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Tree diversity and regeneration status in the different forest types of Kotla watershed (Uttarkashi, Uttarakhand, India)

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Abstract. The present study aimed to assess the diversity and regeneration status of tree species in different forest types viz., Pinus forest (PF), Pinus-Oak mixed forest (POF) and Deodar forest (DF) of Kotla watershed (Barkot, Uttarkashi, Uttarakhand). The data were collected through quadrat method and analyzed quantitatively. A total of 28 tree species, belonging to 21 families were recorded in the sampling area (3 forests 10 plots in each, plot size 400 m^2). Fagaceae, Pinaceae, Ericaceae, Fabaceae and Juglandaceae were the major families (in terms of number of species). The species-area curves (SACs) of PF and DF reached an asymptote while it predicted more species (did not reach asymptote) in case of POF. The resulted values of different diversity indices (i.e., Dominance, Simpson, Shannon, Evenness, Margalef, and Equitability) revealed that the POF was most diverse (in tree diversity) followed by PF and DF. The ranked species abundance (RSA) curve of POF was log normal type but geometric series type for PF and DF. The density-diameter curves (d-d curves) was reverse J-shaped for POF while in case of PF and DF, the higher densities were observed for middle DBH classes in comparison to lowest and highest DBH classes. The overall regeneration status of the forests in the area was fair (25.8% tree, 18.6% saplings and 55.6% seedlings). The present study provides a deeper understanding of tree diversity pattern and regeneration status from a pocket of Indian Himalayan Region (IHR).

Key words: Diversity indices, DBH class, Himalayan Forest, sapling, seedling.

1. Introduction

The Indian Himalayan Region (IHR) as part of the Himalayan Biodiversity Hotspot is rich in biodiversity and natural resources. The species composition of Himalayan forests varies greatly due to the wide range of climatic and topographic conditions. The biodiversity in this region experienced some noticeable impacts, such as changes in species abundance and range, shifts in habitat and change in phenology (Rawat et al., 2020; Dash et al., 2021; Thakur et al., 2021). Among the different phytosociological indicators of forests the natural regeneration status (proportion of adults, saplings and seedlings individuals) is crucial one which helps to predict the future changes in particular forest ecosystem (Sharma et al., 2018). Natural regeneration of forest (tree species) is a biological process by which a forest community replaces itself over the time. It is determined by the density of seedlings and saplings within old canopy (Saxena & Singh, 1982; Khan & Tripathi, 1986; Shankar, 2001). A large number of seedlings, saplings and trees in a forest depicts good regeneration, whereas low number of saplings and seedlings depicts poor regeneration and complete absence of saplings and seedlings depicts no regeneration (Kusumlata & Bisht, 1991; Parveen et al., 2017; Rawat et al., 2018a, b). Understanding the natural regeneration processes and dynamics is crucial for planning and carrying out management activities (Khan & Tripathi, 1986; Ballabha et al., 2013).

The current study aimed to assess the diversity and regeneration pattern of tree species in different forest types in a part of Yamuna River Catchment of Uttarakhand state (NW-Himalaya, India).

2. Materials and methods

2.1. Study area

The Yamuna River originates from the Yamunotri glacier (ca. 6,387 m asl) of Uttarakhand state (NW-Himalaya, India). The river along with rivulets and offshoots forms numerous watersheds in its giant catchment (Yamuna Valley). The valley is spread over Uttarkashi, Tehri and Dehradun district of the Uttarakhand (Fig. 1). The river flows towards Delhi from Dehradun and merge with the holy Ganga River at the Prayagraj in Uttar Pradesh. The Yamuna has great religious significance as the Yamunotri temple (in Uttarkashi, Uttarakhand), a shrine dedicated to the goddess Yamuna, is one of the holiest shrines in Hinduism, and is the part of the Char Dham Yatra in the state.

The Kotla watershed is situated in the upper catchment of the Yamuna Valley near Barkot town (Uttarkashi, Uttarakhand). Kotla watershed, a small perennial stream (called Kotla gad locally) is the main drainage in the watershed which originates from forest (upper ridge) and merge in Yamuna at Banolt near the Tiladi, Barkot. Geographically it is located between 30.868901° to 30.900364° N latitudes and 78.17739° to 78.187412° E longitudes covers as area of about 15 km^2. The elevation of the watershed ranges ca. 1530–2700 m asl. Physiographically, the area represents large forest mountainous terrain that runs into series of ridges (e.g., Jakhali, Dhausali, Akhodika, and Surka) and sub-valley slopes characterized by terraced agricultural lands and village ecosystems. Kotla, Nathergoun, Ghund, Byali, Nald, and Kud are the main villages of kotla watershed. The vegetation of the area dominated by conifer forests at lower and middle zones while broad-leaves species at upper ridges. Chir, Deodar, Banj, Burans, Ayar, Moru, Kail, Raimurando and Kharsu are common tree elements (Fig. 2). The area represents temperate climatic condition with distinct seasons (spring, summer, rainy and winter). The average annual temperature is 11.5° C while the annual rainfall is 1720 mm (climate-data.org). The

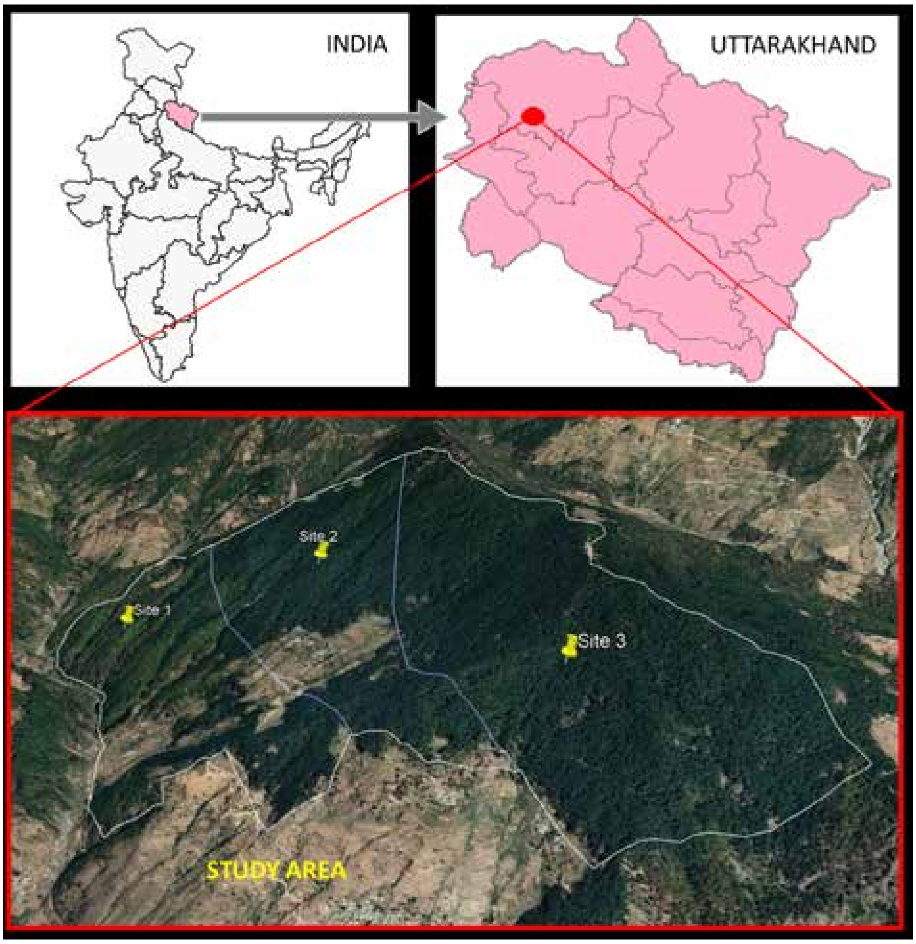

Figure 1. Location map of the study area

Figure 2. Study sites in Kotla watershed (Uttarkashi, Uttarakhand, India): (A) Pinus forest (PF), (B) Deodar forest (DF) and (C–D) Pinus-Oak mixed forest (POF)

soil of the region represents sandy loam textural class and is slightly acidic in nature (Rawat et al., 2021).

Among the various types of species compositions in the area, we selected three dominant types of forests viz., Pinus forest (PF), Pinus-Oak mixed forest (POF) and Deodar forest (DF) vary in their tree species composition and dominance for present study after the reconnaissance surveys. The details of these three forest sites (PF, POF and DF) in the Kotla watershed (Barkot, Uttarkashi, Uttarakhand, India) is given in Table 1.

2.2. Data collection

To collect the data and plant specimens from the area, extensive field surveys were conducted during 2020–2021. The plant specimens (herbarium size) were collected at reproductive stage with relevant information and processed for herbarium record following Jain & Rao (1977). These were identified with help of regional floras and regional herbaria e.g. Herbarium of Northern Regional Centre, Dehradun (BSD) and Herbarium of Department of Botany,

Table 1. General details of three forest types in Kotla watershed (Uttarkashi, Uttarakhand, India).

Attributes	Site 1	Site 2	Site 3
Forest type	Pine forest	Pine-Oak forest	Deodar forest (DF)
Code given	PF	POF	DF
Coordinates	Lat. 30.869745 N, Long. 78.185496 E	Lat. 30.89283 N, Long. 78.186828 E	Lat. 30.891845 N, Long. 78.200819 E
Slope angle	20–50°	35–65°	20–40°
Elevation	1640–1926 m	1700–2020 m	1800–2421 m
Dominant tree species	*Pinus roxburghii*	*Pinus roxburghii*, *Quercus* spp., *Cedrus deodara*, *Rhododendron arboreum*	*Cedrus deodara*, *Pinus roxburghii*, *Cupressus torulosa*, *Ilex dipyrena*, *Quercus* spp.

Hemvati Nandan Bahuguna Garhwal University (GUH). The current accepted names and classification (family) are given as per the Royal Botanic Gardens (Kew) maintained online database (https://powo.science.kew.org/).

To collect the tree community data from each selected forest, a total of 10 samplings plots (size 400 m^2) were placed in stratified random sampling manner. The entire sampling plot of size 20 m × 20 m was considered as a quadrat for mature tree layer.

2.3. Data analysis

Circumference (C) was used to differentiate tree life stages into mature trees (C > 31.5 cm at 1.37 m above ground level), saplings (C = 10.5–31.4 cm) and seedlings (C < 10.5 cm). Circumference was measured with the help of graduated tape (larger trees) and calipers in case of saplings and seedlings. Within each tree quadrat, two sub-quadrats were nested for saplings (size 25 m^2) and four for seedlings (size 1 m^2). The number of individuals of each species were counted within the respective quadrats and noted on their respective field-data sheets (separate sheets for trees, saplings and seedlings).

The quantitative analysis for the obtained data was carried out following Misra (1968). The species-area curves (SAC) for each study site were prepared to understand the species richness pattern with increasing number of sampling units. Ranked species abundance (RSA) curves for all the three forests were obtained using abundance data of each tree species ranked in descending order (Rawat et al., 2020). The density-diameter curves (d-d curves) were prepared to assess the distribution of tree individuals into different DBH classes. The tree individuals were divided into six diameter classes (DBH classes) i.e., 10–20, 21–30, 31–40, 41–50, 51–60 and >60 cm to obtain the d-d curves.

In this study, the various diversity indices viz., Dominance index, Simpson index, Shannon index, Evenness index, Brillouin diversity index, Menhinick diversity index, Margalef index, Equitability index, Fisher's alpha index, Berger-Parker index and Chao-1 index were calculated using tree abundance data of each study site (in the software PAST ver. 3.11, Hammer et al., 2001).

The regeneration status of tree species was determined on the basis of population size of seedlings, saplings and mature trees. Good regeneration, i.e., if particular species is present in seedlings > saplings > trees; fair regeneration, i.e., if species presents in seedlings > saplings ≤ trees; poor regeneration, i.e., if a species survives only in sapling stage, but not as seedling; if a species is presents only in adult form it is considered as not regenerating (Khan & Tripathi, 1986; Shankar, 2001). The MS excel was used for drawing figures (SAC, RSA and d-d curves) and preparing analysis tables.

3. Results and discussion

3.1. Floristic diversity

A total of 552 tree individuals (CBH > 31.5 cm) belonging to 28 species, 25 genera and 21 families were recorded from the sampling area (3 forests 10 plots in each plot size 400 m^2) in the Kotla watershed. The list of recoded species along with nomenclature and family are given in Table 4. The total observed species richness (OSR) varied 11 to 15 among all the studied forests. The occurrence of 28 tree species within just 30 sampling plots indicates a good floristic diversity in the study area as whole. *Quercus* (3 species) and *Pinus* (2 species) were the genera with maximum number of species. Among the families, the highest number of species was observed for Fagaceae and Pinaceae (3 species each) followed by Ericaceae, Fabaceae and Juglandaceae (2 species each). This floristic finding is comparable to earlier such works from other parts of the IHR (Ballabha et al., 2013; Rawat et al., 2018a). The habitat heterogeneity is one of the important underplaying factors that cause differences in the species richness and species composition of Himalayan forests (Tiwari, 2005). Apart from the biotic (disturbance history) and edaphic factors, the altitude, slope, latitude, aspect, rainfall and humidity play an important role in the formation of plant communities and their composition (Rikhari et al., 1989; Bhandari et al., 2000; Parveen et al., 2017; Rawat et al., 2020).

3.2. Species area curve

The species-area curves (SAC) for PF and DF were flattened (towards ends) while it was uprising for POF (Fig. 3). The SACs did not predict more species with increasing number of sampling plots (after 7th plot) for PF and DF while the rising SAC for POF is an indicative that the predicted species

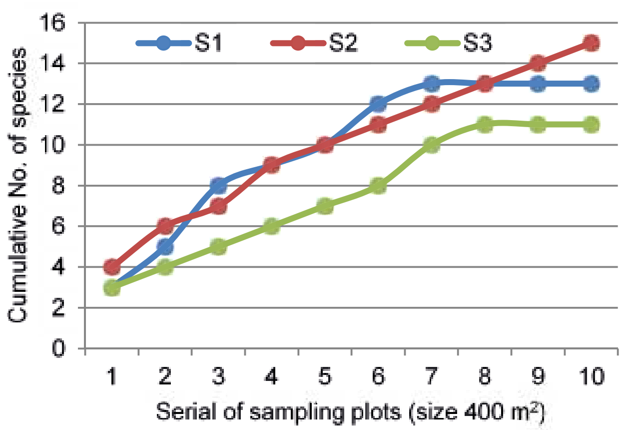

Figure 3. Species-area curves (SAC) for tree layers at different study sites in Kotla watershed

richness is higher than the OSR. It may attribute to the forest types as both PF and DF are conifer dominant forests while POF is a conifer-broad leaved mixed forest with highest species richness. Conifers tend to form pure patches and are poor in tree species richness while majority of broad-leaved species forms mixed patches and SAC predict more species than the OSR (Tiwari, 2005; Rawat et al., 2020).

3.3. Diversity indices

The various diversity indices viz., Dominance index, Simpson index, Shannon index, Evenness index, Brillouin diversity index, Menhinick diversity index, Margalef index, Equitability index, Fisher's alpha index, Berger-Parker index and Chao-1 index for tree species at different forest types are given in Table 2.

It is evident from the results that the dominance followed the opposite trend of diversity and evenness indices at all the sites. Among three forests, *Pinus roxburghii* was dominant at PF while *Cedrus deodara* at DF and both forests represents conifer forest types with low evenness and equality. The ranked species abundance (RSA) curve for POF fits to log normal type while geometric series curve for PF and DF. Steep RSA curves (PF and DF) indicate that the first ranked tree species contribute maximum in the total abundance that results in the low evenness (Fig. 4).

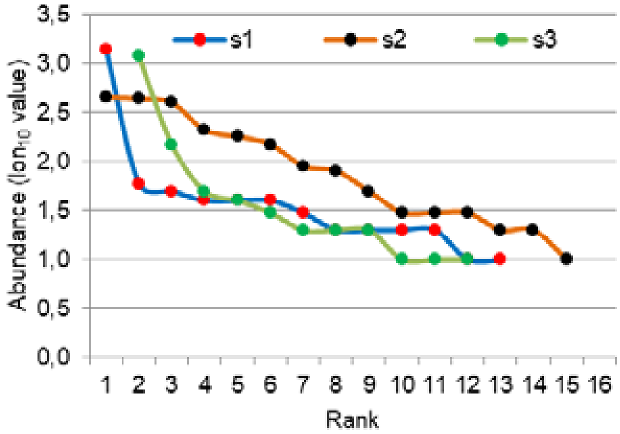

Figure 4. Ranked species abundance (RSA) curves for **three forest** types in Kotla watershed

3.4. Mean density

At the PF, the highest mean density (353 ha^{-1}) was recorded for *Pinus roxburghii* followed by *Mallotus philippensis* (15 ha^{-1}), *Bauhinia variegate*, *Erythrina variegata* and *Wendlandia puberula* (10 ha^{-1} each), while the lowest density was observed for *Quercus glauca* and *Lannea coromandelica* (3 ha^{-1} each). At POF, the maximum mean density (> 100 ha^{-1}) was recorded for *Cedrus deodara*, *Pinus roxburghii* and *Quercus*

Table 2. Tree diversity in different types of forests

Parameters	PF	POF	DF	Mean± S.D.
Diversity				
No. of species	13	15	11	13.0±2.0
No. of genera	13	14	9	12.0±2.65
No. of families	12	12	7	10.332.89
No. of individuals	177	219	156	184.0±32.08
Dominance index	0.64	0.14	0.6	0.46±0.28
Simpson index	0.36	0.86	0.4	0.54±0.28
Shannon index	0.98	2.2	0.97	1.38±0.71
Evenness index	0.21	0.6	0.24	0.35±0.22
Brillouin diversity index	0.89	2.08	0.88	1.28±0.69
Menhinick diversity index	0.98	1.01	0.88	0.96±0.07
Margalef index	2.32	2.6	1.98	2.30±0.31
Equitability index	0.38	0.81	0.41	0.53±0.24
Fisher's alpha index	3.23	3.65	2.7	3.19±0.48
Berger-Parker index	0.8	0.21	0.77	0.59±0.33
Chao-1 index	13.2	15	11.75	13.32±1.63
Tree regeneration status (% no. of species)				
Fair	23.08	26.67	45.45	31.73±12.01
Good	23.08	33.33	9.09	21.83±12.17
Not	23.08	20.0	27.27	23.45±3.65
Poor	30.77	20.0	18.18	22.98±6.80

leucotrichophora while low density for *Juglans regia* (3 ha^{-1}), *Cinnamomum tamala* (5 ha^{-1}) and *Cornus macrophylla* (5 ha^{-1}). *Cedrus deodara* (300 ha^{-1}) showed the maximum density at DF followed by *Pinus roxburghii* (38 ha^{-1}), *Cupressus torulosa* (13 ha^{-1}) while *Pinus wallichiana*, *Quercus leucotrichophora* and *Viburnum cotinifolium* represented low density (3 ha^{-1} each). The tree density of adult trees, saplings and seedlings varied from one forest to another (Table 3).

3.5. Density diameter curves

The density-diameter curves (d-d curves) for all three forests are given in Figure 5. The curve was reverse J-shaped at POF while it did not show a definite pattern at PF and DF where higher density was observed for middle DBH classes in comparison to lowest and highest DBH classes. The reverse J-shaped d-d curves at POF indicates that the younger

Table 3. Densities (ha^{-1}) of the mature trees (mature), saplings and seedlings at different forest types in Kotla watershed

Name of tree species	PF			POF			DF		
	Tr.	Sp.	Sd.	Tr.	Sp.	Sd.	Tr.	Sp.	Sd.
Alnus nitida	–	–	–	38	65	82	–	–	–
Bauhinia variegata	10	10	0	–	–	–	–	–	–
Cedrus deodara	–	–	–	100	56	310	300	135	925
Cinnamomum tamala	–	–	–	5	0	0	–	–	–
Coriaria napalensis	13	19	38	13	28	51	–	–	–
Cornus macrophylla	–	–	–	5	10	0	–	–	–
Cupressus torulosa	–	–	–	–	–	–	12.5	0	0
Engelhardia spicata	5	4	15	–	–	–	–	–	–
Erythrina variegata	10	7	20	–	–	–	–	–	–
Ficus semicordata	5	14	0	–	–	–	–	–	–
Ilex dipyrena	–	–	–	20	30	65	8	6	4
Juglans regia	–	–	–	2.5	0	0	–	–	–
Lannea coromandelica	3	9	22	–	–	–	–	–	–
Lyonia ovalifolia	–	–	–	23	35	70	5	12	28
Mallotus philippensis	15	21	37	–	–	–	–	–	–
Pinus roxburghii	353	89	830	113	165	285	37.5	42	0
Pinus wallichiana	–	–	–	–	–	–	3	2	15
Populus ciliata	8	0	0	–	–	–	–	–	–
Pyrus pashia	–	–	–	8	13	0	–	–	–
Quercus floribunda	–	–	–	53	35	80	10	8	25
Quercus glauca	3	0	0	–	–	–	–	–	–
Quercus leucotrichophora	–	–	–	110	87	65	2.5	5	0
Rhamnus triquetra	5	5	0	–	–	–	–	–	–
Rhododendron arboreum	–	–	–	45	51	20	5	4	10
Symplocos paniculata	–	–	–	8	0	0	5	0	0
Toona ciliata	5	0	0	–	–	–	–	–	–
Viburnum cotinifolium	–	–	–	9	25	0	2.5	0	0
Wendlandia puberula	10	12	0	–	–	–	–	–	–

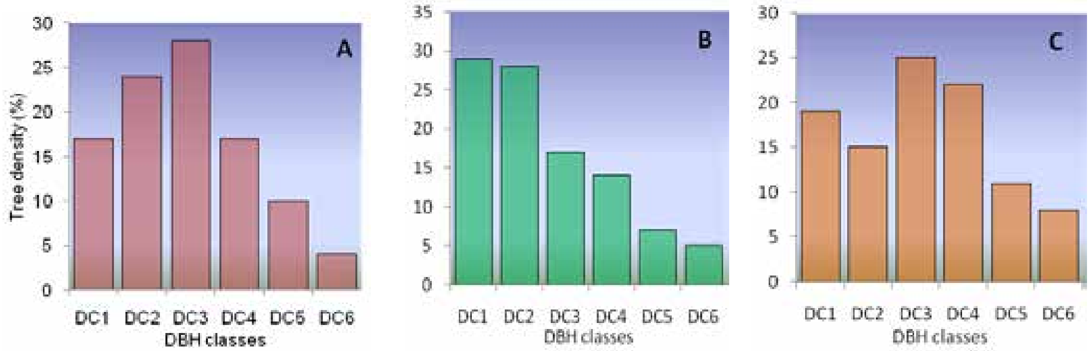

Figure 5. Distribution of tree individuals into different size classes; (A) Site PF, (B) Site POF and (C) Site DF

tree individuals are more in comparisons to mature tree individuals hence archives good or satisfactory regeneration status. The higher tree individuals in middle DBH classes at PF and DF indicating low conversion of younger tree individuals into mature ones in comparison to earlier time hence to future tree community may vary with those of the existing at present study.

3.6. Regeneration potential

The future composition of forests depends on the regeneration potential of existing tree species (Saxena & Singh, 1982). The low tree and shrub density and highest lopped and cut tree density in and around villages is the result of human dependency on forest. Human interference causes great impact on forest regeneration structure (Tyser & Worley, 1992). Vegetation composition of two watersheds areas of Kumoan Himalayas (Ahmed & Khan, 2020). At PF, *Quercus glauca*, *Toona ciliata* and *Populus ciliata* were recorded at adult form (CBH > 31.5 cm) only (not regeneration status). Poor regeneration status was shown by *Bauhinia variegate*, *Rhamnus triquetra* and *Wendlandia puberula* while rest of species represented good (*Coriaria napalensis* and *Mallotus philippensis*) and fair regeneration status (*Pinus roxburghii*, *Erythrina variegata* and *Engelhardia spicata*). Majority of tree species showed fair or good regeneration status at POF. *Cornus macrophylla*, *Pyrus pashia* and *Viburnum cotinifolium* showed poor regeneration status while *Cinnamomum tamala*, *Juglans regia* and *Symplocos paniculata* were observed at mature stage only (not regeneration status). Different tree species show different regeneration status at different forests due to natural or anthropogenic factors (Table 4). Species with good regeneration status will also represent the future community of the forests while poor and not regenerating species may disappear from the particular forests in future.

Table 4. Regeneration status of tree species in the different forest types (Kotla watershed)

Sr. No	Name of tree species	Family	PF	POF	DF
1.	*Alnus nitida* (Spach) Endl.	Betulaceae	–	Good	–
2.	*Bauhinia variegata* L.	Fabaceae	Poor	–	–
3.	*Cedrus deodara* (Roxb. ex D.Don) G.Don	Pinaceae	–	Fair	Fair
4.	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & C.H.Eberm.	Lauraceae	–	Not	–
5.	*Coriaria napalensis* Wall.	Coriariaceae	Good	Good	–
6.	*Cornus macrophylla* Wall.	Cornaceae	–	Poor	–
7.	*Cupressus torulosa* D.Don ex Lamb.	Cupressaceae	–	–	Not
8.	*Engelhardia spicata* Lechen ex Blume	Juglandaceae	Fair	–	–
9.	*Erythrina variegata* L.	Fabaceae	Fair	–	–
10.	*Ficus semicordata* Buch.-Ham. ex Sm.	Moraceae	Poor	–	–
11.	*Ilex dipyrena* Wall.	Aquifoliaceae	–	Good	Fair
12.	*Juglans regia* L.	Juglandaceae	–	Not	–
13.	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	Good	–	–
14.	*Lyonia ovalifolia* (Wall.) Drude	Ericaceae	–	Good	Good
15.	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae	Good	–	–
16.	*Pinus roxburghii* Sarg.	Pinaceae	Fair	Good	Poor
17.	*Pinus wallichiana* A.B.Jacks.	Pinaceae	–	–	Fair
18.	*Populus ciliata* Wall. ex Royle	Salicaceae	Not	–	–
19.	*Pyrus pashia* Buch.-Ham. ex D.Don	Rosaceae	–	Poor	–
20.	*Quercus floribunda* Lindl. ex A.Camus	Fagaceae	–	Fair	Fair
21.	*Quercus glauca* Thunb.	Fagaceae	Not	–	–
22.	*Quercus leucotrichophora* A.Camus	Fagaceae	–	Fair	Poor
23.	*Rhamnus triquetra* (Wall.) Brandis	Rhamnaceae	Poor	–	–
24.	*Rhododendron arboreum* Sm.	Ericaceae	–	Fair	Fair
25.	*Symplocos paniculata* (Thunb.) Miq.	Symplocaceae	–	Not	Not
26.	*Toona ciliata* M.Roem.	Meliaceae	Not	–	–
27.	*Viburnum cotinifolium* D.Don	Viburnaceae	–	Poor	Not
28.	*Wendlandia puberula* DC.	Rubiaceae	Poor	–	–

4. Conclusion

Assessment of diversity and regeneration status of tree species is important for their sustainable utilization, management, and conservation (Rawat et al., 2018b). This study concluded that dominant or pure conifer forests (*Cedrus deodara* forest, *Pinus roxburghii* forest) show poorer diversity in comparison to conifer mixed forest (POF). The overall regeneration status of the forests in the area was fair. The present study provides a deeper understanding of tree diversity pattern and regeneration status from a pocket of IHR.

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