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Effects of Silvicultural Treatments on Forest Carbon Stock: A Case Study of Bhudkaya Buffer Zone Community Forest, Bardia National Park, Nepal

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Enhancement of forest growth through silvicultural treatments is one of the various strategies to increase carbon (C) sequestration in forests. This study was carried out to examine the effects of silvicultural treatments on Bhudkaya Buffer zone community forest (BBZCF) in Bardia National park.

The inventory for estimating above and below ground biomass of forest was carried out using stratified random sampling technique. Group discussion was carried out with the members of BBZCF to know the management practices adopted there. The biophysical data were analyzed using statistical analysis. Soil samples were collected from three different depths 0-10, 10-20 and 20-30 cm in order to determine the soil carbon. Total carbon stock was computed by adding carbon stocks of five different forest pools viz; tree, soil, litter, herb and grass, estimated using standard methods for each plot.

BBZCF adopted general silvicultural treatments like thinning, pruning, selective cutting and

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cleaning in 56.98 ha. The aboveground carbon stock in non-treatment blocks for trees, saplings, litter, herb and grass, and root was calculated at 127.38 t ha^{-1}, 0.16 t ha^{-1}, 0.04 t ha^{-1}, 2.65 t ha^{-1}, and 25.48 t ha^{-1}, respectively and in the treatments block it was estimated as 112.65 t ha^{-1}, 0.1 t ha^{-1}, 0.42 t ha^{-1}, 1.31 t ha^{-1} and 22.52 t ha^{-1}, respectively. Soil organic carbon of silvicultural treatments block was estimated 45.99 t ha^{-1} and non-silvicultural treatments block was estimated 36.05 t ha^{-1}.

Keywords: Carbon stock; Bhudkaya buffer zone community forest; silvicultural treatments.

1. INTRODUCTION

Forests play important role in the global carbon cycle. Forest management strategies to promote long-term storage of carbon could include mitigation of ecosystem disturbances, such as fire and other hazards creating carbon emissions, afforestation to increase the area of forest land and silvicultural practices which increase carbon sequestration [1]. Forests store large amounts of carbon in trees, under-story vegetation and soil. The current carbon (C) stock in the world's forests is estimated to be 44% in soil (up to 1-m depth), 42% in live biomass (above and below ground), 8% in deadwood, and 5% in litter [2]. Forest ecosystems can be sources or sinks of carbon [3], depending on the specific management regime and activities [4].

"Silviculture" is defined as the theory and practice of controlling forest establishment, composition, structure, and growth [5]. Silvicultural treatments include both treatments of regeneration to remove the over-story and establish a new tree population or intermediate treatments (thinning from above, thinning from below, and geometric thinning) to improve the existing stand's commercial value and regulate its growth [6]. Enhancement of forest growth through silvicultural modification of stand density is one strategy for increasing carbon (C) sequestration [7]. Some literature suggests that, in non-silviculture treatments forests, the carbon stock increase with stand age as pools of living biomass [8] and soil carbon accumulate through stand development of older stands [9]. It is also said that, wood from harvesting forests is more effective in assimilating and stocking atmospheric carbon than unmanaged forests [10] and has remarkable contribution on storage and sequestration of carbon from the atmosphere [11]. Community forests (CF) play a significant role to reduce carbon in the atmosphere. CF are recognized to have huge reserves of carbon stored in their biomass and in the soil carbon pool where carbon remains sequestered for long durations in the deeper layers [12]. Community forest management is not only restoring and increasing in stocks but also preventing deforestation and forest degradation, in addition generating high incomes and supporting in poverty alleviation [13]. Few studies have reported effects of silvicultural treatments on forest carbon stock in Nepal. Therefore, to fill this void, the present study has the following objectives (i) to show the effects of silvicultural treatments on forest carbon stock (ii) to explore the silvicultural practices in BBZCF, (iii) estimate the above and below ground total carbon stock of silvicultural treatments and non- treatments blocks of BBZCF.

2. MATERIALS AND METHODOLOGY

The study was conducted in BBZCF of Bardia National Park, in the Mid-westen region of Bardia District, Nepal. It lies within 28°07" to 28°39" N latitude and 81°03" to 81°41" E longitude. The average annual temperature ranges between 31-41°C and annual rainfall is about 2075 mm with the maximum rainfall of 204 mm in the month of August [14]. The total area of Bardia National park is 968 km^2 and BBZCF is 1.0692 km^2 (106.92ha). Soils in Terai regions of Nepal are predominantly sandy loam and loam types of soils have been reported [15]. BBZCF is divided into four sections (1 and 2 and 3 and 4) for the effective management of the forest. The forest is dominated by *Shorea robusta*, *Terminalia tomentosa*, *Buchanania latifolia*, *Dalbergia sissoo, Acacia catechu, Syzigium cuminii*, *Mallotus phillippensis*, *Bombax malabaricum*, *Callicarpa macrophylla* and *Murraya koenigii, Adina cordifolia, Casearia tomentosa, Mitragyna parviflora, Saccharum spontaneum, Imperata cylindrica, Erithrina ravennae, Phragmites karka* and *Arundo donax* [16]. The forest management practices information was collected through informal group discussion with the members of the community forest user groups (CFUGs).

2.1 Sampling

Stratified random sampling was applied to collect the bio-physical data. The two strata namely non-silvicultural block, silvicultural block were delineated with maintaining 1% sampling intensity [17]. Altogether, 35 circular sample plots were distributed on the map of the forest. Out of that, 17 plots were allocated for non-silvicultural treatments forest blocks and 18 for silvicultural treatments forest blocks. Next, the center point coordinates of each plot were uploaded in the Geographical positioning system (GPS). Then, the position of the sample plot was found in the field. The sample plot was then laid out with a quadrat size of 250 m2 for tree diameter at breast height (DBH) larger than 5cm. We used nested sample plots of 100 m2 area for saplings less than 5cm and 1 m^2 for leaf litter, herbs and ground vegetation (LHG), according to the forest carbon measurement guideline [18]. Moreover, soil samples were taken in the center of the plot.

Diameter and height of the plant (DBH>5 cm) were recorded while only diameter was measured for saplings (DBH>1-5 cm). Moreover, samples of litter, herbs and grasses were collected and fresh weights were taken. Soils which were taken from different depths (0-10cm, 10- 20 cm, 20-30 cm) with corer and were carried out for lab analysis. A core ring sampler (5.5 cm diameter and 10 cm long) was used for bulk density.

2.2 Biophysical Measurements

Above ground tree biomass (AGTB) was calculated by using AGTB=0.0509 * $\rho D^2 H$ [19] for dbh (sapling, poles and tree)> 5cm Where,

AGTB = aboveground tree biomass (Kg)
ρ = wood specific gravity (gm cm^{-3})
D = tree diameter at breast height (DBH) (cm); and
H = tree height (m)

The above ground sapling biomass having dbh<5 cm was calculated by national allometric biomass tables which was composed by [20],

(ln (AGSB) = a + b ln (D)

where,

ln = natural log (dimensionless)
AGSB = above ground sapling biomass (Kg)
A = intercept of allometric relationship for sapling (dimensionless)
B = slope allometric relationship for sapling (dimensionless)
D = over bark diameter at breast height (measured at 1.3 m above ground) [cm]

Leaf litter, herbs and grass (LHG) were collected then brought to laboratory and oven dried, their dry weight was taken and the biomass was calculated using unitary method.

(LHG=Wfield A× Wsub sample, dry Wsubsmple, wet×1/1000),

Where,

LHG = biomass of leaf litter, herbs, and grass (t ha^{-1})

W_{field}= weight of the fresh field sample of leaf litter, herbs, and grass destructively sampled within an area of size A (g)

A= size of the area in which leaf litter, herbs, and grass were collected (ha);

$W_{subsample\ ,}$dry= weight of the oven-dry sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content (g); and

$W_{subsample,\ wet}$= weight of the fresh sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content (g).

Then, the root biomass was calculated by using root shoot ratio 0.125% [21]. All the total biomass was converted into carbon by the using a conversion factor of 0.47 [22].

Carbon content in the soil was analyzed by Walkley Black Method [23].

Bulk Density (BD g/cc) = (oven dry weight of soil)/ (volume of soil in the core)

SOC= Organic Carbon Content % x Soil Bulk Density (Kg/cc) x thickens of horizon,

Total carbon= total biomass carbon + soil carbon

2.3 Statistical Analysis

The data were analyzed using statistical packages in MS-Excel and R version-3.0.1. Descriptive statistics and hypotheses testing were used to interpret the results. Shapiro test was used to examine the normality of data. Wilcoxon rank test was performed for comparisons of silvicultural and non silvicultural blocks. Due to failure to meet assumptions of parametric tests, non-parametric tests like Wilcox rank test were used.

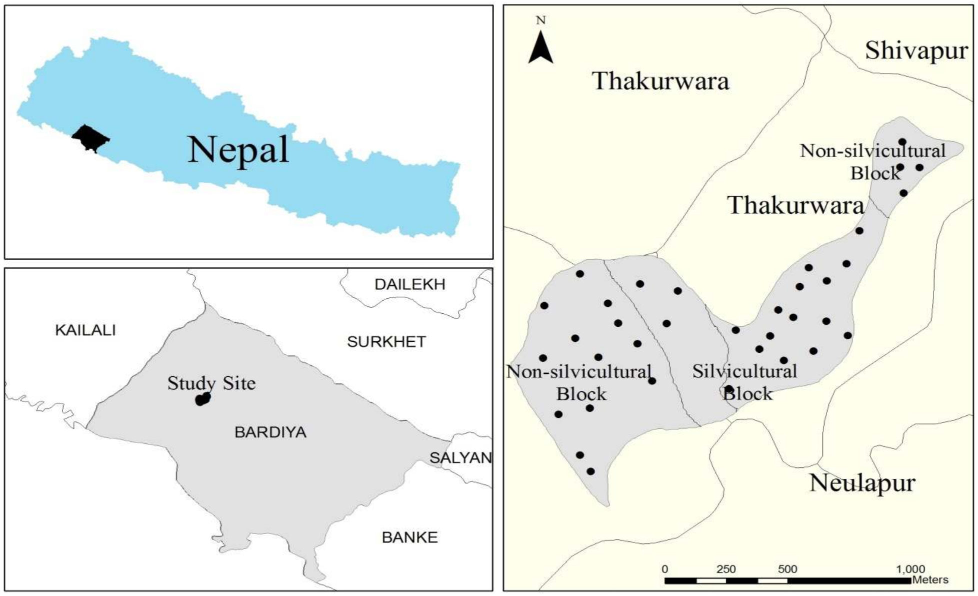

Fig. 1. Map of the study area

3. RESULTS AND DISCUSSION

3.1 Silvicultural Practices

Application of silviculture treatments is to achieve the composition and structure of a forest by enhancing the growth and maintaining the quality of forest [24]. All the members of community forest user group (CFUG) uses forest products. According to the interactions with the user's groups, the condition of forest was very poor before active management by the user's group. The users of Bhudkaya CF have been managing forest according to the operation plans. However, they have concentrated their silvicultural operations in 56.98 ha of total area and 49.94 ha were silvicultural treatments free. The decisions of harvesting intensity and harvesting season were entirely based on the CFUG committee. In India [25] and Ghana [26] different silviculture treatments systems such as coppice, tropical shelterwood, selection, selective felling systems are applied. Selection, clear felling and shelter wood, coppice, and selective felling's, thinning systems are implemented in forests of Nepal [27]. Very limited and not much complex silviculture treatments system, however, has been practiced in BBZCF. The silvicultural treatments and activity includes such as thinning, pruning, weeding/cleaning and selective cutting were done in forests. The practices for manage the forest are as follows:

3.2 Thinning, Pruning, Cleaning and Selective Cutting

Thinning was mostly limited to saplings and trees to maintain a standard spacing between the trees to stimulating better growth. Thinning of the forest was done annually from February to April.

Pruning was used to remove the lower branches of the young trees, to improve the shape of the tree stem as well as increase the clear bole without knots. Similarly, pruning was also scheduled from February to April annually.

Cleaning of the forest floor was done to promote regeneration and control from forest fires. During this operation, when leaf litter, twigs and dead branches were heavily accumulated they were removed from the forest floor. The cleaning of the forest floor was done two times a year in Aswin (September –October) and Chaitra (March-April).

Trees and poles from the forest area were selected and marked by CFUG to produce trees with clear boles and healthy trees. Throughout the selection dead, dying and diseased trees and older and irregular shape trees were selected. Selective cutting of the forest was also done annually from February to April.

3.3 Diameter Size Distribution of Trees

A total of 1242 individuals of tree species were recorded in 35 circular sample plots. The density of the trees in the various DBH classes showed that 68% of the trees within the forest were to greater than 5 cm DBH and 32.04% were classified as saplings. The DBH size distribution of woody individuals showed differences between silvicultural treatments and non-treatments blocks in the community forest (CF). The tree density was found lower in silvicultural treatments block (562 trees per ha) than non-treatments block (680 trees per ha) of the block BBZCF. DBH distribution of trees indicates the forest structure in addition to composition of tree size [28]. Within the forests, number of trees was higher in non- treatments block, in the silvicultural treatments block similar size trees are spread more, this may be the result of different forest management practices such as thinning, planting, pruning. The distribution of the trees DBH within the forest showed the 'reverse J' shaped curve with a steep decline in numbers as size classes increase. The shape of the distribution was similar in both the silvicultural treatments and non- treatments blocks of forest. The reverse-J-shaped diameter distribution might be due to selective cutting of trees, natural mortality, and harvest. Decrease in number of individuals with increase in DBH size classes indicates that the forest is in good regeneration condition, revealing that the BBZCF was a young forest. Young trees absorb carbon at a faster rate than older, mature trees [29]. So the forests with majority of trees in growing stage have large potential to absorb more carbon leading to higher carbon stock.

3.4 Biomass Carbon Stock in Blocks

The carbon stock density would varies according to the geographical location, plant species, age of the stand, above ground input received from leaf litter, decomposition of fine roots below ground, management practices and other operating ecological factors [30]. Biomass in non-treatment blocks of the CF consists of 191.76 t ha^{-1}, whereas it was found 183.66 t ha^{-1} in the treatment blocks of the CF. The aboveground carbon stock in non-treatment blocks for trees, saplings, litter, herb and grass, and root was calculated at 127.38 t ha^{-1}, 0.16 t ha^{-1}, 0.04 t ha^{-1}, 2.65 t ha^{-1}, and 25.48 t ha^{-1}, respectively.

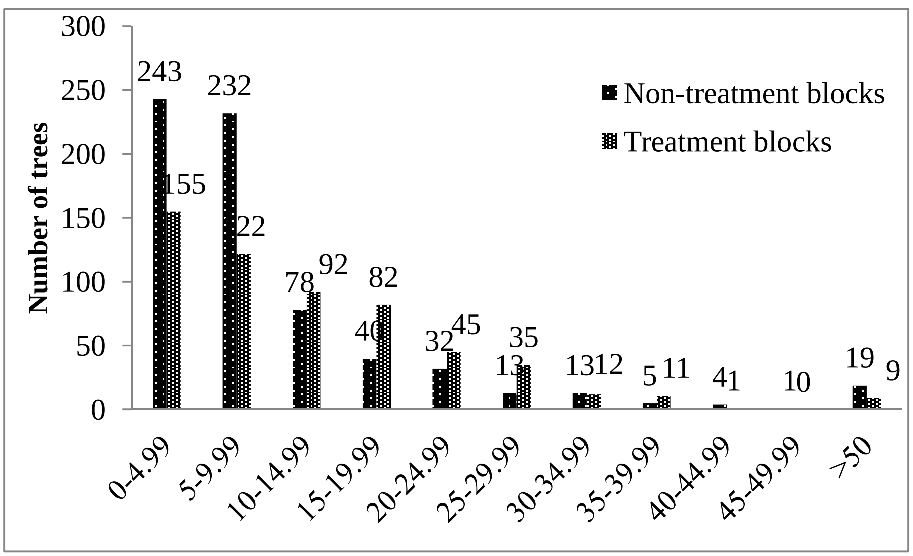

Fig. 2. DBH class distribution of trees within the forests

Table 1. Above and below ground carbon stock of two blocks

Blocks	$ctha^{-1}$						Total
	Above ground				Below ground		
	Tree	Sapling	Herb & grass	Litter	Root	Soil	
Area under Silvicultural treatments	112.65	0.1	1.31	0.42	22.52	46.66	183.66
Non- silvicultural treatments	127.38	0.16	2.65	0.04	25.48	36.05	191.76

Table 2. Average carbon stock and statistical features in Bhudkaya BZCF

Average carbon stock in BBZCF (t ha^{-1})	Mean	Standard error	Standard deviation	Sample variance	Minimun	Maximum
Non-Silviculture Treatments block	92.84	± 18.14	74.79	5595.2	77.38	271.41
Silviculture Treatment block	184.0	±14.91	63.29	4007.42.	76.88	278.84

On the other hand, in treatments block it was estimated as 112.65 t ha^{-1}, 0.1 t ha^{-1}, 0.42 t ha^{-1}, 1.31 t ha^{-1} and 22.52 t ha^{-1}, respectively. Less biomass in the silvicultural treatments block is caused by selective cutting, pruning, thinning and other harvesting practices. Another reason could be that silvicultural treatments blocks of BBZCF has large size trees in lower number, and lower amount of herb and grass The silvicultural treatments sites thinning, selective cutting, pruning has removed older, diseased and trees without clear boles. Thus, silvicultural treatments of forest blocks might result in lower rates of biomass C accumulation. There were a total of 680. There were total 680 woody individuals (437 trees and 243 saplings) in non- treatments block and 569 woody individuals (414 trees and 155 saplings) in silvicultural treatments block. Biomass of the vegetation depends on the diameter of the trees [31]. The lesser biomass is expected due to majority of smaller sized trees and less mass of herb and grass. But in non silvicultural treatments block lesser in litter biomass it may be attributed to lower accumulation of surface litter. It is reported that SOC might be high when there is high growth of vegetation [32]. In contrast, the non- treatments forest blocks have higher biomass but soil organic carbon of silvicultural treatments block (47 t ha^{-1}) is higher than non- treatments block (36.05 t ha^{-1}) in BBZCF.

Increasing production of forest biomass may not necessarily increase the SOC stocks [33]. Litter content was found to be higher in silvicultural treatments block which might have resulted in higher SOC. According to Sevgi and Tecimen release of nutrient from decomposition of litter is a fundamental process in the internal biogeochemical cycle of an ecosystem, and decomposers recycle a large amount of carbon that was bound in the plant or tree to the atmosphere [34]. Forest management activities, especially the harvesting of biomass, has the potential to significantly increase or decrease soil carbon [35]. It is said that forest thinning changes soil temperature, soil water content, and root density and activity, and thus changes soil respiration, which in turn influence soil C cycling [36]. Soil organic carbon in forest soil depends upon forest types, climate, moisture, temperature and types of soil. Low organic carbon in non-treatments block of CFs might be due to low contributions of litter associated with low microbial activity, moisture conditions and organic matter quality.

Total mean carbon stock of both blocks is less than when compared to different forests of Nepal. It is reported values of 65 to 228 t ha^{-1} in the Pokharekhola watershed [37], 314.59 t ha^{-1} of Hill Sal forest of Samikot CF of Parbat [38], (261.8 t ha^{-1}) in Kalidamar CF [39], 279 t ha^{-1}, 197 t ha^{-1} and 202 t ha^{-1} in kharyekhola, Ludhikhola and Charnawati watershed respectively [40]. The differences in carbon density might be variation in density of forests than present study. The lesser carbon density in this study is due to smaller sized trees and low mass of LHG. The present study has dominance of young trees. However present study shows values higher than the values obtained in Newardanda-Kamidanda CF (148.49 t ha^{-1}) [39] and in community managed of Gorkha district (117 t ha^{-1}) [28]. In both Newardanda-kamidanda CF and in community managed forests of Gorkha district, the study was limited only on tree and soil sample excluding the carbon of leaf-litter, herb and grass.

While comparing with international values, mean carbon stock of present study was close with findings of FAO reported a value of 161.8 t ha^{-1} in the world's forests [41] and lower than accounted values (303 t ha^{-1}) in tropical seasonal forest of Southwestern China [42] and 283.80 t ha^{-1} in natural forest of Bangladesh [43] but higher than values of 118.24 t ha^{-1} in subtropical forest of Manipur North-East India [44] and (126 t ha^{-1}) in sub-tropical pine (*Pinus roxburghii*) forests of Pakistan [45]. This dissimilarity in carbon stock may be due to variation in density of forest, species composition, tree DBH, high soil organic carbon and LHG.

3.5 Comparison of Average Carbon Stock

The mean carbon stock of non- treatments forest block was (Biomass + soil) 92.84 t ha^{-1}. It was deviated with value 74.79 from the mean and the sample variance was 5595.2. The value of standard error was 18.14. And minimum and maximum value of this non- treatments forest block was 77.38 t ha^{-1} and 271.41t ha^{-1} respectively. Likewise, the mean of silvicultural treatments forest block obtained by statistical analysis was (Biomass +soil) 184.0 t ha^{-1}. It was deviated with value 63.29 from the mean and the sample variance was 4007.42. The value of standard error was 14.91. And minimum and maximum value of this forest block was 76.88 t ha^{-1} and 278.84 t ha^{-1} respectively.

4. CONCLUSION

BBZCF a CFUG members practiced general silvicultural techniques like thinning, pruning, selective cutting, etc. within limited area for the management of their CF. Both the silvicultural treatments and non- treatments blocks of forests had large tree populations under smaller DBH classes and showed reverse J-shaped distribution. DBH distribution of trees in both blocks indicated that the forest was in immature condition. The result of this research show that carbon stock of non- treatments block forest (191.76 t ha^{-1}) was found to be higher than the silvicultural treatments blocks of forest (183.66 t ha^{-1}). However, the results from the tests reveal that there is no significant difference between silvicultural treatments and non- treatments blocks of Bhudkaya BZCF. Both forests show good biomass and soil carbon sequestration when compared to similar studies. Hence it can be concluded that BBZCF has high potential to sequester carbon. This study has presented that in future CFs can reduce the carbon emission through the sequestration of atmospheric carbon to soil and vegetation and by acting as a natural carbon sink.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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