CARBON PARTITIONING IN SUBTROPICAL *PINUS ROXBURGHII* FOREST, SOLAN, INDIA

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SHAH S, SHARMA DP, TRIPATHI P & PALA NA. 2014. Carbon partitioning in subtropical *Pinus roxburghii* forest, Solan, India. This study was carried out in subtropical chir pine forests covering 33 compartments in two forest ranges of Solan district of Himachal Pradesh, India. Non-destructive method for biomass estimation was adopted for trees whereas harvest method was used to determine the biomass of understorey vegetation, i.e. herbs and shrubs. The total ecosystem carbon density was 247.87 t ha^{-1}. Carbon partitioning in different components of the chir pine forest ecosystem were ranked in the order of soil layer (190.89 t ha^{-1}) > vegetation layer (51.13 t ha^{-1}) > detritus (5.85 t ha^{-1}). More carbon was recorded in soil than vegetation with a soil: vegetation ratio of 4.4. Less carbon stock in vegetation and detritus may be attributed to the fact that in the Indian Himalayan region, the dependency of communities on forests is causing their over exploitation and degradation. This emphasises the need for the conservation of these forests as a potential contender for carbon credit claims under ongoing international conventions and protocols.

Keywords: Destruction, climate, detritus, disturbance, protocol

INTRODUCTION

The challenge of future carbon (C) cycle research is to understand relationships among the components of the global biogeochemical–climate system. In years to come, there will likely be shifts in C storage by terrestrial ecosystems as small shifts in climate cause imbalances from year to year between production and decomposition respiration. Carbon cycle models that attempt to describe terrestrial processes currently do not include a central feature of the dynamics of the system (Post et al. 1990). Both regional and global C cycles are affected by forests because large amounts of carbon in the form of forest biomass are stored in trees and soil and they are also the source of atmospheric CO_2 when disturbed and released by human activities or natural causes such as fire. The biomass stock present in forests determines the potential amount of C that can be added to the atmosphere or alternatively sequestrated on land when forests are managed for meeting emission targets. Carbon in forests constitutes 54% of the 2200 Gt of the total C pool in terrestrial ecosystems (FAO 2001).

Forest ecosystems store more than 80% of all terrestrial aboveground C and more than 70% of all soil organic C worldwide (Jobbagy & Jackson 2000). The magnitude of forest-atmospheric CO_2 exchange is about seven times the current level of annual global anthropogenic C emissions. From 1850 till 2000, roughly 28–40% of global anthropogenic CO_2 emissions resulted directly from deforestation (Houghton 2010). Disturbances may kill trees, resulting in direct and immediate C transfer to the atmosphere (in the case of fire) and a shift in structural elements from live to dead pools (e.g. leaves to litter, trees to snags or logs and live roots to coarse woody debris). Models usually have a set of algorithms dealing with disturbance-induced C transfer among pools and their impacts on biogeochemical cycles (Liu et al. 2004, Zhao et al. 2009). Most of the accounting procedures are straightforward and similar among different models as the C transferred from any live C pool to its dead C equivalent is generally calculated as the fraction that dies (C transfer coefficient) multiplied by the pre-disturbance live C pool.

Understanding the determinants of forest C storage and allocation in different ecosystem components is important for predicting the response of C balance to climate change and forest management (Pregitzer & Euskirchen 2004). The need for reporting C stocks and stock changes for the Kyoto Protocol has placed additional demands for accurate surveying methods that are verifiable, specific in time and space, and that cover large areas at acceptable cost (Krankina et al. 2004). Deadwood, as a C pool, can account for a substantial fraction of stored C. However, only few studies have provided quantitative features and the length of the turnover in comparison with other C-storing components of the forest ecosystem (aboveground biomass, belowground biomass, litter and soil organic C) (Kueppers et al. 2004). The importance of detritus C accounting is evident from the fact that standing and lying deadwood accounts for about 6% of total C stock in the forest (Ravindranath & Ostwald 2008). This study was a preliminary investigation and could act as a tool to study C partitioning in the rest of the forest ecosystems.

MATERIAL AND METHODS

Study area

The study was carried out in 33 forest compartments of the chir pine working circle in two forest ranges, 12 in Solan and 21 in Dharampur, of Solan Forest Division, Himachal Pradesh. The study area is located between 30° 45' and 31° 10' N latitude as well as 76° 55' and 77° 15' E longitude and has an altitudinal range of 600 to 2260 m above sea level (asl). The climate in this division varies from extreme hot in lower elevations to extreme cold in higher elevations. Temperature in lower areas range between 15 and 36 °C and in higher areas, 0 and 24 °C. Precipitation is received both during the rainy and winter seasons, but the bulk of it is received during the rainy season from the south-east monsoon. The area receives on an average 100 cm annual rainfall. Higher reaches receive a little snow. The topography of the division is mountainous with steep to gentle slopes. The forests of Solan Forest Division are pure and mixed stands of chir pine (Champion & Seth 1968). They lie between 900 and 2100 m asl. Little area above 1800 m asl is inhabited by oak and deodar forests. Low lying areas show widespread population of bamboo and are a transitional zone for *Acacia catechu*. A majority of the population is occupied in vegetable production and is essentially agriculturist. Subsidiary occupations are in towns and as daily paid wage labour in various government departments such as the Forest Department and Public Works Department. Since the population is mainly dependent on agriculture for sustenance, dependence on adjoining state forests for their daily requirements is natural.

Forest inventory measurements

In the year 2011, the number of trees in each diameter class were determined through enumeration of all selected compartments. The diameter at breast height (dbh) was determined using tree callipers. Vegetation analysis was done in the rainy season (August till October) and all trees above 10 cm dbh were included in the enumeration.

The most accurate method for calculating C stocks in tree is by measuring the total biomass. For this purpose, volume over bark and biomass were calculated (Brown et al. 1989, Brown & Iverson 1992, Brown & Lugo 1992, Gillespie et al. 1992). Non-destructive method for biomass estimation was adopted for trees, whereas harvest method was used to determine the biomass of understorey vegetation, i.e. herbs and shrubs. The volume of each compartment was determined from volume factors of chir pine for each diameter class, which were obtained from Sharma (2002). The number of trees of each diameter class was multiplied by the corresponding volume factor for the determination of total volume of each compartment.

Using volume of the stem and wood density, total stem biomass was calculated.

$$\text{Biomass (kg)} = \text{Volume (m}^3) \times \text{specific gravity}$$

For *Pinus roxburghii* the specific gravity used for calculations was 0.491 g cm^{-3} (Rana et al. 1989). The branch, leaf and root biomass of *P. roxburghii* was calculated using biomass expansion factors (Rana & Singh 1989).

Nested plot design was adopted for the collection of understorey biomass data. Biomass of shrubs was estimated by laying down 5 m × 5 m quadrats and for herbaceous vegetation, 1 m ×

1 m. Shoot biomass of all shrubs and herbs in each quadrat was harvested at ground level and root biomass was sampled using 25 cm × 25 cm × 40 cm monolith. All harvested materials were put into labelled bags for further analysis. The monoliths were washed with a fine jet of water on 2.0 and 0.5 mm mesh screens. The shoot and root samples were oven dried at 65 ± 5 °C to constant weight and weighed (Woomer 1999). The biomass was calculated as:

Biomass (g) = dry weight (g)

The C stock of vegetation was determined by multiplying total plant biomass with convertible factor which was representative of the average C content in plant biomass. This convertible factor (0.50) shows that 50% of total plant biomass is equal to C (Koach 1989, Roy et al. 2001).

Detritus C stock determination included three components, namely, standing dead trees, fallen trees and surface litter. Standing dead tree biomass was estimated using 31.62 m × 31.62 m quadrats. Standing dead trees falling in the quadrat were enumerated. In order to calculate the biomass of standing dead trees, such trees were assumed to fall under decay class (0) based on classification by Harmon et al. (1996) and Yan et al. (2006). Then mass of the individual was calculated as:

Mass = volume × density

Fallen tree biomass was estimated using 31.62 m × 31.62 m quadrats. Fallen trees in the quadrat were enumerated. The diameter at 1.3 m from the large end was measured using callipers. In order to calculate the biomass of fallen trees, such trees were categorised in decay class 1–5 as given by Harmon et al. (1996) and Yan et al. (2006). Thus density of a particular decay class was used to calculate mass of the individual fallen tree. Mass of the individual was calculated as follows:

Mass = volume × density

Surface litter was collected within a 1 m × 1 m quadrat. Collected samples were weighed, subsampled and oven dried at 65 ± 5 °C to constant weight, ground and ashed. Ash-corrected dry weight was assumed to contain 45% C. Detritus C content was calculated as the product of dry mass and an assumed C concentration of 50%. Standing dead trees, fallen trees and forest floor C stock were separately calculated and summed to estimate detritus C content of the whole plot. The total C sequestered by soil of these forests was determined by estimating C concentration and bulk density at varying layers (humus, 0–20, 20–40 and 40–100 cm) in each forest site. For determining the C concentration in the soil, the method of oxidisable organic C reported by Walkley and Black (1934) was used.

RESULTS

Carbon stock

The total vegetation C stock (trees + herbs + shrubs) including both aboveground and belowground C was 22,253.43 t, with minimum at D-97 Kiar Tatul (95.57 t) and maximum at D-119 Chabil Ki Dhar II (2213.36 t) (Table 1). Total soil C stock (humus + soil or 0–100 cm layer) was 83,076.05 t, with minimum at D-117 Chabil Ki Dhar IV (473.70 t) and maximum at D-176 Charoti Ki Dhar I (7503.41 t). Total detritus C stock was 2544.94 t, with minimum at D-117 Chabil Ki Dhar IV (12.74 t) and maximum at D-176 Charoti Ki Dhar I (233.70 t). The total ecosystem C stock was 107,874.40 t, with minimum at D-159 Anji III (761.57 t) and maximum at D-176 Charoti Ki Dhar I (9267.08 t).

Carbon density

The mean vegetation C density (trees + herbs + shrubs) was 51.13 t ha^{-1}, with minimum at D-97 Kiar Tatul (21.72 t ha^{-1}) and maximum at D-118 Chabil Ki Dhar III (181.61 t ha^{-1}) (Table 1). Mean soil C density (humus + soil or 0–100 cm layer) was 190.89 t ha^{-1}, with minimum at D-135 Kaldhar I (160.90 t ha^{-1}) and maximum at D-155 Bhallon (211.20 t ha^{-1}). Mean detritus C density was 5.85 t ha^{-1}, with minimum at D-135 Kaldhar I (4.52 t ha^{-1}) and maximum at D-119 Chabil Ki Dhar II (6.99 t ha^{-1}). The total ecosystem C density was 247.87 t ha^{-1}, with minimum at D-135 Kaldhar I (191.34 t ha^{-1}) and maximum at D-118 Chabil Ki Dhar III (379.24 t ha^{-1}).

Soil: vegetation ratio

The highest soil: vegetation ratio was recorded in D-97 Kiar Tatul (9.20) while the lowest in D-118

Table 1 Ecosystem carbon stock of selected sample plots in Solan and Dharampur forest ranges in 2011

No.	Forest	Area (ha)	Vegetation carbon stock (t) (trees + shrubs + herbs)	Soil carbon stock (t)	Detritus carbon stock (t)	Ecosystem carbon stock (t)	Soil:vegetation ratio
Solan forest range							
1	D-93 Nandal Nagali	12.4	361.80 (29.18)	2455.20 (198.00)	70.31 (5.67)	2887.31 (232.85)	6.79
2	D-95 Nagali I	3.6	183.52 (50.98)	698.77 (194.10)	20.12 (5.59)	902.41 (250.67)	3.81
3	D-96 Nagali II	4.0	109.92 (27.48)	779.87 (194.97)	19.84 (4.96)	909.63 (227.41)	7.09
4	D-97 Kiar Tatul	4.4	95.57 (21.72)	879.35 (199.85)	20.33 (4.62)	995.25 (226.19)	9.20
5	D-123 Beola	4.4	255.91 (58.16)	887.33 (201.67)	24.64 (5.60)	1167.88 (265.43)	3.47
6	D-135 Kaldhar I	5.6	145.15 (25.92)	901.02 (160.90)	25.31 (4.52)	1071.48 (191.34)	6.21
7	R-26 Nagali	33.6	1363.43 (40.58)	6669.51 (198.50)	203.28 (6.05)	8236.22 (245.13)	4.89
8	D-92 Deora	25.6	786.62 (30.73)	4546.74 (177.61)	141.57 (5.53)	5474.93 (213.86)	5.78
9	D-94 Nandal	8.4	326.61 (38.88)	1653.60 (196.86)	41.66 (4.96)	2021.87 (240.70)	5.06
10	D-89 Gadhog I	9.2	507.12 (55.12)	1504.52 (163.53)	51.06 (5.55)	2062.70 (224.21)	2.97
11	D-90 Gadhog II	13.2	418.50 (31.70)	2235.25 (169.34)	77.48 (5.87)	2731.23 (206.91)	5.34
12	D-98 Bhawan Ki Dhar	19.2	1347.65 (70.19)	3848.96 (200.47)	120.00 (6.25)	5316.61 (276.91)	2.86
Dharampur forest range							
13	R-36 Anji	10.4	600.35 (57.73)	1825.87 (175.56)	60.11 (5.78)	2486.33 (239.07)	3.04
14	R-49 Gadiar	31.2	1241.53 (39.79)	6149.74 (197.11)	191.26 (6.13)	7582.53 (243.03)	4.95
15	D-117 Chabil Ki Dhar IV	2.4	364.32 (151.80)	473.70 (197.38)	12.74 (5.31)	850.76 (354.49)	1.30
16	D-118 Chabil Ki Dhar III	10.4	1888.78 (181.61)	1997.03 (192.02)	58.24 (5.60)	3944.05 (379.24)	1.06
17	D-164 Maltu III	15.6	744.63 (47.73)	3191.53 (204.59)	86.42 (5.54)	4022.58 (257.86)	4.29
18	D-181 Sirguli Ka Tiba III	25.2	1122.16 (44.53)	4730.08 (187.70)	153.47 (6.09)	6005.71 (238.32)	4.22
19	D 182 Kalath III	25.6	1800.91 (70.35)	5190.70 (202.76)	159.49 (6.23)	7151.10 (279.34)	2.88
20	D-172 Bhog Seri III	4.4	293.93 (66.80)	860.40 (195.55)	24.77 (5.63)	1179.10 (267.98)	2.93
21	D-159 Anji III	3.6	128.71 (35.75)	614.82 (170.78)	18.04 (5.01)	761.57 (211.55)	4.78
22	D-160 Anji I	10.4	340.45 (32.74)	2106.62 (202.56)	54.91 (5.28)	2501.98 (240.58)	6.19
23	D-120 Chabil Ki Dhar I	3.6	459.48 (127.63)	730.35 (202.88)	20.77 (5.77)	1210.60 (336.28)	1.59
24	D-150 Gulhari IV	4.4	157.54 (35.80)	727.51 (165.34)	22.44 (5.10)	907.49 (206.25)	4.62
25	D-152 Gulhari II	8.8	279.38 (31.75)	1500.99 (170.57)	48.84 (5.55)	1829.21 (207.86)	5.37

(continued)

Table 1 (continued)

No.	Forest	Area (ha)	Vegetation carbon stock (t) (trees + shrubs + herbs)	Soil carbon stock (t)	Detritus carbon stock (t)	Ecosystem carbon stock (t)	Soil:vegetation ratio
26	D-153 Gulhari I	5.2	117.48 (22.59)	883.69 (169.94)	25.64 (4.93)	1026.81 (197.46)	7.52
27	D-154 Dawala	12.8	832.16 (65.01)	2579.45 (201.52)	79.23 (6.19)	3490.84 (272.72)	3.10
28	D-155 Bhallon	3.2	192.95 (60.30)	675.84 (211.20)	16.83 (5.26)	885.62 (276.76)	3.50
29	D-162 Maltu II	28.4	1050.97 (37.01)	5082.72 (178.97)	164.15 (5.78)	6297.84 (221.76)	4.84
30	D-163 Maltu I	11.2	627.04 (55.99)	1966.80 (175.61)	65.41 (5.84)	2659.25 (237.43)	3.14
31	D-173 Bohali Ki Chali	10.4	365.53 (35.15)	2016.92 (193.93)	59.70 (5.74)	2442.15 (234.82)	5.52
32	D-176 Charoti Ki Dhar I	38.0	1529.97 (40.26)	7503.41 (197.46)	233.70 (6.15)	9267.08 (243.87)	4.90
33	D-119 Chabil Ki Dhar II	26.4	2213.36 (83.84)	5207.74 (197.26)	184.54 (6.99)	7605.64 (288.09)	2.35
Total		435.2	**22,253.43 (51.13)**	**83,076.05 (190.89)**	**2544.94 (5.85)**	**107,874.40 (247.87)**	**145.56**

Figures in parentheses denote carbon density in t ha^{-1}

Chabil Ki Dhar III (1.06) (Table 1). Overall the soil: vegetation ratio was 4.41 for the chir pine forests.

DISCUSSION

The present study showed a mean vegetation C density (trees + herbs + shrubs) of 51.13 t ha^{-1}. The results were in consonance with that of Manhas et al. (2006) who reported a density of 47.42 t ha^{-1} in temperate Indian forests. A vegetation C density of 53.60 t ha^{-1} was reported in temperate forests of Japan (Fang et al. 2005). The mean vegetation C density was minimum at D-97 Kiar Tatul (21.72 t ha^{-1}), probably due to its proximity to human settlements resulting in higher pressure on the forest resources. It was maximum at D-118 Chabil Ki Dhar III (181.61 t ha^{-1}) because of the dominance of younger age classes (the forest falling in periodic block IV of the divisional working plan) that had higher rate of biomass accumulation and high forest density. Atmospheric C incorporation rates into the biomass or soil tend to decrease with forest age, being higher at young or intermediate ages (Saynes et al. 2005, Ostertag et al. 2008). Young growing forests take up C at high rates, while C uptake in mature forests is balanced by C release from decaying vegetation (USDA 1992).

Mean soil C density was recorded as 190.89 t ha^{-1}. Similar results were reported by Bandana (2011) for the forests of Solan, Himachal Pradesh, who reported a soil C density of 156.64–238.53 t ha^{-1} and Raina et al. (1999) who reported a soil C density of 140.30–261.30 t ha^{-1} in the Garwal Himalaya. The mean soil C density was minimum at D-135 Kaldhar I (160.90 t ha^{-1}) due to the physiographic conditions of the site being steep and rocky and hence not conducive for vegetation growth. It was maximum at D-155 Bhallon (211.20 t ha^{-1}) due to the compartment area being small (3.20 ha) and hence manageable compared with compartments spread over a larger area where there were restrictions on the collection of pine needles on forest floor. The differences among stands in soil C may be due to management effects (Harmon & Marks 2002) or differences in site-specific features such as soil texture (Grigal & Ohmann 1992).

The mean detritus C density was 5.85 t ha^{-1}. A managed conifer forest in northern Ontario, Canada had detritus C density of 1–17 t ha^{-1} (Hunt et al. 2010). In north-western Russia, detritus C density ranged from 1 to 8 t ha^{-1} in young and mature intensively-managed stands (Krankina & Harmon 1995). A detritus C density of 14 t ha^{-1} was recorded in temperate forests on Mount Changbai, north-east China (Zhu et al. 2010). Detritus C density was minimum at D-135 Kaldhar I (4.52 t ha^{-1}). It was maximum at D-119 Chabil Ki Dhar II (6.99 t ha^{-1}) due to the preponderance of older age classes (the forest falling in periodic block I of the divisional working plan). Old-growth forests tend to have more standing dead trees, multi-layered canopies with gaps resulting from the deaths of individual trees and coarse woody debris on the forest floor (Naturally:wood 2011).

The total ecosystem C stock was 107,874.40 t and the total ecosystem C density was 247.87 t ha^{-1} (Table 1). The results were in line with the results of Zhu et al. (2010) who found an ecosystem C density of 237 t ha^{-1} in temperate forests of north-east China. Pregitzer and Euskirchen (2004) recorded an ecosystem C density of 239 t ha^{-1} in temperate forests globally and Liao et al. (2010), 284 t ha^{-1} in natural forests by synthesising 86 published studies of 26 countries The ecosystem C density was minimum at D-135 Kaldhar I (191.34 t ha^{-1}) and maximum at D-118 Chabil Ki Dhar III (379.24 t ha^{-1}) due to high C reserve in vegetation.

In the present study, the total ecosystem C density was 247.87 t ha^{-1} and C partitioning in different components of the chir pine forest ecosystem was ranked in the order of soil layer (190.89 t ha^{-1}) > vegetation layer (51.13 t ha^{-1}) > detritus (5.85 t ha^{-1}). A similar status of C density in an artificial forest ecosystem in Sichuan Province of China was reported where total ecosystem C density was 161.16 t ha^{-1}, being ranked in the order of soil layer (141.64 t ha^{-1}) > vegetation layer (18.47t ha^{-1}) > litter layer (1.06 t ha^{-1}) (Huang et al. 2008).

The mean soil: vegetation ratio was 4.41 for the chir pine forests under study. This meant that soil contained more organic C than vegetation. The results were in consonance with the results of Kumar (2003) who reported more C in the soil than in the vegetation for subtropical subtemperate conditions of Himachal Pradesh and also supported by the study of Bandana (2011) in the forests of Solan, Himachal Pradesh. The highest soil: vegetation ratio was in D-97 Kiar Tatul (9.20) due to low vegetation C stock caused by poor forest density and the compartment covering a small area. It was lowest in D-118 Chabil Ki Dhar III (1.06) due to high vegetation C stock.

CONCLUSIONS

This study indicated that soil C reserves exceeded vegetation C reserves which were more than detritus C reserves in subtropical pine forest. The paucity of land in the wake of rapidly rising human population in a developing country like India points to the fact that conservation of the existing forests of the country which are major pools of C is needed. Emerging debates on REDD and REDD+ also make it mandatory that C accounting studies are conducted at a micro level so that claims for payment of ecosystem services are met.

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