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Aboveground carbon stock is related to land cover and woody species diversity in tropical ecosystems of Eastern Ethiopia

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Abstract

Background: Current theories on biodiversity-carbon sequestration relationship describe biodiversity as an important factor influencing carbon storage, either through complementarity effect or by mass ratio effect. So far, the expected form of biodiversity-carbon relationships in tropical ecosystems has not been known with certainty. Therefore, we explored the relationship between aboveground carbon stock and different biodiversity measurement indices (i.e., species richness, species diversity, species evenness, and functional diversity) in different land cover types of Eastern Ethiopia. A total of 48 plots were established using stratified random sampling. Vegetation parameters such as diameter at breast height, diameter at stump height, tree height, and species type were recorded.

Results: We found that the average aboveground carbon stock of the study area is 147.6 ± 17.2 t ha^{-1} (mean, SE) across land cover types. Species richness, Shannon index, and functional diversity together explained 73.5%, 61.4%, 58.9%, and 52.0% of the variation in aboveground carbon storage in woodland, riparian forest, bushland, and farmland, respectively. Functional diversity was a significant predictor explaining the total aboveground carbon stocks (26.7%) across the land cover types. The effects of biodiversity on aboveground carbon storage were mediated by functional diversity and presence and dominance of species. This shows that both the selection effects and the niche complementarity are important for carbon storage. However, the impact of functional diversity effects (niche complementarity) was higher than that of functional dominance effects (selection effects).

Conclusions: Implementation of protected area-based ecosystem conservation practices in the country seems feasible to mitigate climate change and Reducing Emissions from Deforestation and Forest Degradation (REDD+) programme should emphasize on biodiversity conservation.

Keywords: Niche complementarity effect, Functional diversity, Selection effect, Species diversity, Species richness

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Introduction

Global biodiversity is increasingly threatened by human domination of the natural ecosystem and its concomitant impacts that accelerate rates of biodiversity loss and homogenization through invasion (Sala et al. 2000). Loss of biodiversity might cause a significant change in CO_2 exchanges between the land and the atmosphere (Thomas 2013). The change raises fundamental questions such as “will biodiversity loss and variation alter basic ecosystem processes of carbon storage?” To address such questions, in the past 30 years, increasingly considerable attention has been given to in the determination of relationships between biodiversity and ecosystem functions. Although loss of biodiversity is relatively well studied, quantitative assessments of the association between biodiversity and its potential ecosystem function, particularly its role in carbon (C) storage, have not been adequately addressed (Thomas 2013; Harpole et al. 2016).

In terrestrial ecosystems, biodiversity influences both the magnitude (Reich et al. 2001; Tilman et al. 2014) and variability (Bai et al. 2004) of aboveground biomass. Aboveground biomass can significantly determine carbon storage potential of the ecosystem, which plays a significant role in balancing the global carbon budget (Mensah et al. 2016; Forrester et al. 2018). Current theories on biodiversity-carbon sequestration relationship describe biodiversity as an important factor influencing carbon storage, weather, and forest diversity effects which are driven by niche partitioning and facilitation (i.e. the complementarity effect) or by the selection of highly productive species such as the selection effect (i.e., the mass ratio effect) (Cardinale et al. 2012; Madrigal-González et al. 2016; Van Der Sande et al. 2017). The niche complementarity hypothesis states that diverse characteristics of species have a higher divergence of functional traits and can thus help to utilize resources better (Cardinale et al. 2012; Tilman et al. 2014; Yuan et al. 2018). The mass ratio hypothesis states that diversity can increase productivity through selection effects (Loreau and Hector 2001; Oram et al. 2017; Van Der Sande et al. 2017). Positive diversity-productivity relationships have been also found in low diversity mid-latitude (Forrester et al. 2018; Vanhellemont et al. 2018), due to a large canopy packing through complimentary canopy in higher diversity ecosystems (Jucker et al. 2016). Yet, the expected forms of biodiversity-carbon relationships in tropical ecosystems are not fully understood (Cardinale et al. 2012; Liang et al. 2016; Forrester et al. 2018). Thus, a better understanding of how biodiversity affects carbon storage would help direct preservation, conservation, and restoration plans for exploited ecosystems.

Most studies that examined diversity-carbon storage relationships focused principally on species richness as a measure of biodiversity. In fact, biodiversity can be determined in different ways, as the number of species (species richness), the distribution of individuals over species (species evenness), or a combination of richness and evenness, as represented by Shannon index (Stirling and Wilsey 2001). Results of several studies led to the argument that evenness, Shannon index and species richness are different independent indices (Mason et al. 2005; Wilsey and Stirling 2007; MacDonald et al. 2017), and the recommendation that they be treated separately (Stirling and Wilsey 2001; Zhang et al. 2012a). Thus, evaluating the effects of different diversity metrics on carbon stock potential has been demonstrated to be rare (Zhang et al. 2012b; Forrester et al. 2018). The different metrics of diversity may have different predictive powers in different land cover types for predicting carbon storage potential. In this study, we tested the effect of different diversity metrics on aboveground carbon stocks.

Ethiopia is recognized as a hotspot for biodiversity but is suffering from rapid and extensive loss of biodiversity (Myers et al. 2000; Goren et al. 2012; Di Marco et al. 2014). The demand of forest products is quite pronounced as more than 85% of the people living in rural areas that mostly rely on biodiversity for their basic needs such as cattle feed, fuelwood, food, and shelter. In spite of the increasing demand, Ethiopia has been able to maintain a considerable area of land for biodiversity conservation during the last decade. The rate of afforestation in the country is considered to be one of the highest among sub-Saharan countries and has played a role in maintaining biodiversity particularly forest cover and productivity. Despite efforts being exerted to conserve the increasing biodiversity, our knowledge on the role of biodiversity as dynamic C-pools in biogeochemical cycles and the mechanisms underlying the effects of diversity on carbon stock is largely unknown. This would pose challenges to policy development aimed at promoting, managing, or protecting biodiversity to safeguard the atmospheric environment from Greenhouse Gas (GHG) emissions, in addition to providing local people with reasonable means of livelihood. Therefore, it is necessary to understand the role of biodiversity in storing carbon, which is fundamental in quantifying its contribution to climate change mitigation since the quantified amount of carbon indicates the amount of carbon that can be offset (Ditt et al. 2010; Jabareen 2013; Felton and Gustafsson 2016). However, carbon stocks and woody species diversity in different land use types have not been assessed in Babile Elephant Sanctuary. Moreover, it is not clear how different measures of biodiversity are correlated with aboveground carbon stock. Do land use types show variations in aboveground carbon stock? What relationships do exist between different biodiversity measurement indices and aboveground carbon stock under different land use types? Here, we explored the relationships between aboveground carbon stock and different biodiversity measurement indices (i.e., species richness, species diversity, species evenness, and functional diversity) in the different land cover types of Eastern Ethiopia.

Materials and methods

Study site

Babile Elephant Sanctuary (BES) is situated in the Somali-Masaai centre of endemism in Ethiopia. The sanctuary, which is 6892 km^2 in size, was established in 1970 to protect the only viable elephant population in the Horn of Africa. The sanctuary is located 560 km to the east of Addis Ababa (capital city of Ethiopia). Its geographical position is within latitudes of 08° 22′ 30′′—09° 00′ 30′′ N and longitudes of 42° 01′ 10′′–43° 05′ 50′′ E (Fig. 1) and has an elevation ranging between 850 and 1785 m above sea level. Topographically, it is predominantly characterized by flat to gentle slopes, comprising about 84% of the total sanctuary area while the remaining 16% consists of complex valleys and deep gorges. Four main drainage river valleys (Fafem, Dakata, Erer and Gobele) rise from Garamuleta-Gursum highlands, and these extend southwards through the sanctuary to join the Wabi Shebelle River Basin. Wide ranges of wildlife species inhabiting the sanctuary include the African elephant (*Loxodonta africana*), black-maned lion (*Panthera leo*), leopard (*P. pardus*), and Hamadryas baboon (*Papio hamadryads*). The sanctuary is also shelter for a range of antelopes, lesser and greater kudus, leopards, spotted hyenas, wild pigs, warthog, and a variety of reptiles and birds.

Study area and site selection

The study sites were selected using stratified purposive sampling. Four different land cover categories (i.e., treatments) were identified, namely, farmland, riparian forest, woodland, and bushland (Table 1). The description of the land cover classes was based on the standard classes defined by the US Geological Survey (Mohan et al. 2011), and land use land cover study conducted in the study area (Sintayehu and Kassaw 2019).

Sampling and plot establishment

A reconnaissance survey was carried out in order to have an impression of the site conditions and determine samples of farmland, riparian forest, woodland, and

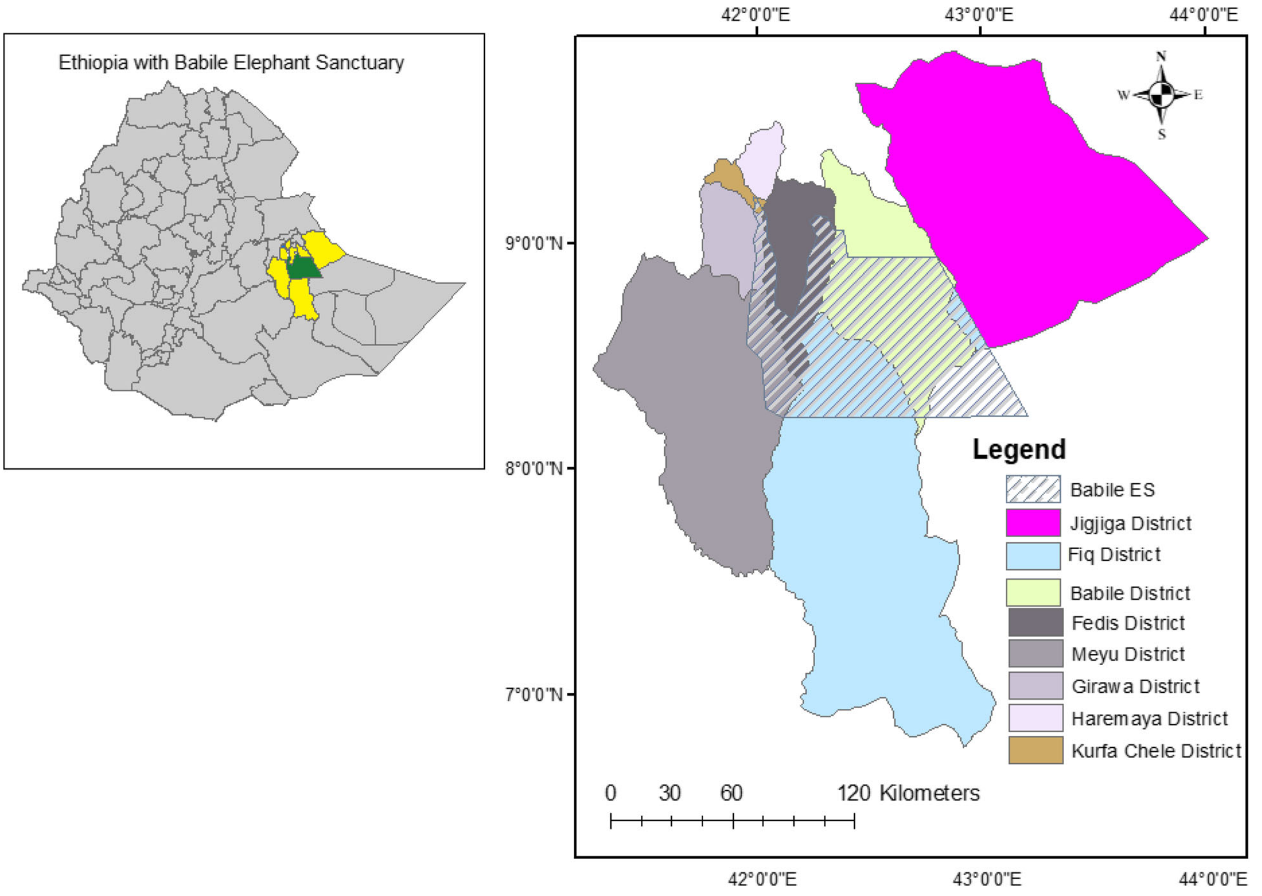

Fig. 1 Location of the study area, Babile Elephant Sanctuary

Table 1 The description of land cover (LC) types used in BES

LC types	General description
Farmland	Area of land ploughed or prepared for growing crops (i.e., both areas identifiably under crop agriculture and land under preparation).
Bushland	Area of land covered with shrubs, bush, and small trees in which multiple stems and branches are produced from the base of the main stem.
Woodland	Area of land dominated by *Acacia* species with mean height of above 5 m and the canopy cover ranges from 10 to 40% for open woodland and above 40.
Riparian forest	A type of forest found along the four major perennial rivers. The vegetation is usually evergreen (due to continuous water supply from the rivers).

bushland cover types. Plant species diversity, vegetation structure, and carbon stock potential of the study area in different land cover types were studied by using a stratified sampling method. First, the study area was stratified according to land cover type. In each land cover type, a total of four transect lines of 1000 m each, which were 300 m apart, were established systematically. In each transect, at an interval of 200 m, main plots of 10 m × 10 m for trees, 4 m × 4 m for shrub, and 1 m × 1 m for herbaceous land were established. Aboveground carbon was assessed for each nested sub-plot (Henry et al. 2011; Dabasso et al. 2014). The assessments were done for two consecutive wet and dry seasons from 2015 to 2017.

Data collection

Aboveground woody carbon assessment

In the established sub-plots (n = 20 per land cover type per season), the woody plant diameters were measured using a diameter tape at breast height (i.e., 1.3 m above ground) (Ditt et al. 2010). Diameter measurement for trees and lianas was taken at breast height (1.3 m) using a calliper. For tree species that branched at breast height, the diameters were measured separately above the swelling, and the average measurements were recorded. For tree species that forked below 1.3 m, individual stem diameters were separately measured and treated as two trees (Abed and Stephens 2003). Tree species were recorded for all trees within the plots using scientific and local names. For trees that were difficult to identify, voucher specimens were brought to the Herbarium of Haramaya University for identification where the voucher specimens of plant species were deposited.

Aboveground herbaceous carbon assessment

Herbaceous materials within 1 m^2 were then clipped at 1 cm stubble height. The clipped materials, together with litters, were put in to paper bags, and their fresh weights were recorded. The aboveground materials of herbaceous plants were oven-dried at 80 °C for 48 h.

Data analysis

Four indices of plant diversity were calculated per plot, namely, species richness, species diversity, species evenness, and functional diversity. Species richness is the total number of species present within a plot in each land cover types. Functional diversity was calculated at the plot level, following the methods of Paquette and Messier (Paquette and Messier 2011).

Functional traits that are related to carbon storage were considered to assess functional diversity (Mensah et al. 2016). Carbon storage is strongly dependent on wood density, diameter of the plant, and maximum plant height. Thus, for functional diversity, we calculated the dispersion for wood density, maximum DBH, and maximum height based on the trait value of the species present at each plot (Mensah et al. 2016). Shannon diversity index (H') was calculated for each plot, which has been used to estimate plant species diversity as:

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

where p_i is the proportion of species i, and S is the number of species (Hill, 1973).

Pielou's index was used to estimate plant species evenness (Hill 2007), which is most widely used in ecology (Zhang et al. 2012a):

$$J' = \frac{H'}{\ln S}$$

where H' represents the Shannon diversity index, and S is the total number of species observed. Biodiversity metrics were calculated using package vegan of R v3.2.0.

Aboveground carbon stocks

Aboveground carbon (AGC) stocks were calculated for all land cover type by summing the values for the nested plots along each land cover type, and dividing by the total sampled area, in ha.

Aboveground carbon assessment of woody species

The diameter at breast height (DBH) (1.3 m above the ground) of all the trees within 10 m × 10 m nested sub-plots and basal diameters (BD) of all shrubs within the 4 m × 4 m nested sub-plots was taken using a flexible measuring tape. Both DCH and BD were recorded, and carbon estimates within each plant were done using allometric equations as described by Henry et al. (2011) as follows:

Trees: Y = 0.1975 × (DBH^(1.1859))

Shrubs: Y = 0.1936 × (BD^(1.1654))

where Y is the fresh weight of trees/shrub biomass (kg).

The results of allometric equation provide fresh biomass estimates. In order to measure dry biomass, the results were multiplied by 60%, and the aboveground carbon content was taken as 50% of the dry biomass weight (Henry et al. 2011; Saatchi et al. 2011). Aboveground carbon estimates within nested sub-plots were converted to carbon in tons per hectare (1 ton = 1000 kg, 1 ha = 10,000 m^2).

Aboveground carbon assessment of herbaceous species

Herbaceous carbon contents were calculated as 50% of oven-dried herbaceous biomass. The results were recorded in a prepared data sheet. Sample results were then converted into carbon tons per hectare (1 ton = 1,000,000 g) (Henry et al. 2011; Dabasso et al. 2014).

Pearson statistical tests were performed to test correlations between aboveground carbon stocks and biodiversity for different land cover types. We used ANOVA using *R*'s "car" package to test the effects of land cover types on total AGC stocks in different seasons. To estimate the variation explained by each biodiversity measurement indices, adjusted R^2 (Bunker et al. 2005) was used. We performed these analyses using the vegan package in *R*. All analyses were carried out in *R* v3.2.2 (R Development Core Team, 2015).

Results

Vegetation structure and floristic composition

A total of 137 plant species were identified and measured over 48 plots of the survey area belonging to 85 genera and 41 families (Appendix in Table 5). The mean stand density was 419 ± 28 stems ha^{-1}. The number of stands ranged from 24 to 2458 stems ha^{-1}. The mean diameter was 1.27 ± 0.21 m, with the majority of trees being found within the smaller diameter classes (Table 2). The mean basal area was 14.34 ± 0.52 m^2 ha^{-1}, with a minimum of 10.48 and maximum of 18.8 m^2 ha^{-1}across the plots.

Diversity of plant species

Species richness in the study area was significantly different among land cover types ($F = 4.65$, $P < 0.01$), as woodland had higher species richness ($n = 48$; Table 2). Species diversity as measured by the Shannon index (H') ranged from 2.62 to 0.78 (Table 2) and was found to be high in the woodland ($H' = 2.62$) and riparian forest ($H' = 2.50$), and low ($H' = 0.78$) for farmland where the high and low H' values were significantly different ($P < 0.05$). Species evenness was not significantly different between land cover types ($F = 0.61$, $P = 0.55$). The functional diversity ranged from 0.80 to 0.92 (Table 2).

Aboveground carbon stocks

The total aboveground carbon stock of the area in different land cover types ranged between 7.14 and 71.16 t ha^{-1} (Table 3). The total carbon stocks from the different land use types showed a statistically significant difference ($P < 0.001$) (Table 3). The largest aboveground C stocks were found for the riparian forest (71.16 ± 0.91 t ha^{-1}), followed by woodland (43.09 ± 0.42 t ha^{-1}), whereas the smallest aboveground C stocks were measured for the farmland (7.14 ± 0.38 t ha^{-1}).

Relationship between diversity and aboveground carbon stocks

Species richness, Shannon index (H'), and functional diversity together explained 73.5, 61.4, 58.5, and 51.6% of the variations in the aboveground carbon storage in woodland, riparian forest, bushland, and farmland, respectively, and the contribution to carbon storage variation differed among the land cover types (Fig. 2).

Functional diversity explained most of the variations in the aboveground carbon storage on riparian forest (42.1%) and woodland (28.1%); more specifically, we found that the more DBH and Hmax of a plot, the greater the increase in carbon storage. Species diversity explained most of the tree carbon storage variation (22.1%) in farmland. Another important source of variation was the interaction between species diversity and functional diversity which explained 11% of the carbon storage variation in riparian forest, 6% in bushland, and 4% in woodland. The relationships between species richness and total aboveground carbon stock were significant for riparian forest enclosures ($r = -0.15$, $p < 0.05$). The relationships between species diversity (Shannon) and total aboveground carbon stock were also significant for bushland ($r = 0.39$, $p < 0.05$) and farmland ($r = 0.52$, $p < 0.05$). Functional diversity showed

Table 2 Species diversity and community structure of plant species in different land cover types in BES

Land cover type	*n* (plot)	*H'*	*S*	*J'*	DBH (m)			Height (m)			Density (stems ha^{-1})
					Mean	Min.	Max.	Mean	Min.	Max.	
Riparian forest	12	2.50	47	0.92	1.87	1.41	2.52	4.31	1.65	5.42	145.6
Woodland	12	2.62	78	0.90	1.05	0.65	1.96	2.06	1.48	2.58	524.5
Bushland	12	1.86	45	0.84	0.18	0.04	0.98	1.28	0.74	2.14	916.4
Farmland	12	0.78	9	0.80	1.56	0.78	3.22	1.78	1.52	2.21	37.27

J' species evenness, *H'* species diversity, *S* species richness, *DBH* diameter at breast height

Table 3 Carbon stocks in the different land cover (LC) types of BES

LC types	Carbon level (t ha^{-1})		
	AG herbaceous carbon	AG woody carbon	Total carbon
Riparian forest (*n* = 12)	15.12 ± 0.25^{a}	56.04 ± 0.71^{a**}	71.16 ± 0.91^{a*}
Woodland (*n* = 12)	26.86 ± 0.03^{a}	16.23 ± 0.41^{b}	43.09 ± 0.42^{b}
Bushland (*n* = 12)	31.41 ± 0.11^{a}	8.81 ± 0.27^{b}	40.22 ± 0.35^{b}
Farmland (*n* = 12)	2.45 ± 0.36^{a}	4.68 ± 0.39^{b}	7.14 ± 0.38^{c}

a* Means with the same letters in the same column are not significantly different at $P<0.05$
AG Above-ground; the same letters in the same column are not significantly different at $P < 0.05$
$^{*}P < 0.05$, $^{**}P < 0.01$

significant relation with total carbon stock, for riparian forest ($r = 0.81$, $p < 0.001$), for woodland ($r = 0.58$, $p < 0.01$), and bushland ($r = 0.45$, $p < 0.05$) (Table 4).

Discussion

The results of the study revealed that the aboveground carbon stocks were positively correlated with biodiversity, which confirms the positive association commonly observed between diversity and biomass in different experimental studies (Cardinale et al. 2006, 2007, 2011; Duffy et al. 2007; Delgado-Baquerizo et al. 2016), as well as in recent in situ forestry studies (Wang et al. 2009; Saatchi et al. 2011; Finegan et al. 2015; Delgado-Baquerizo et al. 2016). Thus, the results support the positive biodiversity-ecosystem functioning hypothesis. This synergistic association suggests that conservation of biodiversity can lead to enhanced quantities of carbon stored in a given area.

The results of the aboveground carbon storage in natural ecosystems (riparian forest, woodland, and bushland) were mainly explained by functional diversity incorporating wood density, maximum diameter, and maximum height traits in natural habitat and carbon stocks. However, we found no association between carbon storage and species richness in the natural ecosystems. Similarly, reports by Zhang et al. (2012a) indicated that no significant relationship was found between aboveground carbon storage and species richness in naturally regenerating conifer stands in China. Species richness only mattered in agricultural land, where increasing the number of species also increased carbon storage. This association was expected because in agricultural land crops, there are planted according to different species functions, including provision of shade, control of wind erosion, and nutrient recycling ability (Richards et al. 2010). Lack of significant correlation between carbon storage and species richness in the natural ecosystems indicates that the ecosystems may have reached saturation in species richness, an effect that can be found in high species richness treatments in experimental grasslands (Cardinale et al. 2011). In those systems, < 15 species are needed to reach the highest values of plant productivity (Loreau and Hector 2001; Van Der Sande et al. 2017). Saturation between carbon storage and species number can differ among sites and is determined by the niche overlap among species (Cardinale et al. 2007).

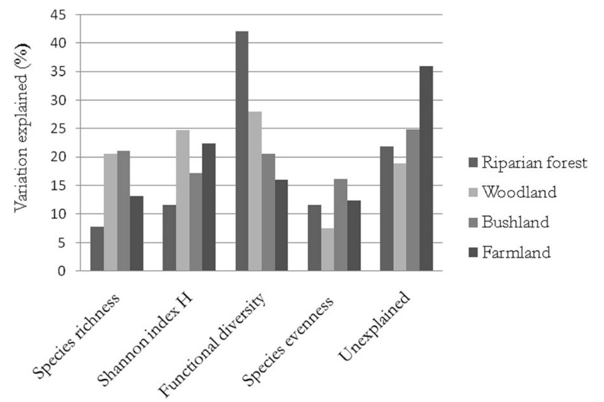

Fig. 2 Proportion of aboveground carbon storage variation explained by different land cover types in BES

The study shows a clear correlation between functional diversity and total carbon stock. The significant positive correlation between aboveground carbon stocks potential and a functional diversity consisting of wood density and maximum diameter traits might be due to complementarity effect, in which a diverse array of species has a greater divergence of functional traits and can thus better utilize limiting resources, thus increasing total ecosystem functioning, than a less diverse community. The complementarity effect is the increase in relative productivity among species in a mixture compared with the productivity of the species grown in monocultures due to positive interactions among species (i.e., facilitation and partitioning of resources) (e.g., Reich et al. 2001; Tilman et al. 2014). Positive diversity-productivity relationships have been found in low diversity mid-latitude forests, potentially due to increased canopy packing through complimentary canopy in higher diversity areas. Studies have showed that plant diversity enhances biomass production, with niche partitioning and positive interactions among species allowing diverse communities to utilize resources more effectively.

We chose wood density, maximum diameter at breast height (DBH), and maximum height as functional traits

Table 4 Pearson correlations (*r*) and generalized linear mixed models to test the relationships between carbon storage with species richness, functional diversity, species dominance, and functional dominance in different land cover types in Eastern Ethiopia

Biodiversity	Carbon storage in different land cover type			
	Riparian forest	Woodland	Bushland	Farmland
Species richness	− 0.15*	0.23	0.52	0.54
Shannon index	0.32	0.15	0.39*	0.52*
Functional diversity	0.81***	0.58**	0.45*	0.34
Species evenness	0.51	0.04	0.13	0.44
Shannon index * functional diversity	0.34	0.28	0.33	0.14

ns not significant

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

related to tree carbon storage (Baker et al. 2004; Jucker et al. 2016). Martinez-Garza (2013) showed that functional traits have been proposed as an improved way to understand forest dynamics in hyper diverse tropical forests because they are considered the redundancy in function of species. This function can cluster species based on their resource use. To link functional traits to a specific function, we need to select traits that are related to carbon storage function of the ecosystem. Wood density partly determines aboveground biomass (Day et al. 2018) and correlates with growth rates and tree mortality (Madrigal-González et al. 2016), a high wood density being associated with long-lived and slowly growing plant species. Similar with the results of previous studies, we found that both basal area and density of woody species are constituents of biomass estimates (Cruz et al. 2004; Jucker et al. 2016; Vanhellemont et al. 2018). These two structural characteristics of aboveground carbon stocks per unit area are themselves largely unrelated to species richness, indicating that diversity is not a correlate of the key structural factors that lead to high biomass in some tropical forest stands (Bunker et al. 2005; Jucker et al. 2016). Woody plant diameter inequality, which has been described as a mechanism associating carbon and biodiversity in boreal forests, was positively correlated to aboveground carbon stock but unrelated to species richness (Paquette and Messier 2011; Harpole et al. 2016). We recognize that our conclusions are based on correlative studies, and that further studies with experimental manipulation, including dominant species traits and interaction among functional traits, are required to thoroughly test this hypothesis. However, our results are a necessary first step towards understanding the role of biodiversity on aboveground carbon stock and identifying the underlying mechanisms.

Our study showed that the aboveground carbon stock potential of natural vegetation was higher than that of agricultural land. A study by Wang et al. (2009) found a 22% reduction in soil carbon stocks when uncultivated land was converted into agricultural land. Any human activities that might have serious impact on soils will, therefore, have major implications in declining carbon stocks in the cultivated land. Conversion of natural vegetation to agricultural land was known to decrease soil carbon stocks due to disturbance of the soil surface (Jiao et al. 2009; Finegan et al. 2015). It is, therefore, important to guard natural landscape from degradation that will eventually interfere with soil condition, thereby reducing the amount of carbon stock potential.

Conclusions

The findings of this study have demonstrated that it is not exclusively that the selection and the niche complementarily effects influence carbon stock. Rather, the results have revealed that the influences were significantly attributable to functional diversity. However, the results require to be substantiated and validated through further studies in similar ecosystems. Therefore, the results of our study support stronger complementary effects that might be due to complementary light-use efficiency of woody plant growth in the understory layer. The findings also instigate that conservation efforts focused on protected area-based biodiversity conservation with ecosystem networks that may benefit both functional biodiversity and ecosystem services linked to carbon storage, like climate change mitigation. In this study, we have estimated aboveground carbon stocks as a case study of tropical deciduous woodland ecosystems under diverse land cover change, taking into considerations spatial and temporal heterogeneity of the ecosystem. The variation in carbon storage with land cover types affirms the need to examine asymmetric variation of environmental resource in the measurement of ecosystem carbon stocks. The results have also revealed that, compared to the cultivated land, natural ecosystems stored substantial amounts of carbon. The results of this study might also lead to initiation of a large-scale study in the Ethiopia deciduous woodland ecosystems on aboveground carbon stocks stored in soils and vegetation to analyze the relationship between structural and functional biodiversity and ecosystem services linked to carbon storage for better planning of ecosystem conservation and management.

Appendix

Table 5 List of plant species identified in the study area

No.	Scientific name	Family	Habit
1	*Abutilon bidentatum*	Malvaceae	Herb
2	*Acacia albida*	Fabaceae	Tree
3	*Acacia brevispica*	Fabaceae	Shrub/Tree
4	*Acacia bussei*	Fabaceae	Tree
5	*Acacia etbaica*	Fabaceae	Tree
6	*Acacia mellifera*	Fabaceae	Shrub/Tree
7	*Acacia nilotica*	Fabaceae	Shrub
8	*Acacia oerfota*	Fabaceae	Shrub
9	*Acacia robusta*	Fabaceae	Tree
10	*Acacia senegal*	Fabaceae	Shrub
11	*Acacia seyal*	Fabaceae	Tree
12	*Acacia tortilis*	Fabaceae	Tree
13	*Acalypha fruticosa*	Euphorbiaceae	Shrub
14	*Achyranthes aspera*	Amaranthaceae	Herb
15	*Acokanthera schimperi*	Apocynaceae	Shrub/Tree
16	*Agava sisalana*	Agavaceae	Shrub
18	*Allophylus rubifolius*	Sapindaceae	Shrub
17	*Aloe pirottae*	Asphodelaceae	Shrub
19	*Asparagus leptocladodius*	Asparagaceae	Shrub
20	*Balanites aegyptiaca*	Balanitaceae	Tree
21	*Balanites glabra*	Balanitaceae	Tree
22	*Barleria eranthemoides*	Acanthaceae	Shrub
23	*Barleria parviflora*	Acanthaceae	Shrub
24	*Berchemia discolor*	Rhaminaceae	Tree
26	*Blepharis edulis*	Acanthaceae	Herb
25	*Blepharis maderaspatensis*	Acanthaceae	Herb
27	*Boscia minimifolia*	Capparidaceae	Tree
28	*Boswellia neglecta*	Burceraceae	Shrub
29	*Buckollia volubilis*	Asclepiadaceae	Climber
30	*Calotropis procera*	Asclepiadaceae	Shrub
31	*Canthium setiflorum*	Rubiaceae	Shrub
32	*Capparis fascicularis*	Capparidaceae	Climber
33	*Capparis sepiaria*	Capparidaceae	Shrub
34	*Capparis tomentosa*	Capparidaceae	Shrub
35	*Carissa spinerum*	Apocynaceae	Shrub
36	*Cenchrus ciliaris*	Poaceae	Grass
37	*Chloris pycnothrix*	Poaceae	Grass
38	*Combretum molle*	Combretaceae	Tree
39	*Commelina stephaniniana*	Commelinaceae	Herb
40	*Commicarpus plumbagineus*	Nyctaginaceae	Climber
41	*Commicarpus sinuatus*	Nyctaginaceae	Climber
42	*Commiphora erythraea*	Burceraceae	Tree
43	*Commiphora schimperi*	Burceraceae	Tree
44	*Corchorus tridens*	Tiliaceae	Herb
45	*Corchorus trilocularis*	Tiliaceae	Climber
46	*Cordia gharaf*	Boraginaceae	Tree
47	*Cordia monoica*	Boraginaceae	Tree
48	*Cordia ovalis*	Boraginaceae	Tree
49	*Crabbea velutina*	Acanthaceae	Herb
50	*Crinum abyssinicum*	Amaryllidaceae	Herb
51	*Crotalaria quartiniana*	Fabaceae	Shrub
52	*Cryptostegia grandiflora*	Asclepiadaceae	Climber
53	*Dichrostachys cinerea*	Fabaceae	Tree
54	*Dicoma tomentosa*	Asteraceae	Herb
55	*Dodonaea angustifolia*	Sapindaceae	Shrub
56	*Dolichos trilobus*	Fabaceae	Herb
57	*Enteropogon macrostachyus*	Poaceae	Grass
58	*Eucilea schimperi*	Ebenaceae	Shrub
59	*Euphorbia abyssinica*	Euphorbiaceae	Tree
60	*Euphorbia burgeri*	Euphorbiaceae	Shrub
61	*Euphorbia cryptospinosa*	Euphorbiaceae	Shrub
62	*Euphorbia polyacanthra*	Euphorbiaceae	Shrub
63	*Ficus vallis-choudae*	Moraceae	Tree
64	*Ficus vasta*	Moraceae	Tree
65	*Flueggea virosa*	Euphorbiaceae	Herb
66	*Grewia bicolor*	Tiliaceae	Shrub
67	*Grewia erythraea*	Tiliaceae	Shrub
68	*Grewia ferruginea*	Tiliaceae	Shrub
69	*Grewia flavescens*	Tiliaceae	Shrub
70	*Grewia kakothamnos*	Tiliaceae	Shrub
71	*Grewia schweinfurthii*	Tiliaceae	Shrub
72	*Grewia tenax*	Tiliaceae	Shrub
73	*Grewia villosa*	Tiliaceae	Shrub
74	*Gutenbergia rueppelli*	Asteraceae	Herb
75	*Hibiscus dogolensis*	Malvaceae	Herb
76	*Hibiscus ludwigii*	Malvaceae	Shrub
77	*Hibiscus micrantus*	Malvaceae	Shrub
78	*Hibiscus ovalifolius*	Malvaceae	Shrub
79	*Indigofera brevicalyx*	Fabaceae	Herb
80	*Indigofera coerulea*	Fabaceae	Herb
81	*Indigofera hochstetteri*	Fabaceae	Herb
82	*Indigofera parviflora*	Fabaceae	Herb
83	*Ipomoea hochstetteri*	Convolvulaceae	Herb
84	*Justcia schimperiana*	Acanthaceae	Shrub
85	*Justicia diclipteroides*	Acanthaceae	Herb
86	*Justicia flava*	Acanthaceae	Herb

Table 5 List of plant species identified in the study area *(Continued)*

No.	Scientific name	Family	Habit
87	*Kleinia odora*	Asteraceae	Shrub
88	*Kleinia squarrosa*	Asteraceae	Shrub
89	*Kohautia caespitosa*	Rubiaceae	Herb
90	*Lannea triphylla*	Anacardiaceae	Shrub
91	*Lantana camara*	Verbenaceae	Shrub
92	*Lantana viburnoides*	Verbenaceae	Shrub
93	*Leucas abyssinica*	Lamiaceae	Shrub
94	*Leucas martinicensis*	Lamiaceae	Herb
95	*Melinis repens*	Poaceae	Grass
96	*Ocimum gratissimum*	Lamiaceae	Shrub
97	*Ocimum lamiifolium*	Lamiaceae	Herb
98	*Oncoba spinosa*	Flacourtiaceae	Tree
99	*Opuntia ficus-indica*	Cactaceae	Tree
100	*Opuntia stricta*	Cactaceae	Shrub
101	*Ozoroa insignis*	Anacardiaceae	Tree
102	*Panicum monticolum*	Poaceae	Grass
103	*Pappea capensis*	Sapindaceae	Tree
104	*Pavetta gardeniifolia*	Rubiaceae	Shrub
105	*Pentarrhinum somalensis*	Asclepiadaceae	Climber
106	*Plectranthus barbatus*	Lamiaceae	Herb
107	*Plectranthus cylindraccus*	Lamiaceae	Herb
108	*Plectranthus puberulentus*	Lamiaceae	Shrub
109	*Plectranthus rupestris*	Lamiaceae	Herb
110	*Plicosepalus curviflorus*	Loranthaceae	Epiphyte
111	*Plumbago zeylanica*	Plumbaginaceae	Herb
112	*Premna oligotricha*	Lamiaceae	Shrub
113	*Prosopis juliflora*	Fabaceae	Shrub
114	*Rhus natalensis*	Anacardiaceae	Shrub
115	*Salvadora persica*	Salvadoraceae	Tree
116	*Sarcostema viminale*	Asclepiadaceae	Climber
117	*Senna obtusifolia*	Fabaceae	Shrub
118	*Senna singueana*	Fabaceae	Shrub
119	*Setaria verticillata*	Poaceae	grass
124	*Solanecio angulatus*	Asteraceae	Climber
120	*Solanum incanum*	Solanaceae	Herb
121	*Solanum nigrum*	Solanaceae	Herb
122	*Steganotaenia araliacea*	Apiaceae	Tree
123	*Sterculia africana*	Sterculiaceae	Tree
125	*Tamarindus indica*	Fabaceae	Tree
126	*Terminalia brownii*	Combretaceae	Tree
127	*Trichilia emetica*	Meliaceae	Tree
128	*Triumfetta heterocarpa*	Tiliaceae	Shrub
129	*Tylosema fassoglensis*	Fabaceae	Climber
130	*Vepris glomerata*	Rutaceae	Shrub
131	*Vernonia cinerascens*	Asteraceae	Shrub
133	*Ximenia caffra*	Olacaceae	Shrub
134	*Zanthoxylum chalybeum*	Rutaceae	Tree
135	*Zinnia peruviana*	Asteraceae	Herb
136	*Ziziphus spina-christi*	Rhaminaceae	Tree
137	*Zornia glochidiata*	Fabaceae	Herb

Abbreviations

BES: Babile Elephant Sanctuary; DBH: Diameter at breast height; BD: Basal diameter; AGC: Aboveground carbon

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