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Biomass and Carbon Stock in the Sal (*Shorea robusta*) Forest of Dang District Nepal

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ABSTRACT

The study was conducted to find the net carbon stock in the Sal (*Shorea robusta)* forest in Bagdaila Chisapani community forest of Dang district, Nepal. The inventory was done by a stratified sampling technique with 0.5% sampling intensity taking into account the woody plants with ≥ 5cm DBH. A total of 49 sample plots of radius 8.94m and 5.64 were established to measure tree biomass and sapling biomass respectively in the forest. The mean above-ground carbon (AGC) was 160.4 t ha^{-1} and the mean below-ground carbon (BGC) was 24.1t ha^{-1}. The mean total carbon stock in the study area was estimated to be 99.02 t ha^{-1}; of which maximum carbon stock of 143.51 t ha^{-1} was found in block number 5. Sal was the major tree species in the CF. The biomass and carbon content in this forest is found quite low as compared to other studies in the Sal forest and other tropical forests which were due to the presence of tree stands of less diameter and height. This study would be helpful in the long-term management of forests, planning, and research purposes. The data from this study could also be taken as a reference document for the participation of community forests in carbon accounting under the REDD+ scheme in Nepal.

INTRODUCTION

Forests store huge amounts of the global carbon (terrestrial above-ground carbon-80% and below ground carbon-40%) and play a significant function in global carbon balance and cycle (Dixon et al., 1994; Kirschbaum, 2000; Eggleston et al., 2006; Candell and Raupach, 2008; Pan et al., 2011). In the forests, carbon is typically reserved in tree trunks, leaves, foliage, and roots referred to as biomass. And they act as a natural brake for climate change and related issues (Gibbs et al., 2007; Fahey et al., 2010). Carbon is generally accumulated in biomass during the photosynthesis process (Alexandrov, 2007; Suryawanshi et al., 2014). All parts of a plant contain carbon, but the proportion in each part varies extremely. The carbon stock (CS) and biomass in the forests usually differ with species, type, age, canopy cover, stand structure, and altitude (Pandey et al., 2014; Karki et al., 2016; Dar et al., 2017). After the death of plants, biomass reaches the soil as soil carbon. When biomass is destroyed, the carbon is re-discharged to the atmosphere (Banik et al., 2018). Forest biomass provides opportunities for ecological visioning, sustainable forest management, enhancement of ecosystem functioning and services (Pan et al., 2013; Panzou et al., 2018), and help in climate change mitigation (Houghton, 2005; Eriksson and Berg, 2007).

The Kyoto Protocol was formulated in 1997 stating the principle that the soil and biomass can sequestrate CO_2 from the air; which is the real solution for climate change (Harishma et al., 2020). Stopping deforestation alone will lead to a reduction of about 18% of atmospheric CO_2 emissions (IPCC, 2007). Emissions reduction can be achieved through proper management of forests with focused objectives of REDD+ programs (Skutsch and Laake, 2008). According to FAO (2011), about 7% of the forests in the world are managed by communities under community forest management programs. These community-managed forests have enough potential to store carbon (Tripathi et al., 2017).

Tropical forests of the world cover 7-10% of the global land (Raha et al., 2020) but store more than 40% of the terrestrial carbon in the form of biomass (Phillips, 1988). These forests contribute about 34% of the primary productivity in terrestrial lands (Lewis et al., 2013). Tropical forests of Nepal are dominated by *Shorea robusta* (Sal) (Jackson, 1994). It is distributed from Terai to 1500m elevation from sea level (Gautam and Devoe, 2006). Sal covers more than half of the tropical forests in the Terai region (Webb and Sah, 2003). The *S. robusta* forests of Nepal are among the important carbon-storing tropical forests (Shrestha, 2008).

Above-ground biomass (AGB) provides crucial information on several global challenges (Brown et al., 1999). Carbon stock is estimated based on AGB (Ketterings et al., 2001; Cao et al, 2001; Mokany et al., 2006). Carbon storage estimation help to meet information related to greenhouse gas (GHG) reduction (Adme et al., 2020). It is also needed to implement climate change-related strategies and programs (eg. REDD+) (Saatchi et al., 2011; Avitabile et al., 2016). Kyoto Protocol, Paris Agreement, and European Union (Regulation 2018/841) have also appealed to estimate, document, and report carbon, carbon emissions, and extent of deforestation (UNFCCC, 2008; UNFCCC, 2015; Forsell et al., 2018). But, in developing countries, the biomass and carbon stocks in tropical forests are feebly estimated (Behera et al., 2017) and limited due to the lack of atmospheric observations (Kaul et al., 2010; Reichstein et al., 2013; Mitchard et al., 2014).

Also in Nepal, very little researches have been conducted relating to biomass and carbon stock in tropical forests. However, several studies are conducted in various regions of the country (Upadhyay et al., 2005; Nepal, 2006; Baskota et al., 2007; Baral et al., 2009; Subedi et al. 2010; Bhusal, 2011; Pandey and Bhusal, 2016). This study was performed in one of the tropical forests of Dang district, Nepal with the aims of estimating the AGC and BGC and intimately finding out the carbon stocks/content based on the biomass.

MATERIALS AND METHODS

Study area

The study was carried out in Bagdaila Chisapani community forest (BCCF) of Dang district (82^0 2’ to 82^0 54’E and $27^0$37’ to 28^0 36’N) (Figure 1). The district lies in the inner Terai region of Nepal and borders India in the south. It covers an area of 290,251 ha with an altitude range of 213m to 2058 m above sea level. Geographically, the district is divided into two parts i.e. Plain valley (Bhabar) and Siwalik Hills. It is bounded by the outer Siwalik Hills in the south and the Mahabharat hills in the north. Three types of climatic zones are observed in the district i.e. lower tropical (<300m, occupy 18.1%), upper tropical (300-1000m, occupy 69.9%), and subtropical zone (1000-2000m, occupy 12%). The annual precipitation of the district varies between 1584 mm and 2287 mm. The soil is dominated by clay and sandy loam (Pandey et al, 2019). Forests cover the maximum area of the district (over 50%) and the remaining land use are agriculture, water body, and others (Ghimire, 2017). The total population of the district is 552,583 (CBS, 2012). BCF lies in Babai rural municipality. The forest has a total area of 254.6 ha dominated by *Shorea robusta*. Scientific forest management program has been applied in the community forest since 2015; hence the total forest area was assigned into eight blocks.

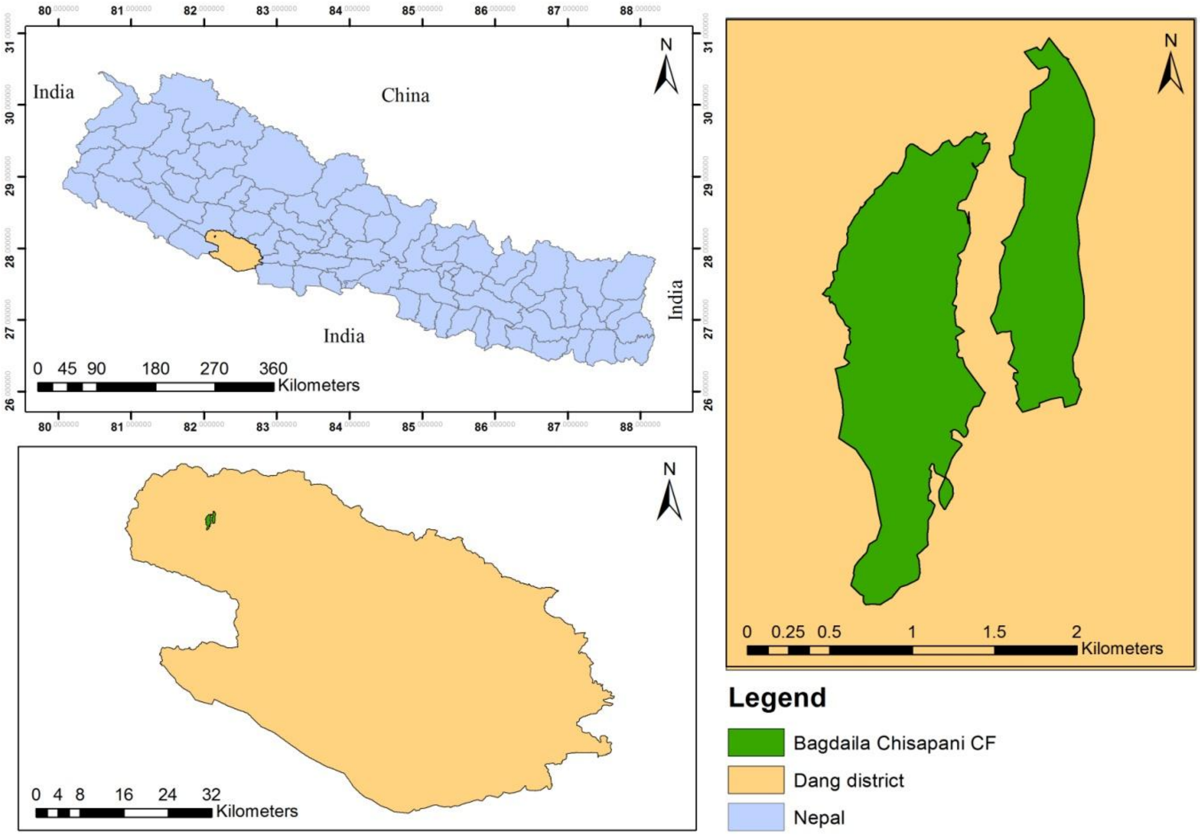

Figure 1: Study area map showing Bagdaila Chisapani CF

Data collection

The primary data was obtained through stratified sampling. The already divided forest blocks during scientific forest management plan preparation were taken as the strata. Total 49 circular plots (0.5% sampling intensity) were prepared in different blocks of the forest. Above-ground biomass for (DBH≥ 5 cm) was measured in the circular plots (r=8.92m). While, above-ground sapling biomass (DBH= 1-5cm) was measured inside nested plots (r=5.64m) (ANSAB, 2010). The total height (H) and diameter at breast height (DBH) of entire trees having DBH≥ 5 cm were measured carefully inside the plots. Secondary data was gathered from several documents obtained and accessed through Google Scholar and Research Gate.

Data analysis

Microsoft Excel was used for the database, simple modeling, and descriptive statistics like percentage, mean and median. The variability in biomass was measured and expressed in the form of the SE (standard error of the mean).

Above-ground tree biomass (AGTB)

It was estimated with the simplified standard regression model where DBH (D), Height (H), and wood density/specific gravity (ρ) were considered for calculation (Chave et al., 2005; Vachnadze et al., 2018; Komolafe et al., 2020).

$$AGTB = 0.0509 * \rho D^2 H \quad (1)$$

(Here, AGTB is in kg, ρ is in g cm^{-3}, D in cm, and H in m). The obtained AGTB value for all individuals of a sapling plot was summed up; then divided by 250 m^2 (sampling plot area). And it was multiplied by 10 to convert into t ha^{-1}.

Above ground sapling biomass (AGSB)

It was estimated with the formula given by (Tamrakar, 2000); which is the logarithmic transformation of the allometric formula.

$$Log\ (AGSB) = a + b\ log\ (D) \quad (2)$$

[AGSB is in kg, a = intercept of algometric relationship (unitless), b = slope algometric relationship (unitless), D is in cm]. (a= -2.4554, b= 1.9026, and R^2= 98.3).

Below-ground biomass (BGB)

$$BGB = 0.15 \times above\text{-}ground\ biomass\ (AGB) \quad (3)$$

Net carbon stock (CS)

It was estimated with the stock method where the total carbon stock/content is supposed to be 47% of the total dry biomass (DB) (Eggleston et al., 2006).

CS = Total DB of the tree x 47% (4)

RESULTS AND DISCUSSION

Forest Biomass

The BCF was divided into a total of eight blocks. The average total biomass of the BCCF was 184.4 t ha^{-1}. There was an average of 263 stems ha^{-1} with a mean DBH of 17.1 cm. The highest number of stems per ha was found at block number 3 followed by block number 7. There was an average of 1421 saplings ha^{-1} with a mean DBH of 4.2 cm. Block number 5 has the highest tree biomass (305.3 t ha^{-1}) followed by block numbers 4, 3, 7, 1, 8, 2, and 6. The result for the total AGB and BGB also follows the same trend in different blocks (Table 1).

Table 1. Biomass in different blocks

Blocks	Tree characteristics					Sapling characteristics			AGB		BGB	Total Biomass
	No of Stems Per ha	Mean DBH (cm)	Mean Height (m)	Tree Biomass (t/ha)	SE	No of Sapling Per ha	Mean dbh (cm)	Sapling Biomass (t/ha)	Total AGB (t/ha)	SE	Below ground biomass (t/ha)	
1	286	17.3	11.5	154.2	12.3	1254.0	4.9	0.95	155.1	12.3	23.3	178.4
2	285.0	14.8	10.5	103.4	14.5	2123.9	4.6	0.98	104.3	14.5	15.6	119.9
3	305.0	18.5	11.6	177.9	15.2	1256.0	4.8	0.82	178.7	15.2	26.8	205.6
4	215.0	19.2	11.5	189.9	9.6	944.0	3.8	0.50	190.4	9.6	28.6	219.0
5	236.0	20.3	14.3	264.7	7.2	1434.0	4.1	0.83	265.5	7.2	39.8	305.3
6	252.0	13.3	11.5	91.7	13.8	1345.0	3.1	0.49	92.1	13.8	13.8	105.9
7	304.0	17.6	12.2	169.3	10.5	1523.5	4.3	0.83	170.1	10.5	25.5	195.6
8	222.0	15.8	11.3	125.9	13.0	1492.0	4.2	0.81	126.6	13.0	19.0	145.6
Average	**263.6**	**17.1**	**11.8**	**182.4**	**12.0**	**1421.0**	**4.2**	**0.7**	**160.4**	**12.0**	**24.1**	**184.4**

Total carbon stock

The total CS in the BCCF was 99.02 t ha^{-1}. The highest CS was in block number 5 (143.51 t ha^{-1}) followed by block numbers 4, 3, 7, 1, 8, 2, and 6. The area of the BCCF is 254.6 ha. Thus, the total CS is estimated to be 25,210.49 tones (Table 2).

Table 2. Carbon content in a different block

Blocks	Above Ground Carbon				Below Ground Carbon (t ha^{-1})	Total Carbon (t ha^{-1})
	Tree (t ha^{-1})	Sapling (t ha^{-1})	Total (t ha^{-1})	SE		
1	72.46	0.44	72.90	5.80	10.93	83.83
2	48.61	0.40	49.01	6.83	7.35	56.37
3	83.61	0.39	84.01	7.16	12.60	96.61
4	89.25	0.24	89.49	4.53	13.42	102.91
5	124.43	0.37	124.79	3.38	18.72	143.51
6	43.08	0.20	43.29	6.47	6.49	49.78
7	79.56	0.39	79.94	4.91	11.99	91.93
8	59.16	0.35	59.51	6.10	8.93	68.44
Average	**85.74**	**0.35**	**86.08**	**5.65**	**12.91**	**99.02**

The CS and biomass in the forests differ with species, type, age, canopy cover, stand structure, and altitude (Pandey et al., 2014; Karki et al., 2016; Dar et al., 2017). In the present study, the total CS is varied from block to block. A study carried out by Gautam and Mandal (2016) in the Sunsari district found that the plant biomass for the undisturbed forest was greater (960.4 t ha^{-1} or 452.06 t C ha^{-1}) than the disturbed forest (449.1 t ha^{-1} or 211.33 t C ha^{-1}); where the stand density for the disturbed forest was 234 stems ha^{-1}. (Ngo et al., 2013) have found the total carbon content higher in the primary forest (337 t C ha^{-1}) than in the secondary forest (274 t C ha^{-1}). Mandal et al., 2013) has found CS higher in Gadhanta-Bardibas CFM (274.66 t ha^{-1}) than in Banke-Maraha CFM (197.10 t ha^{-1}); both of the forests have *Shorea robust* as the dominants species in the Mahottari district of Nepal. Bohora *et al.* (2021) has estimated the total biomass of 1381.30 t ha^{-1} and CS of 649.21 t ha^{-1} in *Shorea robusta* and *Schima wallichi* forest of Makwanpur district. In the research conducted by Ghimire (2017) in the Danphe community forest of Dang district, the average CS was 62.34 t ha^{-1} in 2013 whereas; it was 64.86 t ha^{-1} in the year 2014. The CS is greater in this study as compared to Ghimire (2017). In the Kayerkhola watershed of Chitwan district (dominated by the *Shorea robusta* forest), the sparse area had 89.2 t C ha^{-1} while the dense area had 129.0 t C ha^{-1} (Pandey et al., 2014). The estimated total biomass and CS are quite higher than in our study. Our study area had an immature forest having tree species with small DBH and height which is 17.1 and 11.8 respectively on average. This might be the cause for lower biomass and CS in BCCF.

As compared to the average carbon stock (285.0 t ha^{-1}) of the tropical forests in the world, the Terai regions of Nepal consist of a huge amount of organic carbon (479.29 t ha^{-1}) (Jina et al., 2009). But it is lower when compared with the CFs of Nepal (Charmakar et al., 2021). For the accurate estimation of forest biomass and CS, it requires a precise calculation of both AGB and BGB (Gautam and Mandal, 2016). There was considerable variation in biomass and carbon stock at different blocks. There is variation in the size of the trees in different blocks and CS was found different. The BCCF is a growing forest with small-diameter trees. Thus, the biomass and carbon content in this forest is found quite low as compared to other studies in *Shorea robusta* forest and tropical forest. There is a need to carry studies on a site-specific basis representing different types of forest and conduct growth modeling to ensure the future amount of carbon.

CONCLUSION

This study has assessed the biomass and CS in the BCCF which was estimated to be 184.4 t ha^{-1} and 99.02 t ha^{-1} respectively. A total of 143.51 t ha^{-1} carbon was found in block 5, which was the highest among all blocks. The lowest (49.78 t ha^{-1}) carbon stock was found in block 6. The difference was found due to the presence of trees of higher diameters, with a higher number of trees per ha. The biomass and CS in the BCCF were found distributed in the order of tree, root, and sapling. The forest is concluded to be a growing forest having a relatively small diameter and height; it is suggested to properly manage the forest with different management operations as it has a high potential to sequester a large amount of carbon in the future. This study will help to design the block-wise different potential management inventions which can be done to enhance the quality and productivity of the forest in the future.

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