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Research paper

Carbon Stocks and Anthropogenic Disturbances in Temperate Coniferous Forests of Jammu Region in Western Himalaya, India

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Abstract:

The present study was conducted in moist temperate coniferous forests (1700 to 2800 m asl) of the Bhadarwah region in Jammu division, Union Territory of Jammu & Kashmir (J&K), India, to assess forest biomass, carbon (C) stocks and anthropogenic disturbances prevalent in these forests. Based on the results of the present study, an effort has been made to make practical recommendations for sustainable forest management and C conservation/ sequestration. Eight forest types were selected based on altitude, slope aspect, and dominant tree species. Soil organic carbon (SOC), forest biomass, and C stocks in different forest types were estimated. Significant anthropogenic disturbances in the forest area were identified as grazing by domestic animals, stem cutting, soil erosion, and tree lopping for fuelwood and fodder extraction. Total biomass C density ranged between 15.04 and 260.90 Mgha^{-1}. The values of SOC density ranged from 65.07 to 191.89 Mgha^{-1}. Carbon loss due to anthropogenic activities was estimated to be significantly high at middle altitudes (180.95 Mgha^{-1} in the mixed coniferous forest). Disturbance indices also suggested that middle altitudinal forests were more disturbed. These coniferous forests were found to be very productive and stored large amounts of C in them. Therefore further degradation of these forests will cause loss of large quantities of C stored in vegetation and soils of these forests.

Keywords: Forest biomass; carbon stocks; anthropogenic disturbances; soil organic carbon; disturbance indices.

Introduction

Conifers form a distinct group of plants which are very important in the world’s economy, because they grow on poor soils even under harsh climates, yield timbers that are very suitable for industry and provide a wide range of beneficial non-wood products viz., essential oils, resins, ornamental plants, edible seeds, flavorings, and medicinal products. Coniferous forests constitute a precious global resource not only because of their high ecological, economic, and aesthetic importance but also due to large amounts of Carbon (C) sequestered in them. These forests play an essential role in regional and global C cycles and act as a reservoir of C in their vegetation and soils. Several studies have established that growing trees for C sequestration can provide relatively low-cost net emission reductions for several countries (Bruce et al., 1996), but conservation of forests with vast quantities of C already stored in them is equally important. Therefore, in this context, conservation and reforestation of degraded/disturbed natural coniferous forests are essential. As per the classification of Champion and Seth (1968), western Himalayan forests can be broadly classified into coniferous and broad-leaved forests. Coniferous forests form significant forest cover in the western Himalaya (Shah et al., 2014). Evergreen temperate coniferous forests are dominant in the region; however, a mix of conifers and broadleaf evergreen or deciduous trees can be seen in some of the forests. Temperate coniferous forests in western Himalaya generally sustain high levels of biomass and C stocks as compared to broad-leaved forests of the region (Sharma et al., 2010a).

Jammu division of J&K, India harbors rich biodiversity and luxuriant coniferous forests. Due to unusually wide altitudinal range, rapid change in altitude even at small distances, high endemism, and high amount of stored biomass and C stocks make forests very interesting for ecological studies. Like coniferous forests in other parts of the western Himalaya, these forests are also facing a threat due to anthropogenic disturbances, especially in the vicinity of human habitations. Felling of coniferous trees for timber, fuelwood, resins, raw material, and various other purposes is common in the region. In many cases, both wood and non-wood products from coniferous forests have been over-exploited to the point where extensive damage or loss of these forests has resulted. Ecological factors control the species distribution pattern, composition, and structure of the forests (Hubbell et al., 1999). Understanding forest structure is a prerequisite to describing various ecological processes and modeling the functioning and dynamics of the forests (Elourard et al., 1997). The distribution and dynamics of biological resources must be understood to provide a rational basis for planning and management decisions, without which conservation of these resources in the natural habitats would not be possible (Khoshoo, 1992). It has been realized that the knowledge of forest biomass and C stocks is essential to the conservation and restoration of the environment for the sound management of the Himalayan ecosystem. Therefore, for reforestation/ afforestation, conservation and management of coniferous forests, understanding of distributional range, suitable habitats, and extent and types of disturbances affecting them is necessary.

Lots of studies regarding the structure and composition of temperate forests along an altitudinal gradient have been conducted in other parts of western Himalaya. Still, there is a lack of studies exclusively related to the coniferous forests of the region except few attempts made by Sharma and Baduni (2000) and Sharma et al. (1999, 2001, 2010a, 2010c, 2011b). However, in some earlier studies in other parts of western Himalaya relationships between forest utilization pattern and socioeconomic status of rural people (Sharma et al., 2009a, 2009b, 2011a, 2012), tree biomass and C stocks of major forest types (Gairola et al., 2011a; Sharma et al., 2010a, 2011b), physicochemical properties of soils (Gairola et al., 2012a; Sharma et al., 2010b, 2010c), regeneration dynamics (Gairola et al., 2012b), composition and diversity (Gairola et al., 2011b, 2011c, 2011d; Sharma et al., 2010c, 2010d; Rana et al., 2010) were studied. Information about forest biomass, C stocks, carbon stocks, and prevalent anthropogenic disturbances in the coniferous forests of the

Jammu region is meager. Therefore, keeping the facts described above in view, the present study was undertaken to assess biomass, C stocks and, types and effects of anthropogenic disturbances in the coniferous forests of the Bhadarwah region of Jammu, J&K, India. Based on the results of the present study, an effort has been made to make practical recommendations for sustainable forest management and C conservation/ sequestration.

Material and methods

Study area

The present study was undertaken in conifer dominated forests of Bhadarwah forest division in Doda district of Jammu division in Jammu & Kashmir (J&K) state of India (Figure 1). Bhadarwah forest division has four forest ranges with a total forest area of 1,10,038 ha (Dutt and Kant, 2007). J&K is a predominantly Himalayan state in the north-western part of India (32° 17' N – 36° 58' N latitude, 73° 26' E – 80° 30' E longitude) (Singh, 1995) with an area of 222,236 km^2 (FSI, 2011). It shares a border with the states of Himachal Pradesh and Punjab to the south, and the international border with China in the north and east, whereas Line of Control separates it from Pakistan in the west and northwest. The state is mainly mountainous, except for a short belt adjoining the Punjab plains and Kashmir valley (Figure 1). Forests of the state harbor rich biodiversity with large amounts of C stocks. There are 4439 species (1220 genera and 189 families) of Angiosperms in the state (Singh et al., 1999), and more than 948 plant species are traditionally used as medicine by the indigenous communities of J&K (Gairola et al., 2014). The climate of the study area is a typical moist temperate type, which receives moderate to heavy snowfall during the winter. There are three main seasons in the study area viz., monsoon, or rainy season (July-Sept), warm and dry summer (April-June) and, relatively cool and dry winter (December-March).

The conifer tree species dominate the majority of the forests of the region. As per the classification of Champion and Seth (1968), the study area has west Himalayan dry temperate deciduous (13/C_3), west Himalayan subalpine fir (15/C_1) and moist *Cedrus deodara* (12/C_1C) forests. The preliminary reconnaissance survey of the study area was carried out to determine the nature of the terrain, tree composition, and accessibility of different forest types. Basing on the criterion of dominant tree species, slope aspect, and altitude, eight major forest types were selected for the present study (Table 1). Plants were identified with the help of floras viz., Brandis (1906), Sharma and Kachroo (1981), Sharma and Jamwal (1988, 1998), and Gaur (1999), and matched with authentic herbarium specimens stored at internationally recognized Janaki Ammal Herbarium (RRLH). Valid botanical names with author citations of all the plant species were verified from www.theplantlist.org, Version 1.1 (TPL, 2013). Sampling for the present study was conducted in the natural coniferous forests only, whereas barren lands, forests along roadside, village areas, village governed forest areas, and grasslands were intentionally avoided.

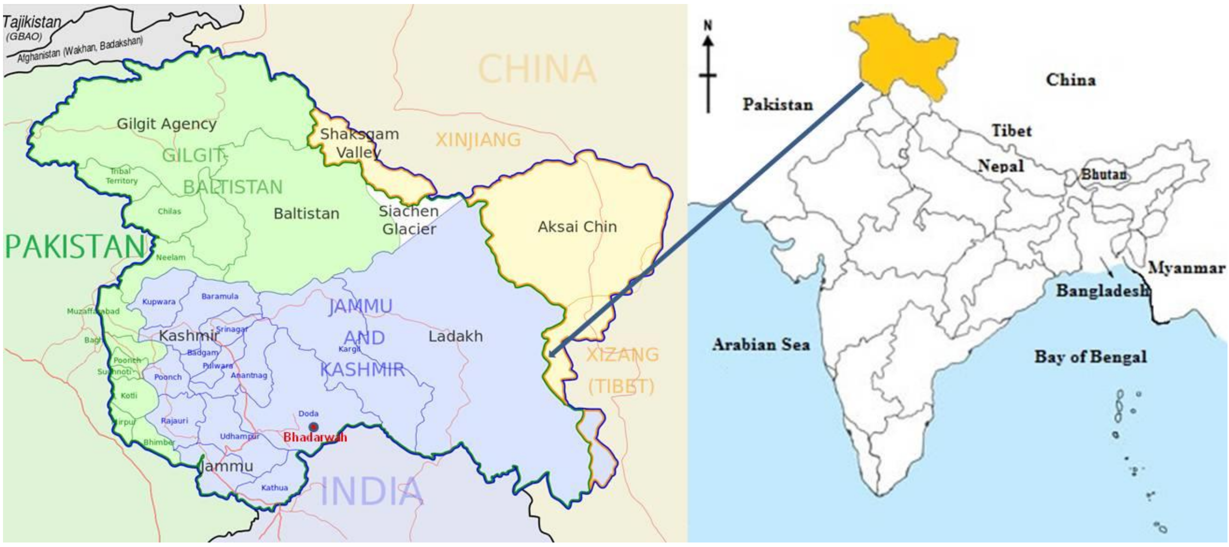

Figure 1: Location map of the study area (including UT of Ladakh) (First part of map modified from Wikipedia).

Table 1: Details of the studied forest types.

FT*	**FT1**	**FT2**	**FT3**	**FT4**	**FT5**	**FT6**	**FT7**	**FT8**
Forest Type	Pure *Cedrus deodara* forest	Pure *Cedrus deodara* forest	Pure *Cedrus deodara* forest	Mixed coniferous forest	Pure *Cedrus deodara* forest	Mixed coniferous forest	Pure *Pinus wallichiana* forest	Mixed coniferous forest
Altitude (m asl)	1700-1800	1800-1950	1950-2100	2100-2200	2200-2300	2300-2450	2450-2600	2700-2800
Slope aspect (facing)	South East	South West	North East	North East	South East	North West	South West	North West
Latitude	32° 59' 46.2"	33° 00' 23.3"	32° 56' 20.7"	32° 55' 42.0"	33° 01' 42.5"	32° 56' 11.0"	33° 01' 40.0"	32° 55' 17.4"
Longitude	75° 43' 19.7"	75° 42' 47.4"	75° 44' 02.6"	75° 45' 50.0"	75° 45' 49.6"	75° 46' 37.0"	75° 46' 13.9"	75° 47' 27.1"

*Forest types represented by FT numbers in successive tables.

Methodology

Biomass estimation and carbon stock assessment

Ten square sample plots of 0.1 ha each were laid out at each forest type (total of 10×8=80) by determining the plot center, to represent the entire altitudinal gradient of a particular forest type (Table 1). For sample plots located on a slope of > 10%, the slope was quantified so that an adjustment can be made to the plot area at the time of analysis (Sharma et al., 2010a, 2011b). The slope angle was measured using Clinometer. True horizontal distance for those arms going against the slope was calculated using the following formula:

$$L = L_s * \cos S \qquad (1)$$

Where L is the true horizontal plot distance, L_s is the standard distance measured in the field along the slope, S is the slope in degrees, and cos is the cosine of the angle. Area of the sample plot was then calculated as:

Area= Plot width × calculated true plot length (L). (2)

After laying out the sample plot, measurements were done on the individual tree basis for growing stock estimation. The height and DBH (diameter at breast height, i.e., 1.37 m) of all the trees falling within the sample plot were measured. The basal cover was calculated by dividing the square of the circumference at breast height with 4π. The basal cover was multiplied with respective densities of the species to obtain total basal cover per hectare (ha), i.e., Gha^{-1} (m^2ha^{-1}) for extrapolation of the results. The height of the trees (≥ 10 cm DBH) on different slope positions was measured following MacDicken et al. (1991). The growing stock density (GSVD) was estimated using local volume equations developed by Forest Research Institute (FRI) and Forest Survey of India (FSI) for the respective species (FSI, 1996). In few cases, where volume equations for the desired species were not available, the volume of that species was calculated as per convention by using the volume equation of similar species having similar height, form, taper, and growth rate (Sharma et al., 2010a, 2011b). The estimated GSVD (m^3 ha^{-1}) was then converted into aboveground biomass density (AGBD) of tree components (stem, branches, twigs, and leaves) by multiplying GSVD of that forest with appropriate biomass expansion factor (BEF) (Brown et al., 1999). The BEF (Mg m^{-3}) is defined as the ratio of aboveground biomass density of all living trees at DBH ≥ 2.54 cm to GSVD for all trees of DBH ≥ 12.7cm. The BEF's for spruce-fir and pine were calculated using the following equations:

Spruce-fir: $BEF= \exp\{1.77-0.34\times\ln(GSVD)\}$ (for GSVD ≤160 m^3 ha^{-1}), (3)

$BEF= 1.0$ (for GSVD > 160 m^3 ha^{-1})

Pine: $BEF= 1.68$ 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 strata. Using the regression equation by Cairns et al. (1997) the below-ground biomass density (BGBD; fine and coarse roots) was estimated for each forest type as following:

$$BGBD= \exp\{-1.059 + 0.884 \times \ln(AGBD) + 0.284\} \quad (4)$$

AGBD and BGBD were added to get the total biomass density (TBD). The total biomass C density (TBCD) was computed by using the following formula:

$$\text{Carbon (C Mg ha}^{-1}\text{)} = \text{Biomass (Mg ha}^{-1}\text{)} \times \text{Carbon \%} \quad (5)$$

The C percentage of 46% was used for the forest types, where *Abies pindrow*, *Cedrus deodara*, *Pinus wallichiana,* and all conifers together constituted more than 50 % (Negi et al., 2003; Manhas et al., 2006).

Soil analysis

In each forest type, composite soil samples were collected from 0–30 cm depth from five random sample plots (8 forest types × 5 sample plots = 40 composite soil samples). To reduce variability, soil samples from five randomly selected points in each of these five sample plots were collected and mixed to form a composite soil sample. Soil samples were packed in bags and brought to the laboratory for soil analysis. Separate soil samples were taken in the field for estimation of bulk density. Bulk density of soil was measured by taking two aggregated undisturbed blocks of soil by a metal cylinder of 30 cm in length and 3 cm in internal diameter. When taking cores for measurements of bulk density, extra care was taken to avoid any loss of soil from the samples. The exact volume of the soil taken by a metal cylinder was determined by measuring the volume of a cylinder. The soil samples were brought to the laboratory, dried in an oven at 105°C for 72 h, and then weighed till two subsequent values were constant. In the soils containing coarse rocky fragments, the coarse fragments were retained and weighed. Bulk density of the mineral soil core was calculated with the help of following formula (Brown, 2004):

$$Bulk.density.(gcm^{-3}) = \frac{Oven.dry.mass.(gcm^{-3})}{Core.volume.(cm^{3}) - \left(\frac{Mass.of.coarse.fragments.(g)}{Density.of.rock.fragments.(gcm^{-3})}\right)}$$

(6)Where, the bulk density is for the < 2mm fraction, coarse fragments are >2mm. The density of rock fragments was taken as 2.65 gcm^{-3}.

Air-dried soil samples were sieved through a 2 mm sieve and then thoroughly mixed. Walkley and Black's rapid titration method (Walkley, 1947) was used for organic carbon (C) estimation (Brown, 2004; Pearson et al., 2005). Since only about 60–86% of soil organic carbon (SOC) is only oxidized in the Walkley and Black method, a standard correction factor of 1.32 (considering the recovery of 76% organic C) was used to obtain the corrected SOC values (De Vos et al., 2007). Using the C concentration data collected by the laboratory analysis, the amount of SOC per hectare was calculated (Brown, 2004):

$$SOC\ (Mgha^{-1}) = [(soil\ bulk\ density\ (gcm^{-3}) \times soil\ depth\ (cm) \times C)] \times 100 \quad (7)$$

In this equation, the C concentration was expressed as a decimal fraction.

Anthropogenic disturbances

In each sample plot, the numbers of cut stumps of each species were identified, and their diameter was recorded. DBH of each cut stump was extrapolated based on the diameter of the cut stump at the base. The same methodology, as given in the earlier section on biomass estimation and carbon stock assessment, was used to estimate approximate C loss due to stem cutting. Anthropogenic disturbances in different forest types were visually observed for their presence or absence in that particular forest type viz., grazing, extraction of non-timber forest products (NTFPs), tree lopping for fodder, and fuelwood. Regeneration loss was observed by the presence of dead or damaged seedlings/ saplings. Loss of topsoil layer with visible water gulley or open soil surfaces were observed as evidence of soil erosion. Grazing was observed by looking for grazed/ semi-grazed remnants of flora, animal excreta in area, pug marks, and grazing animals in the area. Information about these disturbances and their intensity was also confirmed through discussion with local communities. However, these disturbances were not quantitatively estimated, but this will give us a fair idea about the extent of human intervention in these forests. Disturbance Indices (%) were calculated in percentage based on N ha^{-1} and G ha^{-1} employing the following formulae:

$$DI\,(Nha^{-1}) = \frac{CS\,(Nha^{-1})}{TS\,(Nha^{-1}) + CS\,(Nha^{-1})} \times 100 \quad (8)$$

Where DI (Nha^{-1})= Disturbance Index based on Nha^{-1}.

CS (Nha^{-1})= Number of cut stumps in that forest type per hectare.

TS (Nha^{-1})= Total number of live stems in that forest type per hectare.

$$\mathrm{DI}(\mathrm{Gha}^{-1}) = \frac{\mathrm{CS}(\mathrm{Gha}^{-1})}{\mathrm{TS}(\mathrm{Gha}^{-1}) + \mathrm{CS}(\mathrm{Gha}^{-1})} \times 100 \quad (9)$$

Where DI (Gha^{-1})= Disturbance Index based on Gha^{-1}.

CS (Gha^{-1})= $\mathrm{Gha}^{-1}$of cut stumps in that forest type per hectare.

TS (Gha^{-1})= Total $\mathrm{Gha}^{-1}$of live stems in that forest type per hectare.

Results and discussion

Biomass and carbon stocks

The values of N ha^{-1} and G ha^{-1} of tree species in different forest types are given in Tables 2. *Cedrus deodara* was the most widely distributed dominant tree species of the study area, found between 1700 and 2450 m asl (FT1 to FT6). In most of the places, it formed pure forest (FT1, FT3, and FT5). Highest density (340 N ha^{-1}) of *C. deodara* was observed between 1800 and 1950 m asl on the southwest aspect, followed by forest between 1700 and 1800 m asl on the southeast aspect (300 Nha^{-1}). However, G ha^{-1} was highest between 1950 and 2100 m asl on the northeast aspect (82.63 m^2 ha^{-1}). *Abies pindrow* was present only between 2700 and 2800 m asl on the northwest aspect, where it formed conifer mixed forest in association with *Picea simithiana* and *Pinus wallichiana*. *Picea smithiana* was distributed between 1950 and 2800 m asl. It was not dominant in any of the forest types, but between 2300 and 2450 m asl on the northwest aspect, it was a major component of the forest, where it had a density of 70 Nha^{-1} and maximum Gha^{-1} of 40.78 $\mathrm{m}^2\mathrm{ha}^{-1}$. *Pinus wallichiana* was the only coniferous tree species distributed throughout the study area from 1700 to 2800 m asl. However, at most of the forest stands, its density was relatively very low. Between 2450 and 2600 m asl, *P. wallichiana* formed pure forest with a stem density of 250 Nha^{-1}, whereas between 2300 and 2450 m asl *P. wallichiana* was co-dominant tree species with stem density of 100 Nha^{-1}.

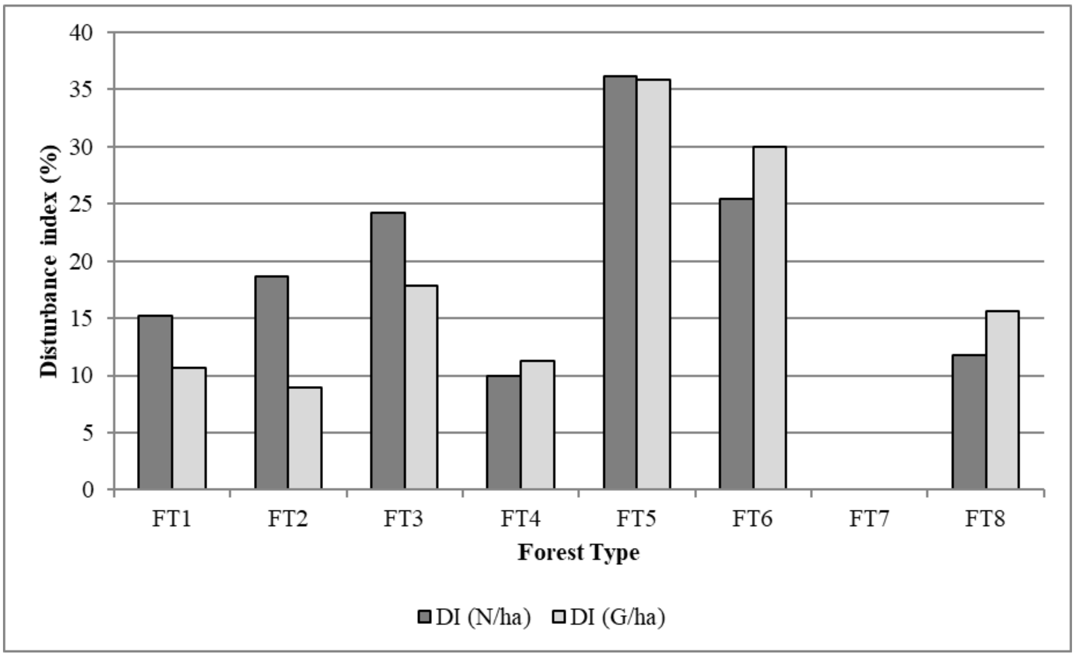

Figure 2: Disturbance indices (DI) based on cut stump Nha^{-1} and cut stump Gha^{-1}.

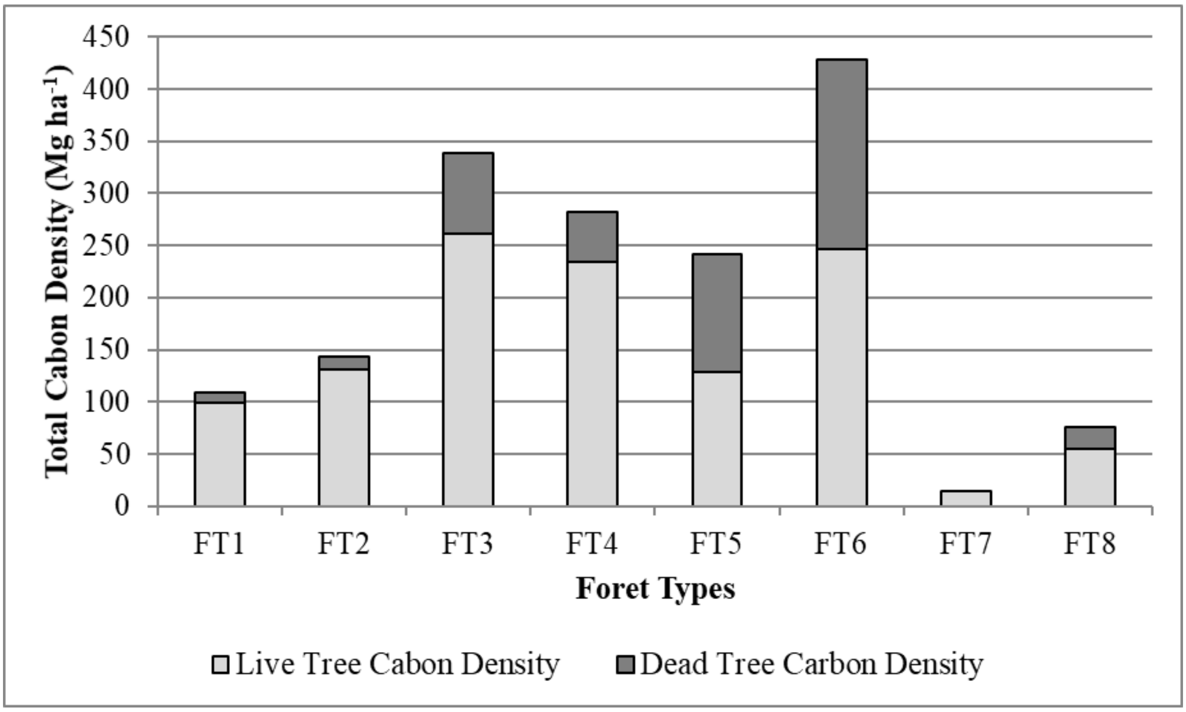

Figure 3: Carbon density in live trees and estimated C loss due to anthropogenic activities (calculated based on dead/ cut stumps).

The values of aboveground biomass density (AGBD), below-ground biomass density (BGBD), total biomass density (TBD), total biomass carbon density (TBCD), soil organic carbon density (SOCD) (top 30 cm) and total carbon density (TCD) have been given in Table 3. Lowest values of AGBD (24.82 Mgha^{-1}), BGBD (7.88 Mgha^{-1}), TBD (32.70 Mg ha^{-1}), and TBCD (15.04 Mgha^{-1}) were reported in pure *Pinus wallichiana* forest between 2450 and 2600 m asl on the southwest aspect. Whereas, highest values of AGBD (462.59 Mg ha^{-1}), BGBD (104.58 Mgha^{-1}), TBD (567.17 Mg ha^{-1}), and TBCD (260.90 Mgha^{-1}) were observed in pure *Cedrus deodara* forest from 1950 to 2100 m asl on the northeast aspect. Values of SOCD ranged from 65.07 Mgha^{-1} (pure *Pinus wallichiana* forest between 2450 and 2600 m asl on southwest aspect) to 191.89 Mgha^{-1} (pure *Cedrus deodara* forest between 2100 and 2200 m asl on northeast aspect). Total C density in different forest types ranged between 80.11 and 357.44 Mgha^{-1}. Values of biomass and C stocks in conifer dominated forests of western Himalaya and present study have been compared in Table 4. Biomass and C stocks in the forests of the study area were comparable to the other parts of the western Himalaya. The present study showed that the coniferous forests of the region were very productive and stored large amounts of C in them. Comparative values of Carbon (%) between other conifer dominated forests of western Himalaya, and the present study is given in Table 5.

Table 2: Stem density (N ha^{-1}) and Total Basal Cover (G ha^{-1}; m^2 ha^{-1}) of trees in studied forest types.

Species [Family]	**FT1**		**FT2**		**FT3**		**FT4**		**FT5**		**FT6**		**FT7**		**FT8**	
	N ha^{-1}	**G ha^{-1}**	**N ha^{-1}**	**G ha^{-1}**	**N ha^{-1}**	**G ha^{-1}**	**N ha^{-1}**	**G ha^{-1}**	**N ha^{-1}**	**G ha^{-1}**	**N ha^{-1}**	**G ha^{-1}**	**N ha^{-1}**	**G ha^{-1}**	**N ha^{-1}**	**G ha^{-1}**
Abies pindrow (Royle ex D.Don) Royle [Pinaceae]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	12.00
Aesculus indica (Wall. ex Cambess.) Hook. [Sapindaceae]	-	-	-	-	10	2.04	-	-	-	-	10	2.58	-	-	-	-
Ailanthus altissima (Mill.) Swingle [Simaroubaceae]	10	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cedrus deodara (Roxb. ex D.Don) G.Don [Pinaceae]	300	33.02	340	48.70	260	82.63	100	52.50	130	44.42	120	25.76	-	-	-	-
Crataegus rhipidophylla Gand. [Rosaceae]	-	-	10	0.10	-	-	-	-	-	-	-	-	-	-	-	-
Ficus palmata Forrsk. [Moraceae]	-	-	10	0.12	-	-	-	-	-	-	-	-	-	-	-	-
Picea smithiana (Wall.) Boiss. [Pinaceae]	-	-	-	-	10	3.51	10	3.18	-	-	70	40.78	-	-	40	1.38
Pinus wallichiana A.B.Jacks. [Pinaceae]	10	0.14	-	-	10	0.39	50	31.16	-	-	100	9.76	250	7.47	60	0.67
Quercus floribunda Lindl. ex A.Camus [Fagaceae]	-	-	10	0.13	-	-	-	-	-	-	10	0.13	-	-	-	-
Robinia pseudoacacia L. [Leguminosae]	-	-	-	-	30	1.17	-	-	-	-	-	-	-	-	-	-
Total/ha	**320**	**33.27**	**370**	**49.05**	**320**	**89.73**	**160**	**86.84**	**130**	**44.42**	**310**	**79.01**	**250**	**7.47**	**130**	**14.06**

Table 3: Forest biomass and C stocks and anthropogenic disturbances in different forest types.

FT*	**AGBD (Mg ha^{-1})**	**BGBD (Mg ha^{-1})**	**TBD (Mg ha^{-1})**	**TBCD (Mg ha^{-1})**	**SOCD in top 30 cm (Mg ha^{-1})**	**TCD (Mg ha^{-1})**	**Anthropogenic disturbances observed**
FT1	171.61	43.53	215.14	98.96	126.39	225.35	Fr, SE, TL, SC, Gr, NTFP, RL
FT2	230.02	56.39	286.41	131.75	118.92	250.67	Fr, SE, TL, SC, Gr, NTFP, RL
FT3	462.59	104.58	567.17	260.9	92.64	353.54	Fr, SE, TL, SC, Gr, NTFP, RL
FT4	415.1	95.03	510.14	234.66	122.78	357.44	SE, TL, SC, Gr, NTFP, RL
FT5	225.39	55.39	280.78	129.16	191.89	321.05	SE, TL, SC, Gr, NTFP, RL
FT6	437.54	99.56	537.09	247.06	83.08	330.14	SE, TL, SC, Gr, NTFP, RL
FT7	24.82	7.88	32.7	15.04	65.07	80.11	SE, Gr, NTFP, RL
FT8	94.7	25.73	120.43	55.4	103.36	158.76	SE, SC, Gr, NTFP, RL

*Forest types represented by FT numbers in successive tables.

Abbreviations: AGBD= Above Ground Biomass Density; BGBD= Below Ground Biomass Density; Fr= Fire; Gr= Grazing; N ha^{-1}= Density; NTFPs= Extraction of Non-Timbre Forest Products; RL= Regeneration Loss; SC= Stem Cutting; SE= Soil Erosion; SOCD= Soil Organic Carbon Density; TBCD= Total Biomass Carbon Density; TBD= Total Biomass Density; TCD= Total Carbon Density; TL= Tree Lopping.

Table 4: Comparative values of biomass and C stocks in other conifer dominated forests of western Himalaya and the study area.

Forest Type	Locality, State	Altitude (m asl)	D (Nha^{-1})	AGBD (Mgha^{-1})	TBD (Mgha^{-1})	AGCD (Mgha^{-1})	BGBC (Mgha^{-1})	TBCD (Mgha^{-1})	Source
Abies pindrow	Kumaun, UK	2500	na	454.6	565.0	213.7	na	265.6	Adhikari et al. (1995)
Abies pindrow	Pauri Garhwal, UK	2600-3100	507	305.3	377.7	na	na	173.7	Sharma et al. (2010a)
Abies pindrow	Anantnag District, J&K	2800-3250	197	237.0	313.9	109.0	26.6	na	Dar and Sundarapandian (2015)
Abies pindrow	India	na	na	na	na	65.03	na	na	Manhas et al. (2006)
Abies pindrow	India	na	na	209.8	na	104.9	na	na	Haripriya (2000)
Abies pindrow (closed forest)	Southern Kashmir, J&K	2025-2656	130	na	na	136.03	35.37	171.40	Wani et al. (2015)
Abies pindrow (open forest)	Southern Kashmir, J&K	2025-2656	110	na	na	59.46	15.46	74.92	Wani et al. (2015)
Abies spectabilis	Bhagirathi catchment, Uttarkashi Garhwal, UK	2814-3252	na	na	460.9	na	na	207.4	Sharma et al. (2015)
Cedrus deodara	**Bhadarwah, J&K**	**1700-1800**	**320**	**171.61**	**215.14**	**na**	**na**	**98.96**	**Present study**
Cedrus deodara	**Bhadarwah, J&K**	**1800-1950**	**370**	**230.02**	**286.41**	**na**	**na**	**131.75**	**Present study**
Cedrus deodara	**Bhadarwah, J&K**	**1950-2100**	**320**	**462.59**	**567.17**	**na**	**na**	**260.90**	**Present study**
Cedrus deodara	Anantnag District, J&K	2050-2300	195	228.3	292.6	105.00	25.7	na	Dar and Sundarapandian (2015)
Cedrus deodara	**Bhadarwah, J&K**	**2200-2300**	**130**	**225.39**	**280.78**	**na**	**na**	**234.66**	**Present study**
Cedrus deodara	Pauri Garhwal, UK	2200-2500	447.5	434.4	533.3	na	na	245.3	Sharma et al. (2010a)
Cedrus deodara	India	na	na	141.2	na	70.6	na	na	Haripriya (2000)
Cedrus deodara	Bhaghirathi catchment, Uttarkashi Garhwal, UK	2814-3252	na	na	464.2	na	na	208.9	Sharma et al. (2015)
Cedrus deodara (closed forest)	Southern Kashmir, J&K	1825-2290	530	na	na	91.38	23.76	115.14	Wani et al. (2015)
Cedrus deodara (open forest)	Southern Kashmir, J&K	1825-2290	200	na	na	43.88	11.41	55.29	Wani et al. (2015)
Conifer mixed broad-leaved	Chamoli Garhwal, UK	2600-2450	na	240.1	298.6	na	na	149.3	Gairola et al. (2011a)
Conifer pure	**Bhadarwah, J&K**	**2100-2200**	**160**	**415.10**	**510.14**	**na**	**na**	**129.16**	**Present study**
Conifer pure	**Bhadarwah, J&K**	**2300-2450**	**310**	**437.54**	**537.09**	**na**	**na**	**247.06**	**Present study**
Conifer pure	**Bhadarwah, J&K**	**2700-2800**	**130**	**94.70**	**120.43**	**na**	**na**	**15.04**	**Present study**
Cupressus torulosa	Pauri Garhwal, UK	2100-2500	810	271.6	336.6	na	na	154.8	Sharma et al. (2010a)

Hardwood and conifer forest	India	na	na	na	na	20.86	na	na	Manhas et al. (2006)
Mainly *Abies pindrow*	Chamoli Garhwal, UK	2500-2600	na	237.9	296.0	na	na	148.0	Gairola et al. (2011a)
Mixed *Awbies pindrow*	Chamoli Garhwal, UK	2100-2500	na	354.6	437.3	na	na	218.6	Gairola et al. (2011a)
Mixed Coniferous	Anantnag District, J&K	2300-2800	196	222.3	284.8	102.3	25.1	na	Dar and Sundarapandian (2015)
Mixed conifers	India	na	na	na	na	46.79	na	na	Manhas et al. (2006)
Mixed conifers	India	na	na	247.55	na	73.65	na	na	Haripriya (2000)
Mixed Oak-pine	Kumaun, UK	na	na	325.8	na	153.1	na	na	Rana et al. (1989)
Pinus roxburghii	Pauri Garhwal, UK	1500-1800	685	239.9	298.0	na	na	137.1	Sharma et al. (2010a)
Pinus roxburghii	Kumaun, UK	1750	na	163.0	199.0	76.6	na	93.5	Rana et al. (1989)
Pinus roxburghii	Pauri Garhwal, UK	750-1250	525	126.2	159.4	na	na	73.3	Sharma et al. (2010a)
Pinus roxburghii	Kumaun, UK	na	na	91.5-232.3	na	43.2-109.2	na	na	Chaturvedi and Singh (1987)
Pinus roxburghii	India	na	na	69.5	na	34.75	na	na	Haripriya (2000)
Pinus wallichiana	Bhaghirathi catchment, Uttarkashi Garhwal, UK	2814-3252	na	na	316.8	na	na	142.5	Sharma et al. (2015)
Pinus wallichiana	Anantnag District, J&K	2200-2400	199	218.3	284.4	100.4	24.7	na	Dar and Sundarapandian (2015)
Pinus wallichiana	**Bhadarwah, J&K**	**2450-2600**	**250**	**24.82**	**32.70**	**na**	**na**	**55.40**	**Present study**
Pinus wallichiana (closed forest)	Southern Kashmir, J&K	1752-2656	170	na	na	93.82	24.39	118.21	Wani et al. (2015)
Pinus wallichiana (open forest)	Southern Kashmir, J&K	1752-2656	140	na	na	29.48	7.67	37.15	Wani et al. (2015)

Abbreviations: na= not available; D= Density; AGBD= aboveground biomass density; TBD= total biomass density; TBCD= total biomass carbon density; BGBC= Below Ground Biomass Carbon; UK= Uttarakhand; J&K= Jammu and Kashmir.

Table 5: Comparative values of Carbon (%) between other conifer dominated forests of western Himalaya and the present study.

Forest types	**Locality, State**	**Altitude**
Abies pindrow	Tapovan, Chamoli Garhwal, UK	2600-310
Abies pindrow	Chaurangikhal, Uttarkashi Garhwal, UK	2600-280

Abies pindrow	Dudhatoli, Pauri Garhwal, UK	2600-3100	2.0-2.2	Sharma et al. (2010d)
Abies pindrow	Mandal-Chopta, Chamoli Garhwal, UK	2500-2600	2.71	Gairola et al. (2012a)
Abies pindrow	Mandal-Chopta, Chamoli Garhwal, UK	2100-2500	2.29	Gairola et al. (2012a)
Abies pindrow	Dudhatoli, Pauri Garhwal, UK	2600-2875	1.7-2.5	Sharma and Baduni (2000)
Cedrus deodara	Dhanaulti, Dehradun Garhwal, UK	1750-2150	0.50-2.25	Nazir (2009)
Cedrus deodara	Binsar, Pauri Garhwal, UK	2200-2500	2.1-3.8	Sharma et al. (2010d)
Cedrus deodara	**Bhadarwah, J&K**	**1700-1800**	**5.33**	**Present study**
Cedrus deodara	**Bhadarwah, J&K**	**1800-1950**	**4.00**	**Present study**
Cedrus deodara	**Bhadarwah, J&K**	**1950-2100**	**3.33**	**Present study**
Cedrus deodara	**Bhadarwah, J&K**	**2200-2300**	**6.72**	**Present study**
Conifer dominated	Gulmarg forest, Baramullah, Kashmir, J&K	2783	3.06-3.97	Dar et al. (2015)
Conifer mixed broadleaf	Duggal-Bhitta, Chamoli Garhwal, UK	2360	3.90	Pande et al. (2001)
Conifer mixed broadleaf	Duggal-Bhitta, Chamoli Garhwal, UK	2400	6.80	Pande et al. (2001)
Conifer mixed broadleaf	Pangarbasa, Chamoli Garhwal, UK	2700	6.90	Pande et al. (2001)
Conifer mixed broadleaf	Pangarbasa, Chamoli Garhwal, UK	2750	6.95	Pande et al. (2001)
Conifer mixed broadleaf	Kanchula Kharak, Chamoli Garhwal, UK	2800	7.10	Pande et al. (2001)
Cupressus torulosa	Jhandidhar, Pauri Garhwal, UK	2100-2500	2.2-2.6	Sharma et al. (2010d)
Mixed coniferous	**Bhadarwah, J&K**	**2100-2200**	**4.47**	**Present study**
Mixed coniferous	**Bhadarwah, J&K**	**2300-2450**	**2.96**	**Present study**
Mixed coniferous	**Bhadarwah, J&K**	**2700-2800**	**4.34**	**Present study**
Oak mixed coniferous	Kewars, Pauri Garhwal, UK	1600-2100	1.09-2.09	Srivastava et al. (2005)
Pinus roxburghii	Pauri Garhwal, UK	1500-2000	0.61-1.91	Nazir (2009)
Pinus roxburghii	Thalisain, Pauri Garhwal, UK	1500-1800	0.9-2.2	Sharma et al. (2010d)
Pinus roxburghii	Bhetagad watershed, Kumaun, UK	1460	na	Kothyari et al. (2004)
Pinus roxburghii	Kumaun, UK	2150	2.54	Usman et al. (2000)
Pinus wallichiana	**Bhadarwah, J&K**	**2450-2600**	**2.34**	**Present study**
Pinus wallichiana-Picea smithiana	Drung forest, Baramullah, Kashmir, J&K	2664	2.86-3.44	Dar et al. (2015)
Temperate Coniferous	Southern Kashmir, J&K	1752-2933	1.03-2.25	Wani et al. (2015)

Abbreviations: na= not available; UK= Uttarakhand; J&K= Jammu and Kashmir.

Anthropogenic disturbances

Disturbances are pervasive features of forest ecosystems, to the extent that there is no clear distinction between successional and mature-phase vegetation (Clark, 1996). Habitat destruction, overexploitation, and invasion by alien species are identified as major causes of biodiversity loss (UNEP, 2001), and these disturbances determine the forest dynamics and tree diversity at local and regional scales (Hubbell et al., 1999). Anthropogenic disturbances play an essential role in determining the change, loss, or maintenance of plant diversity in a forest. While some species may tolerate the disturbance, others may succumb to it (Sagar et al., 2003). Forest disturbances can have consequential effects not only related to loss of biodiversity but also loss of large amounts of C to the atmosphere from these rich C reservoirs. Many different types of anthropogenic disturbances were observed in the region viz., grazing, extraction of NTFPs, regeneration loss, stem cutting, soil erosion, and tree lopping for fodder and fuelwood extraction. The main types of anthropogenic disturbances observed in different forest types have been summarized in the last row of Table 3. Some natural disturbances were also observed at few places in the study area viz., cloud bursts, landslides, and lightning strikes. Remnants of low-intensity forest fire were mainly present at the lower elevations, which were most probably due to human-made causes. Signs of soil erosion were present in all the forest types. Although causes for forest fires and soil erosion could both be human-made and natural, anthropogenic reasons seemed to be the main culprit in the study area.

Generally, coniferous forests are harvested for timber in different parts of the Himalayan region (Sharma et al., 2010a). As such, except at very few places, authors have not seen fresh tree felling, but cut stumps were present in all the forest types except FT7 and condition of some cut stumps suggested that they were felled in the recent past. Occasional tree felling for timber by locals for making wooden houses is also standard practice in the region. Preferable tree species for timber in the area are *C. deodara,* followed by *P. wallichiana* and *A. pindrow*. Disturbance Index (DI) calculated based on cut stump Nha^{-1} and cut stump Gha^{-1} have been presented in Figure 2. Based on these disturbance indices, FT5 was the most disturbed forest type followed by FT6, FT3, and FT2. FT7 was least disturbed with no cut stump found in this forest, which may be due to the regenerating nature of this forest type with remarkably few mature trees. However, our observations showed that there was stronger evidence of grazing in FT7. Disturbance indices also inferred that in FT1, FT4, and FT8, there were low to moderate forest disturbances in the form of stem cutting. Approximate C loss due to anthropogenic activities was estimated using the cut stump diameter, which is presented in Figure 3. It was observed that in FT5 and FT6, large portions of C were lost due to anthropogenic activities, whereas in other forest types, a substantial amount of C was lost.

Besides, that pressure on vegetation due to grazing in the forest area was enormous. Grazing by domestic animals, especially of nomadic Gujjars and Bakerwals communities, was a common sight in the area. Large numbers of domestic animals freely grazed in the forest area. Our discussion with local people revealed that on an average, each Gujjar family could have 50 to 100 sheep and goats along with around 20-25 buffalos, which varies according to the economic condition of the Gujjar family. Similarly, the Bakarwal family can have around 100-200 goats and sheep along with few mules. These nomadic communities visit the study area, especially at higher reaches during summer, and return to lower elevations during winter. In addition to that, local villagers have a fair amount of animals, which also graze in the forest area. This unabated grazing is having a detrimental effect on the ground flora and regeneration of the natural vegetation of the region, which is evident by the deficient regeneration performance of tree species in the area. The forest gaps caused by tree felling are characterized by high herbaceous vegetation (Modry et al., 2004) and abundant herbage (Mayer and Stockli, 2005), which are preferentially grazed by cattle (Carman and Briske, 1985) and other domestic animals. It has been argued that if environmental change produced by disturbance is significant, it may become lethal to a higher number of established species than immediately replaced by immigrants (Sheil, 1999). These open spaces created by tree felling may exacerbate the establishment of shade-intolerant species and promote invasion of exotic or other hardy species in the area. However, currently, no invasive tree species was observed in the study area, but if the present trend continues, it would be interesting to observe the change in vegetation of the study area in the future.

Another significant anthropogenic disturbance prevalent in the area was tree lopping for fuelwood and fodder collection. All the tree species were lopped for fuelwood extraction, but only non-coniferous species were lopped for fodder extraction. The exploitation of fuelwood and timber has profound effects on the biodiversity of the forest ecosystem (Sayer and Whitmore, 1991), often leading to the change in species composition and vegetation structure (Kouki, 1994). The recurrent human interventions for the collection of fuelwood and minor forest products along with grazing and trampling may change the habitat conditions for many associated species (as was also reported by Pandey and Shukla, 1999). Quantitative data about per capita fuelwood and fodder extraction/ consumption from the Jammu region is not available, but in another nearby region in the western Himalaya (Garhwal), Sharma et al. (2009a) found an inverse relationship between forest resource utilization pattern and socioeconomic conditions of the rural people. This also seemed to be right in the case of the present study area. Besides that, there is a limitation of other sources of energy, such as LPG and Kerosene, which are mainly used by people living in towns. Whereas, people living in villages primarily rely on fuelwood collected from the forest areas as a primary source of household energy.

Forest department often plant trees in the region, mainly along roadsides, villages and on forest lands. Most of the time, conifers are planted in the area, which is also scientifically advisable as natural vegetation of the region is coniferous. However, due to the slow growth rate and longer rotation period, the planted coniferous trees take time to establish and do not match the pace of loss due to anthropogenic disturbances. Besides that, for afforestation and reforestation programs, it is a general practice by the forest department to plant saplings in barren and degraded lands. Still, this practice in the region often does not meet much success, as many times, the percentage of survival of the planted saplings is meager. There can be various reasons for this low success rate. For example, soils and lands where these saplings planted are generally non-conducive for the establishment of these plants in the early stages of growth due to poor soil properties. Without inadequate natural canopy cover at some places, these saplings may get higher light intensity than required along with the intense onset of rain, wind, and snow. In many cases on slopes, faster runoff of water also causes problems. In addition to that, when compared to natural coniferous forests where the density of herbs and shrubs is generally very low due to dense canopy, these open planted areas foster a higher density of shrubs and herbs, which hinder the growth of these saplings affecting their survivability.

Conclusion

Ecosystem responses to disturbances vary across spatial and temporal scales (Wangchuk et al., 2015). According to Larson and Paine (2007), response to anthropogenic disturbances varies according to site productivity, with poor sites being less resilient to anthropogenic changes than more productive sites. In these natural coniferous forests instead of relying only on natural regeneration, the forest department should also plant saplings of conifers in forest gaps of respective conifer forests, where mature trees have been removed. As soil quality, slope aspects and environment are already conducive for these conifer trees, and there will be less competition with other hardy plants. The survival rate of these planted saplings will be much higher and will help preserve the natural forests of the region in more or less pristine form. However, if these forest gaps are not refilled with natural vegetation immediately, these forests will degrade severely, making it challenging to reclaim these forests as the quality of soil will also subsequently go down. In addition to that, these gaps may be taken up by the other fast-growing plants, which will also affect natural herbaceous and shrubby flora leading to the loss of biodiversity. In some earlier studies, Sharma et al. (2010a, 2011b) showed that conifer dominated forests of the western Himalaya store large amount of C stocks in vegetation and soil, which is also confirmed in the present study. Therefore degradation of these forests will also cause loss of large amounts of C stored in vegetation and soils of these forests.

Concerns about the widespread degradation of natural resources in the Himalaya have been expressed by many authors (Silori, 2001; Veach et al., 2003). While on the one hand, recognition of the Himalayan forest database among ecologists at a global level is needed, on the other, initiatives are required to strengthen this database further, to enhance our ecological understanding and process/ factors responsible for forest C conservation and management at local and regional levels. Present conditions of other coniferous forests in Jammu and other nearby regions in western Himalaya is more or less the same. We suggest that, along with checking illegal NTFP extraction and timber trade by enforcing laws forcefully, the forest department should try to implement scientific findings to restore degraded forests. Therefore the present study can be taken as a case study to understand challenges faced by coniferous forests of the region. It will help in framing out the conservation planning and management strategies by Government and other agencies. The presented analysis of coniferous forests will serve as baseline information for further studies of the researchers working in the area. In the future, this study can be extended further to unravel the issues related to the effect of these disturbances on a temporal scale.

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Conflicts of Interest

The authors declare no conflict of interest.

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