Carbon Sequestration in Broad Leaved Forests of Mid-Hills of Nepal: A Case Study from Palpa District

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Abstract

This study was carried out to quantify total carbon sequestration in two broad leaved forests (Shorea and Schima-Castanopsis forests) of Palpa district. The inventory for estimating above and below ground biomass of forest was carried out using stratified random sampling. Biomass was calculated using allometric models. Soil samples were taken from soil profile upto 1 m depth for deep soil and up to bed rock for shallow soils at the interval of 20 cm. Walkey and Black method were applied for measuring soil organic carbon. Total biomass carbon in Shorea and Schima-Castanopsis forest was found 101.66 and 44.43 t ha^{-1} respectively. Soil carbon sequestration in Schima-Castanopsis and Shorea forest was found 130.76 and 126.07 t ha^{-1} respectively. Total carbon sequestration in Shorea forest was found 1.29 times higher than Schima-Castanopsis forest. The study found that forest types play an important role on total carbon sequestration.

यो अध्ययन पाल्पा जिल्लाको दुई फरक चौडापाते वनको कुल कार्वन संचितिकरणलाई निर्धारण गर्नकोलागि गरीएको हो । वनको जमिन माथि र तलको वायोमास अनुमान गर्नका लागि गरिएको सर्वेक्षण, नियमित स्याम्प्लीङ विधि अपनाई पूरा गरिएको थियो । बायोमास अलोमेट्रिक विधि अपनाई निकालिएको थियो । माटोको कार्वन मात्रा निर्धारण गर्नको लागि माटोको नमूनाहरु माटोको तहबाट लिइएको थियो, जसमा नमुना गहिरो माटोको लागि १ मिटर गहिरोसम्म र सतही माटोको लागि भुईं ढुङ्गासम्म २० सेन्टिमिटरको अन्तरमा लिइएको थियो । माटोको जैविक कार्वन मापनको लागि walkey and black विधि अपनाईएको थियो । साल र कटुस-चिलाउने वनको कुल कार्वन बायोमास क्रमानुसार १०१.६६ र ४४.४३ टन प्रति हेक्टर पाइएको थियो । कुल कार्वन संचितिकरण चिलाउने कटुस वनमा भन्दा साल वनमा १.२९ सङ्ख्याले बढि पाईएको थियो । यस अध्ययनले कुल कार्वन संचितिकरणमा वनको किसिमले प्रमुख भूमिका निर्वाह गर्छ भन्ने तथ्य उजागर गरेको छ ।

Key Words: Carbon sequestration, *Shorea* forest, *Schima-Castanopsis* forest, Biomass carbon, Soil carbon

Background

Forests play an important role in the global carbon cycle. They can be both sources and sinks of carbon, depending on the specific management regime and activities (IPCC, 2000). It is believed that the goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown et al., 1996). Forest vegetation and soils share almost 60% of the world's terrestrial carbon (Winjum et al., 1992). Vegetation and soils are viable sinks of atmospheric carbon (C) and may significantly contribute to mitigation of global climate change (Bajracharya et al. 1998; Lal, 2004). Estimating stock of carbon under existing forest land, and their distribution within

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the soil profile, provides baseline data to enable us to project carbon sequestration over time. The carbon stock in a forest ecosystem can be broadly categorized into biotic (vegetative carbon) and pedologic (soil carbon) components. As trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases, the atmospheric CO_2 is mitigated. About 43-50% of the dry biomass of trees is carbon (Malhi et al., 2002; Negi et al, 2003). Soil contains the major part of carbon in terrestrial ecosystems. Trees, both in above and below ground biomass, continue to accumulate carbon until they reach maturity; at that point about half of the average tree's dry weight will be carbon (Anonymous, 2004). On the other hand, trees are long-lived plants that develop a large biomass, thereby capturing large amounts of carbon over a growth cycle of many decades. Thus, forests can capture and retain large amounts of carbon over long periods. These stocks are dynamic, depending upon various factors and processes operating in the systems, the most significant being land use, land-use changes, soil erosion, and deforestation (IPCC, 2000).

The carbon stock in forest vegetation varies according to geographical location, plant species and age of the stand (Van Noordwijk et al., 1997). Estimates of the biomass contained within forests are critical aspects of determination of the carbon loss associated with a wide range of land use and land-cover change processes. In order to assess the impact of deforestation and re-growth rates on the global carbon cycle, it is necessary to know the stocks of carbon as biomass per unit area for different forest types. The aboveground biomass and belowground root biomass both need to be measured to enable better calculations of total forest carbon (Hamburg, 2000).

Community Forestry has been accorded the highest priority of Nepal's forestry sector and has been widely acclaimed as a successful forest management approach. During the last 30 years of community forestry implementation, more than 25% of the national forest area is being handed over to more than 14,200 community forest user groups (Kanel, 2006). Forest users groups are protecting community forests for about last 30 years, but forest and soil inventory has been paid little attention regarding the carbon that it sequestrated, hence amount of soil and biomass carbon sequestrated is unknown. Fortunately, Nepal is first among the developing countries which have been selected by the World Bank as a member of the Forest Carbon Partnership Facility (FCPF), an innovative approach to financing efforts to combat climate change (www.worldbank.org). Nepal will receive initial funding from FCPF to Reducing Emissions from Deforestation and Forest Degradation (REDD). Therefore, this study aims to establish the base line information for carbon sequestration potential of different community managed broadleaved forests which is one of the key requirement of REDD, rarely done in Nepal.

Materials and methods

Study area

The study was carried out in two different community managed forests (Bharkes, and Bajha) of Palpa district. Palpa lies between $27^0$14' to $27^0$57' N latitude and $83^0$15' to $83^0$45'E longitude, and is 300 km west from the capital city of Nepal. The district's terrain lies in the Mahabharata and Siwalik ranges. Bharkes and Bajha Community forest lie in the central part of Palpa district. Bharkes is a natural *Shorea robusta* forest which covers an area of 190 ha whereas Bhaja is natural *Schima-Castanopsis* forest which covers an area of 45.0 ha. The management practices implemented in these community forests are thinning and pruning.

Sampling design

Stratified random sampling was used for collecting data for plant biomass. Sixteen and eight sample plots were taken in *Shorea robusta* and *Schima-Castanopsis* forest respectively. The quadrate of size 20 m x 25 m for trees (>30 cm dia), nested quadrate of size 10 m x 10 m for poles (10-29.9 cm dia), 5m x 5m for sapling (>5 cm dia) and 1m x1m for regeneration, grass and herb were laid out for collecting biophysical data. Tree species whose height is below than 1 m and diameter less than 5 cm were considered as shrub (Shrestha and Singh, 2008).

Biophysical measurements

Diameter at breast height of each tree within each plot was measured using diameter tape and height of each tree was estimated using Sunto Clinometer and Abney's level. For woody shrubs, diameter was measured at 15 cm above the ground level (Shrestha and Singh, 2008). All under storey bushes, grasses and herbaceous plants were clipped and the fresh weight of the samples were determined and representative sub sample of 300 gm was taken to lab for oven dry.

Soil sampling

Profile was dug at centre part of the plot up to 1m depth for deep soils and up to bed rock for shallow soils. Soil samples at different depths (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm) were taken. A core ring sampler (4.8 cm in dia. and 6 cm long) was used for bulk density.

Data analysis

Aboveground biomass

The logarithmic transformation of the algometric formulae were used in estimating volume and biomass. The total stem volume of each tree was calculated using the relationship developed by Sharma and Pukkala (1990).

$\ln(V) = a + b * \ln(d) + c * \ln(h)$

Where, V = the total stem volume with bark, d = the diameter at breast height (cm), h = the tree height (m), and a, b, & c are species specific constants shown in Table-1.

Table 1: Parameter a, b and c, and R^2 for major tree species

SN	Types of Species	a	b	c	R2
1	*Shorea robusta*	-2.4554	1.9026	0.8352	98.3
2	*Schima wallichii*	-2.7385	1.8155	10.072	98.3
3	Miscellence in hills	-2.3204	1.8507	0.8223	97.7

Source: Sharma and Pukkala, 1990

After calculating volume of the tree, it was multiplied by the dry density of the wood (Chaturvedi and Khanna, 1982) of the species to get the above ground biomass. The biomass of branches and leaves were estimated using 45 and 11 % of the stem biomass respectively (Sharma, 2003).

Under-growth biomass

Oven dry biomass values for litter, under storey bushes and grasses were calculated using the following formula (Lasco et al., 2005):

$$ODW\ (t) = \frac{TFW - (TFW*(SFW-SODW))}{SFW}$$

Where,

ODW = Total oven dry weight, TFW = Total fresh weight

SFW = Sample fresh weight, SODW = Sample oven dry weight

The biomass of woody perennial shrubs was calculated using the equation developed by Hasse and Hasse (1995):

$Y = a D^b$

Where Y is the total dry biomass (kg), D is the dia. 15 cm above the ground (cm) and *a* and *b* are constants whose values were considered as -4.264 and 1.016 respectively, and with a correction factor of 1.0232 (Hasse and Hasse, 1995).

Belowground biomass

For the study, following relationship suggested by FAO (2000) was used for estimating the root biomass.

- ***For broad leaved vegetation***

Below ground biomass= 0.30 x above ground biomass

- ***Soil organic carbon (SOC)***

The Walkey-Black method was applied for measuring the soil organic carbon (McLean, 1982). Total soil organic carbon was calculated using the formula given below (Awasthi et al., 2005).

SOC= Organic carbon content % x soil bulk density (kg/m^3) x thickness of horizon (m)

- ***Bulk density***

Oven dry weight of soil samples determined for moisture correction. The dried soil then was passed through a 2 mm sieve, the sieved soil was weighed and volume of stones was recorded for stone correction. Following formula was used to calculate the bulk density using stone correction (Pearson et al., 2005).

$$\textit{Bulk density } (g / cm^3) = \frac{\textit{Oven dry mass } (g/cm^3)}{\textit{Core volume } (cm^3) - \dfrac{\textit{Mass of coarse fragments } (g)}{\textit{Density of rock fragment } (g/cm^3)}}$$

Where, the coarse fragments are > 2mm. The density of rock fragments is 2.65 g/cm^3.

Estimation of net carbon content

Total carbon was taken to be 43% of the biomass (Negi et al., 2003). The following formulae were used for computing total above and below ground biomass organic carbon.

Total above ground biomass organic carbon= (total above ground biomass of tree + total under storey biomass + shrub biomass) * 43%

And,

Total belowground biomass organic carbon= (total root biomass of tree) * 43% + total soil organic carbon.

Results and discussion

Properties of forest stand

The mean diameter (14.27 cm) of the stand was high in Bajha (*Schima-Castanopsis)* forest and but large tree (diameter 39.0 cm and height 15.1m) was observed in Bharkes (*Shorea robusta)* forest (Table-2). Tree density was high in Bharkes (*Shorea robusta)* forest (3,057 trees/ha). The Bajha (*Schima-Castanopsis)* forest contained relatively smaller stands (1,237 trees/ha) compared to *Shorea* forest types (Table-2).

Table 2: Properties of forest stand

Types of Forest	No. of stem/ha	Diameter (cm)			Height (m)		
		Mean	Min.	Max.	Mean	Min.	Max.
Shorea Forest	3,057	11.11	5.0	39.0	9.75	3	15.1
Schima-Castanopsis Forest	1,237	14.27	5.0	24.50	10.03	4.1	13.5

Aboveground biomass estimation

The biomass of tree and undergrowth vegetation varies with species, aspect and elevation. Result showed that aboveground tree biomass was found high in *Shorea* forest (177.24 ± 38.88 t ha^{-1}) and low in *Schima-Castanopsis* forest (76.65 ± 15.78 t ha^{-1}) (Table 3). Total aboveground tree biomass was in the order of *Shorea* forest > *Schima-Castanopsis* forest. Undergrowth biomass was high in *Shorea* forest (6.05 ± 1.26 t ha^{-1}) and low *Schima-Castanopsis* forest (3.75 ± 0.52 t ha^{-1}).

Table 3: Distribution of aboveground biomass in two broadleaved forests

Types of Forest	Tree biomass (t ha^{-1})		Undergrowth biomass (t ha^{-1})		Total (t ha^{-1})	No. of plots
	Mean	SE	Mean	SE		
Shorea Forest	177.24	38.88	6.05	1.26	183.29	16
Schima-Castanopsis Forest	76.65	15.78	3.75	0.52	80.4	8

Aboveground carbon sequestration

Total aboveground carbon sequestration was high in *Shorea* forest (78.80 t ha^{-1}) and low in *Schima-Castanopsis* forest (34.55 t ha^{-1}) (Table 4). Larger vegetation carbon sequestration was found in *Shorea* forest and smaller sequestration in *Schima-Castanopsis* forest, which is related to the size and height of tree stands and tree density. The tree density and tree size (dbh and height) were higher in *Shorea* forest compared to *Schima-Castanopsis* forest. Various factors affect ecosystem carbon stocks, including net primary productivity of plants and biomass decomposition (Shrestha and Lal, 2006). Net primary productivity differs according to vegetation type, age of the stand, and the surrounding environment (Shrestha and Singh, 2008).

Table 4: Aboveground carbon sequestration in two broadleaved forests

Types of Forest	Carbon Sequestration (t ha^{-1}) by				Total above Carbon Sequestration (t ha^{-1})
	Stem	Branch	Leaf	Undergrowth	
Shorea Forest	48.85	21.98	5.37	2.60	78.80
Schima-Castanopsis Forest	21.12	9.50	2.32	1.61	34.55

Root biomass and carbon sequestration

Root biomass was high in *Shorea* forest (53.17 t ha^{-1}) and low in Bajha CF (22.99 t ha^{-1}). Similarly, root carbon sequestration was found high in *Shorea* forest (22.86 ± 5.01 t ha^{-1}) and low in *Schima-Castanopsis* forest (9.88 ± 2.03 t ha^{-1}) (Table 5).

Table 5: Root biomass and carbon sequestration by different broadleaved forests

Types of Forest	Root Biomass (t ha^{-1})	Carbon Sequestration by Root (t ha^{-1})	SE Mean	No. of Plots
Shorea Forest	53.17	22.86	5.01	16
Schima-Castanopsis Forest	22.99	9.88	2.03	8

Soil carbon sequestration

- ***Bulk density***

There was large variation in the bulk density (Bd) with respect to depth in the forest soils. There was a gradual increase in the Bd with increase in soil depth in different aspect and elevation. The range of bulk density in two broadleaved forests based on the entire profile (0-100 cm) depths is shown in Table 6. The minimum Bd (0.89 ± 0.057 t m^{-3}) was found at the top soil (0-20 cm) in *Schima-Castanopsis* while maximum Bd (1.148 ± 0.078 t m^{-3}) at the depth of 80-100 cm in *Shorea forest* (Table 6).

Table 6: Bulk density in two broadleaved forests

Soil Depth (cm)	*Shorea* Forest		*Schima-Castanopsis* Forests	
	Mean	SE	Mean	SE
0-20	0.95	0.075	0.89	0.057
20-40	1.01	0.056	0.98	0.086
40-60	1.046	0.068	1.01	0.086
60-80	1.132	0.047	1.06	0
80-100	1.148	0.078	1.19	0

- ***Soil organic carbon (SOC)***

The soil organic carbon in forest soil depends upon forest types, climate, moisture, temperature and types of soil. The SOC was higher at the upper layers and gradually decreased in the soil depth. The Table 7 shows the depth wise distribution of SOC stock in different forests. The maximum SOC (47.26 ± 2.40 t ha^{-1}) was found at the top soil (0-20 cm) in *Schima-Castanopsis* forest and minimum SOC (14.96 ± 2.736 t ha^{-1}) at the depth of 80-100 cm in *Shorea* forest (Table-7). The total SOC was high in *Schima-Castanopsis* forest (130.76 t ha^{-1}) and low in *Shorea* forest (126.07 t ha^{-1}). These results could partly be assigned to the profile depth. This showed that spatial distribution of different forest lands is reflected in SOC stock.

Table 7: Soil organic carbon (t ha^{-1}) in two broadleaved forests

Soil Depth (cm)	*Shorea* Forest			*Schima-Castanopsis* Forest		
	N	Mean	SE	N	Mean	SE
0-20	16	38.02	1.917	8	47.26	2.40
20-40	16	30.11	2.218	8	27.55	1.88
40-60	11	24.17	3.174	7	20.90	2.23
60-80	9	18.81	2.243	2	18.65	1.66
80-100	6	14.96	2.736	2	16.40	0.31

N= number of samples

Total carbon sequestration

Total carbon sequestration was sum of aboveground carbon, root carbon and soil organic carbon.

Total carbon sequestration was found high in *Shorea* forest (227.73 t ha^{-1}) and low in *Schima-Castanopsis* forest (175.19 t ha^{-1}) (Table-8).

Total Carbon sequestration in Shorea forest was found 55% in soil, 35% in aboveground and 10% in root (Table-8). Similarly, Carbon sequestration in *Schima-Castanopsis* forest was found 74% in soil, 20% in aboveground and 6% in root (Table-8).

Table 8: Total carbon sequestration in two broadleaved forests

Carbon Sequestration	CS (t ha^{-1}) in	
	Shorea Forest	*Schima-Castanopsis* Forest
Aboveground Carbon	78.80 (35%)	34.55 (20%)
Root Carbon	22.86 (10%)	9.88 (6%)
Soil Carbon	126.07 (55%)	130.76 (74%)
Total	227.73	175.19

Conclusion

Total biomass carbon sequestration was higher in *Shorea robusta* forest and low in *Schima-Castanopsis* forest. The SOC sequestration was high in *Schima-Castanopsis* and low in *Shorea* forest. Average soil carbon comprised 64.5 % of carbon. Thus, total carbon sequestration in forest vegetation varies depending on forest types. Both forests are good for biomass and soil carbon sequestration. Soil offers a more promising sink for carbon over longer time period under forest cover.

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