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ORIGINAL PAPER

Tree species diversity, richness, and similarity between exotic and indigenous forests in the cloud forests of Eastern Arc Mountains, Taita Hills, Kenya

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Abstract: Biodiversity assessment for tree species was conducted in three forest fragments ofthe Taita Hills, southeastern Kenya to compare species diversity between and within three exotic forest plantations of pine, eucalyptus, cypress and the indigenous forests. The study sites were: Ngangao (120 ha), Chawia (86 ha), and Mbololo (185 ha). A Y-plot design was used to sample 32 plots comprising of 65 subplots. At each subplot, all juvenile trees of 5 cm and above in diameter at breast height (DBH) were enumerated and recorded by species. Tree regeneration (seedlings and saplings) was tallied by species. The Shannon-Weiner Index was used to calculate species diversity and evenness. The derived Shannon's indices were further converted into effective numbers to show the magnitude of differences in species biodiversities. To evaluate differences in species diversities, a one way ANOVA was conducted and to separate the means, Tukey's HSD and Duncan's tests were used for even and uneven number of samples respectively. Jaccard's similarity index was used to assess species similarities. There were more than 58 species whose stem densities varied between 10 and 2 000 trees per hectare. There were significant differences in species diversities between forest types and sites; the indigenous forests showed higher diversities than the exotic forests. Similarly, Chawia sites had higher species diversity than both Ngangao and Mbololo. Chawia also had a higher number of regenerated species than the two other sites, including species such as *Xymalos monospora*, *Rapanea melanophloeos*, and *Syzygium guineense*, which are associated with low levels of disturbance. These findings indicate that the indigenous forest is more diverse in species as would be expected in the tropics. The high species diversity in Chawia could be accounted for by the higher levels of disturbance it underwent, unlike the two other sites. The regeneration of species associated with low levels of disturbance found in the exotic plots of Chawia show the likelihood of presence of long-term soil seed banks. The low regeneration in the exotics plots observed in Ngangao and Mbololo are likely due to the absence of seed banks since some of the plantations were established on bare land (in Ngango), or the inherent physiology (allelopathy) of some of species repelling the regeneration of others.

Keywords: biodiversity; forest fragments; Eastern Arc Mountains; disturbance; exotics; indigenous species

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Introduction

The Taita Hills are the northernmost and only Kenyan part of the of Eastern Arc Mountain chain, which is ranked among the thirty-four "biodiversity hotspots" in the world with respect to high ratios per area of endemic plants and vertebrate species (Conservation International 2005). With over 90% of forest cover loss in the past 200 years, the Taita Hills are among the most threatened biodiversity hotspots in the world (Lovett 1993). Forty percent of plant species, 2% of plant genera and 13% of plants taxa are endemic to Taita Hills; 22 plants in these forests are endemic to only Kenya and Tanzania (Lovett 1993; GEF, 2002; EAWLS 2000).

Over the years these forests have undergone different levels of disturbance. Increased human population led to forest clearings for agriculture, firewood collection and charcoal production

(Beentje, 1988; Collins and Clifton 1984) and hence posed a threat to sustainable biodiversity conservation (Mogaka 2002). Furthermore, exotic plantations of pine (*Pinus spp.* Schiede ex Schlect. & Cham), eucalyptus (*Eucalyptus saligna* R. Baker) and cypress (*Cupressus lusitanica* Miller)—which were established between 1960s and 1980s either as forest stands within the indigenous forests or as individual trees for enrichment planting (Pellikka et al. 2009) as part of the management plans to encourage softwood production, protect the indigenous forests, and mitigate against soil erosion—have inadvertently exacerbated the threats to the biodiversity in these forests (Rogo and Oguge 2000). In Ngangao, the exotic stands were established in barren and rocky areas, while in Chawia, some parts of the indigenous forest were cleared for the establishment of the exotic stands (Pellikka et al. 2009). Whereas original management intentions were admirable, lack of enforcement coupled with increasing land pressures resulted in increased human induced disturbances such as grazing and fire. This consequently led to marked alterations of species compositions in the plantations of exotic species.

Alterations in species composition emanate from forest degradation which affects biodiversity. There are several ways in which forest degradation occurs at the global scale (Krishnaswamy and Hanson 1999; Rogers 1996) or at the local scale (Foley et al. 2007). Decreased forest cover is a type of forest degradation which not only leads to biodiversity loss but also the loss of ecosystem functions (Foley et al. 2005), such as pest control and pollination (Kremen et al. 2007), seed dispersal (Howe and Smallwood, 1982), and provision of water resources (Scott and Lesch 1997; Laurance et al. 2002). Other forms of degradation occur when forest systems experience human induced disturbance (Chazdon 1998) or natural disturbance (Fox 1979), which may result in increased species diversity. Improved diversity in such situations is attributed to species resilience to regenerate or to other factors such as increased light to the forest floor (Senbeta et al. 2002), which favour regeneration of diverse species through new canopy gaps. Species composition may change when disturbance affects canopy structure (Brockaw 1985), which often activates growth of tree species whose seeds may have been preserved in the soil.

Biodiversity is defined by the Convention on Biological Diversity (1992) 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”

The hypothesis for the present study is that diversity of indigenous species regeneration in forests subjected to different levels of disturbance will vary between exotic and the indigenous forest types. In particular, the study examines this hypothesis through assessment of species diversity, richness, and similarity of the regenerated species between the exotic plantations of pine, eucalyptus and cypress, as well as between the indigenous forest and exotic forests.

Assessments of biodiversity are often complex because of the magnitude of species involved. For example, in tropical African forests alone it has been observed that in an area of about 10^6 km^2, there can be between 30,000 and 120,000 flowering plants alone, while in plots of about 0.1 and 1 hectares this variation has been found to range between 30 and 300 tree species (World Conservation Monitoring Centre; WCMC 1992). Improvement in knowledge of patterns and processes of diversity has been gained from FAO resource assessment (1993). However, there is still a lack of detailed survey information on habitat types, species or genetic diversity in many forests in the tropics (Wilcox 1995). Furthermore, species diversity is made more complex in the tropics when exotic plant species are introduced as has happened in most of the East African highlands during the last century (Fimbel and Fimbel, 1995). The lack of quantitative information about the diversity in the exotic plantation forests, which is crucial for the conversion of such forests back to indigenous forests, has increased the problem.

The objective of this study was to assess species biodiversity and similarities between and within the exotic plantations of pine, eucalyptus and cypress, and between the indigenous forest in Ngangao, Chawia and Mbololo with the exotic forest in the forest fragments in the Taita Hills. The assessment was done by exploring the identity and variety of indigenous species that have regenerated within the exotics plantations as well as in the indigenous forest.

Materials and methods

Study area

The Taita Hills are located in southeastern Kenya (3°25′S, 38°20′E) (Fig. 1). The area has two rainy seasons namely, long rains in March-May and short rains in November-December, although due to mist and clouds in the hills precipitation can be a year-round phenomenon. Between 1986 and 2003, average yearly rainfall was 1 132 mm in Mgange at 1 768 m and 587 mm in Voi at 560 m, whereas the yearly maximums may reach 2 000 mm, the minimums are about 200 mm. The research was confined to three remnant forest fragments of Ngangao, Chawia and Mbololo. The topographic characteristics of the study areas are shown in Table 1. The map of the different forest fragments, taken using airborne digital camera imagery acquired in January 25-27, 2004 for Chawia and Ngangao (Pellikka et al. 2009) is shown in Fig. 1.

Table 1, Locations and topographic characteristics of the study sites

Area	Location	Elevation (m)	Area (ha)	Level of disturbance
Ngangao	38°20′33′′E, 3°21′55′′S	1700-1952	120	Medium
Chawia	38°20′31′′E, 3°28′48′′S	1470-1600	86	High
Mbololo	38°29′45′′E, 3°18′15′′S	1500-1779	185	Low

The exotic plots of eucalyptus, pine and cypress that were included in the study were established for timber production in

1950s mainly in the fringes of the indigenous forests.

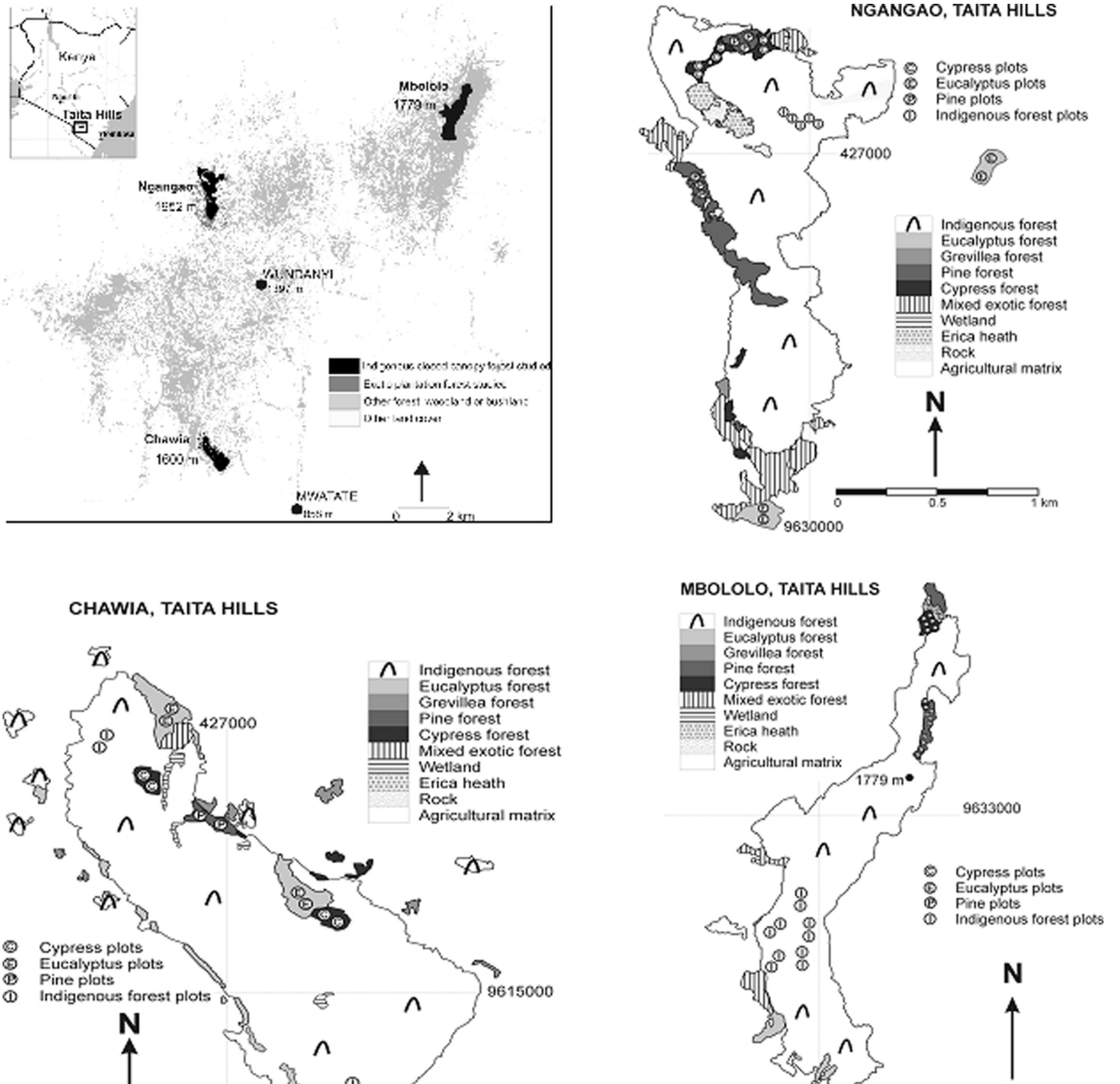

Fig. 1 Locations of the three study sites of the Taita Hills, Kenya and the layout of individual subplots sampled

The most common indigenous tree species in Chawia forest are *Tabernamontana stapfiana* Britten, *Albizia gummifera* (J. F. Gmel), C. A. Sm, *Phoenix reclinata* Jacq, *Macaranga conglomerate* Brenan, (Madoffe et al. 2005; Rogers et al. 2008); In the same site, the exotic species were introduced namely, eucalyptus plantations which cover 6 ha, pine plantations 1 ha and cypress plantations 0.5 ha (Pellikka et al. 2009).

Ngangao's most common indigenous tree species are *T. stapfiana* Britten, *M. conglomerata* Brenan, *A. gummifera* J.F.Gmel, *P. reclinata* Jacq, *Syzygium guineese (*Willd) DC, *Maesa lanceolata* Forssk, (Madoffe et al. 2006; Rogers et al. 2008), and *Cola greenwayi* Brenan, (Beentje 1988). Also in this site, the exotic species, eucalyptus plantations cover 4 ha, pine plantation 10 ha and cypress plantations 4 ha (Pellikka et al. 2009).

The Mbololo forest is the most isolated forest of the three and its common indigenous tree species are *T. stapfiana* Britten, *A. gummifera* J. F. Gmel, *P. reclinata* Jacq, *Newtonia bucchananii* (Baker) G.C.C.Gilbert & Bout, and *Strombosia scheffleri* Engl., (Beentje 1988). The exotic species of eucalyptus, pine and cypress plantations cover more than 5 ha each. Of the three sites, Chawia is considered to be the most disturbed forest fragment (Wilder et al. 1998) studied.

Methodology

The Forest Health Monitoring (FHM) protocol as developed by US Forest Service (USDA 2007) adapted to the tropical forests in the Eastern Arc Mountains of Kenya and Tanzania (Madoffe et al. 2006; Rogers et al. 2008) was used. In this study, two subplots from a minimum of two of the FHM plots representing indigenous forests in Chawia and Ngangao were randomly selected and studied. The same protocol was used to lay and sample vegetation from the exotic plantations of pine, cypress and eucalyptus in Chawia and Ngangao and for all the exotic and indigenous forests of Mbololo, in which there were no prior laid down FHM plots. In total, samples were taken from 65 subplots, out of 32 plots, of which 18, 12, 16 and 19 were from cypress, eucalyptus, pine and indigenous forest plots, respectively (Table 2) and Fig. 1, shows the layout of subplots sampled and Fig. 2 shows the Y plot design comprising of four subplots.

Table 2 Number of plots sampled from each forest types in each forest fragment.

Forest fragment	Forest type				Total
	Cypress	Eucalyptus	Pine	Indigenous	
Ngangao	6	4	6	5	21
Chawia	4	4	2	4	14
Mbololo	8	4	8	10	30
Total	18	12	16	19	65

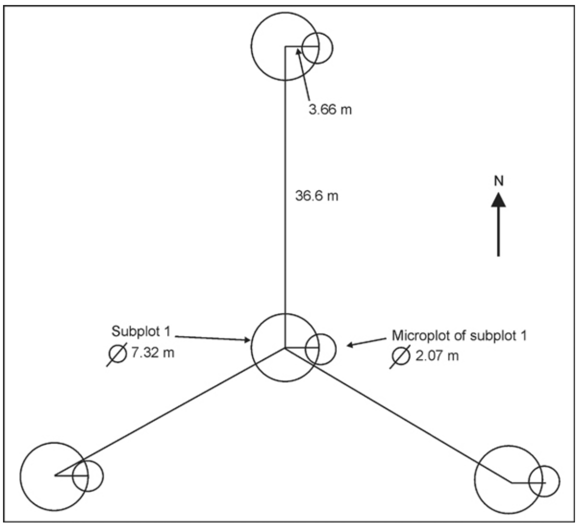

Fig. 2 The Y plot design (USDA, 2006)

Vegetation sampling

In each of the subplots the forest condition was assessed as follows: percentages of ground cover, using a one square meter grid. As a benchmark, juvenile trees of 5cm in diameter at breast height (DBH) were enumerated and recorded by species. Similarly, regenerated seedlings and saplings were also identified and enumerated by species. The identification of the indigenous species was accomplished by a local botanist as well as the use of field instruction manual (USDA 2007).

Data analyses

Species diversity in each of the forests was calculated using a Biodiversity Calculator (Danoff-Burg and Xu 2006) in which the Shannon’s index (H') was chosen. This method was selected because it provides an account for both abundance and evenness (Magurran 1988). It also does not disproportionately favour some species over the others as it counts all species according to their frequencies (Lou 2006; Danoff-burg and Xu 2008). Other parameters such as species richness, (S) and species evenness (H’E) were derived from the same calculator. In addition, the Shannon's indices obtained were converted to *effective numbers* using a method by Lou (2006). This was done in order to analyze the magnitude of the differences in species diversities. To obtain similarities between species, the Jaccard’s index (Krebs 1989) was used between the indigenous and exotic forest types in three forest fragments. Shannon’s index, (H') is defined by:

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

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. The Shannon’s index ranges typically from 1.5 to 3.5 and rarely reaches 4.5 (Gaines et al. 1999).

Species richness (S) is defined by:

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

where, n is number of species in a community.

Species evenness is often assessed by Shannon's equitability index (H'E) which is calculated by:

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

where, $H_{\max}$ is defined as ln S. H'E values ranges from 0 to 1, in which 1 indicates complete evenness.

The Shannon's index values obtained were further converted to *effective numbers* using a method by Lou et al. (2006) in order to analyze the magnitude of the differences in species diversities. The *effective numbers* are calculated as an exponential of the Shannon's index as:

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

The Jaccard’s index (Krebs, 1989) was used to calculate the species similarities between the forest types in different forest fragments. Jaccard's index (Cj) is defined by

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

The values for each variable was derived on per subplot basis, however, they were averaged across the plots. Densities of commonly found indigenous tree species in both the exotic and indigenous plots were calculated on a per hectare basis to show the different regeneration levels in the four forest types and in the three forest fragments. Analyses of variance using one way ANOVA by SPSS 15 for windows were applied (SPSS 2006). To separate the means, Tukey's HSD or Duncan's tests were used in the case of equal and unequal samples respectively.

Results

The characteristics of trees, seedlings and saplings in all the plots are shown in Table 3. No significant differences were found for the stem densities between the exotic and indigenous forest types, although the indigenous plots had higher stem densities than the exotic plots. Similarly, the indigenous plots had higher numbers of regenerated seedlings and saplings which were more in species and higher diversities. Table 3 shows that there were differences in the indigenous tree species regenerated within the different exotic plantations and the indigenous forest with respect to the stem densities, numbers of seedlings and saplings regenerated, species richness, diversity and evenness but not in abundance of species.

Table 3. Characteristics of the indigenous tree species regenerated within the sampled plots from the three forest fragments of the Taita Hills.

Forest type	Tree stem density ($stem{\cdot}ha^{-1}$)	Seedling species (#)	Seedling density	Sapling species (#)	Density per diversity	Species richness (S)	Species diversity (H')	Species evenness (H'E)	Species abundance (N)
Cypress	765^{a}	1.2^{a}	412^{a}	1.5^{a}	359^{a}	0.85^{a}	0.56^{a}	4.17^{a}	3852
Eucalyptus	897^{a}	2.2^{ab}	962^{ab}	1.7^{a}	752^{b}	0.99^{a}	0.64^{ab}	4.00^{a}	3911
Pine	829^{a}	1.7^{a}	312^{a}	2.8^{ab}	376^{a}	1.14^{a}	0.75^{abc}	5.75^{a}	1667
Indigenous	1016^{b}	6.9^{b}	2575^{b}	4.3^{b}	2088^{c}	1.82^{b}	0.78^{c}	11.42^{b}	11015
p-value	≤ 0.05	≤ 0.05	≤ 0.05	≤ 0.05	0	≤ 0.05	0.031	≤ 0.05	NS

The p-value show significance levels of a one way ANOVA test for differences between forest types. Values followed by the different letter superscripts are significantly different at $p \le 0.05$ level.

Between the different exotic species, there were also significant differences in regeneration of indigenous seedlings between Eucalyptus forests and both Cypress and Pine forests. Species diversity for regenerated indigenous species in the Cypress forests was also significantly different from those that regenerated within the Eucalyptus and pine forests. With regard to abundance in terms of numbers of the indigenous species regenerated in the different forests, the Indigenous forest had highest average totals of the abundance than the exotic; however, this was not significantly different from those within the exotic plantations.

Species diversity, richness and evenness

Table 4 presents the species richness (S) abundance of individuals (N), Shannon's index (H'), Shannon's evenness index (H'E) and effective numbers (EF) for the species that regenerated in each of the forest types. An analysis of variance showed that species richness in the indigenous plots was significantly different from the exotic plots ($p \le 0.0001$) while those between the forest sites, showed a significant difference only between Mbololo and Ngangao (p=0.002). No statistical differences were detected in the species abundance (N) between the indigenous and exotic forests types or between the three sites. However, the indigenous plots in Mbololo had high abundance (N) and number of species (S) than the exotic forests. The regenerated species were more in abundance in Mbololo than in either Ngangao or Chawia. Among the exotic plots, pine plots in Chawia had the highest species richness than the rest of the exotic forests.

A comparison within each site revealed that in both Ngangao and Mbolo, the regeneration of indigenous species within the indigenous forest were higher than within the exotic forests, (Shannon's indices 1.97 and 2.05 and Effective numbers 7 and 8) compared to the Shannon's indices (0.82–0.89 and Effective numbers 2 and 3) within the exotic forests at these two sites; which were almost similar. In Chawia, the Shannon's indices were higher for the exotic forests than for the indigenous forest. The highest was for the pines which had Shannon's index of 1.73 and Effective number 6, followed by cypress and eucalyptus respectively. Similarly, the pines had highest number as well as total density of species regenerated. In Chawia, however, the regeneration of the indigenous species was more pronounced in the exotic forests than in the indigenous forest.

The Shannon's diversity indices (H) were higher for indigenous plots than for exotic plots in Ngangao and Mbololo, whereas in Chawia this index was lowest for the indigenous plots. A one way analysis of variance and using Tukey's test to separate the means showed higher significant differences in species diversity indices between the indigenous plots and the exotic plots but not significant differences between the exotic plots.

The application of effective numbers provided information, which facilitated a better way of distinguishing the differences in diversities between the exotic forest types. First of all, the effective numbers were consistent with the Shannon's indices. The effective numbers were higher for exotic plots than for the digenous plots in Chawia; and in all the exotic plots in both Ngangao and Mbololo indicating high diversity. The same effective numbers were also high for the indigenous plots for the Mbololo and Ngangao sites.

Table 4. Number of individual species (N), species richness (S), Shannon's index (H'), Shannon's evenness index (H'E) and effective numbers (EF) for the forest types in the forest fragments in the Taita Hills (n=65 plots) in Taita Hills.

Forest	Forest type	S	N	H’	H’E	EF
Ngangao	Cypress	4(2)	2088	0.88	0.64	
			(2108)	(0.22)	(0.070)	2
	Eucalyptus	3(1)	9044	0.82	0.80	
			(7637)	(0.08)	(0.099)	2
	Pine	5(3)	1588	0.89	0.51	
			(733)	(0.26)	(0.136)	2
	Indigenous	9(2)	1365	1.97	0.89	
			(147)	(0.16)	(0.02)	7
Chawia	Cypress	7(3)	1485	1.53	0.78	
			(457)	(0.26)	(0.216)	5
	Eucalyptus	6(1)	1176	1.31	0.78	
			(825)	(0.08)	(0.071)	4
	Pine	11(1)	2794	1.73	0.72	
			(1123)	(0.15)	(0.032)	6
	Indigenous	5(3)	794	1.07	0.63	
			(573)	(0.36)	(0.056)	3
Mbololo	Cypress	3(1)	6358	0.48	0.39	
			(15609)	(0.13)	(0.062)	2
	Eucalyptus	4(1)	1515	0.83	0.68	
			(391)	(0.12)	(0.041)	2
	Pine	4(1)	1221	1.22	0.81	
			(194)	(0.16)	(0.098)	3
	Indigenous	15(3)	19928	2.05	0.78	
			(39748)	(0.13)	(0.035)	8

Standard error is shown in the parenthesis for Shannon's index (H') and Shannon’s evenness index (H'E); while for Number of individual species (N) and species richness (S), the number in parenthesis denotes Standard Deviation.

The Shannon's evenness index (H’E) showed highest evenness for the indigenous plots of Ngangao site (0.89) and for pine plots in Mbololo site (0.81), while the most uneven plots were those from cypress plots in Mbololo site (0.39). A one way ANOVA for Shannon’s evenness showed that there was a significant difference between the exotic plots and the indigenous plots in general and a significant difference in the evenness of the indigenous species generated between the cypress and the indigenous plots (0.031). With respect to abundance of individual species at each site, the indigenous plots in Chawia had the lowest number (794) compared to the other indigenous plots of Ngangao (1365) or Mbololo (19928).

Species similarity between forest types

Table 5 shows the similarities of species that exist between the different forest types. The highest similarity was (77%) between cypress and pine plots in Chawia. The pine and cypress plots in Ngangao also showed high species similarities (64%), this corresponds closely to species diversity (each had 11 and 13 number of species respectively). In Mbololo, the highest species similarity was 59% between the exotic forests of pine and cypress. The cypress plots in Mbololo were twice as diverse (13 species) as the eucalyptus plots and yet they shared 50% of similarity in species as those in exotic plots of Chawia. Majority of the plots, however, shared less than 30% of the species while some plots such as eucalyptus and indigenous plots of Mbololo and Chawia did not share any species

Stem density

The stem densities (No of stems per ha) for species occurring in at least three plots in an area are shown in Table 6. As expected, higher densities in each of the exotic plots were of the specific species. Another exotic species, wattle tree (*Acacia mearnsii* De Wild) was also typically present in cypress plots of Ngangao and in eucalyptus plots of Ngangao and Mbololo.

Table 5. Percentage in similarities of indigenous species regenerated within the four forest types (C = cypress, E = eucalyptus, P = pine, I = indigenous) from Ngangao, Chawia and Mbololo sites. Values in bold denote significant species similarities from 50.

Forest	Type	Ngangao				Chawia				Mbololo			
		C	E	P	I	C	E	P	I	C	E	P	I
Ngangao	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
	I					31	36	43	17	16	0	26	53
Chawia	C						**50**	**77**	40	30	29	29	29
	E							**54**	48	37	10	29	29
	P								35	32	21	38	35
	I									25	11	32	21
Mbololo	C										**50**	**59**	15
	E											19	0
	P												39
	I												

Table 6. Stem densities of common indigenous tree species occurring in at least three plots at each of the study sites of: Ngangao (NG), Chawia (CH) and Mbololo (MB).

Species	Stem densities (No. of plants/ha)											
	Cuppressus lucitanica			*Eucalyptus saligna*			*Pinus patula*			*Indigenous*		
	NG	CH	MB	NG	CH	MB	NG	CH	MB	NG	CH	MB
A. mearnsii (De wild)	1304	15	7	1529		309	29					
A. gummifera (J.F.Gmel)		44	81	0	74		69	88			132	
C. lucitanica (Miller)	637	956	684	574		44						
E. saligna (R. Baker)			7	2000	706	1103						
M. conglomerata (Brenan)	10	103	15				147	29	15	153		47
M. lanceolata (Engl.)	10		7		29					24		
N. buchananii (G.C.C.Gilbert & Boutique)		29						294		35		512
O. speciosus (DC)				118			29			82		6
P. fulva (Harms)	10	29			15					24		18
P. reclinata (Jacq)		44		15					15		221	
P. patula (Schiede ex Schlect.& Cham)						29	843	235	485			
P. pycnatha (K Schum)					29			147	15		44	676
P. latifolius (R.Br. ex Mirb)	39	29							15	12		47
R.melanophloeos (L) Mez	88	74					10				59	24
R. uhligii (K.schum. & K.Krause)	78	235					353	265				82
T. stapfiana (Britten)		309			338			1088		118	176	76
V. volkensii (K:Schum)	10	15					137	59		24		
X. monospora (Harv.)Baill.		44			29						29	41
S. guineense (Willd)	108	118			103			88	74	71	15	671

Discussion

In general, the indigenous plots had higher species diversity than the exotic species. This coincides with Fimbel & Fimbel (1995), however, in Chawia, the diversity was higher in the exotic plots than in the indigenous plots. In comparison to other studies carried out on species diversity in Chawia and Ngangao (Rogers et al. 2008; Wilder et al. 1998), our Shannon's indices were lower. This is as a result of different survey methods used. Whereas, Rogers et al., (2008), enumerated trees only having more than 12.7 cm DBH, we used a threshold value of 5 cm, in addition, we had to lay new sampling plots which were lacking in the exotic plantations studied by Rogers et al. (2008). The reason that Chawia had the highest species diversity and effective numbers for the exotic plots may be attributed to the fact that the exotic plantations in Chawia were established on land cleared from indigenous forest and which are currently integrated with the indigenous forest. These results are similar to Yirdaw and Luukkanen (2003) who also found higher species diversity in eucalyptus stands that were established close to indigenous forests compared to stands that were further away. Furthermore, high levels of anthropogenic disturbances (Wandago 2002; Mwangombe 2005) in Chawia, and possible presence of soil seed bank associated with initial clearance of the forests (Wassie and Tekatay 2005), may explain the highest level of regeneration of the indigenous species in the exotic plots.

Forest disturbances have been observed to stimulate regeneration of varied species through intermediate succession stages (Chadzon 1998, Hobbs and Huenneke 1992 and Fox 1979); and in Chawia, such disturbances have favored growth of secondary indigenous species such as *T. stapfiana* Britten, *M. lanceolata* Engl. and *P. reclinata* Jacq. (Bytebier 2001). In addition, edge effect could have played a role in the regeneration of species between the three sites. In contrast to Mbololo, Chawia and Ngangao had stronger edge effects due to their locations in the middle of agricultural lands in which both fragmentation and agricultural activities could have played a role. This edge effect may have increased the incidences for movement of propagules by fauna from adjacent forest patches (*e.g.,* Hobbs and Huenneke, 1992). This is likely based on the evidence of presence of highest number of rodents and shrews in Chawia compared to Mbololo and Ngangao (Githiru et al. 2005).

Despite the Taita forests fragments being in a post-extraction and post-abandonment secondary stage (Wandago, 2002), species that indicate low disturbance (*X. monospora* (Harv.) Baill., *S. guineese* Willd*, R. melanophloeos* (L) Mez, were found in Chawia (Chege and Byteibier 2005). This may be an indication of the presence of soil seed banks or that seed dispersals occurred. Like study by Rogers et al. (2008), our results also show low presence of pioneer species *M. conglomerate* Brenan in the indigenous plots of the more disturbed Chawia, in variance to our expectations. We anticipated that gaps in the forest canopy and floor should have encouraged fast growth of pioneer species (Brokaw 1985). Evidently this stage is over in Chawia where, indigenous plots have matured phasing out the pioneer species for the more shade tolerant species (Rogers et al. 2008).

The exotic plantations in Ngangao were established in barren areas (Pellikka et al. 2009), which provided less opportunity for regeneration of indigenous species unless with deliberate introductions. All the exotic plots in Ngangao had almost similar diversities with only slight differences in regeneration. The differences observed between the exotics plots of Mbololo and sites of Chawia and Ngangao are due to the low level of disturbance and fragmentation which Mbololo has experienced; and hence the low level of diversity in the exotic plots. The highest Shannon's indices and effective numbers in the indigenous plots of Mbololo and the presence of few secondary species (*P. reclinata* Jacq, *M. lanceolata* Brenan and *T. stapfiana* Britten) further confirms the low levels of disturbance Mbololo has undergone.

While Mbololo had the highest species richness, Ngangao had more species associated with disturbances such as *M. conglomerate* Brenan, *R. uhlighii* (K. Schum. & K. Krause) and *M. lanceolata* Brenan, confirming observations by Bytebier (2001) of differences in levels of disturbances each of these forests has undergone. In Mbololo however, the pine plots had higher effective number and Shannon's index than eucalyptus and cypress plots because the plots were located in the middle of the indigenous forest, while cypress and eucalyptus were at the edges.

The fewer indigenous species observed in the exotic plots of Mbololo and Ngangao may have been due to high density and inherent physiological characteristics of eucalyptus and pine stands, that could have inhibited regeneration. The densities for eucalyptus in Ngangao and Mbololo were 2000 plants/ha and 1103plants/ha, respectively, while for Chawia it was only 706. The densities for pine were 843 and 485 compared to 235 for Chawia (Table 5). The consequence is not just lack of light for regeneration in high density stand, but also geochemical characteristics that may be present. For instance, Duryea et al. (1999) found that mulches from pine affected the germinations of seeds. In Chawia, regeneration of indigenous species in the exotic plots was in some cases higher than regeneration of exotic species in exotic plots. For example, there were more *T. stapfiana* Britten, *N buchananii* G.C.C. Gilbert & Boutique*, and R .uhligii* K.Schum. & K. Krause, in Pine plots than other exotic species in the same pine plots. In many cases, the regenerated indigenous species were mainly the secondary species of T. *stapfiana* Britten*, P. reclinata* Jacq (Chege and Bytebier 2005), *R. uhligii* K. Schum. & K. Krause and *M. conglomerate* Brenan.

Highest species similarities were observed for pine and cypress plots in Chawia and Ngangao. In each of the sites, these plots were located close to each other; it is thus plausible that similar seed dispersal mechanism were operational and that there may have been similar soil seed bank. The complete absence of similar species between eucalyptus plots and indigenous plots in Mbololo and Chawia implies that the eucalyptus plots cannot support regeneration of species similar to indigenous plots, especially if the stem density is high as was the case in eucalyptus plots. In general, the indigenous plots in Mbololo shared low percentages of species similarity with other plots. The possible explanation is attributed to the low disturbances which provide no options for regenerations except through dispersal and presence of gaps *Ocotea usambarensis,* Engl., which, is extinct in some regions (Burgess et al. 2004) and under threat in Tanzania (FAO 2002), could only be found in indigenous plots of Mbololo with 94 stems although it is also known to be present in Ngangao. *Coffea fadenii* Bridson, wild coffee, could only be found in Ngangao.

The diversity observed in the exotic plots of Chawia may be an indication that without further disturbances the exotic plots will regain their indigenous status as it occurred in Nigeria where, a degraded forest regenerated and recovered to its original status without further disturbances (Onyekwelu et al 2007). In the broader context however, disturbance is considered a key element of landscape diversity, and may be viewed as beneficial to proper functioning of ecosystems (e.g., Rogers 1996; Franklin et al. 2002). Plant diversity is enhanced by a range of successional stages through periodic disturbance of plant communities (Rogers and Ryel 2008). Our findings confirm studies by Wilder et al. (1998) and Githiru et al. (2005) that Mbololo with its highest diversity was the least disturbed, Ngangao has intermediate level of disturbance, and Chawia is the most disturbed of the larger forest fragments in the Taita Hills.

The high species diversity and high abundance of indigenous tree saplings and seedlings in the exotic plantations in the Taita Hills is very encouraging in terms of conservation efforts. International initiatives have been instituted in the Taita Hills in order to increase the indigenous forest cover (Pellikka et al. 2009). The Ngangao and Chawia forest fragments are to be linked with a three-step reforestation plan including forest enrichment, agricultural matrix enrichment and conversion of exotic plantations to indigenous forest. As the indigenous forest enrichment will be carried out by planting indigenous tree species in and around current indigenous forest fragments, the conversion will be carried out by gradual removal of exotic trees from the canopy level to increase light availability for indigenous trees and seedlings in addition to replanting indigenous species.

A GIS-based, least-cost modelling technique was used to determine the most appropriate plantations for restoration (Adriaensen et al. 2006); after integrating all biological and socio-economic data within the corridor (Mwangombe 2005), a set of exotic plantations with highest priority for restoration were identified based on their potential for increasing landscape connectivity and/or importance for the conservation of critically endangered taxa. Through various local initiatives, tree nurseries have been set up to supply seedlings necessary for future (re)planting with indigenous trees (e.g. *P. Africana* Hook. F.) and farmer-friendly exotic trees (e.g. *G. robusta* A. Cunn. ex R.Br). Community Forest Associations have been formed for different forest fragments, and income-generating activities directly associated with indigenous forest have been initiated. Further activities seek international development funding for the establishment of the forest corridor between Ngangao and Chawia.

Conclusions

The rich biodiversity of the indigenous forests of the Taita Hills has been acknowledged by scientists for decades, though we found that exotic plantation forests add to high diversity tree species regeneration. In terms of tree diversity, the indigenous forest in Mbololo, which is the least disturbed, had more diversity than Chawia (most disturbed). Of the exotic forests, Chawia had the highest species biodiversity and Mbololo the lowest; an indication that without further disturbance and under planting by exotic species within the exotic plantation forests, the forests may regain their indigenous status during next decades. This rehabilitation may be enhanced by selective cutting of exotic trees, thus triggering the growth of indigenous species from soil seed banks.

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