# BUDGETING OF BIOMASS AND CARBON STOCK AS ECOSYSTEM SERVICE FROM HIMALAYAN DRY TEMPERATE AND ALPINE FOREST ECOSYSTEM, INDIA

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**Abstract.** The aim of the present investigation was to scrutinize the production of biomass and C storage budgeting that varies in diverse forest types of Himalayan dry-temperate and alpine forest ecosystem, India. Dry-temperate and alpine forest ecosystem is classified into nine forest types *viz*., $13C_1$-Dry broad-leaved and coniferous forests (DBCF), $13C_2$a- Neoza pine forest (NPF), $13C_2$b- Dry deodar forest (DDF), $13C_3$- West Himalayan high level dry bluepine forest (DBF), $14C_1$a- West Himalayan sub-alpine birch forest (SBF), $14C_1$b- West Himalayan sub-alpine fir forest (SFF), $15C_1$- Birch-rhododendron scrub forest (BSF), $15C_3$-Alpine pasture (AP) and $16C_1$-Dry alpine scrub (DAS). Vegetative biomass (trees, shrubs and herbs) was ranged from 0.29 in AP to 252.24 t $ha^{-1}$ in DDF. Total detritus biomass varied significantly among these forest types with maximum in BSF (5.99 t $ha^{-1}$) and minimum in DAS (0.11 t $ha^{-1}$). However, total detritus C density was recorded highest in BSF (3.00 t C $ha^{-1}$) and lowest in DAS (0.06 t C $ha^{-1}$). Among forest types total soil C density (humus + soil) varied significantly in 0-40 cm layer. BSF showed maximum C density (130.39 t C $ha^{-1}$), while minimum was recorded in DAS (37.73 t C $ha^{-1}$. Total ecosystem C density (vegetation + soil + detritus) among forest types displayed highest value for DDF (212.21 t C $ha^{-1}$), whereas minimum value (38.43 t C $ha^{-1}$) for DAS. Hence, this investigation suggests that in dry-temperate and alpine forest ecosystem, DDF should be encouraged for augmentation of biomass and C stock in Indian Himalaya.
**Keywords:** *carbon stock budgeting, detritus biomass, ecosystem carbon density, forest types, Himalaya, vegetation biomass*

## Introduction

Forests among terrestrial ecosystems are natural large biomass and carbon (C) accumulators. These ecosystems confiscate and amass higher C (~350,000 Tg C) compared to any other ecosystem and are an imperative innate ‘brake’ on changing climate. In the last twenty years in particular, there has been an increasing interest in the biomass quantification of forest ecosystems and its potential with regard to C fixation. Familiarity of diverse forest types on biomass C densities is one of the noteworthy components to measure forest lands involvement in the universal cycle of C (Yadav et al., 2019a). A purposeful relationship of floral diversity with C storage and confiscation might have an imperative implication for C sink management not only for afforestation and reforestation type projects but also for the diminution of emission projects that are the centre of attention in forest preservation and management (Gairola et al., 2011; Yadav et al., 2019a). The trouble of change in climate adds substantial stress to our societies and environment which is a fundamental menace to sustainable growth (Parihar et al., 2020; Yadav et al., 2019b). From changing weather patterns that threaten


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production of food, to rising levels of sea that add to the hazard of calamitous flooding, the climate change impacts are global in scope and unparalleled in scale, in terms of ecological imbalances, biodiversity depletions and other environmental changes.

Soils hold almost twofold C stock of the air and ~ 75% organic C pool of the ecological system (Prentice et al., 2001). The alteration in the soil C configuration and abundance can considerably influence the worldwide cycle of C and various other significant processes (Batjes, 1996). The organic C of the soil is sensitive to a multiplicity of aspects including topographical situation, climatic conditions, vegetation type, soil type and their management besides other anthropogenic circumstances (Tan et al., 2004). Aboveground C pools have been investigated extensively in comparison to forest soils (particularly in mountains). C pools are poorly sampled and studied, although underneath forests ~40% carbon of soil is institute (Lal, 2005). High proportion of SOC is recorded in the mountains soils of cold-temperate but with abundant spatial erraticism due to the intricate territory, erratic climate and vegetative communities.

Vegetative C (biotic) and soil C (pedologic) are two major components of the C stock in a forest ecosystem. In terrestrial ecosystems, forests are the utmost productive among their biotic components. Growing trees seize C in tissues and with increase biomass of the tree; the atmospheric $CO_2$ is mitigated (Yadav et al., 2017, 2019c). Trees comprise ~43-50% C of the dry biomass (Malhi et al., 2002; Negi et al., 2003). Trees until reach to the maturity, store C in their biomass (aboveground and belowground), ~50% will be carbon of the mean dry mass of trees (Anonymous, 2004). The long-lived trees build up an enormous magnitude of biomass, by this means large C amounts over many decades of their growth cycle. Thus, forest ecosystems can seize and amass huge amount of C for long duration. These productive characteristics of forests make them attractive for mitigation of changing climate (Nabuurs et al., 2007; Yasin et al., 2018; Yadav et al., 2019d, 2021). Accurate C stocks estimates in forests have been getting worldwide attention as nations bound to execute in arrangement with term and conditions under the UNFCCC (Brown, 2002). Estimates of existing C stock pools, stored in various forest categories may be helpful in making decisions about C management.

Temperate regions forest ecosystems have coverage of 767 million ha worldwide and add ~14% C storage of the forest (Pan et al., 2011). Biomass of the tree is the supreme prospective in temperate forests for C storage (Son et al., 2001; Peichl and Arain, 2006), whereas contribution of understory, detritus, and litter biomass also considerable (Whittaker and Woodwell, 1986). Thus, neglecting the biomass C and C in other components may escort to a significant under assessment of the total C storage. In Himalaya, the role of dry-temperate and alpine forests is vigorous because of their potential to mount up a great magnitude of C in diverse pools; however, the data on diverse C pools is lacking in this forests ecosystem of the Himalayas. Hence, in this study assessed (i) the production of vegetative biomass and C stock budgeting, (ii) soil carbon stock under 0-20 and 20-40 cm layer and ecosystem C stock budgeting in diverse forests types of Himalayan dry-temperate and alpine forest ecosystem.

## Material and methods

### *Study site*

The study area located in district Kinnaur (77°45’00” and 79°00’35” E longitude and between 31°05’50” and 32°05’15” N latitude), Himachal Pradesh, India (*Fig. 1*). This area adjoins part of western Tibet with which it shares its eastern boundary by


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following a well-defined ridge generally along the Zanskar Mountains. The Northern boundary adjoins Lahaul-Spiti district of Himachal Pradesh by following mostly the ridge of Spiti and Satluj river basin until near the international boundary it follows the *Spiti* river and its main tributary, the *Parechhu*. The area has characteristics of extended winters from October to April and squat summers from June to August. Heavy rain fall in monsoon is recorded in outer Himalayas to the arid Tibetan type with a winter snowfall and practically no summer rain. In winter season, whole of the study area experiences heavy snowfall. Parent material comprises of gneiss, schist, phyllites, quartzite and granites. Among the associate of the schistose series micaceous-schists, talcose rocks, phyllites and gneisses are common and sustain good forest of Kail (*Pinus wallichiana*), Deodar (*Cedrus deodara*) and Fir (*Abies pindrow*). The soil profiles are well established under densely populated forest and on edges precipitous, and southern slopes are shallow soil. The soil on gentle hill slopes and colder aspects is moderately deep.

This investigation was carried out during 2016-17 in district Kinnaur in Himalayan dry-temperate and alpine forest ecosystem of Himachal Pradesh in Himalaya (*Table 1*). Different forest types noticed in the study area are 13$C_1$-Dry broad-leaved and coniferous forests (*Quercus ilex–Pinus gerardiana*), 13$C_2$a- Neoza pine forest (*Pinus gerardiana*), 13$C_2$b- Dry deodar forest (*Cedrus deodara*) 13 $C_3$- West Himalayan high level dry blue pine forest (*Pinus wallichiana*), 14$C_1$a- West Himalayan sub- alpine birch forest, 14$C_1$b- West Himalayan sub- alpine fir forest, 15$C_1$- Birch-rhododendron scrub forest, 15$C_3$- Alpine pasture and 16$C_1$-Dry alpine scrub (Champion and Seth, 1968). The observations for all parameters were replicated thrice.

***Table 1.*** *Different forest types and their description under Himalayan dry temperate and alpine forest ecosystem*

| Forest types | Altitude range (m) | Symbol (Champion and Seth, 1968) | Coordinates | |
|---|---|---|---|---|
| | | | Latitude | Longitude |
| Dry broad-leaved and coniferous forests (DBCF) | 2000-2450 m | 13$C_1$ | 31°30’05” and 31°32’11” N | 78°08’59” and 78°10’05” E |
| Neoza pine forest (NPF) | 2300-2750 m | 13$C_{2a}$ | 31°30’29” and 31°47’51” N | 78°08’04” and 78°25’18” E |
| Dry deodar forest (DDF) | 2450-3000 m | 13$C_{2b}$ | 31°28’31” and 31°40’48” N | 78°09’45” and 78°26’17” E |
| Dry bluepine forest (DBF) | 3000-3450 m | 13$C_3$ | 31°29’21” and 31°39’32” N | 78°09’58” and 78°19’05” E |
| Sub-alpine birch forest (SBF) | 3100-3550 m | 14$C_{1a}$ | 31°20’50” and 31°21’20” N | 78°27’17” and 78°27’29” E |
| Sub-alpine fir forest (SFF) | 3150-3550 m | 14$C_{1b}$ | 31°22’25” and 31°29’17” N | 78°21’43” and 78°09’47” E |
| Birch-rhododendron scrub forest (BSF) | 3300-3600 m | 15$C_1$ | 31°25’15” and 31°28’33” N | 78°12’47” and 78°08’53” E |
| Alpine pasture (AP) | 2900-335 0m | 15$C_3$ | 31°39’48” and 31°41’29” N | 78°18’032” and 78°25’53” E |
| Dry alpine scrub (DAS) | 3300-3750 m | 16$C_1$ | 31°33’05” and 31°41’22” N | 78°13’42” and 78°25’23” E |


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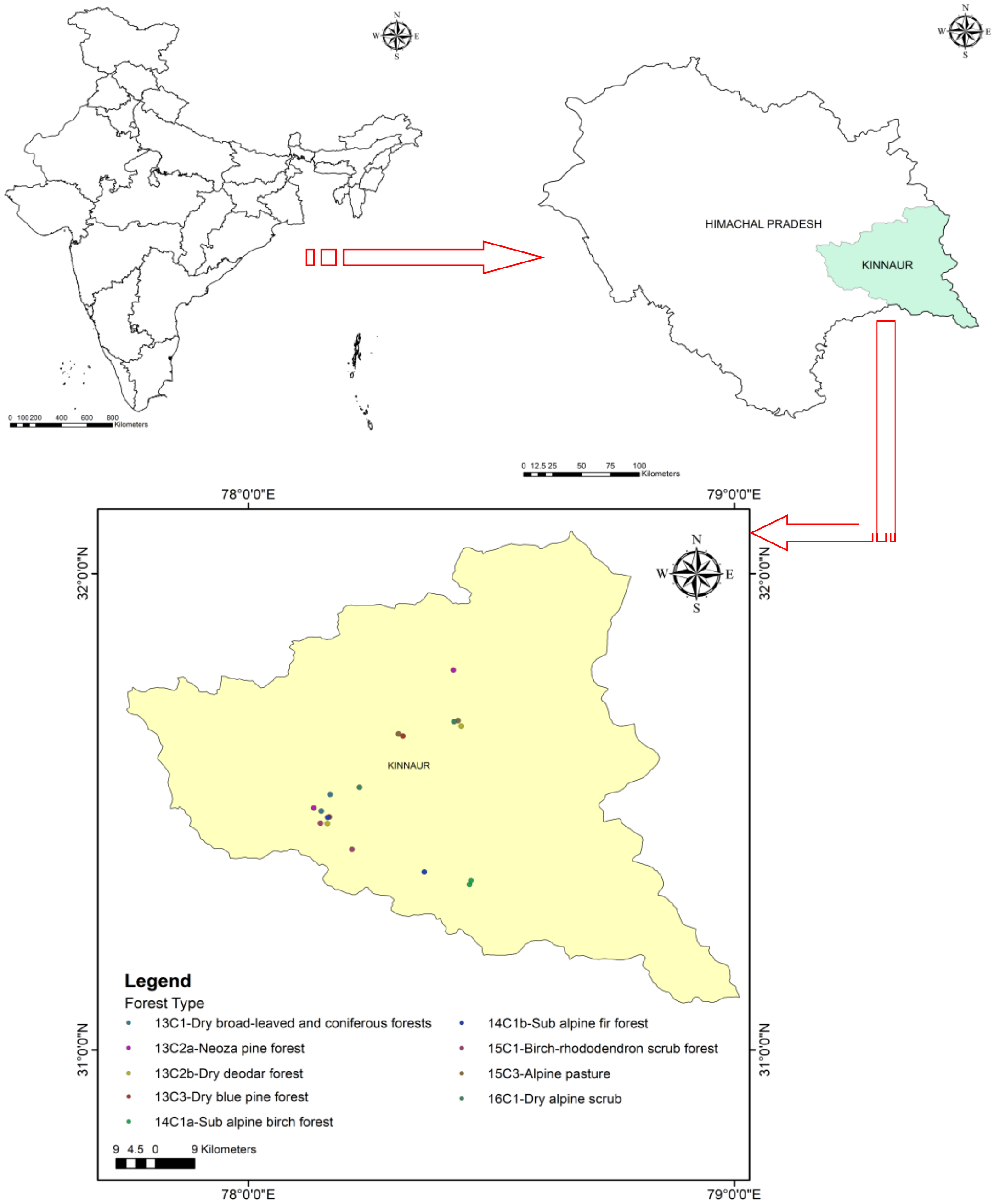


***Figure 1.*** *Location of study area and forest type map of Kinnaur district of Himachal Pradesh, North-west Himalaya*

### *Biomass measurement*

To estimate the biomass, the entire trees falling in the plot (20 m × 20 m) were enumerated. The breast height diameter (DBH) was measured with meter tape. Trees stem volume was determined by number of stem in different diameter class multiplying with respective volume factor given in working plan of Kinnaur Forest Division (Government of Himachal Pradesh Forest Department, 1999-2015) (*Table 2*). Specific gravity was determined from the available literature (Rajput et al., 1985). Stem biomass was multiplied with biomass expansion factor of the given species to arrive at total tree


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biomass (Brown et al., 2002). Trees biomass below the ground was obtained using the guidelines of IPCC (1996) and Cairns et al. (1997). Aboveground tree biomass and belowground tree biomass was added to obtain total tree biomass.

***Table 2.*** *Volume factors diameter class wise (Government of Himachal Pradesh Forest Department, 1999-2015) and specific gravity (Rajput et al., 1985)*

| Species | Diameter Classes | | | | | | | | | Specific gravity ($g/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 + 20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | 80-90 | 90-100 | |
| | Volume factor | | | | | | | | | |
| *Quercus ilex* | 0.054 | 0.25 | 0.558 | 0.958 | 1.5 | 1.867 | - | - | - | 0.825 |
| *Pinus gerardiana* | 0.028 | 0.115 | 0.46 | 0.726 | 1.0 | 1.7 | - | - | - | 0.58 |
| *Cedrus deodara* | 0.03 | 0.23 | 0.71 | 1.70 | 2.55 | 3.4 | 4.25 | 4.81 | 4.81 | 0.468 |
| *Pinus wallichiana* | 0.03 | 0.23 | 0.71 | 1.70 | 2.55 | 3.4 | 4.25 | 4.81 | 4.81 | 0.427 |
| *Abies spp.* | 0.06 | 0.08 | 0.99 | 1.70 | 2.83 | 4.53 | 6.51 | 7.65 | 9.91 | 0.34 |
| *Betula utilis* | 0.06 | 0.16 | 0.29 | 0.47 | 0.69 | - | - | - | - | 0.51 |

The biomass of shrub was measured using 5 m × 5 m quadrates. The shrubs were enumerated occurred within the borders of the quadrates. The tillers base diameter was measured with the help of calliper according to the method given by Chaturvedi and Khanna (1982). The shrubs fresh weight was taken using spring balance. A sub sample of the shrubs was taken to the laboratory for drying to obtain the dried mass of shrubs. The quadrate of size 1 m × 1 m was used to measure biomass of herbs. The herb biomass befalling within quadrate boundaries were cut, weighed, sub-sampled and dried at 65 + 5 °C in oven until constant mass. Surface litter was collected in nine quadrates of 1 m × 1 m, weighed, sub-sampled and oven dried until constant mass.

### *Soil sampling*

Samples of the soil were taken during November-December of 2016 with the help of core sampler from two different soil depth i., 0-20 cm and 20-40 cm. The soil was analysed for organic carbon content after proper drying and sieving as per standard methodology.

### *Carbon estimation*

The biomass was multiplied with a factor of 0.5 (IPCC default value) to obtain the biomass C (*Eq. 1*) in various constituents of the ecosystem. Soil C stock was estimated as per *Equation 2* (Nelson and Sommers, 1996). The litter from forest area was grounded and ashes to assess detritus C density. The ecosystem C was measured according to *Equation 3.*

$$Vegetation\ C\ density = Tree\ biomass\ C + Shrub\ biomass\ C + Herb\ biomass\ C \quad \text{(Eq.1)}$$

$$Soil\ C\ \left(\frac{t}{ha}\right) = [Soil\ bulk\ density\ \left(\frac{g}{cm^3}\right) x\ Soil\ depth\ (cm)\ x\ C] \quad \text{(Eq.2)}$$

$$Ecosystem\ C\ density\ \left(\frac{t}{ha}\right) = Vegetation\ C\ \left(\frac{t}{ha}\right) + Detritus\ C\ \left(\frac{t}{ha}\right) + Soil\ C\ \left(\frac{t}{ha}\right) \quad \text{(Eq.3)}$$


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### *Statistical analysis*

The data collected for various parameters were subjected to statistical analysis and SPSS ver. 16.0 was used for significance level at 0.05.

## Results and discussion

### *Biomass*

#### *Vegetation biomass*

The results have demonstrated that significantly higher tree biomass (aboveground biomass + belowground biomass) was recorded in DDF (250.6 t $ha^{-1}$) than all other forest types (*Table 3*). However, tree biomass of DBF (149.8 t $ha^{-1}$) was found statistically at par with SBF (128.9 t $ha^{-1}$), DBCF (128.11 t $ha^{-1}$) and NPF (96.58 t $ha^{-1}$). Meanwhile, lowest values were obtained in BSF (59.31 t $ha^{-1}$), SBF (47.75 $ha^{-1}$) whereas, nil for AP and DAS, respectively. In case of shrubs, maximum total shrub biomass was obtained in BSF (19.24 t $ha^{-1}$), which was statistically different compared to all other forest types. While, other forest types *viz*., DDF (1.23 t $ha^{-1}$), DBCF (1.05 t $ha^{-1}$), DAS (0.94 t $ha^{-1}$), NPF (0.94 t $ha^{-1}$), DBF (0.78 t $ha^{-1}$), SFF (0.63 t $ha^{-1}$) and SBF (0.58 $ha^{-1}$) were statistically comparable to each other and there was no critical difference among them. Herbaceous biomass varied significantly with maximum in AP (0.58 t $ha^{-1}$) and minimum in DAS (0.36 t $ha^{-1}$) among different forest types.

***Table 3.*** *Vegetation (tree, shrub and herb) biomass (t $ha^{-1}$) under different forest types*

| Forest types | AGB (t $ha^{-1}$) | BGB (t $ha^{-1}$) | Tree biomass (t $ha^{-1}$) | Shrub biomass (t $ha^{-1}$) | Herb biomass (t $ha^{-1}$) | Total vegetation (tree + shrub + herb) biomass (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| DBCF | $103.11^{b}$ | $25.00^{b}$ | $128.11^{b}$ | $1.05^{b}$ | $0.47^{bc}$ | $129.63^{bc}$ |
| NPF | $79.83^{b}$ | $16.75^{bc}$ | $96.58^{bc}$ | $0.94^{b}$ | $0.40^{b}$ | $97.92^{bcd}$ |
| DDF | $207.06^{a}$ | $43.50^{a}$ | $250.56^{a}$ | $1.23^{b}$ | $0.45^{bc}$ | $252.24^{a}$ |
| DBF | $123.83^{b}$ | $26.00^{b}$ | $149.83^{b}$ | $0.78^{b}$ | $0.48^{bc}$ | $151.09^{b}$ |
| SBF | $39.50^{c}$ | $8.25^{c}$ | $47.75^{c}$ | $0.58^{b}$ | $0.53^{ab}$ | $48.86^{de}$ |
| SFF | $104.96^{b}$ | $24.03^{b}$ | $128.99^{b}$ | $0.63^{b}$ | $0.47^{bc}$ | $130.09^{bc}$ |
| BSF | $49.00^{c}$ | $10.31^{c}$ | $59.31^{c}$ | $19.24^{a}$ | $0.42^{cd}$ | $78.97^{cd}$ |
| AP | - | - | - | - | $0.58^{a}$ | $0.58^{e}$ |
| DAS | - | - | - | $0.94^{b}$ | $0.36^{d}$ | $1.30^{e}$ |
| $CD_{0.05}$ | 48.13 | 10.37 | 58.37 | 1.02 | 0.08 | 58.64 |

DBCF- Dry broad-leaved and coniferous forests; NPF- Neoza pine forest; DDF- Dry deodar forest; DBF- Dry bluepine forest; SBF- Sub-alpine birch forest; SFF- Sub-alpine fir forest; BSF- Birch-rhododendron scrub forest; AP- Alpine pasture and DAS- Dry alpine scrub. The superscript on values in lower case letters denotes significance at $p < 0.05$

Total vegetative biomass was maximum in DFF (252.24 t $ha^{-1}$) which was found statistically different than all other forest types (*Table 3*). DBF (151 t $ha^{-1}$), SFF (130.09 t $ha^{-1}$), DBCF (129.63 t $ha^{-1}$) and NPF (97.92 t $ha^{-1}$) were statistically at par and there were no critical difference among them. In SBF (48.86 t $ha^{-1}$), DAS (1.30 t $ha^{-1}$) and AP (0.58 t $ha^{-1}$) forest recorded minimum values and found at par with each other for vegetation biomass.

The vegetation biomass is a decisive ecological variable to comprehend the evolution and probable future distinctions in the climate system. Vegetation biomass is a bigger


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worldwide store house of C compared to the air, and universal atmosphere a net C source is already affected due to fluctuations in the biomass quantity of vegetation and having the prospective either to seize C in forthcoming or even bigger source may become. The quantity of biomass in the vegetation coverage may have a straight consequence on universal climate (including local, regional), predominantly on temperature and humidity of the air. Therefore, a worldwide biomass appraisal and dynamics of biomass is an indispensable contribution to climatic change forecast models, and adaptive and mitigating strategies.

Total tree biomass (above ground + below ground) among diverse forest types ranged from 0.00 - 250.56 t ha$^{-1}$ with highest biomass in DDF followed by DBF, SFF, DBCF, NPF, BSF, SBF and nil for AP and DAS. These variations in biomass of trees in forest are a manifestation of inherent growth characteristics of trees besides the alterations in trees densities (Yadav et al., 2019a, d). The nil values for biomass of tree in AP and DAS were due to the absence of trees in those vegetation-systems. Highest trees biomass in DDF can have a relation to this forest ecosystems greater basal area. Differences in tree biomass are the manifestation of inherent growth characteristics of constituent species, their specific ecological niche, climate difference and tree densities (Yadav et al., 2016, 2017, 2019b, c). Biomass is also having a relation to human or natural disturbances (Lugo and Brown, 1992; Huang et al., 2021).

A cross-section of above-ground biomass, below-ground biomass and total biomass values of trees for certain related forest ecosystem is given in *Table 2*. It is observed that tree biomass values recorded in present investigation is lower compared to those stated in other Himalayan forest type ecosystem (Sharma et al., 2010; Gairola et al., 2011; Dar and Sundarapandian, 2015; Yadav et al., 2019a). This can be ascribed low temperature and rainfall of this climatic zone, which in this region limits the tree growth.

The alteration in shrubs biomass in various forests is having a relationship to species constitution and their inherent growth capability. Ross and Walstad (1986) opined that shrub biomass might be ascribed to factors like age, size, origin, condition and habit of the species. In BSF, foremost shrub was *Rhododendron campanulatum* that lead to in greater biomass due to its hefty habit. The higher values of herbaceous biomass in AP can be ascribed to sufficient sunlight due to absence of overstorey canopy as also reported by Grelen and Whrey (1978), Singh and Singh (1980), Ramakrishna (1984), Hazra and Patil (1986) and Heinrichs and Schmidt (2010).

### *Detritus biomass*

A scrutiny of data in *Table 4* revealed that litter biomass, dead twig biomass, total detritus biomass and total detritus C varied significantly under diverse forest types. Leaf or surface litter biomass was recorded maximum in BSF (3.15 t ha$^{-1}$) that was significantly higher compared to all other forest types while; minimum was recorded in DAS (0.11 t ha$^{-1}$). Results pertaining to dead twig revealed maximum biomass was in BSF (2.84 t ha$^{-1}$) and nil in both AP as well as DAS.

Total detritus biomass was highest in BSF (5.99 t ha$^{-1}$) followed by SFF (5.23 t ha$^{-1}$), DBCF (4.05 t ha$^{-1}$), SBF (3.07 t ha$^{-1}$), DDF (2.57 t ha$^{-1}$), DBF (2.39 t ha$^{-1}$), NPF (1.64 t ha$^{-1}$), AP (0.15 t ha$^{-1}$) and DAS (0.11 t ha$^{-1}$) in descending order, respectively (*Table 4*). Detritus biomass is a pointer of forest management scale if there is more detritus biomass it means the forest has been poorly managed. Here the result reveals though forest have been managed but needs more intense management.


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***Table 4.*** *Litter, dead twig biomass, total detritus biomass (t ha$^{-1}$) and total detritus carbon density under different forest types*

| Forest types | Litter biomass (t ha$^{-1}$) | Dead twig biomass (t ha$^{-1}$) | Total detritus biomass (litter + dead twig) (t ha$^{-1}$) |
|---|---|---|---|
| DBCF | 2.35$^{c}$ | 1.70$^{c}$ | 4.05$^{c}$ |
| NPF | 0.79$^{f}$ | 0.85$^{g}$ | 1.64$^{f}$ |
| DDF | 1.39$^{e}$ | 1.18$^{e}$ | 2.57$^{e}$ |
| DBF | 1.35$^{e}$ | 1.04$^{f}$ | 2.39$^{e}$ |
| SBF | 1.80$^{d}$ | 1.27$^{d}$ | 3.07$^{d}$ |
| SFF | 2.83$^{b}$ | 2.40$^{b}$ | 5.23$^{b}$ |
| BSF | 3.15$^{a}$ | 2.84$^{a}$ | 5.99$^{a}$ |
| AP | 0.15$^{f}$ | 0.00$^{h}$ | 0.15$^{g}$ |
| DAS | 0.11$^{g}$ | 0.00$^{h}$ | 0.11$^{g}$ |
| $CD_{0.05}$ | 0.29 | 0.04 | 0.31 |

DBCF- Dry broad-leaved and coniferous forests; NPF- Neoza pine forest; DDF- Dry deodar forest; DBF- Dry bluepine forest; SBF- Sub-alpine birch forest; SFF- Sub-alpine fir forest; BSF- Birch-rhododendron scrub forest; AP- Alpine pasture and DAS- Dry alpine scrub. The superscript on values in lower case letters denotes significance at $p < 0.05$

## *Carbon density*

### *Soil carbon density*

Humus depth of various forest types is displayed in *Table 5* revealed that BSF exhibited the highest humus depth (4.41 cm) that was significantly high compared to all other forest types under investigation and nil value was stated for AP and DAC, respectively. Soil C density *viz*., humus, 0-20 cm and 21-40 cm varied significantly among various forest types. In the humus layer, significantly higher C density was recorded in BSF (11.30 t C ha$^{-1}$) followed by SFF (8.30 t C ha$^{-1}$), DBCF (4.79 t C ha$^{-1}$), SBF (2.90 t C ha$^{-1}$), DBF (0.63 t C ha$^{-1}$), DDF (0.54 t C ha$^{-1}$), NPF (0.36 t C ha$^{-1}$), and nil for both AP and DAS, respectively.

In the 0-20 cm as well as 21-40 cm soil depth the soil C density of various forest types varied significantly. Soil C density in the depth of 0-20 and 21-40 cm was observed as maximum in BSF (71.55 and47.54 t C ha$^{-1}$) and minimum in DAS (23.70 and 14.02 t C ha$^{-1}$), respectively.

Total soil C density {humus + soil (0-40 cm layer)} showed highest in BSF (130.39 t C ha$^{-1}$). And followed the order: DBCF (111.18 t C ha$^{-1}$) > DDF (84.81 t C ha$^{-1}$) > SBF (74.76 t C ha$^{-1}$) > SFF (73.56 t C ha$^{-1}$) > DBF (56.55 t C ha$^{-1}$) > AP (51.06 t C ha$^{-1}$) > NPF (45.62 t C ha$^{-1}$) and least in DAS (37.73 t C ha$^{-1}$) (*Table 5*).

Higher humus depth in BSF may be because of a dense cover provided by *Rhododendron campanulatum* thereby preventing sun light to reach soil surface and thus hindering its decomposition. The green foliage forming the irregular to regular spherical crown has immense power to enrich the thickness of humus layer over the soil. Meanwhile, nil humus value displayed in AP and DAS may be due to low litter production in these ecosystems along with the high wind velocity and overgrazing.

Worldwide, mean SOC builds up to 1.0 m depth was 12.2 kg m$^{-2}$ in temperate forest (Prentice et al., 2001; Lal, 2005), 13.9 kg m$^{-2}$ in cool temperate wet forest (Post et al., 1982) and 11.3 kg m$^{-2}$ among all forests (Sombroek et al., 1993). Soil C density of 161.9 t ha$^{-1}$ for soil depth of 1.0 m was reported in montane temperate forest (Chhabra


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et al., 2003). The SOC exhibits substantial spatial variability, both vertical within profile of the soil and horizontal as per land use. The OC of the soil lessens with depth even without considering vegetation type (Trujilo et al., 1997). In diverse forest types, the C density diminished with moving down from 0-20 cm to 21-40 cm depth of soil. The OC of the soil is governed by a multiplicity of elements that includes both biological and abiotic, such as diversity of fauna, microclimate, land uses and their management. Litter contribution of root and leaf play significant role in C of forest soil.

***Table 5.*** *Soil carbon stock (t C ha$^{-1}$) under different forest types*

| **Forest types** | **Humus depth (cm)** | **Carbon density (t C ha$^{-1}$)** | | | |
|---|---|---|---|---|---|
| | | **Humus** | **Soil (0-20 cm)** | **Soil (21-40 cm)** | **Total [Humus + Soil (0-40 cm)]** |
| DBCF | $1.28^{c}$ | $4.79^{c}$ | $59.37^{b}$ | $47.02^{a}$ | $111.18^{b}$ |
| NPF | $0.27^{g}$ | $0.36^{g}$ | $28.42^{h}$ | $16.84^{f}$ | $45.62^{g}$ |
| DDF | $0.61^{f}$ | $0.54^{f}$ | $52.52^{c}$ | $31.74^{b}$ | $84.81^{c}$ |
| DBF | $0.74^{e}$ | $0.63^{e}$ | $35.43^{f}$ | $20.49^{e}$ | $56.55^{e}$ |
| SBF | $0.99^{d}$ | $2.90^{d}$ | $44.50^{d}$ | $27.36^{c}$ | $74.76^{d}$ |
| SFF | $3.35^{b}$ | $8.30^{b}$ | $41.18^{e}$ | $24.09^{d}$ | $73.56^{d}$ |
| BSF | $4.41^{a}$ | $11.30^{a}$ | $71.55^{a}$ | $47.54^{a}$ | $130.39^{a}$ |
| AP | $0.00^{h}$ | $0.00^{h}$ | $33.66^{g}$ | $17.40^{f}$ | $51.06^{f}$ |
| DAS | $0.00^{h}$ | $0.00^{h}$ | $23.70^{i}$ | $14.02^{g}$ | $37.73^{h}$ |
| $CD_{0.05}$ | 0.08 | 0.04 | 1.61 | 1.23 | 2.65 |

DBCF- Dry broad-leaved and coniferous forests; NPF- Neoza pine forest; DDF- Dry deodar forest; DBF- Dry bluepine forest; SBF- Sub-alpine birch forest; SFF- Sub-alpine fir forest; BSF- Birch-rhododendron scrub forest; AP- Alpine pasture and DAS- Dry alpine scrub. The superscript on values in lower case letters denotes significance at $p < 0.05$

The upper soil layer remains in dynamic equilibrium with biological and anthropological activities and is generally richer in C than the lower layers. Similar results are also reported earlier by Shrestha et al. (2004) for mountain watershed of Nepal. The growth and functions of vegetation rely on the soil plant nutrients approachability, whilst, SOC dynamics hang on the contribution stated from the growth of vegetation. Thus, in an ecosystem there is an inter-relationship between vegetation type and soil C dynamics (Yadav et al., 2019a). The input can be from aboveground leaf litter and or belowground fine roots (Bloomfield et al., 1996; Yadav et al., 2019a) and their disintegration speeds directed by the microbial activity.

In the present study the soil C pools in forests are lower compared to the OC of soil reported for Garhwal region Uttarakhand (Raina and Gupta, 2013) but are analogous to that stated by other researchers (Wani et al., 2013) in Kashmir Himalayas (Yadav et al., 2019a) central Himalaya and (Panwar and Gupta, 2013) in Himachal Pradesh. It is also evidently clear from the data in *Table 4* that soil C density (humus, 0-20 cm and 21-40 cm) was highest in BSF. Hence, BSF has more capacity to store the C in soil and thus illustrate more carbon mitigation potential.

*Vegetation, detritus and ecosystem C density*

In case of total vegetative C it was testified that highest in DDF (126.1 t C ha$^{-1}$), which was found statistically different than all other forest types (*Table 6*). Meanwhile, the lowest total vegetation C was witnessed in DAS (0.65 C t ha$^{-1}$) and AP (0.29 t C ha$^{-1}$).


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The forest vegetative C stock varies according to geographical location, species and age of the plant in the stand. Vegetation C varies as quantified in our case is more or less in line as stated by Dar and Sundarapandian (2015) for Central Himalayan forest ranges. The highest displayed values of total vegetative C in DDF can be ascribed to greater biomass owing to occurrence of more share of large size tree in the forest community.

Total density of detritus C also varied significantly among diverse forest types (*Table 5*). The significantly higher detritus C was found in BSF (3.00 t C $ha^{-1}$) than all other forest types. And followed the trend: SFF (2.62 t C $ha^{-1}$) > DBCF (2.03 t C $ha^{-1}$) > SBF (1.54 t C $ha^{-1}$) > DDF (1.29 t C $ha^{-1}$) = DBF (1.20 t C $ha^{-1}$) > NPF (0.82 t C $ha^{-1}$) > AP (0.08 t C $ha^{-1}$) = DAS (0.06 t C $ha^{-1}$). Data described in *Table 6* revealed that the ecosystem (vegetation + soil + detritus) C density under diverse forest type varied significantly**.** Ecosystem C density was recorded highest in DDF (212.21 t C $ha^{-1}$) followed by DBCF (178.02 t C $ha^{-1}$), BSF (172.87 t C $ha^{-1}$), SFF (141.22 t C $ha^{-1}$), DBF (133.29 t C $ha^{-1}$), SBF (100.72 t C $ha^{-1}$), NPF (95.40 t C $ha^{-1}$), AP (51.42 t C $ha^{-1}$), and DAS (38.43 t C $ha^{-1}$) in descending order, respectively. Among the forest types dissimilarity in detritus C stock may be owed to stand age structure variations and disturbance, elevation, litter input and its putrefaction rate (Pregitzer and Euskirchen, 2004; Peichul and Arain, 2006; Taylor et al., 2007; Khan et al., 2020). Management history and environmentally controlled disintegration rates probably may be responsible for this difference and, in addition to differences induced by vegetation status with detritus inputs.

***Table 6.*** *Vegetation, detritus and ecosystem carbon density (t C $ha^{-1}$) under different forest types*

| Forest types | Vegetation (t C $ha^{-1}$) | Detritus (t C $ha^{-1}$) | Ecosystem (t C $ha^{-1}$) |
|---|---|---|---|
| DBCF | $64.82^{b}$ | $2.03^{c}$ | $178.02^{b}$ |
| NPF | $48.96^{b}$ | $0.82^{f}$ | $95.40^{e}$ |
| DDF | $126.12^{a}$ | $1.29^{e}$ | $212.21^{a}$ |
| DBF | $75.55^{b}$ | $1.20^{e}$ | $133.29^{c}$ |
| SBF | $24.43^{c}$ | $1.54^{d}$ | $100.72^{d}$ |
| SFF | $65.05^{b}$ | $2.62^{b}$ | $141.22^{c}$ |
| BSF | $39.49^{c}$ | $3.00^{a}$ | $172.87^{b}$ |
| AP | $0.29^{d}$ | $0.08^{g}$ | $51.42^{f}$ |
| DAS | $0.65^{d}$ | $0.06^{g}$ | $38.43^{f}$ |
| $CD_{0.05}$ | 29.32 | 0.15 | 29.61 |

DBCF- Dry broad-leaved and coniferous forests; NPF- Neoza pine forest; DDF- Dry deodar forest; DBF- Dry bluepine forest; SBF- Sub-alpine birch forest; SFF- Sub-alpine fir forest; BSF- Birch-rhododendron scrub forest; AP- Alpine pasture and DAS- Dry alpine scrub. The superscript on values in lower case letters denotes significance at $p < 0.05$

### *Total vegetation, soil and ecosystem C pool*

A cursory glance of the data in *Table 7* and *Figure 2* indicates that highest vegetation C pool was found in DFF (1083118.56 t C). Followed by NPF (546393.60 t C), DBF (228916.50 t C), DBCF (79534.14 t C $ha^{-1}$), SBF (43509.83 t C), DAS (8296.60 C t) SFF (5842.14 t C) and BSF (157.96 t C) in descending order, respectively. Total soil C pool (*Table 7*; *Fig. 2*) was recorded highest in DDF (728348.28 t C $ha^{-1}$) followed by NPF (509119.20 t C), DAS (481585.72 C t), DBF (171346.50 t C), DBCF (136417.86 t C), SBF (133147.56 t C), SFF (6606.42 t C) and BSF (521.56 t C) in descending order,


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respectively. Total ecosystem C pool was recorded maximum in DDF (1822459.48 t C) followed by NPF (1064664.00 t C), DAS (490520.52 t C), DBF (403868.70 t C), DBCF (218430.54 t C $ha^{-1}$), SBF (179382.32 t C), SFF (12682.97 t C) and BSF (691.48 t C) in descending order, respectively (*Table 7; Fig. 2*).

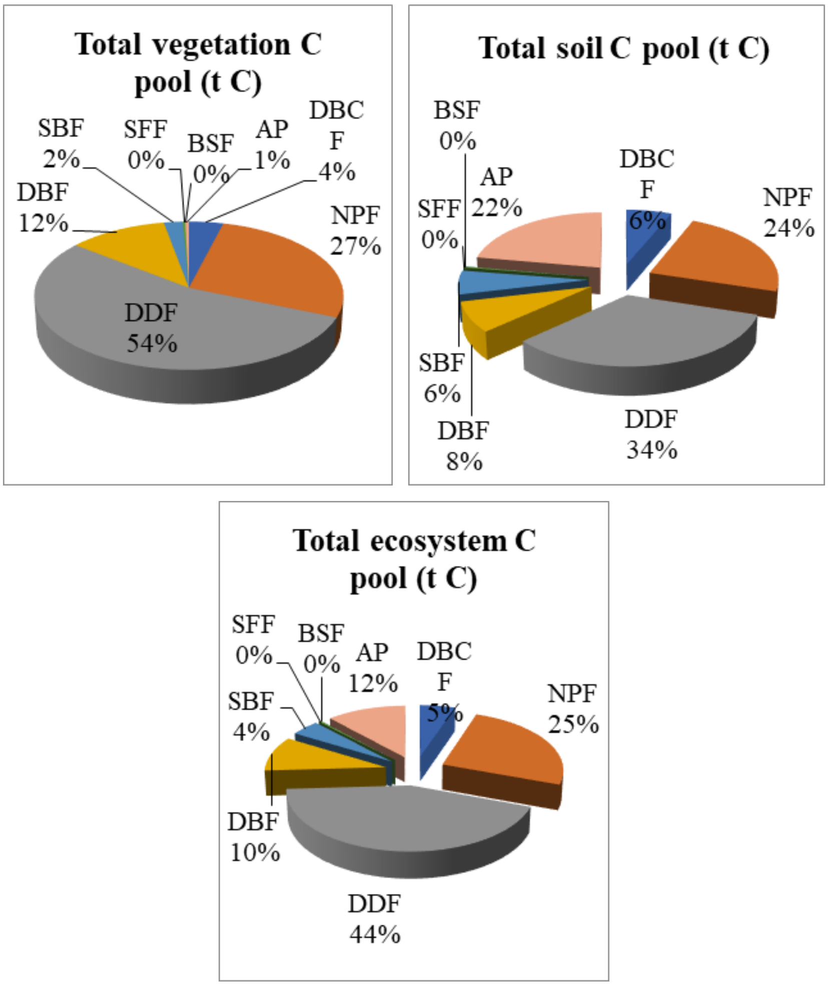


***Figure 2.*** *Total vegetation, soil and ecosystem C pools (t C) under different forest type based on forest area of working plan (1999-2015)*

Vegetative C and soil C of forest hold C stock of ~1240 Pg (Dixon et al., 1994), and C stocks including total terrestrial C stocks vary extensively alongside with latitudes. Of the forest worldwide biomass C stock, in forest of low latitude is 37%, 14% in mid latitude and in high latitudes is 49%. The C density above the ground of plant rises with declining latitudes from tundra to tropical rainforest (Fisher, 1995). Typical C density in plant varies from 40 to 60, 60 to 130, 120 to 194 Mg C $ha^{-1}$ in boreal, temperate and tropical forest, respectively. Forest ecosystem soils encompass around two-thirds of land-dwelling C stock (Dixon et al., 1994). Present investigation revealed that C density differed significantly in different components of various forest ecosystems *viz.*, vegetation, soil, detritus and ecosystem as a whole, with diverse forest types. Uppermost ecosystem C density was noted in DDF. The comparative higher displayed values of vegetative C in addition to soil C density in DDF led to high ecosystem C density.


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***Table 7.*** *Total vegetation, soil and ecosystem C stock (t C) under different forest types*

| Forest types | Area (ha)* | Total vegetation C stock (t C) | Total soil C stock (t C) | Total ecosystem C stock (t C) |
|---|---|---|---|---|
| DBCF | 1227 | 79534.14 | 136417.86 | 218430.54 |
| NPF | 11160 | 546393.60 | 509119.20 | 1064664.00 |
| DDF | 8588 | 1083118.56 | 728348.28 | 1822459.48 |
| DBF | 3030 | 228916.50 | 171346.50 | 403868.70 |
| SBF | 1781 | 43509.83 | 133147.56 | 179382.32 |
| SFF | 89.81 | 5842.14 | 6606.42 | 12682.97 |
| BSF | 4.00 | 157.96 | 521.56 | 691.48 |
| AP | 12764 | 8296.60 | 481585.72 | 490520.52 |

DBCF- Dry broad-leaved and coniferous forests; NPF- Neoza pine forest; DDF- Dry deodar forest; DBF- Dry bluepine forest; SBF- Sub-alpine birch forest; SFF- Sub-alpine fir forest; BSF- Birch-rhododendron scrub forest; AP- Alpine pasture and DAS- Dry alpine scrub; *Source: Working plan of Kinnaur Forest Division (1999-2015)

## Conclusions

Vegetative biomass, vegetative C, soil C and total C stock budgeting revealed that biomass in vegetation and vegetation, soil, detritus and total C varied in various forest types of Himalayan dry-temperate and alpine forest ecosystem of Indian Himalaya. Among vegetation tree accumulated highest biomass and C density followed by shrubs and herbs. Detritus biomass and C was also prominently added in total biomass and C stock. Total soil and detritus C density was highest in BSF than other forest types. Total C pools of vegetation, soil and ecosystem was highest in DDF. Hence, it is noted that dry-temperate and alpine forest ecosystem amassed a enormous amount of biomass in vegetation and C stock that varied in various forest types. It contributes in climate change alleviation and adaptive policies enormously that need to be conserved and strengthen.

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# APPENDIX


***Plate 1.*** *View of different forest types of Himalayan dry temperate and alpine forest ecosystem*


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