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Measuring forest health at stand level: A multi-indicator evaluation for use in adaptive management and policy

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ABSTRACT

Assessments of forest ecosystem health for use in adaptive management need an integrative multi-indicator examination at the stand scale. To assess forest health, we exained multiple forest indicators including diversity, age structure, regeneration, and edaphic factors of the dominant and associated tree species in their natural forest habitats. A stratified random cluster sampling strategy was used to gather vegetation samples from the five main forest types in the Zabarwan Mountain Range—*Acacia* forest (ACFT), Broad leaved forest (BLFT), Oak forest (OKFT), *Pinus wallichiana* forest (PWFT), and Scrub forest (SRFT). The Pearson method and canonical correspondence analysis (CCA) were used to investigate the relationship between tree species and edaphic factors. A total of 22 tree species were found, of which 13 were exotic and 9 were native. The proportion of exotic species was highest in OKFT (85%), followed by BLFT (75%), and the least (50%) SRFT. The BLFT forest type had the highest Shannon diversity while the lowest was the SRFT. ACFT and BLFT forest types have significantly higher Shannon diversity indexes than other forest types. Based on the density-girth class distribution, ACFT & SRFT forest types showed an Inverse-J distribution pattern, indicating a stable population structure. The dominant tree species, such as *Populus alba* in BLFT, demonstrated comparatively no regeneration, whereas *Parrotiopsis jacquemontiana* in SRFT, *Pinus wallichiana* in PWFT, *Quercus robur* in OKFT, and *Robinia pseudoacacia* demonstrated adequate regeneration performance. Overall exotic tree species such as *Robinia pseudoacacia, Prunus cerasifera, Celtis australis, and Ailanthus altissima* showed high/sufficient regeneration performance. The average seedling/tree value for all forest types in the area was 2.14, with the highest value at BLFT (3.61) and the lowest value at SRFT (0.71). In the CCA it showed that SRFT forests were greatly influenced by salinity and organic carbon, whereas ACFT and OKFT forests had comparable habitat preferences and were mutually influenced by electrical conductance and phosphorus availability. *Prunus cerasifera* was the only species positively associated with available calcium. By combining the data of numerous field-based indicators into a single integrated study, our research will give decision-makers an update on a forest's current and anticipated health.

1. Introduction

Tree indicators have frequently been measured as part of forest heath assessments, which assess the health of the forest in plots before combining the results to provide stand-level information (Trumbore et al., 2015; Simons et al., 2021; Rahman et al., 2022). Trees are the primary structural component of an ecosystem and the defining characteristics of a healthy forest system (Haq *et al.*, 2022). Tree species regeneration is what keeps a forests ecosystems general physiognomy intact. Furthermore, the ability of the resident tree species to regenerate

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plays a significant role in maintaining the structure of the forest community (Souza, 2021). In fact, understanding the field based present state of tree regeneration can be used to forecast future forest dynamics and gain crucial insights into the ecological health of a forest ecosystem (Altman, 2020). Protected forests can act as field sites for studies on the natural regrowth of tree species in forest ecosystems, which is essential for guiding the restoration of degraded forest ecosystems and developing effective conservation strategies (Brancalion and Holl, 2020). Therefore, knowledge of diversity, forest structure, and tree species regeneration is necessary for understanding natural forest ecological processes and dynamics, which are vital to the creation of the most effective natural solutions to combat the twin problems of global climate change and biodiversity loss (Seddon et al., 2020; Piana et al., 2021).

Tree species provide resources and habitat for nearly all other forest species, making them crucial to the overall maintenance of the forest's biodiversity (Gebeyehu et al., 2019). The ability of adult trees to produce seeds, the survival of seedlings, and the development of saplings are all ecological traits that affect a forest's ability to regenerate successfully (Haq *et al.*, 2019). Environmental factors, like the soil's composition and biological invasion, have a significant impact on the establishment and growth of seedlings (Vujanović et al. 2022). These factors can lead to variations in the floristic and structural composition of plant communities, which can change the status of native tree regeneration (Maestre et al., 2003; Ali et al., 2019). Mountain forests are increasingly being overrun by a wide range of woody alien species, and this is expected to be one of the major contributors to biodiversity loss, even in the best-managed and protected ecosystems (Genovesi and Monaco, 2013; Haq *et al.*, 2019; Vujanović et al., 2022). Invasive species increase the need to comprehend forest health, as well as the history of management and the distribution of the species, because they have the potential to reduce species diversity and ecological functions on a local level (Balemlay and Siraj, 2021).

Forests display a variety of regrowth patterns due to differences in the species that comprise the forest as well as environmental factors to which the species are exposed (Jin and Qian, 2023). To effectively quantify and anticipate these effects and ensure the conservation and management of forest resources, it is crucial to comprehend the fundamental factors that govern tree establishment, growth, and survival (Kräuchi et al., 2000; Mwavu and Witkowski, 2009). Identification of ecologically beneficial species and species of particular concern are made easier with the help of the inventory of tree species, which offers information on diversity (Garnett et al., 2020). Age distribution and class distribution can also be used to assess the stand structure (Negi et al., 2019). The stand structure has been used to assess the ecological functioning of the forest ecosystem, which aids in the understanding of long-term changes in stand structural diversity and forest health (Zampieri and Pau, 2022; Dar and Reshi, 2015; Ahmad et al., 2019; Shu et al., 2021). In the Himalaya, the world's highest mountain range and a global biodiversity hotspot, limited tree indicators studies are available, particularly in protected forests. We contend that research on multi-forest indicators in protected forests provides a field experiment for assessing the natural recruitment potential of forest tree species. Not only do they display the current status, but they also hint at potential changes in the future. With this knowledge gap in mind, the current study was conducted in five major forest types chosen from the Zabarwan Mountain Range. The primary objectives of the study were to: (i) assess the multiple indicators of forest health, such as patterns of tree composition, diversity, and distribution in the major forest types; (ii) ascertain the age structure and regeneration status of the dominant trees and associated tree species among tree-size classes; (iii) ascertain how native and exotic tree species influence forest stand indicators; and (iv) investigate the effect of soil characteristics on the distribution of tree species in the major forest types. The current study will provide field-based data on tree species' natural regrowth in forest ecosystems, which is essential for directing the restoration of the invaded forest ecosystems and will provide important new insights into the present and future health of the forest.

2. Materials and methods

2.1. Study area

The Zabarwan Range, in India's Union Territory of Jammu and Kashmir, is a brief (32 km) sub-mountain range situated between the Pir Panjal and Great Himalayan Ranges. On its eastern side, the Kashmir Valley is bordered by the Zabarwan Range. It literally refers to the mountain range that divides the Jehlum Valley from the Zanskar Range on the east and west, as well as the Zanskar Range from the north and south sides of the Sind Valley and the Lidder Valley, respectively. The Zabarwan mountain range is renowned for its abundant wildlife. The most notable feature of the range is Dachigam National Park, occupying a territory of 141 km^2, situated between 34°05′ and 34°11′ N and 74°54′ and 75°09′ E (Fig. 1). The area has been protected since 1910 and was made a national park in 1981. The climate of Dachigam can be used to summarize the climate of the Zabarwans. It is located in the sub-Mediterranean region and has two dry seasons, from April to June and September to November. Snow is the primary precipitation source, and it does not melt until June in some areas. The Zabarwan receives an annual rainfall from 32 to 546 mm. The dominant vegetation of the Park is the broadleaved forest, followed by coniferous forest, scrub vegetation, and waterfalls with deep gullies called locally 'Nars' (Haq *et al.*, 2021).

2.2. Sampling design and measurements

We selected 5 major forest types i.e., Broad leaved forest (BLFT), *Pinus wallichiana* forest (PWFT), *Acacia* forest (ACFT), Oak forest (OKFT), and Scrub forest type (SRFT) during the initial phase of field surveys (Haq *et al.*, 2021). In order to gather information about the - multiple forest indicators, we employed a stratified random cluster sampling strategy (Haq et al., 2022a). In the chosen forest types, four square plots of 31.6 m × 31.6 m (≅ 0.1 ha) size were laid out in four main directions (NE, NW, SW, SE). We first fixed the plot center, followed by marking the points toward the four cardinal directions, and then tied the ropes around to demarcate the 0.1 ha plot. In all, we laid a total of sixty square plots (12 plots × 5 forests = 60) for field sampling. In each 0.1 ha sampling plot, two plots of size 5 m^2 were laid in opposite corners for estimation of seedlings and saplings. In each forest type, twenty-four 5 m^2 plots were established. In the current study, 120 plots (24 plots × 5 forests = 120 plots) were sampled to investigate seedling and sapling diversity and density.

Tree regeneration refers to the process that allows aforest to sustain itself through growth and survival of trees from seeds that fall and germinate in-situ. The densities of trees, saplings and seedlings in a particular forest is called its regeneration status whereas the ratio of trees/saplings and seedlings of particular tree species is termed its regeneration performance. Every tree inside the sample plots having a diameter greater than 10 cm diameter at breast height (DBH) was counted and recorded. To evaluate the regeneration status and performance of each tree species in the sampled forest types, each tree species was identified, and the density of seedlings, saplings, and trees was counted per hectare (Haq et al., 2022a). Utilizing the ratio of trees to seedlings and saplings, the effectiveness of the regeneration was evaluated (Gairola et al., 2012). Based on the calculated ratio, the status of forest regeneration as well as for individual tree species was determined. The average ratio of trees to seedlings and saplings of each tree species was used to calculate the overall forest regeneration performance. According to Gairola et al. (2012), each tree species' regeneration status ie. high, moderate, sufficient, hindered, new, and absent, was determined based on the average ratio. The standard taxonomic procedure was followed for the collection of plant specimens. Phytosociological attributes such as frequency, abundance, and density were calculated for an

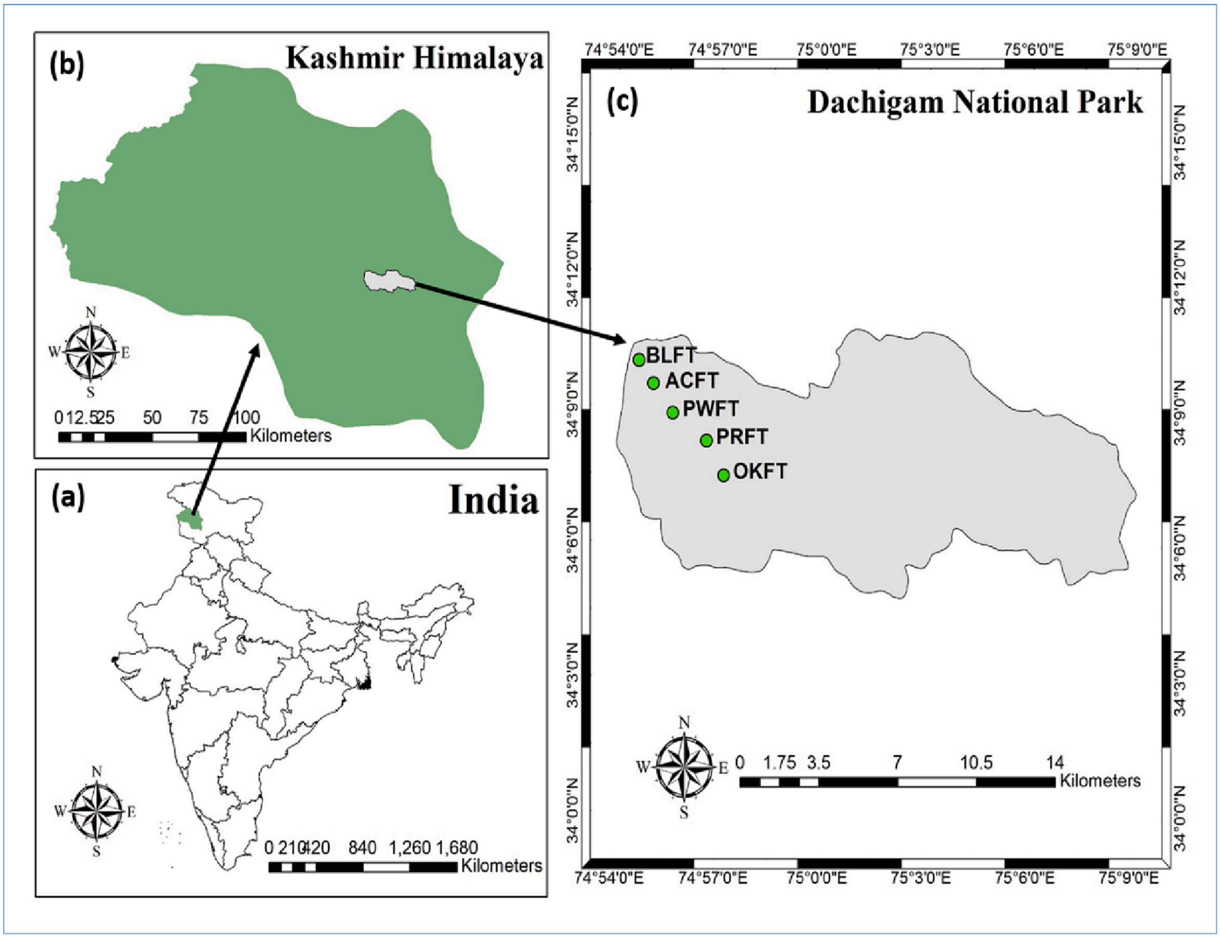

Fig. 1. Maps of the study area. (a) India (b) Kashmir (c) study area within Dachigam National Park situated in the Zabarwan range in Jammu and Kashmir, India. BLFT = Broad leaf forest; ACFT = *Acacia* forest; PWFT = *Pinus wallichiana f*orest; SRFT = *Parrotiopsis jacquemontiana* forest; OKFT = Oak forest.

importance value index for each tree species. Various physiographic parameters, i.e., aspect and altitude, were measured at various forest sites using a GPS device (Garmin, GPS map76cs). The native range of the tree species collected was determined using online resources (https://www.flowersofindia.net/) and recently published research papers (Haq *et al.*, 2022). The tree species were then classified as native or alien to the area.

2.3. Soil sampling

The soil types in the study area are orthods, which have a reddish-brown or black subsoil, a coarse texture, and are frequently acidic. Soil samples were taken at a depth of 9–12 cm from each 0.1 ha plot from the five different forest types, and placed in polythene bags. The soil samples were properly blended and allowed to air-dry before being sieved to remove rocks, trash, and gravel fragments larger than 2 mm in size. Macronutrients (potassium (K), nitrogen (N), and phosphorus (P)), organic carbon, electrical conductivity, salinity, and pH were all tested in the soil samples. The pH was determined with a pH meter (Mettler Toledo pH meter), and the electrical conductivity and salinity were determined with an electrometer (Conductivity TDS Tester–HI98129). Total nitrogen (N) was determined using the Kjeldahl method, P using the Olsen method, and soil organic carbon using the Walkley-Black method (Gupta, 2017).

2.4. Data analysis

Data organization and processing were done using Microsoft Excel 2016. Software programs CANOCO and PAST were used to analyze the phytosociological data for plants that had been gathered. Data from the five forest types were analyzed using a detrended correspondence analysis (DCA), which was supported by reciprocal averaging. DCA, an Eigen vector ordination technique, was used to determine the length of the gradient and the relationship between vegetation types (Ter Braak and Smilauer, 2002). The relationships between tree species and soil parameters were analyzed using canonical correspondence analysis (CCA), which was carried out using CANOCO version 4.5 software. Finding significant gradients between groups of explanatory variables allowed researchers to investigate the relationship between different tree species and soil variables. After CCA, the Monte Carlo test was utilized to ascertain how the explanatory variables would affect the variety of tree species in five different types of forests (Waheed et al., 2022a). Using PAST software 4.10, the Shannon-Wiener, Equitability, and Dominance diversity indices were calculated following (Sajad et al., 2021). The diversity indices of various forest types were compared using the non-parametric Kruskal-Wallis test, followed by the Tukey HSD, and a ridgeline graph with significant difference letters was created using the Origin Pro software (Rahman et al. 2022). The Pearson method was then used to calculate the correlation coefficient between the edaphic properties recorded from five forest types. The results were plotted in a correlogram using the 'corrplot' package. The alluvial diagram was used to demonstrate the relationship between multiple indicators, such as tree species and the nativity of forest types. The chord diagram was used to show the contribution of individual tree species in various regeneration categories in the study area using Origin Pro software (Waheed et al., 2022b).

3. Results

3.1. Tree diversity and distribution

We recorded a total of 22 tree species from 16 genera and 12 families in the study area (Appendix A). The relationships between the documented tree species and families from the five main forest types are depicted in Fig. 2. Only four families—Rosaceae, Salicaceae, Moraceae, and Pinaceae—accounted for half of the tree species collected; the other half belonged to eight (8) families and six (6) families out of the total were monotypic (Fig. 2 & Appendix A).

3.2. Nativity of the forest tree species

The nativity analysis showed that 9 species (41 %) were native, while 13 species (59 %) were exotic to the study area (Fig. 3). Out of the total 9266 seedlings counted in all forest types, 7931(86 %) were contributed by exotic tree species, while the remaining 1335 (14 %) were contributed by tree native species. However, of the 11,683 saplings counted, 10,648 (91 %) were contributed by exotic tree species, with the remaining 1035 (9 %) contributed by native tree species. In the case of trees, exotic species contributed 2610 individuals (60 %) while native species contributed 1710 individuals (40 %). In Oak forest (OKFT), the highest percentage (85 %) of exotic species were reported, followed by 75 % in Broad leaf forest (BLFT), 73 % in *Acacia* forest (ACFT), 55 % in *Pinus wallichiana* forest (PWFT), and a minimum of 50 % in *Parrotiopsis jacquemontiana* forest (SRFT) (Table 1).

3.3. Patterns of forest tree species among forest types

The detailed distribution of 22 tree species across five forest types is depicted in Fig. 3. The diagram shows which tree species belong to which forest type, and the width of each bar represents how diverse the tree species are within each forest type. *Celtis australis* was the common tree species among all five forest types whereas three tree species (14 % of species count) i.e., *Ailanthus altissima, Aesculus indica* and *Morus alba* were common in four forest types (ACFT, BLFT, OKFT, and PWFT). However, four tree species (18 %), i.e., *Populus alba, Prunus cerasus, Prunus persica* and *Salix alba* were unique species at BLFT and three tree species (14 %) i.e., *Ulmus villosa, Abies pindrow* and *Pinus wallichiana* were unique at PWFT and one species *Parrotiopsis jacquemontiana was* unique at SRFT (Fig. 3).

3.4. Diversity of forest tree species among forest types

The diversity indices showed significant differences in tree species recorded from sampling sites of five forest types of Zabarwan Mountain Range, India. The highest number of tree species (16) was reported from BLFT, followed by 11 tree species each from PWFT and ACFT, 9 from OKFT, and the lowest of 4 species from SRFT. The highest dominance index was recorded from SRFT and lowest from BLFT. SRFT and OKFT forest types significantly differed from ACFT, BLFT, and PWFT. The species evenness also demonstrates notable differences among the five different forest types, with the highest species evenness recorded from OKFT and the lowest from SRFT (Fig. 4).

The maximum Shannon and Simpson diversity was also observed in the BLFT and lowest SRFT forest type. Significant differences between the Shannon diversity index and Simpson diversity were found between the ACFT and BLFT districts and other forest types. Shannon diversity index and Simpson diversity of ACFT and BLFT districts are significantly different from other forest types. The maximum and minimum tree density was recorded for SRFT (1290 $\pm$ 199.56 Nha^{-1}) and OKFT (640 $\pm$ 140.95Nha^{-1}) respectively with an overall average of 864 Nha^{-1}. The average value of basal area was reported to be 47.35 m^2/ha, with the highest and lowest values being 74.49 m^{2}ha^{-1} (PWFT) and 15.4 m^{2}ha^{-1} (SRFT), respectively (Table 1).

3.5. Age structure or forest structure

According to the density-girth class distribution in ACFT and SRFT, all girth classes were adequately represented, and the tree species showed relatively higher densities of individuals in the lower girth classes, which decreased as the size of girth classes increased (Fig. 5).

Fig. 5 also shows that in both ACFT and SRFT forest types, the overall density-girth class distribution displayed an Inverse-J distribution pattern. However, the opposite trend was seen in BLFT, PWFT, and OKFT, where there was a higher density of people in the second girth classes, which decreased as the size of the girth classes increased. The overall density-girth class distribution in both forest types showed a unimodal distribution pattern. *Robinia pseudoacacia,* and *Parrotiopsis jacquemontiana* were present in all girth class constitute continuous age structure. *Celtis australis & Ailanthus altissima* in BLFT, *Quercus robur* in OKFT, and *Pinus wallichiana* in PWFT, were present in all girth class constitute continuous age structure.

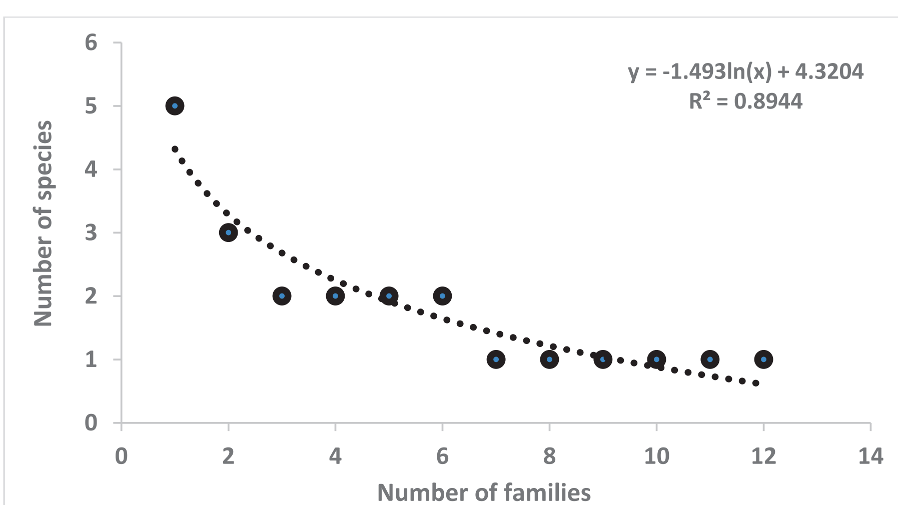

Fig. 2. Species- family relationship of documented tree species from 5 major forest types in the study area.

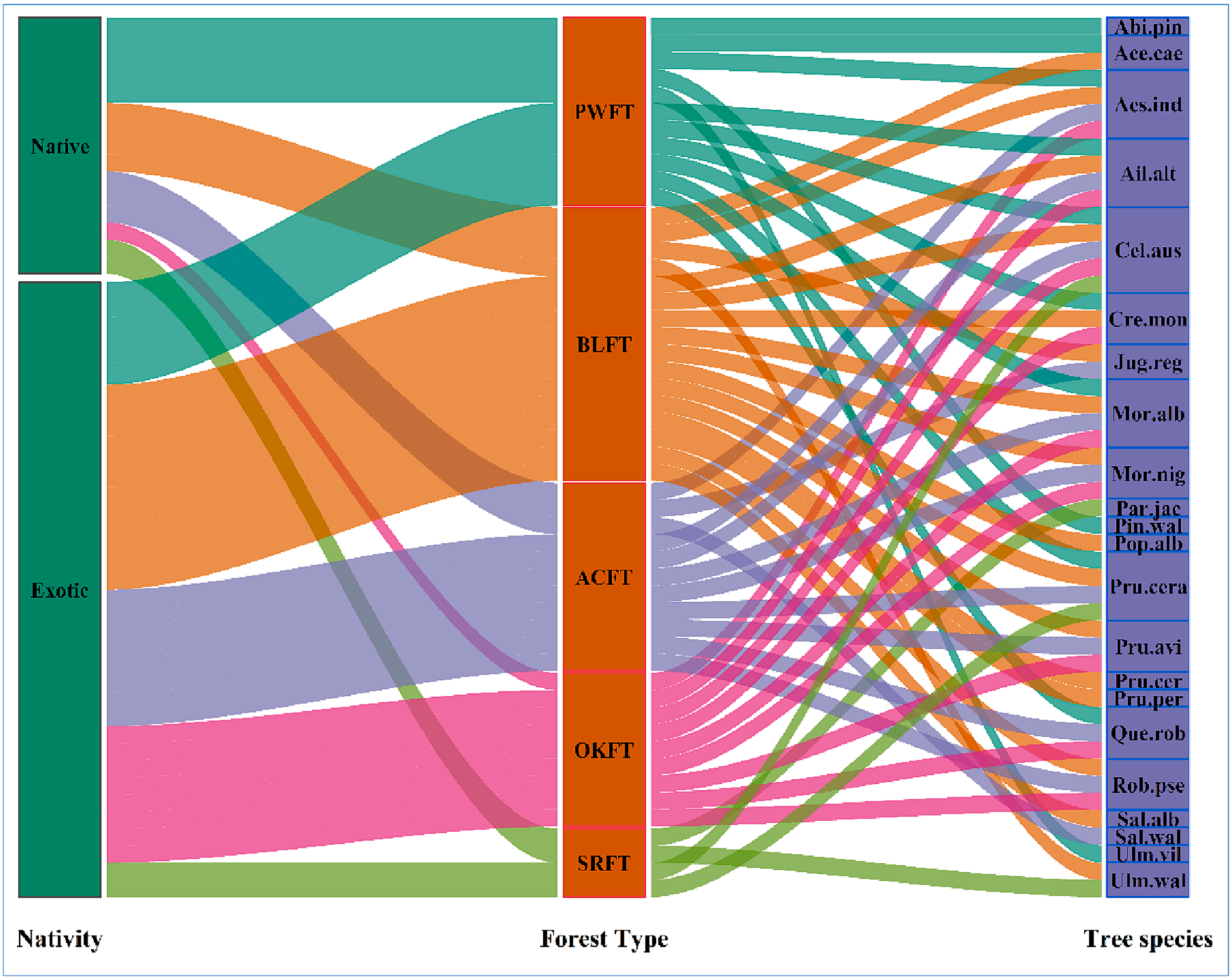

Fig. 3. Alluvial diagram showing the distribution of 22 tree species in the 5 major forest types and the nativity of the tree species in the study area. Appendix A displays the full name of each species.

Table 1
Tree density, basal area, DBH range, average DBH, seedling and sapling density in the five major forest types in the study area.

Forest type	Tree density (Ind/ha)	Basal area (m^2/ha)	DBH range	AVG. DBH	Seedling density (Ind/ha)	Sapling density (Ind/ha)
Acacia forest (ACFT)	672.5 ±204.61	46.82 ± 14.73	12–356	48.26 ±18.08	1300 ±118.18	1025 ±93.27
Broad leaf forest (BLFT)	1042.5 ±367.28	58.63 ±21.57	11–305	42.87 ±16.44	3766.25 ±235.39	5317.5 ±354.5
Pinus wallichiana forest (PWFT)	675 ±148.18	74.49 ±12.09	15–333	30.57 ±11.47	1987.5 ±180.68	2687.5 ±244.31
Oak forest (OKFT)	640 ±140.95	41.41 ± 3.81	13–252	41.30 ±6.82	1293 ±143.66	1966.25 ±218.47
Parrotiopsis jacquemontiana forest (SRFT)	1290 ±199.56	15.40 ± 6.20	10–165	67.70 ±7.11	920 ±230.01	662.5 ±165.62

3.6. Regeneration status of tree species

The density of seedlings in the forest vegetation ranged from a minimum of 920 Ind/ha at SRFT to a maximum of 3766.25 Ind/ha at BLFT. A similar pattern was seen in the number of saplings across all forest types, ranging from a maximum of 5317.5 Ind/ha at BLFT to a minimum of 662.5 Ind/ha at SRFT (Table 2). The average Se/T value for all the forest types in the area was 2.14, with the highest value at BLFT (3.61) and the lowest value at SRFT (0.71). Overall, across all forest types, the Sa/T values were higher than Se/T, with an average of 2.67 (Table 1). For each forest type, the Se/T and Sa/T values for specific tree species are provided in (Table 1). The dominant tree species e.g., *Populus alba* in BLFT, showed no regeneration performance. Tree species such as *Pinus wallichiana* in PWFT, *Quercus robur,* in OKFT, *Parrotiopsis jacquemontiana* in SRFT showed moderate regeneration and *Robinia pseudoacacia* showed sufficient regeneration performance. Tree species like *Juglans regia, Morus nigra* showed hampered regeneration. Overall *Prunus cerasifera, Celtis australis,* and *Ailanthus altissima* showed higher regeneration performance (Fig. 6).Table A1.

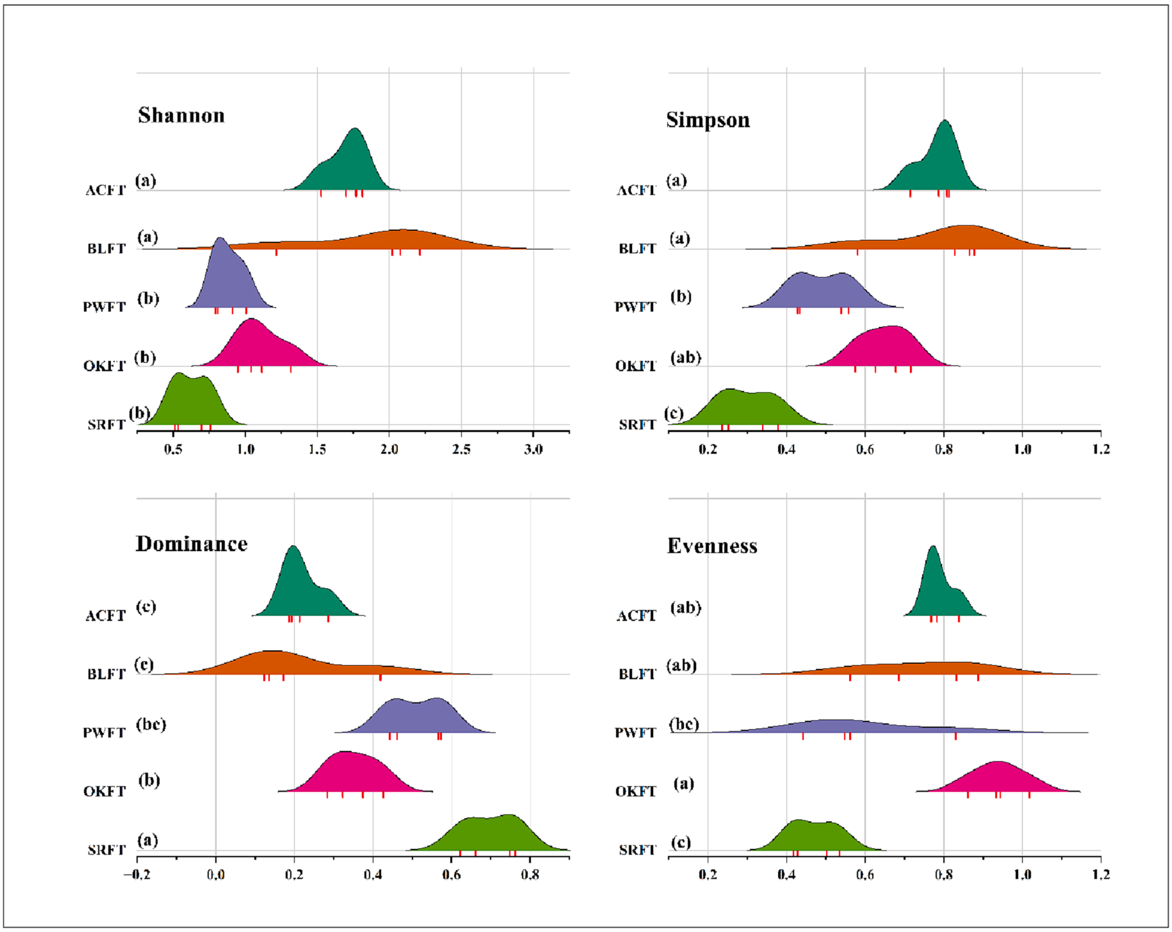

Fig. 4. Diversity profiles of tree species in the 5 major forest types of the study area. The ridgeline diagram depicts the diversity of sampling sites, with the letter of significant difference between different weeds recorded from various sites determined by the Tukey test.

3.7. Role of soil variables

The relationship between tree species across various forest types was depicted using IVI data for all species and soil properties using canonical correspondence analysis (Fig. 7).

The first four axes were responsible for 87.28 % of the total eigenvalue of various tree species (Table 2), which could represent the majority of sequencing data. The availability of P, N, exchangeable Ca, K, pH, OC, EC, and salinity all had significant impacts on species distribution. Along CCA axis 1, the concentrations of available nitrogen (N), potassium (K), pH, salinity, and organic carbon (OC) increased from left to right, while the influence of available calcium (Ca) gradually decreased. Electrical conductance (EC) and phosphorus availability gradually increased from the bottom to the top along CCA axis 2.

The CCA ordination showed that soil factors, as well as forest tree species composition, were almost evenly distributed. The tree species positively associated with salinity, K, and OC included *Parrotiopsis jacquemontiana* and *Ulmus walichiana.* The species impacted by P and EC included *Quercus robur, Prunus avium, Salix wallichiana, Juglans regia,* and *Robinia pseudoacacia. Prunus cerasifera* was the only species positively associated with available Ca (Fig. 6). In the CCA diagram, SRFT forest plots were greatly influenced by salinity and OC, whereas ACFT and OKFT forests had comparable habitat preferences and were mutually influenced by EC and P availability.

3.8. DCA ordination

The species score was used to generate a DCA scattered diagram, which displays the locations of numerous species along the two axes and their connections to the gradients (Fig. 8). *Salix wallichiana, Robinia pseudoacacia, Morus nigra*, and *Ailanthus altissima* can all be seen on the extreme upper left side of the DCA diagram indicating low scores on Axis 1 and high scores on Axis 2. *Ulmus wallichiana,* and *Parrotiopsis jacquemontiana* were in the upper-right corner of the diagram and had high scores on Axes 1 and 2 (Fig. 8). These high scores demonstrate that the corresponding native species prefer scrub environments, which are usually dry and mildly cold. These species' preference for oak habitat is indicated by the clustering of *Prunus avium, Quercus robur, Morus alba, Crataegus monogyna,* and *Aesculus indica* on the lower left side. These species' close proximity to one another suggests that there are microclimatic variations. The fact that *Prunus persica, Celtis australis, Populus alba, Prunus cerasifera, Ulmus villosa, Salix alba,* and *Acer caesium* fell in the center of the diagram indicates that these species are widespread and do not appear to prefer any particular types of forest (Fig. 8). The species-specific DCA ordination had a maximum gradient length for axis 1 of 4.126 and an Eigenvalue of 0.756. Axis 2 had a gradient with an eigenvalue of 0.486 and a length of 3.486. The inertia of all tree species combined was 6.168.

3.9. Relationship of edaphic variables

Pearson correlation was used to determine the relationship between various soil variables. K has a positive relationship with P, N, and OC and salinity has a positive relationship with pH, and EC showed a positive relationship with Ca, while soil pH and Ca had a negative relationship with K, N, P, OC (Fig. 9).

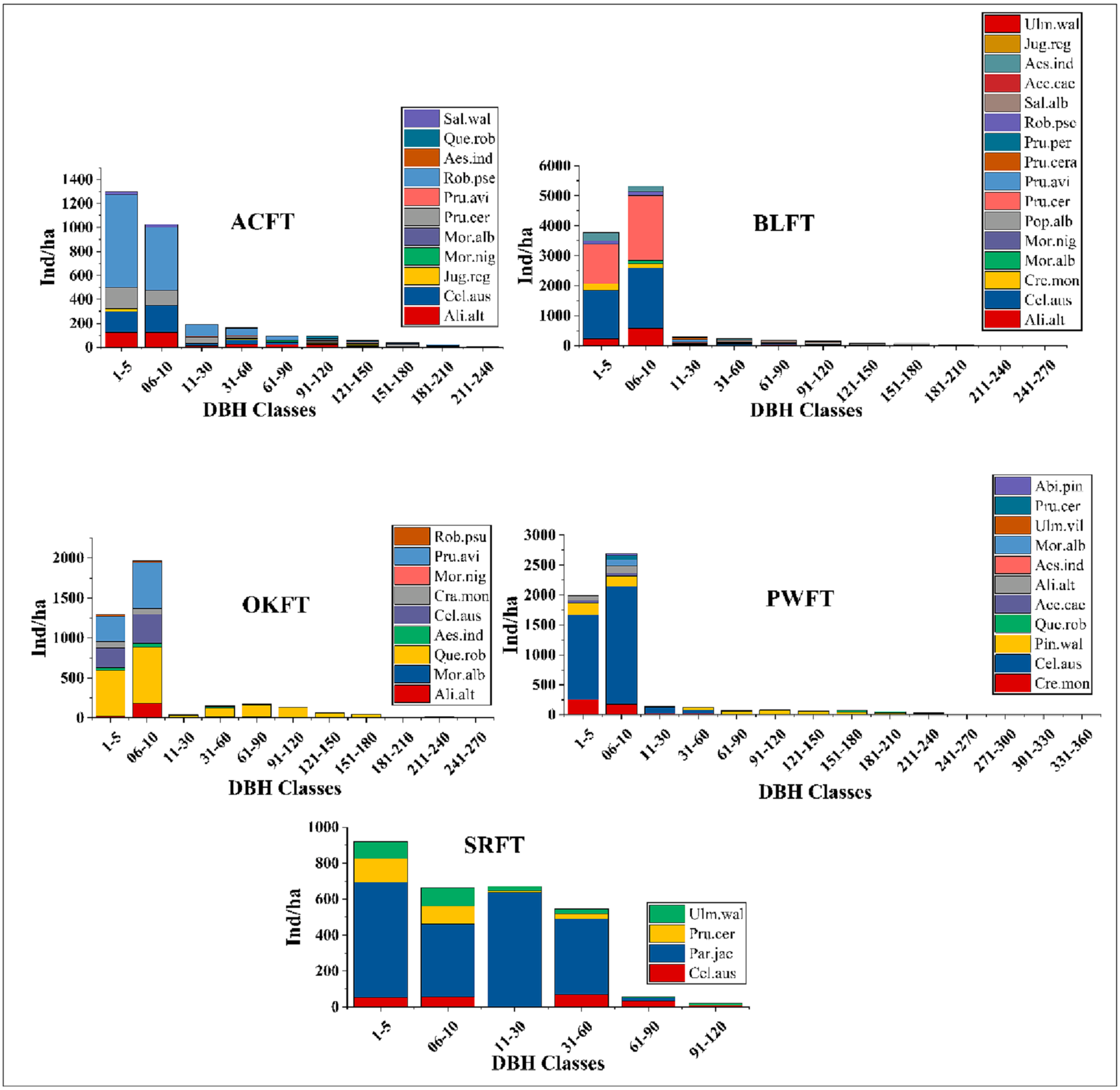

Fig. 5. Contribution of tree species in different girth class of the age structure in the 5 major forest types in the study area. Appendix A displays the full name of each species.

Table 2
Summaries of the four axes of the canonical correspondence analysis using data from the importance value index for the five main forest types in the study area.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigen values	0.921	0.5242	0.4326	0.3175
Explained Variation	32.56	41.03	52.35	63.82
Pseudo-canonical correlation	0.983	0.917	0.942	0.823
Explained fitted variation	37.24	58.13	75.31	87.28
Total inertia	5.23			

4. Discussion

4.1. Tree species composition and distribution

To comprehend the structure and function of forest ecosystems, one must first understand the tree composition of those ecosystems. As in the current study, quantitative analyses of diversity, the condition of tree species' regeneration, and soil properties may serve as a starting point for the creation of management and conservation plans for forests. In this regard, the degree of tree species (N = 22) heterogeneity found in our study was remarkably higher to that found in earlier investigations carried out in nearby Himalayan regions. For example, Singh and Sharma (2022) identified 11 tree species in the northwestern Himalayas and Wani and Pant (2022) identified 18 tree species in the Gulmarg Wildlife Sanctuary in the Kashmir Himalaya. Maletha et al. (2021) reported 12 tree species from the Nanda Devi Biosphere Reserve in the Western Himalaya. This might be explained because of the protected status of our research area, its location, biotic factors, and climatic conditions. Additionally, the park has been intentionally planted with tree species like *Quercus robur, Robinia pseudoacacia, Prunus cerasifera,*

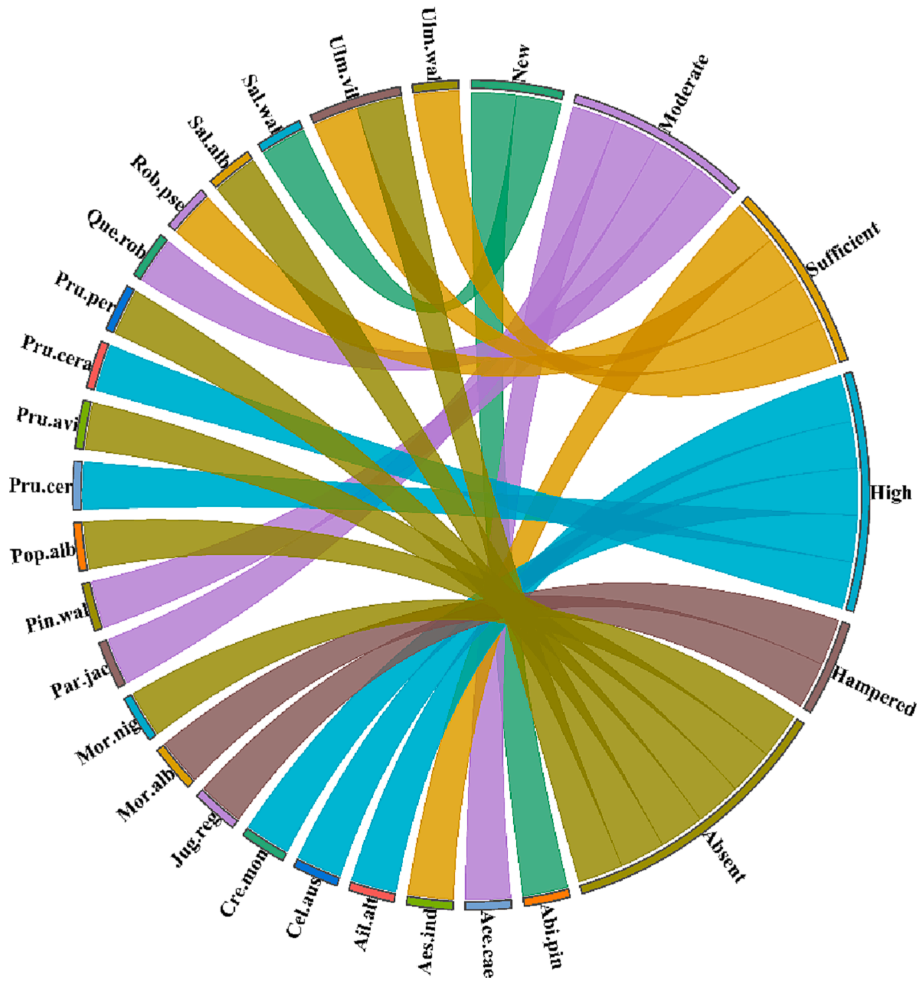

Fig. 6. Chord diagram showing the regeneration performance of individual tree species in the study area. Appendix A displays the full name of each species.

Prunus cerasus and *Populus alba*, which may be another factor contributing to the heterogeneity in the tree composition. On the other hand, our findings are consistent with those of Pandey et al. (2018), who reported 20 tree species from Khangchendzonga National Park in the Eastern Himalaya. Our results are also comparable to those from other mountain regions in terms of patterns of forest tree composition, where Rosaceae, Salicaceae, Moraceae, and Pinaceae were the most prevalent families (Fisaha et al. 2013; Khan et al. 2018; Haq *et al.* 2022). The Rosaceae has a large geographic range, but temperate forests are where it is most diverse (Xiang et al. 2017). Significant forest trees belonging to the Rosaceae serve as homes and food sources for birds, mammals, and other animals (Debussche and Isenmann, 1989). As a result, it is reasonable to assume that these species are more resilient to biotic pressure and have a seed-dissemination mechanism dependent on consumption by vertebrate animals, particularly birds and mammals (Jakovac et al., 2021). This could be because park managers purposefully planted members of Rosaceae family such as *Prunus cerasifera* and *Prunus cerasus*to to fulfill food requirements of wild animals in the study area., which is declared as a National Park. This is explained by ecophysiological characteristics, which demonstrate how well-adapted a particular plant species is to its environment and how well they can withstand harsh climates given that the study area is in the sub-Mediterranean region.

4.2. Patterns of forest tree diversity

The species diversity can be used as a primary indicator to assess the health of a forest ecosystem. We assessed the forest types in this study using a variety of diversity indices. The highest Shannon and Simpson diversity was found in the BLFT and lowest in the SRFT forest types when comparing the floristic diversity of the five forest types. BLFT showed a diverse flora with 16 tree species, including *Populus alba, Ailanthus altissima, Celtis australis, Aesculus indica, Prunus cerasifera,* and *Prunus avium*. It is predicted that as taxonomic diversity increases, functional redundancy will be ensuring greater stability and community resilience (Gastauer et al., 2021). Our results are in line with the predictions of the competition theory that ecosystem stability rises with diversity. Though ecosystem stability remained a function of the number of species planted, higher plant diversity suggested that more species had a stronger positive impact on ecosystem stability (Tilman et al., 2006). In BLFT, 18 % of the species were unique, in PWFT, 14 % of the species, and in SRFT, only one species, *Parrotiopsis jacquemontiana*, was unique. This indicates that the tree species richness of each assemblage, reflecting taxonomic composition, phylogenetic diversity, and functional diversity, is the result of species' ability to adapt to environmental conditions through niche differentiation and speciation (Knapp et al., 2008). The majority of exotic species were found in the OKFT, followed by the BLFT. The success of exotic species can be attributed to both their effective and successful means of dispersal as well as their greater capacity for habitat adaptation (Ni et al., 2021). As a result, introducing exotic species into the park will only exacerbate the impact by increasing competition between invasive and native species. Similar findings were reported by Langmaier and Lapin (2020) who specifically mentioning the effect of alien plants on forests.

Table A1
List of tree species, family and regeneration performance as indicated by the ratio of seedling (Se) or sapling (Sa) to tree density in different forest types in the study area.

Tree species	Family	Code used	Nativity	(Se, Sa/T) Ratio	Average density /ha Se, Sa and T	ACFT	BLFT	PWFT	OKFT	SRFT	Overall (Se, Sa/T) Ratio	Regeneration performance
Abies pindrow (Royle ex D. Don) Royle	Pinaceae	Abi. pin	Native	Se/T	0(Se),25 (Sa)	–	–	–	–	–	0	**New**
				Sa/T	0(T)	–	–	25/0	–	–	25/0	
Acer caesium Wall ex Brandis	Sapindaceae	Ace. cae	Native	Se/T	25(Se),25 (Sa)	–	0/25	10	–	–	0.83	**Moderate**
				Sa/T	30 (T)	–	0/25	10	–	–	0.83	
Aesculus indica (Wall ex Cambess.) Hook.	Sapindaceae	Aes. ind	Native	Se/T	68.75 (Se), 43.75 (Sa)	0/5	5	0/2.5	0.91	0	2.2	**Sufficient**
				Sa/T	31.25 (T)	0/5	3.18	0/2.5	1.81	0	1.4	
Ailanthus altissima (Mill.) Swingle	Simaroubaceae	Ail.alt	Exotic	Se/T	112.5 (Se), 252.5 (Sa)	1.25	3.18	30	1.43	0	2.4	**High**
				Sa/T	46.875 (T)	1.25	3.33	50	10.57	0	5.39	
Celtis australis L.	Cannabaceae	Cel. aus	Exotic	Se/T	701.752 (Se), 879.5 (Sa)	2.18	10.96	8.97	14.43	0.46	6.76	**High**
				Sa/T	103.5 (T)	2.81	13.68	12.46	20.71	0.48	8.47	
Crataegus monogyna Jacq.	Rosaceae	Cre. mon	Exotic	Se/T	183.33 (Se), 208.33 (Sa)	0	11.25	4.55	30	0	7.10	**High**
				Sa/T	25.83 (T)	0	7.5	3.18	30	0	8.07	
Juglans regia L.	Juglandaceae	Jug. reg	Native	Se/T	12.5 (Se),0 (Sa)	0	0/ 22.5	3.18	0	0	0/31.25	**Hampered**
				Sa/T	31.25 (T)	0	0/ 22.5	0/100	0	0	0.4	
Morus alba L.	Moraceae	Mor. alb	Exotic	Se/T	0 (Se),50 (Sa)	0/25	0/40	40	0/25	0	0/23.12	**Hampered**
				Sa/T	23.125 (T)	0/25	2.5	0.5	0/25	0	2.16	
Morus nigra L.	Moraceae	Mor. nig	Exotic	Se/T	0 (Se),0 (Sa)	0	0	0	0	0	0/30.83	**Absent**
				Sa/T	30.83 (T)	0	0	0	0	0	0/30.83	
Parrotiopsis jacquemontiana (Decne.) Rehder	Hamamelidaceae	Par. jac	Native	Se/T	640 (Se),407.5 (Sa)	0	0	0	0	0.6	0.60	**Moderate**
				Sa/T	1072 (T)	0	0	0	0	0.38	0.38	
Pinus wallichiana A. B. Jacks.	Pinaceae	Pin. wal	Native	Se/T	200 (Se),175 (Sa)	0	0	0.56	0	0	0.56	**Moderate**
				Sa/T	354 (T)	0	0	0.49	0	0	0.49	
Populus alba L.	Salicaceae	Pop. alb	Exotic	Se/T	0 (Se),0 (Sa)	0	0/ 142.5	0	0	0	0/142.5	**Absent**
				Sa/T	142.5 (T)	0	0/ 142.5	0	0	0	0/142.5	
Prunus cerasifera Ehrh.	Rosaceae	Pru. cera	Exotic	Se/T	29.5 (Se),469.3 (Sa)	0/45	26.5	0	0	3.3125	1.09	**High**
				Sa/T	27 (T)	0/45	43.5	75/0	315.5/ 0	2.4375	17.39	
Prunus cerasus L.	Rosaceae	Pru. cera	Exotic	Se/T	163.5 (Se), 231.25 9Sa)	1.59	0/95	0	56.75/ 0	0	2.39	**High**
				Sa/T	68.33 (T)	1.14	0/95	0	0	0	3.38	
Prunus avium L.	Rosaceae	Pru. avi	Exotic	Se/T	0 (Se),0 (Sa)	0	0/ 57.5	0	0	0	0/28.75	**Absent**
				Sa/T	28.75 (T)	0	0/ 57.5	0	0	0	0/28.75	
Prunus persica (L.) Batsch	Rosaceae	Pru. per	Exotic	Se/T	0 (Se),0 (Sa)	0	0	0	0	0	0/45	**Absent**
				Sa/T	45 (T)	0	0/45	0	0	0	0/45	
Quercus robur L.	Fagaceae	Que. rob	Exotic	Se/T	191.67 (Se), 233.33 (Sa)	0/ 37.5	0	0/90	1.06	0	0.86	**Moderate**
				Sa/T	224.17 (T)	0/ 37.5	0	0/90	1.28	0	1.04	
Robinia pseudoacacia L.	Fabaceae	Rob. pse	Exotic	Se/T	300 (Se),225 (Sa)	3.44	2.11	0	25/0	0	3.30	**Sufficient**
				Sa/T	90.83 (T)	2.33	2.63	0	25/0	0	2.48	
Salix alba L.	Salicaceae	Sal.alb	Exotic	Se/T	0 (Se),0 (Sa)	0	0	0	0	0	0/140	**Absent**
				Sa/T	140 (T)	0	0/ 140	0	0	0	0/140	
Salix wallichiana Andersson.	Salicaceae	Sal. wal	Native	Se/T	25 (Se),25 (Sa)	25/0	0	0	0	0	25/0	**New**
				Sa/T	0 (T)	25/0	0	0	0	0	25/0	
Ulmus villosa Brandis & Gamble	Ulmaceae	Ulm. vil	Native	Se/T	0 (Se),0 (Sa)	0	0	0	0	0	0/5	**Absent**

(*continued on next page*)

Table A1 (*continued*)

Tree species	Family	Code used	Nativity	(Se, Sa/T) Ratio	Average density /ha Se, Sa and T	ACFT	BLFT	PWFT	OKFT	SRFT	Overall (Se, Sa/T) Ratio	Regeneration performance
				Sa/T	5 (T)	0	0	5	0	0	0/5	
Ulmus wallichiana Planch.	Ulmaceae	Ulm. wal	Native	Se/T	31.67 (Se), 34.17 (Sa)	0	0/ 32.5	0	0	1.52	1	**Sufficient**
				Sa/T	31.67 (T)	0	0/ 32.5	0	0	1.64	1.09	
Average total (Se), (Sa) of the study area Average (T)				**Se/T Sa/T**	**1853.35 (Se), 2331.75 (Sa)**	**1.9**	**3.61**	**2.94**	**2.02**	**0.71**	**2.14**	**Sufficient**
				(T)	**864 (T)**	**1.5**	**5.10**	**3.98**	**3.07**	**0.51**	**2.67**	

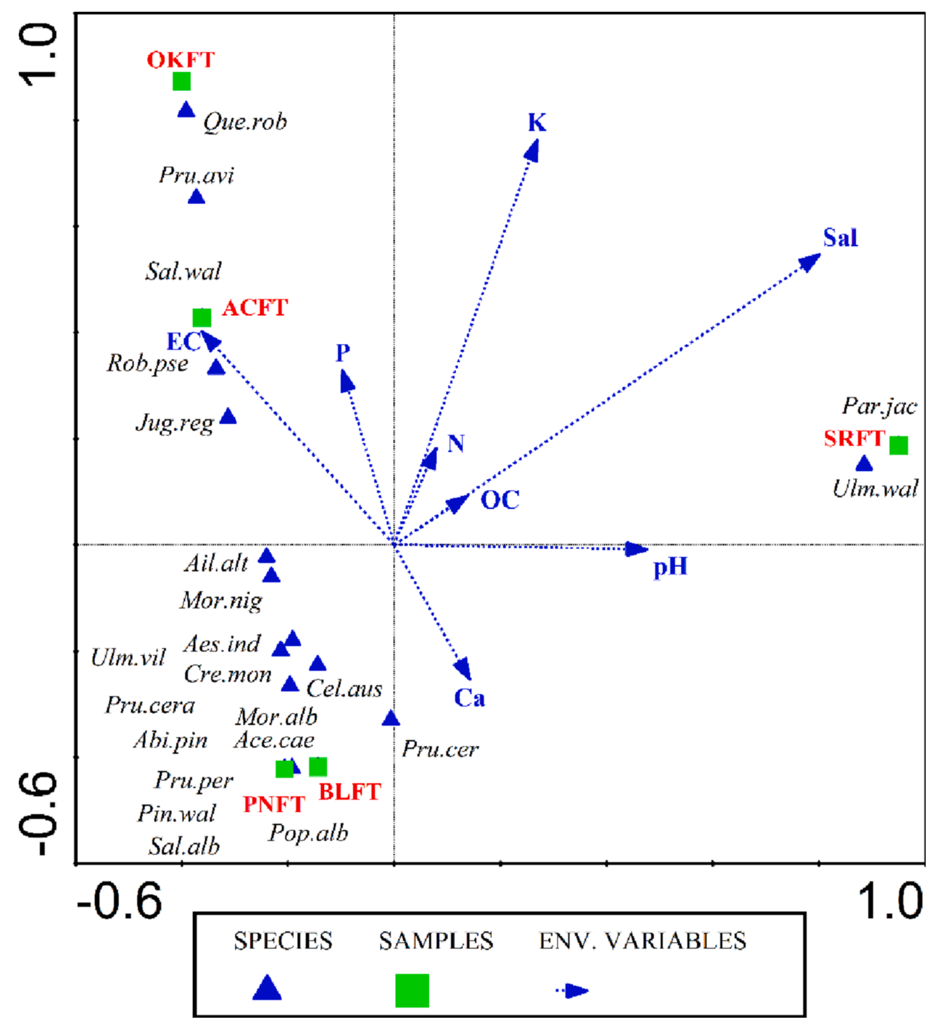

Fig. 7. Diagram from a canonical correspondence analysis illustrating the distribution of tree species affected by soil variables in the five main types of forests found in the study area. In the diagram, the arrow shape denotes the soil variables, the square shape denotes the type of forest, and the triangle shape denotes the species. Th full name of each species is listed in Appendix A.

4.3. Age structure and regeneration performance of tree species

The current approach to estimating forest health status combines information on the structural characteristics and regeneration into a single measure that contains the essential components of terrestrial ecosystems (Smith, 2002; Shu et al., 2021). The structural characteristics of a forest stand are considered to be a trustworthy and repeatable indicator of biodiversity and can have an impact on the heath and functionality of an ecosystem (Haq *et al.*, 2022). The stand structure of the ACFT and SRFT forests had a reverse J-shaped diameter class distribution, indicating a stable population structure. Similar findings have been reported from Afromontane forests (Gebeyehu et al., 2019), the Eastern Himalayas (Rawat et al., 2018) and from western Arunachal Pradesh, India (Paul et al. 2019). In old-growth forests that have not been disturbed and have sustainable regeneration, the size class distribution is J-shaped (Thakur et al., 2021). This demonstrates the dominance of small-sized individuals and a progressive decline in mature tree individuals as DBH increase (Yemata and Haregewoien, 2022). In contrast, a trend showing a unimodal distribution pattern in the density-girth class distribution was seen in the BLFT, PWFT, and OKFT forests,

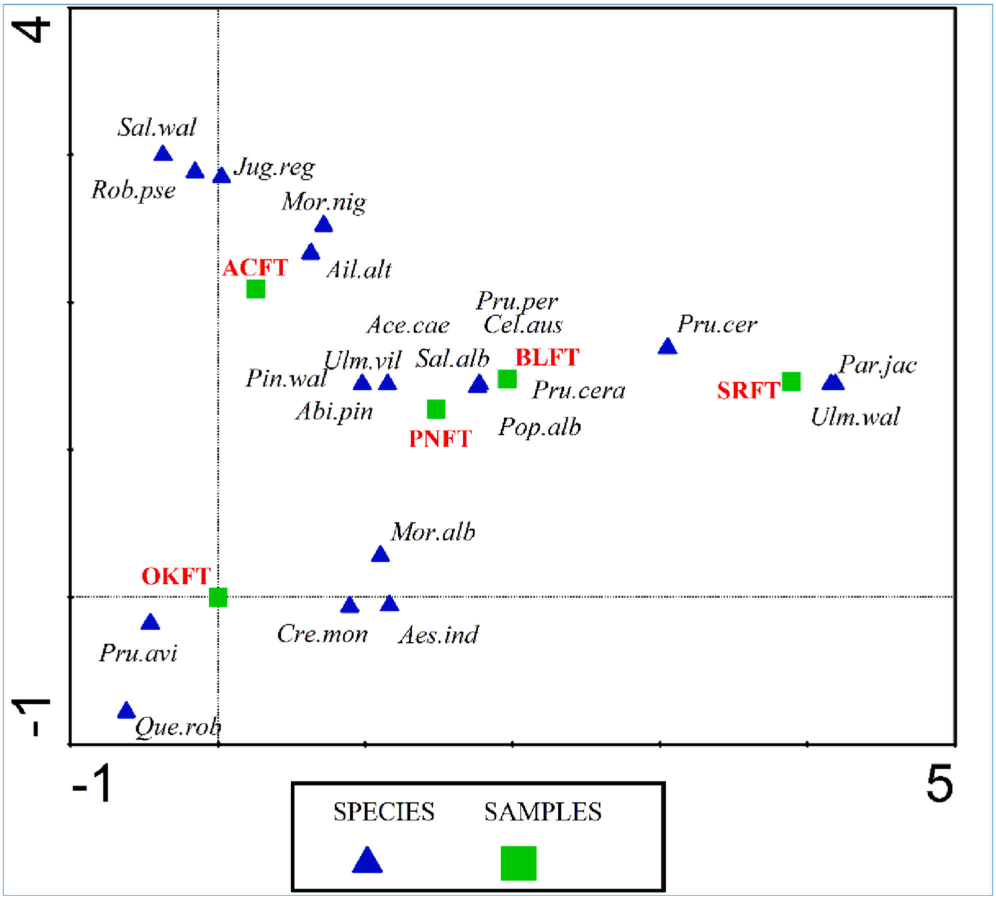

Fig. 8. Diagram from a detrended correspondence analysis displaying the distribution of tree species in the five main types of forests found in the study area. Triangles in the diagram stand in for species, and squares for different types of forests. Each species' full name is listed in Appendix A.

indicating that these forests may be in decline as a result of significant changes in the state and pattern of forest regeneration. This indicates that there is a threat to their survival in the future because of a lack of adequate seedlings. Only species with a roughly equal distribution of individuals in each of the three life stages are predicted to maintain dominance in the near future (Gairola et al., 2012). Our findings concur with those of (Haq et al., 2019a) from a temperate forest in the Kashmir Himalaya and Bhat et al. (2015) and Malik and Bhatt, (2016) from a protected area in the Western Himalaya. Therefore, the quantified relationships between the current density and size distributions provide future insight into the health of the forest and the consequences of recruitment and mortality.

The ability of a community to regenerate under various environmental factors, including climate, soil properties, disturbance patterns, and seed bank composition, is a key factor in determining the community's viability (An et al., 2022). The forest tree species in our study displayed a wide range of regeneration abilities. According to the growth form ratio (seedlings, saplings, and adults), exotic tree species like *Robinia pseudoacacia, Prunus cerasifera, Celtis australis,* and *Ailanthus altissima* demonstrated high/sufficient regeneration performance in contrast to native species like *Pinus wallichiana, Parrotiopsis jacquemontiana, Acer caesium,* and *Ulmus villosa,* exhibited moderate regeneration performance. Exotic species may thus play a significant role in influencing natural regeneration (Demeter et al., 2021). They also permanently alter soil biological, chemical, and physical properties. It alters the species composition of the ground flora beneath its canopy by removing acidophilous and characteristic of forest species, reducing plant diversity, and favoring exotic associations (Nicolescu et al., 2020; Haq et al., 2021a; Vujanović et al., 2022). Tree species with poor regeneration capacities included *Morus alba* and *Juglans regia*. This could be due to a variety of biological stressors exerting pressure, such as a lack of viable seed production, insect and animal predators, unfavorable microclimates, excessive grazing on these post-pioneer (Janssen et al., 2021; Haq et al., 2022b). The moderate regeneration of *Quercus robur* in OKFT may be due to over-dominance, which have emerged as dominant elements in the forest ecosystem. Similarly, Gaira et al. (2022) reported that overabundance altered forest structure in the Khangchendzonga landscape of the Eastern Himalaya. Currently in BLFT two dominant tree species like *Populus alba*, *Salix alba* showed relatively no regeneration performance. This could be due to sexual dimorphism in life history traits (Dering et al., 2016) and the fact that these two species propagate primarily through vegetative propagation, which necessitates human intervention in the form of sapling planting. Seed longevity in the field is likely to be much shorter, as is the 'time window' for regeneration (Karrenberg et al., 2002). Similar findings were reported by Janssen et al. (2021), who also noted that *Populus alba* and *Salix alba* regeneration were virtually non-existent in the mature forest.

4.4. Regeneration status of forest types

Tree population dynamics in a forest ecosystem have an impact on how well forest regenerate (Mathys et al., 2021). A forest's regeneration status can be determined by counting the number of seedlings, saplings, and adults present. It is anticipated that the density of seedlings and saplings of different tree species will alter along with changes in the edaphic conditions and forest structure (Weigel et al., 2022). According to the regeneration analysis, the density of seedlings ranged from 920 Ind/ha to 3766.25 Ind/ha, while that of saplings ranged from a maximum of 5317.5 Ind/ha to a minimum of 662.5 Ind/ha. The dominance of exotic tree species and variations in soil factors may both

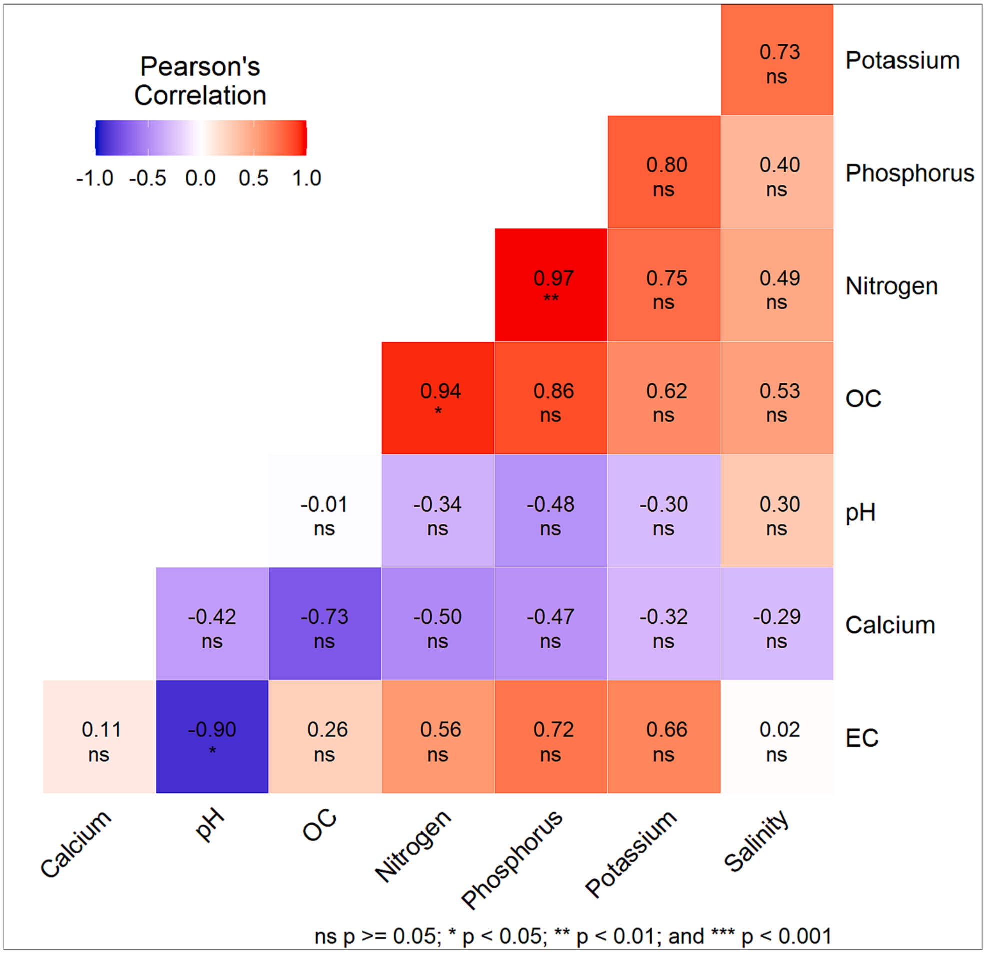

Fig. 9. Pearson correlation between soil variables of 5 major forest types in the study area. The asterisks represent the level significance.

contribute to the observed variation in seedling and sapling density among the different forest types (Freitas et al., 2019). The BLFT forest type contained 75 % exotic species, increasing the number of their saplings and producing a high sapling count. Another factor is the absence of regeneration in the forest of the dominant *Populus alba*, which allows for the flourishing of exotic species. The reported seeding and sapling count are consistent with the data from other forests, such as Kashmir Himalaya's temperate forest, where Haq et al. (2019a) reported that the average seedling density ranges from 1200 to 3200 Ind/ha and the sapling density ranges from 800 to 2300 Ind/ha, respectively. However, Tiwari et al. (2018) reported higher seedling densities from the forests of the Garhwal, Himalaya, ranging from 12,000 to 220,000 Ind/ha and the sapling densities from 1600 to 6800 Ind/ha, respectively. A comparatively lower value of seedling density of 119 Ind/ha to 211 Ind/ha from Pakistan, Himalayas was reported by Shaheen et al. (2016). Akash and Bhandari (2019) reported the seedling and sapling density of 191.65 to 589.02 Ind/ha in Rajaji tiger reserve, from Garhwal Himalaya, India.

4.5. *Role of edaphic properties*

One of the most important elements in forest regeneration is the availability of organic matter and soil nutrients, which have shown having greatest impact on the composition and diversity of forest plant communities (Archer et al., 2007; Sitzia et al., 2012). The development, organization, and distribution of plant communities are significantly influenced by the nutrient content of the soil (Sardans and Peñuelas, 2004). When soil nutrients are stable, the diversity of tree species in various stand is frequently similar (Chen and Cao, 2014). We discovered strong connections between soil parameters in our investigation, comparable to those reported by Matias et al. (2011). In the study area the percentage of organic matter and availability of P, N, exchangeable Ca, K, pH, electrical conductance (EC), varied according to forest types, ACFT and OKFT stands positively associated with available phosphorus and electrical conductance while SRFT strongly associated with salinity, organic carbon, potassium and nitrogen (Haq et al. 2022c). Similar relationships between edaphic characteristics and plant species composition have been discovered in other studies (Malik et al., 2021; Rahman et al., 2022; Waheed et al., 2022a,b), which can be explained by the fact that local edaphic factors affect nutrient availability in various soil types, favoring plant communities with a variety of ecological roles.

4.6. *Insights for forest management and policy*

The current study offers field-based information on the natural regrowth of tree species in forest ecosystems, which is essential for directing the restoration of damaged/invaded forest ecosystems and creating successful conservation plans. Trees are a major biotic component in plantations and in the restoration of forest ecosystems. In order to recover damaged forest ecosystems, native tree species are recognized as a critical resource. Alarmingly, 59 % of the tree species in the park were exotic. As a result, we propose that native species although with moderate regeneration performance, such as *Pinus wallichiana, Parrotiopsis jacquemontiana, Aesculus indica, Acer caesium*, and *Ulmus villosa,* be planted in the park in the future. In addition, park managers purposefully planted exotic species *Quercus robur, Prunus* *cerasifera,* to serve as food for wild animals. As a result, we advise against introducing further exotic species into the park, because doing so will only exacerbate the impact by increasing competition between exotic and native tree species. Because of the overabundance of *Quercus robur* in OKFT, the species has now dispersed into PWFT and ACFT, and will become a dominant component of these forest ecosystem in the future. At the moment, two dominant tree species, *Populus alba* and *Salix alba*, have demonstrated minimal regeneration abilities in the BLFT. Therefore, it is advised that park managers support active restoration of native coniferous and broad-leaved tree species including *Pinus wallichiana, Aesculus indica, Acer caesium*, and *Ulmus villosa,* in order to ensure the long-term survival of the forest. Tree species with poor regeneration capacities particularly *Juglans regia,* need active human interventions to improve their regeneration performance and support food for wild animals. This can be accomplished by planting or sowing native species, which should hasten species recovery. Even though the Park's regeneration status was sufficient, exotic tree species contributed most seedlings (86 %), saplings (91 %), and trees (60 %), which is cause for concern. Exotic species like *Robinia pseudoacacia, Prunus cerasifera, Celtis australis,* and *Ailanthus altissima* showed high or sufficient rates of regeneration in the various forest types. This could eventually turn native forests into monospecific stands of invasive species, which would harm the primary consumers, especially native herbivores. In addition, the distinctiveness of the forest would be lost as a result of an increase in the density of exotic tree species, both inside and outside the colonized patches, as has been seen in other parts of the world (González-Moreno et al., 2013; Lázaro-Lobo and Ervin, 2021). In line with the above-mentioned field observations, it will almost likely result in biodiversity loss, natural resource crises, and habitat collapse. It is crucial that park administrators update their policy to ensure the conservation of the forest and wildlife. Our research will provide up-to-date, field-based, significant new insights into the forest's present and future health.

5. Conclusion

This study, which combined multiple quantitative indicators of diversity, the health of tree species regeneration, and soil properties, reported for the first time on the field-based forest health status, may be used as a starting point for management and conservation plans. 22 tree species were identified in the park, of which 41 % were native and 59 % were exotic. OKFT harbored most exotic species (85 %), followed by BLFT (75 %). The highest Shannon and Simpson diversity was also observed in the BLFT and lowest in SRFT. ACFT and SRFT both displayed an Inverse-J distribution pattern. The BLFT, PWFT, and OKFT, on the other hand, showed a unimodal distribution pattern. According to the growth form ratio (seedlings, saplings, and adults), exotic tree species demonstrated high/sufficient regeneration performance in contrast to native species which exhibit at most moderate regeneration performance. Pearson correlation showed that soil pH and calcium had a negative relationship with potassium, nitrogen, phosphorus, and organic carbon. The findings of our study can serve as guidance for creating long-term forest conservation plans that will safeguard currently existing, ecologically sound forest ecosystems and support the ecological restoration of invaded forest areas in this Himalayan region. They can also provide information for other areas with mountainous forest landscapes.

CRediT authorship contribution statement

Shiekh Marifatul Haq: Conceptualization, Methodology, Data curation, Formal data analysis, Validation, Writing - original draft. **Muhammad Waheed:** Writing - review & editing. **Aadil Abdullah Khoja:** Data curation. **Muhammad Shoaib Amjad:** Conceptualization, Methodology, Supervision, Formal data analysis, Project administration, Writing - review & editing. **Rainer W. Bussmann:** Writing - review & editing. **Kishwar Ali:** Writing - review & editing. **David Aaron Jones:** Writing - review & editing.

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Conflict of interest

All the authors declare no conflict of interest.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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