the planted native tree seedlings and to allow faster recruitment of seedlings from the soil seed bank. Local initiatives to enhance these restorations activities include the establishment of tree nurseries to supply seedlings necessary for planting with native tree species (e.g. *Prunus africana*.) and farmer-friendly exotic trees (e.g. *Grevillea robusta*).

4.2 Forest restoration and management for biodiversity enhancement

Forest restoration can be enhanced by the presence of appropriate conditions, some of which include the following: placement of the plantations, edge effect, presence of gaps, seed dispersal mechanisms with mammals as dispersing agents and an existing soil seed bank. In most cases these factors work in tandem. In the study discussed here, fragments which showed some degree of disturbance (Chawia and Ngangao) had stronger edge effects since they were located in the middle of agricultural lands due to their fragmentation, this

possibly provided opportunities for increased movements of propagules⁵⁴ by fauna from adjacent forest patches especially because high number of rodents and shrews have been reported particularly for the Chawia site⁵⁵. Some of the exotic plantations (e.g. Ngangao) were established on denuded land which eliminated the possibility of the presence of soil seed bank and hence the relative differences in biodiversity observed.

The presence of gaps associated with disturbance is also important in forest ecosystem restoration. The differences in gaps observed at the different study sites showed that at the most disturbed fragmentation of Chawia, there were growths of secondary native species such as *T. stapfiana*, *M. lanceolata*, and *P. reclinata*, which seemed to indicate that disturbance favoured their regeneration. Some studies have shown that forest disturbance does stimulate regeneration of species stipulated to be for intermediate succession stages^{54,56}.

Disturbances as observed in the forests, could have rendered them to be in early or represent a post-extraction and post-abandonment secondary stage⁴⁵, even though some species associated with low disturbance such as *X. monospora*, *S. guinees* and *R. melanophloeos*⁵⁷ were found in the most disturbed site of Chawia. This was possibly an indication of the presence of either seeds in the soil banks or efficient seed dispersals mechanisms. An unexpected observation, however, was the low number of pioneer species which would not be expected with the common presence of gaps in the forest canopy⁵⁸ and this was also noted by Rogers et al.⁵⁹, for *M. conglomerate* in the native forests of the more disturbed Chawia fragment. This shows that the succession stage had been passed in Chawia and that the native forest had matured and therefore, phased out the pioneer species for the more shade tolerant species⁵⁹.

The importance of the presence of soil seed bank is underscored by the observations made at the most disturbed site where, there was a higher regeneration of endemic species namely *Xymalos monospora*, *Rapanea melanophloeos* and *Syzygium guineense* (Willd.) DC which are associated with lower levels of disturbance. This is an indication that a disturbed forest has an inherent potential to regenerate. Thus, without further disturbance the forest can restore itself. This trend has been observed in Nigeria where, a degraded forest recovered to its original status without further disturbances⁶⁰. In the broader context, therefore, disturbance can be considered a key element of landscape diversity, and may be viewed as beneficial to properly functioning systems^{25,61}. This would only occur if deliberate efforts are put in place to ensure that no further disturbances occur such as isolating the sites for restoration and eliminating anthropogenic activities which can create the undesired disturbances.

4.3 Species selection

In the study, there were few native species that regenerated in the exotic forest of the relatively less disturbed fragments of Mbololo and Ngangao. Two possible reasons were the stand densities and the inherent physiological characteristics of some of the exotic species. Stand densities in eucalyptus plantations in Ngangao and Mbololo were 2000 and 1103 stems per hectare, respectively, while in Chawia it was only 706. The densities for pine at the former fragments were 843 and 485 respectively, compared to 235 for Chawia (Table 1). A possible consequence is not only the lack of light for regeneration in a high density stand but also effects of adaptation to particular geochemical characteristics of a given species have been attributed to the exotic species as well. In other studies elsewhere⁶² mulches from pine were found to inhibit the germination of seeds. It is thus plausible that the inherent physiological composition of some of these exotic species could not have favoured the regeneration of other species.

5. Conclusions and recommendations

The rich biodiversity of the indigenous forests of Taita Hills has been acknowledged by scientists for decades. The least disturbed native forests have a much higher diversity among the regenerating seedlings and saplings than in the most disturbed forest. In contrast the exotic forests in a highly disturbed fragment seemed to have the highest species biodiversity; an indication that in the absence of further disturbance and by avoiding replanting with exotic species, the forests may regain their diverse native status. Rehabilitation activities to restore the biodiversity of these forests have been initiated with the involvement of the local communities in which there are assisted regeneration efforts.

The high species diversity and high abundance of native tree seedlings and saplings in the exotic plantations in the Taita Hills is very encouraging in terms of conservation efforts. At the highly disturbed site of Chawia, there was a high species diversity in the exotic forests which, with respect to restoration, requires no special management except for elimination of further disturbance. Regeneration was observed of 58 woody plant species with stem densities varying between 10 and 2000 trees per hectare. Marked differences in species diversity were observed between native and exotics forest types. The native forests showed a higher species diversity. Between the forest fragments however, the most disturbed fragment showed greater diversity than either Ngangao or Mbololo, an indication that more regeneration occurred in Chawia fragment than in the less disturbed forests of Mbololo and Ngangao. The implications from the study are that the native tree species diversity in the mountain cloud forests of East Africa is affected by the level of intensity of the disturbances, and in this area, if forest disturbance is properly regulated with regard to forest type; there are possibilities for the original forest ecosystems to be restored.

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Every ecosystem is a complex organization of carefully mixed life forms; a dynamic and particularly sensible system. Consequently, their progressive decline may accelerate climate change and vice versa, influencing flora and fauna composition and distribution, resulting in the loss of biodiversity. Climate changes effects are the principal topics of this volume. Written by internationally renowned contributors, Biodiversity loss in a changing planet offers attractive study cases focused on biodiversity evaluations and provisions in several different ecosystems, analysing the current life condition of many life forms, and covering very different biogeographic zones of the planet.

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