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Original Paper

Ecosystem Service Potentials and Underlying Influences in a Tropical Rainforest Ecosystem

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Abstract

Tropical ecosystems have vast array of ecosystem services but are largely un-quantified. This study explored the capacity of rainforest ecosystems to deliver ecosystem services and inherent influences that determine such. Forest plots measuring 50m × 50m were set up in 14 locations and used for tree enumeration. Soil samples were collected at four edges and middle of each plot at 0-30cm depth, bulked and analyzed. Aboveground, belowground and soil carbon, and biodiversity variables were equally conducted according to standard procedures. Pearson correlation and regression were used to verify aboveground and belowground carbon relationships and relationships between elevation and carbon capacities, respectively. 85 species within 32 families were enumerated across the ecosystem. Biodiversity patterns showed a diversity index of 3.376, relative dominance of Dialium guineense Willd., (54.34%) and seven other species with ≥ 1% dominance. Species within the ecosystem possessed provisioning and regulating ecosystem values. Carbon estimates showed aboveground biomass range of 1.73 – 6.50 t/ha^{-1}, percentage soil carbon and soil organic carbon ranges of 4.76 – 8.80% and 17.78 – 91.3 t/ha^{-1}, respectively. Elevation did not generally influence the carbon stock of the ecosystem, but had some influence on percentage soil carbon. Effective strategies that would address the reductions in the services were advocated.

Keywords

carbon, climate change, conservation, degradation, sustainability

1. Introduction

Ecosystems are viable landscapes that provide veritable benefits at local, regional and global scales. The benefits and services they provide (referred to as ecosystem services) are varied (e.g., water purification, carbon sequestration, soil retention, water retention, flood mitigation and recreation) and help to achieve multiple development objectives. Ecosystem services (the flow of benefits from ecosystems to people), is fundamental to human well-being (Kleemann et al., 2020). Across tropical ecosystems and landscapes, they serve as a mainstay of livelihood for many households, revenue for regional and local governments and source of food and nutrition for both direct and indirect users. Though different ecosystem service categories (provisioning, regulating, supporting and cultural; MA, 2005), provisioning are much prominent in tropical zones due to the direct benefits to the populace. Biodiversity and functioning ecosystems are critical to maintaining ecosystem services that support human well-being (Weiskopf, 2020). With varieties in taxa, tropical ecosystems such as the rainforest ecosystem provide wide array of ecosystem services; which has both direct and indirect benefits. The potential of the ecosystem to continue providing these are however declining at different spatial scales following increased modification of the ecosystems and loss emanating from land use changes.

Ecosystem loss and degradation is a greater peril for global biodiversity than any other contemporary phenomenon (Bradshaw et al., 2009; Laurance et al., 2012); with the estimates of such losses and associated impacts seen to be greater than previously thought (Isbell et al., 2022). These have wide reaching consequences for the ecosystem services, functions and nature’s contribution to people. Concerns arising from such changes in the ecosystem border on threats and extinction of biodiversity, acceleration of climate change impacts, decreased ecosystem functioning, threat to livelihoods and food security. Though conservation efforts have increased, biodiversity have continued to decline globally (Tittensor et al., 2014). Such trends have grown in scale predominantly due land use changes (Maxwell et al., 2016) and have caused substantial declines in global species richness (Newbold et al., 2020). While this is so, such declines do not affect the species within ecosystems equally; with the result that some species are seen to be more threatened than others. Such patterns are highlights of ecosystems across much of the tropics, and hence, present the need to elucidate the biodiversity patterns (such as their diversity, dominance and rarity), ecosystem service potentials and conservation prospects for the region.

Forest landscapes provide veritable regulatory ecosystem services and mitigate climate change impacts through its carbon sequestration processes. Biomass and soil carbon stores are very vital aspects of stable forest ecosystems and strategic for global carbon cycle (Bangroo et al., 2013). Estimates on such regulatory capacities are varied across ecosystems (such as tropical and temperate ecosystems) and within the same ecosystem due to variations in local factors and biogeography. Carbon stock in forest ecosystems are important components of global carbon cycle and sequester up to 80% and 40% of above ground and below ground carbon in terrestrial ecosystems, respectively (IPCC, 2001). Ensuring accurate estimation of such is hence important for a better understanding of biogeochemical interactions with global climate (Shaw et al., 2008) and in designing management strategies that will help to maximize such ecosystem service. Such assessment is however lacking and in other cases, not detailed for many landscapes across the tropics. This work elucidated the estimates for carbon stock in a rainforest ecosystem and furthermore explored the extent to which such estimates could be influenced by elevation. Besides the regulatory ecosystem services, this work equally explored the biodiversity patterns of the ecosystem, the extent to which they could be relied on for provisioning ecosystem services and the needed strategies to adopt in enhancing sustainable use and efficient management of the ecosystem and its services.

2. Methods

2.1 Study Area/Region

The area for the research is a part of South East Nigeria (Figure 1). The climate is characterized by a humid tropical, tropical wet and dry, and marked rainy and dry seasons. It has a high annual rainfall range of 1,400mm in the North to 2,500mm in the South, and a mean monthly temperature of 27.6^{o}C. Geology of the region comprises of ancient Cretaceous delta, with the Nkporo shale, the Mamu formation, the Ajali sandstone and the Nsukka formation as its main deposits (Ofomata, 1975). The natural vegetations in this region are mainly, rainforest- savanna ecotone ecosystem. The zone experiences about 3 dry months in its northern zone and 1-2 dry months in the south; making it much humid and with sufficient rainfall.

Forest inventory took place in Maku town, Awgu Local government area, Enugu state. This location is characterized by high elevation with hilly features and rugged terrain. The forest in the town is extensive and relatively undisturbed- mainly due to the hilly terrain, very poor accessibility of the forests and quite distant from human dwelling units. The inhabitants live together in a small zone, while the greater part of the land is in the hilly outskirts where farmlands and forests are located.

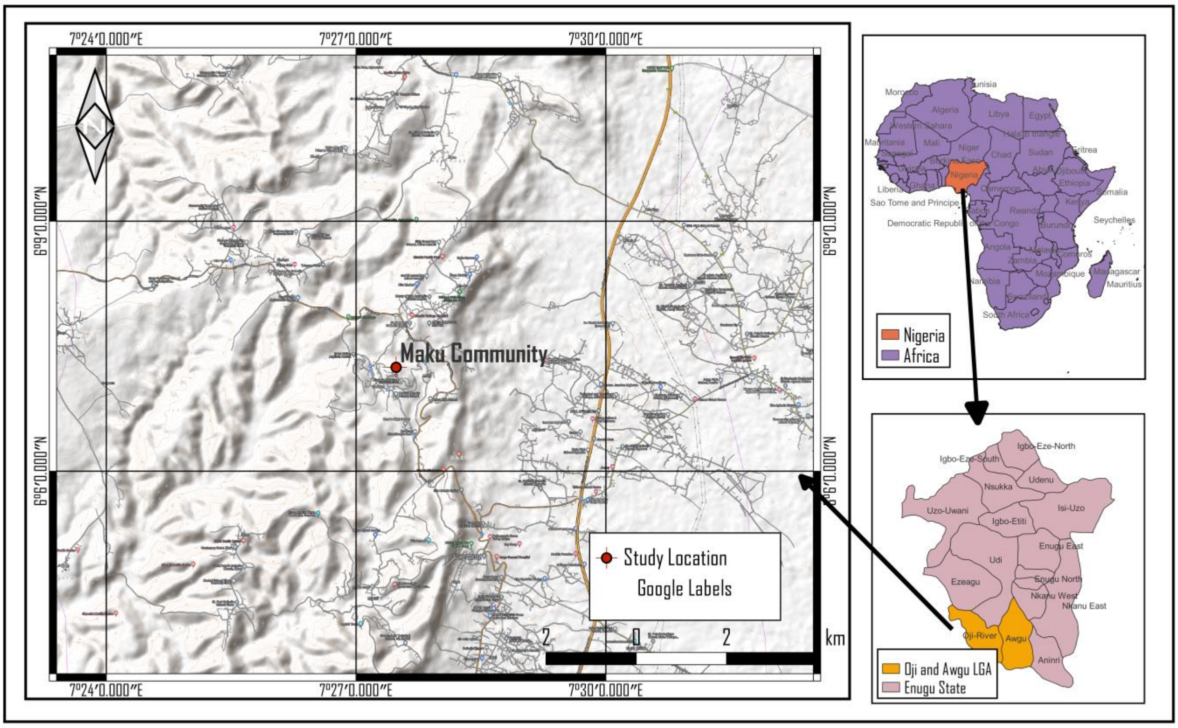

Figure 1. Map of the Study Area Showing the Study Region and Map of Nigeria and Africa Inset

2.2 Data Collection and Analysis

Fourteen forest plots was set up across the zone and used for eliciting information regarding the composition of the forest and their ecosystem service potentials. Each of the plots measured 50m × 50m and was used to enumerate tree species ≥ 10 cm diameter at breast height (DBH measured at 130cm). DBH or girth tape was used to measure the tree stems while a rangefinder was used to measure the heights. Species identification followed the taxonomy of Nigerian plants (Keay, 1989) and The Plant List (2013). Soil samples were collected at 0-30 cm deep at the four edges and middle of each plot and bulked for analysis. Soil organic carbon (SOC) analysis was conducted according to Walkey- Blacks titration method (Jackson, 1973). Elevation was measured at the four corners of each plot with a Garmin GPS and mean score deduced accordingly.

Relative dominance of the ecosystem followed after Cottam and Curtis, 1956:

$$\text{Relative dominance} = 100 \; x \; \frac{\text{Total basal area of a species}}{\text{Total basal area of all species} \ldots} \qquad \ldots\ldots \; \ldots\ldots\ldots\ldots \; (1)$$

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The basal area was calculated as follows:

$$BA = \left(\frac{dbh}{2}\right)^2 x\ \pi \tag{2}$$

Where BA is the basal area (m^2); dbh is the diameter at breast height (cm) and π as pie (3.142).

The diversity of the ecosystem was ascertained following Kent and Coker (1992):

Shannon-Wiener index:

$$H^{'} = -\sum_{i=1}^{s} pi \ln pi.. \tag{3}$$

Where H^{l} is the Shannon-Weiner index, s is the total number of species, pi is the proportion of individuals in the ith species, and ln is the natural logarithm.

Aboveground biomass was calculated with a generalized tree biomass equation suitable for the precipitation zone (Brown, 1997):

$$y = e^{(-3.1141+0.9719\ln(DBH\ x\ H))}$$

Where y is the AGB in kg, DBH in cm, H (tree height) in m. The output was multiplied by 4 to convert the plot size to hectare and then further converted to ton/ha^{-1} by multiplying with 0.001.

BGB was estimated according to Ponce-Hernandez's (2004) non-destructive approach as follows:

BGB = 20% x AGB

Pearson correlation was conducted to verify the relationship between the aboveground carbon and belowground carbon. Regression was used to model the influence of elevation on aboveground carbon, soil organic carbon and % soil carbon.

3. Results

3.1 Overview

A total of 85 species within 32 families were enumerated across the ecosystem.

Biodiversity patterns

Shannon diversity index of 3.376 showed a good diversity for the ecosystem. Forest structure of the region showed a good pattern as is characteristic with forest ecosystems (Figure 2). However, the lower stem category which dominated the ecosystem showed the need to manage the ecosystem better.

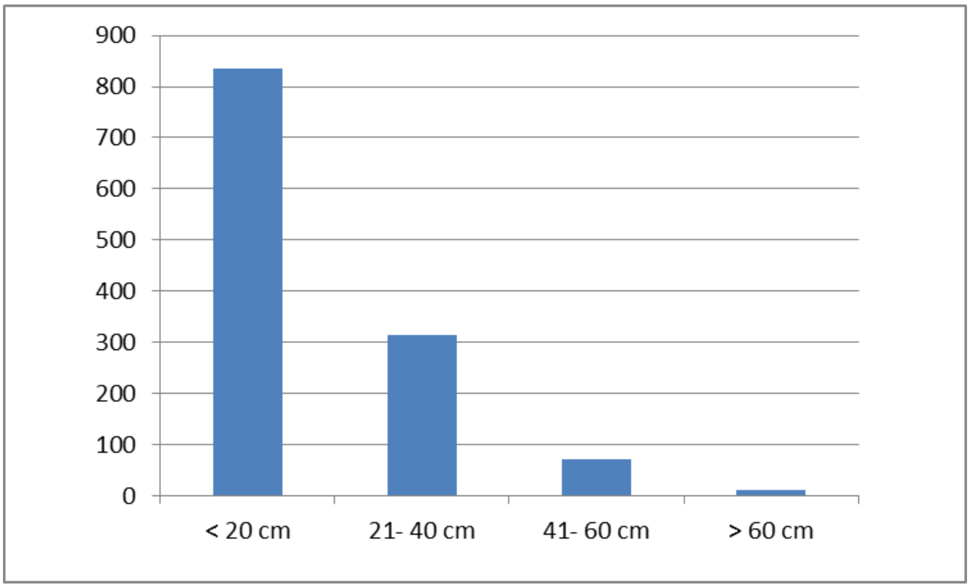

Figure 2. Distribution of Tree Stems according to the Stem Sizes

Notable species had higher frequencies of occurrence and dominated the ecosystem more than others (Table 1).

Table 1. Species Distribution, Frequency of Occurrence and Dominance

Species	Frequency	Relative dominance
Afzelia africana (Sm. Ex pers.)	2	0.01295
Albezia zygia (DC.)	25	1.522577
AlbIzia adianthifolia (Shumach.) W.Wight	20	0.821704
Albizia ferruginea (Guill.)	31	2.817431
Allophlus africanus P.Beauv.	13	0.062734
Anacardium occidentale L.	1	0.001275
Anthocleista nobilis G.Don.	4	0.021524
Anthocleista vogelii (Planch.)	14	0.381333
Anthonatha macrophylla P. Beauv.	28	0.335277
Antiaris africana Engl.	2	0.001439
Baphia nitida Lodd.	2	0.001482
Barteria fistulosa (Mast.)	1	0.000976
Boscia angustifoila A.Rich.	5	0.025453
Brachystegia eurycoma Harms	23	0.715167

Bridelia leichardtii Baill. Ex. Muell.Arg.	1	0.001083
Bridelia micrantha (Hochst.) Baill	1	0.001482
Cantium gabrifolium	19	0.241524
Ceiba pentandra L.	3	0.097585
Celtis mildbraedii Engl.	7	0.038337
Clesistopholis pathens Benth.	37	6.027145
Cola millenii (K. Schum.)	20	0.148152
Cola nitida (Vent.) Schott. & Endl.	1	0.001011
Combretum erythrophyllum (Burch.) Sond.	4	0.064705
Dacryodes edulis (G Don.) H.J.Lam.	1	0.000841
Daniela ogea (Harms) Rolfe ex Holland	2	0.003431
Daniellia oliveri (Rolfe) Hutch. & Dalziel	1	0.001355
Dialium guineense Willd.	283	54.34296
Dichapetalum madagascariense Poir.	4	0.011591
Drypetes gilgiana (Pax) Pax & K.	11	0.044698
Entandrophragma angolense (Welw.)	19	0.271458
Entandrophragma utile Dawe & Sprague	1	0.004333
Enterolobium cyclocarpum	1	0.006012
Ficus capensis Thumb.	2	0.003237
Ficus mucuso Welw. Ex Ficalho	4	0.011711
Ficus polita Vahl.	1	0.001011
Funtumia elastica (P. preuss)	78	6.47335
Garcinia kola Heckel	1	0.000244
Guarea cedrata A.chev.	1	0.000809
Hildegardia bateri (Mast.) Kosterm	3	0.013593
Holarrhena floribunda (G. Don.) Dur. & Schinz	9	0.123115
Hunteria umbellata (K. Shum.) Hallier f.	6	0.041457
Hylodendron gabunense Tuub	5	0.017626
Hymenocardia acida Tul.	1	0.001196
Irvingia gabonensis	13	0.506653
Lannea welwitsschii (Hien) Engl.	1	0.002355
Lecaniodiscus cupanioides Planch.	24	0.391737

Lophira alata Banks ex.	1	0.002989
Lovoa trichilioides Harms	19	0.318062
Macaranga barteri Roberty	12	0.143044
Malacantha alnifolia (Baker) Pierre	3	0.007095
Mangifera indica L.	3	0.057805
Margariteria discoidea (Baill.) G.L Webster	47	1.927786
Markhamia lutea (Benth.) K. Schum.	7	0.051293
Milicia excelsa Welw.	14	0.424517
Milletttia thonngii (Shumach & Thonn.) Baker	18	0.163563
Mitragyna inermis (Wild.) O Ktze	9	0.168106
Monodora tenuifolia Benth.	1	0.000717
Morinda lucida Benth.	1	0.000874
Musanga cecropoides R.Br.	5	0.032465
Myrianthus arboreus P.Beauv.	9	0.042831
Parkia bicolor A.Chev.	3	0.021198
Parkia biglobosa (Jacq.) G.Don	2	0.003431
Pentaclethra macrophylla (Benth.)	114	16.37435
Periscopsis elata (Harms) van Meeuwen	11	0.102526
Piptandeniastrum africanum (Hook.f.)	7	0.314298
Pterocarpus osun Craib	9	0.10468
Pterocarpus santalinoides	12	0.121554
Pycnanthus angolensis (Welw). Warb	22	1.05811
Rauvolfia vomitoria (Afzel.)	13	0.10468
Rhizophora racemosa GFW Mey	2	0.015614
Ricinodendron heudelotti (Baill.)	11	0.188351
Rinorea dentata (Beauv.) Kuntze	4	0.006816
Spathodea campanulata (P. Beauv.)	15	0.250935
Spondias mombin (L.)	19	0.277302
Sterculia oblonga Mast.	4	0.013593
Sterculia rhinopetela K.Schum.	1	0.026532
Sterculia tragacantha Lindl.	27	0.798609
Strombosia pustulata Blume	17	0.238791

Terminalia glaucescens Planch.	1	0.000941
Treculia africana Decene	2	0.013986
Trichilia prieuriana A. Juss	7	0.019139
Vitex doniana	6	0.032666
Vocanga africana Stapt.	7	0.041004
Xylopia aethiopica (Dunal) A. Rich.	25	0.91098
Zanthoxylum zanthoxyloides (Lam.)	2	0.001658
Total	1228	100

3.2 Ecosystem Services

Species distribution within the ecosystem as exemplified with the dominant species were seen to provide suitable ecosystem services- notably timber and nutrition (Table 2)

Table 2. Five Most Dominant Species and Their Ecosystem Values

Species	Total DBH	Basal area	Relative dominance	Mean MHT	Provisioning service
Albizia ferruginea (Guill.)	957.7944	720135.6	2.817431	7.43	Timber
Clesistopholis pathens Benth.	1400.882	1540539	6.027145	10.37	Timber
Funtumia elastica (P. preuss)	1451.811	1654589	6.47335	6.05	Timber
Pentaclethra macrophylla (Benth.)	2309.02	4185285	16.37435	4.85	Nutrition/timber
Dialium guineense Willd.	4206.465	13890064	54.34296	4.7	Timber

MHT = Merchantable height.

3.3 Carbon Storage

Above ground biomass carbon ranged from 1.73 – 6.50 t/ha^{-1} across the plots while % soil carbon and soil organic carbon ranged from 4.76 – 8.80% and 17.78 – 91.3 t/ha^{-1}, respectively (Table 3).

Table 3. Carbon Distribution According to Plots and Elevation

Plot No	Mean Elev	Soil organic carbon (t) Ha	% Soil carbon per plot	AGB (t/ha)
1	366.25	36.53	8.32	4.107792
2	409.5	29.38	8.32	3.198959
3	339.5	91.3	8.8	6.333196

4	354.25	80.83	8.37	6.501084
5	282	47.39	5.91	4.440484
6	303	43.05	8.34	3.790993
7	222.25	48.48	4.76	4.157752
8	219.25	73.02	7.9	6.289452
9	208	59.93	7.34	4.988972
10	211.5	34.57	5.69	2.307163
11	326.25	23.72	6.62	2.345018
12	332.25	23.69	7.35	1.974146
13	339.75	43.67	5.37	3.021327
14	336.75	17.78	6.29	1.725828

*Elev = elevation,

Correlation between aboveground carbon and belowground carbon correlated at 1.00; thus showing a perfect correlation. Regression to establish relationship between elevation and other carbon indices-soil organic carbon, aboveground carbon and % soil carbon showed an R value of .640, which implied that there was an average correlation between them. R2 value of 40.9% total variation in the dependent variable could only be explained by the independent variables.

Table 4. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.640[a]	.409	.232	56.76405

a. Predictors: (Constant), Soil organic carbon, AGB (t/ha), % Soil carbon per plot.

Though the contribution of elevation was not generally significant in the determination of total carbon: (F (3, 10) = 2.310, p = .138; table 5), it however influenced % soil carbon (t = 2.44, p = .035; Table 6).

Table 5. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22333.515	3	7444.505	2.310	.138[b]
	Residual	32221.574	10	3222.157		
	Total	54555.089	13			

a. Dependent Variable: Mean Elev.

b. Predictors: (Constant), Soil organic matter, AGB (t/ha), % Soil carbon per plot.

Table 6. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	55.070	160.287		.344	.738
	AGB (t/ha)	-15.867	12.392	-.400	-1.280	.229
	% Soil carbon per plot	38.858	15.920	.790	2.441	.035
	Soil organic matter	21.109	32.490	.235	.650	.531

a. Dependent Variable: Mean Elev.

4. Discussion

Biodiversity of the ecosystem were diverse and had a good structural pattern. Individual trees within lower stem sizes were more in number and decreased as the stem sizes increased. While this is mostly the pattern within forest landscapes, it showed the extent of disturbances within the landscape and the capacity to which it can provide ecosystem services. Provisioning ecosystem service had a prominent place in the ecosystem and was seen be useful for both timber and non-timber forest products (Table 2). With as much as 85 different species, the ecosystem possessed ample species abundance which is seen to be critically important for the delivery of ecosystem services (Davies et al., 2011; Winfree et al., 2015). Ensuring that ecosystems are not degraded are good strides toward promoting high quality ecosystem provisioning. Disturbed landscapes not only take time to re-grow, it equally experiences a time lag and reduction in its ecosystem service generation; and may then experience social, economic and environmental consequences (Marcos-Martinez et al., 2019). The contributions of ecosystem services are dependent on how lands are managed and benefits are utilized. Emphasis on ecosystem management is hence of much importance and should be given much credence.

Regulatory ecosystem service was mainly captured through carbon storage in the ecosystem. Aboveground carbon were much varied in the ecosystem and ranged between 1.72 – 6.50 t/ha. Forest degradation has direct impacts and determines aboveground biomass estimates (Pan et al., 2011) and variations in ecosystems through natural and anthropogenic processes. Such events shape the structural attributes of forest locations and determine to a great extent the carbon stocks of such landscapes. Belowground carbon was seen to be directly influenced by aboveground carbon. Variations in belowground carbon (0.35-1.30) were equally as a result of the capacity of the aboveground carbon across the plots. With a correlation coefficient of 1.00, belowground carbon was seen to be determined by the capacities of aboveground carbon for each of the forest plots. It is hence evident that forest disturbance and degradation affects not just the aboveground capacity but also its belowground carbon capacity. Since ecosystem services exhibit trade-offs and synergies (Peng et al., 2017), the need to manage it more adequately should be more emphasized; especially because the gain or loss of one service could impact the other adversely or otherwise.

Soil carbon estimates varied across the plots for both percentage soil carbon and soil organic carbon (Table 4). Variations in soil carbon across landscapes are mainly due to land use change processes (Dlamini et al., 2016; Lal, 2021) and other natural degradation processes such as erosion (Lal, 2001; 2004). Though soil carbon was not generally influenced by elevation, percentage soil carbon differed across and within ecosystems due to the physical characteristics of the different landscapes. Hence, within the ecosystem, elevation was found to have some influence on its carbon variations (Table 6). Soil organic carbon was not influenced by elevation and is apparently not influenced by edaphic factors. They are mainly defined by exogenous factors such as its geology and then vary across landscapes and ecosystems following management processes and land uses (Lal, 2021). Enhancing its full potential in the provision of ecosystem services would require conservation, sustainable land use and management pathways.

Biomass (AGB and BGB) and soil carbon stocks are veritable ecosystem services that help in mitigating climate change impacts. Ecosystem disturbance and degradation however affects them at different proportions across forest landscapes and largely determines their carbon pool estimates. As climate change impacts on biodiversity and their ecosystem services are on the increase (Sintayehu, 2018; Weiskopf et al., 2020), there is need to reduce disturbances and ongoing degradation in ecosystems. Reducing potential risks of ecosystem and ecosystem service further decline are concerted concerns in the study area and across much of the tropics; especially because of their importance in global carbon sequestration. Such worrisome scenarios however could be effectively addressed by not just designing policies and strategies to enhance effective conservation, but more importantly, ensuring that such is practiced; especially in tropical landscapes known for weak adherence to such policies. Such narratives need to be changed and will require the corporation and coordination of government and relevant stakeholders.

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