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Full Length Research Paper

Functional distances of woody species, proxy of ecological elasticity and provision for forest management

Shiferaw Abebe[1,3,4]*, Kåre Arnstein Lye[1] and Diress Tsegaye[1,2]

[1]Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, P. O. Box 5003, N-1432 Ås, Norway.
[2]Department of Biology, University of Oslo, P. O. Box 1066 Blindern, N-0316 Oslo, Norway.
[3]Forestry Agricultural Research Center, Ethiopian Institute of Agricultural Research, P. O. Box 2003, Addis Ababa, Ethiopia.
[4]Norwegian Institute for Nature Research (NINA), Gaustadallèen 21, No-0349 Oslo, Norway.

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The natural forests in north western Ethiopia have been dwindling at an alarming rate. However, church forests are found as a spot in each community serving as unique and conspicuous *in situ* conservation of indigenous species. Five church forests with adjacent degraded forests were surveyed to investigate the functional distance and diversity. Fifty woody species were identified both from the church and adjacent degraded forests and have 34 species in common (S_j = 0.68). Eleven new species were recorded in the adjacent degraded forest, but five species which were found in the church forest disappeared. The average functional distances between woody species were 22.3 ± 14.4 (mean ± SD) and 23.8 ± 17.0 for church and adjacent degraded forests, respectively. Dominant woody species were functionally dissimilar. Functional distances between 10 minor of the church and 10 dominant of adjacent degraded forest species were significantly different (χ^2 = 12.24, P = 0.01), suggesting that minor species have offered insurance. Passenger species and some of the dominant species in the church forest have also offered insurance. Functional distance which is a cumulative effect of functional attributes is a proxy for ecological elasticity to disturbances and helps in forest management decisions.

Key words: Church forests, degraded forests, ecosystem, functional attributes, relative abundance, resilience.

INTRODUCTION

The natural forests in north western Ethiopia has been dwindling at alarming rate (Mamo et al., 2006; Gole et al., 2008) due to conversion to arable lands, overgrazing, and excessive utilization for fuelwood and construction triggered by increasing population growth (Haugen, 1989; Taddese, 2001; Zeleke and Hurni, 2001). However, church forests are found as a spot in a landscape in each community (that is, the lowest administrative unit in the region) and mostly represent the original natural forest of the area (Wassie et al., 2005). The degraded natural forests may be composed of a combination of species from the original natural forest and additional new species. The church forests are unique and conspicuous spots serving as an *in situ* conservation, mainly for indigenous trees and shrubs in north western parts of Ethiopia. Though, the churches are mainly built as congregational sites of worship, burials, meditating and religious festivals, they often provide exclusive, secured habitats for plants, animals and microorganisms (Wassie, 2002; Wassie et al., 2005). The reason why church forests survive the intensive deforestation in the region is that, as many people remain adherents to the Orthodox faith which espouses protection of woodland within its

*Corresponding author. E-mail: shiferab@yahoo.com, shiferaw.abebe.zeleke@nina.no. Tel: +47 90727322.

territory, they are reluctant to degrade such areas. Nevertheless, some disturbances such as spot clearing for burial purpose and selective logging for the maintenance of the churches are occasionally carried out. Due to differences in intensity of disturbances, species composition in church and degraded forests may thus be different even if they are located at short distances. Disturbance is thus one of the key factors that shape the structure of vegetation (Rusch et al., 2003; Westoby et al., 2002). Although, a few traits have a general association with responses to disturbance, some studies have documented that plant attributes are specific to a particular disturbance (Girme, 2001; Walker et al., 1995).

The functional attributes of species have pivotal roles for the ecosystem function of a given species assembly (Delarum et al., 2010) and help to predict changes in vegetation and biodiversity in response to changes in environmental factors and land-use shifts at regional and global scales (Rusch et al., 2003). It is now generally accepted that the structure of species assemblages may be as important as the concept of species richness (Naeem and Wright, 2003; Petchey and Gaston, 2006; Petchey et al., 2007; Griffin et al., 2009). This approach signifies the importance of functional diversity than biodiversity (Dalerum et al., 2010). There is thus an increasing interest in quantifying functional diversity. Holling (1973) has introduced the perception of ecosystem resilience as a means to investigate ecological processes. Such ecological resilience can be regarded as a measure of how much disturbance an ecosystem can tolerate without altering its original state (Gunderson, 2000) or amount of disturbance that a species assembly can take up without varying its ecological utility (Walker, 1995). Dominant species of a natural forest are few in number, and they are responsible for performing the bulk of photosynthesis, transpiration and nutrient uptake (Peterson et al., 1998). Dominant species would be functionally dissimilar to each other (Walker et al., 1999). Minor species, which constitute a smaller proportion of the species abundance in the ecosystem are similar to the dominant species in ecological functioning, but react in a different way to environmental requirements and disturbance; as a result they offer insurance to the vegetation after a certain interruption (Walker, 1995; Walker et al., 1999; Bengtsson et al., 2000).

Identifying dominant and minor species and functional distances between the dominant and minor species in a vegetation, therefore, helps to predict the possible structures of a forest and the likelihood of such occurrence (Archibold, 1995; Peterson et al., 1998; Walker et al., 1999). Despite the potential of the church forest in understanding the history of the original ecosystem, consequences of disturbance and resilience mechanism studies are rare (Wassie et al., 2002, 2005, 2010) and absent particularly in relation to functional diversity. Thus, the objectives of the study were to: 1) identify dominant and minor woody species and their functional attributes both in the church and degraded forests, 2) estimate functional diversity of the forests and functional distances between pairs of woody species, and 3) examine how minor species in the church forests have offered resilience for the adjacent degraded forest.

MATERIALS AND METHODS

Study area

The study was conducted in Awabel district of East Gojam administrative zone in Amhara national regional state, Ethiopia. Each community (the lowest local administrative unit) has its own church which is mostly surrounded by natural forests. We selected five churches with natural forest that have adjacent degraded forests for this study: Yeleb Lideta (10° 09' N, 37° 59' E), Yeterbina Gebreal (10° 09' N, 38° 02'), Tsid Mariam (10° 08' N, 37° 58' E), Mehir Abo (10° 06' N, 37° 59' E) and Mekides Mariam (10° 07' N, 38° 00' E). The elevation of the study area ranges from 1100 to 3200 m above sea level. The annual rainfall and mean annual temperature is about 1100 to 1400 mm and 21°C, respectively.

Sampling

Five churches together with five adjacent degraded forests were randomly selected. The five selected churches were: Yeleb Lideta, Yeterbina Gebreal, Tsid Mariam, Mehir Abo and Mekides Mariam. Twelve circular plots with a radius of 5.64 m (100 m^2 area) (approximately 10% of the total area of each church forest) were randomly distributed in each of the church and adjacent degraded forests, a total of 60 plots were established in each of the forest types. Circular plots were used to avoid edge effects (Magurran, 2004). All woody species were recorded. However, seedlings were recorded in a subplot (1 m radius) established in each of the circular plots.

Estimating functional distance and functional attributes

As shown in Table 1, the most important plant functional attributes such as life form, height, leaf area, leaf life time, and fruit type (Archambault, 1998; Walker, 1995; Walker et al., 1999) were used to estimate the functional diversity of the two forests and functional distance between pair of woody species. Some of the attributes play vital role in performing photosynthesis and biomass accumulation by receiving more light for longer periods. Fruit type influences seed dispersal, storage and germination potential and mechanism which in turn have great impact on the regeneration and dominancy of a species (Ngulube et al., 1997; Teketay, 1997; Vanclay et al., 1997; Eriksson et al., 2003). These functional attributes and botanical names for each species were identified in the field according to "Flora of Ethiopia and Eritrea" (Edwards et al., 2000; Hedberg and Edwards, 1989; Hedberg et al., 2006). Specimens were collected for species which were not identified in the field and identified at the National Herbarium at Addis Ababa University. The functional distance was estimated following Walker (1995) and Walker et al. (1999) equation:

$$ED = \left[\sum_{i=1}^{I} \left(A_{ij} - A_{ik} \right)^2 \right]^{1/2}$$

Table 1. Functional attributes and values attached to each attribute.

Functional value	Height (m)	Leaf area (cm^2)	Growth form	Leaf life time	Fruit type
1	0-5	0-10	Shrub	Deciduous	Berry
2	5-10	10-20			Drupe
3	10-15	20-30	Shrub/tree	Semidecidous	Nut
4	15-20	30-40			Capsule
5	> 20	> 40	Tree	Evergreen	Pod

Source: Walker et al. (1999) and Rutina et al. (2005). Note that the two conifer species lack fruits. *Cupressus lusitanicus*, which has dry seeds, is in the table classified as having nut, while *Juniperus excelsa*, which has fleshy seeds, is in the table classified as having a berry.

Where A_{ij} and A_{ik} are the attribute values of species j, k for attribute i, and I is the total number of attributes being considered.

We also classified functional similarity intervals using ecological distance (ED) as functionally similar ($0 \le ED \le 6$), similar to average ($7 \le ED \le 14$), average to dissimilar ($14 \le ED \le 33$) and dissimilar ($ED > 33$) following Walker et al. (1999). Jacard's similarity coefficients (Magurran, 2004) were used to determine the similarities of woody species based on their abundance. The relative abundance of each species (Krebs, 1999; Smith and Smith, 2001) in both church and adjacent degraded forests was compared using a Z test of two proportions in Minitab software version 16.0. Then, a Chi-square test was used to compare the functional distances among the ten most dominant species of the church forest and between the ten least dominant (minor) of the church forest and the ten most dominant species of the adjacent degraded forest.

RESULTS

Relative abundance and similarity of woody species

Fifty woody species have been identified from both the Church and adjacent degraded forests. Fifteen woody species were significantly more abundant in the church forests than in the degraded forests ($P < 0.05$). Similarly, seven woody species were significantly more abundant in the adjacent degraded forests than in the church forest. Five woody species, *Cordia africana* Lam, *Dracaena steudneri* Engel., *Jasmium abyssinicum* Hochst. ex DC., *Malva verticilata* L. and *Olea europaea* L. ssp. *Cuspidata* which were found in the church forest have disappeared in the adjacent degraded forest. Eleven new woody species, *Acalypha fruitcosa* Forssk., *Clausena anisata* (Willd.) Benth., *Combretum molle* R.Br. ex G.Don, *Dodonaea angustifolia* L.F., *Ekebergia capensiss* Sparrm., *ficus plamta* Forssk., *ficus vasta Forssk.*, *Myrsine Africana* L. and *Rhus glutinosa* A. Rich. which were not found in the church forest have been recorded in the adjacent degraded forest (Table 2). Most of the woody species which were dominant in church forests had reduced in abundance in adjacent degraded forests. The similarly between the church and the adjacent forests as a whole was the highest ($S_j = 0.68$) of all indexes (Table 3).

On average, similarity index was higher among church forests ($S_j = 0.52$) compared to adjacent degraded natural forest ($S_j = 0.34$). Mekdes church forest and its adjacent degraded forest were the most dissimilar ($S_j = 0.18$).

Functional distance and diversity

The functional distances between woody spices ranges from 0 to 72 and 0 to 81 and church and adjacent degraded forests, respectively (Appendix 1 and 2). The total number of functional distances between woody species in the church and adjacent forest was 737 and 926, respectively. The average functional distances between woody species were 22.3 ± 14.4 (mean ± SD) and 23.8 ± 17.0 for church and adjacent degraded forests, respectively (Appendix 1 and 2). Out of the total functional distances in the church forests, 14% (106) pairs were functionally similar, 26% (193) pairs were similar to average, 38% (277) pairs were average to dissimilar and 22% (161) pairs were dissimilar for the church forests (Figure 1A). In the degraded adjacent forests, 17% (154) pairs were functionally similar, 23% (215) pairs were similar to average, 33% (304) pairs were average to dissimilar and 27% (253) pairs are dissimilar (Figure 1B). We found significant variation among the four functional distance groups in the distribution of functional distances of the 10 most dominant species in the church forest ($\chi^2 = 21.40$, $P < 0.001$) and between 10 minor of the church and 10 dominant adjacent degraded forest species ($\chi^2 = 12.24$, $P = 0.01$) (Table 4). The average dissimilar ($14 \le ED \le 33$) and dissimilar ($ED \ge 33$) functional groups combined represent 87% of the total functional distances in the church forest (Table 4).

Only the rest 20% of the functional distances among the ten most dominant woody species of the church forest lies in similar to average ($6 < ED \le 14$) and similar ($0 \le ED \le 6$) functional ranges (Table 4). Whereas, the functional groups for average to dissimilar ($14 \le ED \le 33$) and dissimilar ($ED \ge 33$) combined have captured only 66% ($\chi^2 = 12.240$, $P = 0.01$) of the functional distances between the ten minor species of the church forest and the ten most dominant woody species of the adjacent degraded forests. Five woody species (*Carissa spinarum*

Table 2. Woody species identified and their relative abundance and functional attributes.

Species	Relative abundance (%) in 120 plots		Mature leaf area (cm^2)	Height at maturity (m)	Growth form	Leaf life time	Fruit type
	Church	Adjacent					
Acacia abyssinica Hochst. ex Benth.	15[a]	28[a]	0-5	20	Tree	Semi-deciduous	Pod
Acacia nilotica (L.) Willd. ex Del.	17[a]	20[a]	0-5	2-14	Shurb/tree	Evergreen	Pod
Acalypha fruticosa Forssk.	0[a]	3[a]	>40	2-5	Shrub	Semi-deciduous	Capsule
Acanthus pubescens (Oliv.) Engl.	32[a]	30[a]	>40	0-5	Shrub	Deciduous	Capsule
Albizia gummifera (J.F. Gmel.) C.A.Sm.	8[a]	18[a]	0-5	15	Tree	Evergreen	Pod
Asparagus racemosus Willd.	0[b]	7[a]	0-5	7	Shrub	Semi-deciduous	Berry
Bersama abyssinica Fresen.	2[b]	15[a]	>40	2-5	Shrub	Semi-deciduous	Capsule
Buddleja polystachya Fresen.	15[a]	8[a]	>40	4-12	Tree	Semi-deciduous	Capsule
Calpurnia aurea (Ait.) Benth..	58[a]	18[b]	0-5	2-5	Shrub	Semi-deciduous	Capsule
Capparis micrantha A.Rich.	53[a]	13[b]	0-5	0-5	Shrub	Semi-deciduous	Capsule
Carissa spinarum L.	58[b]	83[a]	5-10	0-5	Shrub/tree	Evergreen	Berry
Clausena anisata (Willd.) Benth.	0[b]	15[a]	0-5	0-5	Shrub	Evergreen	Capsule
Clerodendrum myricoides (Hochst.) Vatke	18[a]	3[b]		0-5	Shrub	Evergreen	Capsule
Combretum molle R.Br. ex G.Don	0[a]	2[a]	20-30	2-5	Shrub	Evergreen	Capsule
Cordia africana Lam.	13[a]	0[b]	300	15-20	Tree	Deciduous	Drupe
Croton macrostachyus Del.	32[a]	27[a]	150	25	Tree	Deciduous	Nut
Cupressus lusitanica Lindl. ex Parl.	8[a]	7[a]	0-5	35	Tree	Evergreen	Dry seed
Cussonia holstii Harms ex Engl.	3[a]	7[a]	20-30	0-5	Shrub	Evergreen	Nut
Dodonaea angustifolia L.f.	0[a]	5[a]	5-10	0-5	Shrub	Evergreen	Capsule
Dombeya torrida (J.F.Gmel.) P. Bamps	8[a]	17[a]	100	12-15	Shrub/tree	Semi-deciduous	Capsule
Dracaena steudneri Engl.	3[a]	0[a]	>40	5-10	Shrub/tree	Evergreen	Capsule
Ehretia cymosa Thonn.	8[a]	7[a]	15	0-5	Shrub	Semi-decidous	Capsule
Ekebergia capensis Sparrm.	0[a]	3[a]	>40	20-30	Tree	Evergreen	Capsule
Eucalyptus globulus Labill.	3[a]	2[a]	30-40	30	Tree	Evergreen	Capsule
Euclea racemosa Murr. ssp. *schimperi*	3[a]	8[a]	10-15	3-5	Shrub/tree	Evergreen	Drupe
Euphorbia abyssinica J.F.Gmel.	35[a]	3[b]	0-5	10	Shrub	Evergreen	Capsule
Ficus palmata Forssk.	0[a]	5[a]	>40	20-30	Tree	Deciduous	Berry
Ficus vasta Forssk.	0[b]	8[a]	>40	>20	Tree	Deciduous	Fig, berry
Grewia ferruginea Hochst. ex A. Rich.	60[a]	7[b]	>40	0-5	Shrub	Evergreen	Capsule
Hibiscus micranthus L.f.	12[a]	2[b]	6-30	0-5	Shrub	evergreen	Capsule
Jasminum abyssinicum Hochst. ex DC.	18[a]	0[b]	20-30	5-10	Shrub	Semi-deciduous	Nut
Juniperus excelsa M.Bieb.	8[a]	2[a]	0-5	40	Tree	Evergreen	Fleshy seed
Justicia schimperiana (Nees) T. Anders.	40[a]	5[b]	36-40	0-5	Shrub/tree	Evergreen	Capsule
Malva verticillata L.	7[a]	0[b]	20-30	2-5	Shrub	Evergreen	Capsule

Table 2. contd.

Maytenus senegalensis (Lam.) Exell	58[a]	40[b]	0-5	0-5	Shrub	Evergreen	Berry
Myrsine africana L.	0[a]	5[a]	0-5	0-5	Shrub	Evergreen	Capsule
Ocimum urticifolium Roth	8[a]	7[a]	0-5	1-2	Shrub	Semi-deciduous	Capsule
Olea europaea L. ssp. *cuspidata*	17[a]	0[b]	30	10-20	Tree	Evergreen	Nut
Olinia rochetiana A. Juss.	0[b]	8[a]	0-5	0-5	Shrub	Evergreen	Capsule
Osyris quadripartita Decn.	12[a]	18[a]	0-5	0-5	Shrub	Evergreen	Drupe
Phytolacca dodecandra L'Hérit.	23[a]	3[b]	0-5	2-5	Shrub	Evergreen	Capsule
Pittosporum viridiflorum Sims	30[a]	13[b]	20-30	0-5	Shrub/tree	Semi-deciduous	Pod
Prunus africana (Hook.f.) Kalkm.	3[a]	7[a]	0-5	0-5	Shrub	Evergreen	Pod
Protea gaguedi J.F.Gmel.	25[a]	30[a]	0-5	2-15	Shrub	Evergreen	Pod
Pterolobium stellatum (Forssk.) Brenan	48[a]	18[b]	50	40	Tree	Evergreen	Drupe
Rhus glutinosa A.Rich.	0[b]	12[a]	24	3-10	Shrub/tree	Evergreen	Drupe
Rosa abyssinica Lindley	2[a]	10[a]	0-5	0-5	Shrub	Evergreen	Drupe
Schefflera abyssinica (A. Rich.) Harms	5[a]	13[a]	>40	10-30	Tree	Evergreen	Capsule
Terminalia schimperiana Hochst.	5[a]	15[a]	20-30	2-5	Evergreen	shrub	Capsule
Vernonia amygdalina Del.	8[a]	15[a]	>40	3-10	Shrub/tree	Evergreen	Capsule

Figures with different superscripts indicates that the relative abundance of a species is significantly different ($P<0.05$) in church and degraded forests.

L., *Maytenus senegalensis* (Lam.) Exell, *Calpurnia aurea* (Ait.) Benth., *Justicia schimperiana* (Nees) T. Anders and *Osyris quadripartite* Decn. out of the most dominant 10 woody species of the adjacent degraded forest had similar ecological distance (Appendix 1 and 2).

DISCUSSION

The similarity index shows that church forests are more similar to each other than adjacent degraded forests, suggesting that disturbance can create more dissimilar forests. Our result revealed that functional diversity of the degraded natural forest had increased only by 6% after disturbance considering the church forest as a reference. However, Abebe et al. ('under review') has reported higher species diversity for church forest compared to adjacent degraded forest using the same plots of these forests. A slightly higher mean and standard deviation of functional diversity for the adjacent degraded forest compared to the church forest indicates that disturbance may some how increase functional diversity. However, this occurs at moderate level of disturbance as reported in other studies (Delarum et al., 2010). This study indicates that functional diversity is less sensitive to disturbance than species diversity. This study thus contributes to the increasing interest in quantifications of functional diversity (Petchey et al., 2007; Bracken et al., 2009; Dalerum et al., 2009). The findings of this study must be cautiously interpreted not to diminish the role of the church forest in maintaining intact natural forest of indigenous species. The relative abundance of the species confirms that rare species are many in number and few in abundance and dominant species are few in number but covers most of the area. It agrees with the ecological concept which claims that dominant species are few in number and minor or tail species are many in number, but less dominant (Peterson et al., 1998; Walker et al., 1999).

The result reveals that dominant species are functionally dissimilar to each other, supporting previous findings which claimed that differences in functional niches allow these species to be co-dominant (Walker et al., 1999; Peterson et al., 1998). This implies that less disturbed natural forests have high functional diversity that can play a vital role in avoiding competition among species. This also signifies the advantage of natural forest or mixed plantations compared to monoculture plantations. The functional distances between the

Table 3. Similarity in species abundance among the possible pairs of church forests (Chf) and adjacent degraded forests (Af).

Chf	**Adf**	**Yeleb**		**Yeterbina**		**Tsid Mariam**		**Mekides**		**Mehir**	
	0.68	**Chf**	**Af**	**Chf**	**Af**	**Chf**	**Af**	**Chf**	**Af**	**Chf**	**Af**
Yeleb	Chf	1.00	0.63 (18)	0.63 (20)	0.49 (17)	0.47 (15)	0.38 (11)	0.53 (17)	0.22 (9)	0.49 (17)	0.35 (13)
	AF		1.00	0.52 (20)	0.38 (13)	0.31 (10)	0.35 (9)	0.33 (11)	0.25 (9)	0.31 (11)	0.41 (13)
Yeterbina	Chf			1.00	0.47 (16)	0.50 (15)	0.36 (10)	0.48 (15)	0.30 (11)	0.46 (16)	0.37 (13)
	AF				1.00	0.36 (12)	0.36 (10)	0.52 (16)	0.41 (14)	0.42 (15)	0.33 (12)
Tsid Mariam	Chf					1.00	0.65 (10)	0.62 (16)	0.23 (14)	0.48 (15)	0.34 (11)
	AF						1.00	0.46 (11)	0.37 (7)	0.31 (10)	0.29 (8)
Mekdes	Chf							1.00	0.18 (7)	0.50 (16)	0.36 (12)
	AF								1.00	0.40 (14)	0.39 (12)
Mehir	Chf									1.00	0.50 (13)
	AF										1.00

minor species of the church forest and the dominant species of the adjacent forests suggests that minor species of the church forest have shown tendency of offering insurance in the adjacent degraded forest. The result also confirms that new comer (passenger species) have offered insurance after disturbance. However, some species (*C. spinarum*) which are dominant in the church forest have still remained dominant in the adjacent forest. On the other hand, five species (*C. africana*, *D. steudneri*, *J. abyssinicum*, *M. verticillata* and *O. europaea* ssp. *cuspidate*) which were rare in the church forest were totally absent in the adjacent degraded forest. Their timber quality and sensitivity to browsing made these species extinct locally due to animal and human disturbances. In sum, dominant species and rare species may be functionally similar, but may not be necessarily different in responding to disturbance. Minor species, which offer insurance regenerate in different ways, that is, by seed banks, seedling banks, seed rain or underground stumps (Teketay, 1997; Argaw et al., 1999; Eriksson et al., 2003; Wassie and Teketay, 2006; Wang et al., 2009. About 82% of the species, which are not found in the church forests, have capsule fruits and the rest 12% have berry fruits.

The seed germination strategy and dispersal methods might have contributed to the existence of those species. Tiny seeds from capsule are highly dependent on wind for dispersal and wind dispersal is more limited in the church forests compared to the open adjacent degraded forests. The main disturbances observed in the area were combinations of human disturbances mainly for wood products (that is, fuelwood and construction) and intensive browsing by animals. However, other disturbances such as fire, mineral and water stress, shed, wind, pest, disease and other natural disturbances such as climate change could also be possible causes (Vanclay et al., 1997; Meers et al., 2010). Most of the dominant species in the adjacent degraded forest, except *C. spinarum* are not preferred by animals as a forage or by people for different uses (Bekele-Tesemma et al., 1993). *C. spinarum* which is preferred as browse for animals and for its excellent fire wood is abundant both in church and adjacent degraded forests. Its unique potential and adaptation has helped to perfectly respond to the disturbances and offer insurance. Its sharp thorns are important for resisting browsing pressure. Its amorphous big underground root also helps to produce multiple sprouts after grazing or cutting by people or damage by animals. This suggests that a single species with unique ability in responding to disturbances can also offer insurance for the ecosystem after disturbances.

The result lends hand to the general understanding that disturbance is among the most

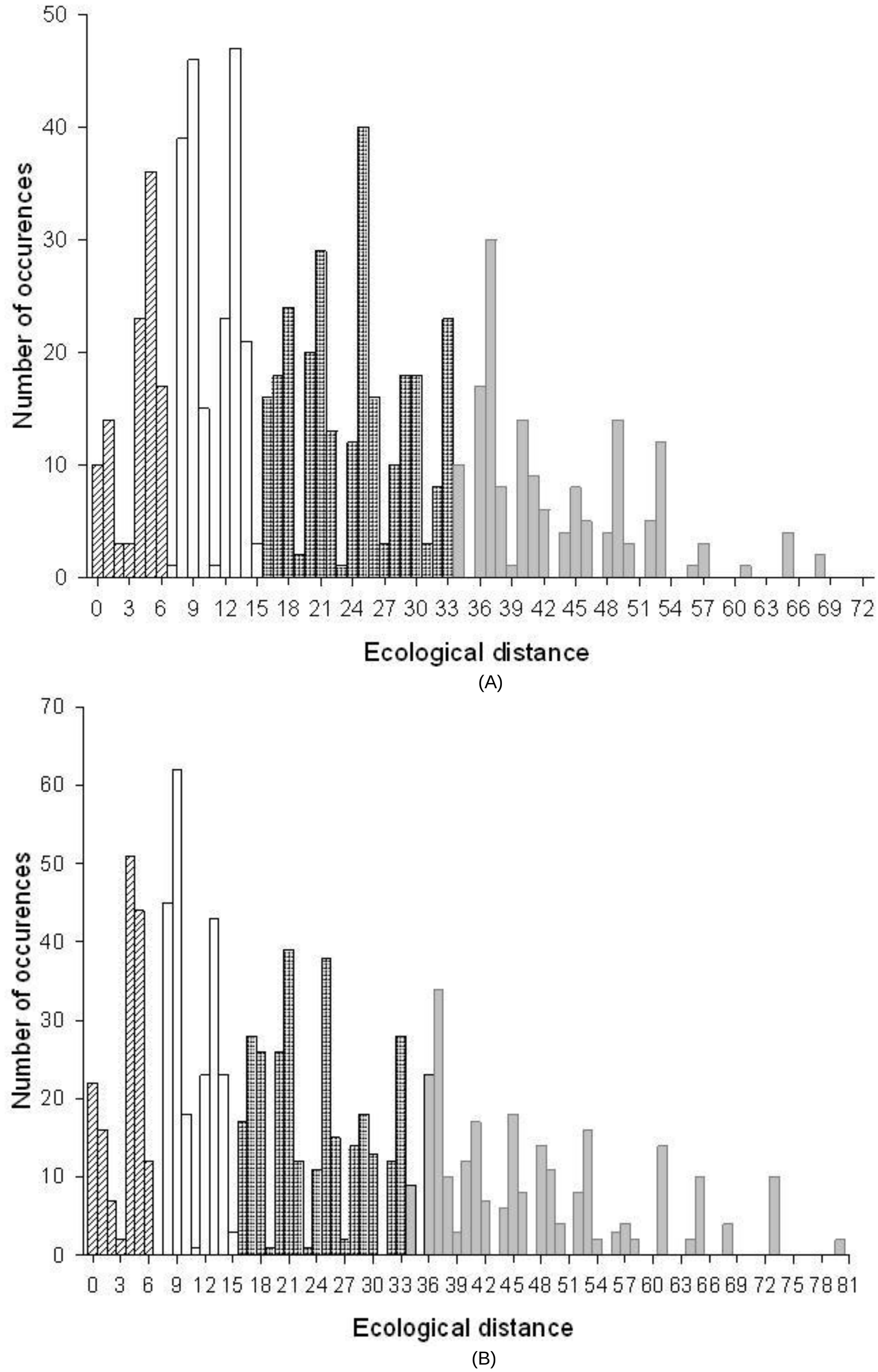

Figure 1. Frequencies of ecological distances for all species pairs in the church forest. Groupings reflect apparent clusters of frequent ecological distances (light hashed, white bars, striped, and grey bars); the lower the ecological distance, the more functionally similar are the two species.

Table 4. Functional distances between 10 most abundant species in the church forest, and between 10 minor church and 10 dominant adjacent degraded forest species.

Functional similarity	Functional distance pairs between species	
	Church dominant	Church minor versus adjacent dominant
Similar (0 ≤ ED ≤ 6)	3	14
Average to similar (6 < ED ≤ 14)	4	20
Average to dissimilar (14 < ED < 33)	19	37
Dissimilar (ED ≥ 33)	19	29
Total pairs	45	100
χ^2	21.40	12.24
P-value	< 0.001	0.01

important key factors shaping the ecologies of the vegetation and attributes that confer success under disturbance are central (Rusch et al., 2003; Girme, 2001; Westoby et al., 2002). Functional diversity which is a cumulative effect of functional attributes is a proxy for ecological elasticity to disturbances. Thus, the concept of functional distances between species may be used as criteria to determine the functional distances between species for plantation and conservation purposes. It can also be used to predict changes in vegetation driven by anthropogenic disturbance such as land-use shifts and climate changes at local, regional and global scales.

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Appendix 1. Functional distance between species and diversity of the church forest.

Species	A.e	A.n	A.p	A.g	B.a	B.p	C.a	C.m	C.s	C.m	C.a	C.m	C.l	C.h	D.t	D.s	E.c	E.g	E.r	E.a	G.f	H.m	J.a	J.e	J.s	M.v	M.s	O.u	O.e	O.q	P.d	P.v	P.g	
Acacia abyssinica																																		
Acacia nilotica	9																																	
Acanthus pubescens	46	41																																
Albizia gummifera	5	4	53																															
Bersama abyssinica	42	29	4	41																														
Buddleia polystachya	18	25	24	21	20																													
Calpurnia aurea	26	13	20	25	16	36																												
Capparis micrantha	26	13	20	25	16	36	0																											
Carissa spinarum	34	21	38	25	26	30	18	18																										
Clerodendrum myricoides	34	13	20	25	8	28	8	8	14																									
Cordia africana	38	49	20	45	24	12	40	40	30	40																								
Croton macrostachys	25	44	33	40	37	9	53	53	49	53	17																							
Cupressus lusitanica	9	12	65	8	53	25	37	37	25	37	49	32																						
Cussonia holstii	33	20	9	32	5	25	5	5	13	5	25	40	40																					
Dombeya torrida	22	21	12	25	8	4	24	24	26	16	16	13	29	13																				
Dracaena steudneri	29	18	21	22	9	9	25	25	19	9	25	30	30	14	5																			
Ehretia cymosa	27	14	13	26	9	29	1	1	17	5	33	46	38	2	17	18																		
Eucalyptus globulus	15	18	49	14	37	9	45	45	33	33	37	18	10	38	13	14	40																	
Euclea racemosa	27	14	33	18	21	25	13	13	1	9	29	46	22	10	21	14	12	28																
Euphorbia abyssinica	9	6	49	2	37	21	21	21	15	21	37	42	10	26	25	20	22	18	10															
Grewia ferruginea	46	25	16	37	4	24	20	20	22	4	36	49	49	9	12	5	13	33	17	33														
Hibiscus micranthus	34	13	20	25	8	28	8	8	14	0	40	53	37	5	16	9	5	33	9	21	4													
Jasminum abyssinicum	28	17	10	29	6	22	6	6	14	6	26	33	33	1	10	13	3	31	11	25	10	6												
Juniperus excelsa	5	8	65	4	53	25	37	37	37	37	57	36	4	44	29	30	38	10	30	10	49	37	37											
Justiia schimperiana	39	18	17	30	5	25	13	13	17	1	37	50	42	6	13	6	8	32	12	26	1	1	7	42										
Malva verticillata	34	13	20	25	8	28	8	8	14	0	40	53	37	5	16	9	5	33	9	21	4	0	6	37	1									
Maytenus senegalensis	45	24	41	36	29	49	13	13	5	13	49	68	36	12	37	30	14	50	6	26	25	13	13	48	18	13								
Ocimum urticifolium	26	13	20	25	16	36	0	0	18	8	40	53	37	5	24	25	1	45	13	21	20	8	6	37	13	8	13							
Olea europaea	12	13	46	9	34	10	34	34	18	26	30	21	5	29	14	13	31	3	15	9	30	26	24	9	27	26	33	34						
Osyris quadripartita	38	17	36	29	24	44	8	8	6	8	48	65	33	9	32	25	9	45	5	21	20	8	10	41	13	8	1	8	30					
Phytolacca dodecandra	30	9	32	21	20	40	4	4	14	4	52	65	33	9	28	21	5	41	9	17	16	4	10	33	9	4	9	4	30	4				
Pittosporum viridiflorum	18	13	12	17	8	12	8	8	14	8	16	29	29	5	8	9	5	25	9	13	12	8	6	29	9	8	21	8	18	16	12			
Protea gaguedi	29	8	33	20	21	41	5	5	21	5	57	68	36	12	29	22	6	42	14	18	17	5	13	32	10	5	16	5	33	9	1	13		
Pterolobium stellatum	21	4	37	16	25	37	9	9	25	9	61	56	24	16	25	22	10	30	18	18	21	9	13	20	14	9	20	9	25	13	5	17	4	
Prunus africana	23	26	53	22	41	13	49	49	25	37	33	18	10	38	17	18	44	4	24	22	37	37	31	18	36	37	42	49	3	41	45	29	50	5
Rosa abyssinica	26	13	40	17	28	32	12	12	2	12	36	53	21	13	28	21	13	33	1	9	24	12	14	29	17	12	5	12	18	4	8	12	13	12

Appendix 1.contd.

Schefflera abyssinica	22	25	48	21	36	8	52	52	38	36	36	17	17	41	12	13	45	1	33	25	32	36	34	17	33	36	57	52	6	52	48	28	49	4
Terminalia schimperiana	34	13	20	25	8	28	8	8	14	0	40	53	37	5	16	9	5	33	9	21	4	0	6	37	1	0	13	8	26	8	4	8	5	16
Vernonia amygdalina	29	18	21	22	9	9	25	25	19	9	25	30	30	14	5	0	18	14	14	20	5	9	13	30	6	9	30	25	13	25	21	9	22	5

Appendix 2. Functional distance between species and diversity of the adjacent degraded forest.

Species	A.e	A.n	A.p	A.g	B.a	B.p	C.a	C.m	C.s	C.m	C.a	C.m	C.l	C.h	D.t	D.s	E.c	E.g	E.r	E.a	G.f	H.m	J.a	J.e
Acacia abyssinica																								
Acacia nilotica	9																							
Acanthus pubescens	46	41																						
Albizia gummifera	5	4	53																					
Bersama abyssinica	42	29	4	41																				
Buddleia polystachya	18	25	24	21	20																			
Calpurnia aurea	26	13	20	25	16	36																		
Capparis micrantha	26	13	20	25	16	36	0																	
Carissa spinarum	34	21	38	25	26	30	18	18																
Clerodendrum myricoides	34	13	20	25	8	28	8	8	14															
Cordia africana	38	49	20	45	24	12	40	40	30	40														
Croton macrostachys	25	44	33	40	37	9	53	53	49	53	17													
Cupressus lusitanica	9	12	65	8	53	25	37	37	25	37	49	32												
Cussonia holstii	33	20	9	32	5	25	5	5	13	5	25	40	40											
Dombeya torrida	22	21	12	25	8	4	24	24	26	16	16	13	29	13										
Dracaena steudneri	29	18	21	22	9	9	25	25	19	9	25	30	30	14	5									
Ehretia cymosa	27	14	13	26	9	29	1	1	17	5	33	46	38	2	17	18								
Eucalyptus globulus	15	18	49	14	37	9	45	45	33	33	37	18	10	38	13	14	40							
Euclea racemosa	27	14	33	18	21	25	13	13	1	9	29	46	22	10	21	14	12	28						
Euphorbia abyssinica	9	6	49	2	37	21	21	21	15	21	37	42	10	26	25	20	22	18	10					
Grewia ferruginea	46	25	16	37	4	24	20	20	22	4	36	49	49	9	12	5	13	33	17	33				
Hibiscus micranthus	34	13	20	25	8	28	8	8	14	0	40	53	37	5	16	9	5	33	9	21	4			
Jasminum abyssinicum	28	17	10	29	6	22	6	6	14	6	26	33	33	1	10	13	3	31	11	25	10	6		
Juniperus excelsa	5	8	65	4	53	25	37	37	37	37	57	36	4	44	29	30	38	10	30	10	49	37	37	
Justiia schimperiana	39	18	17	30	5	25	13	13	17	1	37	50	42	6	13	6	8	32	12	26	1	1	7	42
Malva verticillata	34	13	20	25	8	28	8	8	14	0	40	53	37	5	16	9	5	33	9	21	4	0	6	37
Maytenus senegalensis	45	24	41	36	29	49	13	13	5	13	49	68	36	12	37	30	14	50	6	26	25	13	13	48
Ocimum urticifolium	26	13	20	25	16	36	0	0	18	8	40	53	37	5	24	25	1	45	13	21	20	8	6	37
Olea europaea	12	13	46	9	34	10	34	34	18	26	30	21	5	29	14	13	31	3	15	9	30	26	24	9

Appendix 2. contd.

Osyris quadripartita	38	17	36	29	24	44	8	8	6	8	48	65	33	9	32	25	9	45	5	21	20	8	10	41
Phytolacca dodecandra	30	9	32	21	20	40	4	4	14	4	52	65	33	9	28	21	5	41	9	17	16	4	10	33
Pittosporum viridiflorum	18	13	12	17	8	12	8	8	14	8	16	29	29	5	8	9	5	25	9	13	12	8	6	29
Protea gaguedi	29	8	33	20	21	41	5	5	21	5	57	68	36	12	29	22	6	42	14	18	17	5	13	32
Pterolobium stellatum	21	4	37	16	25	37	9	9	25	9	61	56	24	16	25	22	10	30	18	18	21	9	13	20
Prunus africana	23	26	53	22	41	13	49	49	25	37	33	18	10	38	17	18	44	4	24	22	37	37	31	18
Rosa abyssinica	26	13	40	17	28	32	12	12	2	12	36	53	21	13	28	21	13	33	1	9	24	12	14	29
Schefflera abyssinica	22	25	48	21	36	8	52	52	38	36	36	17	17	41	12	13	45	1	33	25	32	36	34	17
Terminalia schimperiana	34	13	20	25	8	28	8	8	14	0	40	53	37	5	16	9	5	33	9	21	4	0	6	37
Vernonia amygdalina	29	18	21	22	9	9	25	25	19	9	25	30	30	14	5	0	18	14	14	20	5	9	13	30