RESEARCH ARTICLE

Regeneration Problem in *Cedrus deodara* (Roxb.) G. Don Dominated Forests of Kumaun Himalayan Region

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Abstract

Regeneration is essential for the survival and maintaining the composition of the forest species. This study investigates the regeneration status of *Cedrus deodara* across six forest sites in the Kumaun Himalaya at elevations ranging from 1600 to 2400 masl. At lower elevations (1600–2000 masl), the total tree density of *C. deodara* ranged from 606.67 to 786.67 ind ha^{-1}, showing fair regeneration with 13.33 to 160 ind ha^{-1} seedling density and 226.67 to 353.33 ind ha^{-1} sapling density. In contrast, at middle elevations (2000–2400 masl), the total tree density of *C. deodara* ranged from 586.67 to 660 ind ha^{-1} and showed poor regeneration. The absence of seedlings was conspicuous at middle elevations. Species richness was very low at lower elevations, as *C. deodara* formed pure patches, while middle elevations had higher tree richness but lower diversity and evenness. The absence of regeneration at middle elevations can be attributed to high anthropogenic activities. Significant human activities such as picnicking, overgrazing, and fuelwood extraction at middle elevations led to 0% regeneration, whereas sites with restricted human access at lower elevations showed better regeneration. These findings highlight the need for effective forest management and conservation strategies to ensure the sustainability and resilience of *C. deodara*-dominated forest stands.

Highlights

- Middle elevation sites showed 0% regeneration due to significant human-induced disturbances, i.e., picnicking, overgrazing, and fuelwood extraction.
- Only 33% of the studied sites exhibited fair regeneration, mainly at lower elevations with restricted human access.
- 66.67% of the sites had 0 seedling density of *C. deodara*, but the remaining sites showed higher seedling density (13.33-160 ind ha^{-1}).
- The total tree density and species diversity varied across the study sites, indicating different regeneration success across regions.
- Climatic irregularities and human disturbances significantly impacted the regeneration of *C. deodara*, with irregular good seed years affecting higher elevations.

Keywords: *Cedrus deodara*, Density, Diversity, Regeneration, Vegetation

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Introduction

Regeneration is an essential process for a species to survive in a community under a variety of environmental situations, as it keeps the intended species composition and stocking (Khumbongmayum *et al*., 2005; Malik and Bhatt, 2016). The future composition of forests within a stand in space and time is frequently represented by the potential regeneration status of tree species (Henle *et al*., 2004). Any species that regenerates is limited to a specific range of habitat conditions, and the degree to which those circumstances exist is a key factor in determining the species' geographic spread (Pokhriyal *et al*., 2010; Singh *et al*., 2016). Tree species' capacity for successful regeneration depends on the survival and growth of their seedlings and saplings (Singh *et al*., 2016).

A species' regeneration behavior inside a forest can be inferred from its population structure (Pokhriyal *et al*., 2010). The presence of juvenile trees (saplings) under the canopies of mature trees indicates the potential future composition of the forest community (Quevedo-Rojas *et al*., 2015). The population structure, characterized by a sufficient number of seedlings, saplings, and adult trees, serves as an indicator of successful forest species regeneration (Bagri *et al*., 2023). The age distribution of a tree's population can be used to forecast its regeneration status (Tripathi and Khan, 2007). The process of silvigenesis, known as regeneration, is how forests and trees endure over time (Bhuyan *et al*., 2003).

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Cedrus deodara, a gregarious coniferous species, generally grows in pure stands and is distributed throughout the Western Himalayas, from Afghanistan to India. In India, it grows most commonly between 1800 and 2600 meters above sea level (masl) (Kumar *et al*., 2017, 2021). The species grows in dry temperate coniferous forests as well as in western mixed coniferous forests, where it associates with *Picea smithiana*, *Abies pindrow*, and *Pinus wallichiana* at higher altitudes. *Quercus* *leucotrichophora*, *Quercus floribunda*, *Quercus semecarpifolia*, and *Rhododendron arboreum* are broadleaved associates of *C. deodara* at lower sites (Sheikh *et al*., 2021). *A. pindrow* and *P. wallichiana* outcompete *C. deodara* because of the upward migration of *Pinus roxburghii* at higher heights (Pandey *et al*., 2023).

Research on the density and demographic structure of species can provide valuable insights into the ecological dynamics, historical management practices, and current status of species regeneration within forest ecosystems (Tesfaye *et al*., 2010; Gebeyehu *et al*., 2019). The distribution of species cohorts would exhibit a reverse J-shaped curve, indicating healthy or good regeneration if regeneration was occurring continually (Teketay, 2005; Gebeyehu *et al*., 2019). These population structures are typically found in natural forests where external stressors are minimized (Tesfaye *et al*., 2010; Gebeyehu *et al*., 2019).

Climate influences the distribution of plant species, their regenerative processes (Adler and Lambers, 2008), and the emergence of seedlings (Woodward and Williams, 1987). Climate change alone has an impact on ecological dynamics, which in turn has an impact on plant survival and growth (Fitch *et al*., 2007; Walck and Dixon, 2009; Baeten *et al*., 2010). Young seedlings are more prone to climate irregularities than adults. Climate change affects species' seedling dynamics by affecting seed germination and seed lifespan in soil banks. Variations in tree reproductive phenology, as a result of global climate change, can impact germination and stand development (Tewari *et al*., 2017). The Himalayan region exhibits a high susceptibility to the effects of global warming (Singh *et al*., 2010). Himalayan ecosystems are undergoing rapid changes, leading to regeneration challenges owing to the area's physical instability and environmental characteristics (Tewari *et al*., 2016; Pandey, 2023; Hussain *et al*., 2024).

One of the main ecological variables influencing the structure and functioning of forests is disturbance, whether it be natural or caused by humans (Gogoi and Sahoo, 2018). Human activity like deforestation, overgrazing, biomass extraction for fuel wood, and fodder collection causes extensive disruption (Kaur *et al*., 2017; Haq *et al*., 2019). These disturbances disrupt the stability of the ecosystem, causing irreversible changes in the dynamics, composition, and structure of the forest community. These changes may have an impact on existing regional hydrological and climate systems, which can lead to a sharp decline in species richness, increasing the frequency of biological invasions, and causing the loss of forest resources (Kumar and Ram, 2005; Millar and Stephenson, 2015; Haq *et al*., 2019).

The present study was conducted to investigate the regeneration status of *C. deodara* and the survival of naturally emerged seedlings along an altitudinal range from 1600 to 2400 masl elevation. By examining these aspects, the study aims to provide valuable insights into the future composition of *C. deodara* forests in the Kumaun region of the Uttarakhand Himalaya. This information is crucial for understanding the ongoing ecological processes and potential changes in forest structure and composition. The findings can be useful for forest management practices and conservation strategies, ensuring the sustainability and resilience of *C. deodara* forests in the face of environmental changes and anthropogenic pressures.

Material and Methods

Study site

Six *C. deodara*-dominated forests were selected for the study in the Kumaun Himalaya region between 1600 to 2400 masl. Three sites were located at the lower elevational range (1600–2000 masl) and three sites at the middle elevational range (2000–2400 masl). The Kumaun Himalaya extends over an area of 21,033 km^2 and lies between 28° 44'- 30° 49'N lats and 78° 45' to 85° 5'E longs along the eastern and southeastern part of Central Himalaya. The study sites were located in 4 districts of Kumaun, including Almora, Champawat, Nainital and Pithoragarh. (Table 1) (Fig. 1).

The average yearly temperature remains at approximately 13°C. June is the hottest month (18.3°C), and January is the coldest (6.4°C). The driest month is November (50 mm), and the wettest month is July (500 mm). The average annual rainfall is

Table 1: Brief description of study sites

Sites	*District*	*Lat/Long*	*Altitude (masl)*	*Elevational range*	*Dominated*	*Aspect*	*Dominated association*
Lohaghat (Site 01)	Champawat	29°23'41.5"/ 80°05'20.7"	1618	Lower	*C. deodara*	SW	Pure stand
Jageshwar (Site 02)	Almora	29°38'19.9"/ 79°51'23.9"	1886	Lower	*C. deodara*	SW	*Litsea umbrosa*
Chandak (Site 03)	Pithoragarh	29°36'15.1"/ 80°11'45.2"	1927	Lower	*C. deodara*	W	Pure stand
Camel's Back (Site 04)	Nainital	29°23'41.9"/ 79°26'05.8"	2306	Middle	*C. deodara*	N	*L. umbrosa*
Kunjakhadak (Site 05)	Nainital	29°29'19.9"/ 79°21'01.2"	2351	Middle	*C. deodara*	NE	*Q. floribunda*
Cheena Peak (Site 06)	Nainital	29°23'56.9"/ 79°26'12.3"	2360	Middle	*C. deodara*	S	*Q. floribunda*

***Note:** SW= South west, NE= North east, N= North, S= South and W= West

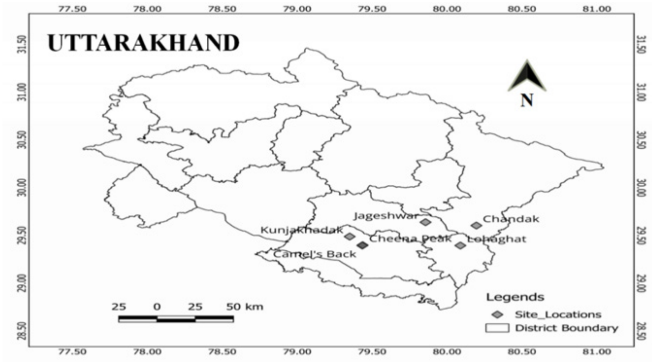

Fig. 1: Map of the study sites

approximately 1500 mm. The average monthly relative humidity falls between 46% in April and 93% in September. The average annual relative humidity is 65.9% (Dugesar *et al.,* 2022).

Vegetation analysis was carried out by placing 15 random quadrats of 10 x 10 m for trees (Misra 1968, Saxena and Singh, 1982) to assess the density and other vegetation parameters at each site (Fig. 2). The distribution pattern of different species was studied using the ratio of abundance to frequency (A/F) following Cottom and Curtis, 1956. This ratio indicates regular (less than 0.025), random (0.025–0.05) and contagious (more than 0.05) distribution of species. The total basal area, relative values of density, frequency and dominance were calculated by following Cottom and Curtis, 1956 and Phillips (1959) and IVI was calculated by following Curtis (1959). Diversity is measured as the number of species occurring within an area of a given size (Huston, 1994). The diversity index was calculated by using the Shannon-Weiner information index (Shannon-Weiner, 1963).

$$(H') = -\sum 3.322(N_i/N)\ \log_{10}(N_i/N)$$

Where N_i = Total number of individual species, N = Total number of individuals of all species

Simpson (1949) proposed for the first time a widely used index, which varies inversely with species heterogeneity and in fact, measures the concentration of dominance (Cd) and was calculated as:

$$Cd = (N_i/N)^2$$

Where N_i = total number of individuals of a species, N = total number of individuals of all species.

In order to understand the regeneration status of tree species, individuals were measured for circumference at breast height (cbh) with a girth measuring tape. At each site, all individuals were counted for each tree species by placing fifteen quadrats of 10x10 m in each site. In addition to seedling and sapling classes (Good and Good, 1972), one more class based on cbh recorded in the present study was arbitrarily established as follows: Seedling-Less than 5 cm cbh, Sapling 6 to 30 cm cbh and trees-above 30 cm From this information the total numbers of individuals belonging to above-mentioned size classes were calculated for dominated species in different sites. The density of each girth class was divided by the total density of all girth classes of that species. The resulting value was multiplied by 100 to yield relative density. The graph of regeneration was developed as the relative density was plotted against the corresponding girth class for each dominant species. The regeneration status of species was determined based on the population size of seedlings, saplings, and trees (Khan *et al.,* 1987) as:

(i) good regeneration if seedlings > saplings >adults;
(ii) fair regeneration if seedlings > or ≤saplings ≤ adults;
(iii) poor regeneration if the species survives only in the sapling stage, but no seedlings (saplings may be <, > or = adults).
(iv) no regeneration if a species is present only in adult form.
(v) new regeneration if the species has no adults but only seedlings or saplings.

Results

Phytosociological Studies

Lower elevation

The phytosociological studies were carried out at three different sites of *C. deodara*-dominated forests standing at lower elevations. The total forest density ranged between 606.67 and 786.67 ind ha^{-1}, which was minimum at site 02 and maximum at site 03. The total forest basal area (TBA) ranged between 44.04 m^2ha^{-1} and 103.46 m^2ha^{-1}, which was minimum at Site 02 and maximum at Site 03. The tree density of *C. deodara* was found to be minimum at site 02 (586.67 ind ha^{-1}) and maximum at site 03 (786.67 ind ha^{-1}). The TBA of *C. deodara* ranged between 44.04 to 103.46 $m^2\ ha^{-1}$. *C. deodara* was the dominant tree species and holds the highest IVI at all sites (Table 2). The sapling density of *C. deodara* ranged between 226.67 to 353.33 ind ha^{-1}, which was low at site 02 and high at site 04, and the TBA of saplings of *C. deodara* ranged between 0.76 to 0.79 $m^2\ ha^{-1}$, which was minimum at site 01 and maximum at site 02. The seedling density of *C. deodara* ranged between 13.33 to 160 ind ha^{-1} (Table 2).

Middle elevation

The phytosociological studies were carried out at three different sites of *C. deodara*-dominated forests standing at the middle elevation. The total forest density ranged between 586.67 and 660 ind ha^{-1}. The TBA ranged between 70.73 and 102.03 m^2ha^{-1}. The tree density of *C. deodara* was found to be minimum at site 04 (433.33 ind ha^{-1}) and maximum at site 05 (593.33 ind ha^{-1}). The TBA of *C. deodara* ranged between 60.69 to 96.01 $m^2\ ha^{-1}$. *C.*

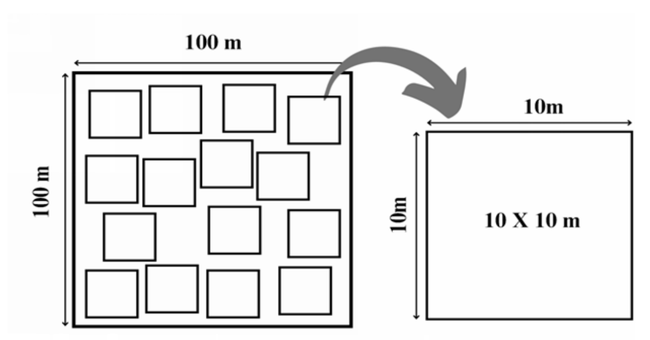

Fig. 2: Plot layout for tree vegetation analysis

Table 2: Vegetational analysis of tree, sapling, and seedling layers in forest stands of ***C. deodara***

Site	*Layer*	*D (ind ha^{-1})*	*F (%)*	*A/f ratio*	*Distribution*	*BA (m^2 ha^{-1})*	*IVI of dominant sp*
Lower elevation							
	Tree	660	100	0.07	Contagious	73.76	300
Site 01	Sapling	353.33	93.33	0.04	Random	0.76	300
	Seedling	160	46.67	0.07	Contagious	-	-
	Tree	586.67	100	0.06	Contagious	43.71	284.2
Site 02	Sapling	226.67	80	0.04	Random	0.79	176.09
	Seedling	13.33	6.67	0.30	Contagious	-	-
	Tree	786.67	100	0.08	Contagious	103.46	300
Site 03	Sapling	-	-	-	-	-	-
	Seedling	-	-	-	-	-	-
Middle elevation							
	Tree	433.33	100	0.04	Random	83.86	199.99
Site 04	Sapling	6.67	6.67	0.15	Contagious	0.02	10.96
	Seedling	-	-	-	-	-	-
	Tree	593.33	100	0.06	Contagious	96.01	258.23
Site 05	Sapling	-	-	-	-	-	-
	Seedling	-	-	-	-	-	-
	Tree	486.67	93.33	0.06	Contagious	60.69	227.09
Site 06	Sapling	-	-	-	-	-	-
	Seedling	-	-	-	-	-	-

***Note: D:** Density, **F:** Frequency, **A/F:** Abundance/Frequency ratio, **BA:** Basal Area, **IVI:** Importance Value Index

deodara was the dominant tree species and had the highest IVI at all sites (Table 2). In the sapling stage, *C. deodara* was found only at site 04 and had a density of 6.67 ind ha^{-1} and the TBA of saplings of *C. deodara* was 0.02 m^2 ha^{-1}. No seedlings were found at any study sites in the middle elevational range of *C. deodara* (Table 2).

Tree Species Diversity and Concentration of Dominance

Lower elevation

At the lower elevational sites, the species richness was very low. Site 01 and site 03 were pure patches of *C. deodara*. Only site 02 was mixed with *L. umbrosa,* which was occurring as an under-canopy species. At site 02, the tree species diversity was 0.21, sapling diversity was 0.97 and seedling diversity was 1.01. The concentration of dominance(cd) of the tree layer was 0.94, cd of the sapling was 0.52 and cd of the seedlings was 0.49. The tree evenness was 0.3, the sapling evenness was 1.39 and of seedling was 1.45. (Table 3)

Middle elevation

At the middle elevational sites, the *C. deodara* forest stands were mixed mainly with *L. umbrosa* and *Q. floribunda*. The tree richness ranged between 5 and 8, which was minimum at site 05 and maximum at site 04. The sapling richness ranged between 2 and 5, which was minimum at site 06 and maximum at site 04. The tree species diversity ranged between 0.51 and 1.66, which was minimum at site 05 and maximum at site 06. The sapling species diversity ranged between 0.81 and 1.57, which was minimum at site 06 and maximum at site 05. Only one species (*L. umbrosa*) was present in the seedling stage, so the diversity was 0 at all three sites. The concentration of dominance(cd) of the tree layer ranged between 0.47 and 0.86, which was minimum at site 04 and maximum at site 05. The cd of the sapling layer ranged between 0.34 and 0.62, which was minimum at site 04 and maximum at site 06. The cd of a seedling layer was 1 at all three sites. The evenness of the tree layer ranged between

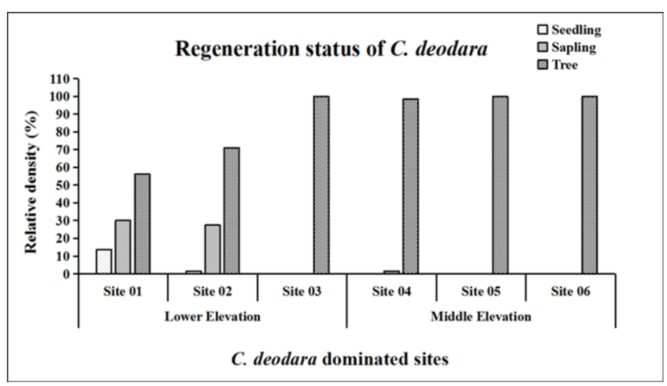

Fig. 3: Regeneration status of *C. deodara* at all six sites

Table 3: Tree species diversity and concentration of dominance of *C. deodara*-dominated forest stands

Site	*Species*	*SR*	*H'*	*CD*	*Evn*
Lower elevation					
	Tree	1	0	1	-
Site 01	Sapling	1	0	1	-
	Seedling	1	0	1	-
	Tree	2	0.21	0.94	0.3
Site 02	Sapling	2	0.97	0.52	1.39
	Seedling	2	1.01	0.49	1.45
	Tree	1	0	1	-
Site 03	Sapling	-	-	-	-
	Seedling	-	-	-	-
Middle elevation					
	Tree	8	1.66	0.47	0.8
Site 04	Sapling	5	1.55	0.47	0.97
	Seedling	1	0	1	-
	Tree	5	0.51	0.86	0.32
Site 05	Sapling	3	1.57	0.34	1.43
	Seedling	1	0	1	-
	Tree	6	0.98	0.7	0.54
Site 06	Sapling	2	0.81	0.62	1.17
	Seedling	1	0	1	-

Note: SR: Species Richness, **H':** Species Diversity, **CD:** Concentration of Dominance, **Evn:** Evenness

0.32 and 0.8, which was minimum at site 05 and maximum at site 04. The evenness of the sapling layer ranged between 0.97 and 1.43, which was minimum at site 04 and maximum at site 05. The evenness of the seedling layer was 0 at all three sites.

Regeneration

C. deodara was regenerating better at lower elevations than sites at middle elevations. The sites at lower elevations showed fair regeneration with a significant presence of seedlings, saplings, and trees. At site 01, the regeneration was fair, with the presence of seedlings, saplings and trees. The relative density of seedlings was less than saplings and the sapling's relative density was less than tree, which indicates good regeneration. At site 02, the seedlings were very less, but the saplings were present in good numbers. In contrast, the sites at middle elevations showed no regeneration. All three sites were dominated by mature and old trees at middle elevations, with an absence of seedlings or saplings, indicating poor regeneration (Fig. 3).

Discussion

The present study shows that a total of 13 tree species were present across all six sites and reveals that sites located at the middle elevation showed 0% regeneration due to significant human activities, including picnic spots, overgrazing, fuelwood and fodder extraction, which increased anthropogenic disturbances. Only 33% of the study sites exhibited fair regeneration, particularly at lower elevations, where restrictions on human access minimized anthropogenic pressures. Similarly, Singh *et al.,* (2023) observed an average regeneration rate of 43.21% across all altitudes, with the highest regeneration occurring at lower elevations in deodar-dominated regions of Kullu Forest Circle of Himachal Pradesh. Their findings further emphasize that the natural regeneration of *C. deodara* is significantly hindered by human-induced factors.

Across all the sites, 66.67% of the sites had 0 seedling density of *C. deodara*. However, in the remaining 33.33% sites, the seedling density of *C. deodara* was comparatively better and ranged from 13.33 to 160 ind ha^{-1}, which was higher than the value (9 ± 3 ind ha^{-1}) of *C. deodara* seedlings reported by Khan *et al.,* (2023). The seedling density ranged between 8 to 16 ind ha^{-1} of other conifers reported by Khan *et al.,* (2023), which was lower than the present study. The value (250 ind ha^{-1}) reported by Das *et al.,* (2021) for *C. deodara* in Himachal Pradesh was higher than the present study. The seedling density of *C. deodara* reported by Rawat and Chandhok (2009) at Govind Pashu Vihar, National Park, Uttarakhand, was within the range of the present study. The saplings of *C. deodara* were present at only 50% of sites across all the study sites (02 sites at lower elevation and 01 site at middle elevation). The sapling density of *C. deodara* at lower sites ranged between 16.67 to 353.33 ind ha^{-1}. However, Das *et al.,* (2021) reported 0 sapling density of *C. deodara* in old growth forest of *A. pindrow* and, higher than the sapling density of *C. deodara* reported by Rawat and Chandhok (2009). The total tree density of *C. deodara* at all sites ranged between 433.33 to 786.67 ind ha^{-1}, which was higher than the values (258-365 ind ha^{-1}) reported for *C. deodara* forest in Garhwal Himalaya by Sheikh *et al.,* (2020), also higher than the values for *Pinus roxburghii* forest of Garhwal Himalaya reported by Kumar *et al.,* (2010) (440–590 ind ha^{-1}) and by Kumar *et al.,* (2021) (135–575 ind ha^{-1}), whereas it was lower than the values 160.01 to 860.02 ind ha^{-1} reported by Lal and Samant, (2019), 510 to 1250 ind ha^{-1} by Singh *et al.,* (2014) and 540 to 830 ind ha^{-1} by Rawat *et al.,* (2020) for *A. pindrow* dominated forest stand of Garhwal Himalaya. Mishra (2017) carried out a study in the Chir pine forest in the Rudraprayag district and reported density ranged from 350 to 438 ind $ha^{-1,}$ which was within the range of the present study. Although the TBA reported by Pandey *et al.,* (2023) for *Picea smithiana* and *C. deodara* mixed forest was 1.29 m^2 $ha^{-1,}$ which has ranged to 73.12 m^2 ha^{-1} for *C. deodara* and *Abies pindrow* mixed forest. In the present study, the TBA ranged from 44.04 to 103.46 m^2 ha^{-1}, which was higher than the values reported by Pandey *et al.,* (2023). Furthermore, the range of IVI (52.50-181.45) reported for *C. deodara* by Pandey *et al.,* (2023) was lower than the values (199.99-300) reported in the present study.

The species diversity calculated in the present study ranged between 0 to 1.66, which was less than the values (0.27–2.17) reported by Lal and Samant (2019) in Kais Wildlife Sanctuary. The seedling, sapling and tree diversity of *C. deodara* and *P. smithiana* mixed forest was 1.11, 1.37 and 1.75, as reported by Lal and Samant (2019) in Kais Wildlife Sanctuary, which was higher than the values reported in the present study for seedling (0–1.01) and trees (0–1.66), however, slightly less than the values reported for sapling (0–1.57) in the present study. Although, the values (0.66–1.26) reported by Singh *et al.,* (2014) for the coniferous forest in the Nainital division were within the range of the present study. In contrast, it was lower than the values (2.3–3.53) reported for Western Himalaya by Malik *et al.,* (2016) and Malik and Bhatt (2015). The concentration of dominance ranged between 0.47 to 1, which was higher than the values (0.06–0.1) reported for Western Himalaya by Malik *et al.,* (2016) and Malik and Bhatt (2015) and it was higher than the values (0.42–0.76) reported by Singh *et al.,* (2014) for coniferous forest in Nainital division.

The correlation matrix (Table 4) revealed that diversity was strongly influenced by species richness and evenness, with both positively contributing to higher diversity, while an increase in the concentration of dominance significantly reduced diversity. In contrast, density showed weaker correlations with these factors, indicating it had a lesser impact on the overall diversity, richness, and evenness of species.

C. deodara cones mature generally post-monsoon and the germination is relatively high in the coming spring (Khanduri and Sharma 2010). However, due to climatic irregularities, the good seed years are becoming irregular, with better seed-producing and regeneration occurring at high elevations (Singh *et al.,* 2017). There are a few studies to indicate that an increase in temperature and decrease in precipitation during the pre-monsoon time, which is among the driest months in the Western Himalayan region can significantly impact the regeneration of *C. deodara*. Potential habitat decline of *C. deodara* in the Western Himalayas at higher elevations has been recorded (Gilani *et al.,* 2020).

Conifers at high altitudes generally tend to form pure patches, whereas towards lower altitudes, they tend to mix with some broad leaf species like *Q. semecarpifolia* and *Q. floribunda*. At the lower elevation sites, regeneration was fair at two sites and completely absent at one site located between 1618 to 1927 masl. Earlier studies carried out by Singh *et al.,* 2016, Lal and Samant, 2019 and Das *et al.,* 2021 have reported fair regeneration of *C. deodara* at upper elevation sites between 2100 to 2800. However, the regeneration was completely absent in the middle elevation sites of the present study. Furthermore, a recent study carried out by Singh *et al.* 2023 reported fair regeneration between 1800 and 2100 masl and poor regeneration between 2100 to 2400 masl range at the Kullu forest Circle of Himachal Pradesh. In the present study also the seedlings were absent across all three sites of middle elevation and saplings in two sites, showing that the species has not been regenerating across these sites in the Kumaun region of Uttarakhand. This could possibly be due to climate irregularities, particularly rising temperatures and altered precipitation patterns.

Table 4: Pearson correlation between tree diversity indices at all six sites

	H'	*CD*	*SR*	*EVN*	*D*
H'	1				
CD	-.999**	1			
SR	.966**	-.954**	1		
EVN	.969**	-.963**	.951**	1	
D	-0.358	0.336	-0.432	-0.508	1

Note: H': Species Diversity, **CD:** Concentration of Dominance, **SR:** Species Richness, **Evn:** Evenness and **D:** Density
** Correlation is significant at the 0.05 level.

The failure of regeneration of *C. deodara* at the lower elevation site in the Kumaun region is a matter of deep concern other than the climatic reasons. Anthropogenic disturbances also play a vital role in affecting the regeneration of the species. Practices like grazing, forest fire, lopping and even the extraction of young poles and saplings for various purposes influence the natural regeneration of the species (Parveen *et al.,* 2017).

A good seed crop followed by sufficient conversion of seedlings into saplings and tree is important for successful natural regeneration. The composition of the forest would depend upon the pace of replacement of the older tree with the younger one (Good and Good, 1972). However, our study indicates that at higher elevations, the species is at risk and a change in the composition of crops is inevitable if the present trend continues.

Regeneration plays a vital role in sustaining the composition of the forest and also the contribution of the species to the forest's composition. As far as our study was concerned on the dominant patches of *C. deodara*, we observed notable challenges at mid and lower elevations, with seedlings largely absent across most studied sites. Although, only a few seedlings were found at the lower elevation sites. It was also observed that the sites near the local residence or picnic spots were not regenerating. These sites were located at the middle range of the study. Whereas, sites which were prohibited for human involvement were more likely to be regenerating. This contrasts with findings by Parveen *et al.,* (2017), who noted fair to poor regeneration of *C. deodara* in disturbed sites of the Nagdev Forest, with good regeneration in more disturbed sites of Bantapani Forest areas. Similarly, Das *et al.,* (2021) reported fair regeneration of *C. deodara* in the Humkhani forest of the Western Himalaya. Rawat *et al.,* (2020), who reported good regeneration of *A. pindrow* in montane forests of the Garhwal Himalaya. Adil *et al.,* (2022) observed good regeneration of *P. wallichiana* and *C. deodara* at middle altitudes, while *A. pindrow* and *P. smithiana* showed good regeneration at upper altitudes.

Conclusion

The study reveals a significant decline in *C. deodara* regeneration at middle elevations (1800–2200 masl), driven by climate irregularities, anthropogenic pressures, and biological limitations. Temperature fluctuations and altered precipitation patterns may disrupt seed germination, while human activities like deforestation and overgrazing further hinder regeneration. Additionally, *C. deodara* exhibits infrequent seed production, and the dominance of mature and over-mature stands may be reducing seed viability. Poor seed dispersal, competition from other species, and soil degradation further exacerbate regeneration failure. These combined ecological and climatic stressors threaten the sustainability of C. deodara forests in this range. Conservation strategies should focus on assessing seed viability, promoting natural regeneration, and mitigating human-induced pressures to ensure long-term forest stability.

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Authors' Contribution

Shahbaz Ali – original concept, collection of samples, analysis of the material, drafting the manuscript; Ashish Tewari, review and supervision; Ambica Agnihotri, editing manuscript.

Conflicts of Interest

All authors declare that they have no conflict of interest.

References

Adil, M., Mugloo, J. A., Rafeeq, J., Dutt, V., Sultan, A., Mughal, A. H., Wagay, O. A., Kaif, M., Bhat, G. M. and Khan, I. (2022). Natural Regeneration status of conifers along Altitudinal Gradient in Shopain Forest Range of JandK, India. *SKUAST Journal of Research*, 24(2), 232-236.

Adler, P. B. and Lambers, J. H. (2008). The influence of climate and species composition on the population dynamics of ten prairie forbs. *Ecology,* 89: 3049-3060.

Baeten, L., Frenne, P. D., Verheyen, K., Graae, B. J. and Hermy, M. (2010). Forest herbs in the face of global change: a single-species-multiple-threats approach for *Anemone nemorosa*. *Plant Ecology and Evolution,* 143: 19–30.

Bagri, A. S., Singh, A., Rawat, D. S., Dhingra, G. K., and Wani, Z. A. (2023). Population structure and regeneration dynamics of tree species in banj oak forests of tehri garhwal, western Himalaya. *Acta Botanica Hungarica*, 65(3-4), 229-246.

Bhuyan, P., Khan, M. L., and Tripathi, R. S. (2003). Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity and Conservation*, 12, 1753-1773.

Cottam, G., and Curtis, J. T. (1956). The use of distance measures in phytosociological sampling. *Ecology,* 37(3), 451-460.

Curtis, J. T. (1959). The vegetation of Wisconsin: An ordination of plant communities. University of Wisconsin pres.

Das, D. S., Dash, S. S., Maity, D., and Rawat, D. S. (2021). Population structure and regeneration status of tree species in old growth *Abies pindrow* dominant forest: A case study from western Himalaya, India. *Trees, Forests and People*, 5, 100101.

Dugesar, V., Satish, K. V., Pandey, M. K., Srivastava, P. K., Petropoulos, G. P., Anand, A., and Behera, M. D. (2022). Impact of Environmental Gradients on Phenometrics of Major Forest Types of Kumaon Region of the Western Himalaya. *Forests*, 13(12), 1973.

Fitch, E. A., Walck, J. L. and Hidayati, S. N. (2007). Agroecosystem management for rare species of *Paysonia* (Brassicaceae): integrating their seed ecology and life cycle with cropping regimens in a changing climate. *American Journal of Botany* 94: 102–110.

Gebeyehu, G., Soromessa, T., Bekele, T., and Teketay, D. (2019). Species composition, stand structure, and regeneration status of tree species in dry Afromontane forests of Awi Zone, northwestern Ethiopia. *Ecosystem Health and Sustainability*, 5(1), 199-215.

Gilani, H., Goheer, M. A., Ahmad, H., and Hussain, K. (2020). Under predicted climate change: Distribution and ecological niche modelling of six native tree species in Gilgit-Baltistan, Pakistan. *Ecological Indicators*, 111, 106049.

Gogoi, A., and Sahoo, U. K. (2018). Impact of anthropogenic disturbance on species diversity and vegetation structure of a lowland tropical rainforest of eastern Himalaya, India. *Journal of Mountain Science*, 15(11), 2453-2465.

Good, N. F., and Good, R. E. (1972). Population dynamics of tree seedlings and saplings in a mature eastern hardwood forest. *Bulletin of the Torrey Botanical Club*, 172-178.

Haq, S. M., Rashid, I., Khuroo, A. A., Malik, Z. A., and Malik, A. H. (2019). Anthropogenic disturbances alter community structure in the forests of Kashmir Himalaya. *Tropical Ecology*, 60, 6-15.

Henle, K., Davies, K. F., Kleyer, M., Margules, C., and Settele, J. (2004). Predictors of species sensitivity to fragmentation. *Biodiversity and Conservation*, 13, 207-251.

Hussain, S., Sharma, S., Bhatti, R. C., and Singh, A. N. (2024). Sustainability in the Indian Himalayan Region: understandings the ecosystem services, climate change impacts, land use shifts and their threats. In *The Himalayas in the Anthropocene: Environment and Development* (pp. 33-57). Cham: Springer Nature Switzerland.

Huston, M. A. (1994). *Biological diversity: the coexistence of species*. Cambridge University Press.

Kaur, H., Gupta, S., and Parkash, S. (2017). Comparative evaluation of various approaches for landslide hazard zoning: a critical review in Indian perspectives. *Spatial Information Research*, 25, 389-398.

Khan, A., Shaukat, S. S., Ahmed, M., Khan, A., Iqbal, J., and Siddiqui, M. F. (2023). Regeneration potential of conifers along an elevation gradient under highly disturbed regimes in the western Himalayan region. *Acta Ecologica Sinica*, 43(1), 117-124.

Khan, M. L., Rai, J. P. N., and Tripathi, R. S. (1987). Population structure of some tree species in disturbed and protected subtropical forests of north-east India. *ACTA OECOL. (OECOL. APPL.)*., 8(3), 247-255.

Khanduri, V. P., and Sharma, C. M. (2010). Male and female reproductive phenology and annual production of male cones in two natural populations of *Cedrus deodara*. *Nordic Journal of Botany*, 28(1), 119-127.

Khumbongmayum, A. D., Khan, M. L., and Tripathi, R. S. (2005). Survival and growth of seedlings of a few tree species in the four sacred groves of Manipur, Northeast India. *Current Science*, 1781-1788.

Kumar, A., and Ram, J. (2005). Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, Central Himalaya. *Biodiversity Conservation,* 14:309–331.

Kumar, A., Sharma, M. P., and Taxak, A. K. (2017). Effect of vegetation communities and altitudes on the soil organic carbon stock in kotli bhel-1A Catchment, India. *CLEAN–Soil, Air, Water*, 45(8), 1600650.

Kumar, M., Kumar, A., Kumar, R., Konsam, B., Pala, N. A., and Bhat, J. A. (2021). Carbon stock potential in *Pinus roxburghii* forests of Indian Himalayan regions. *Environment, Development and Sustainability*, 23, 12463-12478.

Kumar, M., Kumar, S., and Sheikh, M. A. (2010). Effect of altitudes on soil and vegetation characteristics of *Pinus roxburghi*i forest in Garhwal Himalaya. *Journal of Advanced Laboratory Research in Biology*, 1(2), 130-133.

Lal, M., and Samant, S. S. (2019). Compositional and structural diversity of forest vegetation in Kais Wildlife Sanctuary, North Western Himalaya: conservation implications. *Journal of Biodiversity*, 10(1-2), 1-14.

Malik, Z. A., and Bhatt, A. B. (2015). Phytosociological analysis of woody species in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India. *Journal of Forest and Environmental Science*, 31(3), 149-163.

Malik, Z. A., and Bhatt, A. B. (2016). Regeneration status of tree species and survival of their seedlings in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India. *Tropical Ecology*, 57(4), 677-690.

Malik, Z. A., Pandey, R., and Bhatt, A. B. (2016). Anthropogenic disturbances and their impact on vegetation in Western Himalaya, India. *Journal of Mountain Science*, 13(1), 69-82.

Millar, C. I., and Stephenson, N. L. (2015). Temperate forest health in an era of emerging mega disturbance. *Science*, 349(6250), 823-826.

Mishra, B. K. (2017). Assessment of the soil and tree carbon stocks of a Chir pine forest in Garhwal Himalaya India. *International Journal of Geology, Earth and Environmental Sciences*, 7(2), 19-24.

Misra, R. (1968). Ecology Work book. Oxford and IBH Publishing Co. Calcutta, 244.

Pandey, R., Rawat, M., Pathak, A., Mehta, D., Bala, N., Bhatt, I. D., and

Chaturvedi, R. K. (2023). Identification of functional traits responsible for environmental vulnerability of *Cedrus deodara* in temperate forests of Western Himalaya. *Ecological Indicators*, 157, 111302.

Pandey, S. (2023). Land Degradation: Finding solution through Agroforestry in the Indian Himalayan Agro-Climatic Zones. *The Indian Forester*, 149(2).

Parveen, M., Tiwari, P., Rawat, D. S., and Tiwari, J. K. (2017). Tree species richness and regeneration pattern along the anthropogenic disturbance gradients in montane forests of Garhwal Himalaya, India. *Plant Archives,* 17(2): 1247-1254.

Phillips, E. A. (1959). Methods of vegetation study. *Henry Holt and Co Inc,* 107.

Pokhriyal, P., Uniyal, P., Chauhan, D. S., and Todaria, N. P. (2010). Regeneration status of tree species in forest of Phakot and Pathri Rao watersheds in Garhwal Himalaya. *Current science*, 171-175.

Quevedo-Rojas, A., Jerez-Rico, M., Schwarzkopf Kratzer, T., and García-Núñez, C. (2015). Distribution of juveniles of tree species along a canopy closure gradient in a tropical cloud forest of the Venezuelan Andes. *iForest-Biogeosciences and Forestry*, 9(3), 363.

Rawat, D. S., Tiwari, P., Das, S. K., and Tiwari, J. K. (2020). Tree species composition and diversity in montane forests of Garhwal Himalaya in relation to environmental and soil properties. *Journal of Mountain Science*, 17(12), 3097-3111.

Rawat, V. S., and Chandhok, A. (2009). Phytosociological analysis and distribution patterns of tree species: A case study from Govind Pashu Vihar, National Park, Uttarakhand. *New York Science Journal*, 2(4), 58-63.

Saxena, A. K. and Singh, J. S. (1982). A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetatio,* 50(1): 03-22.

Shannon, C. E. and Weiner, W. (1963). The mathematical theory of communication. University of Illinois Press, Urbana.

Sheikh, M. A., Kumar, M., Todaria, N. P., and Pandey, R. (2020). Biomass and soil carbon along altitudinal gradients in temperate *Cedrus deodara* forests in Central Himalaya, India: Implications for climate change mitigation. *Ecological Indicators*, 111, 106025.

Sheikh, M. A., Kumar, M., Todaria, N. P., Bhat, J. A., Kumar, A., and Pandey, R. (2021). Contribution of *Cedrus deodara* forests for climate mitigation along altitudinal gradient in Garhwal Himalaya, India. *Mitigation and adaptation strategies for global change*, 26, 1-19.

Simpson, E. H. (1949). Measurement of Diversity. *Nature*, 163.

Singh, G., Chauhan, V., Thakur, C. L., Verma, M. L., Bishist, R., Prakash, P., Gautam, K. L., Sharma, H., Dogra, R., Kishore, K. and Kumar, M. (2023). Studies on natural regeneration, floristic composition, biomass, carbon density and soil properties along an altitudinal gradient in the north-western Himalayas, India. *Forest Ecology and Management*, 548, 121391.

Singh, N., Tamta, K., Tewari, A., and Ram, J., (2014). Studies on Vegetational Analysis and Regeneration status of *Pinus roxburghii*, Roxb. and *Quercus leucotrichophora* Forests of Nainital Forest Division. *Global Journal of Science Frontier Research*, 14(3): 41-48.

Singh, S. P., Phartyal, S. S., and Rosbakh, S. (2017). Tree seed traits' response to monsoon climate and altitude in Indian subcontinent with particular reference to the Himalayas. *Ecology and evolution*, 7(18), 7408-7419.

Singh, S. P., Singh V. and Skutsch, M. (2010). Rapid warming in the Himalayas: Ecosystem responses and development options. *Climate and Develop,* 2: 221-232.

Singh, S., Malik, Z. A., and Sharma, C. M. (2016). Tree species richness, diversity, and regeneration status in different oak (*Quercus* spp.) dominated forests of Garhwal Himalaya, India. *Journal of Asia-Pacific Biodiversity*, 9(3), 293-300.

Teketay, D. (2005). Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production-population structures. *Tropical Ecology*, 46(1), 29-44.

Tesfaye, G., Teketay, D., Fetene, M., and Beck, E. (2010). Regeneration of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia. *Flora-Morphology, Distribution, Functional Ecology of Plants*, 205(2), 135-143.

Tewari, A., Bhatt, J., Mittal, A., Singh, N. and Tamta, K. K. (2016). Regeneration issues and indicators of seed maturity in *Mallotus phillipensis* muel. Arg. in the tropical Forests of Uttarakhand. *Ecology Environment and Conservation,* (2): 767-773.22

Tewari, A., Mittal, A. and Singh, N. (2017). Seed maturation timing in *Quercus leucotrichophora* A. camus along an altitudinal gradient in Uttarakhand Himalaya. *Environment Conservation Journal,* 18(3): 53-59

Tripathi, R. S., and Khan, M. L. (2007). Regeneration dynamics of natural forests-a review.

Walck, J. L. and Dixon, K. W. (2009). Time to future-proof plants in storage. *Nature,* 462, 721

Woodward, F. I. and Williams, B. G. (1987). Climate and plant distribution at global and local scales. *Vegetatio,* 69: 189-197.