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Assessment of Tree Carbon Stocks of Forests: A Case Study of the Sarwari Khad Watershed, Western Himalaya, India

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Abstract

Forests play a crucial role in the global carbon cycle. Quantification of carbon stocks in the forests of the Himalaya has important implications for climate change mitigation and adaptation. The carbon stocks of the various forest types in the Sarwari khad watershed in Western Himalaya covering subtropical and temperate vegetation (1430 m asl to 2260 m asl) were estimated. The above-ground biomass density was estimated using the biomass expansion factor (BEF) method while the below-ground biomass density was estimated using a regression equation. The different forest types included *Aesculus indica* dominated community, *Pinus wallichiana* dominated community, *Quercus floribunda* dominated community, *Pinus roxburghii* pure stand on slopes, and *Alnus nitida* dominated community and *Pinus roxburghii* dominated community in riparian areas. The total live tree carbon density values ranged from 129.29 Mg ha^{-1} in the riparian subtropical *Alnus nitida* dominated community to 356.74 Mg ha^{-1} in the temperate *Aesculus indica* dominated community. The tree carbon density values showed a strong positive correlation with elevation. The elevation effect was also moderated by other factors affecting carbon stocks, especially the culture of the local people.

Introduction

Forests form an important part in the global carbon cycle (Malhi *et al.*, 2002). They store large quantities of carbon and become sources of atmospheric carbon under anthropogenic or natural disturbances (Brown *et al.*, 1996). Carbon sequestration through forestry as a Clean Development Mechanism (CDM) of climate change mitigation under the Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiative of the United Nations Framework Convention on Climate Change (UNFCCC) provides economic incentives to forest-rich developing countries to protect, better manage, save and enhance their forest carbon stocks, thus promoting the global fight against climate change (Angelsen, 2009). The developing countries require properly validated estimates of forest carbon stocks for effectively taking advantage of the REDD+ program (Salimon *et al*., 2011). Hence, the present study was undertaken with the objective of conducting a case study of a Western Himalayan watershed regarding the biomass and carbon stock in its different forest types so that the information can be used to make decisions about carbon management in these forests.

Materials and Methods

Study area

The study was carried out in the Sarwari Khad watershed in Lug Valley, Kullu, Himachal Pradesh. The studied area lies between 31°55'N to 31°57'N latitude and 77°01'E to 77°02'E longitude (Figure 1). Mid to high hills form the geography of the region. The high hill regions receive snowfall during winter months and serve as a fresh water source for the Beas Basin of Himachal Pradesh. The vegetation of the region is subtropical in the lower hills to temperate in the high hills. The ambient temperature ranges between 7.9°C to 25.6°C (Dundi, 2012). The forest communities studied are localised in the elevation range of 1430 m asl to 2260 m asl.

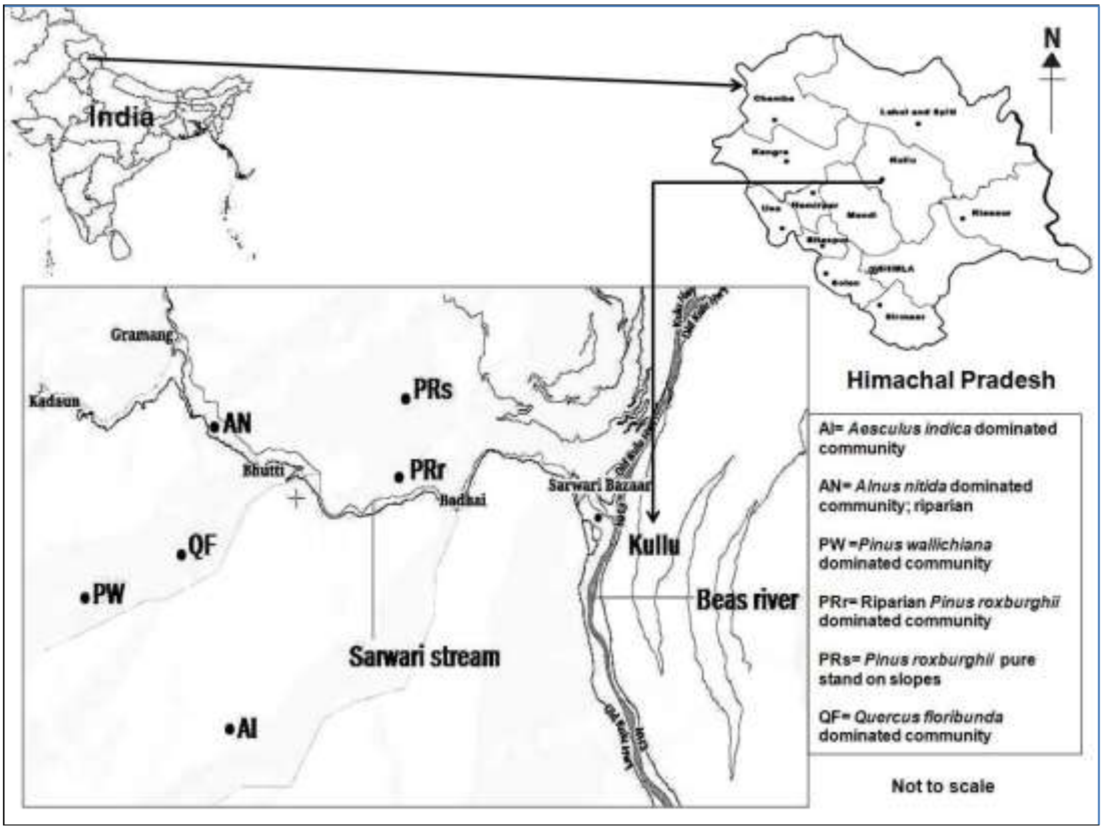

Figure 1 Location map of the study area.

Sampling and data analysis

Carbon stock was assessed following Pearson et al. (2007). Large trees (DBH> 50cm) were enumerated in 20 cm radius circular plots. Middle sized trees (20-50 cm DBH) and small sized trees (10-20 cm DBH) were measured in 14 m and 4 m radius circular plots respectively in a nested manner (Figure 2). The height and CBH (circumference at breast height) of all the trees (>31.5 cm CBH or 10 cm DBH) falling within the sample plot was measured using a measuring tape and a clinometer compass handle. A Sunoh (Japan) analog barometric altimeter of the model SAL 7030, with a resolution of 20 m was used to record the elevation of each forest site. The CBH values were converted to DBH by dividing by pi. A density-diameter distribution for each forest type was prepared. The radial measure in the vertical directions falling on sloping land was corrected in the field to get the true radius using the following formula:

$$R_c = R_r / \cos S$$

Where R_c is the corrected radius, R_r is the required radius, S is the slope in degrees and cos is the cosine of the angle. In such cases, for the horizontal radii (no slope effect) on both directions $R_c = R_r$.

First the tree carbon stock was measured in 5 plots in each forest type and the number of sample plots required for estimation with 10% precision was determined. Subsequently additional plots were sampled. The following formula as described by Pearson *et al.* (2007) was used to estimate the required number of samples:

$$n = (ts/E)^2$$

Where, E = allowable error or the desired half width of the confidence interval. Calculated by multiplying the mean carbon stock by the desired precision, i.e., mean carbon stock * 0.1 (for 10-percent precision), t = the sample statistic from the t-distribution for the 95-percent confidence level; t usually is set at 2 as sample size is unknown at this stage and s = standard deviation of stratum.

The Biomass Expansion Factor (BEF) method of Brown and Schroeder (1999) explained by Pearson *et al.* (2007) was used. The above-ground biomass density (AGBD) was calculated as:

$$\text{AGBD (t ha}^{-1}\text{)} = \text{GSVD (m}^3\text{ ha}^{-1}\text{)} \times \text{BEF (t m)}$$

Where, AGBD= above-ground biomass density, GSVD= growing-stock volume density, BEF = (total above-ground biomass of all living trees above a minimum DBH of 2.5 cm)/(growing-stock volume). [Minimum DBH taken here = 10 cm]

The growing-stock volume density (GSVD) was estimated using the volume tables or volume equations based on the Forest Survey of India (FSI) publication (FSI, 1996) for the respective species within each plot. In cases where the volume tables or volume equations for the desired species were not available, the volumes of those species were calculated using the following formula (Gevorkiantz and Olsen, 1955):

$$V = 0.42 \times B \times H$$

Where V= volume of the tree, B= basal area computed from the DBH, H= height of the tree.

The BEFs for hardwoods, spruce-fir and pines were calculated using the following equations (Schroeder *et al.*, 1997; Brown and Schroeder 1999):

Hardwoods: $BEF = \exp\{1.912 - (0.344 \times \ln GSVD)\}$ (for $GSVD \leq 200\ m^3\ ha^{-1}$),
$BEF = 1.0$ (for $GSVD > 200\ m^3\ ha^{-1}$)
Spruce − fir: $BEF = \exp\{1.771 - (0.339 \times \ln GSVD)\}$ (for $GSVD \leq 160\ m^3\ ha^{-1}$),
$BEF = 1.0$ (for $GSVD > 160\ m^3\ ha^{-1}$)
Pines: $BEF = 1.68\ Mg\ m^3$ (for $GSVD < 10\ m^3\ ha^{-1}$),
$BEF = 0.95$ (for $GSVD = 10 - 100\ m^3\ ha^{-1}$);
$BEF = 0.81$ (for $GSVD > 100\ m^3\ ha^{-1}$).

The equation of Spruce-fir was applied for other conifer dominated forest communities.

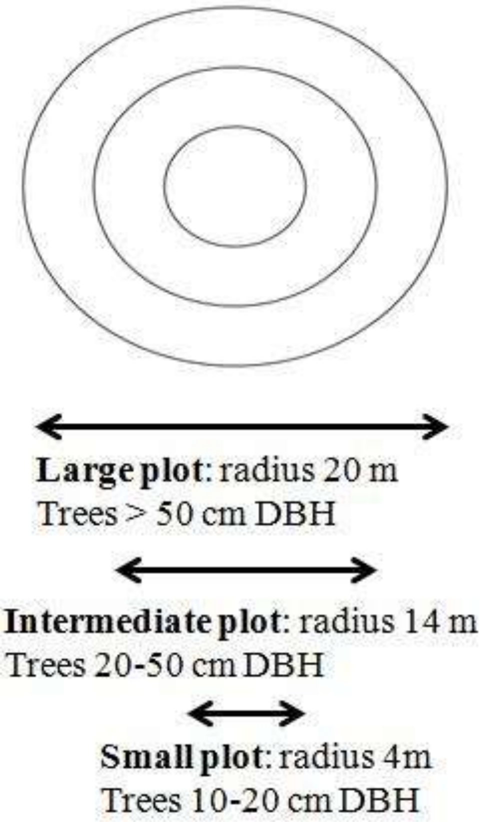

Figure 2 Nested fixed area plots for the sampling of tree carbon stocks

The below-ground biomass density, BGBD (fine and coarse roots) was estimated for each forest type using the regression equation by Cairns *et al.* (1997) as follows:

$$BGBD = \exp\{-1.059 + 0.884 \times \ln(AGBD) + 0.284\}$$

The values of AGBD and BGBD were added to get the total biomass density (TBD). The total tree carbon density (TCD) was calculated using the following formula:

$$TCD\ (Mg\ ha^{-1}) = Biomass\ (Mg\ ha^{-1}) \times Carbon\ fraction$$

Where, Carbon fraction = Carbon percentage/100

The C percentage of 46% was used for the forest communities, where all conifers together constituted more than 50%, while for the forest communities where broadleaved species represented greater than 50%, the C percentage was taken as 45% (Negi *et al.*, 2003;

Manhas *et al.*, 2006). The carbon data from the different forest types were tested for significance first through one-way ANOVA and then if the F-test was significant ($P \leq 0.05$) the Tukey-Kramer's post hoc test was used.

The local people residing in the watershed were interviewed regarding the history of the different forests found in the study area and the plantation details were collected from the forest range officer looking over the watershed area.

Results and Discussion

The different forest types studied and their site parameters are shown in table 1. These forests are of different age. The *Aesculus indica* dominated community is an older forest as compared to the other forests as is evident from the basal area value of 257.23 m^2 ha^{-1} (Table 1) compared to 33.39 to 67.06 m^2 ha^{-1} in the other communities. This becomes clearer in their density-diameter distributions (Figure 3). Interestingly, the maximum DBH class in which trees were found in the other forest types was 70-80 cm while all the trees in the *Aesculus indica* dominated forest had DBH>60 cm. Large sized trees and large basal area in the *Aesculus indica* dominated community could be attributed to protection of the site for cultural reasons. There is a sacred site for worshipping the "*Devi Kupri mata*" in the *Aesculus indica* dominated community located on the top of the hill. Local people believe that this forest developed over a village devastated by a landslide about 600 years ago. This view of the local people can be substantiated by the presence of huge rocks and boulders lying haphazard in the whole forest area. The *Pinus wallichiana* dominated community is a secondary forest developed on an agricultural land, abandoned 35 years ago. The youngest forest is the pure *Pinus roxburghii* stand as can be inferred from its tree density value of 1230 individuals per ha (Table 1) and showing the highest proportion of individuals in the 20-30 cm DBH class among all the forest types assessed in this study and having no trees in a range higher than the 30-40 cm DBH class (Figure 3). This stand was planted by the Himachal Pradesh forest department on denuded steep hill slopes (34°, the highest of all the slopes recorded in the study area, Table 1) to prevent soil erosion. The riparian subtropical *Alnus nitida* dominated community comes in the next higher age category as is indicated by the tree density value of 950 individuals per ha (Table 1) and the reverse-J shaped density-diameter distribution (Figure 3). This forest is the natural riparian vegetation in the watershed. *Alnus nitida* has a special value as it is the only tree used in cremating the dead in the study area and also its wood being drier than *Pinus roxburghii* trees found in that altitudinal range burns more easily than the latter and hence due to logging pressure, this young forest must have developed on a denuded riparian land. The *Quercus floribunda* dominated community showed a reverse-J shaped density-diameter distribution showing that regeneration is in good shape (Figure 3) and had almost the same tree density value as the *Pinus wallichiana* dominated community, but showed higher basal area than the latter (Table 1). The riparian *Pinus roxburghii* dominated community was also planted by the forest department to prevent landslides occurring due to the undercutting of the valley sides, by the fast flowing stream (Negi, 1993) but is older than the pure *Pinus roxburghii* stand on the slopes as is evident from the wider diameter distribution ranges seen in the former and from the presence of associated species including *Alnus nitida, Cedrus deodara, Pinus wallichiana* and *Salix tetrasperma* (Table 2) indicating increased species richness in the later stages of forest succession after the stem exclusion phase, which suppresses the growth of understory, saplings and seedlings (Kotar, 1997). Interestingly the *Pinus roxburghii* trees were planted by the forest department on the drier southern slopes presumably because of their ability to grow on xeric soils (Chaturvedi and Singh 1987).

Table 1: Site parameters in the different forest communities in the Sarwari Khad watershed in the Western Himalaya, Kullu, Himachal Pradesh.

Forest Communty	**Elevation (m asl)**	**Aspect**	**Slope**	**Basal area[a] (m^2 ha^{-1})**	**Tree density[a] (no. per ha)**	**Associated tree species**	**Site history**
Aesculus indica dominated community	2260	NW (320)	19°	257.23 ± 29.24	263.64 ± 20.33	*Acer caesium, Juglans regia, Picea smithiana, Ulmus villosa*	Forest developed after a landslide devastated a village about 600 years ago.
Pinus wallichiana dominated community	2180	NE (70)	21°	47.98 ± 4.48	790.00 ± 67.41	*Cedrus deodara, Cornus macrophylla, Picea smithiana, Pyrus pashia, Quercus floribunda, Quercus leucotrichophora, Taxus wallichiana*	Forest developed after abandonment of agriculture about 35 years ago. Terraces present.
Quercus floribunda dominated community	1940	NE (40)	18°	58.39 ± 5.95	790.91 ± 66.68	*Pinus wallichiana*	Natural forest.
Pinus roxburghii stand on mountain slope	1720	S (180)	34°	67.06 ± 3.94	1230.00 ± 78.95	None (pure stand)	Planted by the forest department between 1975-1980.
Alnus nitida dominated community; riparian	1440	N	0-10°	33.39 ± 2.93	950.00 ± 79.23	*Morus serrata*	Young riparian natural forest.
Pinus roxburghii dominated community; riparian	1430	SW (230)	0°	62.75 ± 5.03	720.00 ± 40.00	*Alnus nitida, Cedrus deodara, Pinus wallichiana, Salix tetrasperma*	Planted by the forest department between 1975-1980.

[a] mean ± standard error

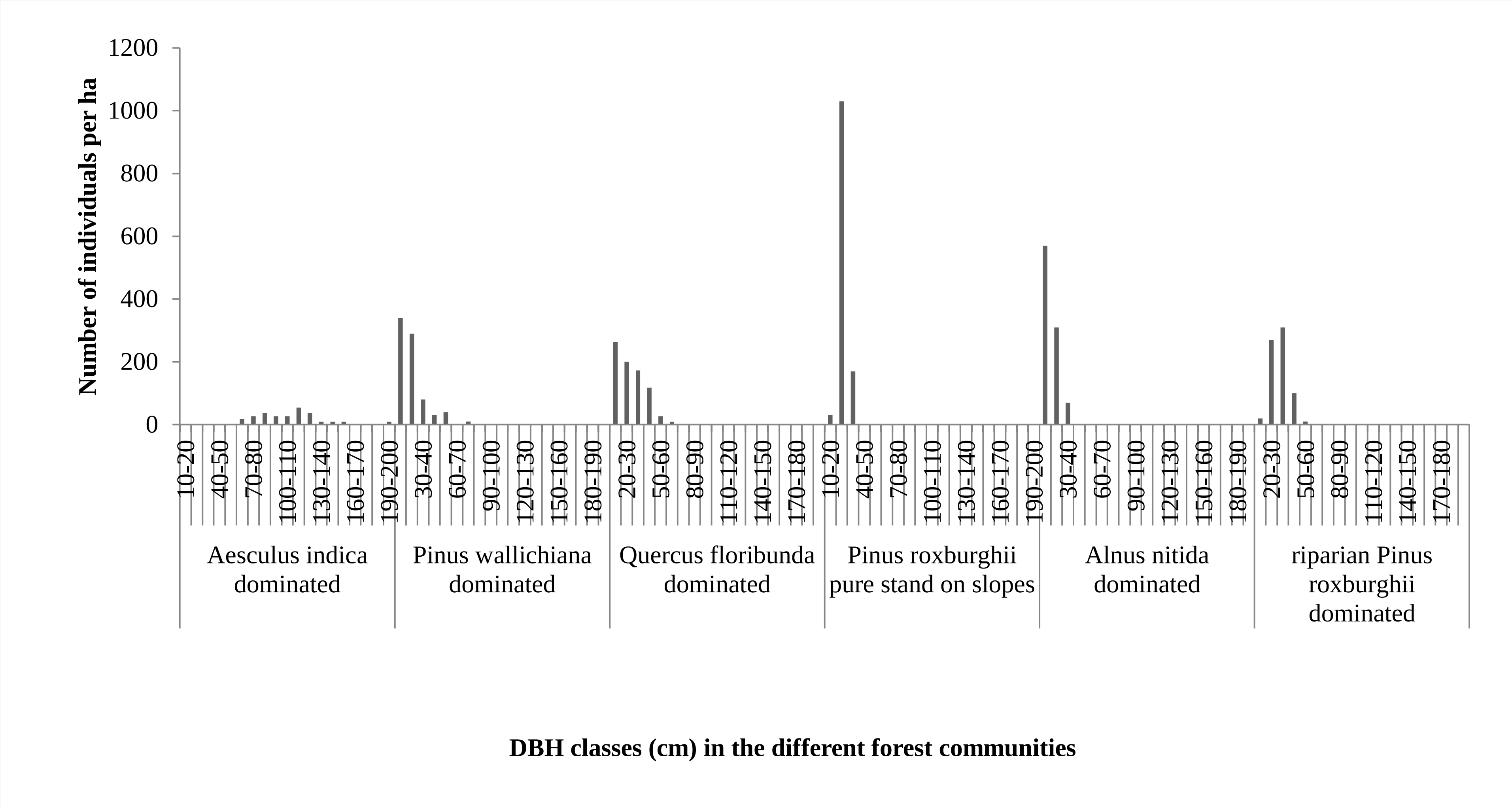

Figure 3: Density-diameter distribution of the trees in the different forest communities of the Sarwari Khad watershed in the Western Himalaya, Kullu, Himachal Pradesh.

The total basal area ranged from 33.39 m^2 ha^{-1} in the Alnus nitida dominated community to 257.23 m^2 ha^{-1} in the *Aesculus indica* dominated community, which can be explained by their diameter distribution (Figure 3). Based on the Tukey-Kramer post hoc test (Table 2), the AGBD, BGBD, TBD, and TCD values of the *Aesculus indica* dominated community were significantly different from all the other forest communities studied in the area, which should be evident from the fact of it being a way too older than all the other forest communities. The plantations must have been required because of denudation of the forest cover in those areas as a result of anthropogenic disturbance. The AGBD, BGBD, TBD, and TCD values of the *Pinus wallichiana* dominated community, the *Quercus floribunda* dominated community, the *Pinus roxburghii* pure stand on mountain slope and the riparian *Pinus roxburghii* dominated community were not significantly different (P<0.05). The *Pinus wallichiana* dominated community however differed significantly (P<0.05) in these values from the riparian *Alnus nitida* dominated community, which could be explained based on the difference in age and the basal area of these two forest communities.

Table 2: The tree carbon stock values (Mg ha^{-1}) in the different forest communities of the Sarwari Khad watershed in the Western Himalaya, Kullu, Himachal Pradesh.

Forest community	n	AGBD	BGBD	TBD	TCD
Temperate forest					
Aesculus indica dominated community	7	652.07 ± 82.14^{a}	140.68 ± 15.59^{a}	792.75 ± 97.72^{a}	356.74 ± 43.97^{a}
Pinus wallichiana dominated community	14	425.01 ± 49.95^{b}	96.17 ± 9.57^{b}	521.18 ± 59.53^{b}	239.74 ± 27.38^{b}
Quercus floribunda dominated community	6	232.80 ± 10.87^{bc}	60.84 ± 2.67^{bc}	293.64 ± 13.44^{bc}	132.14 ± 6.05^{bc}
Subtropical forest					
Pinus roxburghii pure stand on mountain slope	6	270.81 ± 9.95^{bc}	69.55 ± 2.46^{bc}	340.36 ± 12.26^{bc}	156.57 ± 5.64^{bc}
Riparian *Alnus nitida* dominated community	8	227.51 ± 9.23^{cd}	59.81 ± 2.24^{cd}	287.31 ± 11.41^{cd}	129.29 ± 5.13^{cd}
Riparian *Pinus roxburghii* dominated community	7	285.04 ± 22.22^{bc}	67.90 ± 4.70^{bc}	352.94 ± 26.93^{bc}	162.35 ± 12.39^{bc}
Mean values for the study area		349.21 ± 67.29	82.49 ± 12.83	431.36 ± 80.17	196.14 ± 36.04

Values are in the form of mean±standard error; different letter superscripts in a column point out significant differences (P<0.05) following Tukey-Kramer's post hoc test; n = number of plots sampled

The tree carbon density values ranged from 129.29 Mg ha^{-1} in the *Alnus nitida* dominated community to 356.74 Mg ha^{-1} in the *Aesculus indica* dominated community. Except for the *Aesculus indica* dominated community, the AGBD in all the sites ranged from 227.51 Mg ha^{-1} in the *Alnus nitida* dominated community to 425.01 Mg ha^{-1} in the

Pinus wallichiana dominated community, falling within the range of values reported by Sharma *et al.* (2010) in the sub-tropical to temperate zones (350 m asl–3100 m asl) of district Pauri of Garhwal Himalaya, Uttarakhand, India. The tree carbon density value in the *Aesculus indica* dominated community was 356.74 Mg ha^{-1}, which was 52.39% higher than the value for a similar forest reported by Gairola *et al.* (2011) in the Mandal-Chopta forest area of Garhwal Himalaya. The tree carbon density value of the *Pinus wallichiana* dominated community was 239.74 Mg ha^{-1} which was 13.5% lower than that of a similar forest recorded by Dar and Sundarapandian (2015) in the temperate zone of Anantnag district of Kashmir Himalaya in Jammu and Kashmir, India. The average values of TBD and TCD for the study area were 431.36 ± 80.17 Mg ha^{-1} and 196.14 ± 36.04 Mg C ha^{-1} respectively, which were higher than the values obtained by Gairola *et al.* (2011) of 356.8 ± 83.0 Mg ha^{-1} for TBD and 178.4 ± 41.5 Mg C ha^{-1} for TCD in a similar valley slopes of Garhwal Himalaya, India. According to Chhabra et al. 2002, the mean biomass in Indian forests in 1993 was 135.6 Mg ha^{-1}, and among all the states, the highest was recorded in Jammu and Kashmir with the value of 251.8 Mg ha^{-1} and the lowest was found in Punjab with 27.4 Mg ha^{-1}.

The tree carbon density values showed a strong positive correlation (Figure 4) with elevation *($r = 0.7654$; $R^2 = 0.5850$)*. The elevation effect was also moderated by other factors affecting carbon stocks. It was only the *Aesculus indica* dominated community at the highest elevation that was protected for religious values. A similar correlation was found by Gairola *et al.* (2011).

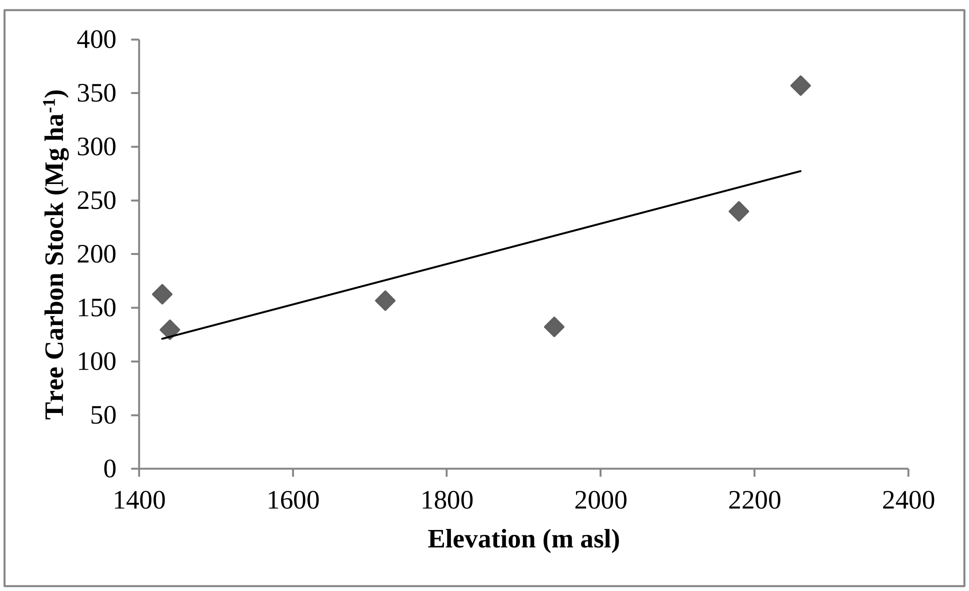

Figure 4: Scatter plot of the tree carbon stock values against elevation in the different forest communities of the Sarwari Khad watershed in the Western Himalaya, Kullu, Himachal Pradesh.

Correlation with elevation: Pearson's correlation coefficient, $r = 0.7654$ and R^2, the coefficient of determination = 0.5850

Conclusions

The highest amount of carbon in the trees was found in the *Aesculus indica* dominated community, which is an older forest compared to the other forest communities in the area and is also under religious protection. This value was higher than values reported for other temperate forests of the Himalaya. This indicates the significance of religious values in the preservation of natural regions in the Himalayas. Hence it is of utmost importance to preserve these forests as a step towards mitigation of global climate change. The least amount of carbon in the trees was found in the riparian *Alnus nitida* dominated community, which is a young forest and is under logging pressure because of their wood being drier, thereby burning more readily than the other trees in the locality and also being the sole one used for the cremation of the dead in the study area. The tree carbon stock values showed a strong positive correlation with elevation. These conclusions point out the implication of culture in the carbon stock values of a landscape.

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Authors' contributions: Mr. S. Ghoshal *developed the main research design; did all the field work, made the final discussion, conclusion, wrote the manuscript and also corresponding author of manuscript.* ***Dr. S. S. Samant*** *added points in the research design, helped in the site selection and identified all the plants in the study area.*

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