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A multivariate analysis of the vegetation of *Cedrus deodara* forests in Hindu Kush and Himalayan ranges of Pakistan: evaluating the structure and dynamics

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Abstract: This investigation focuses on the multivariate analysis of the vegetation of the Hindu Kush and Himalayan ranges of Pakistan, concentrating on the dynamics of *Cedrus deodara* (Roxb. ex D.Don) G.Don. The study includes 47 stands from 23 different locations in the Himalayan region of Pakistan. The point-centred quarter method and 1.5-m radius circular plots were used for the sampling of tree and understorey vegetation, respectively. The size, age structure, and growth rates of *Cedrus deodara* were also examined in order to trace its dynamics, and an attempt was made to determine the relationships between environmental factors and vegetation. The quantitative distribution of understorey vegetation was also assessed as a way of evaluating the floristic association of the forests. The underlying group structure in the vegetation was exposed using Ward's clustering technique. Results of the cluster analysis showed that 6 groups of vegetation could readily be superimposed on DCA ordination. The vegetation was potentially continued. Among the environmental variables, factors such as elevation, pH, organic matter of soil, total nitrogen, and magnesium showed significant correlations with ordination axes. The size-class structure of *Cedrus deodara* exhibited many gaps. In most stands, *Cedrus deodara* exhibited ample recruitment, and relationships between diameter, age, and growth rate were significant in many stands. The study also proposes some recommendations for the maintenance and proper management of these forests.

Key words: Cluster analysis, DCA ordination, vegetation description, dendrochronology, management plan, *Cedrus deodara*

Introduction

The northern area of Pakistan covers about 72,500 km^2 and lies between latitudes 34° and 37° N and longitudes 71° and 74° E (Figure 1). Neighbouring China is linked via the famous Silk Road (Karakoram Highway) through the Khunjirab Pass which, at roughly 4700 m above sea level, is reported to be the highest sealed highway in the world. The area also adjoins the disputed territory of Kashmir to the east and Afghanistan to the west. The investigation of the population structure of vegetation (i.e. density, basal area, size class distribution, age, and growth rate) for economically and ecologically important trees is of great interest to foresters, silviculturists, ecologists, environmentalists, and biologists, yet these demographic parameters are relatively unknown for

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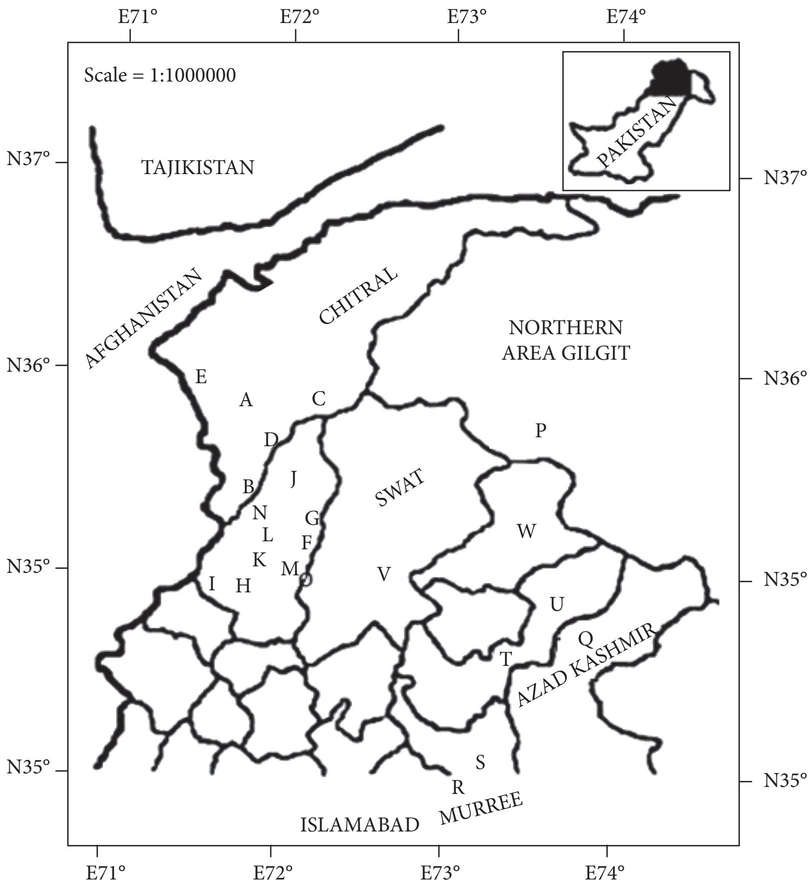

Figure 1. Map of the study areas showing the main locations, represented by letters A-W. Sampling sites (stands) are located around these main locations. For names of the main study locations, please refer to Table 1.

the area. Multivariate techniques are applied to tree vegetation data in order to evaluate the structure and dynamics of cedar dominating forests; understorey species have a great influence on the overstorey, so the quantitative distribution of understorey species is also evaluated. The composition of the understorey species beneath tree canopies often differs with the canopy composition. Overstorey species can directly affect understorey species by altering the precipitation distribution under their canopy, soil bulk density, soil moisture, soil oxygen, soil surface temperature, available sunlight, soil and leaf litter accumulation, soil nutrient concentration, and seed bank density (Warnock et al., 2007). The importance of, need for, and application of age and growth data have been discussed by Ashton (1981). According to Lafon and Speer (2002), the science of dendrochronology has enhanced our understanding of essential concepts such as environmental change, succession, and forest stand dynamics. Tree-ring studies in old-growth forests are valuable sources of information regarding the natural history of central hardwood species (Rentch et al., 2003a, 2003b), as well as the natural disturbance dynamics and development patterns for forest types throughout the region. The spatial distribution of disturbance is determined by factors that influence the size and location of disturbance events. If trees at the gap margin are more likely to die than random canopy trees, for instance, canopy gaps would expand (Worrall et al., 2005).

No thorough quantitative investigation of the vegetation in the study area has been conducted, and the distribution pattern of the important species is relatively unknown. According to Champion et al. (1965), *Cedrus deodara* (Roxb. ex D.Don) G.Don forests gradually extend into the dry inner valleys of the Himalayas. Hussain and Illahi (1991) described the vegetation of the Lesser Himalayan range of Pakistan, stating that deodar cannot tolerate excessively moist conditions and is therefore confined to the drier sites of the Himalayas. Ahmed (1986) gave a quantitative description of the foothills of the Himalayas and discussed the climatic and topographic factors of the region. Ahmed et al. (2006) described the vegetation structure and composition of Himalayan forests in comparison with those found in different climatic zones of Pakistan.

Other than limited local attempts, no comprehensive quantitative investigations have been conducted that describe the vegetation structure and population dynamics of various forests species across the northern region of Pakistan. Bearing these considerations in mind, the present study was undertaken to investigate the phytosociology, vegetation structure, and population dynamics of *Cedrus deodara*, one of the most important and dominant tree species in the northern part of Pakistan. It is anticipated that the present study will provide information to aid in the understanding of the current status, dynamics, and future trends of *Cedrus deodara* forests.

Materials and methods

Vegetation sampling

Sampling was conducted throughout Pakistan in forests that were dominated by *Cedrus deodara*. Though all forests are disturbed to some degree, mature and least-disturbed stands were selected for quantitative sampling. The criteria for the selection of stands were: 1) there should be no sign of recent major disturbance, 2) trees contained in the stand should be at least 60 cm in diameter at breast height (DBH), and 3) each stand should cover a minimum area of 5 ha.

The point-centred quarter method (Cottam & Curtis, 1956) was used for quantitative sampling. In total, 47 stands were sampled from the study area, and 25 points were taken in each stand at regular intervals of 20 m each. Understorey vegetation was sampled in each stand with circular plots 1.5 m in diameter (Mueller-Dombois and Ellenberg, 1974), which were marked at each of the 25 sampling points. GPS was used to record the position, elevation, and aspect of stands while the degree of slope was recorded by a clinometer.

Summarising vegetation data, multivariate analysis, and size frequency classes

The importance value (IV) and absolute values (stand density, trees ha^{-1}, and basal area, $m^2 ha^{-1}$) were calculated according to the methods described by Mueller-Dombois and Ellenberg (1974). The importance value of tree species was calculated as the sum of relative cover, relative density, and relative frequency expressed as percentage of the total. The occurrence of all species, including seedlings/saplings (<10 cm DBH) of trees, shrubs, herbs, and grasses, was recorded in the circular plots. Diameter at breast height measurements (DBH) of trees in each stand were divided into 10-cm DBH size classes and the size structures of conifer trees were determined for each stand. Regression analyses were performed to seek the relationships between elevation, density, and basal area as well as that between density and the basal area of stands. Cluster analysis was performed based on tree species importance values using Ward's clustering technique (Orloci & Kenkel, 1985). Euclidian distance was used as the resemblance function. No standardisation was performed to emphasise quantitative differences between stands. For the purpose of ordination, detrended correspondence analysis (DCA) (Gauch, 1981) was employed using PC-ORD Version 5.10 (McCune & Mefford, 2005).

Age and growth determination

Coring techniques and sample preparation were carried out in accordance with the methods outlined by Stokes and Smiley (1968). Dendrochronological methods were followed for the determination of age and growth rates (Fritts, 1976). Samples were taken from those individual trees that were sound, free from severe competition, and situated on dry ground. At least 2 cores were taken per tree (uphill and downhill) using a hand-operated

Swedish increment corer. The DBH and the height of the core were measured and the bark thickness was recorded on 4 sides of each tree using a Swedish bark gauge. Every sampled tree and core was numbered. The cores were kept in drinking straws to prevent possible damage and were air-dried. Later, the cores were glued in a grooved mount so that tracheids were able to dry in a vertical position. These cores were sanded with a sanding machine, and progressively finer grades of sand papers were used until a suitably polished surface was achieved**.**

An attempt was made to establish cross-dating visually under a variable power binocular microscope. The radial uniformity of the tree and the ring-width pattern of the site were checked by cross-matching the cores from the same tree and different trees. During this process, missing rings and false rings were identified in their correct sequence and each ring was properly dated with regard to the year of its formation.

In each stand, 2 sections were obtained from breast height on small saplings. The rings on these sections were counted. It was assumed that the average height and growth rate shown by these saplings could be used to approximate the time required for the tree to reach the height at which the wood samples were taken (Ogden, 1981). These years were added to the age of each core in order to obtain the total age of the tree. In most cases, cores did not pass through the centre or pith of the tree; therefore, following Ogden (1980), an allowance was made to calculate the number of rings in the missing portion of the core. The missing radius was obtained by subtracting the core length from the crude radius of the tree, and the missing years were calculated from the growth rate of the innermost 20 rings and added to the total age of the core. In this respect, the "reliability" of the core was also calculated by dividing the core length by the crude radius and expressing it as a percentage. This measure gives an approximate idea of how near the end of the core is to the presumed tree centre and hence how reliable the age estimate is. The length of the core was divided by the number of rings present in the core and the average growth rate was calculated in years per centimetre. Linear regression was computed for each site to establish the relationships between age, growth rate, and tree diameter.

Results

Vegetation composition

The locations of main sampling areas are shown in Figure 1. The ecological characteristics of each sampling site, its map location, and absolute quantitative attributes are presented in Table 1. Elevation and slope did not show any significant correlation with stand density/basal area and *Cedrus deodara* density/basal area. Table 2 provides the summary of phytosociological analysis.

Out of a total of 47 stands, *Cedrus deodara* was the leading dominant in 36 stands, while in 8 stands it occurred as the second dominant with an overall average importance value of 70.45% (Table 3). *Pinus wallichiana* A.B.Jacks. showed its presence in 25 stands and was represented as the leading dominant in 9 stands and the second dominant in 15 stands. *Abies pindrow* Royle was represented in 13 stands with an average importance value of 20.26%, occurring as the leading dominant in 2 stands and second dominant in 4 stands. Apart from these, 10 other tree species occurred in 4 or fewer stands, with average importance values ranging between 5.0% and 17.97%. Among these species, *Pinus gerardiana* Wall. ex Lamb. and *Picea smithiana* (Wall.) Boiss. attained second dominance in 4 stands and 3 stands, respectively. Both the average absolute density and basal area were highest for *Cedrus deodara*, at 184 trees ha^{-1} and 41 m^2 ha^{-1}, respectively. *Pinus wallichiana* also exhibited a high average absolute density (92 trees ha^{-1}) and basal area (19-27 m^2 ha^{-1}). The mean density and basal area of *Abies pindrow* were 54 trees ha^{-1} and 12.4 m^2 ha^{-1}, for *Juniperus excelsa* M.Bieb. 24 trees ha^{-1} and 3.4 m^2 ha^{-1}, and for *Taxus wallichiana* Zucc. 26 trees ha^{-1} and 5.4 m^2 ha^{-1}.

Multivariate analysis

Results of multivariate analysis of the vegetation are shown in Figures 2 and 3.

The following 6 groups were derived from the dendrogram resulting from Ward's cluster analysis (Figure 2). These groups were superimposed on DCA ordination. Though the ordination basically exhibited continuity, the groups more or less separated out on the first 2 ordination axes based on cluster analysis (Figure 3).

Table 1. The ecological characteristics of sampling sites and absolute quantitative attributes of 47 stands from *Cedrus deodara* forests.

Location	St. No.	Lat. (N)	Long. (E)	Elev. (m)	Slope (°)	Asp.	Cnp.	Std.	Sba.
A - Kalash Valley	1	35°41′	71°41′	2073	24	SW	Open	126	28.66
	2	35°41′	71°41′	2273	34	N	Open	288	55.19
	3	35°40′	71°45′	2125	27	W	Mod	149	50.07
B - Ziarat	4	35°21′	71°41′	2544	34	W	Open	89	44.87
	5	35°21′	71°46′	2544	34	E	Open	206	48.25
C - Goline Gol Valley	6	35°54′	72°05′	2584	17	N	Open	100	7.84
D - Shashe Kuh	7	35°45′	72°05′	2160	31	N	Closed	631	104.80
	8	35°45′	72°40′	2344	29	S	Mod	403	128.05
E - Chitral G.N.P	9	35°53′	71°41′	2774	26	E	Mod	322	76.45
	10	35°53′	71°46′	2331	20	N	Open	287	36.19
	11	35°52′	71°46′	2217	38	NE	Open	303	36.44
	12	35°49′	71°43′	2927	32	S	Open	260	50.97
F - Barkand Dara	13	35°21′	72°08′	2130	42	E	Open	62	8.95
G - Usheri Dara	14	35°13′	72°13′	2310	33	S	Open	94	18.35
H - Baraul	15	35°11′	71°73′	1920	34	W	Open	99	6.35
	16	35°13′	71°69′	1800	38	E	Mod	129	8.02
	17	35°07′	71°69′	1950	40	E	Open	103	10.32
I - Shahi	18	35°09′	71°32′	2080	35	N	Open	116	8.37
	19	35°03′	71°37′	2150	40	W	Open	130	15.09
J - Kohistan	20	35°54′	72°21′	2400	15	N	Closed	400	65.00
K - Dir Khas	21	35°16′	71°50′	1991	27	W	Mod	368	49.43
L - Janas Banda	22	35°37′	72°14′	2120	30	S	Open	178	39.65
M - Sheringal	23	35°28′	72°02′	2150	48	N	Mod	394	65.80
	24	35°28′	72°07′	2340	50	N	Mod	457	68.00
	25	35°28′	72°07′	2200	30	NW	Mod	195	24.16
N - Dok Dara	26	35°20′	71°55′	2534	41	W	Mod	75	95.82
	27	35°20′	71°55′	2672	40	S	Mod	104	115.17
O - Tormang Dara	28	34°51′	72°03′	2033	28	N	Mod	277	47.00
P - Diamer	29	35°25′	74°06′	2370	35	W	Closed	85	57.48
	30	35°18′	73°04′	2600	40	W	Sct	89	5.90
Q - Azad Kashmir	31	34°15′	73°40′	1960	30	NE	Open	87	41.00
R - Murree	32	34°54′	73°24′	2300	40	SE	Closed	435	83.00
S - Abbottabad	33	34°49′	73°24′	2730	42	SE	Closed	249	59.00
	34	34°49′	73°24′	2600	37	SE	Closed	178	28.00
	35	34°02′	73°24′	2560	10	plain	Mod	333	175.00
	36	34°02′	73°24′	2560	28	SE	Closed	333	84.00
	37	34°02′	73°22′	2320	31	S	Mod	179	41.00
	38	34°14′	73°22′	2300	38	S	Mod	172	20.00
T - Kaghan Valley	39	34°54′	73°28′	2400	23	S	Closed	320	66.00
	40	34°54′	73°28′	2500	33	S	Closed	412	60.00
	41	34°54′	73°52′	1600	20	NE	Closed	222	56.28
	42	34°47′	73°32′	2000	35	E	Closed	338	47.00
	43	34°38′	73°24′	1900	39	NW	Mod	287	96.00
	44	34°38′	73°32′	1650	43	W	Closed	410	36.00
U – Naran valley	45	34°47′	73°33′	2500	12	NW	Mod	284	50.00
V - Alpuri Swat	46	34°54′	72°23′	2350	45	W	Mod	325	43.00
W- Dassu	47	34°45′	72°33′	2650	40	S	Mod	221	26.00

Abbreviations: St. No. = Stand number, Lat. (N) = northern latitude, Long. (E) = eastern longitude, Elev. (m) = Elevation in metres, Asp. = Aspect, Cnp. = canopy, Std. = Stand density (ha^{-1}), Sba. = Stand basal area (m^2 ha^{-1}), Mod = Moderate, Sct = Scattered.

Sampling sites (stand number):

1 = Dyimeli Kalash, 2 = Gambag Kalash, 3 = Barir Kalash-1, 4 = Ziarat Mata Khure, 5 = Ziarat, 6 = Goline Gol-1, 7 = Madaglask Shesheko, 8 = Shaheed Bala, 9 = Gohkshal Chitral-2, 10 = Ispidiar GNPC, 11 = Bronshal GNPC, 12 = Gol National Park Rest House, 13 = Souray Bailo, 14 = Sore Kamar, 15 = Shahikot, 16 = Baraul Banda, 17 = Shalthalo Bala, 18 = Shahi Khwar, 19 = Shahi Awar, 20 = Kumrat, 21= Penhakot, 22 = Janis Kandao, 23 = Shahoor, 24 = Shahoor-1, 25 = Shahoor-2, 26 = Salam Baiky Sar, 27 = Salam Baiky Ghar, 28 = Manji Baba, 29 = Chillas, 30 = Babusar Thak Village, 31 = Kearn, Neelam Valley, 32 = Patriata top, 33 = Ayubia Khera Gali, 34 = Ayubia-5, 35 = Kuzah Gali-1, 36 = Kuzah Gali-2, 37 = Thandyani-1, 38 = Thandyani-2, 39 = Shogran-1, 40 = Shogran-2, 41 = Paras Malakundi, 42 = Khanian, 43 = Shinu-1, 44 = Shinu-2, 45 = Naran valley, 46 = Shangla Pass, 47 = Kohistan.

Table 2. Phytosociological attributes and absolute values of tree species from 47 stands of *Cedrus deodara*-dominated forests in the Himalayan range of Pakistan.

			Phytosociological attributes				Absolute values	
Main location, sites, and stand no.		Species name	Relative frequency	Relative density	Relative basal area	IV	D, ha^{-1}	BA, m^2 ha^{-1}
	A - Kalash Valley							
1	Dyimeli Kalash	*Cedrus deodara*	38.23	41.66	70.29	50.1	53	0.15
		Pinus gerardiana	29.40	30	24.55	27.98	38	7.04
		Quercus baloot	32.36	28.34	5.15	21.95	36	1.47
2	Gambag Kalash	*Cedrus deodara*	34.28	36.66	59.47	43.43	106	32.82
		Pinus gerardiana	19.99	25	14.96	19.90	72	8.26
		Abies pindrow	14.20	15	19.27	16.16	43	0.64
		Pinus wallichiana	11.42	10	3.18	8.40	29	1.76
		Quercus baloot	11.42	6.66	1.39	6.47	19	0.77
		Quercus dilitata	8.58	6.66	1.69	5.64	19	0.94
		Cedrus deodara	34.28	36.66	59.47	43.43	106	32.82
3	Barir Kalash-1	*Cedrus deodara*	100	100	100	100	149	50.07
	B - Ziarat							
4	Mata Khure	*Cedrus deodara*	40.62	41.66	67.77	50.02	373	1.40
		Abies pindrow	40.62	41.66	26.63	37.99	411	0.88
		Picea smithiana	18.76	11.68	5.60	11.99	10	2.59
5	Ziarat	*Cedrus deodara*	60.01	73.33	76.64	69.99	1513	6.98
		Picea smithiana	40.99	26.67	23.36	30.01	551	1.27
	C - Goline Gol Valley							
6	Goline Gol-1	*Cedrus deodara*	100	100	100	100	100	7.84
	D - Shashe Kuh							
7	Madaglask Shesheko	*Cedrus deodara*	11.11	5.0	6.97	7.69	32	7.31
		Pinus wallichiana	55.55	76.66	69.23	67.15	482	72.56
		Abies pindrow	33.34	18.34	23.80	25.16	116	24.93
8	Shaheed Bala	*Cedrus deodara*	57.80	68.33	29.72	51.95	275	38.06
		Pinus wallichiana	42.20	31.67	70.28	48.5	128	89.99
	E - Chitral G.N.P							
9	Gohkshal-2	*Cedrus deodara*	100	100	100	100	322	76.45
10	Ispidiar GNPC	*Cedrus deodara*	50	63.33	78.06	63.78	182	28.25
		Pinus wallichiana	27	18.33	11.10	18.81	53	4.02
		Juniperus excelsa	23	18.34	10.84	17.50	53	3.92
11	Bronshal GNPC	*Cedrus deodara*	75.18	91.66	86.73	84.58	278	31.61
		Pinus wallichiana	24.82	8.34	13.27	15.42	25	4.83
12	Gol.National.Park Rest House	*Cedrus deodara*	86	86	93	88	227	489
		Pinus gerardiana	10	10	6	9	19	57
		Juniperus excelsa	4	4	1	3	63	23
	F - Barkand Dara							
13	Souray Bailo	*Pinus wallichiana*	52.94	65.00	63.26	60.4	41	5.54
		Cedrus deodara	47.05	35.00	36.74	39.6	22	3.41
	G - Usheri Dara							
14	Sore Kamar	*Pinus wallichiana*	64.52	83.75	85.88	78.05	791	5.92
		Cedrus deodara	35.48	16.25	14.12	21.95	15	2.43
	H - Baraul							
15	Shahikot	*Cedrus deodara*	100	100	100	100	99	6.35
16	Baraul Banda	*Cedrus deodara*	100	100	100	100	129	8.02
17	Shalthalo Bala	*Pinus wallichiana*	55.17	54.17	60.07	56.47	56	6.20
		Cedrus deodara	44.83	45.83	39.93	43.53	47	4.12
	I - Shahi							
18	Shahi Khwar	*Cedrus deodara*	100	100	100	100	116	8.37
19	Shahi Awar	*Cedrus deodara*	54.84	68	72.05	64.96	881	0.77
		Pinus wallichiana	45.16	32	27.95	35.04	42	4.32
	J - Kohistan							
20	Kumrat	*Cedrus deodara*	16	28	40	28	110	4
		Pinus wallichiana	71	61	43	58	245	41
		Abies pindrow	1	1	7	3	5	11
		Populus caspica	12	10	10	11	40	9
	K - Dir Khas							
21	Penhakot	*Pinus wallichiana*	60.87	75	70.91	68.93	276	35.05
		Cedrus deodara	39.12	25	29.08	31.07	921	4.38
	L - Janas Banda							
22	Janis Kandao	*Cedrus deodara*	78.57	85.42	86.44	83.48	152	34.28
		Taxus wallichiana	21.43	14.58	13.56	16.52	26	5.37
	M - Sheringal							
23	Shahoor	*Cedrus deodara*	100	100	100	100	394	65.8
24	Shahoor-1	*Cedrus deodara*	100	100	100	100	628	572
25	Shahoor-2	*Cedrus deodara*	75	75	75	75	452	283
		Quercus baloot	25	25	25	25	132	25

Table 2. (Continued).

Main location, sites, and stand no.		Species name	Phytosociological attributes: Relative frequency	Relative density	Relative basal area	IV	Absolute values: D, ha^{-1}	BA, m^2 ha^{-1}
	N - Dok Dara							
26	Salam Baiky Sar	*Cedrus deodara*	82.61	91.25	90.23	88.03	688	6.45
		Picea smithiana	17.39	8.75	9.77	11.97	7	9.37
27	Salam Baiky Ghar	*Cedrus deodara*	100	100	100	100	104	115.17
	O - Tormang Dara							
28	Manji Baba	*Cedrus deodara*	100	100	100	100	277	47
	P - Diamer							
29	Chillas	*Cedrus deodara*	67	85	81	78	1499	341
		Abies pindrow	13.3	7.5	7.8	9.5	132	51
		Acer villosum	6.7	2.5	5.7	5	44	80
		Aesculus indica	6.7	2.5	3	4	44	23
		Quercus baloot	6.7	2.5	2.5	4	44	16
30	Babusar Thak Village	*Cedrus deodara*	48	80	70	66	459	47
		Pinus gerardiana	19	9	13	14	82	40
		Juniperus excelsa	19	5	10	11	66	27
		Quercus baloot	9	4	5	6	33	48
		Abies pindrow	5	2	2	3	16	43
	Q - Azad Kashmir							
31	Kearn, Neelam valley	*Cedrus deodara*	60	60	61	60	52	25
		Pinus wallichiana	40	40	39	40	35	16
	R - Murree							
32	Patriata top	*Cedrus deodara*	83	83	91	78	362	55
		Pinus wallichiana	17	13	9	22	73	28
	S - Abbottabad							
33	Ayubia Khera Gali	*Cedrus deodara*	42	63	67	57	379	100
		Pinus wallichiana	33	26	31	30	159	37
		Abies pindrow	25	11	2	13	68	4
34	Ayubia-5	*Abies pindrow*	62	62	42	55	112	12
		Pinus wallichiana	17	17	16	17	31	4
		Cedrus deodara	13	13	18	15	22	5
		Juglans regia	8	8	24	13	13	7
35	Kuzah Gali-1	*Cedrus deodara*	70	70	87	76	233	159
		Abies pindrow	25	25	12	21	83	15
		Pinus wallichiana	5	5	1	3	17	1
36	Kuzah Gali-2	*Abies pindrow*	60	60	51	57	200	43
		Pinus wallichiana	25	25	28	26	83	23
		Cedrus deodara	15	15	21	17	50	18
37	Thandyani-1	*Pinus wallichiana*	80	80	83	81	143	34
		Cedrus deodara	20	20	17	19	36	7
38	Thandyani-2	*Pinus wallichiana*	50	70	74	65	120	15
		Cedrus deodara	50	30	26	53	52	5
	T - Kaghan Valley							
39	Shogran-1	*Cedrus deodara*	70	86	92	82	274	60
		Pinus wallichiana	20	7	2	10	23	2
		Abies pindrow	10	7	6	8	23	4
40	Shogran-2	*Cedrus deodara*	84	94	95	91	392	56
		Picea smithiana	8	3	4	5	10	3
		Abies pindrow	8	3	4	4	10	1
41	Paras Malakundi	*Cedrus deodara*	55	80	96	76	176	54
		Pinus wallichiana	9	4	1	5	9	0.18
		Juglans regia	18	8	1	9	19	1
		Quercus baloot	9	4	1	5	9	1
		Quercus incana	8	4	1	5	9	0.1
42	Khanian	*Cedrus deodara*	75	83	91	83	282	43
		Pinus wallichiana	25	17	9	17	56	4
43	Shinu-1	*Cedrus deodara*	53	72	75	67	208	72
		Pinus wallichiana	47	28	25	79	79	24
44	Shinu-2	*Cedrus deodara*	100	100	100	100	410	36
	U - Naran valley							
45	Naran valley	*Cedrus deodara*	100	100	100	100	284	50
	V - Alpuri Swat							
46	Shangla pass	*Cedrus deodara*	50	75	77	67	657	19
		Pinus wallichiana	40	20	14	25	175	12
		Abies pindrow	10	5	9	8	44	12
	W - Dassu							
47	Kohistan	*Cedrus deodara*	71	90	93	58	176	361
		Pinus gerardiana	29	10	7	15	196	32

Abbreviations: D, ha^{-1} = density, ha^{-1}; BA, m^2 ha^{-1} = basal area, m^2 ha^{-1}; IV = importance value.

Table 3. Summary of phytosociological sampling of 47 stands, mean importance value (%), absolute density (ha^{-1}), basal area ($m^2 ha^{-1}$), and the order of dominance of *Cedrus deodara* and associated tree species.

Serial No.	Name of species	Mean importance value (%) of species	Mean density of species (ha^{-1})	Mean basal area of species ($m^2 ha^{-1}$)	NSP	Rank		
						1st	2nd	3rd
	Gymnospermae							
1	*Cedrus deodara*	70.45 ± 4.82	184 ± 23	41 ± 6.43	47	36	8	3
2	*Pinus wallichiana*	37.96 ± 5.16	92 ± 21	19.27 ± 4.42	25	9	15	1
3	*Abies pindrow*	20.26 ± 5.21	54 ± 16	12.41 ± 3.15	13	2	4	5
4	*Pinus gerardiana*	17.97 ± 4.01	46 ± 14	4.31 ± 1.97	4	-	4	-
5	*Picea smithiana*	14.74 ± 5.34	21 ± 12	6.55 ± 2.2	4	-	3	1
6	*Juniperus excelsa*	10.50 ± 4.19	24 ± 14	3.37 ± 1.6	3	-	-	3
7	*Taxus wallichiana*	16.52	26	5.37	1	-	1	-
	Angiospermae							
8	*Quercus baloot*	9.64 ± 4.1	17 ± 7	0.93 ± 0.23	4	-	-	1
9	*Quercus incana*	10.11 ± 4.98	17 ± 8	0.96 ± 0.38	4	-	1	-
10	*Juglans regia*	11.00	16	1.35	2	-	1	-
11	*Populus caspica*	11.00	9	0.97	1	-	-	1
12	*Aesculus indica*	4.00	2	1.0	1	-	-	-
13	*Acer villosum*	5.00	3	0.60	1	-	-	1

Abbreviations: NSP = number of stands in which a species is present; 1st, 2nd, 3rd = number of stands in which a species is considered to be the 1st, 2nd, or 3rd most dominant on the basis of importance value (IV).

Group I: *Cedrus deodara - Pinus gerardiana*

Group I is comprised of 3 stands (1, 2, and 4) characterised by a predominance of *Cedrus deodara*, with an average importance value of 47.5% (Table 4). On ordination (axes 1 and 2), these stands occupy the position in the lower left of the configuration (Figure 3). Codominant species *Pinus gerardiana* was restricted to drier sites only, and the Kalash Valley sampling site represents typical dry temperate conditions. *Quercus baloot* Griff., an Angiospermae species, is associated with an average importance value of 9.6% (Table 4). *Abies pindrow* was also found to be a second dominant species at one location (Stand 4). Presumably, localised climatic and edaphic conditions are created in dry temperate areas where species of moist temperate areas can survive and propagate. Ground flora under *Pinus gerardiana* was composed of *Impatiens brachycentra* Kar. & Kir., *Consolida ambigua* (L.) Ball & Heywood, *Sambucus wightiana* Wall. ex Wight & Arn., *Echinops cornigerus* DC., *Fragaria nubicola* Lindl. ex Lacaita, *Pedicularis rhinanthoides rotundata* Schrenk ex Fisch. & Mey, and *Pedicularis chitralensis* Penn. The abundant species under the *Abies pindrow* canopy were *Aconitum*

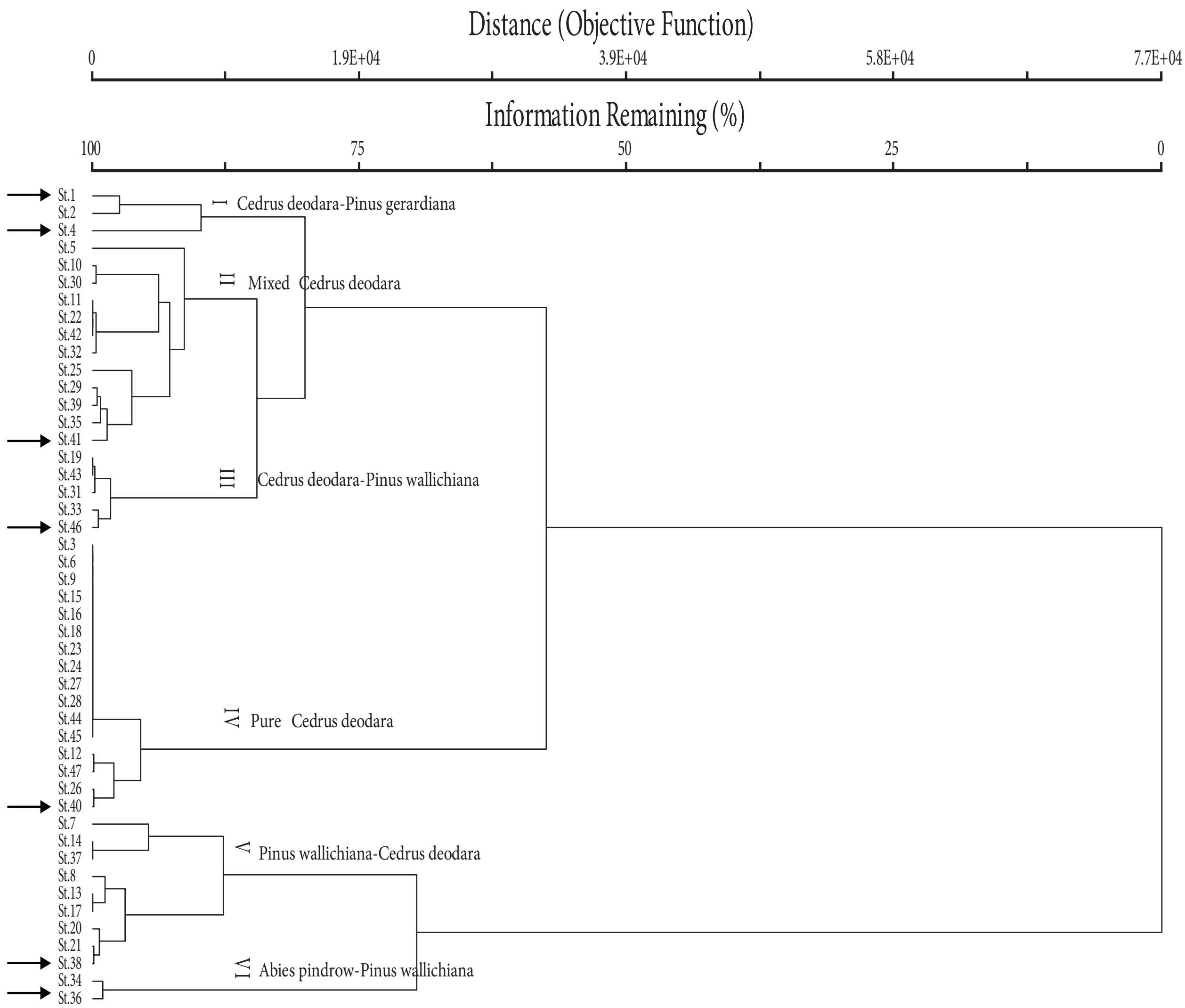

Figure 2. The dendrogram obtained by agglomerative Ward's cluster analysis shows that 47 *Cedrus deodara*-dominated stands were surveyed in the study.

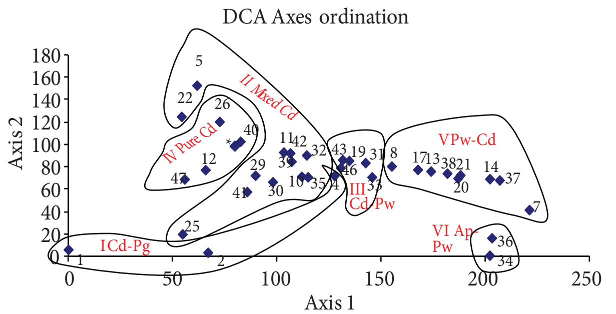

Figure 3. DCA ordination (first 2 axes) of the 47 stands surveyed. The groups derived from Ward's cluster analysis are superimposed on the ordination. An asterisk (*) indicates the pure stands of *Cedrus deodara* (3, 6, 9, 15, 16, 18, 23, 24, 27, 28, 44, and 45).

chasmanthum Stapf ex Holmes, *Aquilegia nivalis* Falc. ex Jacks., *Aconitum leave* Royle, *Geranium rotundifolium* L., *Astragalus amherstianus* Benth. ex Royle, and *Fragaria nubicola*, along with a sizeable number of *Cedrus deodara* seedlings.

Group II: Mixed *Cedrus deodara*

This group is distributed in moist temperate, dry temperate, and subalpine areas of Pakistan. This group consisted of 12 stands (5, 10, 11, 30, 22, 42, 32, 25, 29, 39, 35, and 41). *Cedrus deodara* attained the dominant position with a 75% average importance value (Table 4), while various broad-leaved and conifer tree species are also associated with *Cedrus deodara*.

Table 4. The 6 groups derived from Ward's cluster analysis of all 47 stands and their average tree species composition (average importance value for each group).

S. no.	Species	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
1	*Cedrus deodara*	47.5	75	63	97	31	16
2	*Pinus wallichiana*	2.7	9	33	0	66	21.5
3	*Abies pindrow*	16	6.6	4	0.25	3	56
4	*Pinus gerardiana*	18	*	*	1.5	*	*
5	*Picea smithiana*	4	1	*	1	*	*
6	*Juniperus excelsa*	*	2.4	*	0.2	*	*
7	*Taxus wallichiana*	*	1.4	*	*	*	*
8	*Juglans regia*	*	0.8	*	*	*	6.5
9	*Quercus incana*	2.3	3	*	*	*	*
10	*Quercus baloot*	9.6	1	*	*	*	*

***Absent**

This group occupies the middle-to-left portion on the 2-dimensional ordination configuration.

Pinus wallichiana occupied a second dominant position in stands 10-32 and 39 (Figure 2), showing wide ecological amplitude. *Juglans regia* L., *Quercus baloot* Griff., and *Q. incana* Roxb. were the Angiospermae species associated with *Cedrus deodara*. At lower elevations (1600 m), *Juglans regia* was associated with *Cedrus deodara* with an importance value of only 9%, while *Cedrus deodara* attained 96% of the basal area (Table 2), forming a closed canopy. It also featured *Pinus wallichiana*, *Quercus baloot*, and *Q. incana* with low importance values.

Quercus ilex appeared as a codominant species (stands 29 and 41). *Cedrus deodara* seedlings and other Angiospermae plants were not recorded in the plots due to the highly patchy nature of ground flora distribution. In stand 5, *Picea smithiana* attained a 30% importance value. In stand 22, *Taxus wallichiana* was associated with *Cedrus deodara* at a low importance value (17%). *T. wallichiana* is one of the most disturbed gymnosperms of the northern area. Local people use its branches to decorate welcome gates. Here *Cedrus deodara* showed an 83% importance value with a density of 152 stems ha^{-1}. Species like *Fragaria nubicola* Lindl. ex Lacaita, *Viola canescens* Wall. ex Roxb., *Tribulus terrestris* L., and *Aconitum chasmanthum* Stapf. ex Holmes were present with low abundance.

Group III: *Cedrus deodara - Pinus wallichiana*

This group belongs to moist temperate areas with one exception: the ecotonal zones between dry and moist temperate regions. The group members (stands 19, 43, 31, 33, and 46) are distributed from 1900 to 2730 m on steep slopes of 30° to 42°, located on the lower-middle portion of the ordination plane. Deodar attained an average importance value of 63%, while codominant *Pinus wallichiana* attained a 33% average importance value (Table 4). *Abies pindrow* was present as a third dominant species in stands 33 and 46. Broad-leaved trees were abundant (57%) in plots. *Euphorbia wallichiana* Hk.f., *Viola canescens* Wall. ex Roxb., and *Cynodon dactylon* (L.) Pers. were recorded in 70%-80% of the plots in 1 location, while *Acer caesium* Wall. ex Brandis was found at 2 locations with low frequency. As with other groups, ground flora was poor due to overgrazing and disturbance.

Group IV: Pure *Cedrus deodara*

At 12 different locations (stands 3, 6, 9, 15, 16, 18, 23, 24, 27, 28, 44, and 45) *Cedrus deodara* was recorded as a single dominant species from 1650 to 2770 m on steep slopes of 12° to 50°. These stands showed 99-457 trees ha^{-1} with a basal area of 6.35-115 m^2 ha^{-1} (Table 2). Since in the second subgroup, deodar occupied more than 84% of the importance value, these stands may be considered pure stands

(stands 12, 26, 40, and 47; Table 2). In 2 stands, *Cedrus deodara* was associated with *Pinus gerardiana* and *Juniperus excelsa* (stands 12 and 30), indicating typical dry temperate conditions, while in the other 2 stands, *Picea smithiana* and *Abies pindrow* were the associated species, indicating an ecotonal zone between dry and moist temperate areas.

Our study also recorded 10-19 non-tree species, including seedlings of *Cedrus deodara*, from the forest floor. However, poor floristic similarity existed among the stands. The most commonly occurring understorey plants were *Viola canescens*, found in 30%-80% of the plots at 6 locations. *Rumex dentatus* L. occupied 45%-75% of plots in 2 stands, while *Vicia sativa* L. was recorded in 4 stands at a frequency of 30%-80%. At one location, *Rosa webbiana* Wall. ex Royle, *Ormopterum tuberosum* Nasir, and *Ferula assafoetida* L. were distributed in 70%-90% of plots (Table 5), while at another location, *Oxalis corniculata* L., *Indigofera heterantha* Wall. ex Brand, and *Anagallis*

Table 5. he distribution of understorey species in the study area. Species are listed in decreasing order based on the number of stands in which a species was present. The table presents a summary of circular plots species from different locations of *Cedrus deodara*-dominated forests.

S. no.	Name of species	PRST	RF in St. (range)
1	*Cedrus deodara* (Roxb. ex D.Don) G.Don (seedlings)	41	11.5-100
2	*Cynodon dactylon* (L). Pers.	18	1.9-2.7
3	*Pinus wallichiana* A.B.Jacks. (seedlings)	17	4.8-80
4	*Anagallis arvensis* L.	12	1.8-8.5
5	*Impatiens brachycentra* Kar. & Kir.	9	6.5-10.6
6	*Oxalis corniculata* L.	9	4.5-8.5
7	*Abies pindrow* Royle (seedlings)	8	2.2-17
8	*Geranium rotundifolium* L.	8	26-56
9	*Rumex dentatus* L.	8	1.5-2
10	*Vicia sativa* L.	8	3.9-4
11	*Rosa webbiana* Wall. ex Royle	8	2.7-3
12	*Ormopterum tuberosum* Nasir	8	4.1-9
13	*Consolida ambigua* (L.) Ball & Heywood	7	2.6-4.5
14	*Sambucus wightiana* Wall. ex Wight & Arn.	7	4.3--9.3
15	*Echinops cornigerus* DC.	7	9.1-13
16	*Aconitum chasmanthum* Stapf ex Holmes	7	7.5-9.7
17	*Euphorbia wallichiana* Hk.f.	7	7.1-10.4
18	*Ferula assafoetida* L.	7	3.7-3.8
19	*Indigofera heterantha* Wall. ex Brand.	7	2.6-7.5
20	*Verbascum thaspus* L.	7	2.3-4.8
21	*Fragaria nubicola* Lindl. ex Lacaita	6	6-9.1
22	*Pedicularis rhinanthoides rotundata* Schrenk ex Fisch. & Mey	6	9.1-10.6
23	*Pedicularis chitralensis* Penn.	6	3.3-6
24	*Aconitum laeve* Royle	6	4.1-9
25	*Viola canescens* Wall. ex Roxb.	6	6.1-18
26	*Tribulus terrestris* L.	6	9.1-18
27	*Acer caesium* Wall. ex Brandis	6	3.8-5.2
28	*Clematis montana* Buch Ham.	6	2.1-7.5
29	*Rumex hastatus* D.Don.	6	2.2-11.2
30	*Aquilegia nivalis* Falc. ex Jacks.	5	6.5-9
31	*Thymus serpyllum* L.	5	4.6-10.8
32	*Pteris cretica* L.	5	43
33	*Astragalus amherstianus* Benth. ex Royle	4	9.1-18
34	*Rubus ellipticus* Sm.	4	22
35	*Picea smithiana* (Wall.) Boiss. (seedlings)	3	5.2-11
36	*Trifolium repens* L.	3	2.5-7.5
37	*Cichorium intybus* L.	3	3
38	*Geranium wallichianum* D.Don ex Sweet	3	0.7
39	*Hedera nepalensis* K.Koch	3	9
40	*Pinus gerardiana* Wall. ex Lamb. (seedlings)	2	2.2-7
41	*Medicago polymorpha* L.	2	3.4-5.8
42	*Potentilla nepalensis* Hk.	2	44
43	*Podophyllum emodi* Wall. ex Royle	2	9
44	*Sinapis arvensis* L.	2	6
45	*Brassica campestris* L.	1	9
46	*Aristida adscensionis* L.	1	20

Abbreviations: PRST = Presence of species in number of stands, RF in St. = Relative frequency (range) in stands. Only species with DBH measurements <10 cm are shown.

arvensis L. were recorded in 45%-55% of the plots. Similarly, one location supported *Verbascum thaspus* L. and *Clematis montana* Buch Ham. in 40% of the plots, while understorey vegetation was not recorded in a few stands due to the highly scattered and patchy nature of distribution.

Group V: *Pinus wallichiana - Cedrus deodara*

Cedrus deodara appeared as a second dominant species in this group (stands 7, 14, 37, 8, 13, 17, 20, 21, and 38), except in stand 8. Its importance value ranged from 19% to 43%, with density ranging between 15 and 110 ha^{-1}. *Pinus wallichiana* attained 56%-81% importance values and 40-276 density ha^{-1} (Table 2). *Populus caspica* Bornm., a broad-leaved species, was identified as a third dominant, while a few scattered plants of *Abies pindrow* occurred at 2 locations (stands 20 and 7) with low abundance. This group is distributed between 1990 and 2400 m elevations from ridge tops to steep (33°) slopes and can be found facing varied directions. These stands are displayed on the middle-right side of the ordination diagram. Except for one location (stand 38), all of the sites belong to the dry temperate region of Pakistan.

In 9 sampling sites, only 4 stands supported seedlings of the dominant species. Ground flora was poor, scattered in patches, and with poor floristic similarity among different stands. *Viola canescens* Wall. ex Roxb., *Fragaria nubicola* Lindl. ex Lacaita, *Rumex hastatus* D.Don, *Cynodon dactylon* (L). Pers., *Vicia sativa* L., *Thymus serpyllum* L., *Trifolium repens* L., *Medicago denticulate* L., *Cichorium intybus* L., and *Potentilla nepalensis* Hk. were distributed in 60%-90% of plots in various stands of this group.

Group VI: *Abies pindrow - Pinus wallichiana*

This group comprises only 2 stands (34 and 36). The dominants of the group are *Abies pindrow* and *Pinus wallichiana.* In this group, *Cedrus deodara* attains the position of third dominant on the basis of importance value. These closed canopy stands in the moist temperate areas of Pakistan are located higher elevations (2560-2600 m), at moderate (27°) to steep (37°) slopes, facing the southeast. On ordination (axes 1 and 2), these stands occupied the lower right position of the configuration (Figure 3). *Abies pindrow* attained 55%-57% importance values and 112-200 individuals ha^{-1} densities with 12-43 m^2 ha^{-1} basal areas (Table 2). The importance value of *Cedrus deodara* ranged from 15% to 26% with 22-50 individuals ha^{-1} (Table 2). A broad-leaved species, *Juglans regia* L., was associated with low importance values. Forest floor growth was represented by a few species. Seedlings of *Pinus wallichiana* and *Cedrus deodara* were recorded in 10% to 20% of the plots, while *Abies pindrow* seedlings were found in 80% of the plots (Table 5). *Acer caesium* Wall. ex Brandis is distributed in 40%-70% of the plots. Some associated species recorded from one site only included *Pteris cretica* L., *Geranium wallichiana* D.Don ex Sweet, *Hedera nepalensis* K.Koch, *Podophyllum emodi* Wall., *Rubus ellipticus* Sm., *Thymus serpyllum*, *Brassica campestris* L., *Sinapis arvensis* L., and *Aristida adscensionis* L.

Relationship between ordination axes and environmental variables

Results of the correlation between 3 DCA ordination axes and environmental variables are presented in Table 6. Ordination axis 1 was found to be positively correlated with pH and organic matter ($P < 0.05$) and weakly correlated with Mg ($P < 0.1$). Ordination axis 2 was found to be correlated with elevation and pH ($P < 0.05$). Axis 3 showed correlation with soil nitrogen ($P < 0.05$). Other environmental variables did not show any significant correlation with DCA ordination axes.

Environmental characteristics of groups

With respect to environmental variables, the 6 groups showed some variability (Table 7). Group I is characterised by high water-holding capacity, soil organic matter, potassium, and total nitrogen. Group II is characterised by a higher aspect rating, slightly acidic soil, and high amounts of magnesium. The species of group III can be found on steep slopes (39.2°) and grow in the presence of high conductivity and greater amounts of soil calcium, magnesium, and total dissolved salts. Group IV is characterised by higher soil salinity. Group V exhibited maximum soil compaction when compared to the other groups. Group VI is associated with high elevation and sodium.

Table 6. Deodar correlation of 3 DCA ordination axes with environmental variables such as topographic (elevation, slope, aspect, and canopy) and edaphic (soil compaction, pH, WHC, salinity, and conductivity) factors and soil nutrients (OM, Ca^{++}, Mg^{++}, Na^{+}, K^{+}, total nitrogen, and TDS).

Variables	Axis 1	Prob. level	Axis 2	Prob. level	Axis 3	Prob. level
			1 - Topographic variables			
Elevation	0.0080	ns	0.2933	P < 0.05	-0.0366	ns
Slope	-0.0123	ns	-0.0126	ns	0.1253	ns
Aspect	-0.1261	ns	0.0403	ns	0.0725	ns
			2 - Edaphic variables			
Soil comp.	-0.1707	ns	0.2079	ns	-0.0396	ns
pH	0.2878	P < 0.05	-0.2843	P < 0.05	-0.0925	ns
WHC	0.0105	ns	0.1047	ns	-0.2103	ns
Salinity	-0.1589	ns	-0.0611	ns	0.1995	ns
Conductivity	-0.0865	ns	-0.2425	ns	0.1661	ns
			3 - Soil nutrients			
OM	-0.2875	P < 0.05	0.0205	ns	-0.0551	ns
Ca	0.0667		0.1400	ns	-0.1040	ns
Mg	0.2432	P < 0.1	-0.0530	ns	-0.0269	ns
Na	-0.1764	ns	0.2003	ns	-0.1902	ns
K	-0.0700	ns	0.0482	ns	-0.0069	ns
N	-0.0790	ns	0.0821	ns	-0.2747	P < 0.05
TDS	-0.1235	ns	-0.1398	ns	0.1559	ns

Abbreviations: Prob. level = probability level, Soil comp = soil compaction, WHC = water holding capacity, OM = organic matter, Ca = soil calcium, Mg = soil magnesium, Na = soil sodium, K = soil potassium, N = soil nitrogen, TDS = total dissolve salts, ns = nonsignificant.

Table 7. The 6 groups derived from Ward's cluster analysis using tree vegetation data from 47 stands of *Cedrus deodara*-dominated forests along with the mean values and standard error of their topographic, edaphic, and soil nutrient characteristics (mean ± SE).

Variable	Group I	Group II	Group III	Group IV	Group V	Group VI
1 - Topographic variables of soil						
Elevation (m)	2297 ± 136	2280 ± 78	2218 ± 150	2327 ± 93	2343 ± 218	2363 ± 238
Slope (°)	30.7 ± 3.3	29 ± 3	39.2 ± 2.5	33.6 ± 2.9	27.5 ± 0.5	32 ± 5
Aspect	2.33 ± 0.9	2.67 ± 0.43	2.6 ± 0.6	2.6 ± 0.32	1.5 ± 0.5	1.5± 0.5
2 - Edaphic variables of soil						
Soil comp.	172 ± 14.8	170 ± 10.4	165 ± 21.5	170 ± 8.3	185 ± 10	163 ± 13
pH	5.7 ± 0.26	6.4 ± 0.16	6.1 ± 0.3	6.2 ± 0.12	6.1 ± 0.61	6.2 ± 0.76
WHC	60 ± 4.14	50.8 ± 2.4	54 ± 4.4	54 ± 1.6	54.7 ± 5	55 ± 5.8
Salinity	0.1 ± 0.0	0.12 ± 0.02	0.18 ± 0.04	0.244 ± 0.07	0.1 ± 0	0 ± 0.1
Conductivity	214 ± 9.4	290 ± 40	395 ± 76	364 ± 48	256 ± 19	148 ± 89
3 - Soil nutrients						
OM	6.3 ± 2.13	4.8 ± 0.34	6.1 ± 0.63	5.6 ± 0.33	5.31 ± 0.23	4.5 ± 1.1
Calcium	0.39 ± 0.12	1.04 ± 0.23	1.4 ± 0.29	0.68 ± 0.16	1.1 ± 0.77	0.65 ± 0.33
Magnesium	0.5 ± 0.14	0.54 ± 0.07	0.54 ± 0.06	0.53 ± 0.05	0.43 ± 0.21	0.38 ± 0.16
Sodium	1.3 ± 0.23	0.54 ± 0.08	0.9 ± 0.2	0.79 ± 0.11	0.97 ± 0.49	1.4 ± 0.12
Potassium	1.96 ± 0.35	1.55 ± 0.17	1.8 ± 0.33	1.8 ± 0.14	1.66 ± 0.095	1.85 ± 0.1
Nitrogen	0.46 ± 0.39	0.25 ± 0.06	0.28 ± 0.122	0.16 ± 0.05	0.15 ± 0.065	0.16 ± 0.08
TDS	112 ± 6.6	164 ± 20	210 ± 35	201 ± 26	128.7 ± 9.3	74 ± 45.2

Note: For a key to the symbols used in this table, please refer to Table 6.

Size frequency distribution

Size structure diagrams for *Cedrus deodara* were prepared for each *Cedrus deodara* forest (stand). However, for the sake of brevity, only the data from a few representative stands are presented here (Figure 4). It is indicated that all of the stands are composed of mosaics of mixed size classes, and in some stands, many individuals are found in small size classes with a gradual decrease in numbers in the larger size classes. However, contrary to this situation, in many stands, small-sized trees are completely lacking. The overall distribution of *Cedrus deodara* exhibits a continuous pattern (positively skewed) in which the density is higher in small-sized classes, with a gradual decline in the larger-sized classes (Figure 5).

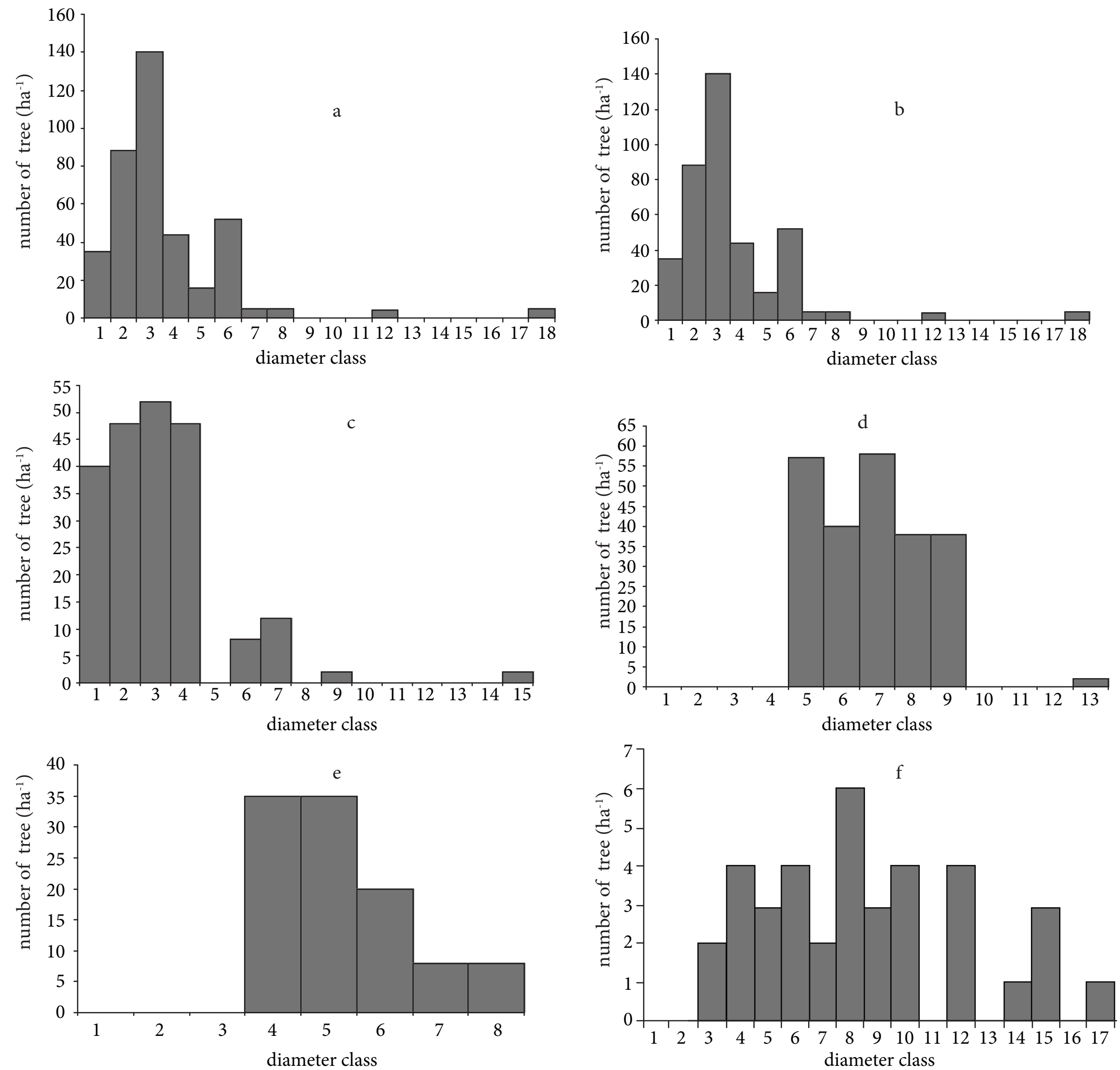

Figure 4. Size class distribution of *Cedrus deodara* trees. Note the differences in the scale of the y-axis (number of trees ha^{-1}). Diameter classes are divided into 10-cm intervals. Class 1 represents 10-19.99 cm, class 2 represents 20-29.9 cm, and so on. a and b- pure *Cedrus deodara* stands (23, 27), c and d- *Cedrus deodara*-dominated stands (12, 35), e and f- stands in which *Cedrus deodara* is not the first dominant (2, 4).

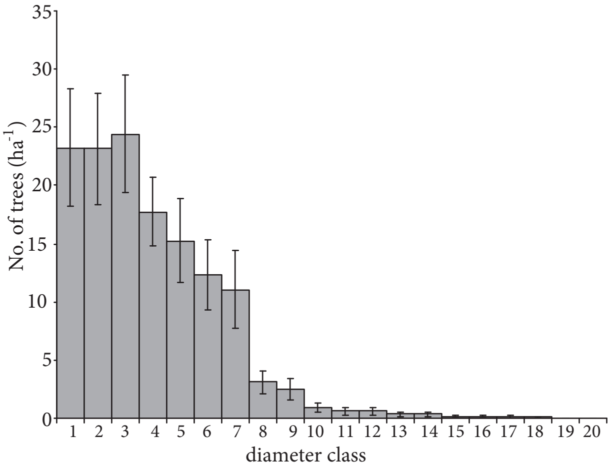

Figure 5. The Overall size class structure of *Cedrus deodara* based on all 47 stands. Diameter classes are the same as in Figure 4. The size class structure shows positively skewed distribution.

Density and basal area

Values for density per hectare (ha^{-1}) and basal area square meter per hectare (m^2 ha^{-1}) of tree species from the forest-dominating *Cedrus deodara* are given in Table 2, while mean density (ha^{-1}) and mean basal area (m^2 ha^{-1}) of tree species are presented in Table 3. Stand density ranged from 62 to 631 ha^{-1}, with an average of 240 ± 19 stem ha^{-1}, and the basal area ranged from 5.89 to 175 m^2 ha^{-1}, with an average of 50.81 ± 5.09 m^2 ha^{-1} (Table 2).

The density of *Cedrus deodara* ranged from 15 to 410 ha^{-1}, with an average of 184 ± 17 ha^{-1}, while basal area varied from 2 to 159 m^2 ha^{-1} with an average of 41.84 ± 4.6 m^2 ha^{-1} (Tables 2 and 3).

The correlation between overall stand density and stand basal area was highly significant ($r = 0.618$, $P < 0.001$). Similarly, a significant correlation ($r = 0.572$, $P < 0.001$) was also obtained between density and basal area of individual species (*Cedrus deodara*) in all stands. It is noteworthy that a wide variance was associated with the 2 variables.

Age and growth rates of Cedrus deodara

In some selected *Cedrus deodara* forests, an attempt was made to describe the age structure and growth rate of the stands studied (Table 8). The correlations between diameter/age and age/growth rates of some selected *Cedrus deodara* forests are presented in Table 9. Due to an insufficient number (less than 6) of wood samples from *Cedrus deodara* trees in some stands, however, these correlations were not evaluated. Instead, linear regression analyses of only 19 stands (all of which provided sufficient sample sizes) are presented in Table 9.

Age estimates

Age varied greatly from tree to tree and site to site, even amongst trees of closely similar sizes (Table 8). The oldest tree, found at the Gohkshal site, was 572 years old and presented DBH of 178 cm; analysis of trees having 176-cm DBH measurements from Ziarat (Mata Khure) revealed ages of 161 and 386 years. Table 8 also shows that the diameters and ages from 23 sites are highly variable. For example, the largest *Cedrus deodara* tree from Ziarat (stand 5) had a DBH of 198 cm but an estimated age of only 273 years, a size and age relationship that contrasts well with the example given above.

Growth rate analysis

Like age, growth rate in *Cedrus deodara* varied greatly among the same sized trees even in a small area. Table 8 shows growth rates in various *Cedrus deodara* forests. The slowest growth rate, 25 years cm^{-1}, was recorded from trees in stands 2 and 8, while the fastest growth rate (1 year cm^{-1}) was obtained from a *Cedrus deodara* tree found in stand 14. However, *Cedrus deodara* trees growing at the Shahi Awar site (stand 19) showed fast growth (2.37 ± 0.5), while the slowest growth (8.29 ± 1.28 year cm^{-1}) was recorded from Kalash (stand 1). On average, *Cedrus deodara* was found to grow at 4.97 ± 0.18 years cm^{-1}.

Discussion

Multivariate analysis

Two-dimensional DCA ordination (axes 1 and 2) showed continuity in vegetation. Cluster analysis using Ward's method yielded 6 groups that could readily be superimposed on the ordination configuration. In the ordination plane (axes 1 and 2), subgroups within main group II could also be distinguished but are not discussed here. The results of ordination supported that for cluster analysis the 2 multivariate methods are complementary (Orloci and Kenkel, 1985).

Table 8. A summary of age and growth rates from *Cedrus deodara* stands from which cores were taken.

Stand no.	DBH range (cm)	Age range (years)	GR range (years cm^{-1})	Mean GR (years cm^{-1}) ± SE	GR range (cm $year^{-1}$)	Mean GR (cm $year^{-1}$) ± SE	NTS
1	12-138	91-250	3.8-19	8.29 ± 1.28	0.05-0.26	0.15 ± 0.01	18
2	10-113	113-233	2.6-24.9	7.86 ± 1.48	0.04-0.37	0.16 ± 0.02	15
3	22-130	40-320	2.7-21.3	5.84 ± 0.57	0.04-0.35	0.19 ± 0.01	33
4	72-176	161-386	3.8-9	5.69 ± 0.50	0.11-0.25	0.18 ± 0.01	11
5	71-198	205-365	4.5-9.6	6.61 ± 0.37	0.1-0.21	0.15 ± 0.00	10
6	23-72	53-126	2.5-6	3.92 ± 0.32	0.16-0.36	0.26 ± 0.01	14
7	25-52	53-103	2.9-7.5	4.02 ± 0.40	0.13-0.33	0.26 ± 0.01	12
8	32-97	114-233	2.6-24.9	4.02 ± 0.40	0.04-0.37	0.26 ± 0.01	15
9	38-178	86-572	2.9-10.9	5.85 ± 0.38	0.09-0.33	0.17 ± 0.01	20
10	67-137	170-469	4.4-14	8.24 ± 0.74	0.07-0.22	0.13 ± 0.01	16
11	23-72	52-136	2.5-6	3.88 ± 0.30	0.16-0.36	0.27 ± 0.01	15
13	29-75.2	33-148	1.79-4.86	3.18 ± 0.25	0.21-0.56	0.35 ± 0.02	16
14	13-95.5	20-112	1.08-5.84	3.20 ± 0.38	0.17-0.93	0.39 ± 0.06	13
15	15-72	28-54	1.48-7.08	2.63 ± 0.47	0.14-0.68	0.45 ± 0.04	11
16	10-90	28-74	1.68-9.66	3.37 ± 0.74	0.10-0.60	0.39 ± 0.04	13
17	11-64	25-48	1.14-5.91	2.79 ± 0.45	0.17-0.70	0.44 ± 0.05	11
18	12-67	25-95	1.84-5.69	3.14 ± 0.39	0.18-0.54	0.36 ± 0.03	12
19	15-52	24-52	1.52-3.05	2.37 ± 0.15	0.33-0.66	0.45 ± 0.03	12
20	48-113	61-215	2.62-10.17	4.40 ± 1.17	0.10.0.38	0.28 ± 0.04	6
21	18-85	42-127	1.73-4.81	3.06 ± 0.34	0.21-0.58	0.36 ± 0.03	9
22	64-115	82-399	3.06-8.10	4.62 ± 0.62	0.12-0.33	0.24 ± 0.02	9
23	40-86	38-178	1.4-4.8	3.16 ± 0.34	0.20-0.71	0.35 ± 0.05	9
28	18-72	31-101	1.29-5.42	3.23 ± 0.31	0.18-0.77	0.35 ± 0.04	14

Abbreviations: DBH = diameter at breast height, Mean GR ± SE = growth rate mean ± standard error, NTS = number of trees (2 samples were taken per tree), Stand no. = stand number, years cm^{-1} = years per centimetre, cm $year^{-1}$ = centimetres per year.

Table 9. The linear regression equations and correlation coefficients between diameter/age and age/growth rates of some selected *Cedrus deodara* forests.

		Regression equation					
Serial no.	**Stand no.**	**Diameter and age**	**r**	**Sign. P <**	**Age and growth rates**	**r**	**Sign. P <**
1	1	Y = 0.413x + 134.56	0.326	ns	Y = 0.006x + 6.92	0.035	ns
2	2	Y = 0.329x + 61.29	0.198	ns	Y = 0.055x + 0.01	0.567	0.05
3	3	Y = 3.15x + 5.49	0.679	0.05	Y = 0.014x + 2.77	0.222	ns
4	4	Y = 0.77x + 40.33	0.056	0.01	Y = 0.018x + 2.97	0.209	ns
5	5	Y = 0.30x + 146.41	0.137	ns	Y = 0.044x + 1.79	0.737	0.001
6	6	Y = 1.06x + 27.38	0.707	0.001	Y = 0.006x + 3.46	0.107	ns
7	7	Y = 0.86x + 99.98	0.432	ns	Y = 0.024x + 11.70	0.154	ns
8	8	Y = 2.26x + 20.45	0.703	0.001	Y = 0.013x + 2.82	0.745	0.001
9	9	Y = 1.09x + 103.59	0.539	0.05	Y = 0.014x + 2.13	0.064	0.01
10	10	Y = 0.90x + 147.46	0.622	0.01	Y = 0.001x + 7.00	0.048	ns
11	11	Y = 0.513x + 160.02	0.421	ns	Y = 0.002x + 8.75	0.017	ns
12	13	Y = 1.437x + 2.54	0.687	0.05	Y = 0.028x + 1.33	0.734	0.001
13	14	Y = 0.781x + 30.46	0.673	0.05	Y = 0.020x + 1.89	0.427	ns
14	15	Y = 0.246x + 30.93	0.509	ns	Y = 0.047x + 0.77	0.235	ns
15	16	Y = 0.476x + 25.45	0.887	0.001	Y = -054x + 5.66	0.024	ns
16	17	Y = 0.128x + 34.94	0.348	ns	Y = -0.011x + 3.24	0.046	ns
17	18	Y = 1.054x + 10.12	0.803	0.001	Y = 0.026x + 1.94	0.434	ns
18	19	Y = 0.241x + 32.18	0.280	ns	Y = 0.035x + 0.95	0.552	0.01
19	28	Y = 0.606x + 28.99	0.629	0.01	Y = 0.009x + 2.77	0.122	ns

Abbreviations: Sign. = significance, P = probability level, ns = nonsignificant.
The relationship between the above mentioned variables are estimated; the stands selected were those that had a sufficient sample size.

Size frequency distribution

Gaps in size-class structure have been frequently reported in the population structure of many tree species (Hutchins, 1981; Pickett & White, 1985; Pickett et al., 1989). The cause of these gaps has never been studied on a wide scale and most of the conclusions are based on the study of disturbed or regenerating stands of different forests. In Pakistan, only a handful of studies have been carried out to examine the present forest structure (Ahmed et al., 1990a, 1990b, 1991; Ahmed & Naqvi, 2005; Wahab et al., 2008). However, no attempt was made to investigate the causes of these gaps. According to Dawson and Sneddon (1969), in unstable forests, dead trees of the various species do not get replaced by a nearly equal number of younger trees. Robbins (1962) has suggested that this was due to the competitive ability of highly evolved angiosperms over gymnosperms. It may be assumed that gaps in the structure do not necessarily mean that the particular size class is absent from the stand or that this situation is indicative of a failure to regenerate at some time in the past. It is quite possible that by chance alone some rare size classes were not included in the sample. Furthermore, age and diameter studies have suggested that the largest tree is not necessarily the oldest tree in the stand, so it is possible that missing individuals in the larger size classes are due to mortality. However, past and present logging history of these forests indicate that this is not the case with regard to *Cedrus deodara* forests, and it is extremely difficult to apply regeneration gap, mortality, or storm theories in these forests.

The large number of individuals in small size classes (10-40 cm DBH) in various stands (Figure 4) implies a wave of recruitment that would take place gradually over time. In these stands, large numbers of *Cedrus deodara* seedlings/saplings were also recorded, indicating a balanced population structure. Despite some gaps or low density in small size classes in individual stands, examination of the overall size-class structure shows, with a positively skewed distribution, a continuous and gradual decline in density from small to large size classes with high density in small size classes and low density in larger classes. Drewa et al. (2008) investigated the stand structure and dynamics of the sand pine, aspects that were known to differ between the Florida panhandle and peninsula; they found that the size and age structure of stand populations of numerous tree species exhibited uneven or reverse J-distributions that could persist after noncatastrophic disturbances. Though large trees are removed from the area, these forests can be managed and protected easily. Many stands showed gaps in small size classes with a flat size structure, indicating no recruitment or cutting of small-sized trees. These unbalanced populations require more attention for conservation and protection efforts.

A stable community maintains the balance between the death of old trees and the birth of new trees, so it seems reasonable that during this long process of maintenance, thousands of seeds and seedlings and hundreds of poles and rickers are weeded out by natural selection. This study shows a large number of seedlings (<10 cm DBH) and large numbers of individuals in a small size class (10-40 DBH) in mature *Cedrus deodara* forests. *Cedrus deodara* seedlings were recorded not only in the canopy gaps, along the tracks and in open areas, but also under their parents' shade. This indicates that light is not the only or major limiting factor for the germination and establishment of *Cedrus deodara* seedlings. However, further and more comprehensive investigations are required on this topic. In some places, a low number of seedlings may be due to grazing and logging. For *Cedrus deodara* forests, the minimum seedling requirement for balanced recruitment needs to be evaluated.

Before comparing *Cedrus deodara* with other tree species, we should consider that *Cedrus deodara* has the ability to grow under a wide range of conditions (i.e. dry, moist temperate, and subalpine). It is a long-lived tree capable of attaining huge sizes and heights. Naturally, gaps in mature *Cedrus deodara* stands may fill as follows. When a mature *Cedrus deodara* dies, some short-lived, light-demanding plants grow faster and fill the gap for a short time. Among these, there may be a few *Cedrus deodara* seedlings. The short-lived plants complete their life cycle and die, but the long-lived *Cedrus deodara* seedlings or saplings remain. This cycle may be repeated several times, depending on the nature of the short-lived plants. During this time, *Cedrus deodara* grows gradually, side by side with other species. Associated angiospermic plants provide better chances of survival for *Cedrus deodara*. Eventually *Cedrus deodara* emerges through the canopy, spreading its branches and producing its normal crown, which may fill the gap that was created 100 or more years earlier.

Density and basal area

The density and basal area show large variations from site to site, and it is assumed that stem density depends on various historic and environmental factors (Ahmed et al., 2006). However, in these forests, anthropogenic disturbances could be an overriding factor. According to Grubb et al. (1963), in undisturbed areas density is closely related to slope; no significant relation was observed in the present study between slope and stand density, stand basal area, *Cedrus deodara* density, and *Cedrus deodara* basal area. It was also recorded that north-facing slopes supported the highest stand density (289 ± 37) and *Cedrus deodara* density (195 ± 32 ha^{-1}), while the lowest stand density (182 ± 42) and *Cedrus deodara* density (128 ± 35) were recorded on west-facing slopes. Stand basal area was highest (54.67 ± 8.51) in the south while *Cedrus deodara* showed the highest basal area (34.76 ± 5.98 m^2 ha^{-1}) on north-facing slopes, though no significant correlation was obtained between these variables.

Age estimates

Only a few age/diameter estimates, using modern dendrochronological techniques, are available in Pakistan. A tree of *Pinus wallichiana* with a 20.5 DBH from the Zhob district attained an age of 112 years, while the same age was estimated from an individual of the same species having a DBH of 65 cm from Ayubia. Similarly, an *Abies pindrow* specimen from Murree had 351 rings with diameter of only 11.3 cm, while a 200-cm *Cedrus deodara* from Kalam was found to be 346 years old. The relationship between diameter and age for *Juniperus excelsa*, *Pinus wallichiana*, *Pinus gerardiana*, and *Abies pindrow* (Ayubia) was highly significant. Recently, Ahmed et al. (2009) presented age and growth rate data from 39 locations, using various Gymnospermae trees. In general, the species investigated showed no relationship between diameter and age. According to Daubenmire (1968), if the diameter is a good indicator of age, the past history of the particular stand is predictable. However, the present study suggests that as far as *Cedrus deodara* is concerned, this may not be possible due to a large variance of diameter at any age and owing to continued cutting and disturbance. In the present study, these 2 variables show a highly significant correlation (Table 9) in some stands, though because of the wide variance in the diameter, any prediction of age from diameter would be unreliable.

Growth rate analysis

Ahmed and Sarangzai (1991) examined the growth rate of a number of conifer species from the Himalayan region of Pakistan. According to them, *Cedrus deodara* from Kalam showed a growth rate of 2-10 years cm^{-1}. They also reported that growth rates decreased with increasing altitude, and they found a significant negative correlation between these 2 variables. Recently, when Ahmed et al. (2009) presented growth rates of some Gymnospermae trees of Pakistan, they found no relation between elevation and growth rates. *Pinus wallichiana* showed fast growth (1.7 years cm^{-1}) in the district of Dir, while *Abies pindrow* from Murree produced narrow (7.0 years cm^{-1}) rings. An average growth rate of 6 years cm^{-1} was recorded for *Picea smithiana* from the Nalter Valley, while the growth rate of *Cedrus deodara* was 4.0 years cm^{-1} from Kalam. Diameter, growth rate, and age were significantly related in stands 8, 9, and 13, while stands 2, 5, and 19 showed no correlation between diameter and age. Although a significant relationship was obtained between diameter and age in many stands (Table 9), no relation was found between diameter and growth rate. Therefore, like age, the growth rate is also not predictable from the diameter. In general, growth rate is the product of a variety of factors (climatic and nonclimatic, genetic, competition, etc.) and detailed investigations are required with respect to these predictor variables.

In summary, *Cedrus deodara* forests are distributed throughout the Hindu Kush-Himalayan region in areas that range from dry to moist temperate. The forests can be found between 1650 and 2927 m of elevation and are predominately controlled by the altitudinal gradient. The density and basal area of *Cedrus deodara* are generally high and vary mostly in response to local climate and, to a lesser extent, other biotic and abiotic factors. In some stands, a stable size and age structure is maintained by *Cedrus deodara* despite the presence of a few gaps in the size class structure. Due to a fair amount of seedling recruitment, these gaps are expected to disappear in the future, provided that the forests remain largely undisturbed. Stands with unstable size structure were also observed; this situation requires attention, and recommendations for dealing with the subject have been advanced. When compared with other tree species from various regions in Pakistan, the growth rate of *Cedrus deodara* is relatively higher, a fact that undoubtedly contributes to the high productivity and standing crop of these forests.

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