Green Sequestration Potential of Chir Pine Forests Located in Kumaun Himalaya

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Abstract

Himalayan forests act as reservoirs of carbon due to their high percentage of forest cover. The biomass values of these forests cluster around two different levels, which dwell between higher values (approximately 400 t/ha for *Shorea robusta* and *Quercus leucotrichophora* forests) and lower values (approximately 200 t/ha) for *Pinus roxburghii* forests. The present study is focused on assessment of variation in tree biomass and carbon sequestration at four sites dominated by chir pine (*P. roxburghii* Sarg.) forests located on two different slope aspects. We calculated the tree biomass following allometric equations based upon circumference at breast height by Chaturvedi and Singh (1982). The tree biomass values ranged between 97.87 ± 9.84 t/ha and 158.97 ± 9.39 t/ha; however, tree carbon values ranged between 46.48 ± 4.67 t/ha and 74.66 ± 7.17 t/ha across the study sites. Rates of carbon sequestration ranged between 0.2 ± 0.01 t/ha/yr and 3.96 ± 1.36 t/ha/yr. The rates were higher on slopes of northern aspect in comparison with southern aspect. The results emphasize that the biomass accumulation was higher in the trees located on northern aspects and can be better managed for developing a payment for ecosystem services strategy for following up of REDD+ in the country.

Climate change can be defined as a natural or anthropogenic situation that is likely to impact human systems, natural ecosystems, and socio-economic systems (Smith et al. 1993, Ravindranath and Sathaye 2002). This trend has been widely studied and reported by many researchers, and the Intergovernmental Panel on Climate Change (IPCC) recently reported that greenhouse gas concentrations are projected to continue to rise, which will lead to increased temperature (IPCC 2018). This will simultaneously enhance existing concentrations of CO_2 and increase gaseous flow in the atmosphere. Bluffstone et al. (2018) reported that this phenomenon of increasing concentrations of greenhouse gases will affect the Earth's susceptibility to climate change. Ravindranath and Ostwald (2008) reported that the amount of stored carbon in global terrestrial ecosystems is 2,477 billion tons, of which soil and vegetation account for approximately 81 and 19 percent, respectively. Matthews et al. (2002) reported that costs of carbon sequestration in forests are reasonably comparable to, and sometimes lower than, the costs of alternative mitigation and abatement approaches toward climate change mitigation. Forests have also widely been recognized to play a significant role in cost-effective mitigation of atmospheric carbon dioxide (Isaev et al. 1995, Krankina et al. 1996, Fang et al. 2001, Richards and Stokes 2004, Sohngen and Brown 2008, Nepal et al. 2012).

When evaluating forest carbon-storage determinants and their allocations to different biomass components as well as micro-ecosystem components, it is necessary to understand climate change impacts on forests and predict the response of carbon balance to climate change and forest management (Kauppi et al. 1992, Turner et al. 1995, Kimble et al. 2002, Food and Agriculture Organization of the United Nations 2003, Pregitzer and Euskirchen 2004). As reported by Krankina et al. (2004), in order for countries to meet commitments to estimating, validating, monitoring, and reporting current and future carbon stocks under the Kyoto Protocol, it has become essential to develop tools and strategies for accurate forest surveying methods that are verifiable, specific in time and space, and cover larger areas at acceptable cost.

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Forest carbon sequestration can be undertaken as the long-term approach for abatement of increasing carbon concentration in the atmosphere. The process of carbon sequestration in context of the forest ecosystem is a safe way to conserve, capture, and store large amounts of carbon in a significant, low-input way, and is also considered by many to be of long-term environmental benefit (Houghton et al. 1985, Harvey 2000, Lehmann and Joseph 2015).

Change in total carbon stocks in forest stands can be assessed by direct measurement of net source and sinks over periods of $\geq$ 1 year. Estimates of biomass, carbon stock, and carbon budget by researchers in India (Ravindranath et al. 1997, Lal and Singh 2000, Chhabra et al. 2002, Sheikh et al. 2010) have been reported on the basis of growing-stock volume data of forest inventories and appropriate conversion factors related to both biomass and carbon. Bhattacharyya et al. (2008) reported that the Himalayan region is rich in dense forest vegetation; the region encompasses nearly 19 percent of the soil organic carbon (SOC) of India and contains 33 percent of the country's SOC reserves. Shah et al. (2013) reported that, at a regional level, the soil carbon stock ranged between 18.87 and 3441.20 t with respect to the humus layer and top 1 m of the soil in the pine forests of Himachal Pradesh.

With respect to regional forest-carbon variations, Uttarakhand State of India has 64.79 percent forest area, of which 16.15 percent (394,383.4 ha) consists of chir pine forest. The recorded per-unit carbon sequestration by chir pine forest was 0.20/ton/ha, and the estimated value of sequestered carbon (in tons) was 30,768.40 t/ha (Uttarakhand Forest Development Corporation 2009–2010).

The amount of carbon accumulated in total forest biomass in Uttarakhand State is 6.61 million tons annually, worth approximately 3.82 billion Indian rupees (US$13 per t carbon) for the assessment year 2016. The amount of carbon that forests sequester is approximately 33 times more than carbon emitted in Uttarakhand through fossil fuel combustion. Sharma and Singh (2010) reported the total standing carbon value of 175.49 t/ha in chir pine forest in the Solan forest division in Himachal Pradesh, based on the current annual increment and remote sensing.

The community-based forest-management system of Uttarakhand has been an important part of forest utilization and its sustainable conservation with respect to natural resources management. These community forests act as the prime example of forest management and are important for the aspect of community dependency upon these forests. These forests are also reported to be notable carbon sinks, storing carbon in above- and below-ground tree biomass, and a significant source of various ecosystem services (Gosain et al. 2015). Tewari and Phartiyal (2007) reported that one community-managed forest can receive up to US$2,200 per year in payment for ecosystem services (PES) for carbon sequestered. Moreover, Vikrant and Chauhan (2014) reported the significance of community-managed forests for carbon stock for the eastern part of the western Himalayan region, which implied the presence of a large sink of forest carbon in the region. With respect to REDD and REDD+ (defined as "countries' efforts to reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks"; Forest Carbon Partnership n.d.), Negi et al. (2012) reported that the existing policies of forest management should encourage planting, reforestation, and afforestation in the forest-deficient regions so that these resources can be managed by the community and forest department in partnership. This strategy could support development of a basis for sale of nontimber forest products such as seeds or fruits and medicinal plants, and potentially allow ecotourism and commercial-based management approaches to evolve economically and financially through PES. This REDD+ system can be defined as having an acknowledged role in conservation and sustainable management of forests and enhancement of forest carbon stocks in developing countries.

India's national strategy (India 2015) aims at increasing and improving the forest and tree cover of the country for enhancement of forest ecosystem services that flow to the local communities, and the carbon service provided by forest and plantations is one of the cobenefits and not the main or the sole benefit. PES is a process that involves the manager and beneficiaries who obtain benefits from sustainable management of natural resources. Keeping the systematic aspect of green sequestration potential in mind, we undertook the present study and gave special focus to chir pine (*Pinus roxburghii*) forests located in Nainital forest division of Kumaun Himalaya, which covers approximately 60,114.5 ha of the forest area (Uttarakhand Forest Development Corporation 2009–2010). We studied tree biomass and carbon sequestration rates for a successive period of 2 years at different positions (ridge top, mid-hill slope, and hill base) of the hill slopes and aspects across four study sites to identify the greatest yield of tree biomass according to the forest location and slope gradient, and analyzed the carbon sequestration potential for developing the action plan for conserving the native pine forest in the Himalayan region with respect to REDD+ and PES.

Materials and Methods

Site description

The study area is within the Kumaun Himalayas, which extend over an area of 21,003 km^2 and lie between 28°44′ to 30°49′N latitudes and 78°45′ to 85°5′E longitudes along the east and southeastern part of central Himalaya (Fig. 1). The four study sites were located between 29.24°N to 30.35°N latitude and 79.27°E to 79.37°E longitude in Nainital district and within the southern Kumaun circle of the Uttarakhand Forest Department. The study sites occupied an altitudinal gradient between 1,540 and 1,860 m covering the range of chir pine forest (Table 1).

Establishment of permanent plots and vegetation analysis

We conducted vegetation analysis in 2009 across all four sites. We placed 120 permanent plots, distributed randomly across the hill slope conditions (i.e., ridge top, mid-hill slope, and hill base) across the study sites (10 plots at each slope point at four study sites = 120 plots). At each slope condition we placed 10 permanent circular plots of 5.65-m radius to represent the 10 by 10-m area. We marked all trees within the permanent plots with yellow paint at 1.37 m circumference at breast height (CBH) from the ground. We estimated tree density, basal area, and other vegetation parameters following standard methodology of Curtis and McIntosh (1950) and Tewari and Karky (2007).

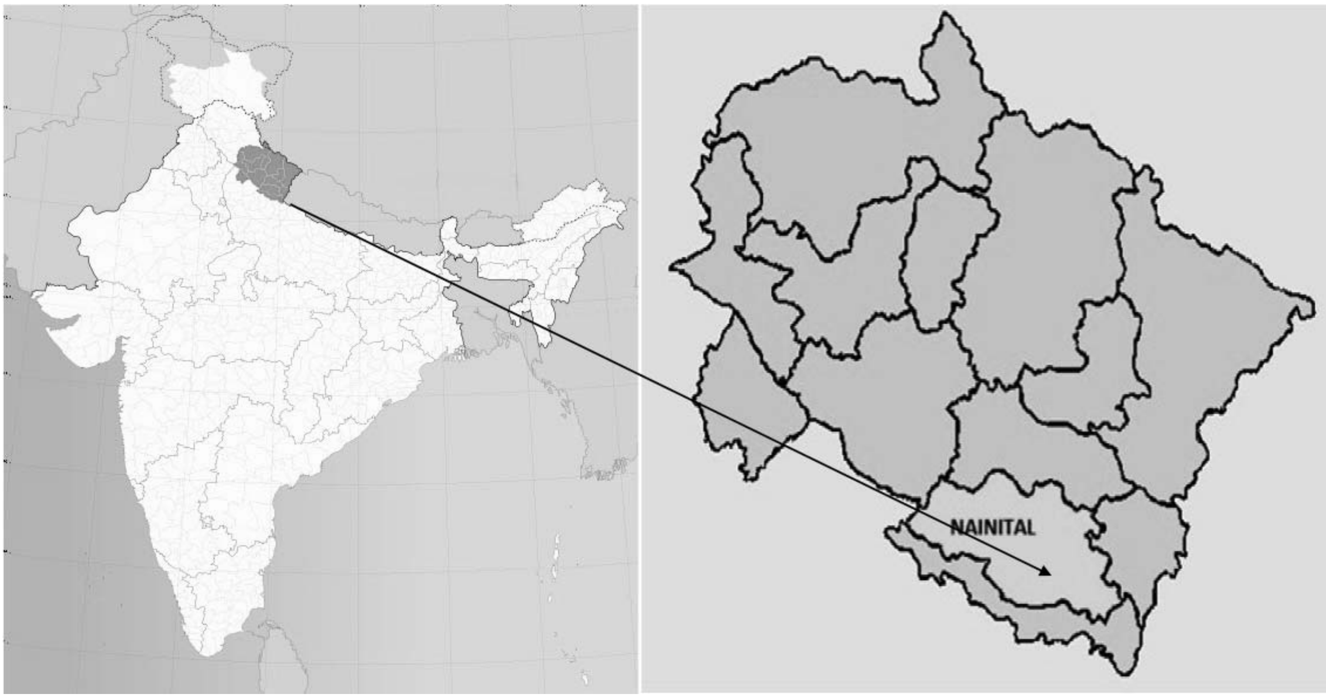

Figure 1.—Map of the study area.

Estimation of tree biomass and carbon sequestration.—For the estimation of tree biomass (below and above ground), we took CBH (breast height = 1.37 m) for all individual trees falling within each circular plot in October 2009 (Year 1) and estimated tree biomass using a previously developed allometric equation based upon CBH by following standard methodology developed by Chaturvedi and Singh (1982):

$$\ln Y = a + b \ln X \quad (1)$$

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

We repeated the measurements in October 2010 (Year 2). We estimated the biomass for each year for different biomass components (i.e., bole, branch, twig, foliage, stump root, and fine roots) for the first year ($Y1$) and the second year ($Y2$), respectively, using the allometric equations. The change (ΔY) in biomass yielded the annual biomass (tons) accumulation as:

$$\Delta Y = Y2 - Y1 \quad (2)$$

We estimated tree carbon following Schlesinger (1991) and Chan (1982) using the following formula (Magnussen and Reed 2004):

$$C = B \times 0.475 \quad (3)$$

where C = carbon value and B = biomass value.

Collection of soil samples and estimation of soil organic carbon.—We collected soil samples from each of the slope positions for different sampling depths (i.e., 0–10, 10–20, 20–30, and 30–40 cm soil depth). From each slope point we took three replicates and brought composite samples to the laboratory for further analysis. We estimated total soil carbon by Total Organic Carbon Analyser (Solid Sample Module SSM-5000A for TOC-V Series Total Organic Carbon Analyser) following the standard methodology of Nelson and Sommers (1996). We conducted the analysis in the laboratory of the Department of Environmental Sciences, College of Basic Sciences and Humanities at the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand.

Table 1.—Description of study sites.

Site	Aspect	Status	Slope position	Slope angle	Altitude (m)
I	Southern	Undisturbed	Ridge top	45°	1,650
			Mid-hill slope	35°	1,595
			Hill base	30°	1,570
II	Southern	Moderately disturbed	Ridge top	65°	1,845
			Mid-hill slope	60°	1,740
			Hill base	50°	1,680
III	Northern	Undisturbed	Ridge top	65°	1,860
			Mid-hill slope	50°	1,760
			Hill base	40°	1,700
IV	Northern	Moderately disturbed	Ridge top	65°	1,750
			Mid-hill slope	60°	1,640
			Hill base	55°	1,540

Results

Vegetation parameters

On the southern slope aspects, the tree density ranged between 390 and 3,050 individuals/ha (trees per hectare). The minimum tree density was at the ridge top of Site I, while maximum tree density was at the hill base of Site I. Total basal area (TBA) ranged between 16.47 and 67.16 m^2/ha across the sites. The minimum TBA was at the hill base of Site I while maximum TBA was at the hill base of Site II (Table 2).

Table 2.—Distribution of vegetation parameters across the studied forests.

Site	Aspect	Slope position	Tree density (individual/ha)	TBA (m^2/ha)[a]	Soil organic carbon (t/ha)
I	Southern	Ridge top	390	53.44	79.07
		Mid-hill slope	1,590	36.79	77.50
		Hill base	3,050	16.47	62.62
II	Southern	Ridge top	730	33.73	30.52
		Mid-hill slope	920	45.80	46.77
		Hill base	780	67.16	31.32
III	Northern	Ridge top	1,120	83.58	23.55
		Mid-hill slope	1,100	60.19	17.36
		Hill base	860	61.00	30.58
IV	Northern	Ridge top	820	95.40	36.72
		Mid-hill slope	850	68.80	27.63
		Hill base	2,400	63.06	42.05

[a] TBA = total basal area.

On the northern slope aspects, the tree density ranged between 820 and 2,400 individuals/ha. The minimum tree density was at ridge top of Site IV, which was 820 individuals/ha, while maximum tree density was 2,400 individuals/ha at hill base of Site IV. Total basal area ranged between 60.19 and 95.40 m^2/ha on this aspect. The minimum TBA was at mid-hill slope of Site III while maximum TBA was at ridge top of Site IV (Table 2).

Soil organic carbon.—The SOC ranged between 30.52 and 79.07 t/ha on the southern aspect and was at minimum at ridge top of Site II and maximum at ridge top of Site I. On the northern aspect the SOC ranged between 17.36 and 42.05 t/ha and was at minimum at mid-hill slope of Site III and maximum at hill base of Site IV. The southern aspect shows greater concentration of SOC in comparison with the northern aspect (Table 2).

Tree biomass and carbon.—In the present study, tree biomass ranged between 97.87 ± 9.84 t/ha and 144.62 ± 11.00 t/ha on the southern aspect during the first year, which increased to 100.71 ± 18.17 t/ha and 146.06 ± 11.04 t/ha in the second year. Tree carbon ranged between 46.48 ± 4.67 t/ha and 68.69 ± 5.23 t/ha during the first year, which increased to 47.84 ± 8.63 t/ha and 69.94 ± 5.70 t/ha in the second year. Carbon sequestration rates on the southern aspect ranged between 0.2 ± 0.01 t/ha/yr and 3.96 ± 1.36 t/ha/yr.

Tree biomass on the northern aspect ranged between 128.88 ± 11.11 t/ha and 157.17 ± 15.09 t/ha during the first year, which increased to 131.58 ± 12.64 t/ha and 158.97 ± 9.39 t/ha. Tree carbon ranged between 61.21 ± 5.06 t/ha and 74.66 ± 7.17 t/ha during the first year, which increased to 62.50 ± 6.04 t/ha and 75.51 ± 4.46 t/ha during the second year. Carbon sequestration rates ranged between 0.43 ± 0.04 t/ha/yr and 2.71 ± 0.85 t/ha/yr on the northern aspect. The northern aspect shows larger values of tree biomass as well as tree carbon in comparison with the southern aspect (Table 3).

Discussion

The present study deals with the influence of slope aspect and slope position on the variation in tree biomass and carbon sequestration rates across chir pine forests in the Kumaun Himalaya region. The results showed a remarkable difference between the tree biomass and carbon sequestration rates across the aspects, and the forest located on the northern aspect showed higher rates of carbon sequestration in comparison with the forest located on the southern aspect. The forests account for 48 percent of the total carbon-storage capacity across terrestrial ecosystems around the globe (Watson et al. 2000, IPCC 2001); therefore, it is very important to promote this green sequestration by these native forests. Trees form the prime part of forest and contribute significantly to the absorption of atmospheric carbon dioxide and storing it in the biomass in the form of carbon. This phenomenon has been reported as autotrophic and heterotrophic respiration by several authors (Folega et al. 2010), and the above- and below-ground component contributes significantly to the carbon stock of the forests (Liu et al. 2014).

In the present study, the tree density ranged between 390 and 3,050 individuals/ha across the study sites, which falls between the ranges of tree density values for native pine forests reported by Chaturvedi (1983), and the larger amount of saplings present at specific sites such as the hill base of Site I and Site IV. It indicates the dominance of younger trees, which is a feature of a good reproduction (Saxena and Singh 1982), thus forming the base for greener sequestration. The tree basal area ranged between 16.47 and

Table 3.—Distribution of tree biomass (tons per hectare), tree carbon (tons per hectare), and carbon sequestration rates (tons per hectare per year) across the studied forests.

Site	Aspect	Slope position	Tree biomass (t/ha) Y1	Tree biomass (t/ha) Y2	Tree carbon (t/ha) Y1	Tree carbon (t/ha) Y2	Carbon sequestration rates (t/ha/yr)
I	Southern	Ridge top	97.87 ± 9.84	100.71 ± 18.17	46.48 ± 4.67	47.84 ± 8.63	3.96 ± 1.36
		Mid-hill Slope	136.76 ± 15.42	137.76 ± 15.54	64.96 ± 7.32	65.43 ± 7.38	0.47 ± 0.06
		Hill base	142.26 ± 12.01	143.42 ± 12.03	68.12 ± 5.71	69.94 ± 5.70	1.82 ± 0.01
II	Southern	Ridge top	135.28 ± 4.56	136.48 ± 4.56	64.26 ± 1.03	64.83 ± 2.17	1.14 ± 0.57
		Mid-hill Slope	134.96 ± 3.39	135.40 ± 3.41	64.11 ± 1.61	64.31 ± 1.62	0.2 ± 0.01
		Hill base	144.62 ± 11.00	146.06 ± 11.04	68.69 ± 5.23	69.38 ± 5.24	0.69 ± 0.01
III	Northern	Ridge top	128.88 ± 11.11	134.41 ± 10.66	61.21 ± 5.06	63.84 ± 5.28	2.63 ± 0.22
		Mid-hill Slope	135.93 ± 9.28	138.64 ± 5.352	64.57 ± 2.54	65.85 ± 4.41	1.87 ± 1.28
		Hill base	130.67 ± 12.73	131.58 ± 12.64	62.07 ± 6.00	62.50 ± 6.04	0.43 ± 0.04
IV	Northern	Ridge top	150.71 ± 13.83	152.67 ± 15.24	71.58 ± 6.57	72.51 ± 7.24	0.93 ± 0.67
		Mid-hill Slope	157.17 ± 15.09	158.97 ± 9.39	74.66 ± 7.17	75.51 ± 4.46	2.71 ± 0.85
		Hill base	134.79 ± 14.69	135.13 ± 16.01	64.02 ± 6.97	64.19 ± 7.60	0.63 ± 0.17

Table 4.—Comparison of above-ground tree biomass (tons per hectare) between Himalayan forests and world forests.

Species	Tree biomass (t/ha)	Reference
Oak–Pine mixed forest (United States)	102	Whittaker and Woodwell (1969)
Pinus patula forest (Darjeeling, West Bengal)	381.3	Singh (1979)
Pinus roxburghii forest (Kumaun Himalaya)	113–283	Chaturvedi (1983)
Pinus roxburghii and *Quercus leucotrichophora* mixed forest (Kumaun Himalaya)	426	Rana et al. (1989)
Pinus roxburghii forest (Kumaun Himalaya)	163.1	Rana (1985)
Pinus roxburghii forest (Central Himalaya)	200	Singh and Singh (1992)
Pinus roxburghii undisturbed forest (Central Himalaya)	280.94–405.52	Raikwal (2009)
Pinus roxburghii forest (Central Himalaya)	—	Sharma and Singh (2010)
Pinus roxburghii and *Quercus leucotrichophora* mixed forest (Kumaun Himalaya)	179.36–485.61	Rawat et al. (2011)

44.28 m^2/ha among the slope positions across the sites, which signifies that at some slope positions the trees are greater in density and in young growth stage, whereas greater basal area indicates the dominance of mature trees with lower density. The greater basal area also relates to higher sequestration and carbon storage capacity.

The tree biomass values across the different slope positions varied between 97.87 ± 9.84 t/ha and 146.06 ± 11.04 t/ha on the southern aspect, whereas tree biomass ranged between 128.88 ± 11.11 t/ha and 158.97 ± 9.39 t/ha on the northern aspect. These values were similar to those reported by Singh (1979), Chaturvedi (1983), Rana (1985), and other authors for pine forests around the world (Table 4). It is important to identify the slope aspect and slope position for the future planting strategy so that the larger yield can be attained from planted trees, and newly planted patches can provide better carbon sinks in the future.

Recent studies in this region have also shown the variation in tree biomass of pine forest between 63.12 ± 7.24 t/ha for above-ground biomass and 17.52 ± 1.92 t/ha for the below-ground biomass (Yadav et al. 2019). The variation among biomass across sites is basically dependent on the presence of mature trees; this was also reported by Kumar et al. (2019), who reported total biomass of 174.03 ± 55.17 t/ha.

Forests located on the northern slope aspect had higher biomass values than the forests located on the southern aspect; and the base position of sites played a significant role in biomass accumulation, which tended to be higher. This could be caused by the storage of nutrients after the downward leaching of nutrients, less disturbance from lopping, higher moisture content, less felling, and low fire frequency in comparison with the other slope conditions (i.e., ridge top and mid-hill slope), as well as increased duration of daylight across the northern aspects, which have been reported at the study locations. On the other hand, the highly disturbed sites on both slope aspects showed less biomass accumulation and a lower rate of carbon sequestration, which requires more detailed microclimate-based studies.

Previous studies have estimated great potential for carbon storage in Indian forests, especially through increasing the area covered by plantations (e.g., Lal and Singh 2000, Bhadwal and Singh 2002, Manhas et al. 2006, Hooda et al. 2007, Baishya et al. 2009). Dense forests have become a sink for carbon and an offset to the rising concentrations of greenhouse gases in the atmosphere (Houghton et al. 2000). Carbon storage in Uttarakhand Himalayan forests ranged from an average of approximately 175 t C/ha for *Pinus roxburghii* forests to approximately 300 t C/ha for *Quercus leucotrichophora* and *Shorea robusta* forests, although higher values are also reported (LEAD India 2007).

The tree carbon sequestration rates ranged between 0.2 ± 0.01 t/ha/yr and 3.96 ± 1.36 t/ha/yr across the study sites. These values are within the range reported by Singh et al. (1985) that denotes that the carbon sequestration rate of Uttarakhand forests ranged between 59 t C/ha in better managed forests and 1.5 to 3 C t/ha in the medium-quality forests. These rates were approximately similar to the earlier rates of carbon sequestration (4.4 t/ha/yr) reported (Table 5) for pure *Pinus roxburghii* by the Kyoto Think Global Act Local project report (2004) and Pant and Tewari (2013, 2014), whereas carbon sequestration rates for forests located at more northern aspects were on the higher side because of the greater density of young trees along with the presence of mature trees with greater biomass.

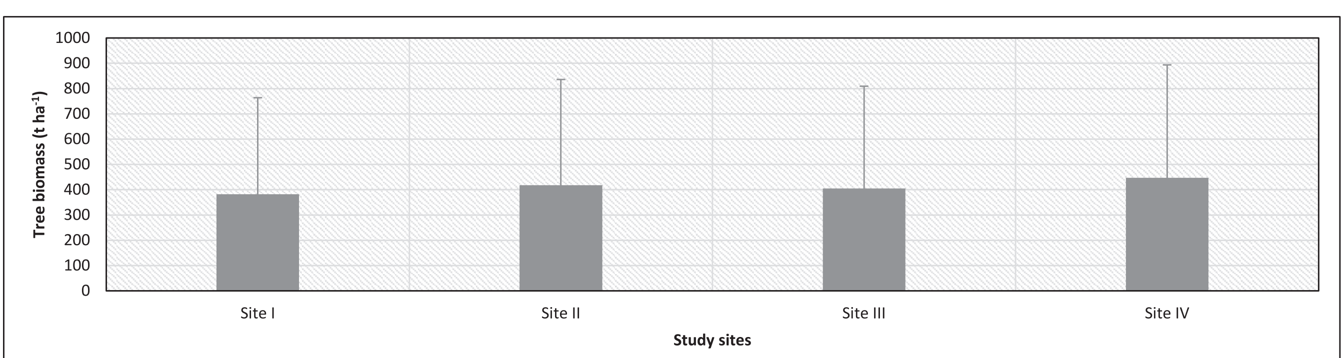

Figure 2.—Distribution of mean tree biomass (tons per hectare t ha^{-1}) across the study sites (bars show fluctuations in values across the sites).

Table 5.—Comparison of carbon sequestration rates of different forest species in central Himalayan forests and world forests.

Forest	Carbon sequestration rate (t/ha/yr)	References
Tropical forest	2.3	Malhi et al. (1998), Press et al. (2000)
Temperate forest	4.19	
Boreal forest	1.4	
Indian Himalayan forest (mean)	2.59	
Mixed *Quercus leucotrichophora* forest	3.6	Kyoto Think Global Act Local (2004)
Quercus semecarpifolia forest	4.51	Singh et al. (2006)
Mixed *Quercus floribunda* forest	8.85	Sah (2005)
Young *Shorea robusta* forest	3.3	Singh et al. (2006)
Old *Cedrus deodara* forest	3.89	Singh (2008)
Mixed *Pinus roxburghii* forest	4.1	Kyoto Think Global Act Local (2004)
Pure *Pinus roxburghii* forest	4.4	Kyoto Think Global Act Local (2004)
Quercus leucotrichophora (Kumaun Himalaya)	1.04–5.0	Singh (2009)
Quercus leucotrichophora and *Pinus roxburghii* mixed van panchayat	56.05–59.85	Rawat et al. (2011)
(Kumaun Himalaya)	21.61–25.03	
Quercus semecarpifolia forest (Kumaun Himalaya)	1.43–3.82	Verma (2012)
Pure *Pinus roxburghii* forest (Kumaun Himalaya)	3.1–6.07	Pant and Tewari (2013)
Mixed *Pinus roxburghii* forest (Kumaun Himalaya)	0.60–4.38	Pant and Tewari (2014)

This information leads to the emphasis on conserving the young generation of trees, specifically seedlings and saplings, for potential carbon storage because they tend to grow fast, increase the rate of carbon accumulation as they increase in biomass, and could support green sequestration as part of forming a PES system for states with a high density of native forests.

Regarding forests located in Uttarakhand Himalayas, most of the studies related to SOC were based on top soil depth (0 to 30 cm), which accounts for a small segment of soil carbon. Carbon content in this surface layer is mostly affected by climatic conditions (Jobbágy and Jackson 2000) and other disturbances, so the vertical distribution of soil carbon can change accordingly. Sheikh et al. (2012) reported that *Pinus roxburghii* forests in Garhwal Himalayas of Uttarakhand state have reported SOC values ranging between 41.60 and 64.80 t/ha.

In the present study, SOC ranged between 62.62 and 79.07 t/ha (Site I) and between 30.52 and 46.77 t/ha (Site II) on southern slope aspects; on northern aspects, it ranged between 17.36 and 30.58 t/ha (Site III) and 27.63 and 42.05 t/ha (Site IV), which is similar to the findings of Rana (1985) and Sheikh et al. (2012). SOC values in the present study are slightly higher at the forests located on southern aspects than the forests located on northern aspects, which could be due to higher humidity deposition under the carpet of pine needles.

Conclusions

The chir pine forests of the Kumaun Himalaya region have been reported to ensure multiple benefits such as fuel and fodder provision as well as revenue generation. In the present study we found that the young trees as well as slope position play a significant role in carbon sequestration. The potential of these forests in terms of carbon-stocks capacity can help the state of Uttarakhand earn carbon credits, reduce deforestation, and eliminate poverty in the long term by ensuring the sustainable management of these forests. On the basis of carbon sequestration potential, these chir pine forests could play an important role as a carbon sink. Thus, knowing the carbon stocks of chir pine forests of Uttarakhand could be a vital contribution to sustainable management of this forest ecosystem and to support the PES system in conjunction with the REDD+ process for obtaining carbon credits and eventual sustainable management of these native forests.

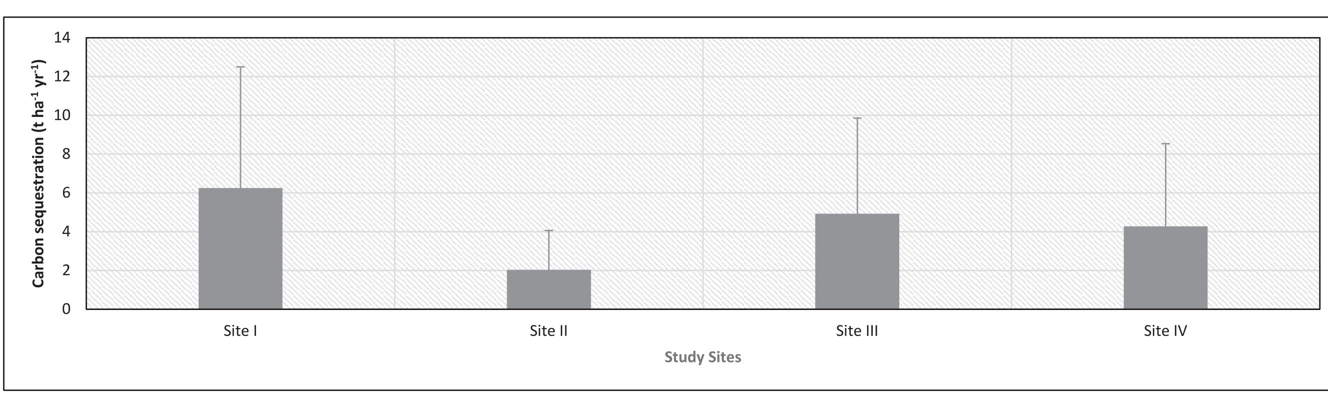

Figure 3.—Distribution of carbon sequestration rates (tons per hectare t ha^{-1}yr^{-1}) across the study sites (bars show fluctuations in values across the sites).

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