RESEARCH ARTICLE

REVISED Conversion of natural forests to farmlands and its associated woody species diversity and carbon stocks in a span of 33 years (1984 to 2016): in the case of southwestern Ethiopia [version 2; peer review: 1 approved, 2 not approved]

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Abstract

Background

Gura-Ferda forest is one of the Afromontane rainforests in the southwestern region of Ethiopia. However, since 1984, large parts of this forest have become increasingly disturbed and fragmented due to forest conversion into forest farm interface and farmlands. The study was conducted to assess changes of woody species diversity and carbon stock in association with the conversion of natural forest to forest farm interface and farmlands.

Methods

Data were collected from natural forest, forest farm interface and farmland which are historically forest lands before 1984. A total of 90 nested plots (20m×20m for natural forest and forest farm interface; 50m×100m for farmland) were established for inventory of woody species. Three 1m×1m subplots were established to collect litter and soil samples. A total of 180 soil samples were collected. The total carbon stocks were estimated by summing carbon stock in the biomass and soil (0-60 cm depth).

Results

Results showed that Shannon-Wiener diversity (H') in forest farm interface ($H' = 1.42 \pm 0.49$) is significantly lower than that of natural forest ($H' = 2.72 \pm 0.31$) but significantly higher than farmland ($H' = 1.08 \pm 0.57$). The total carbon stocks of natural forest ($388.54 \pm 161.63 \text{ Mg C ha}^{-1}$) were approximately 1.53 and 2.67 times higher than that of forest farm interface ($252.95 \pm 41.86 \text{ Mg C ha}^{-1}$) and farmland ($145.58 \pm 25.94 \text{ Mg C ha}^{-1}$).

Conclusion

Our study revealed that along the conversion gradient of natural forest to forest farm interface and farmland there was a significant change of woody species diversity and carbon stocks.

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Approval Status

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Keywords

Forest Farm Interface, Biomass Carbon, Soil Organic Carbon, Litter

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REVISED Amendments from Version 1

Version 1 has been updated with the following changes:

The reviewers' comments and suggestions have been addressed in the updated version of this manuscript. The following changes have been made to improve the manuscript:

1. Abstract: Statistical analysis information updated.
2. Abstract: the carbon stock values have been added
3. Introduction: paragraph updated
4. Methods: Added information regarding bulk density and organic carbon fraction
5. Methods: Clarification on statistical analysis
6. Methods: Complementary information added on method of soil organic carbon determination.
7. Results: Tables formatting and corresponding text updated accordingly. There have been no results removed, only redistributed.
8. Discussion: Additional information on the potential explanations for the findings.
9. Discussion: Complementary information on the sample values of organic matter lost as a result of the conversion of natural forest to forest farm interface and farmland.
10. Conclusion: Complementary information on the contribution of the finding for carbon monitoring in the context of Ethiopia's climate change mitigation strategy.

Any further responses from the reviewers can be found at the end of the article

Introduction

Over the last two decades, forests and forest management have changed dramatically. In 1990, the world's forest area was 4.13 billion hectares (ha) (31.6% of total land area of Earth). According to the UN's Food and Agriculture Organization, this area had shrunk to 3.99 billion hectares (30.6% of Earth's total land area) by 2015¹. Ethiopia's ecosystem is diverse, ranging from the dry lowlands in the east to the high altitudes of the central highlands (Hurni, 1998). The country's unique ecological conditions, as well as its rich flora and fauna, have made it one of the most important biodiversity hotspots on the world². The country's forest land, on the other hand, has been rapidly shrinking over time. From 1990 to 2000, forest losses were estimated to 8.3 million hectares, and from 2000 to 2010, 5.2 million hectares³. This day major parts of the remaining natural forests which harbor high biodiversity are located on steep slopes at high altitude and in the remote southern and southwestern parts of the country. These few remaining high forests are also threatened by anthropogenic activities and converted to agricultural and other land use systems⁴. Similarly, other remaining natural forests have also been threatened by pressure from investors and changed to industrial plantation like coffee and tea^{4,5}. This reduction and conversion of natural forest to other land use systems in many parts of Ethiopia has led to the decline in number and distribution of many plant species, shortage of raw materials for wood processing industries and disturbance of ecosystem services⁶. As a consequence,

forest farm interface has expanded within and around the natural forest. Subsequently, it has resulted the expansion of forest farm interface in and around the forest ecosystem.

"For this study forest farm interface is defined as an area produced by forest encroachment that is officially unclassified as either forest or agricultural lands and is found in areas where intense economic activities such as crop farming, grazing, and the use of forest products predominate. It comprises lands managed by persons with no official use rights and found between natural forest and farmlands"⁷. For the past five decades, the government of Ethiopia has attempted to reforest degraded forests^{4,5}. Hundreds of aid projects have been implemented in different parts of the country to reverse deforestation and forest degradation in the country. However, the success stories were below expectations and the problems are still immense. This resulted from the lack of effective management practices and quantification of the available forest resources. This insufficiency of scientific quantitative data brought lack of responsiveness for sound management of natural resources in the country.

Gura-Ferda forest is one of the Afromontane rainforests in the southwestern region of Ethiopia and grows at altitudes from 700 to 2,300 meter above sea level. During the past decades, especially since 1984, large parts of this forest have progressively been disturbed and fragmented due to forest conversion to settlements, agriculture, and industrial plantation⁸. Nowadays, pressure produced by immigration and investors is increasing forest disturbance. However, there is no quantitative information on the change of species diversity and carbon stocks resulting from the conversion of natural forests to forest farm interface and farmlands. The overall objective of this study was, therefore, to analyze the woody species diversity and carbon stock change in association with the change of natural forests to forest farm interface and farmlands. The study hypothesized that, the conversion of natural forests to forest farm interface and farmlands affect the woody species diversity, biomass and soil organic carbon (SOC) stocks.

Materials and methods

Description of the study area

The study was conducted at Gura-Ferda district of southwestern Ethiopia which is located at 603 km southwest of the capital city Addis Ababa (Figure 1). Geographically, it is positioned between 6°29'12" N and 7°13'22" N latitude and 34°52'23" E and 35°23'59" E longitude. The area coverage of this district is estimated to be 2565.42 km². The annual average rainfall over the period of 1983–2012 was 1639.8 mm, with a maximum of 1946.3 mm and a minimum of 1289.8mm. The area receives a maximum rainfall in October and minimum rainfall in February. The average annual temperature is 23.4°C with a range from 16.1°C–30.6°C. The dominant soil type of the study area is nitisols with soil textural class loam to clay⁹.

As the past data of the Gura-Ferda district specified, since 1984, there was a degradation of natural forest in the area (Table 1). The notable drivers of this forest area decrement were

Figure 1. The nested map of Ethiopia showing the map of study region and zonal map of the study district.

Table 1. Converted area from NF to FFI and FL within the span of 33 years (1984 and 2016).

Land Use Class	1984 (ha)	Area (%)	2016 (ha)	Area (%)
Natural Forest	90872	100	67049	73.78
Forest Farm Interface	-	-	21155	23.28
Farmland/Settlement	-	-	2668	2.94
Total	90872	100	90872	100

Source (Authors Data)

resettlement, crop investment and fuel wood. According to the office of Gura-Ferda district, in 1984, the populations of the district were 149. However, in 2016 they were increased to 45,028¹⁰. Moreover, during 2003/4 legal resettlement, massive deforestation of natural forest were accompanied for house construction of immigrants^{4,11}. Next to resettlement, the taken

up of forest by investors is other key drivers for the degradation and deforestation of natural forests in the area. According to ¹⁰, there were more than 30 investors who were involved in different agricultural investment especially coffee and rubber tree plantation. These investors had been used shrub land, natural forest, and grass lands for investment.

Methodology

Data source. For the purpose of this research both primary and secondary data were employed. Primary data were obtained through field survey of the study area. Secondary data used were satellite images and publications such as articles, data from district land administration offices and censuses results. Multi-sensor and multi-temporal Landsat images were downloaded from United States Geological Survey (USGS) (<https://earthexplorer.usgs.gov>) (Table 2). Accordingly, satellite images of 1984 and 2016 were used for this study. Images of the year 1984 were taken because it was the time when the government organized a resettlement program at the study area. Similarly, images from the year 2016 was selected

because it was the time when recent agricultural systems were expanded and government was focused on commercial investments in the area. Since it is a time of free atmospheric cloud, satellite images in the months of December to January were used.

Stratification of study area. Before the resettlement program of 1984, all areas used for the sampling unit in this study time were covered by forest. However, nowadays, it is observed that the area has three discrete categories. These are: natural forest, forest farm interface and farmland (Figure 2; Figure 3).

- **Natural forest (NF):** land with trees, shrubs and other vegetation that originally emerged on its own without

Table 2. Time series satellite images of the study area.

Acquisition date	Path/Row	Cloud cover (%)	Sensor type	Spatial resolution (m)	LU/LCC related events
28/12/1984	170/055	0.0	TM	30x30	Government Organized Resettlement Program
26/12/2016	171/055	0.0	OLI/TIRS	30x30**	Recent Agricultural Expansion and focusing of government on commercial investments

** Panchromatic sharpened to 15m to favor visual interpretation

Figure 2. map of NF of Gura-Ferda district in 1984 (Source: Authors).

Figure 3. map of NF, FFI and FL of Gura-Ferda district in 2016 (Source: Authors).

the influence or direct intervention of man covering more than 0.5 ha and growing to a height of more than 2m and a canopy cover of more than 20%¹².

- **Forest-farm interface (FFI):** an area produced by forest encroachment that is officially unclassified as either forest or agricultural lands and is found in areas where intense economic activities such as crop farming, grazing, and the use of forest products predominate. It comprises lands managed by persons with no official use rights and found between natural forest and farmlands⁷.
- **Farmland (FL):** an area which has been converted to intensive mono cropping with few/no scattered trees due to high disturbance

Sampling techniques. Three transects with a total of 30 plots (10 plots on each transect) were established on NF, FFI, and FL using a compass and a geographic positioning system (GPS). A distance of 200 meters (m) separated the transect lines and sample plots from each other^{13,14} (Figure 4). Each land use system's sample plot size was selected based on the expected

density of woody species^{15,16}. To collect vegetation data for both NF and FFI, a nested plot design of 400m² with 25m² and 1m² size was employed (tree, sapling and seedling, respectively). Plot size of 50 m × 100 m was used for FL¹⁷. Seedlings with a height ≤ 50 centimeter (cm) and a diameter at breast height (DBH) ≤ 2.5 cm were counted from 1 m*1 m quadrat. Individuals with a height ≥ 50 cm and a DBH ≥ 2.5 cm were classified as saplings and counted. The diameter and height of all woody species with a DBH ≥ 5 cm were measured in the 400 m² sample plots.

DBH of sampled dead wood was measured following the techniques used by 18 and 17. A complete list of woody species was made for each plot throughout the whole area and documented by local name. Species identification for common species was done in the field via different plant identification keys. However, for the less common species plant sample specimens were pressed and identified at the National Herbarium of Ethiopia, Addis Ababa University. Litter samples were collected from 1 m × 1 m subplot within the main plot. The collected fresh litter was weighed right on the site. Then the evenly mixed samples were taken to the laboratory and oven dried at 65°C for 24 hours to determine dry to fresh weight ratio.

Figure 4. Sampling design of woody species in the studied land use systems of Gura-Ferda district.

Soil samples were collected from the sub-plots used for litter sampling. Two sets of soil samples were taken, one set for the determination of organic carbon fraction (%C), and one set for the determination of soil bulk density. A total of 90 soil samples (layers of 0–30 and 30–60 cm) were collected for %C analysis using soil auger. In addition, similar size of undisturbed soil samples was collected separately for determination of soil bulk density.

Data analysis

Diversity analysis. Shannon-Wiener index (H') was used to determine diversity of woody species of the study area. H' was determined through the analysis of two components of species diversity. These are the species richness (the number of species in the sample plots) and evenness of species (abundance distribution among species).

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

Where p_i is the proportion of individuals found in the i^{th} species, S is the total number of species, and $\ln$ is the natural logarithm

Similarity measures are one of the most intuitive and often used methods for comparing two or more sites or samples in terms of species overlap. To compare the similarity and/or dissimilarity of NF, FFI, and FL, a percentage similarity index was calculated. This similarity index was chosen because it includes quantitative data (abundance) in its calculation, which overcomes the limitation of Sorenson's and Jaccard's similarity index, which only consider qualitative data (species list). A matrix of percent similarity index makes it easy to interpret when comparing more than three sites¹⁹.

$$\text{Percentage similarity index} = \frac{200 \sum \min(y_{ki}, y_{kj})}{\sum y_{ki} + \sum y_{kj}} \quad (2)$$

Where y_{ki} is the abundance of k^{th} species at compared land use i and y_{kj} is the abundance of k^{th} species at compared land use j

Biomass carbon stock estimation. Allometric equation developed by 20 was used for estimating the aboveground biomass of woody species in NF (Table 3). Biomass of standing dead wood which has branches was also estimated using this allometric equation. This equation was selected since it was established for estimating the biomass of woody species in tropical natural forests. Moreover, this equation used diameter at breast height and wood density which was the most important biomass predictor variables. The biomass of woody species in FFI and FL was estimated using allometric equation developed by 21,22 since it was developed for land use systems having more or less similar climatic properties as those in the current study area. Woody density was taken from the document of Ethiopia's fForest reference level submission to the United Nation Framework Convention on Climate Change (UNFCCC)¹².

Aboveground biomass of standing dead wood which has no leaves was estimated following the procedure used by 18. The biomass of felled dead wood was estimated using allometric equation developed by 23. The total biomass of the dead wood was estimated by summing up of the standing, logged and felled dead wood. Finally, estimated biomass of woody tree species in NF, FFI and FL were converted to carbon (C) stock using carbon fraction value of 0.5, 0.48, and 0.48 respectively^{21,24}. The loss on ignition method was used to estimate percentage of organic matter in the litter. The amount of C in the litter was estimated through multiplying of litter organic matter by 0.50²⁵.

Soil organic C stock estimation (SOC). Soil analyses were undertaken at Wondo Genet College of Forestry and Natural Resources soil laboratory. The soil samples for bulk density were oven-dried at 105 °C for 48 hours. Bulk density was estimated by the core method²⁶. The soil samples for %C were air -dried and analyzed using Walkley-Black method²⁷. A SOC stock (Mg C ha⁻¹) was determined through fixed depth method by multiplying of %C, bulk density (g/cm³), soil organic C fraction (%C) and soil depth (cm))^{25,28}.

$$SOC = BD \times Depth \times \%C \times 100 \quad (3)$$

$$BD_{soil} = \frac{ODW}{CV - \frac{RF}{PD}} \quad (4)$$

Where: BD soil is soil bulk density (g/cm³), %C is percent of organic C fraction, ODW is oven dry weight of soil (<2mm fraction) (g/cm³), CV is soil core volume (cm³), RF is mass of coarse fragments (g) = insignificant in our case, and PD is density of rock fragments (g/cm³) = 2.65 g/cm³

Total C stocks. Total C stock (Mg C ha⁻¹) was calculated by summing up of biomass C stocks (above-and-below) and SOC stocks.

Statistical analysis

The stand structural parameter, diversity indices, biomass C stock and SOC stock data were described by mean and standard deviation. One-way ANOVA were performed ($\alpha = 0.05$) to compare Shannon, Simpson, evenness, and C stocks among NF, FFI and FL. For SOC stock, two-way ANOVA was used since soil depth were considered as study factor together with land use types. Fisher's Least Significant Difference (LSD) post hoc test was used to compare means that demonstrated significant variations in SOC. All data were checked for normality prior to doing the analysis of variance using

Kolmogorov-Smirnov test. The data were analyzed using Statistical Package for Social Science (SPSS version 20). All tests were conducted at 95% confidence level.

Results

Woody species diversity

A total of 64, 27 and 21 woody species belonging to 37 families were recorded and identified in the sample plots of Gura-Ferda NF, FFI, and FL respectively (Table 4). Moraceae, with 29% of woody species, was the most well-represented woody species family in NF, followed by Rubiaceae (24%). Only one or two woody species were found in the other families. The 3rd and 4th most abundant families were Olacaceae and Fabaceae, respectively. In FFI, the Moraceae and Meliaceae families were the most abundant woody species families, accounting for 45% and 27% of all woody species, respectively. Euphorbiaceae and Moraceae were the most abundant family in FL. The Simpson (D) and Shannon diversity index (H') value of NF is significantly higher ($p=0.001$) than that of FFI and FL. The D of FL was higher than that of FFI, but the difference was not significant. The H' in NF was 1.91 and 2.52 times higher than the H' of FFI and FL, respectively (Table 4). Evenness was significantly higher ($p<0.05$) in FL than that in NF and FFI.

The three land use types shared only 12 of the 70 woody plant species. The percent similarity index for NF with FFI, NF

Table 3. Allometric equations used to estimate the biomass C stocks of NF, FFI and FL in Gura-Ferda district, southwestern Ethiopia.

Land Use		Equation	R ²	D (cm)	% C	Source
Natural Forest	Woody species	AGB = $\rho \times d^2 \times H \times 0.0559$	-	≥5	50	20
		BGB = $0.20 \times AGB$	-	≥5	50	24
Forest Farm Interface	Woody species	AGB = $0.225 \times d^{2.341} \times \rho^{0.73}$	0.98	≥5	48	21,22
		BGB = $0.28 \times AGB$	-	≥5	48	
Farmlands	Woody species	AGB = $0.225 \times d^{2.341} \times \rho^{0.73}$	0.80	≥5	48	21,22
		BGB = $0.28 \times AGB$	-	≥5	48	

Table 4. (Mean ± SD) of Species richness, evenness, Simpson diversity index and Shannon diversity index of NF, FFI and FL in Southwestern, Ethiopia.

Land use	Species richness	Shannon (H')	Simpson (D)	Evenness (J)
Natural forest	64	2.72±0.31 ^c	0.91±0.03 ^c	0.76±0.10 ^b
Forest-Farm interface	27	1.42±0.49 ^b	0.58±0.16 ^a	0.49±0.10 ^a
Farm land	21	1.08±0.57 ^a	0.59±0.26 ^b	0.96±0.06 ^c
P-Value		0.00	0.00	0.00

with FL, and FFI with FL was 10.95 %, 5.23 %, and 9.90 %, respectively. As a consequence, NF and FFI were the most similar, while NF and FL were the least similar. Woody species such as *Albizia gummifera*, *Cordia africana*, *Croton macrostachyus*, *Diospyros abyssinica*, *Ficus sur*, and *Lepidotrichlea volkensii* were common across all land uses.

C stocks

The basal area of woody species in NF ($61.02 \pm 46.51 \text{ m}^2 \text{ ha}^{-1}$) was 2.23 and 10.54 times higher than FFI ($26.79 \pm 12.16 \text{ m}^2 \text{ ha}^{-1}$) and FL ($5.79 \pm 6.00 \text{ m}^2 \text{ ha}^{-1}$), respectively (Table 5). The density of woody species in the study area was 1256.67 ± 553.28 individuals per hectare for NF, 822.5 ± 195.68 individuals per hectare for FFI and 110.83 ± 70.92 individuals per hectare for FL.

Where, AGBC is aboveground biomass C stocks, BGBC is belowground biomass C stocks, TBC is total biomass C stocks, SOC is soil organic C stocks and TCS is total C stocks. Different letters show significant ($p < 0.05$) different between Land Uses, and similar letters not significance differences

The mean aboveground biomass (tree/shrub, dead wood and litter) C stocks of FFI ($63.4 \pm 30.46 \text{ Mg C ha}^{-1}$) are significantly

lower than the adjacent NF ($132.75 \pm 132.61 \text{ Mg C ha}^{-1}$), but significantly higher than that of FL ($14.16 \pm 15.05 \text{ Mg C ha}^{-1}$). The mean aboveground biomass C stocks of NF were approximately 2.1 and 9.37 times higher than FFI and FL (Table 5). The mean overall dead wood C stock of the study area was $2.3 \pm 2.84 \text{ Mg C ha}^{-1}$ for NF and $5.6 \pm 6 \text{ Mg C ha}^{-1}$ for FFI (Table 6). The mean litter biomass C stock for aboveground biomass was $0.66 \pm 0.29 \text{ Mg C ha}^{-1}$ for NF and $0.5 \pm 0.19 \text{ Mg C ha}^{-1}$ for FFI.

Different letters on similar soil parameters of different land uses indicate a significant difference across Land Uses ($p < 0.05$), but similar letters do not show a significant difference across Land Uses.

A belowground biomass C stock in the NF was significantly higher ($p < 0.001$) than the belowground biomass C stocks of FFI and FL (Table 5). The mean belowground biomass C stocks in the NF, FFI and FL were $25.96 \pm 22.76 \text{ Mg C ha}^{-1}$, $11.46 \pm 5.93 \text{ Mg C ha}^{-1}$ and $2.83 \pm 3 \text{ Mg C ha}^{-1}$ respectively. The total biomass C stocks in NF was by 2 % and 18.5 % higher than FFI and FL. From the total biomass C, the contribution of dead wood and litter covers only 1.4% and 0.4% in NF, respectively, while, it covers about 6.9% and 0.6% in FFI.

Table 5. (Mean $\pm$ SD) C stocks of NF, FFI and FL (Mg C ha^{-1}) in Guraferda District, southwestern Ethiopia.

Biomass component	Natural Forest	Forest Farm Interface	Farm Land	P-Value
AGBC (Mg C ha^{-1})	132.75 ± 132.61^c	63.4 ± 30.46^b	14.16 ± 15.05^a	0.00
BGBC (Mg C ha^{-1})	25.96 ± 26.66^c	11.46 ± 5.93^b	2.83 ± 3.01^a	0.00
TBC (Mg C ha^{-1})	158.71 ± 159.26^c	74.86 ± 36.29^b	16.99 ± 18.06^a	0.00
SOC (Mg C ha^{-1})	229.83 ± 31.42^c	178.09 ± 36.21^b	128.59 ± 21.07^a	0.00
TCS (Mg C ha^{-1})	388.54 ± 161.63^c	252.95 ± 41.86^b	145.58 ± 25.94^a	0.00

Where, AGBC is aboveground biomass C stocks, BGBC is belowground biomass C stocks, TBC is total biomass C stocks, SOC is soil organic C stocks and TCS is total C stocks. Different letters show significant ($p < 0.05$) different between Land Uses, and similar letters not significance differences

Table 6. (Mean $\pm$ SD) of Bulk density (g cm^{-3}), %C and SOC (Mg C ha^{-1}) of NF, FFI and FL in Gura-Ferda District, southwestern Ethiopia (n = 30).

Depth (cm)	NF			FFI			FL		
	BD	%C	SOC	BD	%C	SOC	BD	%C	SOC
0 – 30 cm	0.92 ± 0.08	4.61 ± 0.60	127.2 ± 17	0.87 ± 0.09	3.43 ± 0.46	89.5 ± 26.9	0.81 ± 0.09	3.02 ± 0.67	73.4 ± 15.75
30 – 60 cm	1.03 ± 0.07	3.32 ± 0.35	102.58 ± 23	0.98 ± 0.07	3.01 ± 0.36	88.58 ± 22.69	0.89 ± 0.05	2.07 ± 0.75	55.2 ± 8.8
Total (0 – 60 cm)	0.97 ± 0.07^b	3.95 ± 0.47^c	229.83 ± 31.4^c	0.92 ± 0.08^{ab}	3.23 ± 0.41^b	178 ± 36.2^b	0.84 ± 0.07^a	2.55 ± 0.71^a	128.59 ± 21^a

Different letters on similar soil parameters of different land uses indicate a significant difference across Land Uses ($p < 0.05$), but similar letters do not show a significant difference across Land Uses.

Within each land use, %C and SOC stock was significantly higher ($p < 0.001$) in the top layer (0–30 cm) than in the lower layer (36.9% and 0.6% 0–60 cm) (Table 5). The top layer stocked 57.11%, 55.46%, and 57.09% of the total SOC in the NF, FFI and FL respectively. The total SOC stocks (0–60 cm depth) were significantly different among all land uses. SOC stock significantly differs along depths for all land uses. With respect to conversion of NF to FFI, 22.5% of SOC stocks (0–60 cm) were lost. Similarly, 44.05 % of SOC stocks (0–60 cm) were lost in conversion of the NF to the FL.

The total C stock of the study area was calculated by summing up all the C value of each pool. Accordingly, the total C stock (Mg C ha^{-1}) is significantly different among the three-land uses. The total C stock in NF was $388.54 \pm 161.63 \text{ Mg C ha}^{-1}$. While the total C stocks for FFI and FL were $252.95 \pm 41.86 \text{ Mg C ha}^{-1}$ and $145.58 \pm 25.94 \text{ Mg C ha}^{-1}$ respectively (Table 5). Of which, the SOC accounted for 59.15%, 70.40%, and 88.33% for NF, FFI and FL, respectively. The total C stock of NF was approximately 1.54 and 2.67 times higher than that of FFI and FL.

Discussions

Woody species diversity

The degree of human interference and disturbance caused by overexploitation of forest resources, overgrazing, the establishment of new settlements, and the conversion of forest to coffee plantation for long periods could be attributed to the variation in species composition among the NF, FFI, and FL of Gura-Ferda district. Almost all of the woody species found in the FFI and FL were not planted, but rather were left over from the conversion of the NF to the FFI and FL. The Gura-Ferda NF is floristically low when compared to other moist afro-montane forests like Jibat humid Afro-montane forest (183 species), Sirso moist evergreen Afro-montane forest (74 species)²⁹, and Bonga forest (243 species)³⁰. It is, however, higher than Gendo moist afro-montane forest (38 species)³¹ and Gole Forest (46 species) in Kamba district, Southern Ethiopia³².

As shown in Table (1), FFI which emerged after the resettlement program of 1984 accounts for 23.28% of the NF within 1984–2016-year interval. As reported by 11, and 10, the main problem related to land use land cover change at Gura-Ferda district was agricultural investment, fuel wood collection, wood for house construction and farm implementation, wild-fire, resettlement, land certification, poor governance within the district, and subsistence agricultural land expansion.

According to Gura-Ferda district land administration report, large areas of extra land were recorded for each farmer. The farmers had expanded their farmland into nearby forest, shrub/bush land and grass land and used those land uses for commercial crop production. Therefore, this increment of unregistered or unplanned farms and FL resulted from above mentioned drivers are the main causes for the loss of woody species diversity in the study area.

The main reason for the lower woody species diversity in FFI in relation to NF in the study area is due to the application of intensive thinning of different woody species in the system in order to reduce shading effect. 33 also reported that, managing forest for coffee production has resulted in significant changes in species diversity, composition and vegetation structure in coffee forests of southwestern Ethiopia. The number of woody species recorded in Gura-Ferda NF is comparable to the Komba-Daga moist evergreen forest in southwestern Ethiopia (62 woody species)³⁴. For instance, the number of woody species recorded in the Gura-Ferda NF of the current study area is substantially higher than those reported for Agama tropical Afro-montane forest of Ethiopia (39 woody species)³⁵. However, the number of woody species in the current studied NF is lower than the woody species recorded for Wondo Genet Afro-montane forest in the central highlands of Ethiopia (72 woody species)³⁶.

Our results also indicated that, the woody species richness in FFI of the current study is comparatively lower than woody species in agroforestry system of south-central and southern highlands of Ethiopia^{37,38}. Since maximizing coffee production is the main goal, most of the native trees have been cleared by cultivators and few shade plant species are retained in highly populated coffee shrubs.

C stocks

The study showed how C stocks in biomass and soils were varied across different land use systems. NF had higher biomass C stocks compared to FFI and that of the FL. 39 and 40 reported higher biomass C in forest land use system as compared to other land cover types in northwestern Himalaya and northern Ethiopia, respectively. From the studied land use systems of this area, most of the C was stocked in NF. The accumulation of high C stock in NF was attributed by the presence of diversified woody species in the NF in comparison with FFI and FL. Additionally, the NF has found to accumulate larger aboveground biomass in the litter compared with that of FFI. This result is in line with the result of 40 which stated that tree density, diversity and diameter have an effect on biomass C.

Case studies have showed as different land use systems stocked different amounts of C in their biomass component. Accordingly, the biomass C stocks recorded in the NF of the current study area is substantially lower than the biomass C stocks of Adaba-Dodola community forest, southeastern Ethiopia⁴¹. The biomass C stocks of NF of the current study area was approximately three times lower than the biomass C stocks reported for woody plants of Mount Zequalla Monastery in Ethiopia⁴². Similarly, the biomass C stocks of FFI in this study was higher than that of the coffee based agroforestry system in Gera, Jimma Zone, South-West Ethiopia⁴³. The difference in biomass C stocks might be due to various factors such as difference in diversity of trees (woody and non woody) of larger sizes, the used allometric equation, soil condition and climate factors. For instance, in the coffee based agroforestry system studied

by 43, trees aboveground biomass was determined using⁴⁴ allometric equations. But, for this study, the generic equation developed by 20 and 21 were used for woody tree species. The biomass C stocks of the FFI of the current study area was relatively equivalent with the total biomass C stocks of fruit coffee system of indigenous agroforestry systems of the south-eastern Rift Valley escarpment, Ethiopia⁴⁵.

The average mean above ground biomass C stock of the FFI was higher than the mean biomass C stocks of organic polyculture coffee, non-organic polyculture coffee and organic Inga species in Chiapas, Mexico⁴⁶. The variability among these systems in this respect might be because of differences in species composition, site characteristics, management practices, land holding sizes, ancillary factors (e.g. soil condition, climate, system age, land-use history), and adopted allometric model for biomass estimation⁴⁷.

Concentrations of SOC decreased with an increment of depth in all NF, FFI and FL. The highest SOC stock in the NF might be attributed to the lower organic carbon turnover rate as a result of minimum soil disturbance in the system, and more litter fall inputs from different wood tree species. While in the FFI, common intensive management practices like cleaning, weeding, burning and relocation of biomass might influence accumulation of litter carbon. It was in agreement with results by 48 who claimed the diminishing trend of SOC content with depth in his study in Kafa, Southwest Ethiopia. 49 also observed a declining trend in SOC concentration with depth in the Central Rift Valley area of Ethiopia.

The total SOC stocks at soil depth for the three land use systems in this study were within the range of SOC stocks reported for other similar systems in Ethiopia⁵⁰. The upper layer (0–30 cm depth) SOC stock of FFI in this study area was higher than the mean SOC (65.2 Mg C ha⁻¹) of Nitisol soil under agroforestry systems in Ethiopia⁵⁰. The result of SOC in 0–30 systems cm depth in FFI was also higher than the 0–30 cm depth SOC recorded in Gununo watershed agroforestry practices⁵¹, and 0–30 cm depth SOC (60.8 Mg C ha⁻¹) of Indonesia homegarden agroforestry system⁵².

The results indicate that 22.5% and 44.05% of SOC stocks (0–60 cm) were lost in conversion of the NF to the FFI and FL respectively within 33 years. Another meta-analysis of 53 found that SOC decreased by 44.5% following conversion from a NF to a crop field. 54 also found that SOC decreased by 30.9% after 15 years of deforestation in the Bale Mountains of Ethiopia.

Conclusion

FFI in the southwestern part of Ethiopia plays an important role in maintaining more woody species and sinks of C. The higher contribution of NF to climate change mitigation is mainly due to the higher diversity and density of larger woody

species in the system as compared to the adjacent FFI and FL. Trees in particular play substantial roles for enhancing biomass C stocks in forests and any other land use systems. However, the increment of FL found adjacent to the NF and FFI showed a lower role of biodiversity conservation and C stock. This shows that sustainability of the system is questionable. If the NF is not sustainably managed and certification of land is not carried out in the area, there will be expansion of FFI and FL which will cause further deforestation and forest degradation. Therefore, it needs to recognize FFI as part of climate change mitigation strategies, as it can also provide much benefit to the community and a potential to reduce pressure on adjacent NF. The quantified C stocks would be beneficial to Ethiopia's economy and environment, encouraging the country to contribute even more to global warming mitigation while also providing income. The estimated C sequestration potentials of NF, FFI, and FL along the natural forest to farmland conversion gradient will necessitate the implementation of sustainable strategies, collaboration among actors, and promotion of best sustainable land management practices in order to improve marketing channels and institutional settings for effective C trading.

Data availability

https://datadryad.org/stash/share/00HE1stnxm6T5knrJC_qa7ou4-FyICjuw6hfGbobMXOM

Author contribution

Tamiru Kefalew is a lecturer at school of Agriculture and Natural Resource, Madda Walabu University, Ethiopia. He planned the study, Developed or designed methodology, collected data, identified the species, and involved in preparation of the manuscript

Mulugeta Betemariam is a lecturer at school of Agriculture and Natural Resource, Madda Walabu University, Ethiopia. He contributed in planning the study, Developing or designing methodology, analyzing the data and writing manuscript

Motuma Tolera Assistance Professor at Hawassa University, Wondo Genet College of Forestry and Natural Resources, Ethiopia. He contributed in acquisition of the financial support, original draft review & editing

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I read the manuscript carefully, and appreciate authors attempt to integrate ecological and GIS skills for analyzing the change in woody plant diversity and carbon sequestration potential in Gura-Ferda moist evergreen Afromontane forest. Nevertheless, the manuscript has many limitations to be considered for indexing, see my comments under each specific section below.

Title

"Conversion of natural forests to farmlands and its associated woody species diversity and carbon stocks in a span of 33 years (1984 to 2016): in the case of southwestern Ethiopia"- it is not fit with or well represent the contents of the manuscript. The inconsistency can be illustrated, for example, from:

- The title reads "Conversion of natural forests to farmlands", but in the text starting from introduction up to the conclusion, the authors deal with Forest land use, forest farm interface land use and farmland use, although forest farm interface land use is not yet known in Ethiopia and elsewhere in the world.
- Again, the title reads "its associated woody species diversity and carbon stocks in a span of 33 years (1984 to 2016)", but the authors analyse the current woody species diversity and carbon stocks across land use gradients, i.e. not change of species and carbon stock in a span of 33 years (from 1984 to 2016). The authors did not conduct any analysis that shows woody plant species and carbon stocks change across the land use gradients (the change could be positive (e.g. species gain or native species conservation) or negative (e.g. loss of species)) within specified period of time.

Thus, I recommend the authors to change the title.

Abstract

I also have concerns in abstract. Specifically:

- First, Gura-Ferda forest belongs to moist evergreen Afromontane forest, see [Friis et al.](#)

(2010): *Atlas of the potential vegetation of Ethiopia*. Royal Danish Academy of Science and Letters, Copenhagen.

Thus, I recommend authors to use "moist evergreen Afromontane forest" here in Abstract and throughout the text.

- Second, what is forest farm interface land use? Is it degraded forest or agroforestry system or what? Somewhere in the text (I think in the discussion section), is treated as coffee management system, authors can use it for stratifying the study site (as they did it in methods section), but as to me it is confusing to use it as a land use. I suggest you find other universally known or acceptable term, at least from Ethiopian perspective. For study area stratification, it is okay to use "forest farm interface"
- Third, the authors did not conduct analysis that show or revealed changes in species diversity and carbon stocks across the land-use gradients; See your methods and results and other related studies. Off course, you did land cover change analysis but not woody plant species and carbon stocks change (see my comment above also).

Thus, these need attention and clarification to improve the abstract and its conclusion.

Introduction

The introduction is hard to follow and to identify research gap/s.

a) The authors start with the problem of forest management and conversion. The introduction can benefit more on understanding the impact of land use change (i.e. deforestation, forest degradation and agricultural intensification) on biodiversity, if authors acquainted with and incorporated recent findings from IPBES: The global assessment report on and ecosystem biodiversity services summary for policymakers; *WWF: Living planet report 2020: Bending the curve of biodiversity loss globally*; Shumi *et al.* (2019): Conservation value of moist evergreen Afromontane forest sites with different management and history in southwestern Ethiopia¹, and other related works that focus on the problems of sustainable land use nowadays.

b) In the introduction, the authors stated that "Ethiopia's ecosystem is diverse, ranging from the dry lowlands in the east to the high altitudes of the central highlands (Hurni, 1998). The country's unique ecological conditions, as well as its rich flora and fauna, have made it one of the most important biodiversity hotspots on the world", I suggest getting out of such notions, especially in higher education system of Ethiopia, as we are in era of Anthropocene and those kind of approaches are misleading biodiversity conservation and land management practices. E.g. see Jackson and Sax (2010): Balancing biodiversity in a changing environment: extinction debt, immigration credit and species turnover².

c) After introducing southwestern biodiverse forest, the authors stated "Similarly, other remaining natural forests have also been threatened by pressure from investors and changed to industrial plantation like coffee and tea", this breaks the flow of idea. As far as the study is conducted in southwestern Ethiopia, I would suggest if the narratives of introduction could start with global aspects of biodiversity loss, then, in Ethiopia, and finally specific in southwestern Ethiopia.

d) Then, they wrote "This reduction and conversion of natural forest to other land use systems in many parts of Ethiopia has led to the decline in number and distribution of many plant species, shortage of raw materials for wood processing industries and disturbance of ecosystem services⁶. As a consequence, forest farm interface has expanded within and around the natural forest.

Subsequently, it has resulted the expansion of forest farm interface in and around the forest ecosystem.”, here, one can ask or raise concerns such as:

- A contradicting arguments, loss of species at local or landscape level in southwestern Ethiopia (or ???) and lack of raw materials for industries – large plantation or advocating for land use intensification.
- I do not think that the cited reference (6) is the correct one here.
- What is the impact of deforestation, forest degradation and agricultural or land use intensification on to local people, e.g. Meinit people, who used to live in forest (I think in that forest)? But see Ango *et al.* (2014): Balancing Ecosystem Services and Disservices: Smallholder Farmers’ Use and Management of Forest and Trees in an Agricultural Landscape in Southwestern Ethiopia³, and Shumi et al. (2019a): Woody plant use and management in relation to property rights: a social-ecological case study from southwestern Ethiopia⁴, for how the local community depend on woody plant species than favoring raw materials for wood processing industries or commodification of landscape, business as usual approaches. In fact, granting such provisioning and cultural ecosystem service to local people at local level also underpins important regulating and supporting ecosystem services. See Raudsepp-Hearne *et al.* (2010): Ecosystem service bundles for analyzing tradeoffs in diverse landscapes⁵.
- What is forest farm interface? Is it degraded forest or degraded farmland (arable land, grazing land and homegarden)? Or is it secondary forest? I do not agree with the definition provided by authors in subsequent paragraph. (See my comment above).
- Check for redundancy of the last two sentences.

e) The authors stated: “Hundreds of aid projects have been implemented in different parts of the country to reverse deforestation and forest degradation in the country. However, the success stories were below expectations and the problems are still immense. This resulted from the lack of effective management practices and quantification of the available forest resources. This insufficiency of scientific quantitative data brought lack of responsiveness for sound management of natural resources in the country.”. According to these statements, the problem of biodiversity loss is not land use change (i.e. deforestation, forest degradation and agricultural intensification), rather it is lack of monitoring of restoration, and existing forest management in the country. I suggest to clearly focus on what to be studied in the region.

f) What is the need of bringing “Gura-Ferda forest is one of the Afromontane rainforests in the southwestern region of Ethiopia and grows at altitudes from 700 to 2,300 meter above sea level.” into introduction? Better to take it to methods section.

g) The reason why the authors analyze the woody species diversity and carbon stock change in Gura-ferda forest (i.e. the research gap/s) is not indicated or stated clearly. Specifically, why carbon stock? The hypothesis is also weak or, obvious, i.e. change in woody plant species diversity and carbon stock from forest to degraded forest and then, to farmland is obvious, so what makes their hypothesis unique?

Materials and methods

- 1) If I am not mistaken Gura-Ferda district is situated in Bench-Majji zone, in SNNP region, I do not know why the authors afraid to mention this give clear information of about their study area.
- 2) I suggest taking "Table 1" under methodology.
- 3) Under methodology, instead of "Data source", I suggest land use mapping and stratification of study area". Then, remove "Table 2"; "Figure 2"; and "Figure 3", as these are not the focus of the study. Here, maybe see the methods in my paper, Shumi *et al.* (2019): Conservation value of moist evergreen Afromontane forest sites with different management and history in southwestern Ethiopia¹.
- 4) I suggest deleting "Figure 4", as sampling method is described well in text.
- 5) Take subtitle "Biomass carbon stock estimation" and "Soil organic carbon (SOC) stock estimation" under methodology before data analysis.

Results

- a) Where is the results of species change analysis? Change analysis is the aim of the study.
- b) How the authors compare species diversity in forest with forest farm interface and farmland? Here, different ecosystems, land use types are suitable for different groups or guilds of species, mainly forest specialist species, generalist species and pioneer species. See my paper, Shumi *et al.* (2019): Conservation value of moist evergreen Afromontane forest sites with different management and history in southwestern Ethiopia¹.
- c) Why the Simpson (D) index? As it is not specified under methods section. What is the difference between the Simpson (D) and Shannon diversity index (H')?
- d) Here, many abbreviations "NF", "FFI", "FL", "D", "H" may confuse the readers.
- e) Where is the results of carbon stock change analysis? Carbon stocks change analysis is the aim of the study.
- f) I suggest taking "Where, AGBC is aboveground biomass C stocks, BGBC is belowground biomass C stocks, TBC is total biomass C stocks, SOC is soil organic C stocks and TCS is total C stocks. Different letters show significant ($p < 0.05$) different between Land Uses, and similar letters not significance differences" to "Table 5" caption.
- g) Again, "Different letters on similar soil parameters of different land uses indicate a significant difference across Land Uses ($p < 0.05$), but similar letters do not show a significant difference across Land Uses." to "Table 6".
- h) Take "The total C stock of the study area was calculated by summing up all the C value of each pool." to the methods section.

Discussions

1) The discussion opened by statement: "The degree of human interference and disturbance caused by overexploitation of forest resources, overgrazing, the establishment of new settlements, and the conversion of forest to coffee plantation for long periods could be attributed to the variation in species composition among the NF, FFI, and FL of Gura-Ferda district. Almost all of the woody species found in the FFI and FL were not planted, but rather were left over from the conversion of the NF to the FFI and FL.". What about species adaptation to different environment or land uses? See my comment above.

2) It is not clear why the authors compare this forest, "moist evergreen Afromontane forest" with Jibat humid Afromontane forest, "Dry Afromontane forest". The same with Gendo moist afromontane forest, Gole Forest, and Wondo Genet Afromontane forest. Here, not only the biophysical conditions of the forests, but also the methods used by matters. Maybe check this?

3) The authors said "As shown in Table (1), FFI which emerged after the resettlement program of 1984 accounts for 23.28% of the NF within 1984–2016-year interval. As reported by 11, and 10, the main problem related to land use land cover change at Gura-Ferda district was agricultural investment, fuel wood collection, wood for house construction and farm implementation, wildfire, resettlement, land certification, poor governance within the district, and subsistence agricultural land expansion.", here, they want to discuss species diversity change – forest degradation or land cover change? How does land certification and poor governance within the district affect land cover change?

4) While their analysis did not quantify species loss, why the authors reported species loss in "Therefore, this increment of unregistered or unplanned farms and FL resulted from above mentioned drivers are the main causes for the loss of woody species diversity in the study area.", is not clear.

5) Why are farmers blamed here? Alternatively, are they investors? Very contradicting statement "According to Gura-Ferda district land administration report, large areas of extra land were recorded for each farmer. The farmers had expanded their farmland into nearby forest, shrub/bush land and grass land and used those land uses for commercial crop production."

6) Is there coffee management systems in the area? If so, I suggest to discuss or brining in this issue in the introduction also.

7) The discussion on carbon stocks also needs attention, including justification – clearly stating problem statement in the introduction for conducting carbon stock study in the area.

Conclusion

Authors suggest the needs for land use certification for the system to be sustainable, i.e. "If the NF is not sustainably managed and certification of land is not carried out in the area, there will be expansion of FFI and FL which will cause further deforestation and forest degradation.". But, in Ethiopia, particularly in southwestern Ethiopia, land use certification did not guarantee land tenure security and biodiversity conservation. See my paper Shumi *et al.* (2019a): Woody plant use and management in relation to property rights: a social-ecological case study from southwestern Ethiopia⁴.

The authors call for landscape commodification than biodiversity conservation. As I read it from

the manuscript, although not yet clearly stated, carbon stock assessment for landscape commodification seems to be the main essence of this study. In emerging social-ecological system research, however, researchers in this field argued that landscape commodification or marketing has an impact on both the ecosystem services (biodiversity protection) and human, particularly local people well-being, for example, see Go´mez-Baggethun and Naredo (2015): In search of lost time: the rise and fall of limits to growth in international sustainability policy⁶; Osborne *et al* (2021): The political ecology playbook for ecosystem restoration: Principles for effective, equitable, and transformative landscapes⁷; and Pham *et al* (2021): REDD+ finance in Brazil, Indonesia and Vietnam: Stakeholder perspectives between 2009-2019⁸. From Ethiopian context, how could the authors concede this argument? I would like to know the stand of the authors in this regard.

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8. Pham T, Moeliono M, Yuwono J, Dwisatrio B, et al.: REDD+ finance in Brazil, Indonesia and Vietnam: Stakeholder perspectives between 2009-2019. *Global Environmental Change*. 2021; **70**. [Publisher Full Text](#)

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

No

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My research areas are social-ecological system resilience, particularly woody plant biodiversity conservation and ecosystem services, local people well-being, human-nature connectedness and landscape sustainability.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 17 December 2021

<https://doi.org/10.5256/f1000research.79432.r101375>

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Sigit D. Sasmito

NUS Environmental Research Institute, Singapore, Singapore

The authors have addressed my previous concerns adequately. The revised version of the manuscript is much improved. I have only two minor comments: 1) authors may need to use less abbreviation throughout the manuscript text to improve the paper readability, 2) please add fieldwork sampling year in the sampling technique for any future relevant study. Great work!

Is the work clearly and accurately presented and does it cite the current literature?

No

Is the study design appropriate and is the work technically sound?

No

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

No

Are all the source data underlying the results available to ensure full reproducibility?

No

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Wetlands ecology and greenhouse gas monitoring

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 20 October 2021

<https://doi.org/10.5256/f1000research.31345.r92406>

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Sigit D. Sasmito

¹ NUS Environmental Research Institute, Singapore, Singapore

² NUS Environmental Research Institute, Singapore, Singapore

This manuscript presents a set of assessments of tree species diversity and carbon stocks following land-use change. Such of this study is of interest broad audience in the context of land-based climate change mitigation strategies.

I have a few suggestions below which may be used to improve the current manuscript.

- I'd suggest providing carbon stocks value across land-use change in the abstract's result section.
- I'd drop the current first paragraph in the intro. It is too broad and you have to be direct to the Ethiopia case.
- Some references may be needed for the following statement "For the past five decades, the government of Ethiopia has attempted to reforest degraded forests." and other few next sentences in this paragraph.
- Table 1: I didn't see how the authors get the data presented in Table 1. What is the unit of the area data in 1984 and 2016?
- For Tables 6,7 and 8: I'd suggest authors provide n sample size in addition to the current mean and SD. The soil C stocks are pretty high indeed. To support your soil carbon stocks

numbers, I'd suggest providing the bulk density and %C (carbon content) in an additional table.

- For the discussion section under carbon stocks: could you further explore whether soil erosion occurs following forest degradation? This erosion may lead to organic matter loss from the upper soil layer.
- To test if the forest conversion or land-use change generates soil carbon loss, you may use both the fixed depth and mass balance approach. See the following paper for further information about two approaches: Gifford, R. M., & Roderick, M. L. (2003). Soil carbon stocks and bulk density: spatial or cumulative mass coordinates as a basis of expression?. *Global Change Biology*, 9(11), 1507-1514¹.
- In the conclusion section, I'd suggest adding a few sentences describing how your study could support current literature on this topic and carbon monitoring in the context of climate change mitigation strategy in Ethiopia.

Good luck!

References

1. Gifford R, Roderick M: Soil carbon stocks and bulk density: spatial or cumulative mass coordinates as a basis of expression?. *Global Change Biology*. 2003; **9** (11): 1507-1514 [Publisher Full Text](#)

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Wetlands ecology and greenhouse gas monitoring

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have

significant reservations, as outlined above.

Author Response 12 Nov 2021

Mulugeta Betemariyam

Dear Sigit D. Sasmito

We are grateful for insightful and constructive comments on our manuscript, "Conversion of natural forests to farmlands and associated woody species diversity and carbon stocks in southwestern Ethiopia during 33 years (1984 to 2016)." We have attempted to address all comments in this revised manuscript and believe that the manuscript, especially the language, has substantially improved. Track changes for changes made to the original version were added to the page where specific changes were required. Our responses to the specific comments are presented below.

I have a few suggestions below which may be used to improve the current manuscript.

I'd suggest providing carbon stocks value across land-use change in the abstract's result section

- Thank you for your comments; the carbon stock values have been added to the revised manuscript abstract.

I'd drop the current first paragraph in the intro. It is too broad and you have to be direct to the Ethiopia case.

- Thank you for your constructive comment. We kindly revised accordingly.

Some references may be needed for the following statement "For the past five decades, the government of Ethiopia has attempted to reforest degraded forests." and other few next sentences in this paragraph.

- Thanks for the information; the suggested paragraph for removal from the introduction section has been removed.

Table 1: I didn't see how the authors get the data presented in Table 1. What is the unit of the area data in 1984 and 2016?

- Thank you for your input; in the amended manuscript, the technique for obtaining the data in table one, as well as the unit of the area shown in the table, are clearly defined.

For Tables 6,7 and 8: I'd suggest authors provide n sample size in addition to the current mean and SD. The soil C stocks are pretty high indeed. To support your soil carbon stocks numbers, I'd suggest providing the bulk density and %C (carbon content) in an additional table.

- Thank you for your comment; the sample size has been put to the table's heading as recommended.

For the discussion section under carbon stocks: could you further explore whether soil erosion occurs following forest degradation? This erosion may lead to organic matter loss from the upper soil layer.

- Thank you for your comment; the sample values of organic matter lost as a result of the conversion of natural forest to forest farm interface and farmland are mentioned in the amended manuscript's discussion section.

To test if the forest conversion or land-use change generates soil carbon loss, you may use both the fixed depth and mass balance approach. See the following paper for further information about two approaches: Gifford, R. M., & Roderick, M. L. (2003). Soil carbon stocks and bulk

density: spatial or cumulative mass coordinates as a basis of expression? Global Change Biology, 9(11), 1507-15141.

- Thank you for sharing us with the sources from which we can obtain additional information. In this study, we employed the fixed depth method to determine the soil organic carbon. As stated in the results section, there was no significant variation in bulk density among the land uses. The estimation of soil organic carbon by employing fixed depth is recommended by authors who were cited in our paper method section if the bulk density is not indicated as a significant difference.

In the conclusion section, I'd suggest adding a few sentences describing how your study could support current literature on this topic and carbon monitoring in the context of climate change mitigation strategy in Ethiopia.

- Thank you for your suggestion. We include a statement in the conclusion section outlining how our research could contribute to current literature on the issue and carbon monitoring in the context of Ethiopia's climate change mitigation strategy.

Competing Interests: No competing interests

Reviewer Report 04 June 2021

<https://doi.org/10.5256/f1000research.31345.r83476>

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Arshad Ali

¹ Department of Forest Resources Management, College of Forestry, Nanjing Forestry University, Nanjing, China

² Department of Forest Resources Management, College of Forestry, Nanjing Forestry University, Nanjing, China

I read your paper carefully, and found it an interesting idea to compare three land use types such as NF, FFI and FL. I found a very interesting hypothesis at the end of introduction, but unfortunately your experimental design and statistical analyses do not allow to test this hypothesis in a clear way.

For example, you selected plots with different sizes and hence it is hard to compare with ANOVA only or any other simple statistics. I suggest testing the direct and indirect effects of plot size, and land use types (i.e., three categories) on species diversity, structure and biomass using structural equation models or multiple linear mixed effect models. Otherwise, it is hard to understand results and hence hard to get right conclusions.

Why did you used different biomass equations for NF, FFI and FL? Is this not affecting the biomass estimation amongst three types?

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

No

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

No

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My broad-scale research interests are in the area of forest or plant ecology, particularly related to multiple abiotic and biotic controls on ecosystem functions and processes.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 12 Nov 2021

Mulugeta Betemariyam

Dear Arshad Ali

We are grateful to the reviewer for insightful and constructive comments on our manuscript, "Conversion of natural forests to farmlands and associated woody species diversity and carbon stocks in southwestern Ethiopia during 33 years (1984 to 2016)." We have attempted to address all comments in this revised manuscript and believe that the manuscript, especially the language, has substantially improved. Track changes for changes made to the original version were added to the page where specific changes were required. Our responses to the specific comments are presented below.

I read your paper carefully, and found it an interesting idea to compare three land use types such as NF, FFI and FL. I found a very interesting hypothesis at the end of introduction, but unfortunately your experimental design and statistical analyses do not allow to test this hypothesis in a clear way. For example, you selected plots with different sizes and hence it is hard to compare with ANOVA only or any other simple statistics. I suggest testing the direct and indirect effects of plot size, and land use types (i.e., three categories) on species diversity,

structure and biomass using structural equation models or multiple linear mixed effect models. Otherwise, it is hard to understand results and hence hard to get right conclusions.

- In the statistical analysis section, we apologize for not explicitly expressing which types of statistical tests we utilized for the investigated parameters. We explicitly detailed how we test parameters in the revised manuscript. On comparison, the authors agreed that differences in sample sizes (plot size) affect carbon stocks, species richness, and structure. However, even if the sample size (plot size) for Farmland and other land uses for which comparison was made (NF, FFI) were different, the authors reached the comparison result after the individual plot size for each land use was converted to Ha (hectare) base, which the ANOVA can do for statistical differences. So, after similarizing the unit (ha) for each land use, we compared carbon stocks, diversity indices, and structural parameters among the three land uses following the ANOVA procedures.

Why did you used different biomass equations for NF, FFI and FL? Is this not affecting the biomass estimation amongst three types?

- Many researchers have suggested that site conditions, management strategies, socioeconomic considerations, and farmer preferences could influence the distribution, diversity, and type of woody species (Tolera *et al.* 2008; Faye *et al.* 2011; IPCC, 2006; Chave *et al.* 2014; Kuyah *et al.*, 2012). In our study area, 75 percent of the 70 different species identified do not have a specific allometric equation developed for them. As a result, we used an allometric equation developed for an agricultural landscape in Kenya (Kuyah *et al.*, 2012), which has essentially similar biophysical features to the research area for estimating the biomass of FFI and FL, and an allometric equation developed for natural forests in the tropical region by Chave *et al.* (2014) to estimate the biomass carbon stocks of natural forest.

Competing Interests: No competing interests

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