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Response of Topographic and Biodiversity Variables on Biomass and Carbon Density in Community Forests of Himalayan Foot-hills

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Abstract

Locality factors such as climatic, topographic, biotic, and edaphic characteristics largely govern the forests' structure and composition and have a vital role in providing forest ecosystem services. The impact of locality factors on biomass production and carbon sequestration of forests varied with sites. The study assesses the responses of different topographic and biotic factors on forests' biomass, soil organic carbon (SOC), and total carbon density (biomass and SOC) in Ghaledanda Ranakhola and Ludi Damgade Community Forests (CFs) of Gorkha district, Nepal. The generalized linear models were used employing the data from 89 sample plots of 250 m^2 size each to see whether there are significant differences between predictor and response variables under consideration. The result showed that forest structure, elevation, the sign of wildlife presence, and the slope has a significant influence on forest biomass and carbon mass. The SOC differ significantly with different elevation ranges and aspects in CFs. The higher the elevation, the more the SOC was found. Similarly, the total carbon density (biomass plus SOC) in forests significantly different with CFs, elevation, the sign of wildlife presence, and topographic slope. Moreover: the southern aspect harbored significantly lower SOC; signs of wildlife presence facilitates the higher carbon density; higher the elevation and steeper the slope the lower the carbon density in the forests and regeneration status, diversity (species richness), aspects showed insignificant influence in total carbon density. The results could provide insights for forests' carbon balance under different attributes of topographic and biodiversity. Replication of similar research covering a broad geographical area could be useful to generalize the findings.

Keywords: Biotic factor; Ecosystem service; Nepal; Species richness; Topographic attribute

INTRODUCTION

The forests are the foundation for all terrestrial ecosystems. Sustainable management of those natural resources not only safeguard biodiversity and ecosystem services but also maintain quality and healthy physical environment (FAO 2019). As Nepal belongs to the sub-tropical region, however, the physio-climatic characteristic allows possessing tropical to alpine climate and corresponding vegetation type (GoN 2014). Despite having almost 45 percent of the forested area of the country (DFRS 2015a), of which more than one-third of forests are managed by the local communities (GoN 2016), their contribution to the national economy is well below double digits (NPC 2019) despite forests provide an enormous intangible contribution in socio-cultural, environmental and biophysical aspects. Moreover, community forests (CFs) in the hills largely focus on protection (Sharma and Acharya 2004) which also hinders the economic conversion of the forests. As Forest Resource Assessment report has given the credits to the CFs as one of the remarkable reason for forests' cover increase in mid-hills (DFRS 2015b), these forests (CFs) are largely lacking management intervention mainly due to limited understanding of governing environmental and anthropogenic factors.

Topographic factors (mainly: slope, aspect, elevation) affect mountain forests through their direct influence on radiation and moisture (Maren *et al.* 2015). These topographic factors are also linked to the biodiversity of ecological communities, including composition and variability of traits of plants and soil organisms in the forest ecosystem (Diaz *et al.* 2009) through governing the composition and structure of the forest. Such enrichment on biodiversity allows wildlife premium readiness funds in addition to carbon conservation and biomass production in the forests in some instances (Dinerstein *et al.* 2012). Moreover, the biodiversity of forested ecosystems has an important role to play for long-term carbon storage (Diaz *et al.* 2009). However, there are still ambiguities and discourses on whether biodiversity and biomass (carbon) can be conserved in the same forests (Maraseni *et al.* 2016). Several studies are in place on the biomass and carbon estimation, and reducing emissions from deforestation and forest degradation (REDD+) monitoring, and assessment issues (eg. Upadhyay *et al.* 2005; Baskota *et al.* 2007; Oli and Shrestha 2009; ANSAB 2011; Pandey et al. 2014a; Pandey et al. 2014b; Pandey and Bhusal 2016) and on forest stand characteristics (Pandey and Pokhrel 2020), carbon stocks and soil properties with topographic factors (eg. Maraseni and Pandey 2014; Maren *et al.* 2015). However, very limited documentation on biomass and carbon dynamics in the region is found due to the lack of reliable data on essential ecological parameters (Upadhyay *et al.* 2005). Moreover, the species-specific disproportionate contribution of carbon in a few species such as of *Shorea robusta* and *Pinus roxburghii* forests type are much documented (DFRS 2015a). However, biomass and carbon assessment on mixed-species forest types are limited (Torres *et al.* 2019). Realizing these facts, the study tried to assess the biomass, SOC, and their relationship with topographic and biodiversity variables in mixed forest types (both broad-leaved and conifer, and naturally regenerated and planted ones) in the foothills of Himalayas, Nepal. The results would be a reference for policy framing for multiple-use forestry in diverse topographic and biodiversity characteristics globally, in general, and in Nepal in particular.

MATERIAL AND METHOD

Study Area

This study was carried out in the Gorkha district that extends between 27°15'-28°45'N and 84°27'-84°58'E, in the Middle hills and High Mountains of Nepal (Figure 1). The district covers an area of 3614.70 km^2, with an elevation ranging from 228 meters to 8,163 meters above sea level (asl). Gorkha possesses five distinct types of vegetation belts according to the altitudinal range, namely; tropical, subtropical, temperate, sub-alpine, and alpine offering a wide array of vegetation. The district receives an average annual rainfall of 1,776 mm and average annual maximum and minimum temperatures were 26.1^0 C and 15.9^0 C, respectively (DDC 2011).

The study was carried out in two CFs, namely: Ghaledanda Ranakhola Community Forest and Ludi Damgade Community Forest. These CFs were chosen for the following reasons; i) community forest was formed 10 years ago and has a good level of experience in forest management intervention; ii) easily accessible; iii) forests exist in the ecological transition – ecotone of tropical and subtropical climate thus would be important for comparison, and iv) forests comprises all sorts of variables intended to consider for the study.

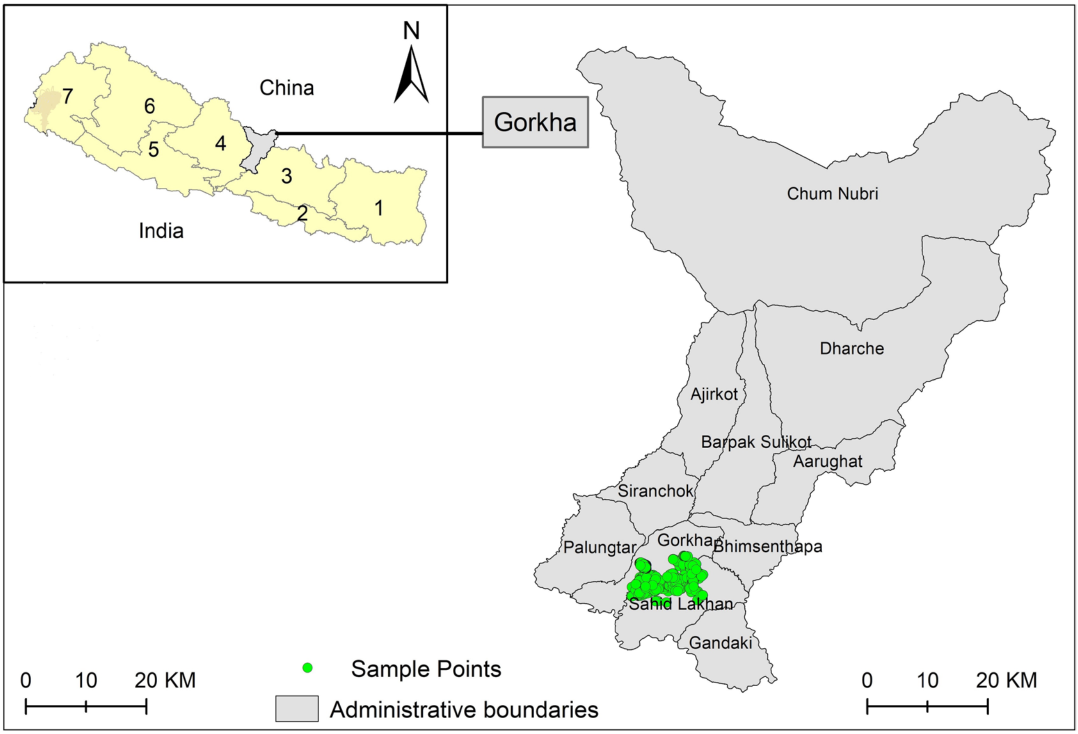

Figure 1: Map Showing the Study Area and Sample Plots [The Digit in the First Map Indicates the Administrative Division of Nepal; 1= Province 1, 2= Province 2, 3= Bagmati Province, 4= Gandaki Province, 5=Lumbini Province, 6=Karnali Province, and 7= Sudurpachhim Province

Ghaledanda Ranakhola Community Forest

Ghaledanda Ranakhola Community Forest was formally handed over to the Ghaledanda Ranakhola Community Forest Users Group in 1998 having 459 households (HHs). This CFUG comprises the majority of indigenous people[1]. The CF covers an area of 194.2 hectares (ha) but this study considered only the area which falls under the Ludikhola sub-watershed (181.7 ha) primarily to ensure a better comparison of responses among the variables. The forest has a sub-tropical climate, facing south-east, south, and south-west, with an elevation ranging from approximately 700 m asl to 1100 m asl. The main species found in the area is *Shorea robusta* (>80% crown dominated) and the understory is dominated by *Schima wallichii* and *Castanopsis indica*. Some mature but unexploited *Schima wallichii* were also common in this forest.

Ludi Damgade Community Forest

Ludi Damgade Community Forest was handed over to the Ludi Damgade Community Forest Users Group in 1993 and comprises 503 HHs of different ethnic groups and castes. The total forest area is 270.7 ha and elevation extends between 650 m asl to 1050 m asl[2]. Forest mainly comprises of four species, namely; *Shorea robusta*, *Schima wallichii*, and *Castanopsis indica* as naturally regenerated stands with *Pinus roxburghii* plantation in small patches. Associated common species found include *Clistocalis species*, *Syzygium cumini*, *Lyonia ovalifolia*, *Wendlandia coriacea*, and *Engelhardtia spicata*. Within this forest, the study considered an 86.9 ha area that falls under Ludikhola sub-watershed.

Sampling Design

Using the random sampling method, concentric circular sample plots of size 250 m^2 were laid throughout the forest-based on the area coverage as prescribed by Subedi *et al.* (2010). To record the elevational range correctly, systematically, five different elevations were taken based on elevational extend of the community forests as mentioned in their operational plans. These elevations were 800 m, 850 m, 900 m, 950 m, and 1000 m, in which 20 sample plots for each elevations were taken except for 1000 m (i.e. 9 plots). Randomisation was made for each plot along the contour up to the required number of sample plots to maintain the standardised distance between the plots for that elevation. By random number of 10m interval starting from 10m and continuously to 100 m, the required number of sample plots for each elevation were located and measured. Altogether 89 plots were sampled in a similar manner covering the total sample area of 2.23 ha in a sampling intensity of 0.83 percent. The main reason for selecting circular plots was that they were easy to layout, covering a greater area with a lesser perimeter which reduces the bias that might arise on border trees (Subedi *et al.* 2010).

Measurements in Plots

Sample plots were laid out using a standardized-length rope stretched from the center of the sampling plot to its periphery. All the trees marked within the inscribed periphery around the center and starting measurement from the north and heading in a clockwise direction. Each tree was recorded, together with its species name. Trees on the border were included if

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1 Ghaledanda Ranakhola Community Forest Users Group Operational Plan 2008

2 Ludi Damgade Community Forest Users Group Operational Plan 2008

>50 percent of their basal area fell within the plot and were excluded otherwise. Diameter at breast height (DBH) was measured for all trees of size greater than 5 cm at 130 cm above the ground-level from the uphill side. The total height of the tree was measured by using Vertex IV and Transponder. Woody species having a girth at breast height (GBH) <16 cm or DBH<5 cm were regarded as regeneration (saplings). A total number of individuals was counted within a 5.64 m radius for saplings and within a 1 m radius for seedlings in nested plots. Woody species with a height of less than 1.30 cm were considered as seedlings. Soil organic carbon was determined by collecting samples from the depth of 30 cm. within a radius of 0.56 m within the sample plots, from three depths, 0-10 cm, 10-20 cm, and 20-30 cm were collected from the center of the plots.

Names of woody species were identified from the researcher's previous experience for familiar vegetations and also collected the herbarium sample from the forests for both known and unknown species. Herbariums were pressed and framed in a standardized wooden frame with all required labeling. For identification, all the collected herbariums were brought to the Central Department of Botany, Tribhuvan University. GPS instrument was used to measure the topographic aspect and elevation of the sample plots. Likewise, Abney's level was used to measure the slope in degree, and woody species richness was accounted for from the record from data collection sheets.

Data Analysis

Biomass density, SOC, and total carbon density data were analyzed using the guidelines published by Asia Network for Sustainable Agriculture and Bio-resources (Subedi *et al.* 2010). The allometric equation for moist forest type "[Above ground total biomass (AGTB) = 0.0509 x pD2H]". was used to estimate the forest biomass density (Chave *et al.* 2005). The biomass stock density of a sampling plot has been converted into carbon stock density using IPCC (2006) default carbon fraction of 0.47 (IPCC 2006). Saplings' biomass was calculated by using national allometric biomass tables (Tamrakar 2000). SOC was calculated using methods as did by Pearson *et al.* (2007). Measurements of root biomass are indeed highly uncertain, and the lack of empirical values for this type of biomass has for decades been a major weakness in ecosystem studies (Geider *et al.* 2001). To simplify the process for estimating below-ground biomass, MacDicken (1997) root-to-shoot ratio of 1:5 was used. Biomass on leaf litters, grasses, dead wood, and stumps in Nepalese forests is less than 1 percent (DFRS 2015a), so they were excluded from the analysis. The field sample was analyzed in the lab to determine the SOC. Lab work was done in the Nepal Agriculture Research Council (NARC) Soil Laboratory, Lalitpur, Nepal. In the laboratory, SOC was analyzed using Walkley-Black's Wet Oxidation method (Walkley and Black 1934). The following models were fitted and tested using primary data.

Mathematically,

$Y_{is} = a_{ijs} + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + a_7X_7 + e_{ijs}$ ... *(Model 1)*

Where,

Yis = Biomass density; SOC density; and Total carbon density; aijs = intercepts; X1= Community forests, X2= Elevation (m asl), X3= Indication/sign of wildlife, X4= Topographic aspect; X5= Slope in degree;

X6= Woody species richness; X7= Total count of recruitment (seedlings plus saplings); and e_{ijs} are the error terms. And a_1, ..., a_7 are constants for corresponding predictor variables.

Response variables such as biomass density, SOC, and total carbon density were tested against individual predictors considering Poisson distribution, and a Chi-square test was carried out. But due to the overdispersion of the data, we used Quasi-Poisson distribution tests fitted with log-linked functions. Final models were tested for each response variable against every predictor variable but the output result showed that there was no significant reduction in the ratio of deviances. Thus, final models were tested for each response variable against the combination of factors as explained in the aforementioned model (Model 1). All these data were analyzed using R and Rstudio (R Core Team 2018) and MS Excel.

RESULTS

Biomass density, SOC density, and total carbon density were taken as response variables, whereas CFs, elevations, an indication of wildlife signs, aspect, slope, regeneration count (seedlings and saplings), and species richness were considered as explanatory variables.

Frequency, Density, and Range of Variables

Overall characteristics of each community-managed forest were briefly described in the study area heading. Here is the synopsis of the forests' characteristics under consideration (Table 1).

Table 1: Basic Characteristics of Forests

Variables	Unit	Quantity	Remarks
Species richness	Unit- average no. of species/ plot	17	Total of 26 woody species recorded
Tree density	Number / ha	1468.8	
Sapling density	Number / ha	2695.8	Recruitment or regeneration
Seedling density	Number / ha	32522	
Biomass density	Tons / ha	151.15	
SOC density	Tons / ha	46.76	
Total carbon density	Tons / ha	117.8	
Elevation ranges of forests	m asl	690 - 1015	
Slope (Vertical angle)	Degree	0 - 45	0-5=plain, 5-15= gentle, 15-30=medium, >30=steep
Sign of wildlife	Absence/Presence	0/1	Fur, hairs, bones, burrow, holes, pellets/dungs, etc.
Aspect (Horizontal angle)	Degree	0-360	North, east, south, west

Biomass Density

Biomass is considered as above-ground biomass and below-ground biomass. For this analysis, the cumulative of both forms are taken into account.

Table 2: Test Outcomes between Biomass Density and Explanatory Variables

Variables	Estimate	Std. Error	P-value
Intercepts	5.080130	0.558658	8.84e-14 *
Ludi Damgade CF	-1.104632	0.668903	0.102781
Elevation at 850 m	-0.359102	0.193072	0.066763
Elevation at 900 m	-0.633305	0.236092	0.008963 *
Elevation at 950 m	-1.541581	0.386183	0.000150 *
Elevation at 1000 m	0.208174	0.714989	0.771724
Indication of wildlife	0.306598	0.151675	0.046758 *
North aspect	0.471577	0.306883	0.128528
South aspect	0.082063	0.240484	0.733863
West aspect	0.229968	0.284518	0.421457
Slope in degree	0.038033	0.011021	0.000915 *
Species richness	-0.058663	0.037538	0.122268
Regeneration status	-0.002782	0.004205	0.510197

Note: Asterisk (*) indicate the significance at the 5% level

Results showed that CFs (Ludi Damgade CF and Ghaledanda Ranakhola CF) had a significantly different level of biomass density, while elevation, presence of wildlife, and slope had a significant influence on the biomass density in the study area. On the other hand, the topographic aspect, regeneration status, and woody species richness have no significant response to the biomass density of the forests (Table 2). The result found that the presence of wildlife had a positive and significant increase in the amount of biomass in the study area. Test results showed a significant reduction of residual deviance (4971.0) of response from environmental variables on 76 degrees of freedom against the null model (9885.8) on 88 degrees of freedom. The dispersion parameter for the Quasi-Poisson family was taken to be 67.55. Residuals' deviances ranged from -20.39 to 19.25 at -1.358 median. The residuals of the final model and the relationship between total biomass densities with significant explanatory variables are presented in Figure 2.

Soil Organic Carbon Density

Results showed CFs (two different CFs), elevation, and aspect had significantly different SOC densities in the study area. However, slope, an indication of wildlife, regeneration status, and woody species richness had no significant response to SOC in the forests (Table 3). Southern aspect harbors the significantly lowest SOC. The responses from the variables on SOC are presented in Table 3.

Table 3: Test Outcomes between SOC Densities and Environmental Variables

Variables	Estimate	Std. Error	P-value
Intercepts	3.9392034	0.1656113	< 2e-16 *
Ludi Damgade CF	-0.2598140	0.1055610	0.01611 *
Elevation at 850 m	0.0712359	0.0677034	0.29605
Elevation at 900 m	-0.1301273	0.0807747	0.11133
Elevation at 950 m	0.2764959	0.0886024	0.00255 *
Elevation at 1000 m	0.3735267	0.1296333	0.00514 *
Indication of wildlife	0.0186954	0.0465643	0.68918
North aspect	0.1081001	0.0859083	0.21213
South aspect	-0.1600675	0.0664451	0.01842 *
West aspect	0.0196641	0.0814381	0.80985
Slope in degree	0.0007436	0.0033823	0.82658
Species richness	-0.0130679	0.0121930	0.28722
Regeneration status	0.0001847	0.0011886	0.87695

Note: Asterisk (*) indicate the significance at the 5% level

The test summary showed a significant reduction of residual deviance (150.24) which indicates that the response from environmental variables at 76 degrees of freedom against the null model (267.76) at 76 degrees of freedom is found to be significant in which dispersion parameter for Quasi-Poisson family was taken to be 1.98 and residuals' deviances were ranged from -2.954 to 2.790 at 0.04 median. The residuals of the final model and the relationship between SOC densities with significant explanatory variables are presented in Figure 2.

Total Carbon Density

Results showed that intercept, elevation, presence of wildlife, and slope have significant influence ($p<0.05$) on total carbon density in the study area whereas CFs, aspect, regeneration status, and woody species richness have no significant response to the total carbon density. (Table 4). Moreover, results revealed that the greater the slopes, the higher the carbon density in the study area. The interrelationship between total carbon density and predictors as topographic and diversity variables is presented in Table 4.

Table 4: Test Outcomes between Total Carbon Densities with Environmental Variables

Variables	Estimate	Std. Error	P-value
Intercepts	4.947824	0.345400	< 2e-16 *
Ludi Damgade CF	-0.543158	0.278410	0.054752
Elevation at 850 m	-0.221023	0.128043	0.088383
Elevation at 900 m	-0.469865	0.155087	0.003344 *
Elevation at 950 m	-0.700800	0.200277	0.000784 *
Elevation at 1000 m	-0.001465	0.319470	0.996354
Indication of wildlife	0.199656	0.095526	0.039956 *
North aspect	0.276825	0.185217	0.139160
South aspect	-0.033399	0.144731	0.818119
West aspect	0.120397	0.173522	0.489896
Slope in degree	0.023142	0.006941	0.001325 *
Species richness	-0.044978	0.024168	0.066609
Regeneration status	-0.001545	0.002581	0.551221

Note: Asterisk (*) indicate the significance at the 5% level

The test result showed the significant ($p < 0.05$) reduction of residual deviance (1542.7) of response from environmental variables on 76 degrees of freedom against the null model (2843.8) on 88 degrees of freedom while the dispersion parameter for the Quasi-Poisson family was taken to be 21.35 and residuals' deviances ranged from -10.61 to 11.83 at -0.559 median. The residuals of the final model and the relationship between SOC densities with significant explanatory variables are presented in Figure 2.

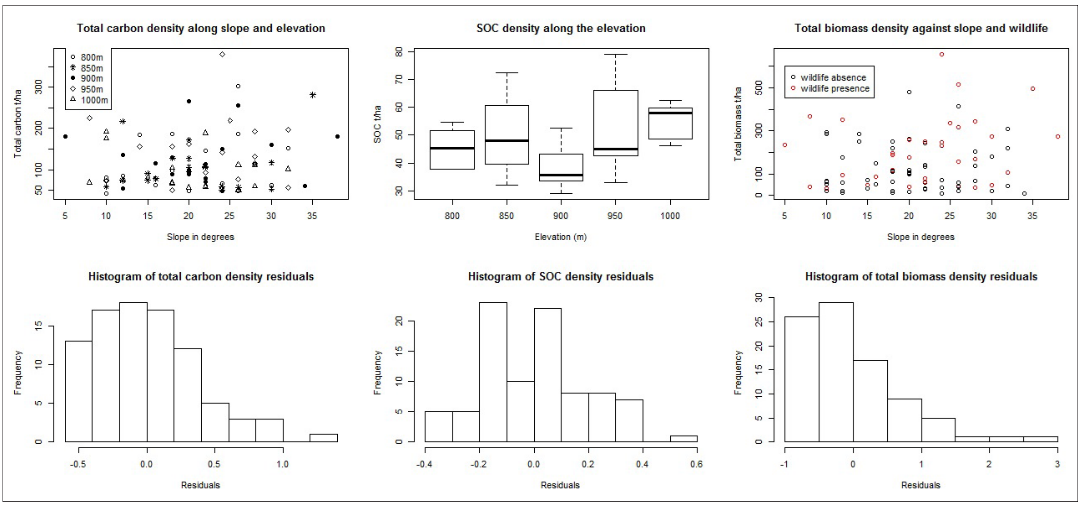

Figure 2 Biomass, SOC, and Carbon Density with Significant Explanatory Variables and the Histograms of Residuals of the Final Model.

DISCUSSIONS

Analysis of Variance test shows biomass density was significantly different ($p < 0.05$) concerning elevation (Table 1). The decreasing trend of biomass density with increasing elevations was attributed to lesser DBH-sized trees at the higher elevations. This result can be compared with the national average of carbon density (176.95 t/ha) (DFRS 2015a) and Middle-hills forests (138.11 t/ha) (DFRS 2015b). Moreover, this result was far less than the finding in the humid tropical forest of the eastern coast of Tamilnadu, India (307 t/ha) (Ramachandran *et al.* 2007), the tropical rain forest of Thailand (275 t/ha) (Terakunpisut *et al.* 2007), broadleaved forests of tropical America (170 t/ha), tropical Africa (260 t/ha), and tropical Asia (215 t/ha) (FAO 2019). The lesser density of carbon was attributed to the sub-tropical vegetation type having smaller-sized trees, frequent removal of biomass from CFs, and methodological differences in the study area.

Results revealed that biomass of high-altitude rangeland has relatively of high critical compared to low altitude rangeland (Limbu and Koirala 2011), however contrasting, this study observed different findings. This may be largely attributed to anthropogenic disturbance factors in our study area. In contrary to these, aboveground biomass varied between 246.8 and 320.9 Mega grams per hectare (Mg ha^{-1}) and did not differ along the gradient ($p > 0.579$) (Torres *et al.* 2019). However, our results show significant variation in carbon stock density despite smaller elevational gradients. This may be due to the ecotone effects and micro-climatic variation in the study. Also, higher elevation comprised of smaller sized trees as a result, relatively lower biomass in the forests was observed primarily because of the high intensity of anthropogenic disturbances. Similarly, biomass stocks did not differ between aspects in an arid zone of Nepal (Maren *et al.* 2015). However, this study finds significantly different stocks due to the different degrees of exposure to sunlight and other resource availability such as soil moisture. Our results indicate that the wildlife presence did not hamper the forest's biomass and carbon stocking rather foster the accumulation of higher biomass by reducing the resource competition by consuming bushes and weeds, forages, and ferns. In addition to this, healthy ecosystem functioning might possess higher productivity and dynamism in the forest ecosystem. The higher the slope, the higher is the biomass because as the slopes increase, difficulties to access the area increases resulting in reduce disturbances in terms of biomass removal.

The wide variation of responses to SOC finds with the predicting variables under consideration (Table 3). Decreasing SOC with increasing altitude from 185.6 to 160.8 C t ha^{-1} and from 141.6 to 124.8 t C ha^{-1}in temperatures *(Quercus leucotrichophora)* and subtropical *(Pinus roxburghii)* forests, respectively was observed (Sheikh *et al.* 2009). SOC varied between 40.3 $Ctha^{-1}$ on the south-west aspect in *Pinus roxburghii* forest in the Himalaya region (Sharma *et al.* 2011). However, soil properties did not vary between slope and aspects, except for potassium (highest in south-facing slopes) (Maren *et al.* 2015) as the soil properties also had a significant effect on the level of SOC in the forests (Pandey *et al.* 2019). The main reason for having low SOC density in the southern aspect may be due to the steep slopes in the south-facing aspect thus allowing the SOC to leach and erode as is seen in most of the Nepalese landscapes including the study area. Also, intense rain during the monsoon season carries away the litters and twigs because of steep slopes compared to relatively stable topographies.

The total carbon stock density has varied responses from predating variables under consideration in the study (Table 4). Similar studies found different results in various parts of Nepal. Studies show that the total carbon density ranged between 77.3 C t ha^{-1} on the south-east aspect of *Quercus leucotrichophora* forest in the Himalayas, Nepal (Sharma *et al.* 2011). This indicates that the similar geographic landscape harbors an almost similar quantity of carbon stocking in the forest ecosystem. However, carbon stocks did not differ between aspects in the trans-Himalayas region of Nepal (Maren *et al.* 2015). But our findings show the difference in the carbon stocking in the forests (CFs). This difference may attribute to the synergy responses such as the different intensity of sunlight, soil moisture availability, wind pattern to receive the precipitation, amount of litter that would be available for humus formation. Consistent with our findings, total carbon density (SOC + biomass carbon) was significantly higher on northern aspects as compared with southern aspects in India (Sharma *et al.* 2011). Likewise, in Tanzanian Montane forests, biomass carbon was normally distributed to tree *species richness and evenness* (Shirima *et al.* 2015). However, there was no significant relationship between carbon density and biodiversity collaborative forests at the Mahottari district of Nepal (Mandal *et al.* 2013).

Our results show the significant effect of species richness on carbon density. This may be due to the intermediate successional stage of forests which indicates that more species compete for the same resources due to high degrees of the crowdedness of the stocking in the area (Table 1). Also, some studies suggest that biodiversity of forested ecosystems has important consequences for long-term carbon storage which allows incorporation into the design, implementation, and regulatory framework of climate change mitigation initiatives (Diaz *et al.* 2009). One of the good examples would be a case in Nepal as the wildlife premium readiness fund would enable the expansion of carbon monitoring pilot programs (Dinerstein *et al.* 2012). In such a situation, the REDD+ mechanism need to emphasize biodiversity conservation as well (Mandal *et al.* 2013; Pandey *et al.* 2014b)

In connection to biodiversity and carbon conservation in CFs of Nepal, the result indicates that both ambitions could be achieved in the same space and during the same time (Table 4). For instance, in REDD+ programs, most of the countries in the Asia-Pacific region are being involved in the implementation of REDD+ through REDD+ readiness and the implementation of national REDD+ strategies (FAO 2019). In line with this, Nepal has the National REDD+ Strategy in place for its implementation (MoFSC/REDD 2015;

Maraseni *et al.* 2020). Through this REDD+ program and strategy implementation, one can address economic, environmental, social, and environmental issues through an effective results-based payment system in carbon credits (FAO 2019; Poudyal *et al.* 2020). Moreover, Dinerstein *et al.* (2012) has proposed three possible options for applying the premium: embed premiums in a carbon payment; link premiums to a related carbon payment as transactions; and linking premiums to non-carbon payments for conserving ecosystem services (PES). However, each option has merits and demerits that incentive payments will improve the livelihoods of rural poor on one hand and challenges the establishment of a subnational carbon credit scheme, on the other (Dinerstein *et al.* 2012). As CFs have significant contributions to the livelihoods of the forest-dependent community, they can also enhance carbon sequestration in vegetation, vegetation diversity, and soil carbon through improved forest management (Upadhyay *et al.* 2005; Poudyal *et al.* 2019).

CONCLUSION AND POLICY IMPLICATION

Under the same management system and same species dominated condition, CFs, elevation, slope, and presence/absence of wildlife has a significant influence on biomass density. Meanwhile, SOC density differs significantly with forests, elevation, and topographic aspects. Results indicate that the steeper the slope, the higher the total carbon density in CFs. Total carbon density significantly decreased with higher elevation. The presence of signs of wildlife has a very positive correlation with the amount of biomass production envisages that biodiversity and carbon can be conserved in a single forest at a time. However, aspect, woody species richness, and regeneration status - recruitments (number of seedlings and saplings) have no significant influence on the total carbon density in CFs. Besides, the presence of wildlife, recruitments, species richness, and slope have little influence on SOC density. This indicates that SOC hardly influences the external factors as mentioned in the forests.

The overall findings suggest that the zonation can be maintained from a carbon and biodiversity conservation point of view considering elevation, tree species, topographic aspect of a forest. In this context, topographic and biodiversity characteristics rather than physical boundaries (eg roads, streams) are to be considered for multiple-use forests in changing scenarios. As the sites having richer in biodiversity has the higher density of carbon signifies that the biodiversity and carbon can be enhanced in a single forest without jeopardizing traditional goods and services from the forests as local communities get. These findings would be a reference for policy framing on the verge of changing context to manage the forests for optimizing ecosystem services with due respect to customary rights of the local communities. Finding suggests that the biodiversity value also should be included in an upcoming carbon deal as a dual conservation objective (carbon and biodiversity) fulfill by the Nepalese forests.

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