International Journal of Ecology and Environmental Sciences 41 (3-4): 177-188, 2015
ISSN: 0377-015X (Print); 2320-5199 (Online)

Ecosystem Services of Forests: Carbon Stock in Vegetation and Soil Components in a Watershed of Kumaun Himalaya, India

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ABSTRACT

This study was carried out across eighteen forest stands dominated by *Pinus roxburghii* and *Quercus leucotrichophora* forests to understand vegetation patterns and physico-chemical properties of soils in Khulgad watershed (District Almora in Uttarakhand) with a particular focus on carbon stock in vegetation and soil pool. C-sequestration in vegetation pool was also estimated. Oak forests were found rich in species diversity as compared to Pine forests. The above ground biomass of Oak forests (189.8 Mg ha^{-1}) was also computed significantly greater than the Pine forests (119.1 Mg ha^{-1}), and consequently the more carbon stock in vegetation pool (91.1 vs 56.6 Mg ha^{-1}). Also, C stock in soil of Oak forests was found more than twice as compared to Pine forests (171.8 vs 73.7 Mg ha^{-1}). C input to forest floor through litter fall was computed 5.97 Mg ha^{-1} for Oak forests and 4.21 Mg ha^{-1} for Pine forests, and over 98% of this input was accounted for by leaf litter. Thus in terms of total C pool (vegetation + litter + soil), Oak forests (268.87 Mg ha^{-1}) had two times greater C than the Pine forests (134.48 Mg ha^{-1}). However, net primary productivity (NPP) computed for tree layer of Pine forests (9.04 Mg ha^{-1} yr^{-1}) was markedly greater as compared to Oak forests (5.68 Mg ha^{-1} yr^{-1}). Thus C-sequestration rate in Oak and Pine forests was recorded 2.64 Mg ha^{-1} yr^{-1} and 3.96 Mg ha^{-1} yr^{-1}, respectively. Oak forests were also characterized by high SOM, soil moisture, WHC and soil fertility (N, P, K), and all the soil nutrients in these forests decreased with increasing soil depth (0-90 cm). Oak forests should therefore be conserved and maintained to mitigate the climatic change impacts through stocking more C in vegetation and soil pool.

Key Words: Biomass; Biodiversity Index; Forest Floor Litter; Soil C Pool; Khulgad Watershed; Oak and Pine Forests

INTRODUCTION

The Central Himalayan forest vegetation ranges from tropical dry deciduous forests in the foothills to alpine meadows above timberline, and productivity of the intact stands in these forests is comparable to some of the most productive forests of the world (Singh and Singh, 1992). In the mid-montane belt of Uttarakhand state in Western Himalaya, Pine (*Pinus roxburghii*) and Oak (*Quercus spp.)* form the dominant forest vegetation and provide a range of ecosystem goods and services to the inhabitants (Joshi and Negi 2011). These forests have been extensively studied for their structural and functional attributes in both Kumaon (Tiwari and Singh 1985, Upreti et al. 1985, Singh and Singh 1987, Dhar et al. 1997, Rikhari et al. 1990, Singh et al. 2014) and Garhwal Himalayan region (Nautiyal et al. 2004, Anthwal et al. 2006, Kumar and Bhatt 2006, Uniyal et al. 2010 and Sharma et al. 2011). In a seminal paper, Singh et al. (1984) reported that the late successional Oak forests are being replaced by the early successional Pine forests that have implications on the nutrient cycling and structure and functioning of forests in this region. In the recent years carbon stock and carbon sequestration value of these forests has gained much importance as a mitigative tool in the face of climate change (Singh 2007). Thus, earlier studies confined to biomass productivity and soil physico-chemical proper-ties have gradually switched over to C stock and C sequestration potential of forest vegetation in this region (Semwal et al. 2007, Sheikh and Kumar 2010, Sharma et al. 2011, Negi et al. 2012). Moreover, high climatic and topographic diversity coupled with anthropogenic pressure in the Himalayan region demands more data to correctly understand the vegetation attributes and C stocking potential of these forests.

Vegetation influences the physico-chemical properties of soil to a great extent and play an important role in the soil formation (Champion and Seth 1968). It improves the soil structure, infiltration rate, aeration and water holding capacity (Kumar et al. 2004). Soil carbon depends on the aboveground input received from litter and decomposition of fine roots below ground (Rasse et al. 2006). Vegetation and soils are viable sinks of atmospheric carbon and significantly contribute to mitigation of global climate change (Winjum et al. 1992, Phillips et al. 1998, Lal, 2004, Smith 2004). Globally forest vegetation and soils share almost 60% of the terrestrial carbon (Winjum et al. 1992, Woomer et al. 1999, Bohn 1997). About three times more carbon is contained in soils than in the world's vegetation, and soils hold double the amount of carbon that is present in the atmosphere (Sheikh et al. 2009).

Litter fall is an important component of nutrient recycling in forest ecosystems (Melillo et al. 1982, Upadhyay et al. 1989, Hobbie 1992), and its turnover depends upon a variety of factors such as season, vegetation type, soil condition, species composition, age of trees, canopy cover, biotic factors and density of the forest stand (Wairiu and Lal 2003, Rawat et al. 2009, Rawat 2012). Forest vegetation contributes lots of organic matter to the soil in the form of leaves, twigs, stems, flowers and fruits, which after decomposition results in the formation of soil organic matter (SOM) and release of nutrients. Therefore, information on bio-mass productivity of forest ecosystems, litter fall and soil nutrient dynamics, particularly in relation to species composition and forest strata is not only important from the stand point of fundamental ecology, but also relevant for planning conservation and management of forests (Singh and Singh 1987). The objective of this study was to describe vegetation pattern and quantify C sequestration and C stocks in the vegetation and soil pool of the two dominant forests types of Western Himalaya. This study was expected to understand the forest type difference with regards to C sequestration and C stocking and planning conservation and management of these forests to mitigate the impacts of climate change.

STUDY AREA

The study area is situated in Sitlakhet forests (Khulgad watershed) of Almora district in Kumaun Himalaya (between 29^0 34' N latitude and $29^0$33.56' E longitude) ranging from 1782 to 2122 m asl altitude. In this watershed broadleaf Oak (*Quercus leucotrichophora*; Banj Oak) and conifer (*Pinus roxburghii*; Chir Pine) tree species make the dominant forests and occupy 36 km^2 area of the watershed. In the Kumaun Himalayan region Oak (Genus *Quercus*) forms the climax vegetation between 1000-3600 m asl, while Chir (Genus *Pinus*) forests occur at lower altitudes (1000-1500 m asl), having low total species richness of shrubs and herbs. There is a great altitudinal, slope and aspect variations in this watershed that produces a diversity of climate and occurrence of forest vegetation. Rainfall in the study area varies from 1000 mm in lower altitudes to 2000 mm per year in the higher altitudes. This region has a short monsoon season from July to August, and fairly long dry season from November to April, with occasional snow fall in the high hills during winter. The local people depend upon these forests for a variety of biomass needs such as fuelwood, fodder, leaf litter for manuring cropfields, wild edibles and raw material for cottage industries. Thus these forests face biotic pressure of various magnitudes year-round.

METHODOLOGY

Vegetation Analysis

In this watershed nine quadrats were laid randomly in nine representative stands separately for both the forest types for estimation of selected tree layer structural and functional attributes during peak growing season of 2014. Size of the quadrats used for tree (10 x 10m), shrub (5 x 5m) and herb (1 x 1m) was followed from Saxena and Singh (1982). The different size classes of the vegetation used were: tree (>30 cm, circumference at breast height, cbh); sapling (10-30 cm, cbh), and seedlings (<10 cm, cbh). Data were analyzed for different phytosociological attributes viz., density, frequency, abundance, basal area and importance value index (IVI) following Cottam and Curtis (1956). Species richness (Margalef 1958), Shannon -Wiener diversity index (Shannon and Weaver 1963), Simpson dominance index (Simpson 1949), and evenness (Pielou 1966) were also computed based on the phytosociological data. Dispersion pattern of individual plant species was calculated as an abundance/frequency (A/F) ratio. A/F ratio <0.025 indicates regular distribution, between 0.025 and 0.05 indicates random distribution and >0.05 indicates contagious distribution (Cottam and Curtis 1956).

Forest Biomass and C-Stock Estimation

Tree layer biomass was estimated using the allometric regression for each tree component developed by Chaturvedi and Singh (1987) and Rawat and Singh (1988) as follows:

$$\ln Y = a + b \ln X$$

where, ln = natural log, Y= dry weight of component (kg), X= CBH (cm), a = the y intercept and b = slope of regression.

Biomass of herbs and shrubs was estimated using destructive method. Representative samples of shrub biomass harvested and oven dried and multiplied with density to compute total biomass. To estimate the herb biomass total harvest from the sample plots (quadrats) was carried out, oven dried and dry weight was estimated and expressed as dry weight (Mg ha^{-1}) of forest. Carbon stock (C) was determined using the biomass value of tree species multiplied by a factor (C= biomass × 0.475) following Magnussen and Reed (2004). Forest floor litter mass was estimated by using 1 x 1 m quadrats (nine quadrats in both the forests studied for phytosociological analysis) in both the Oak and Pine forests soon after litter fall during May-June, 2014. Litter collected was oven dried, separated for various components and weighed and expressed as kg dry weight ha^{-1}. Organic carbon (Mg ha^{-1}) through litter fall was estimated as 50% of litter fall (Humberg 2000).

Net Primary Productivity (NPP) and Carbon Sequestration Rate

All trees within the nine permanent plots (quadrats) were marked with white paint at 1.37 m from the ground. Trees measured for cbh in permanent plots in the first year (July 2014) were re-measured in the second year (July 2015). Using the allometric equation given by earlier workers (Chaturvedi and Singh 1987, Rawat and Singh 1988) the biomass of different components (bole, branch, twig, foliage, stump root, and fine roots) for the first year (Y_1) and the second year (Y_2) was determined. The change (ΔY) in biomass between two years gives the annual biomass accumulation (NPP) as: $\Delta Y = Y_2 - Y_1$. where, ΔY = net primary productivity, Y_1= first year biomass, Y_2= second year biomass.

The difference between the carbon content estimates based on NPP was taken as the carbon sequestration rate (McDicken 1997, Tewari et al. 2008).

Soil Sampling and Analysis

Soil samples were collected at three depths (0-30 cm, 30-60 cm and 60-90 cm) from the same nine plots used for vegetation analysis in both the forest types across summer, rainy and winter seasons. To minimize the effect of the inherent site variability three replicates of soil from each plot were sampled and mixed to make a composite sample for each depth. Soil samples were brought to the laboratory in air tight polythene bags, sorted for stones, roots and other recognizable plant parts, dried under shade for about 3 days until constant weight, sieved (using a 2 mm sieve) and kept for further nutrient analysis. Soil bulk density was determined using a metal core sampler of known volume (ISO 1993), and the soil samples were oven dried at 65^0 C till constant weight, and the bulk density was measured as follows:

$$\textbf{Bulk density (g cc} - \textbf{1)} = \frac{\textbf{Weight of oven dried soil}}{\textbf{Volume of soil}}$$

Soil pH (soil: water ratio 1:5) was measured with the help of pre-calibrated digital pH meter with buffer solutions of 4.0, 7.0 and 9.2 (Black and Allen 1975). Soil water holding capacity (WHC) was determined by Hilgard Cup method (Cassel and Neilson 1986), and soil moisture was determined gravimetrically (ASTMD 2216). Among the chemical parameters, soil organic carbon (SOC) was determined by modified Walkley and Black (1934) method, total Nitrogen by the Kjeldahl digestion method (Parkinson and Allen 1975), and total phosphorus with a modified version of Olsen's method (Olsen and Sommer 1982). Carbon stock in soil was calculated as follows (Joao Carlos et al. 2001):

$$\text{C-stock} = d \times BD \times C \text{ content}$$

where, d is the soil depths (cm), BD is the bulk density and C is the carbon in percentage.

Soil organic matter (SOM) was measured as follows (Singh and Singh 1992):

SOM (%) = SOC (%) × 1.724;
where 1.724 is Van Bemmelen factor.

RESULTS AND DISCUSSION

Vegetation Properties of Forests:

Oak Forest

In the Oak forests the dominant tree species was *Q. leucotrichophora* having the highest density (666 trees ha^{-1}) and IVI (158.96), and the least dominant species was *Pinus roxburghii* (density= 111 trees ha^{-1} and IVI = 45.25) (Table 1). Across the sampled plots tree density ranged between 111 and 666 trees ha^{-1}, and the total tree density was computed 1254 trees ha^{-1}. Tree diameter was found ranging from 7.0-128.0 cm, and mean value was computed 48.31 cm across the nine sample plots. The dominant shrub in the forest was *Lantana camara* (IVI = 57.39), which is an invasive species. The total tree sapling density was found 1154 ind ha^{-1} and seedling density (612 ind ha^{-1}) (Table 1). Tree density recorded by us for Oak forests was comparable to that reported (range = 1100-1500 trees ha^{-1}) by Rana et al. (1985), Dhar et al. (1997), Kusumlata and Bisht (1991), However, lower values of tree density 320-940 trees ha^{-1} (Saxena and Singh 1982, Singh et al. 1994, Sharma et al. 2011) and higher values (2144 trees ha^{-1}) have also been reported (Uniyal et al. 2010). Species richness in Oak forest was recorded as: tree species (5), shrubs (11) and herb species (79) (Table 3). Simpson's Index (D) was computed for tree (0.599), sapling (0.387), shrub (0.115) and herb (0.112) layer. Shannon-Wiener index (H) (range = 0.833-2.21) reported by us for the study forests was comparable to Central Himalayan forests (range = 0.33-2.95) reported by earlier workers (Saxena and Singh 1982, Ralhan et al. 1982, Tripathi et al. 1987, Rikhari 1990, Bargali et al. 1997). Higher species diversity is generally thought to indicate a more complex and healthier community because a greater variety of species allows more species interactions, hence greater system stability, and indicates good environmental conditions (Prescott 2002, Giri et al. 2006). Most of the tree species showed regular distribution across the sampled plots.

Pine Forest

In the Pine forests the dominant tree species was *Pinus roxburghii* having the highest density (911 trees ha^{-1}) and IVI (140.78), and the least dominant species was *Rhododendron arboreum* (density = 222 trees ha^{-1} and IVI = 19.57) (Table 2). Across the sampled plots tree density ranged between 222 and 911 trees/ ha, and the total tree density was found 2798 trees ha^{-1}. Tree diameter was found ranging from 9.0-111.0 cm, and the mean value was computed 41.34 cm across the nine sample plots. The dominant shrub in the forest was *Berberis asiatica* (IVI = 39.52). The total tree sapling density was found 1798 ind ha^{-1} and the seedling density (500 ind ha^{-1}) in Pine forests (Table 2). The tree density reported here is much higher to that reported (580-1400 trees ha^{-1}) in Garhwal Himalaya (Rawal and Pangtey 1994, Bhandari et al. 1997, Kala 2004), and (500-575 trees ha^{-1}) in Kumaun Himalayan Pine forests (Ralhan et al. 1985, Kumar and Ram 2005). Species richness in Pine forest was recorded as: tree species (5), shrubs (8) and herb species (69) (Table 3). Simpson's Index (D) was computed for tree (0.693), sapling (0.267), shrub (0.336) and herb (0.132) layer, respectively. Shannon-wiener index (H) was found high for shrub and herb layer than the tree layer. Most of the tree species showed regular distribution across the sampled plots.

Biomass and C-stocks in Oak and Pine forests

In the Oak forest total above ground biomass (mean across nine sample plots) was computed to be 189.65 Mg ha^{-1} (Table 4). The tree layer contributed > 98 % of this biomass. Similarly, the total aboveground biomass in Pine forests was computed to be 119.05 Mg ha^{-1}, and tree layer contributed > 98% of this biomass (Table 5). Total biomass (tree + shrub + herb layer) for Oak forests (189.75 Mg ha^{-1}) was significantly higher than the Pine forests (119.1 Mg ha^{-1}). In the Oak forests of Central Himalaya biomass values reported (range = 286-782 Mg ha^{-1}) are much higher as compared to present study (Negi et al. 1983, Rawat 1983, Rana 1985, Singh and Singh 1992). Low density of the Oak forests was the main reason behind the lower biomass. Similarly, in *P. roxburghii* forests values of biomass reported (range = 113-443 Mg ha^{-1}) is much higher to our reports (Chaturvedi and Singh 1987, Sharma et al. 2011). However, low value of biomass for Pine forests (range = 113-283 Mg ha^{-1}) have also been reported in this region (Singh and Singh 1982, Sheikh and Kumar 2010).

The mean value of C-stock in the Oak forests (tree + shrub + herb layer) was computed to 90.1 Mg ha^{-1}, and tree layer contributed >98% of this C-stock (Table 4). Similarly, in the Pine forest mean value of C-stock (tree + shrub + herb layer) was computed 56.6 Mg ha^{-1}, out of

Table 1. Frequency, density, abundance, A/F ratio and IVI of Oak forests

Species	Frequency (%)	Density (trees ha^{-1})	Abundance	A/F ratio	IVI
Oak forest (Tree)					
Quercus leucotrichophora	100	666	11.2	0.112	158.96
Lyonia ovalifolia	22	222	1	0.045	23.85
Rhododendron arboreum	22	222	2.2	0.100	28.82
Pinus roxburghii	66	111	1.5	0.022	45.25
Myrica esculenta	55	133	2.4	0.043	43.12
Total	265	1254	18.3	0.324	300
Oak forest (Sapling)					
Quercus leucotrichophora	44	155	3.5	0.035	110.22
Lyonia ovalifolia	33	333	1	0.045	45.38
Rhododendron arboreum	22	222	1	0.046	32.97
Pinus roxburghii	11	110	1	0.015	61.95
Myrica esculenta	33	333	1	0.018	49.48
Total	143	1154	7.5	0.159	299.98

Table 2. Frequency, density, abundance, A/F ratio and IVI of Pine forests

Species	Frequency (%)	Density (trees ha^{-1})	Abundance	A/F ratio	IVI
Pine forest (Tree)					
Pinus roxburghii	100	911	9.11	0.091	140.78
Lyonia ovalifolia	33	222	1	0.031	24.24
Rhododendron arboreum	22	222	1	0.045	19.57
Quercus leucotrichophora	44	666	1	0.023	73.29
Myrica esculenta	55	777	1.4	0.026	42.08
Total	254	2798	13.51	0.215	299.98
Pine forest (Sapling)					
Pinus roxburghii	66	133	2	0.031	116.6
Lyonia ovalifolia	11	111	1	0.091	26.45
Rhododendron arboreum	33	333	1.5	0.045	46.91
Quercus leucotrichophora	11	666	1	0.090	43.84
Myrica esculenta	44	555	1	0.023	66.17
Total	165	1798	6.5	0.281	299.97

Table 3. Species richness and diversity of tree, shrub and herb layers in Oak and Pine forests

Parameters	Oak forest				Pine forest			
	Tree	Sapling	Shrub	Herb	Tree	Sapling	Shrub	Herb
Simpson's Index (D)	0.599	0.387	0.115	0.112	0.693	0.267	0.336	0.132
Simpson's Index of diversity (1-D)	0.401	0.613	0.884	0.888	0.307	0.733	0.663	0.868
Shannon-wiener index (H)	0.833	1.183	2.21	2.01	0.671	1.373	2.34	2.13
Species richness	5	4	11	79	5	3	8	69
Species evenness	1.192	1.69	2.11	1.98	0.959	1.964	2.59	2.17

Table 4. Biomass (Mg ha^{-1}) and C-stock (Mg ha^{-1}) in Oak forests

Plots	Tree layer		Shrub layer		Herb layer	
	Biomass	C-stock	Biomass	C-stock	Biomass	C-stock
1	111.34	52.88	2.11	1.01	0.13	0.06
2	315.36	149.79	1.23	0.58	0.29	0.14
3	98.43	46.74	2.5	1.19	1.03	0.49
4	285.24	135.49	1.39	0.66	0.03	0.02
5	248.12	117.86	2.64	1.26	0.41	0.19
6	149.97	71.24	1.8	0.85	0.54	0.26
7	213.39	109.91	3.2	1.52	0.23	0.11
8	120.29	57.13	2.13	1.01	0.99	0.47
9	142.79	67.83	1.31	0.62	0.79	0.38
Mean	187.22±26.84	89.87±12.91	2.04±0.23	0.96±0.11	0.49±0.12	0.24±0.06

Table 5. Biomass (Mg ha^{-1}) and C-stock (Mg ha^{-1}) in Pine forests

Plots	Tree layer		Shrub layer		Herb layer	
	Biomass	C-stock	Biomass	C-stock	Biomass	C-stock
1	103.15	48.99	2.1	0.99	0.15	0.07
2	105.00	49.89	1.2	0.57	0.21	0.09
3	169.66	80.59	1.06	0.51	0.13	0.06
4	106.24	50.45	1.13	0.54	0.15	0.07
5	92.94	44.15	0.98	0.47	0.64	0.31
6	102.71	48.79	2.07	0.98	1.19	0.57
7	87.59	41.61	1.13	0.54	0.97	0.46
8	176.3	83.74	0.97	0.46	1.07	0.51
9	111.02	52.73	1.16	0.55	0.53	0.25
Mean	117.17±10.81	55.66±5.13	1.32±0.15	0.63±0.07	0.56±0.14	0.26±0.08

which tree layer contributed >98% (Table 5). Our values of C-stock in Oak forests biomass are much lower as compared to 300-334.1 Mg ha^{-1} reported by Rana et al. (1989) and Semwal et al. (2007), and comparable to that reported (77.3-102.8 Mg ha^{-1}) by Sharma et al. (2011). Similarly, in Pine forests higher values (77.8-203.7 Mg ha^{-1}) (Sharma et al. 2011) and lower values, 59.8 Mg ha^{-1} (Sheikh and Kumar 2010), and 92.0 Mg ha^{-1} (Rana et al. 1989) have been reported.

Net Primary Productivity and C Sequestration Rate in Oak and Pine Forests:

Carbon sequestration is the process by which the atmospheric CO_2 is absorbed by tree through photosynthesis and stored as carbon in plant biomass (bole, branches and roots), and some part of soil. The carbon sequestrated away from the atmosphere in the vegetation for at least 50-100 years and can be used as an important mitigation tool against the climate change (Singh 2007). Total tree layer biomass in the first year in Oak forests (mean = 187.22 Mg ha^{-1}) increased in the next year (mean = 192.89 Mg ha^{-1}) in 2015 (Table 6). Average above-ground NPP of tree layer of Oak forests was thus computed to 5.68 Mg ha^{-1} yr^{-1}. More than two times density of tree layer of Pine forests as compared to Oak forests (2798 vs 1254 trees ha^{-1}) was the main factor behind high C sequestration in Pine forests. In Pine forests tree layer biomass (mean = 117.17 Mg ha^{-1}) in year 2014, increased (mean = 127 Mg ha^{-1}) in 2015 (Table 7), thus aboveground NPP of Pine forests tree layer was computed to be 9.04 Mg ha^{-1} yr^{-1}. Rawat and

Table 6. Biomass (Mg ha^{-1}), Net primary productivity (NPP; Mg ha^{-1} yr^{-1}) and C sequestration rate (Mg ha^{-1} yr^{-1}) in Oak forests during 2014 and 2015

Plots	Biomass		NPP	Carbon stock		C sequestration
	Year 2014	Year 2015		Year 2014	Year 2015	
1	111.34	117.12	5.78	52.88	55.63	2.75
2	315.36	319.56	4.26	149.79	151.79	1.99
3	98.43	102.69	4.27	46.74	48.78	2.03
4	285.24	293.11	7.87	135.49	139.23	3.74
5	248.12	251.73	3.61	117.86	119.57	1.17
6	149.97	156.40	6.43	71.24	74.29	3.06
7	213.39	220.66	7.27	101.36	104.8	3.45
8	120.29	127.25	6.95	57.13	60.44	3.31
9	142.79	147.51	4.7	67.83	70.44	2.24
Mean	187.22±26.84	192.89±26.84	5.68±0.51	89.87±12.91	91.66±12.74	2.64±0.27

Table 7. Biomass (Mg ha^{-1}), Net primary productivity (NPP; Mg ha^{-1} yr^{-1}) and C sequestration rate (Mg ha^{-1} yr^{-1}) in Pine forests during 2014 and 2015

Plots	Biomass		NPP	Carbon stock		C sequestration
	Year 2014	Year 2015		Year 2014	Year 2015	
1	103.15	113.07	9.92	48.99	53.70	4.71
2	105.00	118.13	13.13	49.89	56.11	6.23
3	169.66	179.28	9.63	80.59	85.16	4.57
4	106.24	116.33	10.08	50.45	55.26	4.79
5	92.94	98.75	5.80	44.15	46.91	2.76
6	102.71	109.33	6.61	48.79	51.93	3.14
7	87.59	96.20	8.61	41.61	45.69	1.09
8	176.30	190.42	14.12	83.74	90.45	6.7
9	111.02	114.49	3.460	52.73	54.38	1.64
Mean	117.17±10.81	127±11.35	9.04±1.14	55.66±5.13	60.52±5.39	3.96±0.65

Singh (1988) reported NPP in Oak forests ranging from 11.1-13.2 Mg ha^{-1} yr^{-1} in Central Himalaya. Higher ANPP in Pine forests (7.6-18.7 Mg ha^{-1} yr^{-1}; Chaturvedi and Singh 1987) and 14.4-17.3 Mg ha^{-1} yr^{-1} (Rana et al. 1989) and 6.54-12.76 Mg ha^{-1} yr^{-1}; Pant and Tewari (2013) reported in Nainital forest division, is quite higher as compared to present study. C-sequestration rate in Oak and Pine forests in the present study was recorded 2.64 Mg ha^{-1} yr^{-1} (range = 1.71-3.45 Mg ha^{-1} yr^{-1}) and 3.96 Mg ha^{-1} yr^{-1} (range = 1.09-6.7 Mg ha^{-1} yr^{-1}), respectively (Tables 6 and 7). In Pine forests mean C-sequestration values have been reported to 3.1-6.07 Mg ha^{-1} yr^{-1} in Central Himalaya (Pant and Tewari 2013), and 0.65-4.32 Mg ha^{-1} yr^{-1} in Oak forests (Anonymous 2011). Jina et al. 2008 reported C-sequestration rate in Chir-Pine forests ranging from 5.06-6.66 Mg ha^{-1} yr^{-1} in non degraded and 10.7-1.27 Mg ha^{-1} yr^{-1} in degraded forests in Central Himalaya.

Litter Fall and Organic Carbon Input

Litter fall is an important component of forest ecosystems that transfer the organic matter and nutrients from tree to the soils and maintains soil fertility. The litter fall quality and vegetation type play an important role in soil formation. The upper layer of soil has high nutrients contents due to high level of humus and soil organic matter. In this study total litter fall we computed in Oak forests (11.94 Mg ha^{-1}), was higher than the Pine forests (8.42 Mg ha^{-1}). To the total litter fall the contribution of Oak leaf litter (30.3%) was markedly lower than that contributed by leaf litter of Pine forests (49.0%). Organic carbon input through litter fall in Oak forests (5.97 Mg ha^{-1}) was also computed slightly higher than for the Pine forests (4.21 Mg ha^{-1}). The values of litter fall recorded by us were found within the range (4.2-15.4 Mg ha^{-1} yr^{-1}) reported earlier by Singh et al. (1994), and slightly higher than reported (5.8-7.7 Mg ha^{-1} yr^{-1}) by Singh and Singh (1992) for the Oak and Pine forests of this region. Similarly, litter fall values in Pine forests have been reported ranging from 4.2-6.5 Mg ha^{-1} yr^{-1} by Singh and Singh (1992). However, markedly low values (2.0-3.8 Mg ha^{-1}) have also been reported for six Central Himalayan forests, with 54-84% contribution of leaf litter (Mehra et al. 1985).

Soil Physico-chemical Characteristics

Data on the physico-chemical properties of soil across the seasons and soil depths for both the Oak and Pine forests (Table 8) reveal that Oak forests were rich in all the physico-chemical properties as compared to Pine forests. Higher soil moisture (mean = 9.22 vs 5.77%), and water holding capacity (mean = 31.4 vs 22.7%) of Oak forests as compared to Pine forests is a characteristic feature that is considered advantageous for ecosystem attributes, such as species diversity, biomass productivity and C sequestration (Singh and Singh 1992). It was remarkable to note that all soil physico-chemical properties in both the forests decreased with increasing depths. Similar trend has been reported in Oak and Pine forests of this region (Joshi and Negi 2015).

Total soil nitrogen (mean across three depth) recorded by us for Oak forests (range = 0.33-0.54%) was significantly higher than the Pine forests (range = 0.24-0.39%), and found similar to that reported by Rikhari (1990) (0.416-0.702%) and Bhandari et al. (2000) (0.25-0.31%) for Oak forests. However, lower values (range = 0.12-0.26%) have also been reported for Pine forests (Khanna 1986, Jina et al. 2008). Similarly, the Oak forest soil was rich in phosphorus (mean = 0.44±0.32%) and potassium (mean = 88.09±1.92 kg ha^{-1}) as compared to Pine forests (P = 0.35±0.0.21 %, and K = 71.91±1.45 kg ha^{-1}). In the Oak forest the SOC (mean = 1.53%) was significantly higher as compared to Pine forests (mean = 0.91%) (Table 8). SOC values reported here are comparable (1.83-4.5%) to those reported for Oak forests in Kumaun Himalaya (Uperti 1982, Uperti et al. 1985). However, much lower values of SOC (range = 0.8-2.3%) have also been reported for Oak forests (Khera et al. 2001), and Pine forests (0.62-0.75%) in this region (Singh et al. 2009). A wide range (0.2-6.9%) of OC has been reported for the forest soils of Garhwal region (Chaudhary 1987). C:N ratio is an indication of N limitation of soil for circulation for the growth of microbial communities responsible for SOM decomposition. In our forests the low C:N ratio (Oak= 3.44; Pine=2.72) was found limiting to microbial growth and mineralization of soil nutrients and warrants further studies to explain the region.

Soil organic matter (SOM) is an important component of soil system and major source of N and P for the

Table 8. Soil physico-chemical characteristic in Oak and Pine forests (mean across 0-90 cm depth)

Soil parameters	Oak forests				Pine forests			
	0-30 cm	30-60 cm	60-90 cm	Mean	0-30 cm	30-60 cm	60-90 cm	Mean
SOC %	2.41±0.021	1.33±0.017	0.87±0.023	1.53±0.02	1.59±0.016	0.83±0.019	0.35±0.017	0.91±0.01
SOM %	4.15±0.17	2.29±0.63	1.51±0.23	2.65±0.34	2.66±0.21	1.43±0.19	0.59±0.14	1.56±0.18
pH	5.54±0.48	5.59±0.38	5.10±0.44	5.41±0.44	6.27±0.09	6.12±0.12	5.67±0.37	6.02±0.19
SMC %	13.98±0.98	8.46±0.87	5.26±0.79	9.22±0.88	8.05±0.62	5.39±0.44	3.87±0.74	5.77±0.60
WHC %	40.80±1.26	30.44±1.98	22.89±0.56	31.37±1.27	25.82±0.79	21.27±1.12	21.06±0.92	22.71±0.94
N %	0.541±0.045	0.413±0.039	0.332±0.071	0.43±0.05	0.389±0.042	0.318±0.071	0.242±0.044	0.32±0.18
P %	0.46±0.030	0.439±0.027	0.415±0.041	0.44±0.32	0.361±0.013	0.352±0.016	0.334±0.034	0.35±0.21
K (kg ha^{-1})	93.72±2.13	90.89±1.98	79.67±1.67	88.09±1.92	89.5±2.09	77.78±1.39	66.45±1.86	77.91±1.45
C:N Ratio	4.46±0.00	3.22±0.00	2.62±0.00	3.44±0.00	4.09±0.00	2.61±0.00	1.45±0.00	2.72±0.00

decomposers, microbes and determines the production potential of soil. SOM can absorb and hold substantial water, up to 20 times its mass (Ghosh et al. 1981, Ravindranth and Gadgil 1997). SOM in the form of surface residues can also influence water retention directly by reducing evaporation rates and increasing the infiltration of water. Most soil organisms are heterotrophic and gain their energy from decomposing SOM. A significantly greater SOM for Oak forests (2.65 vs 1.56%) indicates that Oak forests are characterized by high water retention capacity and most desirable for water conservation in mountain watersheds.

A close examination of soil physico-chemical properties revealed that the SOC varied significantly across the depth (Table 8). SOC and SOM decreased with increasing depths across all the sampled plots of Oak and Pine forests (Table 8). It can be attributed to the fact that humus formation and decomposition of organic matter takes place in upper soil layers (Gairola et al. 2012). The upper soil layer remains in dynamic equilibrium with biological and anthropological activities and thus is generally richer in C than the lower layers. Similar results were also reported by Raina et al. (2009) in Mussoorie forests of Uttarakhand. In this region higher organic matter in the soils under Oak and Pine forests has been reported by several workers (Kushalappa 1967, Singh et al. 1993, Chander et al. 1998, Bisht and Lodhiyal 2005).

Soil C- Stocks in Oak and Pine Forests

Biomass and carbon stocks in forest vegetation depend upon various factors like geographical location, plant species, age of the stand, rainfall, climate and vegetation cover etc. (Van Noordwijk et al. 1997, IPCC 2000). Soil organic carbon (SOC) holds a very important role in global C cycle as it is the largest terrestrial C pool. In our study carbon stock in soil (0-90 cm depth) of Oak forests (171.79 Mg ha^{-1}), was computed more than two times as compared to Pine forests (73.67 Mg ha^{-1}). However, our values are much lower as compared to that reported in the Central Himalayan forests (166.8-440.10 Mg ha^{-1}) by Rana et al. (1989), and comparable to that recorded for Oak (142 Mg ha^{-1}) and Pine (62 Mg ha^{-1}) forests by Jina (2009), and Jina et al. (2008). Low values of SOC for Oak forests (96.4 Mg ha^{-1}) and Pine forests (61.1 Mg ha^{-1}) has also been reported in this region (Negi et al. 2015).

CONCLUSION

In conclusion this study has shed more light on the selected structural and functional aspects of the two dominant forests of mid-montane belt of the Central Himalayan region. The Oak and Pine forests studied by us varied considerably with regards to species richness, density of trees, regeneration status, biomass productivity and soil physico-chemical characteristics. Oak forests were found superior in all the vegetation and soil attributes. However, low tree density of Oak forests realized almost half of the C sequestration value as compared to Pine forests. Of particular interest is higher percentage of SOC and SOM, aboveground biomass and higher input of litter in Oak forests that resulted in significantly greater C stock (vegetation + litter + soil pool) (268.83 vs 134.43 Mg ha^{-1}) than the Pine forests. In the Oak forests the soil holds almost double C stock as compared to that contained in above ground vegetation. Therefore, Oak forests should be conserved and maintained to mitigate the climatic change impacts through stocking more C in vegetation and soil pool.

ACKNOWLEDGMENTS

This study was funded by Earthwatch Institute, India under a project entitled, “Assessment and Quantification of Forest Ecosystem Services with Special Emphasis on Pollination in the Indian Himalayan Agro-ecosystems”. Thanks are due to Dr S.S. Samant, Dr R.S. Rawal, Dr S. Sharma and Dr V. Agnihotri, Scientists, GBPIHED, for help and inputs to carry out this study.

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Received 24 September 2015;
Accepted 29 October 2015