Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci. (Oct–Dec 2022) 92(4):861–867
https://doi.org/10.1007/s40011-022-01381-z

RESEARCH ARTICLE

# Carbon Stock Availability in Forests of the Zabarwan Mountain Range in Kashmir Himalaya

**Valeed Ahmed Khan[1] · Shiekh Marifatul Haq[2] · Umer Yaqoob[3] · Faiza Bashir[4] · Musheerul Hassan[5]**

Received: 31 March 2021 / Revised: 9 January 2022 / Accepted: 30 March 2022 / Published online: 25 July 2022


**Abstract** Assessing forest carbon and its fluctuations in mountainous areas is especially important for carbon budgeting, wildlife protection, assessing ecosystem vulnerability, and a variety of other ecological and environmental purposes. Conservation and maintaining carbon stocks in forests are widely recognized as a relatively low-cost option for mitigating climate risks. The present research was carried out to evaluate the C stocks in the forests of Zabarwan mountain range of Kashmir Himalaya. We carried out random sampling of tree vegetation in the five (5) major forest types in the study area. The carbon stock was calculated and analyzed using hierarchical cluster analysis. The data were subjected to hierarchical cluster analysis via, using PAST software ver.3.14. We recorded 20 forest tree species taxonomically distributed among 15 genera. The total carbon stock in the study area was 872.45 Mg C ha$^{-1}$ and could store an average of 174.49 Mg C ha$^{-1}$. Highest total carbon stock (258.46 ± 47.53 Mg C ha$^{-1}$) was observed for *Pinus wallichiana* forest, followed by Broad-leaved forest (230.84 ± 84.04 Mg C ha$^{-1}$), whereas the least value (56.68 ± 16.19 Mg C ha$^{-1}$) was observed for Scrub forest type. The decreasing trend in total carbon stock was *P. wallichiana* forest > Broad-leaved forest > *Acacia* forest > Oak forest > Scrub forest. The most significant tree species in terms of carbon stock was *P. wallichiana, Quercus robur, Celtis australis,* and *Robinia pseudoacacia.* The results indicated that the forests of the Zabarwan range show a good signal toward an opportunity in effectively conserving the carbon storage of Kashmir Himalayas by checking destruction of lush green woody forests.

**Keywords** Forest · Cluster analysis · Tree structural attributes · PAST software · Kashmir Himalaya

**Significance Statement**: Assessing forest carbon and its fluctuations in mountainous areas is especially important for carbon budgeting, wildlife protection, assessing ecosystem vulnerability, and a variety of other ecological and environmental purposes. Conservation and maintaining carbon stocks in forests are widely recognized as a relatively low-cost option for mitigating climate risks. The results indicated that the forests of the Zabarwan range show a good signal toward an opportunity in effectively conserving the carbon storage of Kashmir Himalayas by checking destruction of lush green woody forests.

✉ Shiekh Marifatul Haq
snaryan17@gmail.com

Valeed Ahmed Khan
valeedahmedkhan@gmail.com

Umer Yaqoob
umerraj6668@gmail.com

Faiza Bashir
scholar.faiza@gmail.com

Musheerul Hassan
musheer123ni@gmail.com

[1] Department of Environmental Science, University of Kashmir, Hazratbal Srinagar, Jammu and Kashmir 190006, India

[2] Wildlife Crime Control Division, Wildlife Trust of India, Noida, Jammu and Kashmir 201301, India

[3] Zonal Educational Office Vehil, Srinagar, Jammu and Kashmir 192303, India

[4] Biological Research Center, Institute of Plant Biology, Hungary Academy of Sciences, Szeged, Hungary

[5] Clybay Research Private Limited, Bangalore 560114, India

## Introduction

Vegetation biomass is a key component of forest ecosystem [1] and represents habitats which support majority of species and provide valuable ecosystem services for human use [2]. Climate change has a significant impact on global forest biodiversity, and it is likely to be the leading cause of biodiversity loss in the near future [3]. Among all worldwide ecosystems, Himalayan forest ecosystem undergoes greater modifications than other ecosystems [4]. The elevated atmospheric level of carbon dioxide can be mitigated by increasing the area under forest cover [5]. To reduce the imminent increase in biodiversity loss and climate risks in the Zabarwan sub-mountains range, a National Park was established in 1981. In the sub-urban landscapes, National Parks (NPs) are currently employed as principal tool for maintaining biodiversity and mitigate climate change [6]. Furthermore, the landscapes surrounded by NPs are the main indicators of the speedy climatic changes which can interfere with anthropogenic disturbances (viz. climate changes and modifications in the land use patterns) and other deteriorations [7]. Thus, these events make forest conservation critically important for mitigating climate change [8].

In community ecology, the major challenge is to understand the factors that influence the productivity, spatial variation, growth, composition and other ecological attributes of woody trees species [9]. As the large-scale environmental change is predicted to intensify the consequences of land-use change [10], the managers and conservation scientists ought to pick out the handiest methods to hold the integrity of biodiversity and ecosystem services and other processes [11]. The response of the net exchange of $CO_2$ to climate depends on the response of carbon uptake growing stock volume density (GSVD) and on the carbon residence times resides in terrestrial ecosystems [12]. In Indian Himalayas, the status of NPs is very special, where human intervention is only allowed to perform a particular activity. In NPs, natural factors have some consequences on the growth, biomass and structure of wood trees, and the effect of these factors can be easily assessed in these areas. These natural drivers affect the spatial variation of productivity in the NPs, indicating the productivity of a specific part in accordance with the standing biomass at a given period of time. Managers, policymakers, and conservation activists needed to understand the conditions under which NPs offer conservation benefits. The accurate assessment of carbon of the most critical factors for sustainable forest resource management in protected areas. Numerous studies revealed the competency of NPs in reducing the deforestation rate [13]. However, in order to assess the role of existing NPs under REDD+, a thorough assessment of their ability to secure forest carbon is critical.

Within the mountain ecosystems field, the Indian Himalayan Region (IHR) is of particular importance. Despite the fact that the Himalayan mountain range accounts for only 18% of India's total geographical area, it is home to more than 50% of India's forest cover and more than 40% of the endemic species found on the Indian subcontinent [14]. Some critical regions of IHR, such as the Zabarwan sub-mountain range, have received little attention in terms of ecological research. Dachigam National Park (DNP) is a significant feature of the range, which is why its various forests were chosen for the current study. Despite the fact that our research was conducted over a small-scale distance between selected forest types, the diversity of tree species in these forests varied, with different dominant species. These forests support a rich diversity of wildlife and provide important ecosystem carbon sequestration and storage functions [15]. This region therefore provides an ideal place to evaluate changes in carbon stock. This study specifically addresses the research questions on (i), to evaluate the tree C stocks in the forests of Zabarwan range in Kashmir Himalaya, (ii) what is the contribution of different tree species in the total C stock? Additionally, all the collected data will be useful in devising new management framework policies, the diversely vegetative landscapes could be turned into vast C sequesters which could prove critical role in mitigating the regional (Zabarwan sub-mountains range) as well as global climatic crises.

## Materials and Methods

### Study Area

The central part of Kashmir valley located in the territory of Jammu and Kashmir, India, consists of Zabarwan Range, a sub-mountain range of 32 km long and is located in between Himalayan range and Pir Panjal. The Zabarwan mountain range is enriched with wildlife and acquires great Himalayan features. One of the significant features of the range is Dachigam National Park (DNP), and that is the reason for the selection of its different forests for the current study [15]. DNP covers an area of 141 $km^2$ which extends between 34° 05′ N–34° 11′ N and 74° 54′ E–75° 09′ E (Fig. 1). The study area has an altitude range of 5704 to 6334 feet. The details of sampled forest types are shown in Table 1. The average rainfall in the area is 660 mm, but like other regions of the country, there is no any such particular rain season. The maximum reported average temperature is 2 °C in the winter and 27 °C in the summer. According to Dachigam Management Plan 2011–2016, the entire Dachigam National Park is mountainous, with crystalline rocks such as granite, phyllites, and schists, as well as lime stone buried in them. The Dachigam National Park is surrounded by a fold of the Zanskar range, which forms

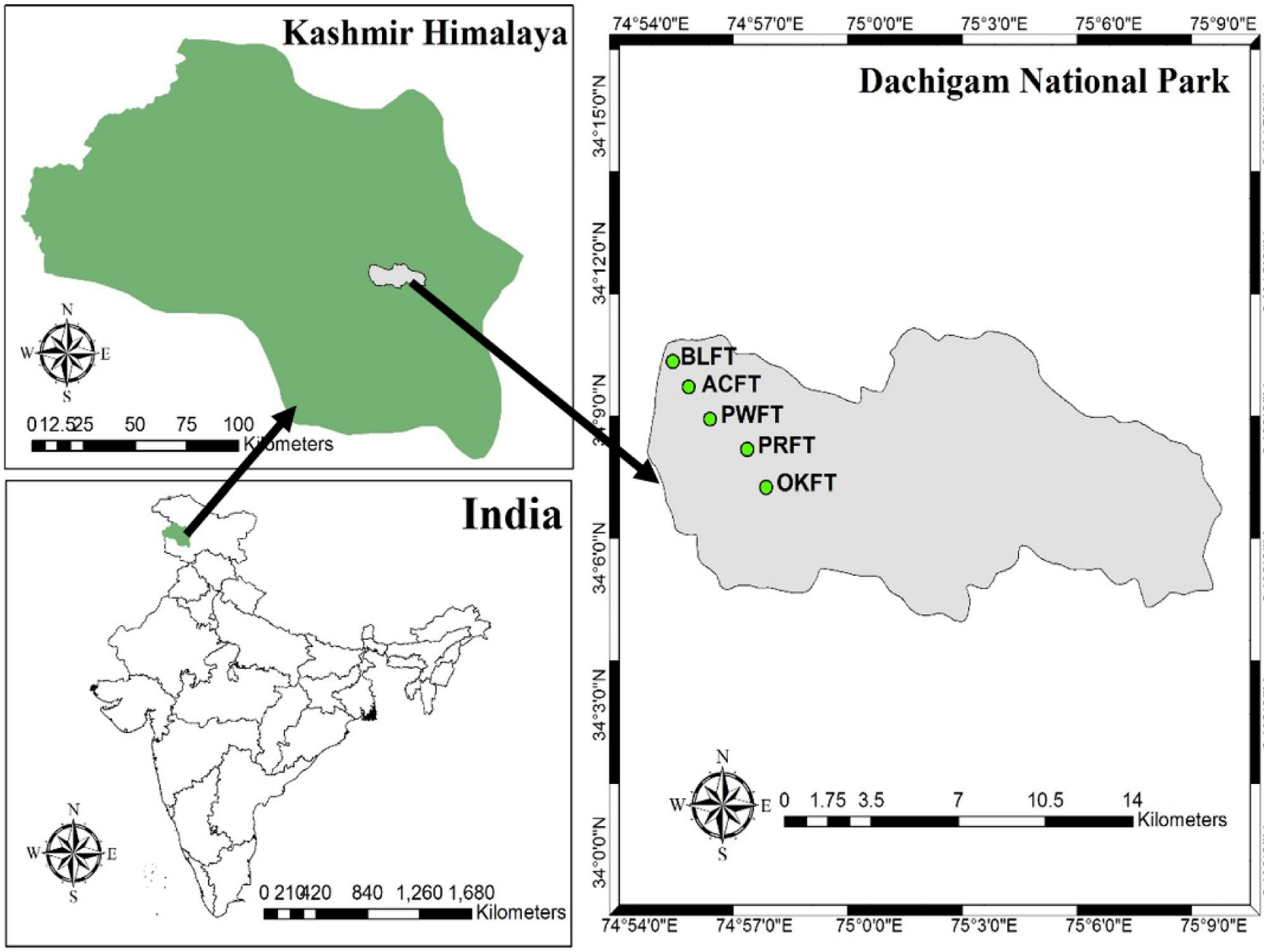


**Fig. 1** Map showing Jammu & Kashmir, India (**a**), and Dachigam National Park (**b**) in the Zabarwan range of the Kashmir Himalayan biogeographic zone

**Table 1** General details of sampled forest types in the Zabarwan range of the Kashmir Himalaya

| Forest type | Latitude | Longitude | Altitude in feet | Canopy cover | Dominant tree species |
|---|---|---|---|---|---|
| *Acacia* forest (ACFT) | 34° 09′ 0374″ N | 74° 54′ 57.75″ E | 5593 | 63 ± 8.1 | *Robinia pseudoacacia, Juglans regia* |
| Broad leaf forest (BLFT) | 34° 09′ 638″ N | 74° 54′ 570″ E | 5704 | 67 ± 7.38 | *Populus alba, Salix alba, Ulmus wallichiana* |
| Oak forest (OKFT) | 34° 08′ 243″ N | 74° 55′ 349″ E | 5712 | 78 ± 2.17 | *Quercus robur, Morus alba* |
| *Pinus* forest (PWFT) | 34° 08′ 516″ N | 74° 55′ 040″ E | 6334 | 59 ± 11.5 | *Pinus wallichiana, Celtis australis* |
| Scrub forest (PRFT) | 34° 08′ 3368″ N | 74° 55′ 29.11″ E | 5756 | 74 ± 2.21 | *Parrotiopsis jacquemontiana*, *Ulmus villosa* |

the core of the range. The majority of the sediments that make up these ranges date from the Cambrian through the Tertiary periods. The soil depth at Dachigam is less than 25 cm on the slope from lower to middle reaches, putting it in the category of very shallow soils [16]. The most dominant forests of the park are broadleaved and coniferous, in between these forests are the meadows [17].

### Sampling and Data Analysis

Several field surveys and tours of Zabarwan range were carried out during 2018–2019 to investigate the landscape, trees composition, species distribution and approachability of various forest types of the range. The main forests of the range include Broad-leaved forest (BLFT), *Acacia* forest (ACFT); Oak forest (OKFT), *Pinus wallichiana* forest (PWFT), and

Scrub forest (SRFT) [17, 18]. The details of the sampled forest types are shown in Table 1. Random floral sampling was performed for all selected forest types, and 12 square plots of 0.1 ha were laid in four different directions: north-east, south-east, north-west and south-west. In the current study, total, 60 plots (0.1 ha) were sampled. Slope angle and tree height were measured with clinometers and Ravi multimeter, respectively.

At each site, the height and dbh (diameter at breast height, 1.37 m above the ground) were measured for each individual tree falling inside the sampling plot. The trees only with dbh $\geq$ 10 cm were individually sampled [19]. Growing stock volume density (GSVD) was calculated via the volume equations set by the Forest Survey of India (FSI 1996) and further consultation with recent studies [20–22]. For the tree species where the volume equations were unavailable, same the congeneric equations were used with same plant height, growth, form and canopy. The values for aboveground biomass density (AGBD) of tree components (stem, branches, twigs and leaves) were extracted from GSVD, which was calculated by multiplying biomass expansion factor (BEF) with the GSVD of tree species [23]. The equations by Sharma et al. [24] and Haq et al. [25] were used for calculating the GSVD of hardwood tree species. For the belowground biomass density, the equation by Cairns et al. [26] was used. BGBD (fine and coarse roots) was estimated for each tree species as $\text{BGBD} = \exp\{-1.059 + 0.884 \times \ln(\text{AGBD}) + 0.284\}$. The total biomass density (TBD) was calculated by summation of AGBD and BGBD. The total C density (TCD) was computed using formula as Carbon ($\text{CMgha}^{-1}$) = Biomass (Mg $\text{ha}^{-1}$) $\times$ Carbon %. For the forest types, with dominancy of all coniferous constituted greater than 50%, the C percentage used was as 46%. In forests, where conifers and broadleaved species are equally distributed or broadleaved species counted higher than 50%, the C percentage used was as 45% [24, 27].

### Data Analysis

Associational analyses among ecological variables and plant compositions were carried out with clustering analysis [28]. Sorensen's (Bray–Curtis) distance was used to identify significant differences among the different forest types and microclimatic similarities [29] with the help of PAST software ver.3.14. (https://www.techworld.com/download/office-business/past-314-3330821/linkid=163338).

## Results and Discussion

The basal area, density, BGBD, AGBD, biomass and C stock of different forest types are shown in Table 2. The present study results indicate that coniferous dominated forests types had higher C stocks than the broad-leaved forest types. Carbon budget of forest ecosystem is affected by many factors which include biotic (structure and function of tree species and forest type) and abiotic factors like soil property, droughts, forest floor, its humidity, aridity and temperature [30]. The average total carbon stock (TCD) was estimated to be 174.49 $\text{MgCha}^{-1}$ (range 56.68–258.46 $\text{MgCha}^{-1}$), the maximum TCD was recorded for *P. wallichiana* forest (258.46 Mg C $\text{ha}^{-1}$), and the least TCD of 56.68 Mg C $\text{ha}^{-1}$ was reported for Scrub forest type. Forests capture atmospheric $CO_2$ via the process of carbon sequestration, there serves as an excellent tool for mitigation. The extent of atmospherically captured and storage carbon can be quantified by knowing the total carbon stock in forests. Here, we presented the results of an assessment of the potential forest carbon availability in the protected forests of Kashmir Himalaya and we provided insight into how these forest carbon potentials are spatially distributed across the forest types. According to our calculations, total forest carbon stock in the study was 872.45 Mg C $\text{ha}^{-1}$ and could store an average of 174.49 Mg C $\text{ha}^{-1}$. The overall values of the carbon stock of the forests of the current study are in the range reported by several workers in Himalaya, *e.g.,* TCD values of 107.8 to 234.1 $\text{MgCha}^{-1}$ and 92.06–245.31 $\text{MgCha}^{-1}$ were reported by [24] and [27] from mid to high altitude forests in the Garhwal Himalaya, India; [28] reported an average TCD value of 151.38 Mg C ha-1 from Pakistan, Himalaya. The trend in carbon pattern in the present study was as *P. wallichiana* forest > Broad-leaved forest > *Acacia* forest > Oak forest > Scrub forest. *S*imilar pattern of carbon stocks in forests of Himalaya was reported by [24, 27] further supported

**Table 2** Basal area, density, belowground biomass density (BGBD), aboveground biomass density (AGBD), total biomass density (TBD), total C density (TCD) in different forest types of the Zabarwan range of the Kashmir Himalaya

| Forest type | Basal area ($m^2$/ha) | Density (Ind/ha) | BGBD (Mg/ha) | AGBD (Mg/ha) | TBD (Mg/ha) | TCD (Mg C/ha) |
|---|---|---|---|---|---|---|
| *Acacia Forest* | 46.82 ± 14.73 | 850 ± 204.61 | 113.11 ± 23.54 | 289.70 ± 64.95 | 402.81 ± 88.48 | 181.26 ± 39.81 |
| Broad leaf forest type | 58.63 ± 21.57 | 1057.5 ± 367.28 | 143.75 ± 50.88 | 369.23 ± 135.95 | 512.98 ± 186.77 | 230.84 ± 84.04 |
| Oak Forest | 41.41 ± 3.81 | 640 ± 140.95 | 91.40 ± 5.75 | 231.29 ± 13.99 | 322.69 ± 19.29 | 145.21 ± 8.68 |
| *Pinus wallichiana* Forest | 74.49 ± 12.09 | 707.5 ± 148.18 | 140.07 ± 25.98 | 376.85 ± 69.12 | 516.92 ± 95.06 | 258.46 ± 47.53 |
| Scrub forest | 15.40 ± 6.20 | 1197.5 ± 199.56 | 39.44 ± 10.58 | 86.52 ± 25.42 | 125.96 ± 35.99 | 56.68 ± 16.19 |

our findings. The most dominant trees species in terms of C was *Populus alba* contributing of 57.08 Mg C ha-1 in BLFT, *P. wallichiana* in 233.56 Mg C ha-1 in PWFT, *Quercus robur* in 131.83 Mg C ha-1 in OKFT, *Robinia pseudoacacia* in 65.21 Mg C ha-1 in ACFT, *Parrotiopsis jacquemontiana* 29.41 Mg C ha-1 in SRFT, and the contribution of remaining co-dominant tree species in respective forest type is shown in Table.3. When compared to the rest of the tree species, *P. wallichiana, Q. robur, Celtis australis,* and *R. pseudoacacia* store the most C stock. Similar results were reported by Sajad et al. & Haq et al. in northern part of Kashmir Himalayas. Any attempt to discuss of tree carbon stock must essentially consider soil carbon and other site-specific factors scrutinized carefully. However, our study focused primarily on assessing tree carbon stock of forest types. It is suggested that any study regarding carbon storage should consider forest structure as well as soil carbon in future.

In the study area, there were a total of 20 tree species belonging to 15 genera and 12 families. The individual tree contribution of each tree species to C stock in different forest types is shown in Table 3. We distinguished 4 clusters from the 20 tree species through cluster analyses using Bray–Curtis neighborhood clustering. Based on C stock values, distinct grouping of species in clearly segregated clusters was reported in cluster analysis. The four tree communities were identified through cluster analysis of 20 tree species using PAST software. On the dendrogram, *Q. robur* was grouped separately on the extreme left, while as on the extreme right *P. wallichiana* and *Crataegus monogyna* form individual branches with minimum similarity (Fig. 2). Based on species coexistence at sites closely related in geographical occurrence, all other species were clustered in single distinct groups. *Morus Alba, Prunus avium, Populus Alba, Prunus persica, Ulmus wallichiana*, *Salix alba*, *C. australis, Acer caesium* formed a cluster with maximum similarity. Similarly, *P. jacquemontiana*, *Ulmus villosa*, *Prunus armeniaca* displayed maximum resemblance at cut level 2. It was due to their presence within same forest type which significantly separated these from the rest at maximum similarity (Fig. 2). Cluster analysis distinguished 4 clusters from the 20 tree species using Bray–Curtis neighborhood clustering. The cluster analysis based on location, biomass and C stock values clearly segregated the tree species into distinct clusters. Similar classifications were also carried out by previous worker from Pakistan Himalayas [28].

**Table 3** Species wise C stock contribution of tree in different forest types of the Zabarwan range of the Kashmir Himalaya

| Tree species | ACFT | BLFT | OKFT | PWFT | PRFT | Average C stock | % contribution C stock |
|---|---|---|---|---|---|---|---|
| *Acer caesium* | 0.32 | 2.11 | 0 | 0.87 | 0 | 0.67 | 0.37 |
| *Aesculus indica* | 0.69 | 13.11 | 4.4 | 1.29 | 0 | 3.89 | 2.23 |
| *Ailanthus altissima* | 17.11 | 9.81 | 1.53 | 0.145 | 6.16 | 6.95 | 3.98 |
| *Celtis australis* | 17.11 | 36.79 | 1.18 | 14.48 | 11.78 | 16.26 | 9.32 |
| *Crataegus monogyna* | 0 | 0.75 | 0.11 | 3.545 | 0 | 0.88 | 0.51 |
| *Juglans regia* | 25.89 | 11.81 | 0 | 0 | 0 | 7.54 | 4.32 |
| *Morus alba* | 9.26 | 17.81 | 5.59 | 0.3 | 0 | 6.59 | 3.77 |
| *Morus nigra* | 18.39 | 13.67 | 0.55 | 0 | 0 | 6.52 | 3.73 |
| *Parrotiopsis jacquemontiana* | 0 | 0 | 0 | 0 | 29.41 | 5.88 | 3.37 |
| *Pinus wallichiana* | 0 | 0 | 0 | 233.56 | 0 | 46.71 | 26.77 |
| *Populus alba* | 0 | 57.08 | 0 | 0 | 0 | 11.41 | 6.54 |
| *Prunus armeniaca* | 1.67 | 0.47 | 0 | 0.465 | 1.57 | 0.83 | 0.47 |
| *Prunus avium* | 6.5 | 10.54 | 0 | 0 | 0 | 3.41 | 1.95 |
| *Prunus cerasus* | 1.45 | 5.14 | 0 | 0 | 0 | 1.31 | 0.75 |
| *Prunus persica* | 0 | 4.21 | 0 | 0 | 0 | 0.84 | 0.48 |
| *Quercus robur* | 13.71 | 0 | 131.83 | 0.085 | 0 | 29.12 | 16.69 |
| *Robinia pseudoacacia* | 65.21 | 4.93 | 0 | 0 | 0 | 14.02 | 8.04 |
| *Salix alba* | 0.7 | 26.41 | 0 | 0 | 0 | 5.42 | 3.11 |
| *Ulmus villosa* | 3.21 | 0 | 0 | 3.715 | 7.74 | 2.93 | 1.68 |
| *Ulmus wallichiana* | 0 | 16.14 | 0 | 0 | 0 | 3.22 | 1.85 |
| Total C stock | 181.22 ± 39.81 | 230.78 ± 84.04 | 145.19 ± 8.68 | 258.46 ± 47.53 | 56.66 ± 16.19 | 174.46 | 100 |

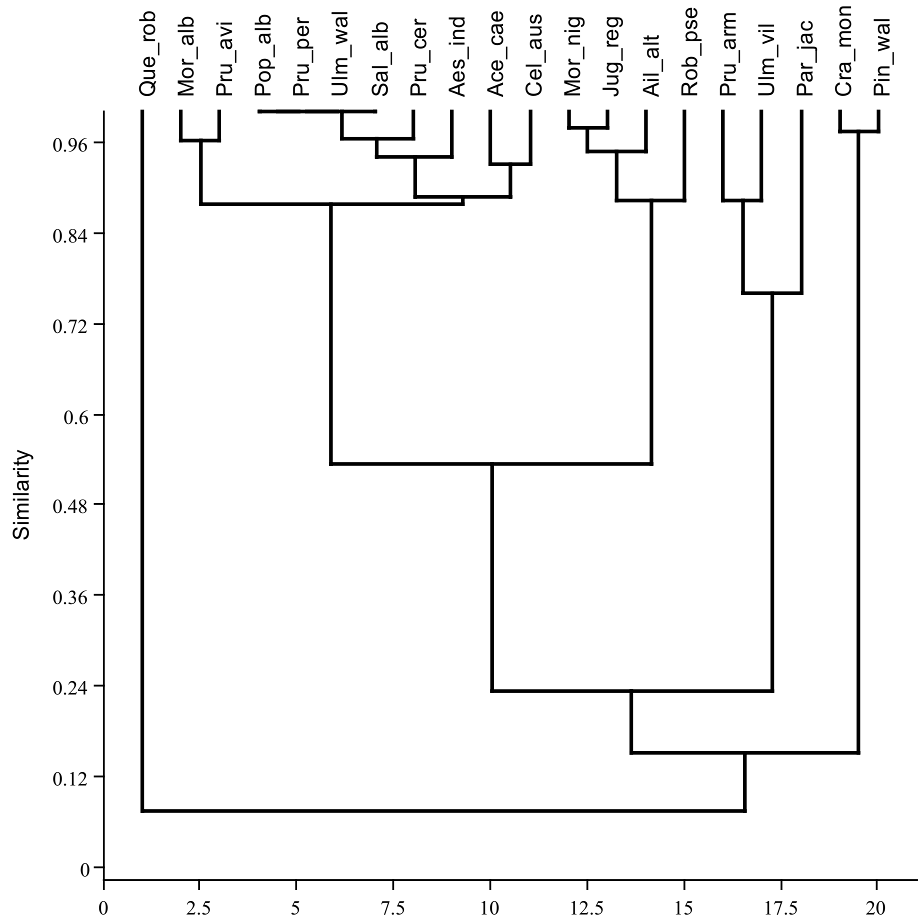


**Fig.2** The cluster dendrogram of 20 tree species showing 4 plant community types in the Zabarwan range of the Kashmir Himalaya

## Conclusion

The study clued that in the Zabarwan range, the forest shows a good signal toward an opportunity in effectively conserving the carbon storage in regional forests of Kashmir Himalayas by checking destruction of lush green woody forests. Compared to afforestation, safeguarding mature forests is a wiser step in reducing carbon emission which is home to a huge quantity of C stocks. Thus, our results underscore the significant role of protected forest area in biodiversity and regional C storage. With these framework policies, the diversely vegetative landscapes could be turned into vast C sequesters which could prove critical role in mitigating the regional (Kashmir Himalayas) as well as global climatic crises.

**Acknowledgements** The authors are thankful to those who directly or indirectly helped us during the study.

**Author's Contributions** VAK carried out the field study. SMH compiled the data; SMH, UY, FB and MUH wrote and revised the manuscript. All authors read and approved the final draft of manuscript.

**Declarations**

**Conflict of interest** The authors declare that they have no conflict of interest.

## References

1. Guo Q (2007) The diversity–biomass–productivity relationships in grassland management and restoration. Basic Appl Ecol 8(3):199–208
2. Herold M, Carter S, Avitabile V, Espejo AB, Jonckheere I, Lucas R, McRoberts RE, Næsset E, Nightingale J, Petersen R, Reiche J (2019) The role and need for space-based forest biomass-related measurements in environmental management and policy. Surv Geophys 40(4):757–778
3. Barnes AD, Weigelt P, Jochum M, Ott D, Hodapp D, Haneda NF, Brose U (2016) Species richness and biomass explain spatial turnover in ecosystem functioning across tropical and temperate ecosystems. Philos Trans R Soc B Biol Sci 371(1694):20150279
4. Dai Y, Peng G, Wen C, Zahoor B, Ma X, Hacker CE, Xue Y (2021) Climate and land use changes shift the distribution and dispersal of two umbrella species in the Hindu Kush Himalayan region. Sci Total Environ 2:146207

5. Jiang M, Medlyn BE, Drake JE, Duursma RA, Anderson IC, Barton CV, Boer MM, Carrillo Y, Castañeda-Gómez L, Collins L, Crous KY (2020) The fate of carbon in a mature forest under carbon dioxide enrichment. Nature 580(7802):227–231
6. Gurney GG, Cinner J, Ban NC, Pressey RL, Pollnac R, Campbell SJ, Setiawan F (2014) Poverty and protected areas: an evaluation of a marine integrated conservation and development project in Indonesia. Glob Environ Chang 26:98–107
7. Gaston KJ, Jackson SF, Cantu-Salazar L, Cruz-Piñón G (2008) The ecological performance of protected areas. Annu Rev Ecol Evol Syst 39:93–113
8. Koh LP, Zeng Y, Sarira TV, Siman K (2021) Carbon prospecting in tropical forests for climate change mitigation. Nat Commun 12(1):1–9
9. Lomolino MV (2001) Elevation gradients of species-density: historical and prospective views. Glob Ecol Biogeogr 10(1):3–13
10. Visconti P, Bakkenes M, Baisero D, Brooks T, Butchart SH, Joppa L, Maiorano L (2016) Projecting global biodiversity indicators under future development scenarios. Conserv Lett 9(1):5–13
11. Berry PM, Fabók V, Blicharska M, Bredin YK, Llorente MG, Kovács E, Geamana N, Stanciu A, Termansen M, Jääskeläinen T, Haslett JR (2018) Why conserve biodiversity? A multi-national exploration of stakeholders' views on the arguments for biodiversity conservation. Biodivers Conserv 27(7):1741–1762
12. Carvalhais N, Forkel M, Khomik M, Bellarby J, Jung M, Migliavacca M, Ahrens B (2014) Global covariation of carbon turnover times with climate in terrestrial ecosystems. Nature 514(7521):213–217
13. Joppa LN, Loarie SR, Pimm SL (2008) On the protection of "protected areas." Proc Natl Acad Sci 105(18):6673–6678
14. Gairola S, Sharma CM, Ghildiyal SK, Suyal S, Rana CS, Butola DS (2009) Biodiversity conservation and sustainable rural development in the Garhwal Himalaya. Report and Opinion 1(4):6–12
15. Haq SM, Shah AA, Yaqoob U, Hassan M (2021) Floristic quality assessment index of the Dagwan stream in Dachigam National Park of Kashmir Himalaya. In: *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, pp1–8
16. Naqash RY, Sharma L (2011) Management plan for Dachigam National Park (2011–2016). Jammu & Kashmir, Srinagar, pp 172
17. Haq SM, Malik ZA, Rahman IU (2019) Quantification and characterization of vegetation and functional trait diversity of the riparian zones in protected forest of Kashmir Himalaya, India. Nordic J Bot 37(11):10047
18. Champion HG, Seth SK (1968) A revised survey of the forest types of India. Manager of publications
19. Knight DH (1963) A distance method for constructing forest profile diagrams and obtaining structural data. Trop Ecol 4:89–94
20. Dar JA, Sundarapandian S (2015) Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. Environ Monit Assess 187(2):55
21. Wani AA, Joshi PK, Singh O (2015) Estimating biomass and carbon mitigation of temperate coniferous forests using spectral modeling and field inventory data. Eco Inf 25:63–70
22. Rashid I, Bhat MA, Romshoo SA (2017) Assessing changes in the above ground biomass and carbon stocks of Lidder valley, Kashmir Himalaya, India. Geocarto Int 32(7):717–734
23. Brown SL, Schroeder P, Kern JS (1999) Spatial distribution of biomass in forests of the eastern USA. For Ecol Manag 123(1):81–90
24. Sharma CM, Baduni NP, Gairola S, Ghildiyal SK, Suyal S (2010) Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. For Ecol Manag 260(12):2170–2179
25. Haq SM, Calixto ES, Kumar M (2020) Assessing biodiversity and productivity over a small-scale gradient in the protected forests of Indian Western Himalayas. J Sustain For 2:1–20
26. Cairns MA, Brown S, Helmer EH, Baumgardner GA (1997) Root biomass allocation in the world's upland forests. Oecologia 111(1):1–11
27. Gairola S, Sharma CM, Ghildiyal SK, Suyal S (2011) Live tree biomass and carbon variation along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya (India). Curr Sci 2:1862–1870
28. Shaheen H, Khan RWA, Hussain K, Ullah TS, Nasir M, Mehmood A (2016) Carbon stocks assessment in subtropical forest types of Kashmir Himalayas. Pak J Bot 48:2351–2357
29. Sorensen T (1948) A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. Videns kiSelskab Biologiske Skrifter 5:1–34
30. Brando PM, Paolucci L, Ummenhofer CC, Ordway EM, Hartmann H, Cattau ME, Hartmann H, Cattau ME, Rattis L, Medjibe V, Coe MT, Balch J (2019) Droughts, wildfires, and forest carbon cycling: a pantropical synthesis. Annu Rev Earth Planet Sci 47:555–581