Vegetos (2021) 34:822–833
https://doi.org/10.1007/s42535-021-00265-3

RESEARCH ARTICLES

Dynamics of carbon storage and status of standing vegetation in temperate coniferous forest ecosystem of north western Himalaya India

Muzamil Ahmad Sheikh[1] · Avinash Tiwari[1] · Jasra Anjum[1] · Sangeeta Sharma[1]

Received: 26 December 2020 / Revised: 27 June 2021 / Accepted: 1 July 2021 / Published online: 28 July 2021

Abstract

Natural ecosystems, which operate as a sink, play an important role in determining the concentration of CO_2 in the atmosphere and have a large storage capacity, assisting in mitigation of problem that has a negative impact on the human population. Forests are one of the most important carbon sinks in the terrestrial ecosystem, with the best example being the Western Himalaya, where healthy and sustainable vegetation is prized. Standard methodology was adopted for assessing the different parameters of carbon related information to enumerate the status of carbon storage and its trend in sustaining the ecosystem of the area. The current research displays the annual increment and carbon dynamics in various vegetation components and levels. Trees, shrubs, and herbs help to fix atmospheric carbon in a variety of forms, including AGC, BGC, and TC. The concentration of carbon-fixing potential was measured on an annual and seasonal basis, with herbs having the highest mean annual increment, followed by shrubs and trees. *Pinus wallichiana* had the largest annual carbon stock change among trees, followed by *Cedrus deodara*, *Picea smithiana*, and *Abies pindrow*. *P. wallichiana* topped the increase percentage with 60.58%, followed by *C. deodara* 33.35%, *P. smithiana* 5.61%, and *A. pindrow* 0.45%. Litter was also investigated as a potential source of mitigation, with the best results observed during the autumn months. Natural coniferous forests provide a regulating ecological service in the region by maintaining carbon dioxide levels in the form of biomass, according to the study.

Keywords Carbon status · Coniferous forests · Variation · Western Himalaya

Introduction

Global warming is a consequence of an increase in the earth's surface temperature, which is expected to continue in the following decades due to human influence. This has become a major issue, with predictions of a temperature increase of 1.0–3.5 °C in the next 50–100 years (Rustad et al. 2001). These ramifications have prompted the release of a variety of gases that have a significant impact on climate change (Li et al. 2014). Carbon sequestration is the natural process of absorbing CO_2 from the atmosphere and storing it in diverse pools such as oceans, terrestrial ecosystems, and so on (Sundquist et al. 2008; Kirschbaum 2003). Carbon sequestration is now a topic of international debate in the context of climate change, and the idea of mitigating it through forest protection and management was first proposed in 1992 and a number of countries signed the UN Framework Convention on Climate Change. The third meeting of the United Nations Framework Convention on Climate Change (UNFCCC), which later became the "Kyoto Protocol," was held in 1997 in Kyoto, Japan, with the main goal of reducing greenhouse gas emissions by 5% or more by 2012, and was extended until 2017 in the climate conference held in 2017 in the Durban Climate Conference (Cop-17). Even in the event of a COVID-19 pandemic, underdeveloped countries worked hard to tackle the problem, paying $100 million per year from 2021 to 2025. (Cop-25). Natural forests have a high proclivity for carbon sequestration (Joshi et al. 2013), making them the most important carbon sinks that influence atmospheric carbon dioxide concentrations (Zhou et al. 2006). Forests played a significant part in the research of climate change in terms of net carbon emission and global storage (Terakunpisut et al. 2007) because they absorb carbon dioxide through photosynthesis and are thus

✉ Muzamil Ahmad Sheikh
muzamiljabbar11@gmail.com

[1] School of Studies in Botany, Jiwaji University, Gwalior, India

considered carbon sinks (Valentini et al. 2000; Kuimi and Jayakumar 2012; Dhruw et al. 2009). Litter components found on forest floors have a significant part in carbon sequestration, accounting for 8% of total potential (Heath et al. 2003; Chojnacky and Amacher 2006), and changes with seasons and altitude (Sheikh et al. 2017). The alarming rise in atmospheric carbon dioxide levels over the previous few decades has prompted research into numerous areas to determine the cause because of their mitigation and control capacity, the mitigation rate and forests are rising in importance.

With a land contribution of 65% in the entire region, the Western Himalayas are temperate evergreen forests with continual litter fall throughout the year, offering a home to a variety of natural resources (Kashyap et al. 2014). The rate of carbon sequestration in temperate forests of the central Himalaya has been calculated on an annual basis (Jina et al. 2008), with all types of vegetation storing carbon and having the ability to mitigate climate change (Sharma et al. 2011). The rate of carbon sequestration is influenced by the type of vegetation as well as the location of the area (Han et al. 2010). Coniferous forests have a higher carbon sequestration potential than deciduous forests throughout time (Shorabi et al. 2016; Wani and Qaisar 2014) and contribute 14% of carbon stock (Pan et al. 2011) with a variety of services, one of which is the regulating ecosystem service (Hicks et al. 2014). The current study aims to assess the impact of coniferous forests on carbon storage on an annual and seasonal basis, with a focus on parameters related to growth rate and change in carbon stock, because the Himalayas have the greatest potential for sequestering more and more carbon due to their growing nature. The goal was to calculate the present carbon pool and the state of the southern Himalaya of Anantnag district.

Materials and methods

Study area

The study was carried out at four sites of Anantnag district viz. Daksum (Site 1), Pahalgam (Site 2), Kokernag (Site 3) Kuthar (Site 4) and with coordinates, (Site 1 Latitude 33°34′43.1 N, Longitude 75°23′17.2E), (Site 2 Latitude 33°57′08.3 N, Longitude 75°18′43.4E), (Site 3 Latitude 33°34′43.1 N Longitude 75°23′17.2E) and (Site 4 Latitude 33°34′43.1 N Longitude 75°23′17.2E). Elevation of corresponding sites was 2370 m.a.s.l. for Site 1, 2115 m.a.s.l for Site 2, 2029 m.a.s.l Site 3 and 1986 m.a.s.l Site 4 respectively (Fig. 1). The climate in the Kashmir Himalayas is variable and fluctuates greatly throughout the year. The temperature in the valley fluctuates from 15 to 20 degrees in the spring (March–May), from 20 to 35 degrees in the summer (June–August), and from 35 to 10 degrees in the autumn (September–November).

Sampling techniques

The study region was sampled using a random sampling method, with 32 permanent sample plots (20 m × 20 m) laid out depending on several characteristics such as anthropogenic activities, protected or open type, and altitudinal variance. Living trees with a diameter of less than 10 cm were used to determine tree density and biomass. Before converting to carbon, the diameter at breast height (DBH) was used to estimate biomass. The measurements were taken with a simple measuring tape and then translated to diameter equivalents using the formula: Diameter (cm) = (circumference cm/π). Trees with many stems were cut apart at the base and photographed separately. 32 permanent quadrat of (5 m × 5 m) were taken for shrub estimation and similar number of (1 m × 1 m) were laid down for herbs.

Estimation of biomass

For tree biomass, a non-destructive method was chosen because it was easier than destructive procedures. The study region was a natural forest, and damaging methods were not desired due to authorization and other concerns. The biomass that is attainable for temperate forests was estimated using an allometric equation. $Y = 34.4703 - 8.0671D + 0.6589\ D2$ (Anderson and Ingram 1989) D is the diameter at breast height in cm, while Y is the above-ground biomass in kg. 50% of biomass was taken as carbon in the current study (Brown 2001; Brown and Lugo 1982, Bhat and Ravindranath 2011, Dixon et al. 1994, Cannell and Milne 1995, Terakunpisut et al. 2007). The ground biomass (BGB) was calculated by taking 15% of the above-ground biomass (Mac Dicken 1997). The overall biomass of the research area included both above and below ground biomass. Carbon stock estimation was also done using a similar process.

Herb and litter carbon

Herbs were harvested at base level and weighed using a digital scale of ± 1 g error on site and recorded the fresh weight. 50 gm subsample of each sample was taken for moisture content determination However, if the weight was less than 50 gm, the entire sample was used to estimate the weight. The samples after collection were subjected to air drying followed by oven drying at 65–70° C for at least 48 h or till

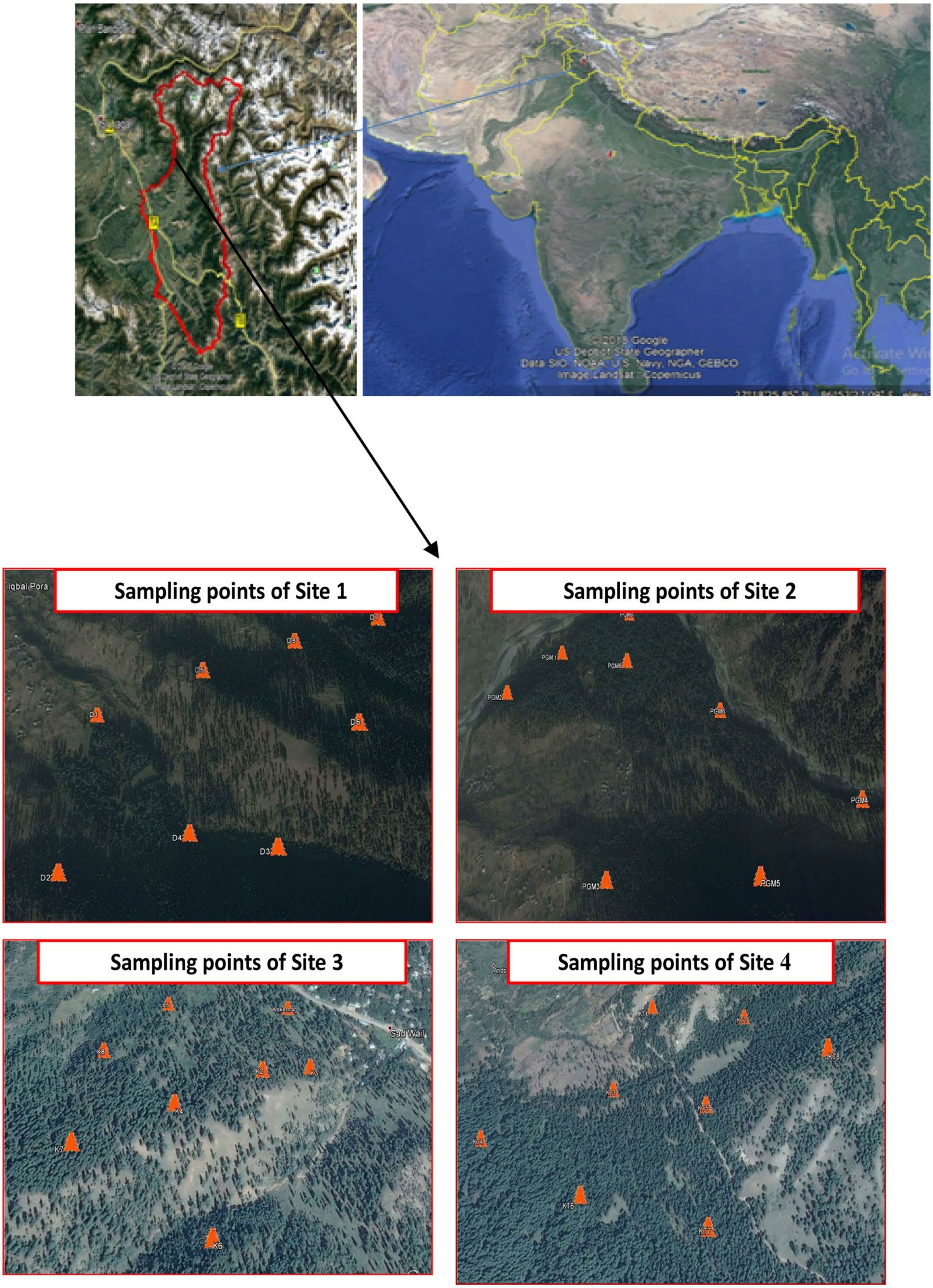

Fig. 1 Overall all observation of the study area with GPS instrument showing satellite view and sampling plots at different sites

the samples reached their stable weight. Total dry weight of the samples was estimated using the equation (Hairiah et al. 2001). Similarly for litter, subsamples were taken from 96 litter traps established at the study site for estimation carbon.

$$\text{Total dry weight}\left(\text{kg m}^2\right) = \frac{\text{Total fresh weight (kg)} \times \text{Subsample dry weight (g)}}{\text{Subsample fresh weight (g)} \times \text{sample area}\left(\text{m}^2\right)}$$

Carbon content was found 50% by oven dry weight (Schliesinger 1991).

Estimation of shrub carbon

Representative plants were selected from a 5*5-m plot and picked at the root in three sizes: larger, medium, and smaller, with weighing in between. Following the collection of fresh weight, harvested subsamples were air dried for a few days before being oven dried for 72 h at 120 °C. The AGB of each plot was estimated as $AGB = a \times WB + b \times WM + c \times WS$ (Xu et al. 2010). Where WB, WM and WS are dry weights of the big, middle and small samples respectively and a, b and c are the counted numbers of corresponding quadrats.

Carbon variation

Carbon increment is actually the change in growth rate of plants with accumulation of carbon at particular time interval and was calculated as ($\Delta C = C_2 - C_1$) where, ΔC = rate of carbon, C_1 = Carbon in initial year, C_2 = Carbon in final year.

Relative mean increment calculated was $RMI = Vt2 - Ut1/Ut1$ where RMI = relative mean increment, Vt_2 = final mean increment at particular time and Ut_1 = initial mean increment at particular time. Annual carbon change was calculated by difference method (Penman et al. 2003). $\Delta C = (Ct_2 - Ct_1)/(t2 - t1)$. Where, Ct_2 = Carbon in final year, Ct_1 = Carbon in initial year, t_1 and t_2 are initial and final year respectively.

Mortality and recruitment rate

Mortality rate for the study site was calculated by Sheil et al. (1995) with following equation.

$M = [1 - \{(N0 - m)/N0\}1/\Delta t]$ where, N_0 is tree density in first year, m = number of dead/cut down/ fell down trees after final year. ΔT = difference between initial time t_1 and final time t_2 of sampling time and recruitment rate was also calculated by Sheil et al. 1996 with following equations.

$R = [(N_0 + r)/N_0\}1/\Delta t - 1]$ where, N_0 is tree density in first year of observation, r = number of trees recruited (planted, natural regeneration) during the period of observation.

Statistical analysis

Using sigma stat 3.5 software, the statistical analysis was done to assess for significant differences between various samples using analysis of variance (ANOVA). Following the Student–Newman–Keuls range test (SNK), descriptive analysis with Normality test and equal variance test was used to assess the difference at a significance level of $P < 0.05$.

Results

Density and carbon stock

For the measurement of carbon in a 2-year interval, significant variation was revealed at $P < 0.05$ using ANOVA after passing the normality and equal variance tests. During the years 2014–2016, tree density and above ground carbon were measured, with *Pinus wallichiana* dominating the region with 420.5 trees per hectare, followed by Cedrus deodara 242.7, Picea smithiana 32.03, and Abies pindrow 4.68 respectively. All of the species recorded for carbon estimation on an annual basis varied significantly with respect to different components (Table 1) and growth rate was pragmatic on an increment basis, with *P. wallichiana* averaging 8.56 ton/ha in 2 years, followed by *C. deodara* 3.42 tonnes, *P. Smithiana* 0.71 and *A. Pindrow* 0.05 ton/ha. When assessing the below-ground carbon of all the species, a similar trend was seen, with *P. wallichiana* showing an increase of

Table 1 Carbon (ton/ha) estimation at different time intervals in different species

Vegetation	AGC 2014	AGC 2016	BGC 2014	BGC 2016	TC 2014	TC 2016
P. wallichiana	196.24 ± 6.5	204.8 ± 8.2	29.34 ± 1.4	30.59 ± 1.6	225.58 ± 8.0	235.39 ± .4
C. deodara	61.36 ± 43.7	64.78 ± 6.2	9.17 ± 6.5	9.69 ± 6.9	70.53 ± 9.1	74.47 ± 53.1
P. smithiana	30.41 ± 7.6	31.12 ± 7.7	4.56 ± 0.9	4.67 ± 1.1	34.97 ± 8.7	35.79 ± 8.9
A. pindrow	0.47 ± 0.4	0.52 ± 0.5	0.20 ± 0.2	0.22 ± 0.2	0.67 ± 0.6	0.74 ± 0.7

The values expressed are mean standard error ($p < 0.05$) in comparison to different species

AGC above ground carbon, *BGC* below ground carbon, *TC* total carbon

1.25 ton/ha, followed by *C. deodara* 0.52 ton/ha, *P. smithiana* 0.11 ton/ha, and *A. pindrow* 0.02 ton/ha. Total carbon increment varied significantly among the species, with the largest increase of 9.81 ton/ha in *P. wallichiana*, followed by 3.94 ton/ha in *C. deodara*, 0.82 ton/ha in *P. smithiana*, and 0.07 ton/ha in *A. pindrow* (Fig. 2). Different DBH class estimations were also thoroughly investigated, with the conclusion that the 20–40 cm class sequesters the most carbon from the atmosphere (Table 2).

Carbon stock in shrub vegetation

Among the many sites in the area, the study site noticed little undergrowth vegetation at Site 1 and Site 2. Between 2014 and 2016, the data revealed an increase in above ground carbon of 0.69 ton/ha, below ground carbon of 0.11 ton/ha, and an increase in total carbon of 0.80 ton/ha. (Table 3, Fig. 3).

Carbon stock in forest floor vegetation

During the assessment of seasonal and annual carbon stocks in forest floor standing vegetation in the western Himalayas, significant observations at $P < 0.05$ were observed with normality and equal variance tests passing. The above-ground carbon stock was measured during different seasons of the year, including Autumn, spring, and summer, as well as seasonal and annual variations. Summer had the highest annual carbon increase of above ground standing forest floor (0.115 ton/ha), followed by autumn (0.032 ton/ha) and spring (0.012 ton/ha). Below ground, carbon increment followed the same trend. Summer had the highest increase in total carbon in herb plants, with 0.132 ton/ha (Table 4, Fig. 4).

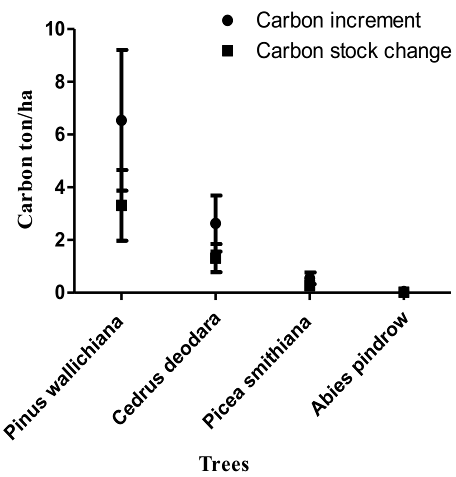

Fig. 2 Carbon increment and annual stock change in different components of tree species

Annual carbon stock change

Carbon change is the potential for carbon fixation that contributes to the ecosystem services given by natural forests, and it was shown to differ considerably ($P < 0.05$) at the research location. Carbon stock change was evaluated on an annual basis among different components of tree species, with the highest value being 4.32 ton/ha/year for *P. wallichiana*, followed by 1.71 ton/ha/year, *C. deodara*, 0.35 ton/ha/year, *P. smithiana*, 0.35 ton/ha/year, *P. smithiana* and *A. pindrow* 0.025 ton/ha/year respectively. *P. wallichiana* had the largest carbon stock change of 0.65 ton/ha/year, followed by *C. deodara* 0.26 ton/ha/year, *P. smithiana* 0.05 ton/ha/year, and *A. pindrow* 0.004 ton/ha/year, respectively. During the 2-year period, similar findings were seen in annual carbon change of total carbon, with *P. wallichiana* dominating the area with 4.97 ton/ha/year, followed by *C. deodara* 1.97 ton/ha/year, *P. smithiana* 0.40 ton/ha/year, and *A. pindrow* 0.029 ton/ha/year, respectively (Fig. 2). The total carbon 0.397 ton/ha/year, which is the sum of the above ground and below ground carbon, was used to estimate the annual carbon stock change in shrub vegetation (Fig. 3). Summer had the biggest above-ground carbon stock change of herbs with 0.057 ton/ha/year, followed by autumn 0.016 ton/ha/year, and spring 0.006 ton/ha/year, respectively. Similarly, the change in below-ground and total carbon stocks was consistent with the findings (Fig. 4).

Assessment on proportion basis

In the research area, the density of different species was calculated as a percentage, with *P. wallichiana* dominating 60.07%, followed by *C. deodara* 34.67%, *P. smithiana* 4.57%, and *A. pindrow* 0.66%. *P. wallichiana* was found to have 66.23% AGC, 49.6% BGC, and 60.58% TC when the increment percentages of several tree characteristics were calculated. *C. deodara*, on the other hand, had 27.66% AGC, 20.63% BGC and 33.35% TC. *P. smithiana* demonstrated 5.77% increase in AGC, 28.96% increase in BGC, and 5.61% increase in TC. 0.32% AGC, 0.79% BGC, and 0.45% TC were found in *A. pindrow*. For carbon estimation, shrubs were evaluated and expressed as a percentage. Similarly, over the research period, the percentage of forest floor increment was taken into account. Summer is the most popular season (72.32%) across all components, followed by autumn (20.12%) and spring (7.54%).

Carbon variation of litter

Annual variation was detected in numerous components such as needles, branches, bark, and cones, and across all increments among different sites, Site 2 was determined to

Table 2 Distribution of carbon in different species along with mortality and recruitment rate at different sites within different DBH classes

DBH Class	Site 1				Site 2				Site 3				Site 4			
10–20 cm	PW	CD	PS	AP	PW	CD	PS	AP	PW	CD	PS	AP	PW	CD	PS	AP
Plots	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
TD	269	50	31	25	3	–	–	–	3	75	–	–	122	369	–	–
AGC	9.78	3.70	0.30	0.25	0.14	–	–	–	0.06	0.30	–	–	2.09	7.21	–	–
BGC	1.47	0.56	0.04	0.04	0.02	–	–	–	0.01	0.04	–	–	0.31	1.08	–	–
TC	11.25	4.26	0.34	0.29	0.16	–	–	–	0.07	0.34	–	–	2.40	8.29	–	–
MR	0	0	0	0	0	–	–	–	0	0	–	–	0	0	–	–
RR	0	0	0	0	0	–	–	–	0	0	–	–	0	0	–	–
21–40 cm																
TD	216	75	6	125	22	75	–	75	81	125	–	–	53	200	–	–
AGC	33.53	4.50	1.72	10.50	7.51	9.20	–	11.20	26.67	12.90	–	–	10.47	50.37	–	–
BGC	5.03	0.67	0.26	1.57	1.13	1.38	–	1.68	4	1.93	–	–	1.67	7.56	–	–
TC	38.56	5.17	1.98	12.07	8.63	10.58	–	12.88	30.67	14.83	–	–	12.35	57.93	–	–
MR	0	0	0	0	0	0	–	0	0	0	–	–	0	0	–	–
RR	0	0	0	0	0	0	–	0	0	0	–	–	0	0	–	–
41–60 cm																
TD	31	100	44	–	337	100	–	25	275	25	–	–	50	122	–	–
AGC	18.71	10.20	23.4	–	235.54	12.50	–	9.11	157.23	6.20	–	–	31.65	74.94	–	–
BGC	2.81	1.53	3.51	–	35.39	1.87	–	1.36	23.58	0.93	–	–	4.75	11.24	–	–
TC	21.51	11.73	26.91	–	271.34	14.37	–	10.47	180.82	7.13	–	–	36.40	86.19	–	–
MR	0	0	0	–	0	0	0	0	0	0	–	–	0	0	–	–
RR	0	0	0	–	0	0	0	0	0	0	–	–	0	0	–	–
61–80 cm																
TD	6	–	35	–	119	25	–	–	13	–	–	–	16	25	–	–
AGC	8.85	–	46.78	–	147.93	4.90	–	–	15.07	–	–	–	19.08	48.79	–	–
BGC	1.33	–	7.01	–	22.19	0.73	–	–	2.26	–	–	–	2.86	7.32	–	–
TC	10.18	–	53.8	–	170.12	5.63	–	–	17.34	–	–	–	21.94	56.11	–	–
MR	0	–	0	–	0	0	–	–	0	–	–	–	0	0	–	–
RR	0	–	0	–	0	0	–	–	0	–	–	–	0	0	–	–
81–100 cm																
TD	6	–	19	–	6	–	–	–	6	–	–	–	6	6	–	–
AGC	12.96	–	43.83	–	12.29	–	–	–	6.58	–	–	–	16.60	27.87	–	–
BGC	1.94	–	06.57	–	1.84	–	–	–	0.99	–	–	–	2.49	4.18	–	–
TC	14.9	–	50.41	–	14.13	–	–	–	7.75	–	–	–	19.09	32.05	–	–
MR	0	–	0	–	0	–	–	–	0	–	–	–	0	0	–	–
RR	0	–	0	–	0	–	–	–	0	–	–	–	0	0	–	–

Results were estimated on average basis (ton/ha) for carbon estimation and density trees per ha

TD = tree density, *AGC* = above ground carbon, *BGC* below ground carbon, *TC* total carbon, MR mortality rate (%/year), *RR* recruitment rate (%/year). *PW Pinus wallichiana*, *CD Cedrus deodara*, *PS Picea smithiana*, *AP Abies pindrow*

Table 3 Carbon content in shrub vegetation (ton/ha) (mean, ± within SD)

Vegetation	AGC 2014	AGC 2016	BGC 2014	BGC 2016	TC 2014	TC 2016
Shrub	2.56 ± 1.6	3.25 ± 2.1	0.38 ± 0.2	0.49 ± 0.3	2.94 ± 1.8	3.74 ± 2.4

be the most variable, followed by Site 4, Site 1, and Site 3. All of the components were estimated separately, and the findings were collected on a seasonal basis, with autumn having the highest litter fall and anually Site 4 has the largest cone increase, followed by Site 2, Site 1, and Site 3. Needle carbon increment was highest at Site 2 and lowest at Site 3. Similarly, yearly branch and bark increase was highest at Site 2 and lowest at Site 3. (Fig. 5). Similar results were

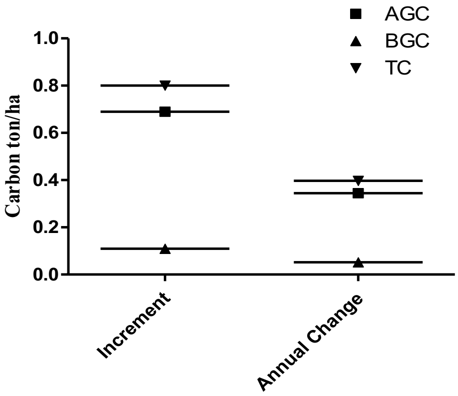

Fig.3 Carbon increment and stock change in different components of shrub vegetation

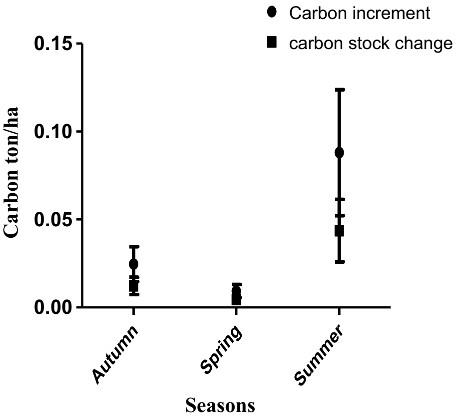

Fig. 4 Annual carbon increment and stock change in different components of herb vegetation

estimated in increments during the spring season, with no significant fluctuation at $P < 0.05$ ($r^2 = 0.34$). Among different sites of the study area, Site 1 showed highest value followed by Site 2, Site 3 and Site 4 respectively. On annual basis, the component wise increment for branch was highest at Site 1 and lowest at Sites 3 and 4. At Site 2, the needle have the highest, while the cone and bark both contributed the most (Fig. 6). During the summer, the combined carbon increment contribution of all components was found to be highest at Sites 2 and 4, followed by Sites 1 and 3. Among the various components, Site 2 had the most contribution for needle increment, similarly cone had the highest contribution at Site 1 and Site 2, branch had the biggest contribution at Site 4 and Site 2, and bark increment was only discovered at Site 4 with no increment at the other sites (Fig. 7).

Carbon pool, mortality and recruitment rate

The total yearly carbon pool in all components was evaluated, and the aggregate total of all the respective features was computed (Fig. 8) with trees contributing the most, followed by litter, shrubs, and herbs, in that order. Although the soil carbon pool adds to the total pool, the study only looked at standing vegetation, therefore SOC participation was overlooked. For the abovementioned criteria, parameters such as mortality and recruitment rate were taken into account for observing the present situation of the area by keeping a continuous record of density

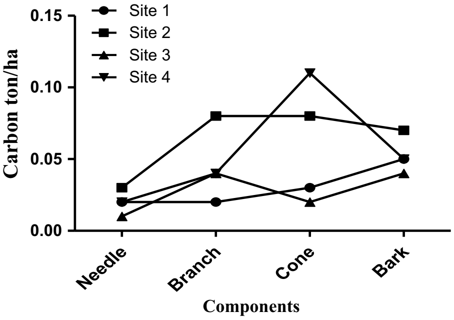

Fig. 5 Annual carbon increment in different components of litter during autumn season

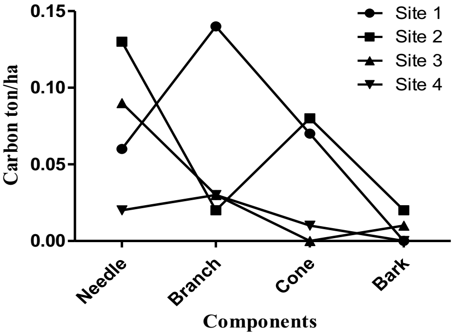

Fig. 6 Annual carbon increment in different components of litter during spring season

Table 4 Carbon Stock in forest floral (Herb) vegetation (ton/ha) (mean, ± within SD)

Components	Autumn		Spring		Summer	
Year	2014	2015	2015	2016	2015	2016
AGC	0.095 ± 0.04	0.127 ± 0.05	0.190 ± 0.01	0.202 ± 0.02	0.132 ± 0.02	0.247 ± 0.02
BGC	0.014 ± 0.01	0.019 ± 0.02	0.028 ± 0.01	0.030 ± 0.01	0.020 ± 0.01	0.037 ± 0.01
TC	0.109 ± 0.02	0.149 ± 0.03	0.218 ± 0.02	0.232 ± 0.03	0.152 ± 0.01	0.284 ± 0.01

The values expressed are mean standard error ($P < 0.005$) in comparison to different seasons

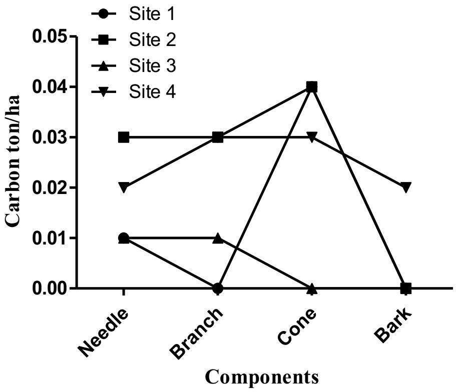

Fig. 7 Annual carbon increment in different components of litter during summer season

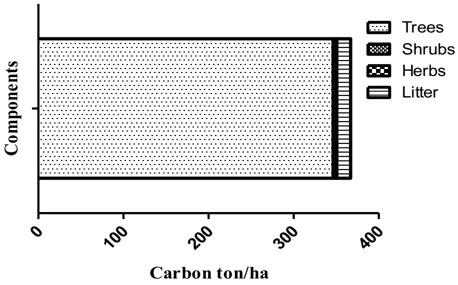

Fig. 8 Total annual carbon pool of standing vegetation along with litter

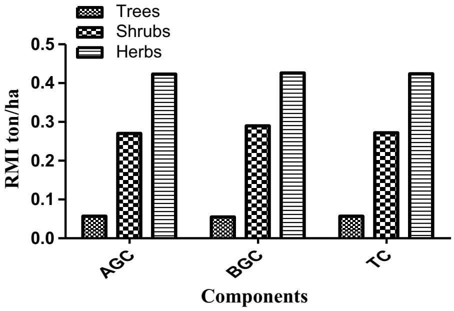

Fig. 9 Relative mean increment of different standing vegetation types of the area

regardless of nature, size, girth, and so on. During the study period, both regeneration and plantation, as well as fall down due to natural calamity or artificial force, were examined, and neither a rise in the number of trees nor a decrease in the number of trees were seen (Table 2).

Relative mean increment

When assessing relative mean increment of different vegetation types in the research area, significant variance $p < 0.05$ ($r^2 = 0.99$) was detected. Herbs on the forest floor are the most abundant, followed by shrubs and trees. Herbs were found to be the fastest growing vegetation in the research region, followed by shrubs and trees (Fig. 9).

Discussion

Forests have produced biomass for a long time, but disturbance by anthropogenic activity has resulted in a dramatic decrease over time (Naburaas and Schelaas 2002). Through the Kyoto Protocol (UNFCCC 1997), the dynamics of these forests in carbon dioxide variation from the atmosphere compelled management of carbon sequestration in natural forests with sustained yield of various goods along carbon credit route from forest ecosystems (Karjalainen 1996; Thornley and Cannell 2000). Tree density is influenced by the dominance of a certain species in a given area as a result of geographic location, climatic circumstances, nutrient concentration, soil type, and altitudinal variation. Due to its dominant nature, *Pinus wallichiana* had the highest tree density and relationship with carbon mitigation potential in the western Himalayas (Bhat and Ravindranath 2011). Because of the short time frame to predict variation in tree density, there was no variation in tree density over the 2 years, but carbon change was extremely appealing (Aryal et al. 2014) over a 2-year period. Aubinet et al. 2002 conducted a 5-year study of carbon dioxide flux in mixed forests, which validates the current research. Ullah and Al-Amin (2012) conducted a similar investigation in which they calculated AGC, BGC, and TC and found that the results followed the same pattern as the current study. Pant and Tewari (2013), Jina et al. (2008), and Wani et al. (2015) all found a similar trend in natural forest carbon sequestration and mitigation potential. Wani et al. 2014 calculated yearly carbon increases in C. deodara species, which supported the current findings when monitored on an annual basis for the same species. Forest increment (Xia et al. 2009) directly indicates the growth rate with a positive link among all vegetation types in the forest ecosystem, demonstrating carbon fixation through biomass creation. The carbon capture potential was projected in different ranges using DBH classes (Piyaphongkul et al. 2011), which guides the relationship between age and carbon dynamics (Aryal et al. 2014). The carbon estimation within different DBH classes demonstrated the maximum fixation potential in 21–40 cm and 41–60 cm, and less contribution in 81–100 cm, with the rationale that the smaller number of species within such diameter classes contribute less to carbon fixation as time goes on (Aryal et al. 2014). As a result, the current observation predicts that young forests are key carbon sinks that can aid in carbon sequestration over a long period of time (Pan et al. 2011; Le Quere 2013).

The contribution of shrubs to carbon sequestration revealed an important role and can be considered an active pool in carbon mitigation, as demonstrated by Labata et al. 2012, who estimated the results from a 3-year study on a kg/ha basis, which were more or less similar to the results from a 2-year study when converted to ton/ha. Rawat and Giri (2013) investigated shrub carbon estimation as well, with results that were nearly identical to those of the current study. Zhao et al. (2012) investigated the above-ground biomass estimation of shrubs and found that biomass and carbon estimation of shrubs have an impact on ecosystems, which ties in with the current research. When compared to deciduous forests, it was discovered that deciduous forest shrubs store more carbon than temperate forest shrubs (Salunkhe et al. 2014). The explanation for the lack of undergrowth vegetation is likely due to the allelopathic influence of tree species growing next to shrub vegetation, which causes stunted growth. Various biological and anthropogenic factors are also to blame for the reduced amount of shrub vegetation in the study area. Carbon mitigation was directly connected with growth rate and other relevant parameters, while shrub vegetation gave less information about its contribution to carbon fixation. Due to anthropogenic demand during peak summer months for diverse uses such as fuel wood, grazing, tourism, and so on, shrub contribution was minimal.

Anthropogenic pressure was also applied to the herbs in the form of grazing and trash removal, which indirectly affects the growth of floral plants by supplying nutrients to the soil (Chen 2015; Marble et al. 2011). The herb estimation results of (Rawat and Giri 2013) are consistent with the current study, and mitigating potential varying with different seasons was a strong signal for grazing lands where only small plants are growing to participate in carbon sequestration (Ghosh and Mahanta 2014). Because the grass growing in the forest is neither grazed by animals nor taken out by locals, the maximum herb carbon was discovered in the autumn. Rawat (2013) came to the conclusion that forest floor vegetation has a large carbon sequestration potential. Ullah and Al-Amin (2012) Amin's research of all plant carbon components yielded similar results when compared to the current study. The development pattern of forest floor vegetation is also affected by environmental flux, with different seasons having varying environmental circumstances such as temperature, precipitation, soil moisture, nutrient availability, and so on. Herb carbon stock change was assessed on an annual and seasonal basis, with yearly carbon stock change varying significantly.

For the explanation of ecological variables and to counterbalance the climatic circumstances of the area, carbon stock change on an annual basis demonstrated higher fixation potential of standing vegetation in distinct components with greatest density of *P. wallichiana*. The projected annual carbon stock change of surviving trees (Bhat and Ravindranath 2011) is consistent with the findings of the current study. The proportional assessment gives an indication of the relevance of particular species in the research region, which reflects the same species' potential to regulate environmental circumstances (Baishya and Barik 2011; Bramyrd 1979). Due to its density and adaptability, *P. wallichiana* dominated with the highest percentage obtained. The largest annual increment was detected in young plants with a diameter at breast height of up to 30 cm, indicating that young aged plants thriving in the area possessed dominance power (Liu et al. 2003). The mean annual increment reflected the growth rate of the study site (Pandey et al. 2017), with relative mean increment indicating the species' ability to grow quickly. The results showed that herbs are the fastest growing vegetation, with the highest relative mean increment value, while shrubs and trees have the lowest, possibly due to physiological processes and the nature of vegetation. Litter variation was directly related to environmental and anthropogenic activity (Kavvadias et al. 2001; Pedersen and Hansen 1999). Different components of litter were calculated on a seasonal basis (Sheikh et al. 2017) and were found to be related to vegetation, growth rate, and seasons (Ogunyebi et al. 2012), with the highest levels occurring during the autumn season. Litter not only serves to reduce carbon dioxide emissions, but it also decomposes and aids in the regeneration of biodiversity. The lowest carbon content observed during the spring season is due to the growth of new components on trees that replace the existing old ones. As a result, it takes time for various components to mature and fall down, which happens in the summer and autumn. (Ogunyebi et al. 2012) analysed seasonal variation and found similar results, with the highest litter fall occurring during the autumn season. According to Rawat (2012), summer has the biggest litter fall, followed by spring and winter, which contradicts the current study. The reason for this could be the nature of the vegetation, geographical position, altitudinal variance, and climate of the area.

The parameters of mortality and recruitment rates are indicators of the area's diversity indices, with which the estimation of various parameters has a direct relationship (Bhat and Ravindranath 2011). The study area's mortality and recruitment rates were both neutral, with no increase or decrease in the number of species counted for the density in the first year of sampling. These variables have a significant impact on carbon mitigation with a positive relationship (Phillips 1996), as well as the impact of internal climatic conditions on the habitat of numerous organisms (Nascimento et al. 1999). Various workers have assigned rates to various girth classes of plants (Turner 2001), some of whom are opposed to the viewpoints (Swaine 1987). Maritenz-Ramos and Alvarez-Buylla (1998) predicted a high mortality rate in more diameter classes due to susceptibility to natural environmental calamities. and others linked less diameter classed plants with physico-chemical parameters and argued their relationship with mortality (Lutz and Harplen 2006). The current findings can be discussed and linked to species adaptability and availability of nutrients for long-term growth, in addition to effective management, which not only protects the old ones but also allows young ones to regenerate and contribute to density, resulting in an impact on carbon levels.

Conclusion

Because of its young and dense vegetation, the Western Himalaya had a strong potential to store atmospheric carbon and showed signs of moderating environmental carbon dioxide. The forests had negligible mortality rate and a significant annual mean carbon addition, indicating long-term carbon storing potential. All of the components' annual stock changes were easily contributing to carbon dioxide cleanup in the environment. Shrubs and herbs also have a positive impact on overall carbon sequestration potential. Continuous litter fall throughout the year not only serves to maintain the soil ecosystem through decomposition, but it also aids in carbon dioxide mitigation. Only anthropogenic disturbance is a future issue. Local encroachment and tree felling by official or unauthorised means should not be permitted. The forest service should take a great interest in the management of these natural resources so that future generations can benefit from this ecosystem-regulating service.

Acknowledgements The authors acknowledge with gratitude the divisional forest officer Anantnag and Lidder division for permission. The range officers along with foresters and forest guards are highly acknowledged for their support, cooperation and assistance during the research work. School of Studies in Botany, Jiwaji University, Gwalior is also acknowledged for providing the necessary laboratory facilities to carrying out the research work. Dr. Mehraj Ahmad Sheikh, DFO Jammu and Kashmir forest department, Imtiyaz Ahmad Wani, Department of Geo informatics, University of Kashmir for supporting in mapping of the study sites. Mr. Altaf Ahmad Bhat and Javaid Ahmad Ganie, School of Mathematics, Dr. Nisar Ahmad Dar, Department of English, Jiwaji University, Gwalior are acknowledged for their help, cooperation and suggestions in editing the manuscript.

References

Anderson JM, Ingram JSI (eds) (1989) Tropical soil biology and fertility. A handbook of methods. C.A.B International, Wallingford

Aryal RD, De Jong JHB, Ochoa-Gaona S, Esparza-Olguin L, Mendoza-Vega J (2014) Carbon stocks and changes in tropical secondary forests of southern Mexico. Agric Ecosyst Environ 195:220–230

Aubinet M, Heinesch B, Longdoz B (2002) Estimation of the carbon sequestration by a heterogenous forest: night flux corrections, heterogeneity of the site and inter-annual variability. Glob Change Biol 8:1053–1071

Baishya R, Barik S (2011) Estimation of tree biomass, carbon pool and Net primary production of an old-growth *Pinus kesiya* Royle ex. Gordon forest in North eastern India. Ann Sci 68:727–736

Bhat DM, Ravindranat NH (2011) Above-ground standing biomass and carbon stock dynamics under a varied degree of anthropogenic pressure in tropical rain forests of Uttara Kannada District, Western Ghats India. Taiwania 56:85–96

Bramyrd T (1979) The effect of man on the biogeochemical cycle of carbon in terrestrial ecoysytem. Global Carbon cycle Scope 13

Brown S (2001) Measuring and monitoring carbon benefits for forest-based projects: experience from pilot projects, can carbon sinks be operational?. In: Resources for the Future (RFF) workshop proceedings. Washington DC 1–19.

Brown S, Lugo AE (1982) The storage and production of organic matter intropical forests and their role in the global carbon cycle. Biotropica 14:161–187

Cannell MGR, Milne R (1995) Carbon pools and sequestration in forest ecosystems in Britain. Forestry 68:361–378

Chen CF (2015) A Preliminary study on carbon sequestration potential of different green roof plants. Int J Res Stud Biosci 3:121–129

Chojnacky DC, Amacher MC (2006) From soil to trees: Estimating carbon with FIA data in eastern U.S. forests. In: Paper presented at Ecology and Society, Am. 91st Annual Meeting; Memphis. TN.

Dhruw SK, Singh LJ, Singh AK (2009) Storage and sequestration of carbon by leguminous and non-leguminous trees on red lateritic soil of Chhattisgarh. Indian Forester 135:531–538

Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC, Wisniewski J (1994) Carbon pools and fluxes of global forest ecosystems. Science 263:185–190

Djomo AN, Knohl A, Gravenhorst G (2011) Estimations of total ecosystem carbon pools distribution and carbon biomass current annual increment of a moist tropical forest. For Ecol Manage 261:1448–1459

Ghosh PK, Mahanta SK (2014) Carbon sequestration in grassland systems. Range Manag Agrofor 35:173–181

Giri N, Rawat L (2013) Assessment of biomass carbon stock in an *Ailanthus excelsa* Roxb. plantation Uttarakhand, India. J Ecol Nat Environ 5:352–359

Hairiah K, Sitompol SMV, Noordwijk M, Palm C (2001) Methods for sampling carbon stock above and below ground ASB lecture Serie Note 4B, vol 23. International Centre for Research in Agro forestry Bogor, Indonesia

Han XH, Atsushi T, Mitsuru T, Shiqing L (2010) Effects of land-cover type topography on soil organic carbon storage on Northern Loess plateau, China. Acta Agriculturae Scandinvica Sect B Soil Plant Sci 60:326–334

Heath LS, Smith JE, Birdsey RA (2003) Carbon trends in U.S. forest lands: a context for the role of soils in forest carbon sequestration. In: Kimble JM, Heath LS, Birdsey RA, Lal R (eds) The potential of US forest soils to sequester carbon and mitigate the Greenhouse effect. CRC Press LLC, Boca Raton, pp 35–45

Hicks C, Woroniecki S,Fancourt M, Bieri M, Garcia RH, Trumper K, Mant R (2014) The relationship between biodiversity, carbon storage and the provision of other ecosystemservices: critical review for the forestry component of the international climate fund. Cambridge, UK. UNEP 2014

Jina SB, Sah P, Bhatt MD, Rawat YS (2008) Estimating carbon sequestration rates and Total Carbon Stockpile in Degraded and Non-Degraded sites of Oak and Pine Forest of Kuman Central Himalaya. Ecoprint 15:75–81

Joshi NR, Tewari A, Singh V (2013) Biomass and carbon accumulation potential towards climate change mitigation by young plantation of *dalbergia sissoo Roxb*. And Eucalyptus hybrid in terai central Himalaya India. Am J Res Com 1:261–274

Karjalainen T (1996) Dynamics and potentials of carbon sequestration in managed stands and wood products in Finland under changing climatic conditions. For Ecol Manage 80:113–132

Karky BS, Banskota K, Skutsch M (2007) Reducing carbons emissions through community managed forests in Himalaya, ICIMOD, Kathmandu, Nepal

Kashyap SD, Dagar JC, Pant KS, Yewale AG (2014) Soil conservation and ecosystem stability: natural resource management through agroforestry in Northwestern Himalayan Region agroforestry systems in India livelihood security and ecosystem services. Adv Agrofor 10:21–55

Kavvadias VAD, Alifragis A, Tsiontsis G, Brofas SG (2001) Litter fall, litter accumulation and litter decomposition rates in four forest ecosystems in northern Greece. For Ecol Manage 144:113–127

Kirschbaum MUF (2003) To sink or burn? A discussion of the potential contribution of forest to green house gas balances through storing carbon or providing bio fuels. Biomass Bioenerg 24:297–310

Kuimi TV, Jayakumar S (2012) Methods to estimate above-ground biomass and carbon stock in natural forests. Rev J Ecosyst Ecogr 2:4

Labata MM, Aranico CE, Catalina A, Tabranza E, Patricio PH, Amparado FR (2012) Carbon stock assessment of three selected agroforestry system in Bukidnon, Philippines. Adv Environ Sci Int J Bioflux Soc 4:5–11

Li YQ, Zhao XY, Zhang FX (2014) Accumulation of soil organic carbon during natural restoration of desertified grassland in china's Horqin Sandy Land. J Arid Land 7:332–3340

Liu BG, Podrazsky VV, Liao YC (2003) Diameter and height growth analysis for individual White Pine trees in the area of Kostelec nad Černými lesy. J Sci 49:544–551

Lutz JA, Halpern CB (2006) Tree mortality during early forest development: a long- term study of rates, causes and consequences. Ecol Monogr 76:257–275

Mac Dicken KG (1997) A Guide to mountain carbon storage in forestry and agroforestry Projects. In: Arlington VA (US): Winrock. International Institute for Agricultural Development, Forest Carbon Monitoring Programme

Malhi Y, Baker TR, Phillips OL, Almeida S et al (2004) The above-ground coarse wood productivity of 104 Neotropical forest plots. Glob Change Biol 10:563–591

Marble SC, Prior SA, Runion B, Torbert HA, Gilliam CH, Fain GB (2011) The importance of determining carbon sequestration and greenhouse gas mitigation potential in ornamental horticulture. Am Soc Hortic Sci 46:240–244

Martinez-Ramos M, Alvarez-Buylla RE (1998) How old are tropical forest trees? Trends Plant Sci 3:400–405

Nabuurs GJ, Schelhaas MJ (2002) Carbon profiles of typical forest types across Europe assessed with CO2FIX. Ecol Ind 1:213–223

Nascimento HEM, Dias AS, Tabanez AAJ, Viana VM (1999) Structure and dynamics of tree populations of a semideciduous seasonal forest fragment in the region of Piracicaba. Braz J Biol 59:329–342

Ogunyebi AO, Omole AO, Bada SO (2012) Seasonal variation in litterfall in an age series *Gmelina Arborea* plantation in A Nigerian rain forest. Asian J Sci Technol 4:1–5

Pan Y, Birdsey RA, Fang J, Houghton R et al (2011) A large and persistent carbon sink in the world's forests. Science 19:988–993

Pandey KK, Gupta G, Mishra VS, Maurya D (2017) Carbon sequestration potential of Kafal (Myrica esculenta): an indigenous, multipurpose and medicinal tree species in high hills of Western Himalaya. Int J Curr Microbiol Appl Sci 6:852–858

Pant H, Tewari A (2013) Carbon sequestration potential of chir pine (*pinus roxburghii.* Sarg) Forest on two Contrasting aspects in Kuman Central Himalaya Between 1650–1680 m Elevation. Appl Ecol Environ Sci 1:110–112

Pederse LB, Hansen JB (1999) A comparison of litter fall and element fluxes in even aged Norway spruce, Sitka spruce and beech stands in Denmark. For Ecol Mange 114:55–70

Penman J, Gytarsky M, Hiraishi T, Kruger D, Pipati R, BuendiaL, Miwa K, Nyara T, Tanable K, Wagner F (2003) Good practice guidance for land use, land use change and forestry, IPCC, 2003

Phillips OL (1996) Long-term environmental changes in tropical forests: increasing tree turnover. Env Conser 23:35–248

Piyaphongkul J, Gajaseni N, Na-Thalang A (2011) A Comparative study of carbon sequestration potential in aboveground biomass in primary forest and secondary forest, Khao Yai National Park. Biomass Remote Sens Biomass: 199–212. https://doi.org/10.5772/16552

Quere Le et al (2013) The global carbon budget 1959–2011. Earth Syst Sci Data 5:165–185

Rawat VS (2012) Litter fall and soil nutrient returns in community managed forest in Lamgara block of Uttarakhand. Nat Sci 10:38–42

Rawat SV (2013) Carbon sequestration rates in Van Panchayat Forests and their benefits under red. J Asian Sci Res 3:396–402

Rustad LE, Campbell JL, Marion GM et al (2001) A meta-analysis of the response of soil respiration, net nitrogen mineralization, and above ground plant growth to experimental ecosystem warning. Oecologia 126:543–562

Salunkhe O, Khare PK, Gwalwanshi DR, Uniyal S (2014) Biomass estimation from herb, shrub and litter component of tropical dry deciduous forest of Madhya Pradesh state of India. J Ecol Photon 109:358–362

Schliesinger WH (1991) Biogeochemistry, an analysis of global change. Academic press, New York

Sharma CM, Gairola S, Baduni NP, Ghildiyal SK, Suyal S (2011) Variation in carbon stocks on different slope aspects in seven major forest types of temperate region of Garhwal Himalaya India. J Biosci 36:701–708

Sheikh MA, Tiwari A, Sharma S (2017) Carbon sequestration potential of various litter components in temperate coniferous forests of Kashmir Himalaya India. Arch Agric Environ Sci 2:162–166

Sheil D, May R (1996) Mortality and recruitment rate evaluations in heterogeneous tropical forests. J Ecol 84:91–100

Sheil D, Burslem DFRP, Alder D (1995) The interpretation and misinterpretation of mortality rates measures. J Ecol 83:331–333

Shorabi H, Bakhtiari BS, Ahmadi K (2016) Above and below ground biomass and carbon stocks of different tree plantations in central Iran. J Arid Land 8(1):138–145

Sundquist E, Burruss R, Faulkner S, et al (2008) USGS fact sheet: carbon sequestration to mitigate climate change. U.S. Geological Survey. https://doi.org/10.3133/fs20083097

Swaine MD, Lieberman D, Putz FE (1987) The dynamics of tree populations in tropical forests: a review. J Trop Ecol 3:359–366

Terakunpisut J, Gajasen IN, Ruankawe N (2007) Carbon sequestration potential in aboveground biomass of thong pha phum national forest Thailand. Appl Ecol Environ Res 5:93–102

Thornley JHM, Cannell MGR (2000) Managing forests for wood yield and carbon storage: a theoretical study. Tree Physiol 20:477–484

Turner IM (2001) The ecology of trees in the tropical rain forest. Cambridge University Press, p 107

Ullah MR, Al-Amin M (2012) Above and below ground carbon stock estimation in a natural forest of Bangladesh. J Sci 58:372–379

UNFCCC (1997) The Kyoto Protocol to the Convention on Climate Change. Climate Change Secretariat, Germany. 34

Valentini R, Matteucci G, Dolman AJ (2000) Respiration as the main determinant of carbon balance in European forests. Nature 404:861–865

Wani NR, Qaisar KN (2014) Carbon per cent in different components of tree species and soil organic carbon pool under these tree species in Kashmir valley. Curr World Environ 9:174–181

Wani NR, Qaisar KN, Khan AP (2014) Biomass, carbon stock and carbon dioxide mitigation potential of *Cedrus Deodra* (Deador) under temperate conditions of Kashmir. Can J Pure Appl Sci 8:2677–2684

Wani AA, Joshi KP, Singh O (2015) Estimating biomass and carbon mitigation of temperate coniferous forests using spectral modeling and field inventory data. Ecol Inform 25:63–70

Xia BJ, Zhang CG, Zhang YS, Shao BH (2009) Growth process and diameter structure of *Pinus tabulaeformis* forest for soil and water conservation in the hilly loess region of China. Afr J Biotech 8:5415–5421

Xu M, Cao CX, Tong QX et al (2010) Remote sensing based shrub above-ground biomass and carbon storage mapping in Mu Us desert, China. Sci China Tech Sci 53:176–183

Zhao J, Cao C, Yomwan P (2012) Aboveground Shrub Biomass Estimation based on Landsat Data in mu us sandy land, china. The 33rd Asian Conference on remote sensing.

Zhou GY, Liu S, Li ZA et al (2006) Old-growth forests can accumulate carbon in soils. Science 314:1417. https://doi.org/10.1126/science.1130168