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Seedling dynamics and community forecast for disturbed forests of the Western Himalayas: a multivariate analysis

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Abstract: The present study focuses on the forest structure of highly disturbed sites in Western Himalayan regions in Pakistan. In this study, the regeneration potential of conifer species is a key point for the assessment of future conifer status in disturbed environment by employing multivariate techniques. The forests are composed of four conifer species *Pinus wallichiana* A. B. Jacks, *Pinus roxburghii* Sarg., *Cedrus deodara* (Roxb.) G. Don, and *Abies pindrow* (Royle ex D. Don) Royle., associated with broadleaved species *Quercus baloot* Griffith, *Quercus dilatata Raf.*, and *Aesculus indica* (Wall. ex Cambess.) Hook. Cluster analysis shows five groups when *Pinus wallichiana* (PW) forms the largest group, incorporates with other conifers and broadleaved species and in some cases it overlaps with its subgroups forming a pure larger group. Similarly in DCA (ordination) overlapping exists in all the axes while elevation is the only variable that shows a highly significant ($P < 0.001$) correlation with conifers. *Cedrus deodara* (CD) with *Quercus baloot* (QB) and *Aesculus indica* (AI) shares a significant ($P < 0.05$) correlation in the same habitat while there is no correlation between the remaining conifers. It is anticipated that overlapping in cluster analysis and ordination and non-significant correlations in cluster analysis and ordination are due to the highly disturbed nature of the sites. It is also suggested that seedling recruitment and development are highly affected due to the anthropogenic disturbance. Therefore, proper maintenance of the forest, proper management and conservational practice should be imposed.

Keywords: cluster analysis; correlation; DCA ordination; conifer regeneration; canonical correspondence analysis (CCA)

Forests are considered as the repositories of biological diversity and a pool of natural biota. Today's forests are under pressure of the increasing human population worldwide (Hladnik et al. 2020). This has brought a tremendous influence on forest structure and has become crucial to understand and identify forest responses against environmental variability (Woods et al. 2000; Uriarte et al. 2004; Uzoh et al. 2012). Changing forest dynamics can be effectively understood by studying the plant community composition that could be a fundamental resultant of changes in ecological processes of a habitat (Uzoh et al. 2012). The environmental resources act as limiting factors that influence the co-existence of species (Grubb 1977) while species occurrence in patches in the spatial distribution is an indication of disturbance (Denslow 1985). Therefore, in disturbed forests, the structure of overstorey dynamically affects the understorey community composition and determines their distribution over a scale of light, temperature and other available resources (Gilliam and Roberts 2003; Mou et al. 1993 & 2005). According to Juřička et al. (2019); Mou et al. (2005) and Lkhagvadorj et al. (2013) successful regeneration of forest key species can be implemented by providing maximum opportunities that can maintain sustainable development in a forest ecosystem. There are studies addressing deforestation and disturbance in forests like those by Juřička et al. (2019); Mou et al. (2005); Hladnik et al. (2020);

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Kelling et al. (2019); Ma et al. (2016) contributed to the knowledge of various forest problems at present. Hladnik et al. (2020) claims unnatural causes like urbanization, agriculture and frequently present livestock in the forest to be the governing reason that has created abiotic and biotic stress and breakage in the ecosystem chain.

Conifers are the dominantly and widely distributed forest species all over the world. Ahmed (1984) mentioned the deteriorating condition of coniferous forests in northern areas of Pakistan. Some studies (Khan et al. 2018a, 2018b, 2020) claim a considerable loss in vegetation and forest cover due to anthropogenic activities. Disturbances and loss of species in forests of Pakistan were reported by many authors like Siddiqui et al. (2013); Ahmed et al. (2009); Khan and Ahmed (2019) but no study has been focused on seedling development and its effect in highly disturbed forests of Pakistan. The future trend of these forests can be estimated by employing multivariate techniques considered as a useful tool for the community structure analysis. Seedling dynamics provides fundamental knowledge of forest response and comprehensive assessment of conifer regeneration in future (Khan 2019). In the present study, our focus is to determine the future forest structure on the basis of current seedling density, specifically conifer seedlings in association with broadleaved species dominating in our sampled disturbed forest. The main objective of this study is the future assessment of a regeneration potential of disturbed forest in moist temperate areas of Murree. The study has been conducted in Pakistan's most famous Murree hills lying at the Himalayan region, extremely prone to human interference for expanding human population and tourism development.

MATERIAL AND METHODS

The study was conducted in Pakistan's famous tourist hill station called Murree, located in the west of the Himalayan Mountains (Figure 1). The studied area is located at 1 636 m to 2 672 m above sea level, on north and south facing slopes of a moist temperate forest with an average annual rainfall of 1,904 mm. Coldest month is January with 1.8 °C minimum temperature while hottest month is June with 25 °C, monsoon season begins from the end of June and lasts over the month of August. Sampling was carried out by plotting thirty quadrates at different disturbed sites following Ahmed and Shaukat (2012). Selection of sites aiming at the disturbance level was visually observed, where the frequency of livestock and humans, logged trees, human activities like construction of roads and buildings and other agricultural activities could be seen. In thirty disturbed sites, one quadrate

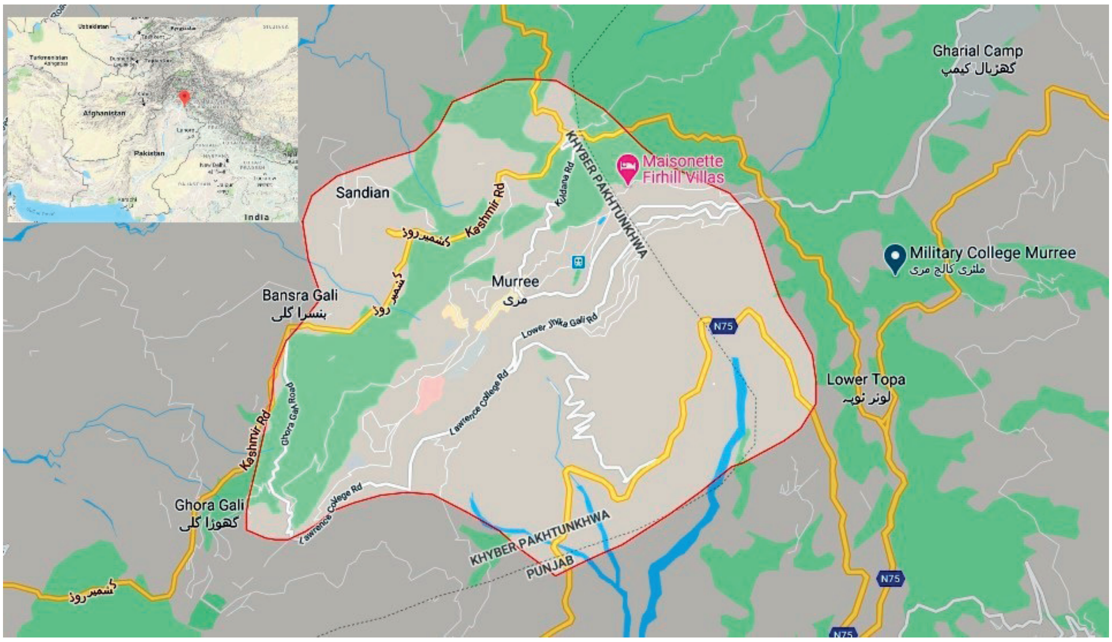

Figure 1. Present map of the study area

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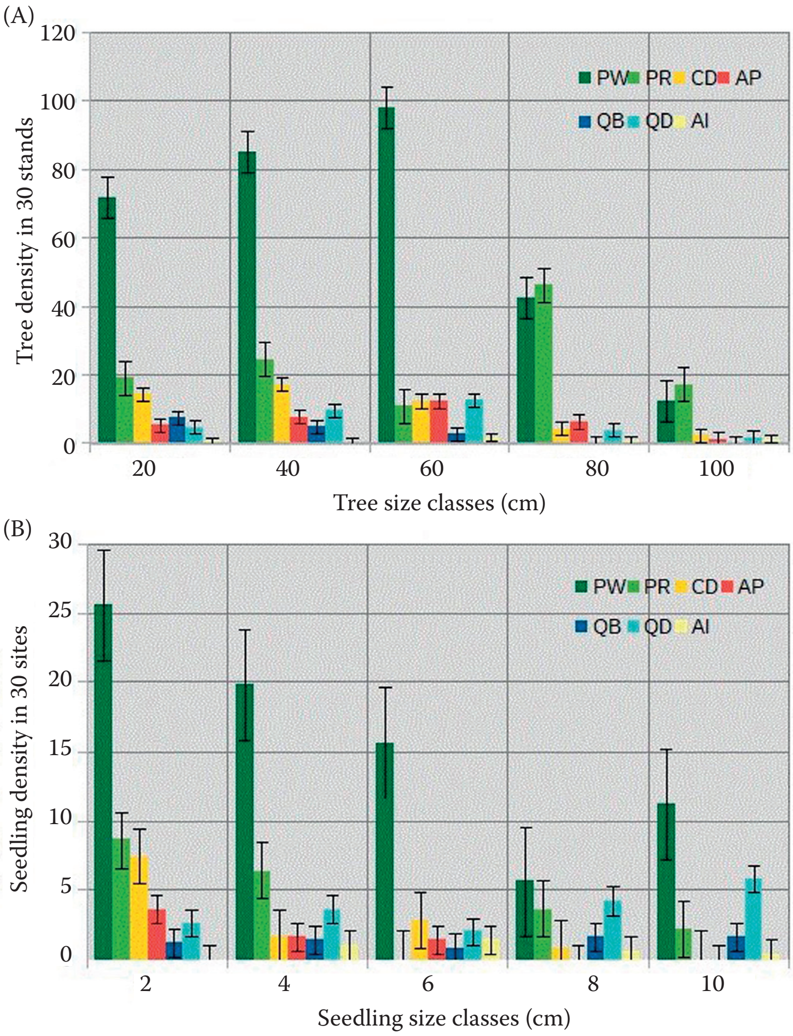

Figure 2. Density of conifer and broadleaved trees in the respective size classes obtained from thirty stands in the disturbed sites (A), conifer and broadleaved species seedling density in diameter size classes (B)

PW – *Pinus wallichiana*, CD – *Cedrus deodara*, AP –*Abies pindrow*, PR – *Pinus roxburghii*, QB – *Quercus baloot*, QD – *Quercus dilatata*, AI – *Aesculus indica*

(100 × 100 m) was used in each site for trees and ten circular plots of 1.5 m radius to record seedling density, diameter at breast height (DBH) and frequency. Recorded sizes of trees were arranged at an interval of 20 cm diameter, *i.e.,* 20, 40, 60, 80 and 100 cm (Figure 2A). The classification of seedlings with respect to their DBH was also arranged at an interval of 2 cm DBH, *i.e.,* 2, 4, 6, 8 and 10 cm (Figure 2B) following Ahmed (1984). Soil samples were taken from each of the thirty stands, from a depth of 10 cm by using an auger for identification of physiochemical properties. HANNA HI98194 Multiparameter (Singapore) was used to detect dissolved oxygen (DO), oxidation-reduction potential (ORP), temperature, salinity, pH, total dissolved salts (TDS) while atomic absorption was used for detection of potassium and sodium ions. The Kjeldahl method was used for nitrogen detection (Bremner 1960), phosphorus estimation was done according to Fog and Wilkinson (1958) using a colorimeter. GPS was used to record topography of the sites. Maximum water-holding capacity (MWHC) was detected according to USDA (1951) and soil organic matter (OM) was evaluated by burning soil in an incubator at 400 °C. Density and frequency of conifers were recorded and analysed by using MINITAB version 17 and R Studio version 3.0. and PCORD version 5.0 for multivariate outputs.

RESULTS

The sampling area is presented in Figure 1, from which four conifer species *Pinus wallichiana* (PW), *Pinus roxburghii* (PR), *Cedrus deodara* (CD) and *Abies pindrow* (AP) were identified with co-associated broadleaved species *Quercus baloot* (QB), *Quercus dilatata* (QD) and *Aesculus indica* (AI). Tree and seedling density per hectare in the studied sites was recorded (Figure 2A, B). The highest mean density was occupied by *Pinus wallichiana* (309 ± 6)

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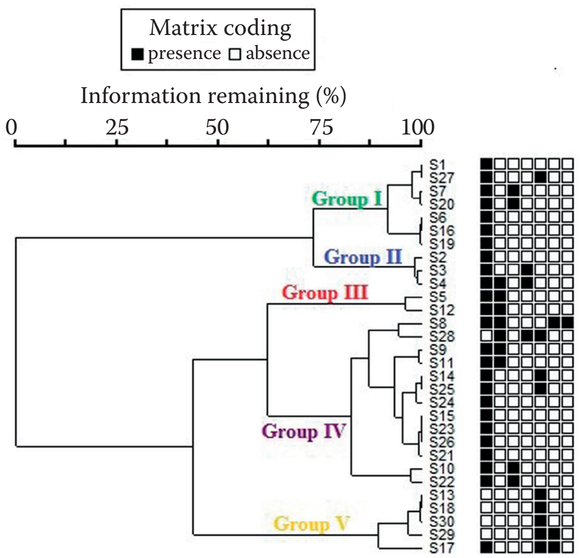

Figure 3. Cluster dendrogram of seedling density in thirty sites

and the second highest by *Pinus roxburghii* (118 ± 5) while *Cedrus deodara* and *Abies pindrow* had the lowest number of trees, *i.e.* 50 ± 2 and 32 ± 2, respectively. *Pinus wallichiana* was leading with the highest mean seedling density in all size classes, *i.e.* 26 ± 4, 20 ± 2, 16 ± 2, 6 ± 1 and 11 ± 1 in 2-, 4-, 6-, 8- and 10-cm size classes, respectively. The remaining conifer species were found in 2- to 6-cm classes while the density and frequency of conifers declined in higher classes that showed a low number of seedlings with larger diameter (Figure 2B).

Seedling cluster

A dendrogram obtained from Ward's cluster analysis elaborated the remaining 50% information which was produced from 3.5×10^4 Euclidean distance based on the seedling density (Figure 3) of conifer species along with three dominant broadleaved species in the sampled area. Five groups were produced. The largest Group I consisted of *Pinus wallichiana* separated from the other tree species showing its integrity across the whole study area over the other species. Group II was composed of *Cedrus deodara, Abies pindrow* and *Quercus baloot* showing the flexible association of *Quercus baloot* with *Cedrus deodara* and *Abies pindrow* whilst in Group III *Quercus dilatata* and *Aesculus indica* were separated due to their occasional occurrence in stands. Group IV was well separated from the rest of the groups, it was also a single species group of *Pinus roxburghii,* which was present only in an ecotone zone and its habitat (subtropical) was different from other conifers of the moist temperate zone.

Clustered conifer seedling density is explained in Table 1, in addition, a seedling density relationship with environment is further explained in Table 2. Mean seedling density of *Pinus wallichiana* was highest in Group II (37 ± 1.7 seedlings·ha^{-1}) while *Cedrus deodara* attained a higher position in Group III (20.5 ± 0.5 seedlings·ha^{-1}). *Abies pindrow* and *Pinus roxburghii* showed the highest density in Group IV (12 ± 3 seedlings·ha^{-1}) and Group V (16.2 ± 2.5 seedlings·ha^{-1}), respectively. *Quercus baloot* seedlings appeared in Group II and III, when the highest density was found in Group II (4 ± 2 seedlings·ha^{-1}). *Quercus dilatata* was frequent in Group IV and V, it showed higher density in Group V (5 ± 0 seedlings·ha^{-1}). *Aesculus indica* seedlings were placed in Group IV with 2 ± 0 seedlings·ha^{-1}.

As presented in Table 2, five groups were produced and the tabulation was made in accordance with environmental variables including edaphic, topographic variables and soil nutrients. Among edaphic variables pH (8.5 ± 3.5) and OM (8.35 ± 0.55%) were found highest in Group III, whereas TDS (226 ± 60.2 mg·L^{-1}), conductivity (0.57 ± 0.20 μ·cm^{-1}) and salinity (0.25 ± 0.1 PSU) were highest in Group II. The ORP value of 53 ± 3.71 mV was highest in Group V. MWHC 38 ± 4.15% and 38 ± 3.1% was highest in Group I and V, respectively. Soil nutrients shown in the table had higher values of phosphorus and sodium in Group V (2.23 ± 0.14 mg·gm^{-1} and 0.99 ± 0.2 mg·gm^{-1}, respectively) while higher levels of potassium and nitrogen were

Table 1. Mean density·ha^{-1} of seedlings in five groups of cluster analysis

Conifer species	Group				
	I	II	III	IV	V
PW	21 ± 1.6	37 ± 1.7	12.5 ± 4.5	8.25 ± 1	8 ± 0
CD	0	3 ± 0	20.5 ± 0.5	4.75 ± 1.4	0
AP	4.5 ± 0.5	0	0	12 ± 3	0
PR	2 ± 0	0	0	5 ± 0	16.2 ± 2.5
QB	0	4 ± 2	5 ± 0	0	0
QD	0	0	0	5 ± 0	2.5 ± 1.5
AI	0	0	0	2 ± 0	0

PW – *Pinus wallichiana*, CD – *Cedrus deodara*, AP –*Abies pindrow*, PR – *Pinus roxburghii*, QB – *Quercus baloot*, QD – *Quercus dilatata*, AI – *Aesculus indica*

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Table 2. Mean values of edaphic, topographic variables and soil nutrients in five groups of the seedling cluster analysis

Variables	Group I	Group II	Group III	Group IV	Group V
Topographic variable:					
Elevation **(m)**	2 131 ± 145	2 131 ± 57	2 229 ± 100	2 035 ± 82	1 843 ± 25
Edaphic variables					
pH	7.68 ± 0.1	7.41 ± 0.23	8.5 ± 3.5	7.72 ± 0.08	7.61 ± 0.05
TDS (mg·L^{-1})	199 ± 31.35	226 ± 60.2	189 ± 33	171 ± 13.44	192 ± 20.20
Conductivity (μ·cm^{-1})	0.47 ± 0.1	0.57 ± 0.20	0.41 ± 0.07	0.36 ± 0.03	0.33 ± 0.06
Salinity (PSU)	0.14 ± 0.02	0.25 ± 0.1	0.18 ± 0.03	0.16 ± 0.01	0.16 ± 0.02
ORP (mV)	30.04 ± 11.61	41 ± 13.78	22.95 ± 23.35	48 ± 2.71	53 ± 3.71
OM (%)	7.21 ± 0.53	7.12 ± 0.15	8.35 ± 0.55	7.15 ± 0.24	7.52 ± 0.32
MWHC (%)	38 ± 4.15	34 ± 6.6	34.5 ± 10.5	29.69 ± 1.81	38 ± 3.1
Soil nutrients					
P (mg·gm^{-1})	0.31 ± 0.04	0.44 ± 0	1.25 ± 0.83	1.27 ± 0.23	2.23 ± 0.14
K (mg·gm^{-1})	1.97 ± 0.28	0.16 ± 0.03	0.66 ± 0.15	1.3 ± 0.14	0.91 ± 0.11
Na (mg·gm^{-1})	0.76 ± 0.14	0.14 ± 0	0.64 ± 0.51	0.68 ± 0.12	0.99 ± 0.2
N (%)	0.88 ± 0.19	0.31 ± 0.05	0.43 ± 0.11	0.34 ± 0.06	0.4 ± 0.06
Seedling density·ha^{-1}	22.57 ± 1.11	40.66 ± 3	33 ± 5	13 ± 1.1	18.8 ± 4.2

TDS – Total Dissolved Salts, ORP – Oxidation-Reduction Potential, OM – Organic Matter, MWHC – Maximum Wate-Holding Capacity, P –Phosphorus, K – Potassium, Na – Sodium, N – Nitrogen.

present in Group I (1.97 ± 0.28 mg·gm^{-1} and 0.88 ± 0.19%, respectively). A topographic element that was represented by elevation showed the highest value in Group III: 2 229 ± 100 m.

Seedling ordination

DCA ordination results from thirty stands in the study area are represented in Figure 4A-C. Seedlings of conifers and associated broadleaf tree species which were dominant in the area were recorded for further examination. Figure 4 shows a continuous distribution pattern drawn in a two-dimensional ordination plane. Five main groups were obtained from Ward's cluster analysis which was then applied on DCA ordination. There was overlapping on some axes among the stands. All five groups showed clear separation between them on axis 1 and 2 while on axis 1 and 3 there was frequent overlapping in the stands indicating a greater extent of disturbance on axis 2 and 3.

Pinus wallichiana was the only species that was present in all five groups when Group I and II were groups dominated by *Pinus wallichiana* and very few seedlings of other species present were there. *Cedrus deodara* was present in a dominant proportion in Group III while *Abies pindrow* was dominant in Group IV. *Pinus roxbhurgii* was found dominant in Group V where the associated broadleaf tree species were present at lower density at a seedling level as *Quercus baloot, Quercus dilatata* and *Aesculus indica* were poorly represented in the area.

The correlations obtained from seedling ordination with the environmental variables on three axes mostly produced non-significant relationships (Table 3). Among all other variables, elevation was the only variable that possessed a highly significant ($P < 0.001$) correlation with axis 1. On the basis of presently existing conifer and broadleaf species seedlings in the disturbed sampled sites, a strongly negative correlation was seen between pines (Figure 5). However, all four conifers did not show any correlation with each other. Whereas the broadleaved species can be expected to form communities with conifers as they appeared in a positive relationship with *Cedrus deodara* and a strongly positive relationship between *Quercus dilatata* and *Aesculus indica* would also be expected to form a successful community in future.

Canonical correspondence analysis (CCA)

Canonical correspondence analysis was used to develop a close insight into the relationship of tree species seedlings with the environmental complex

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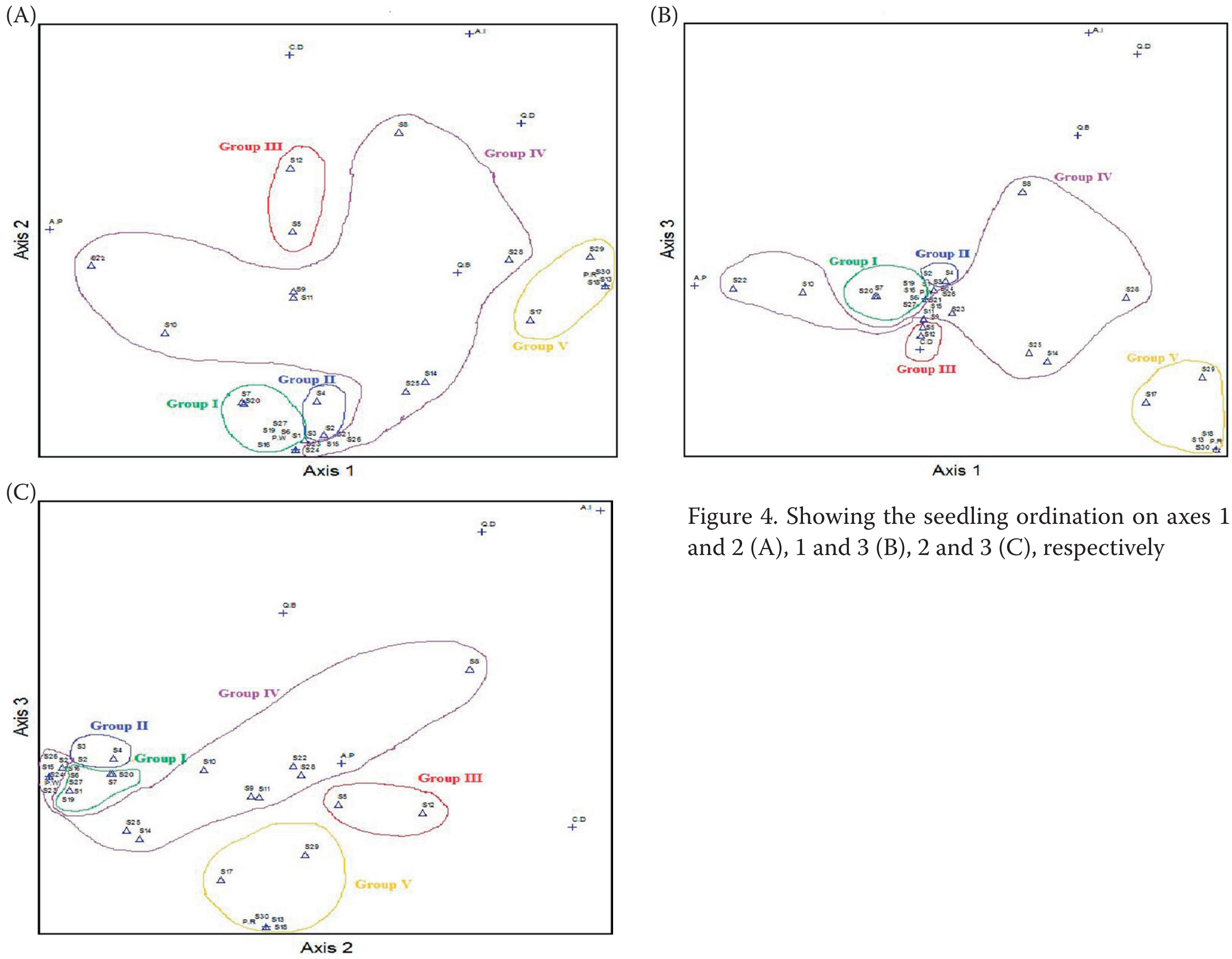

Figure 4. Showing the seedling ordination on axes 1 and 2 (A), 1 and 3 (B), 2 and 3 (C), respectively

Table 3. Correlation coefficients (*r*) and environmental relationships, i.e. topographic, edaphic variables and soil nutrients, with three axes of seedling ordination

No.	Variables	Axis 1 *r*	Axis 1 *P*	Axis 2 *r*	Axis 2 *P*	Axis 3 *r*	Axis 3 *P*
Topographic							
1.	Elevation (ft)	0.47	P < 0.001	0.18	ns	0.23	ns
Edaphic variables							
1.	pH	0.06	ns	0.21	ns	0.18	ns
2.	TDS ($mg \cdot L^{-1}$)	0.03	ns	0.27	ns	0.1	ns
3.	Conductivity ($mg \cdot gm^{-1}$)	0.17	ns	0.29	ns	0.06	ns
4.	Salinity (PSU)	0.08	ns	0.16	ns	0.03	ns
5.	ORP (mV)	0.27	ns	0.14	ns	0.17	ns
6.	OM (%)	0.21	ns	0.11	ns	0.00	ns
7.	MWHC (%)	0.21	ns	0.03	ns	0.22	ns
Soil nutrients							
1.	Nitrogen (%)	0.18	ns	0.15	ns	0.21	ns
2.	Phosphorus ($mg \cdot gm^{-1}$)	0.22	ns	0.19	ns	0.21	ns
3.	Potassium ($mg \cdot gm^{-1}$)	0.15	ns	0.15	ns	0.12	ns
4.	Sodium ($mg \cdot gm^{-1}$)	0.11	ns	0.03	ns	0.04	ns

TDS – Total Dissolved Salts, ORP – Oxidation-Reduction Potential, OM – Organic Matter, MWHC – Maximum Water-Holding Capacity, P – probability level, ns – non-significant

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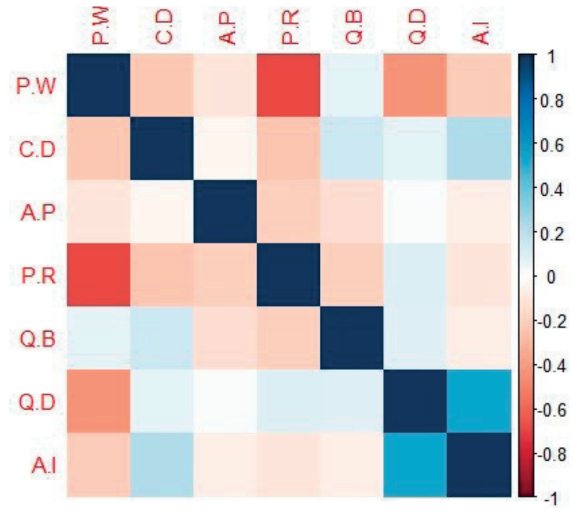

Figure 5. Correlations between seedlings of dominantly occurring tree species in the study area.

PW – *Pinus wallichiana*, CD – *Cedrus deodara*, AP –*Abies pindrow*, PR – *Pinus roxburghii*, QB – *Quercus baloot*, QD – *Quercus dilatata*, AI – *Aesculus indica*

imposed in the disturbed forest (Økland and Eilertsen 1994). The dominating environmental factors on axis 1 were certainly elevation and potassium (K^+) ions while the other coherent factors (OM, MWHC and *Cedrus deodara* seedlings) significantly ($P < 0.05$) influenced axis 1 (Table 4). Axis 2 was dominated by elevation and OM ($P < 0.001$) and co-dominated by *Quercus dilatata*, *Aesculus indica* and salinity ($P < 0.01$). Both the axes showed a strongly positive correlation with elevation while conductivity, dissolved oxygen and salinity occupied a weakly positive correlation on axis 1. The other variables showed no correlation with each other or species whereas the oxidation-reduction potential (ORP) was evaluated as a strongly negative variable in the environment. The CCA model featured mismanagement of the environmental resources and declination of conifers in the area. A highly significant ($P < 0.001$) relationship was obtained for broadleaf species with the environment claiming the susceptibility of replacement of conifers in the future as these broadleaved species bear a higher degree of tolerance against disturbance as shown in Table 4 and Figure 6.

DISCUSSION

Forest management is necessary for the conservation of biodiversity, forest ecosystem and climatic sustainability. For development of forest management strategies, we employed seedlings as an ecological tool for prediction of the future forest community. Seedlings are the indication of forest regeneration that can define the vegetation type in future. The present study was aimed at the identification of the condition of conifers as there was a higher degree of human interference like logging, construction and agricultural activities as well as presence of livestock. Collectively, it resulted in lowering of soil productive capabilities, destruction of older trees and loss of seedlings by grazing pressure. As our results showed, early seedling stages contain relatively greater density of pines. Greater size classes showed only *Pinus wallichiana* and *Pinus roxburghii* seedlings in a considerable number whereas a very poor density and frequency of *Cedrus deodara* and *Abies pindrow* seemingly close to decline from the stands was revealed. Juřička et al. (2019) experienced low density in greater diameter classes from grazing sites.

Khishigjargal et al. (2013) considered seedling and sapling establishment to be the most crucial step due to interspecific and intraspecific resource competition, in addition to which having escaped

Table 4. Species-environment relationship scores, variance (%) and significance factor from CCA

Axis	Eigenvalue	Variance (%)	Variable	Correlation with axis 1	Variable	Correlation with axis 2
1	0.43053	43.87	CD	$P < (0.05)$	QD**	$P < (0.01)$
2	0.24627	25.1	OM	$P < (0.1)$	AI**	$P < (0.01)$
3	0.17912	18.25	MWHC	$P < (0.05)$	OM***	$P < (0.001)$
4	0.06584	6.71	P	$P < (0.05)$	K	$P < (0.05)$
5	0.052287	5.33	K**	$P < (0.01)$	Salinity**	$P < (0.01)$
6	0.0072427	0.74	Elevation***	$P < (0.001)$	Elevation***	$P < (0.001)$

**$P < (0.01)$, ***$P < (0.001)$, CD – *Cedrus deodara*, QD – *Quercus dilatata*, OM – Organic Matter, AI – *Aesculus indica*, MWHC – Maximum Water-Holding Capacity, P –Phosphorus, K – Potassium

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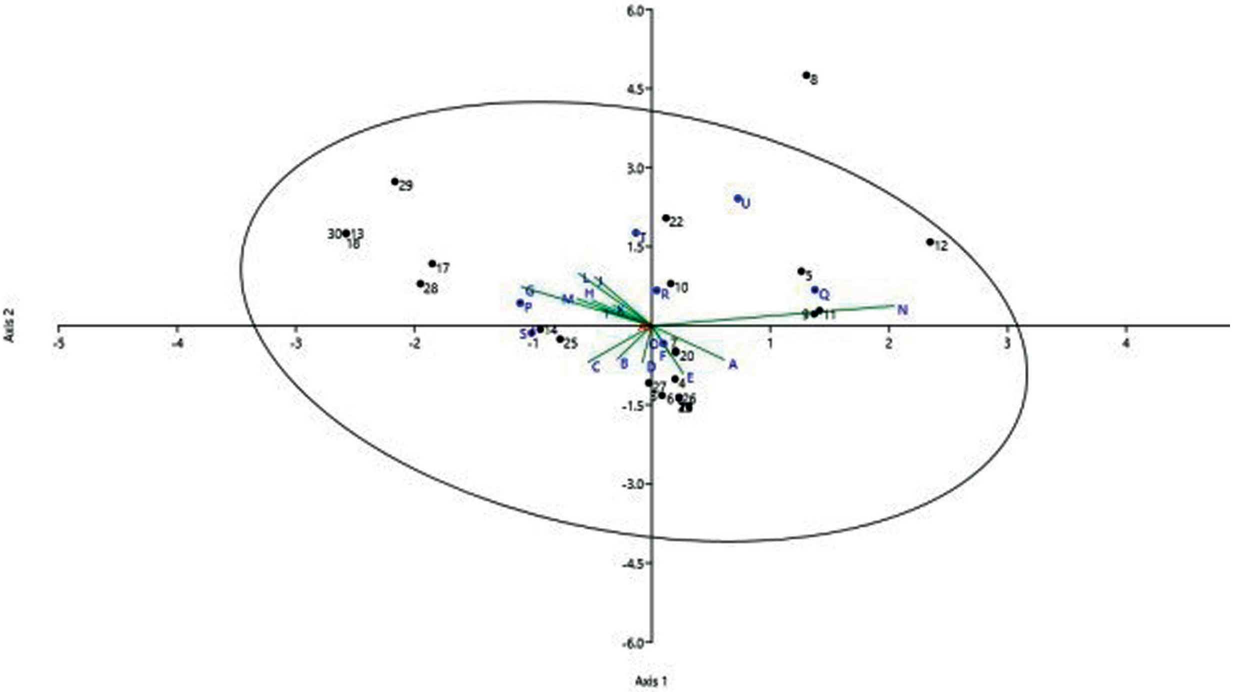

Figure 6. Scatter plot showing the coherence of tree species seedlings and environmental variables in a two-dimensional symmetry

from grazing animals has become another task for seedlings to survive (GIZ 2016). GIZ (2016) and (Ludwig et al. 2014) recorded a low number of seedlings/saplings with the poor rate of increase in height from disturbed sites in Mongolian forest, considered it as result of open canopy in the forest as the seedlings are sensitive to direct light so they could not be able to tolerate direct exposure to light. Nevertheless, the protected sites in Mongolia were undamaged (GIZ 2016). Juřička et al. (2018) found mature trees in good health in disturbed forests of Northern Mongolia. Murree sites have statistically indicated the poor condition of soil environment. Even though the forests lie in the moist temperate zone, the moisture and nutrient content of soil was not sufficient to support forest vegetation. Moisture content determines the health of the forest (Dulamsuren et al. 2009; Yang et al. 2006), serves as a limiting factor for vegetation distribution and forest structure (Anenkhonov et al. 2015). In our sites, soil moisture and nutrients were greatly influenced and destructed due to construction and overgrazing in these areas. Therefore, only the elevation was correlated positively with conifer species density. Stress was observed among conifer seedlings and no correlation was observed among them but they positively correlated with broadleaved species indicating a possibility of mixed conifer-broadleaved community in future. The non-correlated relationship among conifer seedlings might be due to interspecific competition in an environment with limited resource availability (Khan 2019). The analysis showed a probability of successful community formation between conifers and broadleaved species rather than a pure conifer forest. A wider range of tolerance limits in *Pinus wallichiana* permitted the pine to be successfully distributed throughout the forest under disturbance. *Pinus roxburghii* was the second most frequently found species throughout the stands at a lower elevation in the subtropical zone and maintained its existence in a highly disturbed environment. *Cedrus deodara* and *Abies pindrow* were subjected to severe logging as observed in the studied sites, hence they were found in the most vulnerable condition in regard of regeneration. However, *Cedrus deodara* showed positive correlations with the environmental variables among the other conifers, indicating a greater degree of tolerance evaluated by CCA (Økland et al. 1994). Canonical correspondence analysis pro-

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vided useful information for the assessment of vegetation in accordance with environmental variables (Økland 1996).

Summarily, removal of older trees contributed to a low abundance of seeds and biological interference lowered the survival possibility of conifers in these forests, leading to the conifer regeneration in a vulnerable state. Therefore it is suggested to protect seedlings by reducing overgrazing, anthropogenic disturbance, removing invasive weeds that increase competition as well as inhibition to seedling regeneration and increasing plant cover in these forests. It is also predicted that conifer seedlings would regenerate if they were allowed to grow; the fact that they still survived in such a disturbed condition is an indication of their tolerance compatibility. A successful forest structure can be predicted with the associated broadleaf trees predominantly of *Quercus dilata* and *Aesculus indica.*

CONCLUSION

In the light of predefined results, the present seedling status of the studied forest is vulnerable, however, some conifers predominantly pines (*Pinus wallichiana* and *Pinus roxburghii)* are evenly distributed in their respective areas, *i.e.* tropical to moist temperate zones. Pines seemingly persisted under disturbance and therefore the seedlings were recruited fairly in the forest. The other inhabited conifers such as *Cedrus deodara* and *Abies pindrow,* which were codominated in the area for several past decades, are now diminishing from the forest as their regeneration state is lower than in other conifers. Current investigations recommend a serious conservation strategy to be implemented in the forest for future existence of conifers, as they are in need for the sustainability of forest structure and natural vegetation diversity.

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